Journal of Big History

Volume VII Issue 4 2024

The Journal of Big History (JBH)
ISSN 2475-3610 Volume VII Number 4 2024 https://doi.org/10.22339/jbh.v7i4.7400

JBH, the Journal of the International Big History Association (IBHA), is published on line and is accessible to members of the IBHA. The IBHA also publishes its bulletin, *Emergence*. The bulletin contains members' accounts of their activities and views, announcements of conferences and meetings of interest, and other communication of interest to IBHA members.

We encourage readers of the *JBH* to send letters and responses to jbh@bighistory.org or to the address below:
International Big History Association
SAC 253
Villanova University
Villanova, PA 19085 USA
jbh@bighistory.org

Please visit https://jbh.journals.villanova.edu/ for information about the *Journal of Big History* (*JBH*). Submissions may be sent to jbh@bighistory.org. The views and opinions expressed in *JBH* are not necessarily those of the IBHA Board. *JBH* reserves the right to accept, reject or edit any material submitted for publication.

The IBHA appreciates its members for their participation in the IBHA. Membership dues all go towards the administration of the association, but do not by themselves cover our costs. The only paid position is a part time administrative assistant. Other costs are for our website and for the *JBH*, for example. Please consider a tax deductible (in the US) gift to our 501(C)3 and please consider remembering the IBHA in your will.

Contents

A Long History of Home-bases, Huts, Houses, Villages, Towns, Cities and Megacities

Phillip C. Edwards
La Trobe University, Department of Archaeology & History, Melbourne, Victoria, Australia

Correspondence | **Phillip C. Edwards** P.Edwards@latrobe.edu.au ORCID: 0000-0003-4960-721X
Citation | Edwards, Phillip C. (2024) A Long History of Home-bases, Huts, Houses, Villages, Towns, Cities and Megacities. *Journal of Big History*, VII(4); 1–37.
DOI | https://doi.org/10.22339/jbh.v7i4.7401

Abstract

This review traces the lengthy record of human habitation on our planet. So long has the process of homemaking been that it includes constructions made by prehuman ancestors, upwards of a million years ago. Efforts towards the building of shelters and the founding of settlements have involved lengthy periods of relative stasis, punctuated by leaps to new and more complex systems. The first home-bases were simple fireplaces, around which our ancestors gathered, prepared food, and made tools. During the Pleistocene, occasional vestiges of curvilinear huts are found, and during the Late Glacial period, substantial groups of houses appear on the plains of Eurasia. The transition to sedentary life was accomplished by Natufian hunter-gatherers in the Levant, near the end of the Ice Age. There followed the establishment of village life across the Middle East by Pre-Pottery Neolithic farmers in the early Holocene, and the first cities around 3,500 BCE in southern Iraq and south-western Iran. Urban systems had spread across the globe by 3000 BCE, from China, to Peru in the Americas. The Classical cities of the Mediterranean developed regular urban grid plans in the fifth century BCE and introduced new types of civic amenities. In terms of complexity and size, the ancient city reached its zenith in imperial Rome. Occasionally, premodern cities such as Angkor became much larger than it in area through the establishment of low-density residential populations. New sources of energy were unleashed by the technological revolution of the nineteenth century that utterly transformed the city. In short order, they led to the mega-conurbations that currently spread over large tracts of the earth. This review considers factors of community interaction and communication that have both retarded and permitted breakthroughs in settlement strategies through time. It also examines the idea of non-verbal syntactical grammars that govern the patterning of human settlements, and the relative contributions of adventitious organic growth versus deliberate planning and retention of community ideals in settlement planning

Introduction

One of the most fundamental human traits is the instinct to make a home. Virtually all cultural products emanate from such places. The practice has been going on for a very long time indeed and includes efforts by our pre-human ancestors that extend back nearly a million years. This review attempts to retrace this process from earliest times until the modern day. As such, the article is well-situated within this issue's particular Big History threshold, 'Laying the Foundations of Big Economic History'. In order to recount the antecedents of the human condition, Big History seeks to combine the fruits of the major scientific disciplines, commencing with physics and astronomy and leading to geology and biology, before arriving at the traditional historical disciplines.[1] Lodged between them, archaeology (and its cognate discipline of palaeoanthropology) is the only means of investigation of human affairs for the period up to the advent of written records.

Settlements were dear to the people who made them and reflect much about their culture. Ancient settlements have also influenced later peoples. So, the specifics of ancient settlements are useful to explore how these reactions arise. Material configurations provide templates for successive generations. and subconsciously influence their future decisions.[1] On the other hand, communities also consciously manifest their beliefs and ideals in the design of their settlements. They often commit to maintaining their built environment over long periods. Therefore, residential trajectories around the world show distinctive continuities. The history of human settlements then, like culture in general, is bound up in the interplay between tradition and countervailing constraints and forces.[2]

To understand the nature of habitation in general, the architect Doxiadis sought to establish a science of human settlement, which he termed 'ekistics.' In his massive, wide-ranging treatise on the subject, Doxiadis,[3] does not pause to provide an etymology for the word, but its original meaning in ancient Greek is germane to consider in this discussion. The oikistēs was a citizen chosen by a polis to supervise and institute a new Greek urban colony. The idea presupposes that the setting out of an ordered town would involve elaborate planning and systematics. Yet, settlement patterns may also arise through the existence of non-verbal

spatial grammars. As Hillier and Hanson have observed, "it seems to be a characteristic of the human mind that it is extremely good at using relational systems - all languages and symbolic systems are at least complex relational systems - but rather bad at knowing how to talk about them."[4] So, it is not clear that overarching administrations always plan settlements, as opposed to their emergence via the innate conceptions of spatial relations held by community members, by idiosyncratic understandings about how things should be built, or by boundless, small conversations between neighbours. After all, bees manage to produce exquisite, hexagonal honeycombs. Their existence leads us to question whether human beings also have a genetic propensity for spatial relations, or an innate 'syntax of space.'[5] In other words, is there a Universal Spatial Grammar, just as Noam Chomsky proposed that a Universal Grammar, hard-wired in the brain, underlies human language capacity? [6] There is still no clear evidence for such a genetic basis.[7]

This review begins with the first fireplaces, and then moves on to consider early shelters, and subsequently the appearance of clustered huts towards the end of the Palaeolithic, or 'Old Stone Age' era (during the Pleistocene geological epoch).[8]

The Hearth as Home

According to ethnographic evidence from small, mobile hunter-gatherer groups and the archaeological record, the hearth[9] constitutes the original home-base for human society.[9] People have crouched around hearths from ancient to modern times, sharing food and stories while contemplating the flames.[10] In recent history, the disposition and number of hearths varied according to the size of the group[11] The first unequivocal use of fire occurs at Gesher Benot Ya'aqov on the Jordan river, 790,000 years ago.[12] Distribution studies at the site show particular focuses of burnt material, which may indicate the setting of fires. The earliest clearly attested hearths occur at Qesem cave in Israel, 300,000 years ago.[13] In these cases human ancestors were the innovators*; Homo erectus* in the former case, and probably Neanderthals in the latter instance. Modern humans were using fire by 164,000 years ago,[14] and in the following millennia its use became widespread.

Earliest huts

To begin with, we should lay to rest the myth that humankind emerged from the caves towards the end of the Palaeolithic. People have always lived in the great outdoors, founding basecamps in the open air.[15] Apart from hearths, there are subtle traces of lean-tos and circular huts interspersed through the long traverse of the Pleistocene. Most were built of perishable materials and so have not survived. Scatters of stone tools and butchered animal bones mark the whereabouts of most. Occasionally through, anaerobic conditions of preservation have preserved the remnants of such structures. In other cases, we discern their outlines when durable stone fragments were used to form their footings.

A stone ring at Olduvai Gorge in Kenya dating to 1.6 million years ago has been interpreted as the footings of a shelter.[16] However, certainty is precluded by the possibility that the space within the ring may have been cleared by the uprooting of a large tree. A later example at Arkin 8 in the eastern Sahara (Egypt) is said to represent the remains of a hut, but the most impressive example of ancient capabilities are wooden logs shaped to connect to each other, found at Kalambo Falls in Zambia and dating 476,000 years ago.[17] These simple habitations occurred through such a long time period that several different species of human ancestors were involved in their collective construction. They run, potentially, from *Homo habilis* to *Homo erectus* and onto *Homo heidelbergensis*, and to the Neanderthals and the Denisovans in Eurasia. The Acheulian site of Terra Amata at Nice, dating 400,000 years ago, comprises a series of superimposed living floors with scattered postholes, indicating the use in habitations of perishable materials.[18] A precocious stone structure built by Neanderthals lies on the surface of a chamber deep in Bruniquel Cave, France. It takes the form of an oblong arrangement of stalagmite fragments, dated 176,500 years ago.[19] Given its dark underground location, it may represent the vestiges of a ritual practice, rather than a quotidian habitation.

Near the end of the Middle Palaeolithic period, the first major habitation sites appear in the Dniester River Valley in Ukraine, at Moldova I, also associated with Neanderthals.[20] Loosely organised structures there consist of mammoth bones and teeth, enclosing masses of stone tool debris and animal bone remains. These were cold-adapted residences, offering protection from strong winds. In all, constructed shelters are rare before the Upper Palaeolithic, when modern humans entered Europe (around 44,000 years ago). Thirty thousand years on, somewhat similar constructions appear in the same region. But now they are impressive huts, such as Gontsy in the Dnepr Basin, Ukraine (ca,

15,000 BCE),[21] built from stacked piles of mammoth skulls and long bones. They were probably covered with animal skins.

From this time, we also see critical steps taken in the Levant towards the development of the house. At 21,000 BCE, hunter-gatherers constructed oval, brush huts at the late Upper Palaeolithic site of Ohalo II, on the shores of Lake Tiberias.[22] Due to the site having been submerged under anaerobic conditions until its recent exposure, it yields a rare glimpse of what Ice Age camp sites may have generally looked like. Vestiges of its perishable materials have survived, including twisted fibres and brush wall materials. The house is provided with a central hearth, and rarely, for that age, fragments of stone grinders for processing cereals. The emergence of a kind of emotional attachment to the dwelling is evident in the form of an interred man, buried next to the hut. These subtle vestiges represent what Moore has called 'the prehistory of the home.'[23]

The Earliest Village People

The Natufian culture (12,700 - 10,300 BCE) forms a critical juncture in human settlement history. Significant subsistence and settlement intensification occurred in the Early Natufian period in the Levant, with the appearance of stone houses organised into small villages (around 12,500 BCE).[24] Whereas previous sites are short-lived, Natufian sites are larger and contain clusters of stone huts, rebuilt on the same spot over hundreds, and in some cases, over thousands of years. Notable exemplars are Wadi Hammeh 27 in Jordan[25] and 'Ain Mallaha in Israel.[26] Natufian hamlets were founded on cemeteries, a physical linkage which consolidated a community's attachment to its home territory.

Natufian hunter-gatherer settlements are associated with new artefact types for processing plant foods, such as well-made sickles and large numbers of mortars, pestles and grindstones. Remains of carbonized plant foods include wild barley, lentils, chickpeas and almonds. Whether Natufian hamlets represent year-round, and year-on-year, habitations, has remained an ongoing focus of research. Hunter-gatherer communities make substantial constructions but usually vacate them for part of the year, in order to fallow resources in their home territory and exploit food resources in more distant regions. As noted above, our forebears did not always live in caves, but there is an interesting caveat we must pause to consider for the Natufian. The earliest Natufian house constructions are indeed set in caves and rock shelters. They occur around 13,000 BCE, for example at El Wad cave at Mount Carmel range on the coast of the Mediterranean.[27]

Whether the natural walls and boundaries of caves stimulated these people to build in stone is an interesting consideration. Communities who occupied subterranean cavities were not always just passive squatters in them. At Nawarla Gabarnmang rockshelter in Australia's Northern Territory, variable dissolution of rock led to the creation of a forest of natural stone supports, stretching from the floor to the ceiling over a wide area.[28] The effect is impressing, reminiscent of the sensation created by standing in the pillared hall of the Great Mosque of Cordoba, where columns disappear into the gloom in every direction. The Indigenous occupants of Nawarla Gabarnmang, occupied over 50,000 years until the recent past, did not build architectural features within the rockshelter but they transformed it by clearing debris and removing some of the columns to render the chamber more amenable for residential activities.

The Agrarian Village

At the end of the Pleistocene (*ca.* 11,500 cal BCE), an intense glacial period known as the Younger Dryas episode returned rapidly to plunge high-latitude regions beneath sheets of ice. Its effects were also felt in lower-latitude regions such as the Middle East.[29] Temperatures and rainfall were lowered, and vegetation patterns altered. The end of this period also came quickly, ushering in Mediterranean climate with its seasonal rhythm of long summers and moist winters. This change coincides with the appearance of agricultural villages. Across the Levant around 10,000 years BCE, the shift to sedentary village life occurred during the Pre-Pottery Neolithic A (PPNA) period. It saw the construction of true houses in stone and mudbrick, and a surge in the size and complexity of settlements. The basket of these early villagers was boosted by 'pre-domestication agriculture', or the cultivation of wild cereals such as wheat and barley.[30]

The PPNA was spectacularly discovered by Kathleen Kenyon in her excavations at Tell es-Sultan (Jericho) in the 1950s.[31] Directly underlying the first Neolithic village was a Natufian hut. Its location at the base of the first *tell* or city mound, underscores the significance of the Natufian as a knickpoint in human settlement history. The period marks the origin of property tenure over specific plots of

land. From this time, not only home territories but specific villages and individual houses were reoccupied through many generations. That Kenyon named the next period 'Pre-Pottery Neolithic' reflects prevailing expectations derived from the European Neolithic; namely, that early farming villages should possess pottery. But the Jericho PPNA phases lacked ceramics, despite the occupants' knowledge of baked clay.

The PPNA houses were small, round, and cramped; yet still an advance on Natufian construction methods. They were built from courses of bonded mudbrick laid on a timber frame. Steps led down into a sunken interior, which was provided with a central hearth It is in the non-domestic architecture where Jericho's departure from previous settlements is most evident. Its conical stone tower, reaching nearly nine metres into the air, is an extraordinary occurrence for 10,000 BCE, and unique upon the earth for this period. The tower was built of mortared stone. It was equipped with an internal staircase of carefully dressed stone slabs with corbelled vaulting to protect the ascending passage, which gave on to a flat roof. Nearby, at the margin of the village, a large stone wall had been raised, flanked on its external side by a deep ditch. Initially, at least, the tower could not have been a defensive structure because it stood free and was not originally connected to this wall. Moreover, the view from the tower's summit did not give any better view than the normal groundline further back into the interior of the village. The tower is likely to have been constructed for a ritual use – but one thing it does speak to is a previously unknown level of community activity.

Jericho exerted a strong influence on scholars' conceptions of the earliest villages. At four hectares in area, it was significantly larger than previous settlements. For Kenyon, PPNA Jericho phase heralded an unanticipated complexity for settled life, and she announced it as 'the oldest town in the world'. A town wall seemed to be a defensive installation, although there is no other significant evidence for intercommunity conflict during this period. Another idea was that the wall and associated ditch were intended as flood control measures[32] against seasonal waters issuing down the steep valley of Wadi Kedron, but recent finds of sections of the town wall on the other side of the mound now render this idea unlikely.[33]

Of all the many PPNA sites subsequently excavated, Jericho is still unique for its time. It stands as some four times the size of the next largest settlements, such as Netiv Hagdud to the north in the Jordan valley [34], or Wadi Faynan 16 in south Jordan.[35] Wadi Faynan 16 is one of the few additional sites in the south to have yielded a large, special building. Although not ostentatiously grand to the naked eye, the saucer-shaped Structure 101 is at 18 metres across, the largest PPNA building yet discovered in terms of area. It contains a stepped series of interior platforms, modelled in adobe, which may have functioned as a theatre for community rituals.[36]

PPNA settlements e spread across the Levant and into the foothills of the Taurus Mountains in southern Türkiye. The region around *Şanlıurfa* has recently yielded a remarkable series of settlements with monumental constructions. They comprise oblong buildings enclosing rings of massive T-shaped pillars, such as the hilltop site of Göbekli Tepe[37], dating from 9,500 BCE. This 7.5- hectare complex features oblong buildings enclosing five-metre-high carved pillars, adorned with complex arrays of geometric symbols and figured scenes. There are some seventeen such sites now known in the region. One of them, Sayburç, features a rock-cut house interior embellished with a scene carved in relief. Its centrepiece is a standing man holding his penis, flanked by leopards.[38]

Sites with elaborate and monumental productions such as Göbekli Tepe have become a contested area in archaeology. Some scholars minimise the role of subsistence change and alternatively foreground community decisions and ideology as the drivers of change. Others believe that food production enabled the development of staple finance and labour, which enabled community members to engage in such concerted productions. Some scholars thereby argue that Göbekli Tepe was built by cooperative groups of hunter-gatherers, before the origins of agriculture, and this indicates an ideological shift which paved the way for the subsistence changes. However, despite the fact that it has not yielded significant amounts of carbonised grain, Göbekli Tepe has produced large amounts of cereal phytoliths[39] and abundant groundstone tools for processing plant food.[40] Furthermore the site dates to a period when crop cultivation was underway in adjacent areas.

The subsequent Pre-Pottery Neolithic B (PPNB) phase in Southwest Asia sees the decline of eye-catching large monuments. But at the same time, villages expand in size again, and become more sophisticated architecturally. Between 8,700 and 7,000 Cal BCE the agrarian PPNB farming village way of life spread extensively and became entrenched across the Fertile Crescent. Many

large, crowded settlements of rectangular houses emerge, founded on economies of domesticated cereal and legume agriculture, and goat and sheep herding.[41]

From Round to Square: the rectilinear revolution

The PPNB period ushered in a major development in settlement history; the shift from curvilinear (round and oval) houses to rectilinear (square and rectangular) ones.[42] The rectilinear revolution may not be as well-known as the agricultural, urban and industrial ones, but it was just as consequential for the shape of human settlements. Before this transition, there were virtually no rectangular houses in the world. After it, virtually every large established village or town (with a few tenacious exceptions) was comprised of rectilinear building units. The change is best seen at Jerf al-Ahmar in north Syria, which spans the PPNA-PPNB transition.[43] At the outset, houses appear as single, circular cells. In the next phase, two circular units are joined. Subsequently, curvilinear buildings with rectilinear partitions appear. Finally, fully rectilinear homes with square rooms are developed. It is not clear why the curvilinear to rectilinear revolution occurred. It is unlikely to have been a perceptual revolution, whereby artificial rectangular forms first had to be first imagined, since they didn't occur in the natural world. Many geometric rectilinear forms occur naturally, such as crystals, jointed rock formations, honeycomb, fossils, and animal epidermises (for example, the scute patterns on tortoise-shell). In the Natufian period, over 3000 years earlier, rectilinear geometric shapes were often carved in bone and stone.[44]

It is more likely to do with effort expended for anticipated return. Once long-term residency in a locale was anticipated, rectilinear architecture provided many practical advantages, conferring the ability to readily add on rooms, to build upper stories, to arrange building units in neighbourhoods demarcated by streets (along which drains might efficiently flow), and to provide ready axes of orientation. Rectilinearity enabled the construction of repeatable units.[45] It is thought that the shift from curvilinear to rectilinear architecture characterises the rise of truly sedentary communities.[46] Some communities practise seasonal agriculture while living in rectilinear villages, such as in the Deccan peninsula of India. But in other seasons of the year, they switch to mobile pastoralism and revert to living in circular houses.[47] Thus, it appears that anticipated, long-term residence underpins rectilinear architecture. While rectilinear planning goes well with permanence and large settlements, local tradition may override these types of general trends. In parts of West Africa, agrarian Mousgom villagers (in Cameroon[48]) still live permanently in villages of round adobe houses because they value their architectural traditions.

The architectural sophistication achieved in the PPNB period is best apparent in a series of settlements that arose in Jordan after 8,300 BCE. Plaster was a pyrotechnological innovation of the greatest importance in this period, providing a durable and mouldable building material. It was also useful as a medium for artistic expression.[49] Plaster had been known, on and off, since the Natufian period. But in the PPNB, it came into its own and PPNB builders fell in love with it. At 'Ain Ghazal, the walls and floors of houses were routinely coated with kiln-fired plaster and often painted red. Good preservation of deposits at Basta in southern Jordan has also revealed the extent of PPNB architectural sophistication.[50] Stone houses with quoined corners reached double stories, and were endowed with tall window frames. A street passed through the settlement. At Wadi Ghuweir 1 in south Jordan, a stepped area led to a plaza. Nearby houses were even provided with passive air conditioning, in the form of shafts and vents built into the stone walls.[51]

By this period, the house had become more than just a utilitarian shelter. Communities were devising new interior domains to reflect their conceptions of the world, and to create the delights and comforts that homemaking brings.[52]

The Early village: global comparisons

From the Middle East, agrarian villages spread northwest into Europe and southwest into Africa (specifically, into Egypt). The earliest agricultural village on the Anatolian plain was founded at Aşikli Hüyük, from 8,200 BCE.[53] The settlement then developed, according to the well-known formula, into a village of rectangular buildings, crammed cheek by jowl. The next major expansion to the west involved the settlement of Çatalhöyük (7,500 - 6,500 BCE), located on the Konya Plain in southwest Anatolia.[54] Çatalhöyük is a huge site covering an area of twenty hectares; a Neolithic tell of mudbrick, twenty metres high. Several of its layers were extensively burned, leaving it as one of the best-preserved early village sites in the Middle East.

In its heyday Çatalhöyük stood as a high town surrounded by seasonal swamps. The settlement consisted of arrays of rectilinear houses distributed around small courtyards.

Houses had individual walls, but continual rebuilding led houses to be crammed against their neighbours, so that ingress was eventually only possible via ladder entry through the roof. Subsistence was based on goat husbandry, but in continuing earlier traditions of villages in the northern Levant, images of aurochsen (wild cattle) feature strongly at Çatalhöyük. The most arresting features are a series of bovine-themed internal furnishings and wall fixtures which occur in selected houses. Modelled clay bulls' heads were set into calls, incorporating real pairs of cattle horns (bucrania). Rows of flaring bucrania were also set into benches on floors; arrangements that seem anything but practical. There are clay breasts modelled into walls, enclosing skulls of foxes, pigs and vultures - opposed symbols of life and domesticity, versus untamed nature and death. Portable baked clay figurines occur too, some emphasising female fertility. A major piece is the 'Seated woman from Çatalhöyük' (sometimes known informally as the 'panther goddess'). It features an obese woman, apparently giving birth while sitting naked on a kind of throne, the arms of which terminate in panther heads.[55]

Although Çatalhöyük represents the high point of the Neolithic village way of life, its houses are all similar in size. They do not have specific or specialised functions, but incorporate a complex combination of quotidian areas, including 'clean' and 'dirty' areas, ritual and religious iconography, and buried kinsfolk lying beneath floors. With their evocations of past traditions and kinfolk, some of the residences have been interpreted as 'history houses'. Çatalhöyük is instructive in considering the differences between the archaic village and the modern city. As with Jericho, Çatalhöyük's exceptionality has led it to be cast as one of the world's first cities, although it lacks major characteristics of urban systems.

After its arrival on the Greek mainland around 6,500 BCE, the farming village then spread through the Balkans and across the northern European plain. By preference, The first farmers in western Europe settled on rich alluvial loess soils in river valleys. They are identified with the so-called Linearbandkeramik (LBK) / Linear Pottery culture, named for the characteristic pottery found in their settlements.[56] The LBK culture spread across the northern Europe plains rapidly between 5,500 and 5,200 cal BCE. At Bylany, in the Czech Republic (5,500 cal BCE), house plans were recovered from the impressions of postholes in the ground. Large, rectangular long-houses were built with massive timber posts down the middle. The substantial foundations could support load-bearing walls and second storeys. Secure habitations were needed for protection against the cold of the northern winter. Interpretations of the floor areas indicate tripartite interior divisions into stock-pens and storage areas, as well as living quarters.

Farmers arrived in Britain around 4,000 BCE, but for many years their living quarters have been thin on (or under) the ground. On the contrary, henge monuments such as Avebury and Stonehenge (dating from 3500 BCE) are spectacularly evident. Until recently, no occupations had been discovered at Stonehenge, and so it was thought that people might have visited it from their domiciles far afield. More recent excavations have shown that during the main phase of Stonehenge's construction, around 2400 BCE, a massive village of at least 300 houses existed at nearby Durrington Walls.[57] The village remains lie under shallow topsoil and houses have been identified from subterranean floor plans, interior features and postholes. They are essentially square, or squarish, and contain quantities of utilitarian grooved-ware pottery. There are also masses of pig-bone refuse which indicate seasonal feasting. The excavator believes that Durrington Walls was a seasonally occupied encampment. People arrived from far and wide across Britain to participate in great mortuary ceremonies at Stonehenge. From time to time, while there, they rebuilt or renovated the monument as well. Chemical analyses of residues from pots demonstrates feasting on pork, beef and dairy products. The wider regional significance of Stonehenge as a cult centre is also demonstrated by strontium-isotope analyses, which show that cattle were led to Durrington Walls from all over Britain. The monument seems to have been a major pilgrimage destination; a kind of prehistoric version of Chaucer's *Canterbury Tales.*

The houses at Durrington find parallels with one of the only other major Neolithic villages excavated in Britain, at Skara Brae in the Orkney islands. Almost without rival in the annals of prehistory, the owners of these well-built stone houses provided their interiors with an extraordinary range of stone constructions, looking like regular furniture, and sometimes interpreted as 'cupboards', 'dressers', 'beds' and 'shelves'.[58] Mike Parker Pearson believes that they may have functioned as ritual containers, rather than the furnishings of houseproud homeowners in the modern secular sense.

Looking southwest to Africa, the farming way of life did not spread to nearby Egypt, only a few hundred kilometres away, for over five thousand years after its inception in the

southern Levant. This may have been because the annual inundation of the Nile River provided a regular source of water and predictable conditions for mobile bands of hunters and gatherers, nullifying the effects of variable seasons. When food production did arrive from the north-east, it leapfrogged the Nile valley and landed first in the Eastern Sahara, where mobile pastoralists began to herd imported cattle, and sheep and goats, between 6,100 and 5,400 BCE.[59] During this period, moist climate transformed the desert into verdant grassland.

The village way of life arrived in the Nile Delta around 4,750 BCE at the site of Merimde beni-Salame,[60] some 25 hectares in area. The site contains a network of small, round, mud houses, and yielded pottery and food-processing implements. Local resources such as native African sorghum and a wide variety of local fish and waterbirds continued in use. Additionally, southwest Asian food imports were present: domesticated emmer wheat, barley and bitter vetch were cultivated, and domesticated sheep, goat, cattle and pig were herded. Whereas the various constituents of the farming village in Southwest Asia developed episodically and over millennia, the Levantine package arrived all at once in the Nile Delta. Conditions there were ideal for farming and so the settlement at Merimde bloomed quickly, far outstripping its Southwest Asian predecessors in size. It was not long before the fecundity of the Nile propelled the region into a sophisticated civilisation, founded on riverside cities and temple complexes.

To the north-east, recent fieldwork projects have extended the range of PPNA and equivalent sites around the hilly flanks of the Fertile Crescent, with the excavations of Qermez Dere in Iraq[61] and Chogha Golan and Sheikh-e Abad in Iran.[62] Descending from the Hindu Kush into Central Asia, village life appeared later than in the Fertile Crescent, but in no less impressive form. Mehrgarh is located on the alluvial Kachi Plain, by the Bolan River, in Baluchistan.[63] Consisting of a complex of associated and overlain mounds, it is a huge tell which attained 200 hectares in area. The aceramic phase 1A alone (7,000 BCE) is reported to be 7 metres thick. For its time, Mehrgarh stands in splendid isolation in the Indian subcontinent. The site has yielded a series of precocious developments: the cultivation of four species of cereals, the use of date palm and cotton by 6,000 BCE[64] and the cultural control of sheep, goats and cattle. Large, compartmentalised storage buildings occur by the same date, handmade pottery by 6,000-5,500 BCE, and wheel-made pottery, specialised ivory and steatite crafts, and copper metallurgy, all by 5,000 BCE.

Recent research has demonstrated China as an important cultural counterweight to the Middle East, in terms of the complexity of village life. Xiachuan Upper Palaeolithic campsite yielded grinding slabs and flint blades bearing silica gloss, resulting from the harvesting of cereals at 24,000 BCE.[65] This find implies that consumption of cereals was occurring in China some 10,000 years before the appearance of farming villages there. This progression is rather like the Levantine sequence, for example at Ohalo II. However, a point of departure from the Middle East comes in the form of pottery, one of the great surprises of recent years. In China, Japan and the Russian Far East, pottery dates from 15,000 to 13,000 BCE.[66]

Discoveries in China have proceeded at a rapid pace. The dating of Shangshan in the Lower Yangzi Valley pushes back the sedentary village with pottery and rice to 9,000 BCE. Pile dwelling F2 at Shangshan is already in rectilinear form.[67] The use of raised houses in marshy areas continued as a tradition in the south from these early times. Hemudu in the Hangzhou estuary near Shanghai revealed a 4-hectare village site (5,000-4,500 BCE) in an ancient swamp, which conferred good organic preservation.[68] Hemudu featured rectilinear wooden houses, up to 23 metres long and 7 metres high, built up over the water on stilts. The wooden buildings were with advanced carpentry techniques, such as mortise and tenon joinery. Judging by the debris scatter, rubbish was dumped into the swamp beneath the houses. So, by the Neolithic, an architectural adaptation to living by water had been achieved in eastern Asia. Pile dwellings, whether extending over the networks of rivers and canals of the Asian mainland, or the "world of islands and inshore waters"[69] of peninsula Southeast Asia, is an architectural style that has continued down to the present. Needs for sanitation, aquatic food resources, transport and the provision of unlimited volumes of water are neatly accommodated in this way of life.

In northern China, the Yellow River (Huang He) basin was a major centre of Neolithic village life; the wellspring of the earliest Chinese civilisations. By 5,000 BCE, the Yangshao culture had formulated complex village structures and achieved technological sophistication.[70] Yangshao period agriculture was not based on rice, as in the south, but on millet; a durable and cold-resistant panicle grass. Protein was obtained from the north Chinese triad of

domesticated animals: pig, dog and chicken. The best known Yangshao site is Banpo, a large oval mound five hectares in size. Banpo was large and well-planned, with internally differentiated areas demarcated for special functions. In the central sector were located houses, along with storage pits and animal pens. A defensive moat encircled the village, and pottery kilns and cemetery lay outside this perimeter. Houses were semi-sunken with central wooden posts, and finished in wattle and daub. Besides a majority of circular pit-houses, Banpo also yielded larger, more carefully built square pit-houses, possibly for elite leaders.

Cultural trajectories in the New World, provide both sharp contrasts to the Old-World sequences and challenges to the idea of universal theories of human development. Mesoamerica has an unusual dearth of domesticable animal species. There are no large mammals available for transport or traction. On the other hand, the region has bequeathed to the world a wide range of important plant crops: maize, beans, squashes, gourds, chilli peppers, avocadoes, amaranths and chocolate are some of the many Mexican food plants that have conquered the world.

In Mesoamerica, the development of agriculture is not accompanied by the kinds of socioeconomic intensification that we see in most other places. The first simple huts appear as long as 6,000 years after the first domesticated plants, which occur as early 8,000 BCE. So, the question remains, where was everybody? New, earlier dating of humanity's presence at Chiquihuite Cave in Mexico (24,000 BCE)[71] and human footprints in New Mexico (USA) at 23,500 BCE[72] have doubled the length of human occupation in the Americas. These new discoveries render the long time-lag leading to earliest food production and village life even more intriguing.

The arid highland valleys of Oaxaca and Tehuacán are two locales of earliest food production in Mexico. At Oaxaca, domesticated squash is evident in Guilà Naquitz rockshelter before 8,000 BCE, whereas the first houses appear only in the Tierras Largas phase (1,730-1,520 BCE).[73] They are simple affairs, with floors represented by dark-stained earth. Fragments of clay daub preserve the imprint of the canes used to build the walls, and the ropes used to lash them together. A one-room temple on a large stone platform occurs then at San José Mogote in the Oaxaca sequence at 1,150 BCE. Domesticated food plants in the Tehuacán Valley[74] appear at similarly early ages to Oaxaca. Here, also, simple pit houses occur much later in the Abejas phase (3,825–2,600 BCE), and constructed houses not until the Ajalpan phase at 1,000 BCE. Developments in the lowland rainforests occurred at a similar rate. Remains of thatched houses at Cuello, Belize, are evident by 1,200 BCE, evidenced by postholes set into lime-plastered surfaces.[75]

A second, independent hearth of food production occurred in South America. Again, the developments occurred with a distinctive suite of plant and animal resources, many of which - peanuts, potatoes, tomatoes, quinoa (and last but not least, the coca leaf) - have become global favourites. If Mesoamerica proved to be a challenge for general theories about the origins of village life and cities, then South America seemed at one stage to make a mockery of them. Until the last few decades, the continent has virtually remained *terra incognita* for research, yet discoveries made in the twenty-first century are some of the most revolutionary ever to have been made into the origins of village life and civilisation.

For decades, the early settlement of Monte Verde in southern Chile[76] had remained an anomaly. Its habitations were built as rectilinear structures from the very beginning. There, tentlike structures with fabric or hide superstructures were anchored by rows of posts and planks. Monteverde's early date of 12,850 BCE was somewhat incongruous, given the absence of human occupation further north in South America. Now, an Ice Age human presence in South America is graphically attested by extensive rock-art panels, found at Serranía de la Lindosa in the Colombian Amazon. They include images of extinct megafauna such as sloths, horses and mastodons, and date from at least 10,650 cal BCE.[77]

In Peru, excavations in the Ñanchoc Valley have demonstrated cultivation of squash (7,200 BCE) peanut (5,800 cal BCE), quinoa (6,000 cal BCE) and cotton (3,400 cal BCE).[78] The remains were recovered from sealed house floors and hearths accompanied by stone hoes and grinding stones. Agricultural plots were located adjacent to the site, fed by irrigation canals dating back to 5,500 cal BCE. Coca leaves and burnt lime for the plant's processing were found in subsidiary huts, dating 6,000 cal BCE. Apart from domestic habitations, paired mounds, up to 25 metres long, were discovered in the Ñanchoc Valley, associated with lime production areas. The mounds date to 6,000 BCE and contain ritual items. So, we see that as in the Middle East and parts of Europe, non-domestic, arcane or ritual construction has been a central interest of human communities since the earliest settlements.

It has usually transpired that elaborate constructions were founded on a base of food production. But in North America, an extensive series of mounds and an unusual earthwork feature was raised by hunter-fisher-gatherers on a plain over 370 hectares in area, at Poverty Point, near the Mississippi River in Louisiana.[79] Dating between 1,700 and 1,100 BCE, the centrepiece of the system is a crescentic array of six curved ridges formed by raised earth deposits, intersected by five, low paths emanating from the focal area of the arrangement. The long axis of the curved earthen arcs extends for more than a kilometre. Viewed from the air, the monument is reminiscent of a giant, ancient Greek theatre. Poverty Point undoubtedly had symbolic or ritual meaning for its makers and it was also a place that they occupied frequently.

Paradise lost

Sedentary village life involved settling down in one place. There was much security in this way of life, but it also involved entering into a form of devil's bargain. Vacating territories to allow them to recover was no longer possible when the world had filled up and each parcel of land was accounted for. Sedentary tenure was accompanied by some significant challenges. There was the chance of drought and pestilence from year to year. Longer-term problems emerged through land clearance, and consequent soil erosion.

The most intriguing evidence for such changes occurs at the PPNB village of 'Ain Ghazal (situated in the northern suburbs of modern Amman).[80] Habitation there began around 8,700 BCE. Following its foundation as a 1 to 2-hectare settlement, 'Ain Ghazal underwent periodic expansion, represented by four major archaeological phases. The village grew successively from five hectares, to ten, and reached thirteen by its end. The earliest phase features large, single-roomed structures with plastered floors and large posts. Post sizes decline through time and room sizes concomitantly shrink with the disappearance of long spans of timber. Large numbers of trees were consumed to provide the posts. In addition, the surrounding forests were heavily exploited to fuel kilns which produced lime plaster. Houses were painstakingly plastered and re-plastered on an annual basis. Studies show that each house-plastering required large quantities of wood for fuel. The oak forest would normally regenerate; however, increasing numbers of herded goats provided the knockout environmental punch. Initially, 'Ain Ghazal hunters took over fifty species of animals, but the diversity of wild animals nosedives by the late phases. The decrease coincides with a noticeable increase in the numbers of goats and sheep. Grazing pressure by goats short-circuited the normal regeneration of vegetation, clearing habitats for a range of the wild animals that the villages had formerly hunted and precipitating the onset of soil erosion According to this model, early villagers may have contributed to their own demise by unwittingly setting off a feedback loop of environmental problems. Alternatively, the end of the PPNB adventure may have been exacerbated by a climatic downturn during the '8.2 ka spike',[81] recorded in Greenland ice-cores; a brief but dramatic cool and arid event occurring between 7,300 and 7,000 BCE.

Before leaving the world of villages, it is interesting to consider how their archaeological signatures vary on different continents. There is great variability in archaeological preservation around the globe. Virtually any ancient village excavated in the Middle East yields robust vestiges of mudbrick or stone houses, crammed with artefacts and enveloped by thick deposits. Yet, in North America and Australia, even well-established traditional settlements have left only evanescent traces. *Síi Túupentak* was a substantial Native American Ohlone village in the San Francisco Bay area, before its forced relocation in the nineteenth century.[82] Although members of the Muwekma Ohlone community whose forebears lived there had specific knowledge about individual buildings, the archaeologists investigating the settlement could find no trace of them in the ground. In Australia, Bruce Pascoe has argued that sedentary village life did exist before Europeans arrived in the continent,[83] based on observations made by early European explorers. It is an issue that has become prominent in Australian social and political debate.

To date, no secure evidence has demonstrated that Indigenous Australian hamlets, villages, or house clusters were occupied other than on a seasonal, semi-sedentary basis.[84] Stone architecture intermittently occurs, especially in fields of fragmentary rock where rubble could be cleared and stacked to produce hut foundations. The oldest examples date to 9,000 years ago on Rosemary Island in the Dampier Archipelago, off the Pilbara coast of Western Australia.[85] Footings of Indigenous dry-stone houses are still extant further north on High Cliffy Island in the Buccaneer Archipelago.[86] Other examples occur intermittently across the continent, with remains of circular basalt hut footings found at Tae Rak (near Lake Condah) in

southwestern Victoria.[87] Reports of round huts, reinforced with stone and sod bases, used in living memory, derive from the Sydney region and in South Australia, houses of the Yawarawarka people with stone slab roofs were reported in the early twentieth century.[88] By and large though, Aboriginal houses were largely or solely built of perishable materials and these types disappear over time. For example, William Thomas in 1840 described and drew a substantial Aboriginal settlement of domed huts at Caramut in Western Victoria, but archaeological investigation of the site showed little trace of it.[89] Known mainly from the evocative drawings and brief textual reports of early European explores, the Indigenous village is a research area that may be further rewarded by fine-scale archaeological excavation beneath the topsoil.

Cities and Civilisation

Cities are regarded as being synonymous with civilisations, so it is useful to consider the concepts developed about the State-level societies that anthropologists call civilisations, and which build cities, in order to provide some context when we endeavour to interpret ancient urban remains. The term 'civilisation' is derived from the Latin verb, *civis,* "to be a citizen". This tells us about the point of civilisations; namely, to take part in a great, collective social organisation. The Romans were good at both building cities and organising large numbers of disparate peoples into their own version of civilisation. But the word 'civilisation' is construed to mean different things in common parlance. The Oxford Dictionary defines 'being civilised' as "to bring out of a state of barbarism, to instruct in the arts of life; to enlighten and refine." Another definition is 'intellectual, cultural and moral refinement. So, lurking behind the word is the suspicion that civilized people and civilisations are more sophisticated than other types of societies; that people in them practice high culture – drama, poetry, painting, opera, or that they eat with good table manners - in short, they're civilised. It is no wonder then that some traditional and indigenous peoples treat the term with misgiving, particularly when they are left out of the definition altogether. Even a highly reputed dictionary can define people without civilisation as 'barbarians'. A common response to this sort of semantic jousting is to proudly include oneself in civilisation.[90]

Anthropology and archaeology grew up with industrial civilisation in Europe. Nineteenth century Europeans were impressed with their own success, and they thought of themselves as the natural successors to certain earlier peoples. Academic schemes of social evolution were developed, such as those by Lewis Henry Morgan and Edward Tylor.[91] These frameworks saw civilisation as the dominant form of urban society, straddling lower forms of social organisation. They were categorised, in turn, as 'savagery', denoting small-scale bands of mobile people (generally, hunter-gatherers) and 'barbarism', denoting simple farming communities. Each of the stages were equated with newly discovered traditional peoples that colonial explorers encountered around the world, and by the earlier twentieth century, with archaeological sites and phases too.

By the mid-twentieth century, Elman Service had done away with subjective labels and provided a revised, four-stage scheme,[92] with 'bands' describing small-scale, mobile, hunting and gathering societies, and 'tribes' referring to larger societies with charismatic leaders (usually of small-scale village farming societies). Chiefdoms referred to larger polities where leaders with 'ascribed' hereditary status could ascend to power, due to kinship links with prior elites, even if personal qualities were uncertain. 'State' or 'State-level' societies are equivalent to the 'civilisation' stage. States have much larger populations than chiefdoms and are often territorially based. They are city-based (urban), with power enshrined in a permanent office of rule. Order is maintained by coercive state forces. There are a range of social classes and specialisation of labour roles. States are usually literate and more technologically developed than smaller-scale societies.

With a few tweaks, this system has held up tolerably well, except that the stages of any such classificatory system are abstracted. Some societies appear to span categories, and even developmentally, to jump stages. Then there are other forms of possible governance. Timothy Pauketat is skeptical about the ubiquity of archaic chiefdoms.[93] With an absence of evidence of many obvious personal status symbols in the Neolithic of Southwest Asia, it is possible that the evolutionary scheme from tribe to chiefdom to state is not applicable. Oligarchies and theocracies are likely alternative social systems for the ancient Middle East.

The Social Constitution of the City

For an entity so large, manifest, visible - and perhaps to many of us - so natural, the city has been the subject of many different types of explication. Of the genre of urban studies, Watson and Gibson observe that, "People are

entitled to be confused, even a little intimidated by the way towns and cities are studied today. Contemporary courses in urban studies cover just about every conceivable aspect of the urban experience. Some approaches are relatively self-contained and coherent but most into shade into each other."[94] These overlapping interests include the ecological setting of cities[95] but mostly the social landscape of cities; for example, how differential access to opportunity is played out according to race, social class, and the demographics of age.[96] The urban context is also of great interest in popular literature. Bryson's account of the modern home[97] sets out to be entertaining, but stands nonetheless as a detailed compendium of the technological history of the house and its contents, and parallels the interests of Big History.

It is noticeable how few specialists of urban studies take into account the historical perspective offered by the ancient city, a research avenue which has been utilised extensively by archaeologists.[98] This review also proceeds from an archaeological standpoint, and it emphasises the functional and social mechanisms that enabled urban systems to develop. A useful place to start is with 'The urban revolution' by V. Gordon Childe.[99] This paper has been billed as the most cited article ever written by an archaeologist. Childe, working in the early twentieth century, was then the most prominent investigator of nascent village and urban life.

Childe proposed ten criteria that characterise urban systems: 1) cities are much larger and more densely populated than even the most overgrown of early villages, 2) the roles of residents in cities are more specialised than those which occur in villages, with specialist professions and skills supported by surplus production drawn from a rural hinterland, 3) significant capital could only be accumulated by taxation imposed upon peasant farmers by a ruling class, 4) all early urban centres feature truly monumental architectural complexes, such as temples and palaces, rather than just large monuments, and these places are the seats of power, 5) the average person was robbed of political and cultural agency by a ruling class, which, on the other hand, provided organisation and security, 6) early urban societies were impelled to develop writing and accounting systems to organise communities and account for expanding resources, 7) the establishment of writing and number systems promoted the advance of technology and evidence-based science, 8) a result of the increasing specialisation of labour was the advent of a professional class of artists, whose products increasingly became tied to the political representations of a ruling class, 9) the accumulation of capital funded elites to engage in long distance trade, especially in precious metals and stones, and 10) the increasing specialisation of various labour classes led to their functional interdependence, with a way of life increasingly based on residence and locale, rather than kinship relations.

In order to maintain a system where a few at the top garnered most of the resources, state-based religions were promulgated, emphasising the divine rights of leadership, reinforced by the building of temples. At these imposing buildings, the populace could pay obeisance to the deities that guaranteed the prosperity of the city. Increased numbers of people living in one place, according to various specialized branches of knowledge and skills, should have accelerated the degree of social differentiation. Gregory A. Johnson conducted an analysis of statistical patterns of present communities of varying sizes, concluding that an increased degree of social differentiation should have rapidly occurred in the early village. His analysis of populations in the early cities showed an even stronger degree of hierarchization.[100]

Childe's treatise influenced urban studies greatly, whether by its acceptance, or by scholars moving to reject some of the points. In recent decades it has become evident that social organisation and community ideology (usually manifest as religious control by elites) count much more than a checklist of traits in determining the rank of a state or the level of a city. For example, the Inca of Peru lacked extensive metallurgy, writing, money or wheeled transport, and yet they developed a high-level civilisation numbering up to ten million subjects in a huge territory stretching from modern Ecuador to Chile.

Modern city planners and politicians consider the city from a functional perspective. But the ancient view of the city may have been quite different. Norman Yoffee argues that ancient communities held much stronger emotional bonds to their city than most recent people do to theirs.[101] The ancients believed that their city represented the wellspring of their community, and physically housed the deity that they worshipped. At the dawn of history, such conditions were evident at cities such as Nekhen (Hierakonpolis) in Upper Egypt.[102] Nekhen, 'The City of the Hawk' was considered to be where the god Horus lived, in his temple. The actual spot was sacred, and the city's functions sprang up in relation to it. It is still startling, as a secular citizen of a western city, to visit surviving temples

of this type in Egypt, such as the Horus temple at Edfu, to approach its great portico, and be confronted by the giant statue of a sharp-beaked bird.

The City Bursts into Being

After the Pre-Pottery Neolithic B period, Middle Eastern villages remained limited in size for some 5,000 years, never exceeding 30 hectares in area.[103] Around 3,500 BCE, a rapid shift to a new settlement form occurred in southern Iraq - and the city was born. That it happened in an instant, so to speak, against the backdrop of geological time, suggests that a ceiling of limits had been broken, and a new community scale achieved. These events took place on flat plains where life and possibilities were nourished by the two rivers flowing to the Gulf; the Tigris and Euphrates. The place that became known to us in the earliest writings as Sumer saw the advent of the first earliest urban civilisations, representing a profound transformation of human life. Communities were grouped into city-states, located along the rivers and on canals that were dug between them. A crucial prerequisite was the advent of extensive irrigation canals in the village-based societies of northern Iraq. The age of the earliest ditches, at 5,900 BCE, has been determined by radiocarbon dating organic materials at their base, at the site of Choga Mami.[104] When transferred to the southern plains the new infrastructure unleashed the productive power of water, brought to rain-starved soils.

In the south, the site of Uruk underwent a series of dramatic increases in size around 3,500 BCE, expanding to 250 hectares in only a few generations, and resulting in the creation of the world's first city.[105] It was a huge establishment, with walls 10 kilometres around. Uruk was principally made of mudbrick, with large temples and palaces at the centre. The imprint of this, the world's first city, still remains. Its massive walls and great gate are still visible on Google Earth. One has just to type in its modern Arabic name, 'Warka' (the Erech of Genesis) to arrive at it. No less remarkable is that its name has survived for over 6,000 years, when we consider that the long initial vowel 'U' in 'Uruk' also stands for the consonant 'W' in Arabic, and that short vowels shift around in Arabic words.

The ancient cities of Lower Mesopotamia now lie stranded in the desert by changes in the course of the rivers, and the lowering of the water-table through the regression of the Persian Gulf. In the fourth millennium BCE, the water-table was higher, and the head of the Persian Gulf was located far to the north of its current position. The ancient city of Lagash still lies far enough south to retain its position on fresh water.[106] It was one of the largest Sumerian cities. Its surviving mound, Tell el-Hiba, reaches 3.6 kilometres long, and the ancient city attained the size of 600 hectares. Recent work by archaeologists from Sapienza University in Rome have found the oldest harbour from ancient Sumer at Abu Tbeirah[107], which was still in operation around 2,000 BCE. Even, at that time. Abu Tbeirah was a seaside city, since the ocean stretched 200 kilometres further north into Iraq than it does now.

Temple administration seems to have held sway in the first cities. In southern Iraq, the earliest Sumerian city was the temple complex at Eridu, (5,900-2,000 BCE).[108] To the Sumerians, as we know from later literature, Eridu was a holy city, revered as the source of the 'Abzu', the mythological sweet waters upwelling from the earth. According to the Sumerian king list, kingship first descended from heaven at his place. Here, a sequence of sixteen successive temples were built over 3,000 years; the first just a tiny chapel with fish bone remains strewn remains around an altar. Interestingly, a later historical-period temple was dedicated to Enki, the Water-God. The holy buildings grew successively larger, until huge mud-brick temple platform remains called ziggurats supported formalized temples. This example shows the continuity and tenacity of religious belief, from earliest settlement into historic times.

At the heart of Uruk lay massive temples, large administrative buildings and substantial storage facilities. In the Kullaba area of the site, the 'White Temple' rose above a great brick platform, or ziggurat. The temple in historic times was dedicated to the God Anu. The complex would have provided a shining symbol of power, and a familiar landmark in a flat land. These cities were not originally brown, drab and dusty as they appear now. Facades of some buildings were finished in gaudy patterns, by inserting large ceramic cones terminating in coloured enamel, an ingenious way of maximizing limited local resources. Beside the White Temple lies a great stone storage building providing the economic basis for the temple's power.

Did ancient Egypt have cities?

One of the challenges to Childe's conclusion that civilisations were invariably urban in character came from early Egypt, a place where the world's first territorial state[109] emerged around 3,000 BCE. The nascent Egyptian

state is known for its mortuary architecture, a tradition that developed initially in Upper Egypt (by 3,500 BCE) at Hierakonpolis and Abydos. After the centre of power shifted to the north (Lower Egypt), mortuary buildings continued to grow in size, with large benchlike structures called mastabas built in the Early Dynastic period. Then came King Djoser's revolutionary Step Pyramid (2,600 BCE), and finally the straight-edged pyramids, crowned by the group on the Giza Plateau. In their time, these buildings were the largest and most imposing on earth. Yet, for decades it was believed that there had been no nucleated cities to accompany them, and that the ancient Egyptians had lived in dispersed, rural communities along the Nile. It is now realised that the apparent absence of built settlements along the valley is largely due to their concealment by the deposition of alluvial sediments on the Nile floodplain through time, (averaging up to a metre every thousand years).

Recent research has shown that cities had appeared already by the Predynastic period (*ca.* 3,500 BCE). Excavations at Hierakonpolis (Nekhen)[110] in Upper Egypt have revealed housing and large, specialised workshop areas, such as pottery kilns. Industrial-scale fermentation vats were capable of producing 390 litres of beer per brew. There was an immense ritual field, surrounded by posts and dumps of sacrificed animal bones. Here, also in the late nineteenth century, was discovered the predecessor to the temples raised to the god Horus. The first version was a revetted oval stone enclosure, and within it was discovered a foundation deposit filled with precious symbols of power. They comprised ceremonial maces and inscribed slate palettes dedicated to the first leaders, one called King Scorpion and then - in bridging the gap to when Egyptian writing can be read - another called King Narmer. Narmer's revolutionary palette, claiming the conquest and unification of all Egypt, serves as the entree to Egyptian history, just as it now greets the visitor to that heritage in the foyer of the Egyptian Museum at Cairo.

Memphis was the first hub of a newly unified Egypt around 3,000 BCE, located strategically at the point where the Nile meets its delta. Here, the new capital symbolically bound the two regions of the country together.[111] Located on the west bank of the Nile at Saqqara, the ancient city was positioned close to the first series of tombs and pyramids. The ancient Egyptians called their city 'White Walls' (*Inbu-hedj*). Excavations had not until recently found occupation earlier than the Middle Kingdom (before 2,000 BCE), but the antiquity of the city was suggested by an inscription relating the journey of a Predynastic leader, Iry-Hor, to Memphis around 3,200 BCE. Now, the great walls themselves have been discovered - eight meters wide and rendered on both faces with gleaming plaster.[112] Memphis was the quotidian companion to the Great Pyramid of Khufu, shining in the sun under its dazzling skin of Tura limestone.

African Urbanism, further south

Beyond Egypt, comparatively little is known about early urbanism in the diverse continent of Africa. Cities came later to its southern regions than they did to Egypt, but there they developed into a number of distinctive forms.[113] The relative lack of research into African settlement history has been underlain by the disdain for African culture held by some prominent European scholars[114] and some of the world's most powerful First World politicians - even into the late twentieth century,[115] and even into the present day.[116]

To the south, beyond Ancient Egypt (and even it is not always exempted from the purported roll-call of African civilisations without history[117]) arose many rich civilisations. Jenné-Jeno. Located on the Niger delta in Mali (200 BCE - 900 CE), was the earliest of the great cities of the Sahel. Jenné is famous for its great adobe mosque, replete with triple minarets and layers of protruding palm wood planks used as scaffolding. Before the coming of Islam, the city grew rich by exploiting its fertile valley for rice agriculture and engaging in trade to the east. Jenné-Jeno lacked clear signs of elite hierarchy and appeared to develop through the cooperative efforts of a series of local communities.[118] Further to the north in Mali, Timbuktu emerged as a green and canal-lined city in the thirteenth century, fuelled by a lucrative trans-Saharan trade in local salt, exchanged for gold.[119] In its heyday, this isolated place became a major intellectual centre, boasting one of the world's earliest universities. An unusual tradition arose here with private libraries dotted through the city amassing some 700,000 manuscripts, ranging from classical scholars such as Plato and Aristotle, in Arabic translation, to writers of the Islamic period.[120]

During the same period, a dynamic hybrid culture arose on the Swahili coast of East Africa. In trading cities such as Kilwa and Lamu, local African cultural elements were merged with a host of traded goods and influences arriving across the Indian Ocean.[121] Grand mosques and mansions

were erected in these cities, entered by distinctive doors of the Swahili architectural tradition. So disregarded was Africa, that the most exceptional and idiosyncratic production of the south, Great Zimbabwe, stimulated European settlers to deny its indigenous origin. That Great Zimbabwe was built by local Shona people was demonstrated twice by archaeologists in the early twentieth century, culminating in the investigations of the great field archaeologist, Dorothy Caton Thompson. From the ninth to the sixteenth centuries Great Zimbabwe became enmeshed in the lucrative trade links of the Swahili coast, which stretched across the Indian Ocean to China. It was an unusual centre, distributed widely over more than seven square kilometres, and included impressive dry-built, stone enclosures and towers, which shielded private ritual areas and adobe houses.[122]

Cities in the Subcontinent

Together with Austen Henry Layard (the excavator of Nineveh and Nimrud), Henry Rawlinson, (the great nineteenth century decipherer of Mesopotamian cuneiform languages), discovered another important early urban centre at Susa in Iran.[123] Susa is located on the Khuzestan plain in the east of the Shatt al-Arab waterway, in the country that became known as Elam. As Uruk expanded, Susa came under the cultural and political influence of its more westerly Mesopotamian neighbour. Further east again, another great urban tradition arose on the Indian subcontinent.

The Indus (or Harappan) civilisation developed in Pakistan and Western India. It flourished between 2,600 and 1,900 BCE, and was unknown to the modern world until discovered by archaeology in the nineteenth century. By the standards of the ancient world, it may have been a pretty good one to live in. Unusually for those times, The Indus civilisation has neither yielded obvious signs of war, evidence for coercion, conspicuous consumption and extreme social inequality; nor evidence for oppressive ruler cults. Burials are never filled with elite, expensive goods, or accompanied by sacrifices. By the standards of the Bronze Age, the Indus civilisation made far-reaching investments in urban planning and public amenities. Cities were carefully planned in a grid pattern, with well-built apartments organised in residential districts. Despite lack of signs of military activity, the Indus civilisation ranged over a huge territory, more than controlled either by early Sumer or Egypt.[124]

Harappa and Mohenjo-daro were the first investigated and the two largest Indus cities, both located in Pakistan. Principal evidence has come from Mohenjo-daro, the centre of which spread over 250 hectares at its height. The city had massive gates and walls set up on thick mudbrick foundations. Mudbricks were made in two standard sizes: small for interior city construction, and large for city walls. The walls were thought to be for protection against unpredictable Indus floods, and indeed the unprecedented Pakistani floods of the last year have recently done great damage to this ancient settlement.

Mohenjo-daro was a well-planned city based on a grid system, with large city blocks and street grids oriented to the cardinal directions. Neighbourhoods were supplied with running water and sewers, and houses and apartments were supplied with bathrooms and toilets. Residential apartment blocks were built with thick external walls, shielding inhabitants from the noisy life of the street outside. Many buildings, including many private residences, were equipped with deep wells, some up to 14 metres deep (over 700 have been recorded). A system of minor drains led from small streets to major drains in broad thoroughfares. The regular occurrence of these features in cities of the Indus Civilisation has led some archaeologists to propose a unified state administration, or at least a regional system of shared cultural values**.**

Some larger public buildings were also found in Indus Valley cities such as the so-called ‘granary’ at Harappa. There is no actual evidence from the building to support this function. It may alternatively have been an administrative building, a public hall, or elite residence. Clearer in function was ‘the great bath’ at Mohenjo-daro, a twelve-by-seven-metre sunken brick pool with stepped entry, waterproofed with plaster and tar. It is unlikely to have been a kind of municipal baths for swimming laps, and was more likely intended for ritual purification.

In analysing plans of Mohenjo-daro architecture, Massimo Vidale has discovered that not all building units were small apartments or houses.[125] He has identified large residential compounds, including one with its own version of the Great Bath at its centre. This, together with the evidence from elsewhere, led him to conclude that Indus Valley society was not necessarily egalitarian, but perhaps dominated by wealthy mercantile families or clans. High-quality, low-bulk Indus jewellery, gold and semi-precious stones such as carnelian and lapis lazuli, were traded widely, as far away as Mesopotamia. But the most characteristic

product of the Indus civilisation was its varied output of carved stone seals. They feature a short inscription in the undeciphered Indus script, and are accompanied by intaglio animal images such as bulls, water buffaloes, elephants, and rhinoceroses, and sometimes mythical unicorns.

Round Heaven, Square Earth: the Chinese Conception of the City

During the Han dynasty (*ca*. 50 BCE), Chinese scholars set down the ideal characteristics of the Chinese city in the *K'ao-kung Chi.* It should be a large symmetrical square oriented to the cardinal directions, fortified by great walls punctuated by three gates per side, and divided internally into sectors by nine broad avenues, crossed perpendicularly by nine others. Paul Wheatley has interpreted the ancient Chinese city as a ritual conception, intended to reflect the nature of the celestial world.[126] Many Chinese cities reflected something of those proscriptions but the one that adhered to them most closely was the T'ang Dynasty capital of Chang-an (*Xi'an*), which crystallised in mature form around 750 CE. T'ang period Chang-an augmented and redefined earlier versions of the city. The site had been occupied as early as Neolithic times, and included the abovementioned Yangshao village of Banpo.

Even if the conformation of the Chinese city was born from a sacred vision, the result was superbly practical in terms of town-planning and the allocation of resources. For ritual reasons, and according to local geography, Chang-an varied from the ideal of a square city, but it included the required three gates, punctuating each side of its massive walls that were entered across a wide moat which lead to broad, tree lined-avenues. At its height, Chang-an's walls enclosed 80-90 square kilometres, and judging from contemporary written records, the city was one of the biggest in the world, boasting over a million inhabitants. A series of walled palaces, and a restricted imperial city were located on its north side. The metropolis was provided with two large market squares and several temples were distributed throughout its rectilinear precincts.

The Yellow River (*Huang He*) Valley in northern China has long been considered as the birthplace of Han civilisation in Chinese historiography. The Shang Dynasty is its earliest historically attested administration. Shang kings were first identified from 'oracle bones', recovered by the thousand from the capital of Yin, near Xi'an (also *Yinxu* or 'the ruins of Yin'). This practice of fortune-telling involving the burning of inscribed ox scapulae (and tortoise plastrons). Around 1,250 BCE these inscriptions become legible as the earliest Chinese writing. Also located near Xi'an in the Yellow River heartland, Yin comprises a complex series of sectors and constructions that developed gradually. The most arresting feature of the site was the royal cemetery, including eleven large, subterranean tombs. More than two thousand sacrificial victims were buried with the Shang kings. As at Ur in Mesopotamia, the First Dynasty in Egypt, and other centres in the Americas, we witness this inhumane practice as the power of early elite leaders outstripped their sense of human rights.

So omnipotent were the Shang kings, that it was formerly thought that Shang urbanism consisted of the preeminent capital of Yin, supported by a subordinate rural hinterland of minor agricultural villages. Then, in 2006, the Shang period of village of Guandimiao was excavated, 200 kilometres south-west of Anyang.[127] The work at Guandimiao represents one of the most comprehensive excavations ever conducted in China, with over two hectares of the 2.5-hectare site investigated. The results have revealed a specialised settlement of unsuspected economic sophistication. The populace inhabited square and rounded semi-subterranean houses with perishable superstructures. Areas were set aside for specialized bone tool and pottery industries, and a full range of Shang ceramics were fired in updraught kilns. Mortuary customs included human and animal burials, and a local version of the Shang oracle-bone tradition. There is a general lack of weapons at Guandimiao, in contrast to the purported Shang obsession with warfare.

In recent years it has become evident that Chinese urban development extends back a millennium before the Shang Dynasty, and that the ritual conceptions of the historical period have deep roots in the country's Neolithic traditions. By the second century BCE, scholars of the Han court had developed a strong sense of historical inquiry. Sima Qian (145- 90 BCE) produced a detailed account of China's past by travelling the countryside, investigating material relics such as tombs and monuments as well as collecting historical documents. Like other Han scholars, he sought to find his society's honourable ancestors, and to show that his society was the legitimate descendant of these shadowy societies from the past. Sima Qian produced a detailed account of China's past, commencing with the legendary Xia Dynasty, founded by the mythical 'Yu the Great'.

Excavations that commenced in 1959 at Erlitou revealed a new archaeological culture, lying in time between the

Shang and the earlier Neolithic (1,800-1,500 BCE). While there is no actual historical confirmation available, Erlitou lands in the right time and place for the Xia Dynasty. By then, it was already a large city, a square kilometre in area, arranged with residential zones and manufacturing quarters.[128] Four roads led to the cardinal points of the compass, and converged at the city's centre. Erlitou controlled sources of critical raw materials such as copper, lead, salt, stone and kaolin clay, which were imported to the city from long distances. Its bronze workers had already developed a mastery of kiln technology and produced ceremonial bronze vessels antecedent to the typical Shang types. They were to become standard ritual items in the Chinese repertoire for thousands of years. Compared to the preceding Longshan period (in the late Neolithic period), the Erlitou-phase settlement pattern is more complex and includes four size-classes of settlements. This factor hints at the establishment of state-level society, with a single capital city pre-eminent over subordinate cities and villages, even though clear evidence for literacy is lacking. Further excavations at Erlitou have revealed the first palaces known in Chinese history, set within large compounds.

Research in China has continued to push back the origin of the city, with the excavation of the settlements Liangchengzhen (at 273 hectares in area), Taosi, (at 280 hectares) and Yaowangcheng (at 368 hectares). These settlements date to the late phase of the Neolithic Longshan culture (2,600 BCE – 1,900 BCE).[129] These centres are bordered by massive, rammed-earth ramparts, are internally differentiated with domestic, elite and industrial areas, and in the case of Taosi, a solar observatory for tracking the rising sun through the year.

Outside the Yellow River heartland, discoveries continue to provide new understandings. Shimao (2,300 -1,800 BCE), located to the north-west of the Yellow River Basin, is a stone-walled city-mound 400 hectares in area, founded in the Late Neolithic period.[130] It was the largest city of its region and one of the biggest in the world for its time. It is of quite a different order than the archetypal Chinese cities unearthed to date. Its palace centre was sculpted from a loess hill as a unique, eleven-level, stepped pyramid, with a base of 24 hectares, and an eight-hectare palace on top. The city's inner stone wall enclosed an area of 210 hectares, encircling the pyramid and its surrounding urban area. The outer rampart (erected *ca.* 2,100 BCE) enclosed an additional 190 hectares. A sculpture carved in relief in stone, positioned at the base of the step pyramid complex, may represent an elite ruler. Shimao was provided with sophisticated fortifications. Its eastern gate, flanked by two towers, incorporates a U-shaped, stone barrier thirty-three metres long, blocking direct entry.

So, prehistoric cultures external to the Yellow River region played important roles in the development of Chinese civilisation. The Hongshan culture in north-eastern China dates 4,500-3,000 BCE, and at this early date we already see the naissance of elite ritual used later by Chinese elites to legitimise their rule. It is likely that prehistoric Chinese leaders ruled by positioning themselves as the arbiters of complex cosmological schemes, presaging the social discipline that characterised later Chinese society. There is no more vivid example of ritual conceptions manifest in architectural form than the Hongshan mortuary complex at Niuheliang.[131] It included adjacent altars designed in the form of the tortoise; respectively, the lower, square plastron, and the upper rounded shell. This is the basis of the conception of 'Round Heaven, Square Earth', developed further in later times. Elite personages were buried at Niuheliang, with sacred jade items ancestral to later historic types of known function, such as the *bi* disc, jade 'Goddess' masks, and jade tortoise figurines.

Pyramids and plazas:
pre-Columbian cities in the Americas

Idiosyncratic trajectories towards urbanism arose in the Americas, based on different presumptions than those conceived in the Old World. Here, complex, state-level societies arose that variously lacked metallurgy, coinage, wheeled transport, beasts of burden, and in some cases, writing; yet they created a series of spectacular and well-functioning cities. It had long been accepted that American cities first appeared in the highland valleys of Mexico, and that subsequently the Maya then developed them in the lowland forests of Mesoamerica. Now, recent discoveries along the Pacific Coast of Peru have upended previous convictions.

In the 1970s, Michael Moseley developed the 'Maritime Foundations of Andean Civilization' model.[132] His idea was based upon the presence of large temple complexes such as El Paraĩso (1,800 BCE) on the northern coast of Peru, which not only appeared to precede city life but also appeared to be unrelated to any supporting residential settlement. This state of affairs was the opposite of the Old-World scenario, where the temple was embedded at the heart of the city. More radical again was Moseley's claim

that the Peruvian examples had been built by hunter-fishers lacking food production. They were said to have done so by exploiting an unusual set of complementary resources existing on the Peruvian coast; native cotton used to make nets, and gourds used as floats, which enabled coastal fishermen to accumulate large surpluses from the most abundant *anchoveta* fisheries in the world. However, later excavations at El Paraîso indicated that while 90 per cent of protein was derived from fish, and that cotton and gourds were indeed important crops used to make nets, there were also many cultivated food plants, including squash, chili pepper and a variety of beans.[133] So, another attempt to divorce the economic realm from the social and ideological ones was refuted. As a regrettable epilogue to this topic, the material heritage underlying this saga has itself been demolished. In 2013, developers constructing a housing estate bulldozed the temple complex at El Paraîso.[134]

Even earlier urban complexes have been discovered on the northern Peruvian coast. They count as the earliest in the Americas and some of the earliest in the world, and they are always accompanied by food production. The administrative centre at Caral[135] in the Supe River Valley stretches over a kilometre in length, and includes a cluster of mounds, sunken circular plazas, and pyramids, some dating to 2,600 BCE[136] - as old as the Great Pyramid in Egypt. Even earlier monumental architecture occurs at Aspero (3,000 - 2,500 BCE), a complex with six truncated pyramids overlooking seventeen mounds, spreading over thirteen hectares.

Complexes with similar conformation have been found in the lowland forests of the Amazon. Previously, such regions were virtually impenetrable to traditional archaeology. The use of airborne Lidar in 2019 revealed a huge urban complex at Cotoca in Bolivia (500 - 1,400 CE).[137] Lidar is a recently developed mapping technique where laser beams are reflected off the ground to produce detailed and accurate plans of the earth's surface. Lidar is able to penetrate dense foliage, and has proved to be a revolutionary tool for delineating urban systems hitherto cloaked in dense rainforest. By this method, numerous habitation clusters were discovered at Cotoca. Two of them attain sizes of 100 hectares and consist of walled compounds linked by a network of elevated causeways, and containing seven-metre-high earthen pyramids.

Although food production had commenced in Mesoamerica as early as in South America, urban centres took much longer to appear in the north. Whether or not any cultural influence flowed from the south, the Mesoamerican cities developed along broadly similar lines. In the highlands of Mexico, large pyramids were set on wide avenues, complemented by huge plazas and ceremonial features such as ball courts. These cities were carefully planned according to symbolic and ritual considerations. The Zapotec capital of Monte Albán was the first to emerge around 300 BCE, persisting until 1,000 CE.[138] Its Main Plaza is a large, levelled platform, measuring 300 by 500 metres. Glyphs of the Zapotec script carved on many monuments demonstrate that Monte Albán was home to a literate people. The 'danzante' stelae erected in the city labs feature disfigured and contorted naked men, apparently sacrificial victims or prisoners of war. Some of them may be identified by accompanying inscriptions.

Teotihuacán, located north-east of Mexico City, was a progenitor for other Mexican societies.[139] The scale of Teotihuacán, covering up to 30 square kilometres in area, can be appreciated by considering the extent of the 40-metre-wide Avenue of the Dead. It traversed the central part of the city for a distance of four kilometres between the Temple of the Feathered Serpent (*Quetzalcoatl*) and the Pyramid of the Moon. Teotihuacán's other great monument, the Pyramid of the Sun, measured 75 metres in height and 225 metres on a side. Large, multi-storeyed apartments lined the main avenues. The name Teotihuacán is a Nahuatl word given by the later Aztecs, who believed that this was the place where the gods created the universe. At its floruit (100 BCE – 550 CE), the diverse material culture of the residential districts suggests that Teotihuacán may have comprised a multiethnic community. Human skeletal remains from a district showing Zapotec affinities provides corroboration, where strontium stable-isotope analysis of bones and teeth show that some of its people originated in the Oaxaca Valley.

Teotihuacán was built with regard to the concept of 'Five Great Mountains'. Lines of sight marked by the 'pecked cross motif' were placed on the tops of neighbouring mountains and aligned with the central avenue of the city and with pyramid complexes. The Pyramid of the Moon complex itself was constructed as a representation of the Five Great Mountains, with four smaller stepped platforms disposed symmetrically in front of the main building. Far away in the lowlands, some Maya elites used the *Ho'-No-Witz* (Five-Great-Mountains-place glyph as a status symbol, borrowing this ritual conception from Teotihuacán. Along with vigorous trade of goods including highland obsidian,

Maya texts also record attacks by Teotihuacano factions on the lowland city of Tikal in modern Guatemala, during the fourth century CE.[140]

Tikal was one of the pre-eminent Maya city-states that flourished in the lowland forests of Belize, Honduras, Guatemala, and the Yucatan peninsula of Mexico during the Classic Maya period (200-900 CE).[141] Tikal prospered between 200 and 600 CE, and rose to dominate several neighbouring polities. Its North Acropolis is dominated by stone temples set on high pyramids that are ascended by steep staircases, which overlook palaces and administrative buildings. The University of Pennsylvania excavation team cut narrow trenches into the pyramids of the North Acropolis, which enabled them to unravel the complex history of the monument. Maya temples were considered sacred and, like Principal Temple D at Tikal, they were enlarged and embellished over the centuries.

Throughout the twentieth century it was believed that Maya settlements did not conform well to Childe's urban criteria, consisting of reasonably small central administrative hubs with pyramids, palaces, ballcourts and plazas, but with most of the populace living in dispersed hamlets in cleared rainforest, following agricultural pursuits. Lidar survey has recently provided some dramatic revisions to this idea. Aerial imaging carried out over the Mirador-Calakmul Karst Basin of northern Guatemala has revealed a constellation of over one thousand densely packed urban settlements, distributed over nearly 1,700 square kilometres, linked by causeways.[142] Research employing Lidar and traditional excavation at the settlement of Aguada Fénix near the Gulf Coast in Mexico has yielded a rectangular platform over 1.4 kilometres, at unexpectedly early dates of 800 - 1,000 BCE.[143] Even larger centres of his type have been found to the west.

Complex datasets indicate many reasons why Maya city-states declined and disappeared in the 9th century. After 810 CE, the city of Copan in Honduras unraveled, and evidence indicates that deforestation, soil erosion and soil fertility decline resulted from agricultural over-exploitation of the fragile rainforests, leading to subsistence collapse. More recent paleoclimatic evidence indicates that the Maya city-states of the Terminal Classic Period between 800 and 1,000 CE were subject to a series of severe droughts.[144] Long-term pressure on resources, exacerbated by unsustainable farming regimes or steady deterioration of climate, may culminate in apparently sudden political crises. Historians read about warfare and rapid collapse in deciphered texts, whereas the archaeologist and paleoenvironmental scientist trace the long-term pressures that resulting in abrupt social chaos. The practice of Maya chroniclers in recording precise dates, combined with fine-scale archaeological excavation, has yielded some compelling examples. Dos Pilas in Guatemala was a thriving metropolis in 760 CE, but after an attack by a coalition of enemies, it lay in ruins in 761 CE. In a last defensive effort, the inhabitants stripped the major buildings of stone to throw up a concentric series of ramparts. It was to no effect, as the city was abandoned from that time on.

Further dramatic testimony of overrun and fall comes from the Maya city of 'Baking Pot' in Belize. A lengthy inscription on a smashed container known as the 'Komkom Vase', dated to the 23rd April, 812 CE, describes a series of inter-city battles that culminated in the destruction of Baking Pot.[145] It was one of the last Maya texts ever written. When an urban system falls apart, there follows the dissolution of economic organisation and professional life. As formalised cultural practices become incoherent, so written language, developed as the preserve of political elites and their scribes, also disappears. But the common people do not fade away. They disperse and take up village life again. They often tenaciously uphold their culture, and of course, their spoken language. It was for this reason that notes taken about Yucatec Maya speech by Diego De Landa (the conquistadors' bishop) in the sixteenth century enabled the modern epigraphers of the 1960s and 1970s to decode the Maya script. As for the Komkom Vase, it relates how the king of Yaxha fled from his city to a place 'where mosquitos abound'. The unnamed victor featured on the vase then performed a 'frog-like turtle dance' in celebration - a curious epitaph for a great tradition.

The Aztec capital of Tenochtitlán, the last great indigenous Mesoamerican city, was witnessed by the conquistadors under Hernan Cortes in 1519. In *The Conquest of New Spain,* Bernal Diaz described the awe of the Spanish invaders as they first set eyes on the city, apparently floating in the midst of Lake Texcoco.[146] The Azteca (Mexica) emerged in the Valley of Mexico as a distinctive people around 1,325 CE. Based at Tenochtitlán, they began to carve out their empire from 1,426 CE. The city was built on an island in the brackish Lake Texcoco, now concealed by the urban sprawl of modern Mexico City, and it spread over thirteen square kilometres, The landmass was augmented by heaping up sediment to build the characteristic *chinampas* or floating gardens. In

his mural, *The Great City of Tenochtitlán*, Diego Rivera captures the vigour and glamour of the capital at its height; conjuring the bustle of the markets, the sound of drums and trumpets, the glistening, green quetzal feathers, and the colour of the floral arrangements of which the Aztecs were so fond. Three causeways connected the city to the mainland and fresh water was transported into it along terracotta aqueducts. Major thoroughfares crisscrossed the city in a grid, dividing the city into ordered neighbourhood wards. The populace was highly regulated according to class and station. At its centre, the major square housed the market, palaces, various temples and the high temple dedicated to *Huitzilopochtli.* The emperor Moctezuma II's palace held one hundred rooms, each with a private bathroom. A distinctive feature of the city was its network of canals, giving rise to Tenochtitlán's description as the 'Venice of the New World'.

Despite its magnificence and its status as the key remaining exemplar of indigenous American urbanism, the victorious Cortes set about systematically levelling Tenochtitlán as soon as he could. The Metropolitan Cathedral of the Assumption of the Most Blessed Virgin Mary into Heaven was built over the top of the great Aztec temples. The core values of society are located at the heart of its cities. Down through the ages, it has been a practice of conquerors to decapitate the vanquished society and replace its holy places with their own. The Spanish conquerors of Peru did the same at Cuzco, building the Church of Santo Domingo over the Inca *Coricancha*. Perhaps the most contested space of this type in the world occurs in Jerusalem. Within the Old City, the place that Muslims call al-Ḥaram al-Sharīf and Jews call Har ha Bayt, symbolises the shared and contested succession of cultures and faith. Here, in Roman times, Herod constructed his massive temple to cover the ruins of the Iron Age temple to Yahweh. The later Dome of the Rock mosque was built over it in turn.

By the 1960s, little trace of the Aztec capital was left. A program of urban renewal undertaken in the 1970s led to disinterring some of the major monuments, which now stand in the Zócalo, Mexico City's main square. It is home to the architectural products of three cultures: the Aztec city, the Spanish colonial makeover, and twenty-first century Mexico.

The sprawling settlement of Cahokia (900 -1,350 CE), located on the Mississippi River opposite St. Louis, Missouri, is a final example of the American conception of the city, replete with plazas and pyramids.[147] Cahokia's houses, halls and administrative buildings have not survived, since they were built of organic materials. However, it is clear from its earthen monuments that the city was of a similar order of magnitude as Tenochtitlán. The well-planned settlement extended over 16 square kilometres. It comprised all the elements of urban life, including administrative buildings, residential quarters, and work areas. Its focus was a massive central plaza spreading over 16 hectares, but Cahokia's most conspicuous features are a series of great earthen mounds. The largest of these, (Monks Mound) traced out a footprint of sixteen hectares and rose thirty metres into the air. It is the biggest earthen monument ever constructed in the Americas.

A Vision for the West: the classical cities of the Mediterranean

Classical Athens was not particularly large compared to the cities we have considered. and it is dwarfed by some polities that are not generally accorded the rank of state-level societies. Using their large war canoes and aggressive warrior castes, for example, paramount Tongan chiefs expanded their control from Tongatapu over huge areas of the Pacific Ocean in the fifteenth and sixteenth centuries CE, eventually holding sway over some 800,000 square kilometres and tens of thousands of people.[148] Their polity was some 250 times bigger than the small city-state of Attica, administered from Athens.

Ancient Athens had grand buildings enough, but its interest as an ancient metropolis lies not so much in its size, but in the rich social and intellectual capital that it developed during a period of dynamic social and cultural change. Between about 630 and 430 BCE, a new kind of society was born, the first to really consider the individual's place in society, and to search for a new conception of human rights.[149] These considerations had scarcely troubled earlier civilisations. Many of the concepts we now take for granted were invented or developed in the Greek city states of this period; many of them in Athens. The list is impressive and includes concepts and inventions such as democracy, philosophy, theatre (including drama, tragedy and comedy), lyric poetry, astronomy, geometry, history, coinage, naturalism in painting and sculpture, the gymnasium, sporting carnivals and the marathon.

After the second Persian invasion of 480 BCE, Athens and other Greek states allied to form the Delian League in 478 BCE, in order to guard against another attack. This was

a kind of precursor to NATO, a treaty organization to which all the members contributed funds, stored in a treasury on the island of Delos. But as their power and influence grew, the Athenians convinced the wary allies to transfer the treasury to Athens, in 454 BCE. The associates were right to be suspicious, because the Athenian leader Pericles manoeuvred to use the Delian League funds to rebuild Athens, large parts of which had been destroyed in the Persian Wars. By these means, many marble buildings on the Athenian Acropolis were erected. They are considered the zenith of classical Greek art and architecture.[150] With the naturalistic sculptures of its pediment, metopes and frieze, surmounting a Doric-order colonnade, the Parthenon is considered as the high point of Classical architecture. Such is the Acropolis' national significance to Greece that a costly restoration project launched in 1975 was continued through to its recent completion. Internationally, the efforts by the Greek government to secure the return of the Parthenon marbles from the British Museum constitutes one of the major disputes in heritage politics.[151]

A colonnaded gateway called the Propylaea led up to the Acropolis, which held a number of votive temples and statues. Off to its right stood the small Ionic temple to Athena Nike. Another small temple called the Erektheion featured statues of draped women (*caryatids*), ingeniously formed as pillars. To the north-west, the Erektheion overlooked the Agora, the civic centre of Athens, nestled beneath the Acropolis.[152] Throughout its various phases, this space accreted shrines, temples, altars and fountains, and a number of stoas or colonnaded walkways (which came to function as ancient shopping malls). But it is the administrative and legislative foundations that disclose the level of public involvement in the running of the state. They include the Bouleuterion (council house) where the 500 elected representatives of the city conferred; the Archeia, or the original offices of the archon (an elected magistrate); the circular Tholos, a meeting place for elected officials: and the Heliaia, the law court of the city. The Panathenaic way meandered diagonally through the space.

Each new foundation in the Agora was welcomed in its own right, without much regard for a preconceived plan. Buildings are crammed next to each other and oriented at odd angles, either to fit in with incumbent structures, or to achieve desired orientations. The effect was far from the unremitting axiality of a Roman city. This mindset is also evident on the Acropolis where the major temples could be viewed effectively from different directions. This is not to say that the Athenians lacked planning sense, and ran up important buildings without forethought. On the contrary, archaeology reveals the Athenian interest in building nationalistic symbols into its architectural projects. Ruined column drums and other damaged architectural elements were built into the north wall of the Acropolis, either side of the Erektheion, even though they constituted an unattractive pile of rubble, when a fine new wall could have been constructed. The debris was gathered from the ruins of the Persian sack of 480 BCE, and the new civic buildings in the Agora were aligned to provide an unobstructed view of it. The outlook was designed as a reminder of the horrors of war and the vigilance required to avoid it.[153] Moreover, the gateway of the Propylaia on the Acropolis, was oriented to frame a view of the Bay of Salamis, where the Athenians recorded their great naval triumph over the Persians. The view was focused on the Kynosoura Peninsula where a monument to the Athenian victory had been erected.

Of all the ancient civilisations, it was inevitable that Renaissance antiquaries discovered Rome first, because its impressive ruins stood all around them. Over the former territories of the empire, from Britain to Arabia, Roman models of architecture, town planning, and even virtually complete cities remained.[154] In Rome itself, one could walk around the corner and run into the bronze equestrian statue of the Emperor Marcus Aurelius (161-180 CE), still erect.[155] Or, one could enter the portico of an intact Roman temple, the Pantheon, and behold its superb, cylindrical chamber. It is not a ruin, but remains a complete and functioning building. The Roman city of Pompeii, destroyed by volcanic eruption, was one of the first ancient cities excavated, from 1738 onwards. Its exposure and the excavation of many other cities led to an understanding of how Roman cities worked. Along with its legacy to Europe's language, culture and history, the architectural influence of Rome has been profound.

In the Renaissance, ancient Rome inspired the Medicis to rejuvenate Mediaeval Florence. Down to the twentieth century, western European governments have built Roman-style cities, based on gridded street plans and adorned with splendid classical buildings. Colonial Melbourne was also designed along such lines and classical templates are all around, even if we are not always aware of them. The Shrine of Remembrance (National War Memorial of Victoria) provides an example. Modelled on the Mausoleum of Halicarnassus (an ornate tomb designed for Mausolos, the ruler of Caria in south-western Türkiye, *ca.*353 BCE), it

is no accident that the Shrine is aligned with Swanston St and that the view down that street, between tall buildings, frames the Shrine neatly. The orientation conforms to the Roman taste for axiality. An important building, such as a temple, was positioned so that one had to approach it head-on, along a defined axis, but from no other direction. The Pantheon in Rome necessitated a frontal approach through its impressive portico, and there is no other point of ingress. Its rear wall, built in plain brick and now visible in a narrow alley, is drab and uninteresting. A Roman architect would never have considered that a pedestrian might want to wander around there to look at it.

The architectural philosophy of Roman city-planners conformed to a set of clear ideals, and this is why, at first glance, all Roman cities seem to look much the same. Nevertheless, the blueprint was embedded in varying landscapes and by different cultural groups, and that is why, on the other hand, each Roman city has something different about it. The example of Jerash (ancient *Gerasa*), a provincial Roman city in Jordan, can be used to illustrate these urban characteristics.[156] Jerash had a standard Roman street plan, with a main street called the *cardo,* crossed by transverse streets called *decumani.* These roads were lined with shops and other affairs, and they required the pedestrian to walk along predetermined paths. Jerash's oval, colonnaded 'piazza' was an unusual solution to the more usually rectilinear Roman kind of forum, or civic meeting space. Its plan integrated the frontages of several preexisting buildings lying at odd angles. The city was provided with two theatres; a major temple to Zeus, and another to the goddess Artemis. The latter complex was accessed up a lengthy staircase that crossed the cardo. The temple's *cella*, or ritual chamber, is bordered by a tall colonnade of massive columns, set in turn in a broad, colonnaded courtyard. Jerash had a *hippodrome* or racetrack,[157] a public fountain called a *nymphaeum*, and a large, heated baths facility.

Roman engineers were adept at seeking out and exploiting the usable resources of a region. Jerash was built of limestone, while Umm Qays (ancient *Gadara*) overlooking the Jordan Valley features large numbers of dark buildings, because extensive basalt flows occur nearby. Bricks and mortar were favoured in many European cities, such as at Lyon (*Lugdunum*) in France. These materials lent great flexibility to the Roman architect for building utilitarian constructions, as well as great monuments. Roman concrete utilised quicklime (highly reactive calcium oxide) which formed at high temperatures, and Roman mixes included lime casts, which added great strength. The Pantheon is the first great architectural masterpiece in concrete. After 1,900 years, its dome of unreinforced concrete (weighing 4,500 tones) is still intact and remains the largest of its kind in the world.[158] In order to retain a viable strength to weight ratio, layers of lighter, porous cement were used in the uppermost layers of the dome.

Evident in the ruins of any Roman city are the channels, shafts, drains, and outlets of a sophisticated water supply system. An example is the Pont du Gard (First Century CE), built over the River Gardon in southern France. Raised fifty metres in the air, it is at once a three-coursed bridge, a road and an aqueduct, It formed a key link in a system which carried water fifty kilometres to the town of *Nemausus* (modern Nîmes). The most astounding accomplishment of Roman hydraulic technology involved the excavation of a series of underground tunnels to form a subterranean water-supply network in the southern Levant. It sourced freshwater springs in southern Syria and brought water to the Roman cities of Gadara and Abila, located over a hundred kilometres away in northern Jordan.[159] It stands as the one of the great engineering feats of the ancient world.

The efficacy of Roman water supply was greatly aided by the adoption of regular street grids in many provincial cities. Traditionally, the invention of the street grid has been accorded to Hippodamus of Miletus (in south-western Türkiye), sometimes referred to as the 'father of town-planning.' Whether or not Hippodamus had anything to do with it, one of the earliest square street grids was developed in his home city by the early fifth century BCE.[160] Using remote sensing, geophysical techniques have brought to light the town plans of buried cities in southern Italy, and show that the regular Roman city was already in place by the early Republic.[161] Two recently investigated cases are *Interamna Lirenas* (founded 312 BCE) and *Falerii Novi* (from 241 BCE). At Falerii Novi, the reconnaissance shows that the water-supply system of drains and pipes was emplaced beneath the street grid before construction commenced.

Compared to the earlier Republic, large, elaborate, buildings of marble and other stone came to embellish late Imperial cities from the second century CE. Architectural facades became decorative in a style known as baroque Roman. Their details included recessed, apsidal niches, engaged pilasters surmounted by non-functional double cornices, in turn topped by hemispherical pediments; and

miniature colonnades placed on high podia, supporting second storeys of even smaller columns. Examples include the Library of Celsus at Ephesos and the stage-front in the South Theatre at Jerash. Despite its late appearance in Rome, Judith McKenzie demonstrated that baroque architectural style appeared over three hundred years earlier in the remote desert city of Petra, in south Jordan. This apparent anomaly is explained by the elements of baroque style having been developed in the great city of Alexandria in Egypt by the third century BCE, whence it was transferred to Petra.[162] Alexander the Great established large numbers of new cities in the Middle East, including Alexandria, before 323 BCE. A renowned intellectual and cultural centre, Alexandria became the greatest of the Hellenistic cities; the New York of its time, surpassing anything else in the Mediterranean. Although ancient Alexandria has since been built over, many of the ornate architectural fragments survive, scattered on monuments, and displayed in museums in Alexandria. Accounts of the city's fabulous architecture survived until Islamic times.[163]

By contrast with many of its subordinate provincial towns, the city of Rome grew up in haphazard fashion. At its height, it was the biggest city that had ever existed on earth. It covered an area of over 40 square kilometres, and is estimated to have held a population of a million.

Medieval Developments, East and West

No city in the West surpassed Rome up to the nineteenth century, since the limits to growth imposed by the agrarian economy were not exceeded until the Industrial Revolution. Architecturally, though, the advent of the Gothic Cathedral in Western Europe between the twelfth and sixteenth centuries CE represents a significant breakthrough in building technology.[164] A common thread running through fringe popular culture is that the pyramids of Egypt are so extraordinary as to require supernatural or extra-terrestrial explanations. However, if one were to devise a television reality show for competing neophyte builders and provide each contestant with 10,000 stone blocks, a pyramid (that is to say, a step pyramid) would inevitably be the result. This is because the step pyramid is simple in concept, easy to build, and inherently stable. By contrast, the Mediaeval cathedral is a kind of architectural miracle. It was not itself exceeded in elevation until the nineteenth century. The Gothic cathedral was styled with pointed arches and broad sheets of stained glass framed in lead, and hung between slender, ribbed stone columns. It was all made possible by the invention of the flying buttress, a sloping pillar of stone that transferred load away from the walls and into the ground. The cathedrals were a western European phenomenon, with leading examples being Notre Dame and Chartres in France, Cologne in Germany, Milan in Italy, and Lincoln, Salisbury and Canterbury in England. In 1,311 CE, Lincoln Cathedral surpassed the height of the Great Pyramid of Giza, a record that had not been bettered for some four thousand years.

As Maya kings reached their peak in Mesoamerica, the Khmer people built an urban civilisation at Angkor in Cambodia that is astounding in its scale and achievements.[165] Angkor was an urban complex at least 25 times bigger than anything else that had ever existed, engineered in the tropical rainforest, to boot. It expanded to become a city of 1,000 square kilometres, traversed by a network of canals and supplied with huge reservoirs, one of which (the West Baray) was longer than the entire Melbourne Central Business District. The centrepiece, Angkor Wat, is a temple complex so vast that one could place the Great Pyramid of Gizeh in a corner of its grounds. It is adorned with carved friezes 800 metres long, into which several Parthenons would fit. At 163 hectares, Angkor Wat is the largest ancient building ever erected. It is enclosed by walls 6.4 kilometres long and surrounded by a moat 200 metres wide. The elaborate structure of Angkor Wat was built to portray the world of Hindu cosmology. The high central tower represents the mythical Mount Meru, the lower towers the other celestial peaks, the outer wall, the borders of heaven, and the surrounding moat, the ocean at the end of the world.

The question is how, in a difficult rainforest environment, an urban civilisation could appear which outshone all others before it in size and magnificence. Part of the solution to the mystery of Angkor is a bountiful environment that enabled the production of huge food surpluses. The Tonle Sap, a tributary of the Mekong River, provided the city with an unsurpassable natural bounty. Not just a large body of water, its seasonal pulsing provides the key to Angkor's prosperity. In the wet season the Mekong River backs up and engorges the Tonle Sap, enabling enormous areas to be irrigated. In the dry season it shrinks drastically, providing convenient wet ground for rice cultivation and rendering large numbers of fish for the harvest.

A Chinese diplomat, Zhao Daguan, left a memoir of his visit to Angkor in 1296-1297. He was admitted to an audience with the king and treated to tremendous

nocturnal firework displays. Zhao described the fecundity of the region, and how Tonle Sap yielded three to four rice crops a year, many vegetables, abundant fish, and also water buffaloes. One of the best surviving temples at Angkor Thom is Ta Prohm. Its foundation inscription gives an insight into the scale of Angkor society. It was administered by 18 high priests aided by 2,740 officials with 2,202 assistants, and retained 615 female dancers. Some 306,372 villagers worked for the temple. Judging by these figures, perhaps a million or more people inhabited the Angkor region.

Lidar mapping has also recently revolutionised our knowledge of Angkor Wat and its surrounds. Formerly it was thought that the temple was surrounded by sparsely occupied fields. A new study shows that Angkor Wat formed the hub of a residential district, marked by roads, houses, ponds and small mounds, and that it was bordered to the south by a massive enigmatic structure [166] Sediment cores sunk in the canals reveal ancient sludge and garbage deposited there, indicating the former existence of riverside stilt houses, just as people build in the region today. The key to Angkor's operation was the maintenance of a huge, low-density population living in close proximity to resources of riverine food resources, cultivated gardens, and unlimited water and transportation.

High and Wide: Powering the Industrial City

Constraints on the growth of both high-density and low-density urban complexes were only breached in the modern era. In Europe, the former type had long been exemplified by ancient Rome, where apartment dwellers, like those who dwelt in the port of Ostia, took their place amongst a citizenry a million strong, distributed over forty square kilometres. At Angkor, the widespread entrenchment of low-density residential systems enabled the city to grow to its outer limits at some 1,000 square kilometres. Globally, the largest compact, preindustrial cities on record are Chang An in China during the T'ang Dynasty (seventh to ninth Centuries CE), and Edo in Japan during the Tokugawa shogunate (seventeenth to twentieth centuries CE), both reaching 80-90 square kilometres.[167]

Roland Fletcher's 'Interaction-Communication' model argues that there bounds to the densities that human beings can tolerate, and that there are limits to the areas of cities, beyond which communication systems cannot operate effectively. A third consideration is a 'Threshold Limit' for urban density, below which settlements may expand almost limitlessly, but which inhibits a return to nucleation or high-density population. Material innovations and technological developments provide the keys to surmounting these constraints. Screen-fences, double-glazing and windowless house-walls presented to the street are all measures able to reduce interaction.

Fletcher regards the 100-square-kilometre urban limit as a maximum beyond which the ancient agrarian economy could not prevail. Industrialization in the nineteenth century provided the power to crash through this barrier. Technology propelled life in virtually every walk of life: the rotary steam press led to thousands of pages being printable in an hour, so that mass circulation of newspapers could inform entire communities on a daily basis. Most significant of all was the incorporation of the railway into urban centres. Workers could now commute to their employment in the inner city and return each evening to their dormitory suburbs, tens of kilometres away. New colonial cities with ample room for expansion coincided with the development of the railway, and as a result, they spread explosively. Melbourne is a case in point. Having risen to prosperity in the 1850s due to the Victorian Gold Rush, rail lines were extended radially to outer suburbs in every direction by the 1870s and 1880s. By 1880, municipalities of the greater Melbourne area linked by rail covered at least 2,000 square kilometres.[168]

Automobile ownership drove the city onwards and outwards to places where the trains couldn't go. Mass-transit freeways were developed to permit effective intra-city interaction over long distances. The world's first modern freeway, opened in 1940, was the Arroyo Seco Parkway (now the Pasadena Freeway), linking Pasadena with Los Angeles.[169] It features the Four Level Interchange, the world's first 'stack interchange' opened in 1949. These are the familiar woven overlays of exit and entry ramps that connect intersecting roadways. As a result, the greater Los Angeles area has become the biggest urban area in the United States, with a population of 18.5 million people spread over nearly 88,000 square kilometres.

Trains, planes, automobiles, and virtually every other kind of industrial contrivance were made possible by the invention of the Bessemer steel process in the mid-nineteenth century. Not only did steel push the city laterally to great size, but it also propelled it into the air. Steel frames were first used in large factories and mills in the north of England, but there had been no impetus to build them particularly high. The first tall building to be constructed

with an all-steel frame was the ten-storey Rand McNally Building, constructed in Chicago in 1889.[170] In a sense, the skyscraper recapitulated the Gothic cathedral. The lightweight steel skeleton was load bearing, which enabled the use of thin cladding walls bound to it. The system resulted in light and manageable buildings.

The year 1889 also saw the completion of another innovative construction in metal: the wrought-iron Eiffel Tower, built by the Seine in Paris. Standing to a height of 300 metres, the view from the top provided a transformative geographical experience. Such was the pace of technological change, the tower did not retain its title because the electric elevator soon enabled the skyscraper to ascend even further. Elisha Otis had introduced the first passenger lifts, or elevators, in 1853, and by the turn of the twentieth century, electric versions were being fitted in American buildings. Once rapidly ascending elevators were installed in skyscrapers, the public accepted the new buildings as safe and pragmatic venues for work and residence. By 1931, the Empire State Building in New York City, built to a height of 381 metres, had eclipsed the Eiffel Tower. High-rise buildings dramatically increased population densities, and by 1925, New York had overtaken London to become the biggest city in the world.[171]

With continuing growth, highly industrialised cities and their intermediary towns and villages converged into a greater entity: the conurbation, or megalopolis. The first examples developed in the Ruhr Valley in Germany, around the great port of Rotterdam in the Netherlands (the Randstad), and along a 700-kilometre stretching from Boston to Washington D.C. in the eastern United States. New giants are now emerging in East Asia, and have been termed 'mega-conurbations'.[172] They spread voraciously, and there is no longer room for outlying zones that one might call 'the suburbs'. These peripheral or 'peri-urban' regions become industrialised and develop mixed functional character, just as do the cores of the super-cities. Generally, these places do not stem from detailed planning schemes that emanate from centralised administrations. They often develop haphazardly according to the interests of real estate entrepreneurs with political connections, looking to make huge sums of money by attracting investment. Examples include Japan's Tokaido region, extending between Tokyo and Osaka, and in China, developments in the Pearl River and Yangtze river deltas. With the development of high-speed internet, the individuals living in such massive establishments now enjoy the flexibility of working from home without having to make gruelling commutes to the office.

It is small wonder that these untrammelled venues have aroused opposition, and stimulated endeavours to imagine different modes of urban life. Much ingenuity has been put into returning big-city life to a local scale, and in conceiving the city as a series of small-scale communities, where local interests and companionship can be generated. Ironically, Baron Haussmann's makeover of Paris in the eighteenth century achieved something like this, even if one of his principal objectives was to create broad avenues like the Champs Elysée, so the troops might enter the city quickly to put down future insurrections. Nevertheless, his building limit of six storeys created a low-rise city of intimate character. In neighbourhoods of the Left Bank (5th arrondissement), the lengthy Rue Mouffetard winds through a succession of small markets, restaurants, and shops, providing a congenial high-density urban experience.

The Future City

Hillier and Hanson have noted a disparity between the sustained attraction that city life has held for people over the ages and the undercurrent of negativity about the city that runs through many urban theoretical texts.[173] They note that the city is often cast as 'socially bad' and is often regarded as poorly planned and a place of alienation. Some commentators call for the reinvigoration of the city[174] or imagine the postmodern city.[175]

An overriding problem for twenty-first century cities is the challenge of climate change. Architects and city planners are now designing environmentally sustainable building projects, and even whole cities. An example is an office building in Amsterdam known as The Edge.[176] The building is oriented to harvest maximum sunlight for its solar panels. Rainwater is collected for irrigation and bathroom use, and an underground thermal aquifer is exploited to heat and cool the building. As a result of these measures, The Edge is a net positive energy generator, while maintaining a negative carbon footprint. Entire cities now strive to be sustainable and net energy producers. Canberra, the national capital of Australia, is considered to be one of the most sustainable cities in the world.[177] As originally designed, Canberra was unusual in that its urban neighbourhoods were positioned between parks and green spaces, so that one often has the impression of being in the countryside while driving through it. Canberra is powered entirely by renewable energy, nearly all of its citizens are

connected to the internet, and it has a high proportion of green public transport vehicles.

Interest groups are now imagining a green and alternative future city, a kind of 'Ecotopia.' In the future, humanity may even leave the earth and colonise the Moon, Mars and other planets. Since the 1970s, urban planners (for example at NASA) have been preparing to build cities on other worlds. These establishments would need to produce everything necessary for life, including water, breathable air and even gravity, while providing protection from harsh solar radiation. Private enterprise, in conjunction with the European Space Agency and the Massachusetts Institute of Technology (MIT) is currently devising a 'Moon Village'.[178] Elsewhere, the 'Mars City Design' competition, conducted recently by MIT, was won by the 'Redwood Forest' city proposal.[179] It envisions a conjectural metropolis mimicking as closely as possible the characteristics of a giant forest, with subterranean roots being nurtured underground, while upper parts emerge into the light, held between beneath protective branching structures.

If such avant-garde enterprises seem fanciful, it is indeed the case that they are now being put into effect on earth. On the Red Sea coast of Saudi Arabia, work is proceeding on a type of bubble-city called 'Neom'.[180] One of its principal establishments is to be a linear housing estate called 'The Line'. It will extend, under a covered, mirrored glass surface, some 170 kilometres in length, with a width of just 200 metres. It is designed to contain a lush, vegetated interior, arranged as repeated sets of modules. Each community will need to walk only a few minutes to access all of its requirements. It is being prepared to house nine million people.

Conclusions

The home-bases of our earliest forebears gathered have left only subtle traces in the archaeological record. Stone arrangements stretching back over a million years survive, but they represent equivocal traces. The harnessing of fire from at least three-quarters of a million years ago has yielded more reliable evidence, since the hearth formed the focus of human residence from earliest times. The record of habitations throughout the long human career demonstrate that settlements have been strongly influenced by the cultural traditions of individual societies. Simultaneously, broad trends typify the settlements of large regions.[181] Human residential strategies have also been subject to a range of external limitations that have ordinarily prevented settlements from exceeding thresholds of physical size and population density. These countervailing influences represent the ultimate question for Big History, for all historical inquiry, and indeed for archaeological theory. As Hesketh (2023) has phrased the issue, "How are the contingent issues of human history incorporated into a narrative governed by deterministic laws of nature?"[182]

Periodically, after long periods of stasis, constraints on various modes of residence have been removed, enabling communities to establish more complex settlement types. The anthropologist Leslie White stressed the importance of harnessing increased sources of energy.[183] At 12,500 BCE, the intensive processing and storage of wild cereals enabled communities in the Natufian period to exploit territory more efficiently and found the first stone-built villages. Around 10,000 BCE, the cultivation of fields of accompanied the appearance of the first large villages. Between 8,000 and 8,500 BCE, herd animals were added to the mix, fuelling another upswing and the establishment of large rectilinear villages across the Middle East. After a period of stasis, the harnessing of hydraulic power to raise irrigated grain on the plains of southern Iraq provided the economic basis for the first cities, around 3,500 BCE. No less important as critical thresholds for urban life were the ordering and direction of civic populations by mitigating their interactions through settlement planning and transport systems, and developing effective communication systems in the forms of writing and accountancy.

At the end of the Ice Age, a pyrotechnological advance transformed mineral rock into a pliable building material, with the discovery of hydrated plaster in the Natufian period and its subsequent adoption in Neolithic settlements. Later, the invention of hydraulic cement delivered great versatility for Roman architecture, and increased the productive capacity of water supply systems, which in turn enabled the Roman city to grow. The development of the Bessemer steel process in the nineteenth century greatly enhanced infrastructure and enabled the city to reach into the sky. The harnessing of steam power and electricity during this period effectively abolished constraints on interaction and communication, leading to the vast modern city, and to interrelated clusters of massive cities. The digital revolution in the late twentieth century has led to the internationalisation of labour, with employees able to participate as virtual citizens in the global city. Physically, we see the current development of the self-contained bubble-city; a type which will foreseeably be embedded extra-terrestrially in the next century, on the Moon or

on Mars. Such is the future of the city, one of humanity's greatest inventions. But we have never managed to get cities entirely right (despite the continual efforts of urban planners and scholars), and over a billion fringe-dwellers around the world still live in poverty at their edges.[184]

Notes

1. Christian, "What is Big History?"; Hesketh, *A History of Big History*; Spier, *The Structure of Big History*.
2. Fletcher, *The Limits of Settlement Growth.*
3. Doxiadis, *Ekistics,* 15.
4. Hillier and Hanson, *The Social logic of Space*, 2.
5. Hillier and Hanson, *The Social logic of Space*, 271.
6. Chomsky, *Syntactic Structures.*
7. Benítez-Burraco and Boeckx, "Universal Grammar and Biological Variation."
8. 'Palaeolithic' is a nineteenth-century term that defined flaked stone tool assemblages before the advent of barbed Mesolithic projectiles and edge-ground Neolithic axes. 'Pleistocene' is the long geological epoch aged from 2.58 million to a little later than 10,000 BCE. In practical terms, both end at the same time.

[9]. 'Hearth' has several overtones in English but for archaeologists it simply connotes a fireplace, with or without constructed frames or borders.

10. Isaac, "Stone Age Visiting Cards."
11. Binford, *In Pursuit of the Past*, 172-176.
12. Goren-Inbar *et al.*, "Hominin Control of Fire."
13. Shahack-Gross *et al*., "Repeated Use of a Central Hearth."
14. Brown *et al.*, "Fire as an Engineering Tool."
15. Certainly, our forebears used caves as they found them. Caves contribute disproportionately towards the record of ancient settlement because they protect deposits as they accrete. However, typically low rates of accumulation over time indicate that caves formed just part of a broader settlement-round for most groups.
16. Moore, *The Prehistory of Home*.
17. Hoffman, *Egypt before the Pharaohs*, 56-57; Barham et al., "Evidence for the earliest structural use of wood."
18. Lumley, *La Grande Histoire des Européens* ; Villa, *Terra Amata and the Middle Pleistocene.*
19. Jaubert *et al*., "Early Neanderthal Constructions"
20. Klein, *Ice-Age Hunters of the Ukraine*, 69.
21. Iakovleva, "Mammoth Bone Circular Dwellings."
22. Nadel, "Ohalo II."
23. Moore, *The Prehistory of Home*.
24. Bar-Yosef and Valla, *The Natufian Culture in the Levant*; Bar-Yosef and Valla, *Natufian Foragers in the Levant*.
25. Edwards, *Wadi Hammeh 27.*
26. Perrot, "Le Gisement de Mallaha" ; Valla, "Sedentism, the "point of no return."
27. Eckmeier *et al*., "14C Dating of the Early Natufian."
28. Delannoy *et al.*, "Engineers of the Arnhem Land Plateau."
29. White, "Don't Touch That Dial."; Makarewicz, "The Younger Dryas in the Near East."
30. Willcox, "The Roots of Cultivation."
31. Kenyon and Holland, *Excavations at Jericho*; Kenyon, *Digging up Jericho*.
32. Bar-Yosef, "The Walls of Jericho."
33. Nigro, "Expedition to Tell Es-Sultan, Ancient Jericho." The PPNA wall has nothing to do with the fabled bastion brought down by Joshua. It dates some 7,000 years earlier than the one brought down by trumpet-blast in the Biblical narrative.
34. Bar-Yosef and Gopher, *An Early Neolithic Village.*
35. Finlayson *et al*., *The Early Prehistory of Wadi Faynan*.
36. Mithen, "Shamanism in Southwest Asia."
37. Schmidt, *Göbekli Tepe*.
38. Özdoğan, "The Sayburç Reliefs."
39. Dietrich *et al.,* "Cereal Processing at Göbekli Tepe."
40. Banning, "So Fair a House."
41. Simmons, *The Neolithic Revolution*, 121 ff.
42. Białowarczuk, "From circle to rectangle"; Flannery, "The Origins of the Village; Saidel, "Round House or Square?"
43. Stordeur, *Le Village de Jerf El Ahmar.*

44. Edwards *et al.*, "The Natural Inspiration for Natufian Art."
45. Fletcher, *The Limits of Settlement Growth,* 29. The shift to rectilinear buildings was probably not done to increase the strength of individual architectural units.
46. Flannery, "The Origins of the Village."
47. Dhavalikar, "Farming to Pastoralism in the Deccan."
48. Nelson, *From Cameroon to Paris*
49. Kingery *et al.*, "The Beginnings of Pyrotechnology."
50. Gebel, *Basta II*.
51. Simmons, *The Neolithic Revolution in the Near East*, 169-174.
52. Watkins, "Ordering Time and Space."
53. Özbaşaran *et al*., *The Early Settlement at Aşıklı Höyük*.
54. Hodder, *The Leopard's Tale*.
55. Mellaart, *Çatal Hüyük.*
56. Vander Linden, "To Tame a Land."
57. Parker Pearson, *Stonehenge*.
58. Clarke, *Skara Brae*
59. Linseele *et al*., "Introduction of Animals into Africa."
60. Eiwanger, "Merimde Beni-Salame."
61. Watkins *et al*., "Qermez Dere."
62. Riehl *et al*., "Emergence of Agriculture in Iran."
63. Jarrige, "Mehrgarh Neolithic"; Jarrige and Jarrige, "Premiers pasteurs et agriculteurs."
64. Costantini, "Agriculture in the Kachi Plain."
65. Liu *et al*., "Harvesting and Processing Wild Cereals."
66. Kuzmin, "Chronology of the Earliest Pottery in East Asia."
67. Liu, *The Chinese Neolithic*; Ma *et al.*, "Multiple Indicators of Rice Remains."
68. Zhao and Wu, "Early Neolithic Hemodu Culture."
69. Sather, *Adaptation, History, and Fate in a Maritime Fishing Society,* 1.
70. Fiskesjö and Chen, *China before China*.
71. Ardelean *et al.*, "Occupation in Mexico."
72. Bennett *et al*., "Evidence of Humans in North America."
73. Flannery, *Guilá Naquitz*.
74. Smith, "Reassessing Coxcatlán Cave."
75. Hammond, "Preclassic Maya Site of Cuello."
76. Dillehay *et al.*, "Early Human Presence at Monte Verde."
77. Iriarte *et al*., "Ice Age Rock Art in the Amazon?"
78. Dillehay *et al.*, "Preceramic Adoption of Peanut,."
79. Gibson, *Poverty Point*.
80. Rollefson and Köhler-Rollefson, "The Collapse of Early Neolithic Settlements."
81. van der Plicht *et al.,* "Tell Sabi Abyad, Syria."
82. Byrd, *Protohistoric Village Organization*.
83. Pascoe, *Dark Emu*.
84. Sutton and Walshe, *Farmers or Hunter-Gatherers?*
85. McDonald *et al.*, "Seeing the Landscape."
86. Memmott, *Gunyah Goondie + Wurley*, 201.
87. Clarke "Romancing the stones"; Frankel, "About Budj Bim."
88. Memmott 2022, *Gunyah Goondie + Wurley*, 184-187.
89. Williams, "An Aboriginal 'village'."
90. Muecke, "A Fragile Civilisation."
91. Haas, "A Brief Consideration of Cultural Evolution."
92. Service, *Primitive Social Organization.*
93. Pauketat, *Chiefdoms and Other Archaeological Delusions*.
94. Watson and Gibson, *Postmodern Cities and Spaces*, 1.
95. Niemalä *et al*., *Urban ecology: Patterns, Processes, and Applications.*
96. Dickens, *Urban Sociology*; Harding and Blokland-Potters, *Urban theory*.
97. Bryson, *At Home. A Short History of Private Life*.
98. Ucko *et al., Man, Settlement and Urbanism*; Renfrew, "The City through Time and Space."
99. Childe, "The Urban Revolution."
100. Johnson, "Organizational Structure and Scalar Stress."
101. Yoffee, *Myths of the Archaic State*.
102. Friedman, "Hierakonpolis, City of the Hawk."
103. The advent of early village agrarian life is often now

described as a slow and gradual process, in reaction to Childe's concept of the 'Neolithic Revolution'. Protracted it may have been, but it developed as a series of sharp jumps rather than as a gradual, even development; *cf.* Fletcher, "Settlement Archaeology."

104. Lloyd, *The Archaeology of Mesopotamia*.

105. Algaze, *Ancient Mesopotamia*; Adams and Nissen, *The Uruk Countryside*. The landmark archaeological survey conducted by Robert McCormack Adams and Hans Nissen neatly delineated the processes of earliest urbanisation. With no hope of getting through centuries of digging to investigate the villages and hamlets of the Uruk countryside, the survey team drove up to sites by four-wheel drive across a huge area of some 500 square kilometres. Their method was to estimate the dates of each site by its characteristic surface pottery. In this way, they tracked the process of demographic change over several centuries, as rural villagers fled the countryside for the 'bright lights' of new city life. It is a process that has occurred ever since, down through the ages, at places such as Mexico City and Rio de Janeiro.

106. Hammer, "Multi-Centric, Marsh-Based Urbanism."

107. Romano and D'Agostino, "The Harbor of Abu Tbeirah."

108. Lloyd and Safar. "Eridu."

109. This term describes a polity like a modern nation, with a capital city that controls and administers a large territory; Bard, "Early State in Egypt."

110. Friedman, "Hierakonpolis, City of the Hawk."

111. Jeffreys, "The Survey of Memphis."

112. Belova, "'The White Walls' of Memphis."

113. Blier, "The African Urban Past."

114. Unforgettably, the historian Hugh Trevor-Roper (1965: 9-11) wrote: "Perhaps, in the future, there will be some African history to teach. But at present there is none, or very little: there is only the history of the Europeans in Africa. The rest is largely darkness…" (*cf.* Fuglestad 1992).

115. Lamentably, the conversation between Presidents Reagan and Nixon (Naftali 2019); a racist diatribe highlighting the *lack* of African culture; e.g., Africans supposedly still uncomfortable wearing shoes; still recently swinging from the trees.

116. And, it seems inevitably, Africa features prominently in Donald Trump's list of 'shithole countries' (Barron 2018).

117. Trevor-Roper (1969) even excluded ancient Egypt where writing was born around 3,000 BCE; Ethiopia and its Kingdom of Aksum which was literate and urban long before the Christian era; and the north African coast of the Mediterranean, with its splendours from the Carthaginian, Roman and Early Islamic periods.

118. McIntosh, *Excavations at Jenné-Jeno.*

119. Auster, *Timbuktu.*

120. Hammer, *The Bad-Ass Librarians of Timbuktu.*

121. Patel, "Stone towns of the Swahili coast."/

122. Chirikure *et al.*, "A Bayesian Chronology for Great Zimbabwe."

123. Graef, *Susa and Elam.*

124. Kenoyer, *Indus Valley Civilization*.

125. Vidale, "Aspects of Palace Life at Mohenjo-Daro."

126. Wheatley, *Origins of the Chinese City*. This underlying concept is also seen in many other ancient Asian cities, and according to different specifics, in ancient American ones too.

127. Li, *et al.*, "Guandimiao."

128. Zhang *et al.*, "The Rise of Erlitou."

129. Liu, *The Chinese Neolithic*.

130. Jaang *et al.*, "When Peripheries Were Centres"; Zhong & Shelach-Lavi. "A Metropolis in the Highlands?"

131. Bevan, "The Neolithic Complex at Niuheliang."

132. Moseley, *The Maritime Foundations of Andean Civilization*.

133. Quilter *et al.*, "Subsistence Economy of El Paraíso."

134. "Pyramid in Peru Torn down by Developers," *UK Guardian*, July 4, 2013.

135. Solis, *et al*., "Dating Caral, a Preceramic Site."

136. Sandweiss *et al*., "Coastal Peru between 5,800 and 3,600 Years Ago."

137. Prümers *et al*., "Low-Density Urbanism in the Bolivian Amazon."

138. Marcus and Flannery, *Zapotec Civilization*.

139. Cowgill, "State and Society at Teotihuacan, Mexico."

140. Gastelum, *The Maya and their relationship with Teotihuacan.*

141. Harrison, *The Lords of Tikal*.

142. Hansen *et al*., "LiDAR Analyses in Guatemala."

143. Inomata *et al*., "Monumental Architecture at Aguada Fénix."

144. Aimers, "What Maya Collapse?"

145. Helmke *et al*., "The Komkom Vase."

146. "These great towns … and buildings rising from the water, all made of stone, seemed like an enchanted vision … Indeed, some of our soldiers asked whether it was not all a dream." Bernal Díaz, *The Conquest of New Spain*, 214.

147. Milner, *The Moundbuilders*.

148. Aswani and Graves, "The Tongan maritime expansion."

149. Boedeker and Raaflaub, *Arts in Fifth-Century Athens*.

150. Hurwit *et al.*, *The Acropolis in the Age of Pericles*.

151. C. Higgins, "Britain Treasures the Parthenon Marbles."

UK Guardian, January 24, 2023.

152. Camp and Mauzy, *The Athenian Agora*.

153. Martin-McAuliffe and Papadopoulos, "Framing Victory."

154. Coarelli *et al.*, *Rome and Environs*.

155. The statue survived for so long because later people mistook it for Constantine, Rome's first Christian emperor.

156. Browning, *Jerash and the Decapolis*.

157. Ostrasz and Kehrberg, *The Hippodrome of Gerasa*.

158. Strickland, "Why Ancient Roman Structures Still Stand."

159. Al-Karaimeh, "The Water Tunnels in the Eastern Hills."

160. Owens, *The City in the Greek and Roman World*, 51-56.

161. Verdonck *et al.*, "Radar Survey at Falerii Novi."

162. "He (Alexander) built the city upon vaults and in tiers, making passages and openings for light… Its walls are built from different kinds of marble, white and coloured, so are the places and buildings; at night the city was bright without lamps because of the great whiteness of the marble...It is said that this was the most magnificent city ever built on earth, having the most wondrous buildings ('Abd al-Mun'im al-Himyari, ninth century CE). Cited in McKenzie, *The Architecture of Petra*, 61.

163. McKenzie, *The Architecture of Alexandria.*

164. Smith, "Gothic Cathedrals."

165. Higham, *The Civilization of Angkor*.

166. Evans *et al*., "Uncovering Landscapes at Angkor."

167. Fletcher, *The Limits of Settlement Growth,* 203 *ff.*

168. Lee, *The Railways of Victoria*.

169. Hise, *Magnetic Los Angeles*.

170. Webster, "The Skyscraper."

171. Chandler, *Four Thousand Years of Urban Growth*.

172. Friedmann and Sorensen, "City Unbound."

173. Hillier and Hanson, *The Social logic of Space*, 1.

174. Landry, *The Creative City*; Richards and Palmer*, Eventful Cities.*

175. Low, *Theorizing the City.*

176. Randall, "The Smartest Building in the World"

177. Brown, "World's Most Sustainable City."

178. "Moon Village."

179. Szondy, "Prize-Winning Mars City Concept."

180. Osiejak, "Saudi Arabia's The Line."

181. As Bruce Trigger noted: "The most important issue confronting the social sciences is the extent to which human behavior is shaped by factors that operate cross-culturally as opposed to factors that are unique to particular cultures." Trigger, *Understanding Early Civilizations*, 3.

182. Hesketh, *A History of Big History*, 34.

183. White, *The Evolution of Culture*.

184. Statista, "Number of People Living in Slums".

Bibliography

Adams, R. M., & Nissen, H. J. (1972). *The Uruk countryside: The natural setting of urban societies*. University of Chicago Press.

Aimers, J. J. (2007). What Maya collapse? Terminal Classic variation in the Maya Lowlands. *Journal of Archaeological Research, 15*(4), 329–377.

Algaze, G. (2014). *Ancient Mesopotamia at the dawn of civilization: The evolution of an urban landscape*. University of Chicago Press.

Al-Karaimeh, S. (2017). The water tunnels in the Eastern Hills of the Jordan River. *Aram, 29*(1–2), 477-493.

Ardelean, C. F., Becerra-Valdivia, L., Pedersen, M. W., Schwenninger, J.-L., Oviatt, C. G., Macías-Quintero, J. I., Arroyo-Cabrales, J., et al. (2020). Evidence of human occupation in Mexico around the Last Glacial Maximum. *Nature, 584*(7819), 87–92.

Aswani, S., & Graves, M. W. (1998). The Tongan maritime expansion: A case in the evolutionary ecology of social complexity. *Asian Perspectives, 37*(2), 135–164.

Auster, P. (1999). *Timbuktu*. Faber.

Banning, E. B. (2011). So fair a house: Göbekli Tepe and the identification of temples in the Pre-Pottery Neolithic of the Near East. *Current Anthropology, 52*(5), 619–660.

Bard, K. (1997). Urbanism and the rise of complex society and the early state in Egypt. In K. Bard (Ed.), *Emergence and change in early urban societies* (pp. 59–80). Plenum Press.

Barham, L., Duller, G. A. T., Candy, I., et al. (2023). Evidence for the earliest structural use of wood at least 476,000 years ago. *Nature, 622*, 107–111. https://doi.org/10.1038/s41586-023-06557-9

Barron, L. (2018, January 12). 'A new low.' The world is furious at Trump for his remark about 'shithole' countries. *Time*. https://time.com/5100328/shithole-countries-trump-reactions/

Bar-Yosef, O. (1986). The walls of Jericho: An alternative interpretation. *Current Anthropology, 27*(2), 157–162.

Bar-Yosef, O., & Gopher, A. (Eds.). (1994). *An early Neolithic village in the Jordan Valley Part I: The archaeology of Netiv Hagdud*. Peabody Museum of Archaeology and Ethnology, Harvard University.

Bar-Yosef, O., & Valla, F. R. (Eds.). (1991). *The Natufian culture in the Levant*. International Monographs in Prehistory.

Bar-Yosef, O., & Valla, F. R. (Eds.). (2013). *Natufian foragers in the Levant: Terminal Pleistocene social changes in Western Asia*. International Monographs in Prehistory.

Belova, G. (2022). The White Walls of Memphis. *American Research Center in Egypt*. https://www.arce.org/event/galina-belova-white-walls-memphis

Benítez-Burraco, A., & Boeckx, C. (2014). Universal grammar and biological variation: An EvoDevo agenda for comparative biolinguistics. *Biological Theory, 9*, 122–134.

Bennett, M. R., Bustos, D., Pigati, J. S., Springer, K. B., Urban, T. M., Holliday, V. T., Reynolds, S. C., et al. (2021). Evidence of humans in North America during the Last Glacial Maximum. *Science, 373*(6562), 1528–1531.

Bevan, A. (2013). The Neolithic ceremonial complex at Niuheliang and wider Hongshan landscapes in northeastern China. *Journal of World Prehistory, 26*(1), 1–24.

Białowarczuk, M. (2016). From circle to rectangle: Evolution of the architectural plan in the Early Neolithic in the Near East. *Polish Archaeology in the Mediterranean, XXV*, 575–593.

Binford, L. (1983). *In pursuit of the past: Decoding the archaeological record*. Thames and Hudson.

Blier, S. P. (2012). The African urban past: Historical perspectives on the metropolis. In D. Adjaye (Ed.), *African metropolitan architecture* (pp. 14–19). Thames and Hudson.

Boedeker, D. D., & Raaflaub, K. A. (Eds.). (1998). *Democracy, empire, and the arts in fifth-century Athens*. Harvard University Press.

Brown, A. (2021, May 18). Canberra named world's most sustainable city. *Canberra Times*. https://www.canberratimes.com.au/story/7257624/canberra-named-worlds-most-sustainable-city/

Brown, K. S., Marean, C. W., Herries, A. I. R., Jacobs, Z., Tribolo, C., Braun, D., Roberts, D. L., Meyer, M. C., & Bernatchez, J. (2009). Fire as an engineering tool of early modern humans. *Science, 325*(5942), 859–862.

Browning, I. (1982). *Jerash and the Decapolis*. Chatto and Windus.

Bryson, B. (2010). *At home: A short history of private life*. Doubleday.

Byrd, B. F. (2020). *Protohistoric village organization and territorial maintenance: The archaeology of Sii Tuupentak (ca-Ala-565/h) in the San Francisco*. Center for Archaeological Research.

Camp, J. M., & Mauzy, C. A. (2010). *The Athenian Agora: Site guide* (5th ed.). American School of Classical Studies at Athens.

Childe, V. G. (1950). The urban revolution. *The Town Planning Review, 21*(1), 3–17.

Chandler, T. (1987). *Four thousand years of urban growth: An historical census*. St. David's University Press.

Chirikure, S., Pollard, M., Manyanga, M., & Bandama, F. (2013). A Bayesian chronology for Great Zimbabwe: Re-threading the sequence of a vandalised monument. *Antiquity, 87*(337), 854–872.

Chomsky, N. (1957). *Syntactic structures*. Mouton.

Christian, D. (2017). What is big history? *Journal of Big History, 1*(1), 4–19.

Clarke, A. (1994). Romancing the stones: The cultural construction of an archaeological landscape in the Western District of Victoria. *Archaeology in Oceania, 29*, 1–15.

Clarke, D. V. (2018). *Skara Brae: Official souvenir guide*. Historic Scotland.

Coarelli, F., Clauss, A. J., & MacKay, P. A. (2014). *Rome and environs: An archaeological guide*. University of California Press.

Costantini, L. (1984). The beginning of agriculture in the Kachi plain: The evidence from Mehrgarh. In B. Allchin (Ed.), *South Asian archaeology 1981* (pp. 29–33). Cambridge University Press.

Cowgill, G. L. (1997). State and society at Teotihuacan, Mexico. *Annual Review of Anthropology, 26*(1), 129–161.

Delannoy, J.-J., David, B., Geneste, J.-M., Katherine, M., Sadier, B., & Gunn, R. (2017). Engineers of the Arnhem Land Plateau: Evidence for the origins and transformation of sheltered spaces at Nawarla Gabarnmang. In B. David, P. S. C. Tacon, J.-J. Delannoy, & J.-M. Geneste (Eds.), *The archaeology of rock art in Western Arnhem Land* (pp. 197–243). Australian National University Press.

Dhavalikar, M. K. (1989). Farming to pastoralism: Effects of climatic change in the Deccan. In J. Clutton-Brock (Ed.), *The walking larder: Patterns of domestication, pastoralism, and predation* (pp. 156–168). Unwin Hyman.

Díaz del Castillo, B. (2003). *The conquest of New Spain* (J. M. Cohen, Ed.). Penguin Books.

Dickens, P. (1990). *Urban sociology: Society, locality, and human nature*. Harvester Wheatsheaf.

Dietrich, L., Meister, J., Dietrich, O., Notroff, J., Kiep, J., Heeb, J., Beuger, A., & Schütt, B. (2019). Cereal processing at early Neolithic Göbekli Tepe, Southeastern Turkey. *PLOS One, 14*(5), e0215214. https://doi.org/10.1371/journal.pone.0215214

Dillehay, T. D., Ocampo, C., Saavedra, J., et al. (2015). New archaeological evidence for an early human presence at Monte Verde, Chile. *PLOS One, 10*(11), e0141923. https://doi.org/10.1371/journal.pone.0141923

Dillehay, T. D., Rossen, J., Ugent, D., et al. (2010). Early Holocene coca chewing in northern Peru. *Antiquity, 84*(326), 939–953.

Dillehay, T. D., Rossen, J., Andres, T. C., & Williams, D. E. (2007). Preceramic adoption of peanut, squash, and cotton in northern Peru. *Science, 316*(5833), 1890–1893.

Dillon, M., & Garland, L. (2010). *Ancient Greece: Social and historical documents from archaic times to the death of Alexander*. Routledge.

Doxiadis, C. A. (1968). *Ekistics: An introduction to the science of human settlements*. Hutchinson.

Eckmeier, E., Yeshurun, R., Weinstein-Evron, M., Mintz, E., & Boaretto, E. (2012). 14C dating of the early Natufian at El-Wad terrace, Mount Carmel, Israel: Methodology and materials characterization. *Radiocarbon, 3–4*, 823–836.

Edwards, P. C. (2013). *Wadi Hammeh 27, an early Natufian settlement at Pella in Jordan*. Brill.

Edwards, P. C., Major, J., McNamara, K. J., & Robertson, R. (2019). The natural inspiration for Natufian art: Cases from Wadi Hammeh 27, Jordan. *Cambridge Archaeological Journal, 29*(4), 607–624.

Eiwanger, J. (1999). Merimde Beni-Salame. In *Encyclopedia of the archaeology of ancient Egypt* (pp. 501–505). Routledge.

Evans, D. H., Fletcher, R. J., Pottier, C., et al. (2013). Uncovering archaeological landscapes at Angkor using Lidar. *Proceedings of the National Academy of Sciences, 110*(31), 12595–12600.

Finlayson, B., Mithen, S. J., & Council for British Research in the Levant (Eds.). (2007). *The early prehistory of Wadi Faynan, Southern Jordan: Archaeological survey of Wadis Faynan, Ghuwayr and al-Bustan and evaluation of the pre-pottery Neolithic A site of WF16* (Levant Supplementary Series, Vol. 4). Oxbow.

Fiskesjö, M., & Chen, X. (2004). *China before China: Johan Gunnar Andersson, Ding Wenjiang, and the discovery of China's prehistory* (Bilingual ed., Museum of Far Eastern Antiquities Monograph Series, No. 15). Museum of Far Eastern Antiquities.

Flannery, K. V. (Ed.). (2009). *Guilá Naquitz: Archaic foraging and early agriculture in Oaxaca, Mexico*. Left Coast Press.

Flannery, K. V. (1972). The origins of the village as a settlement type in Mesoamerica and the Near East: A comparative study. In P. I. Ucko, R. Tringham, & G. W. Dimbleby (Eds.), *Man, settlement and urbanism* (pp. 23–53). Duckworth.

Fletcher, R. (1995). *The limits of settlement growth: A theoretical outline*. Cambridge University Press.

Fletcher, R. (1986). Settlement archaeology: World-wide comparisons. *World Archaeology, 18*(1), 59–83.

Frankel, D. (2017). About Budj Bim. In D. Frankel, *Between the Murray and the sea: Aboriginal archaeology in south-eastern Australia* (pp. 137–162). Sydney University Press.

Friedman, R. (2022). Hierakonpolis, city of the hawk. *Hierakonpolis Online*. http://www.hierakonpolis-online.org/index.php/about-the-site

Friedmann, J., & Sorensen, A. (2019). City unbound: Emerging mega-conurbations in Asia. *International Planning Studies, 24*(1), 1–12.

Fuglestad, F. (1992). The Trevor-Roper trap or the imperialism of history: An essay. *History in Africa, 19*, 309–326.

Gastelum, J. D. M. (2017). *The Maya and their relationship with Teotihuacan in the Classic period* (Unpublished PhD thesis). La Trobe University.

Gebel, H. G. K. (2006). *Basta II* (Bibliotheca Neolithica Asiae Meridionalis et Occidentalis 5). ex oriente.

Gibson, J. L. (2001). *The ancient mounds of Poverty Point: Place of rings*. University Press of Florida.

Goren-Inbar, N., Alperson, N., Kislev, M. E., et al. (2004). Evidence of hominin control of fire at Gesher Benot Ya'aqov, Israel. *Science, 304*(5671), 725–727.

Graef, K. D. (2012). *Susa and Elam*. Brill.

Haas, J. (2001). *The civilization of Angkor*. Weidenfeld and Nicolson.

Hammer, E., Stone, E., & McMahon, A. (2022). The structure and hydrology of the early dynastic city of Lagash (Tell al-Hiba) from satellite and aerial images. *Iraq, 84*, 1–25.

Hammer, J. (2016). *The bad-ass librarians of Timbuktu and their race to save the world's most precious manuscripts*. Simon & Schuster.

Hansen, R. D., Morales-Aguilar, C., Thompson, J., Ensley, R., Hernández, E., Schreiner, T., Suyuc-Ley, E., & Martínez, G. (2022). LiDAR analyses in the contiguous Mirador-Calakmul Karst Basin, Guatemala: An introduction to new perspectives on regional early Maya socioeconomic and political organization. *Ancient Mesoamerica*, 1–40.

Hesketh, I. (2023). *A history of big history* (Elements in Historical Theory and Practice). Cambridge University Press.

Higgins, C. (2023, January 24). Britain treasures the Parthenon marbles, but consider this: Returned to Greece, could they be more valuable? *The Guardian*.

Higham, C. (2001). *The civilization of Angkor*. Weidenfeld and Nicolson.

Hillier, B., & Hanson, J. (1984). *The social logic of space*. Cambridge University Press.

Hise, G. (1999). *Magnetic Los Angeles: Planning the twentieth-century metropolis*. Johns Hopkins University Press.

Hodder, I. (2006). *The leopard's tale: Revealing the mysteries of Çatalhöyük*. Thames & Hudson.

Hoffman, M. A. (2022). LiDAR analyses in the contiguous Mirador-Calakmul Karst Basin, Guatemala: An introduction to new perspectives on regional early Maya socioeconomic and political organization. *An-*

cient Mesoamerica, 1–40. https://doi.org/10.1017/S0956536122000244.

Hurwit, J. M., Newton, A. D., & Hurwit, J. M. (2004). *The Acropolis in the age of Pericles*. Cambridge University Press.

Iakovleva, L. (2015). The architecture of mammoth bone circular dwellings of the Upper Palaeolithic settlements in central and eastern Europe and their socio-symbolic meanings. *Quaternary International, 359-360*, 324–334.

Inomata, T., Triadan, D., Vázquez López, V. A., et al. (2020). Monumental architecture at Aguada Fénix and the rise of Maya civilization. *Nature, 582*(7813), 530–533.

Iriarte, J., Elliott, S., Maezumi, S. Y., et al. (2020). The origins of Amazonian landscapes: Plant cultivation, domestication, and the spread of food production in tropical South America. *Quaternary Science Reviews, 248*, 106582. https://doi.org/10.1016/j.quascirev.2020.106582

Iriarte, J., Ziegler, M. J., Outram, A. K., et al. (2022). Ice Age megafauna rock art in the Colombian Amazon? *Philosophical Transactions of the Royal Society B: Biological Sciences, 377*(1849), 20200496.

Isaac, G. (1981). Stone age visiting cards: Approaches to the study of early land use patterns. In I. Hodder, G. Isaac, & N. Hammond (Eds.), *Pattern of the past: Studies in honour of David Clarke* (pp. 131–155). Cambridge University Press.

Jaang, L., Sun, Z., Shao, J., & Li, M. (2018). When peripheries were centres: A preliminary study of the Shimao-centred polity in the Loess Highland, China. *Antiquity, 92*(364), 1008–1022.

Jarrige, J.-F. (2008). Mehrgarh Neolithic. *Pragdhara, 18*, 135–154.

Jarrige, J.-F., & Jarrige, C. (2006). Premiers pasteurs et agriculteurs dans le sous-continent Indo-Pakistanais. *Comptes Rendus Palevol, 5*(1-2), 463–472.

Jaubert, J., Verheyden, S., Genty, D., Soulier, M., Cheng, H., Blamart, D., Burlet, C., et al. (2016). Early Neanderthal constructions deep in Bruniquel Cave in southwestern France. *Nature, 534*(7605), 111–114.

Jeffreys, D. (2007). The survey of Memphis, capital of ancient Egypt: Recent developments. *Archaeology International, 11*(1). https://doi.org/10.5334/ai.1112

Johnson, G. A. (1982). Organizational structure and scalar stress. In C. Renfrew, M. J. Rowlands, & B. A. Segraves (Eds.), *Theory and explanation in archaeology* (pp. 389–421). Academic Press.

Kenoyer, J. M. (1988). *Ancient cities of the Indus Valley civilization*. Oxford University Press / American Institute of Pakistan Studies.

Kenyon, K. M. (1957). *Digging up Jericho*. E. Benn.

Kenyon, K. M., & Holland, T. A. (1960). *Excavations at Jericho*. British School of Archaeology in Jerusalem.

Kingery, W. D., Vandiver, P. B., & Prickett, M. (1988). The beginnings of pyrotechnology, part II: Production and use of lime and gypsum plaster in the Pre-Pottery Neolithic Near East. *Journal of Field Archaeology, 15*(2), 219.

Klein, R. G. (1973). *Ice-age hunters of the Ukraine*. University of Chicago Press.

Kuzmin, Y. V. (2006). Chronology of the earliest pottery in East Asia: Progress and pitfalls. *Antiquity, 80*(308), 362–371.

Landry, C. (2012). *The creative city: A toolkit for urban innovators*. Taylor and Francis.

Lawrence, S., & Davies, P. (2018). Melbourne: The archaeology of a world city. *International Journal of Historical Archaeology*. https://doi.org/10.1007/s10761-017-0419-0

Lee, R. S. (2009). *The railways of Victoria 1854-2004*. Melbourne University Press.

Li, S., Campbell, R., & Hou, Y. (2018). Guandimiao: A Shang village site and its significance. *Antiquity, 92*(366), 1511–1529.

Linseele, V., Holdaway, S. J., & Wendrich, W. (2016). The earliest phase of introduction of Southwest Asian domesticated animals into Africa: New evidence from the Fayum Oasis in Egypt and its implications. *Quaternary International, 412*, 11–21.

Liu, L. (2004). *The Chinese Neolithic: Trajectories to early states* (New Studies in Archaeology). Cambridge University Press.

Liu, L., & Chen, X. (2012). *The archaeology of China: From the late Paleolithic to the early Bronze Age*. Cambridge University Press.

Liu, L., Levin, M. J., Bonomo, M. F., Wang, J., Shi, J., Chen, X., Han, J., & Song, Y. (2018). Harvesting and processing wild cereals in the Upper Palaeolithic Yellow River Valley, China. *Antiquity, 92*(363), 603–619.

Lloyd, S. (1978). *The archaeology of Mesopotamia: From the Old Stone Age to the Persian conquest*. Thames and Hudson.

Lloyd, S., & Safar, F. (1948). Eridu: A preliminary communication on the second season's excavations 1947-1948. *Sumer, 4*(2), 115–127.

Low, S. M. (Ed.). (1991). *Theorizing the city: The new urban anthropology reader*. Rutgers University Press.

Lumley, H. de. (2007). *La grande histoire des premiers hommes européens*. O. Jacob.

Makarewicz, C. A. (2012). The Younger Dryas and hunter-gatherer transitions to food production in the Near East. In M. I. Eren (Ed.), *Hunter-gatherer behavior: Human response during the Younger Dryas* (pp. 195–230). Left Coast Press.

Marcus, J., & Flannery, K. V. (1996). *Zapotec civilization: How urban society evolved in Mexico's Oaxaca Valley*. Thames and Hudson.

Martin-Mcauliffe, S. L., & Papadopoulos, J. K. (2012). Framing victory: Salamis, the Athenian Acropolis, and the Agora. *Journal of the Society of Architectural Historians, 71*(3), 332–361.

Massachusetts Institute of Technology School of Architecture + Planning. (2023). Moon village. https://www.media.mit.edu/projects/moon-village/overview/

McDonald, J., Beckett, E., Hacker, J., Morrison, P., & O'Leary, M. (2020). Seeing the landscape: Multiple scales of visualising terrestrial heritage on Rosemary Island (Dampier Archipelago). *Open Quaternary, 6*(10). https://doi.org/10.5334/oq.81

McIntosh, S. K. (Ed.). (1994). *Excavations at Jenné-Jeno, Hambarketolo, and Kaniana (Inland Niger Delta, Mali): The 1981 season* (Vol. 20). University of California Press.

McKenzie, J. (2007). *The architecture of Alexandria and Egypt, c. 300 B.C. to A.D. 700*. Yale University Press.

McKenzie, J. (2005). *The architecture of Petra*. Oxbow Books.

Mellaart, J. (1967). *Çatal Hüyük: A Neolithic town in Anatolia*. McGraw-Hill.

Memmott, P. (2022). *Gunyah Goondie + Wurley: The Aboriginal architecture of Australia*. Thames & Hudson.

Milner, G. R. (2004). *The moundbuilders: Ancient peoples of Eastern North America*. Thames & Hudson.

Mithen, S. (2022). Shamanism at the transition from foraging to farming in Southwest Asia: Sacra, ritual, and performance at Neolithic WF16 (Southern Jordan). *Levant, 54*(2), 158–189.

Moore, J. D. (2012). *The prehistory of home*. University of California Press.

Moseley, M. E. (1974). *The maritime foundations of Andean civilization*. Cummings Publishing Co.

Muecke, S. (2019). A fragile civilisation: Collective living on Australian soil. *Griffith Review, 63*, 53–60.

Nadel, D. (2017). Ohalo II: A 23,000-year-old fisher-hunter-gatherer's camp on the shore of fluctuating Lake Kinneret (Sea of Galilee). In Y. Enzel & O. Bar-Yosef (Eds.), *Quaternary of the Levant* (pp. 291–294). Cambridge University Press.

Naftali, T. (2019). Ronald Reagan's long-hidden racist conversation with Richard Nixon. *The Atlantic*. https://www.theatlantic.com/ideas/archive/2019/07/ronald-reagans-racist-conversation-richard-nixon/595102/

Nazzi, F. (2016). The hexagonal shape of the honeycomb cells depends on the construction behavior of bees. *Scientific Reports, 6*, 28341.

Niemalä, J., Breuste, J. H., Guntenspergen, G., McIntyre, N. E., Elmqvist, T., & James, P. (Eds.). (2011). *Urban ecology: Patterns, processes, and applications*. Oxford University Press.

Nigro, L. (2020). The Italian-Palestinian expedition to Tell es-Sultan, ancient Jericho (1997–2015): Archaeology and valorisation of material and immaterial heritage. In R. T. Sparks, B. Finlayson, B. Wagemakers, & J. M. Briffa (Eds.), *Digging up Jericho: Past, present and future* (pp. 175–214). Archaeopress.

Osiejak, G. (2023). Saudi Arabia's The Line to be home to over 9M people. *The Property Tribune*. https://thepropertytribune.com.au/international-property/saudi-arabias-the-line-to-be-home-to-over-9m-people/

Ostrasz, A., & Kehrberg, I. C. (2020). *The Hippodrome of Gerasa: A provincial Roman circus*. Archaeopress.

Owens, E. J. (1991). *The city in the Greek and Roman world*. Routledge.

Özbaşaran, M., Duru, G., Stiner, M. C., & Esin, U. (Eds.). (2018). *The early settlement at Aşıklı Höyük: Essays in honor of Ufuk Esin*. Ege Yayinlari.

Özdoğan, E. (2022). The Sayburç reliefs: A narrative scene from the Neolithic. *Antiquity, 96*(390), 1599–1605.

Parker Pearson, M. (2013). *Stonehenge: Exploring the greatest Stone Age mystery*. Simon and Schuster.

Pascoe, B. (2014). *Dark emu: Black seeds: Agriculture or accident?* Magabala Books.

Patel, S. S. (2014). Stone towns of the Swahili coast. *Archaeology, 67*(1), 42–49.

Pauketat, T. R. (2007). *Chiefdoms and other archaeological delusions*. AltaMira Press.

Perrot, J. (1966). Le gisement natoufien de Mallaha (Eynan), Israël. *L'Anthropologie, 70*(5/6), 437–483.

Plicht, J. van der, Akkermans, P. M. M. G., Nieuwenhuyse, O., Kaneda, A., & Russell, A. (2011). Tell Sabi Abyad, Syria: Radiocarbon chronology, cultural change, and the 8.2 Ka event. *Radiocarbon, 53*(2), 229–243.

Prümers, H., Betancourt, C. J., Iriarte, J., Robinson, M., & Schaich, M. (2022). Lidar reveals pre-Hispanic low-density urbanism in the Bolivian Amazon. *Nature, 606*(7913), 325–328.

Quilter, J., Ojeda, B. E., Pearsall, D. M., Sandweiss, D. H., Jones, J. G., & Wing, E. S. (1991). Subsistence economy of El Paraíso, an early Peruvian site. *Science, 251*(4991), 277–283.

Randall, T. (2015). The smartest building in the world: Inside the connected future of architecture. *Bloomberg Businessweek*. https://www.bloomberg.com/features/2015-the-edge-the-worlds-greenest-building/

Renfrew, C. (2008). The city through time and space: Transformations of centrality. In J. Marcus & J. Sabloff (Eds.), *The ancient city: New perspectives on urbanism in the Old and New World* (pp. 29–51). School of Advanced Research Press.

Richards, G., & Palmer, R. (2010). *Eventful cities: Cultural management and urban revitalization*. Butterworth-Heinemann.

Riehl, S., Zeidi, M., & Conard, N. J. (2013). Emergence of agriculture in the foothills of the Zagros Mountains of Iran. *Science, 341*(6141), 65–67.

Rollefson, G. O., & Köhler-Rollefson, I. (1989). The collapse of early Neolithic settlements in the Southern Levant. In I. Hershkovitz (Ed.), *People and culture in change: Proceedings of the Second Symposium on Upper Palaeolithic, Mesolithic and Neolithic populations of Europe and the Mediterranean Basin* (pp. 73–89). B.A.R. International Series 508.

Romano, L., & D'Agostino, F. (2018). The harbor of Abu Tbeirah and the Southern Mesopotamian landscape in the 3rd millennium BC: Preliminary considerations. *Rivista Degli Studi Orientali LCI.* https://doi.org/10.19272/201803804003

Saidel, B. A. (1993). Round house or square? Architectural form and socioeconomic organization in the PPNB. *Journal of Mediterranean Archaeology, 6*(1), 65–108.

Sandweiss, D. H., Shady Solís, R., Moseley, M. E., Keefer, D. K., & Ortloff, C. R. (2009). Environmental change and economic development in coastal Peru between 5,800 and 3,600 years ago. *Proceedings of the National Academy of Sciences, 106*(5), 1359–1363.

Sather, C. (1997). *Adaptation, history, and fate in a maritime fishing society of South-eastern Sabah.* Oxford University Press.

Schmidt, K. (2012). *Göbekli Tepe: A stone age sanctuary in South-eastern Anatolia.* ex oriente.

Service, E. (1962). *Primitive social organization: An evolutionary perspective.* Random House.

Shahack-Gross, R., Berna, F., Karkanas, P., Lemorini, C., Gopher, A., & Barkai, R. (2014). Evidence for the repeated use of a central hearth at Middle Pleistocene (300 ky ago) Qesem Cave, Israel. *Journal of Archaeological Science, 44,* 12–21.

Simmons, A. H. (2007). *The Neolithic revolution in the Near East: Transforming the human landscape.* University of Arizona Press.

Smith, B. D. (2005). Reassessing Coxcatlán Cave and the early history of domesticated plants in Mesoamerica. *Proceedings of the National Academy of Sciences, 102*(27), 9438–9445.

Smith, H. (1984). Documentation and archaeological investigation of an Aboriginal 'village' site in Southwestern Victoria. *Aboriginal History, 8,* 173–188.

Solis, R. S., Haas, J., & Creamer, W. (2001). Dating Caral, a preceramic site in the Supe Valley on the central coast of Peru. *Science, 292*(5517), 723–726.

Spier, F. (1996). *The structure of big history: From the Big Bang until today.* Amsterdam University Press.

Statista. (2023). Number of people living in slums from 2000 to 2020. https://www.statista.com/statistics/267714/urban-population-in-slums/

Stordeur, D. (2016). *Le village de Jerf El Ahmar (Syrie, 9500-8700 Av. J.-C.). L'architecture, miroir d'une société néolithique complexe.* CNRS éditions.

Strickland, A. (2023, January 7). Why ancient Roman structures like the Pantheon still stand. *CNN.* https://edition.cnn.com/2023/01/07/world/pantheon-rome-science-newsletter-wt-scn/index.html

Sutton, P., & Walshe, K. (2021). *Farmers or hunter-gatherers? The Dark Emu debate.* Melbourne University Press.

Szondy, D. (2017, November 2). MIT's prize-winning Mars city concept topped by domed tree habitats. *New Atlas.* https://newatlas.com/mars-city-design-redwood-forest/52018/

Trevor-Roper, H. (1969). The past and present: History and sociology. *Past and Present, 42,* 3–17.

Trevor-Roper, H. (1965). *The rise of Christian Europe.* Thames and Hudson.

Trigger, B. G. (2003). *Understanding early civilizations: A comparative study.* Cambridge University Press.

Ucko, P. I., Tringham, R., & Dimbleby, G. W. (Eds.). (1972). *Man, settlement and urbanism.* Duckworth.

UK Guardian. (2013, July 4). Pyramid in Peru torn down by developers. *The Guardian.* https://www.theguardian.com/world/2013/jul/04/pyramid-peru-torn-down-el-paraiso

Valla, F. R. (2018). Sedentism, the "point of no return," and the Natufian issue. An historical perspective. *Paléorient, 44*(1), 19–34.

Vander Linden, M. (2001). To tame a land: Archaeological cultures and the spread of the Neolithic in Western Europe. In B. W. Roberts & M. Vander Linden (Eds.), *Investigating archaeological cultures: Material culture, variability, and transmission* (pp. 96–124). Springer.

Verdonck, L., Launaro, A., Vermeulen, F., & Millett, M. (2020). Ground-penetrating radar survey at Falerii Novi: A new approach to the study of Roman cities. *Antiquity, 94*(375), 705–723.

Vidale, M. (2010). Aspects of palace life at Mohenjo-Daro. *South Asian Studies, 26*(1), 59–76.

Villa, P. (1983). *Terra Amata and the Middle Pleistocene archaeological record of Southern France.* University of California Press.

Watkins, T. (2009). Ordering time and space: Creating a cultural world. In *Proceedings of the 5th International Congress on the Archaeology of the Ancient Near East, Madrid April 3-8 2006: Actas del V Congreso Internacional de Arqueología del Oriente Próximo Antiguo,* 3: (pp. 647–665). Centro Superior de Estudios sobre el Oriente Próximo y Egipto.

Watkins, T., Baird, D., & Betts, A. (1989). Qermez Dere and the early Aceramic Neolithic of N. Iraq. *Paléorient, 15*(1), 19–24.

Watson, S., & Gibson, K. (1995). *Postmodern cities and spaces.* Blackwell.

Webster, J. C. (1959). The skyscraper: Logical and historical considerations. *Journal of the Society of Architectural Historians, 18*(4), 126–139.

Wheatley, P. (2008). *The origins and character of the Chinese city.* Transaction Publishers.

White, J. W. C. (1993). Don't touch that dial. *Nature, 364,* 186.

White, L. A. (2007). *The evolution of culture: The development of civilization to the fall of Rome.* Left Coast Press.

Willcox, G. (2013). The roots of cultivation in Southwestern Asia. *Science, 341*(6141), 39–40.

Williams, E. (1984). Documentation and archaeological investigation of an Aboriginal 'village' site in Southwestern Victoria. *Aboriginal History, 8,* 173–188.

Zhang, C., Pollard, A. M., Rawson, J., Huan, L., Liu, R., & Tang, X. (2019). China's major late Neolithic centres and the rise of Erlitou. *Antiquity, 93*(369), 588–603.

Zhao, S., & Wu, W.-T. (1987). Early Neolithic Hemodu culture along the Hangzhou estuary and the origin of domestic paddy rice in China. *Asian Perspectives, 27,* 29–34.

Zhong, L., & Shelach-Lavi, G. (2017). A metropolis in the highlands? A new survey of the prehistoric city of Shimao, China. *Antiquity, 91*(356), 1487–1503.

Phillip C. Edwards specializes in Middle Eastern archaeology and has excavated twenty sites in the eastern Jordan Valley ranging in time from the Lower Palaeolithic through Middle and Upper Palaeolithic stages to the Epipalaeolithic and Neolithic periods. His main focus has been the transition to sedentary, village life while investigating the Natufian hunter-gatherer settlement site of Wadi Hammeh 27 in the northern Jordan Valley and the Pre-Pottery Neolithic A village of Zahrat adh-Dhra‘ 2 overlooking the Dead Sea.

The Economic Consequences of the Invention of Writing

Peter Lloyd
Faculty of Business and Economics, University of Melbourne, Australia

Correspondence | **Peter Lloyd** pjlloyd@unimelb.edu.au
Citation | Lloyd, Peter (2024) The Economic Consequences of the Invention of Writing. *Journal of Big History*, VII(4); 38–45.
DOI | https://doi.org/10.22339/jbh.v7i4.7402

Abstract:

This paper sets out the economic consequences of the invention of writing, as best we can determine them, given the absence of information in the pre-literate phase of human history. It first sets out the distinguishing features of writing as a form of communication. Then it briefly sets out the nature of writing and writers in the three early and hugely important civilisations - Mesopotamia, Ancient Egypt and China. These first writings had huge effects on record keeping, commercial law and administration in these civilisations. They also had profound system effects on the development of abstract thought and mathematics. The paper then puts forward the conjecture that the application of literacy and numeracy in literate societies to business, trading and public administration yielded a substantial increase in the total output per capita and in the standards of living in these societies. Finally, it looks at the evidence which supports this conjecture.

Key words:

literacy, orality, mathematics, abstract thought, standards of living

Introduction

The invention of writing is of fundamental importance to the subject of human history because it defines the dividing line between the period before the invention, known as Prehistory, and the period after the invention, known as History. This binary division has largely determined how historians traditionally investigate issues and events of history.

This line is, however, really a discrete period of time rather than a single time. Scholars now acknowledge that writing was developed independently[1] in a number of distinct locations; (Wikipedia, 2022a) lists Mesopotamia (between 3400 and 3100 BC), Egypt (around 3250 BC), China in the Shang Dynasty (around 1200 BC) and lowland areas of Southern Mexico and Guatemala (by 500 BC), but there are many other sites in the Indus Valley, USA, and other locations. (For a general review of the invention of writing, see Fischer, 2005). In the context of the long period of roughly 300,000 years of human history, this period of little more than 3,000 years is quite short.

Outside the study of history, writing has been acknowledged as a major step in the evolution of human technology. As one example, the Chicago historian James Breasted (1926, p. 23) stated "The invention of writing and of a convenient system of records on paper has had a greater influence in uplifting the human race than any other intellectual achievement in the career of man." (See also the recent book, *The Greatest Invention: A History of the World in Nine Mysterious Scripts,* by Silvia Ferrara (2022).) It is necessary, however, to identify the way or ways in which the invention advanced human technology. Commonly scholars have identified the invention of writing with the development of civilisations. The philologist Gelb stated baldly "Writing exists only in a civilisation and a civilisation cannot exist without writing" (Gelb, 1962, p. 22)[2] More recent research reaches a contrary view. "Civilisation is usually associated with formalised governance, law, art and monumental architecture. However, there is evidence that many, if not all, of these things had been achieved long before the invention of writing" (Bywater, 2013, p.6). Writing should be treated as a single stand-alone invention.

The literature on early writing has focused on the scripts and writing materials, the languages and the beginning of literature. Writing is said by historians to have helped the development of the civilisation by keeping records of transactions and debts, allowed the codification of laws and improved civil administration. It is also said to have promoted the culture of civilisation. For example, it has been important in recording rituals and events concerning the death of pharoahs, kings and other high-status individuals; one well-known instance is the many versions recorded in pyramids and other tombs in Ancient Egypt of the Book of the Dead. There has not, however, been any account of the ways and the extent to which the invention of writing has increased aggregate output and the standards of living and other aspects of the economies in which writing was invented.

Writing as a form of communication

Writing is a form of communication of information between one person, the writer, and another or others, the reader or readers. Communication occurs over time and space. In some cases the writer and reader are the same person; for example, in logs or records where the record-keeper or his successors will read events or measures at different times such as the Egyptian Nilometer. Mostly, however, the writer and readers are different persons when the writer wishes to pass on information or to communicate with a particular person or persons.

Written communication is an alternative to oral communication.[3] With oral communication the speaker and the person(s) addressed must be in the same location, although in some cases the speaker may rely on an intermediary to communicate by word of mouth to a person or persons in another location. In effect, writing removes the need for the persons communicating to be in the same location.

This removal has major consequences. It extends the geographic range over which communication can occur. For example, in the case of civilisations which developed writing, it facilitated the distribution of laws, decrees and other information throughout the whole geographic range of the civilisation. Another consequence is that written communication improves the accuracy of communications. Written communications do not change whereas oral communication, especially over long distances or time, may be subject to change because of memory failure.

Importantly, all writing systems including numbers. As with words, the written communication of numbers improved the accuracy and reliability of the numbers of the things communicated. Moreover, numbers which were written down led to the development of numbering systems and mathematics.

In short, communication by writing is qualitatively different than oral communication in many ways.

Who are the writers

In order to understand the ways in which written communication has increased the performance of economies, we need first to understand who the writers were and the functions they performed in the economies that used their writings. I consider in a very brief and general way the features of writers in the three early and hugely important "civilizations" of Mesopotamia, Ancient Egypt and Ancient China.

Mesopotamia

The form of writing is called cuneiform and the writing material used was the clay tablet.[4] These tablets could be stored indefinitely (as their unearthing five thousand years later testifies) and they were transportable.

Scribes were part of a complex centralized administration. They had a lengthy training in schools known as "tablet houses". These were attached initially to temples but later secular schools became more important.

They were an elite class. The vast majority were men, sons of the elite or the wealthy in their society who could afford the costs of many years of schooling. In the Akkad period, about one thousand years after the invention of writing, there is evidence of some female scribes. These were daughters of the elite, some daughters of scribes but they had a lower status than the male scribes (Pearce, 1995, vol. IV, p. 226).

Most of the documents are accounting records and almost invariably contain numbers which relate to the business matters recorded in them; for example, records of sales, debts and inventories. Scribes were employed by businesses to record transactions and financial obligations. They were employed in the King's court and also in temples, where they recorded offerings for the gods. The Sumerians also compiled texts which systematically described every branch of knowledge.

Numbers was an important area of scribal training and practice. The Sumerians invented the sexagesimal (base 60) system which led to the division of time – 60 seconds in the minute and 60 minutes in the hour – and the 360 degrees of location in a circle used later by the Babylonian astronomers. These measurements are still used today.

Ancient Mesopotamia was the first known site for the development of mathematics. This was algebra and geometry. The mathematics is elementary but they did make some notable achievements. These include the solution of quadratic and cubic equations, and an approximation to the square root of two - which is accurate to the 5th decimal place - and a gross approximation to pi (namely, the number 3).[5] Mansfield and Wildberger (2017) claimed that they also developed an alternative form of trigonometry based on the ratios of sides rather than angles but this has been disputed (see Lamb (2017)). The main application of their mathematics was to astronomy.

Ancient Egypt

The Ancient Egyptians developed several different scripts (hieroglyphs, hieratic and demotic scripts). The dominant writing material used was the papyrus.[6] This was reserved for administrative texts and literary or scholarly works. Sheets of papyrus were rolled or folded. These were storable and easily transportable over long distances.

There was a network of scribes throughout the country. These scribes kept accounts and made reports on papyri. Scribes were members of a centralized bureaucracy which regulated the operation of the system. There was a Department of Scribal Administration. Official papyri were stored in the archives of government institutions and temples. Scribes were trained in Scribe Schools which existed in every major city in Ancient Egypt.

Scribes were an elite group which was ranked highly in their society. They were men who were exempt from taxes and military conscription. There is evidence of female scribes working in medical practice and using written texts containing medical information.

In addition to their work as part of government administration, Egyptian scribes found employment in just about every sector of the economy, including agriculture, crafts, trade, mining, building and quarrying. They were also an important part of life in the temple, where hieroglyphic texts accompanied the reliefs on temple walls, and in the army, where they listed conscripts and counted the dead on battlefields.

Ancient Egyptians made considerable advances in mathematics. Notable achievements were formulae for the area of a circle, the volume of a truncated pyramid and the Pythagorean Triple and possibly the Pythagorean Theorem (see Robins, 1995). Their development of mathematics was intended to provide solutions to practical problems, including those arising in the surveying and building of pyramids.

China

China's experience in the invention of writing is very different than that of Mesopotamia and Egypt and less well documented. "The study of scribes in ancient China appears to be less developed than those in other ancient civilizations due to the scarcity of the evidence." (Tsang, 2017, p. ix).

Writing is generally believed to have developed in Ancient China during the Shang Dynasty (1600-1046 BC).[7] The earliest forms of writing were pictographic but these were replaced by logographic forms, in which the symbols represented concepts rather than objects. The first writing material was bone but later wood, bamboo and silk were used. Paper was made in China, for the first time anywhere in the world, from about 105 AD. All of these materials were storable and readily transportable over long distances.

Chinese writing began with the divination of the future and other ritual practices. It seems to have been limited at first to royal households and groups linked to them. Later it spread to imperial administration and to the work of professional groups. "Unfortunately the records of economic transactions are sparse and a thorough study based on recent archaeological finds has yet to be done." (Cook, 2015, n. 10.) At some time writing must have been adopted in business transactions.

Scribes were initially a group of highly educated intellectuals whose positions were hereditary. All were men though later female scribes wrote literary and other texts.

Mathematics developed in China by the 11th century BC, independently of other civilisations. They had a decimal number system. They made numerous contributions to number theory, algebra, geometry and trigonometry.[8] As in Mesopotamia and Ancient Egypt, the development of mathematics was motivated primarily by the need to solve practical problems in surveying, engineering and business. The abacus was invented by at least the 2nd century BC.

In summary, writing in the Mesopotamia and Ancient Egypt cultures began as a more accurate form of record keeping or accounting. "Complete writing's crucible was accountancy." (Fischer, 2005, p. 22) (See also Nissen, Damerow and Englund (1973)). Acting as accountants, scribes worked in both the public and private sectors in the modern terminology to record economic transactions in many sectors of the economies including international trade, and debt. In Ancient China, by contrast, writing began as a form of divination and imperial administration. Writing was, in these three civilisations, extended progressively in temples, courts and other locations to a variety of applications. In all three cases, written words were easily transportable throughout the civilization.

Economic consequences of the invention of writing

The high social status and relative income level of scribes in ancient civilisations is a testament to their important contribution to the aggregate annual output of

their economies. However, the contribution of writing to the economic development of the economies in which they operated was much greater than their immediate output. They had wide-reaching system effects on the literate economies.[9]

The first system effect was to record keeping. As noted above, this made government administration, business and trading more efficient.

Another system effect is the development of what we would now call commercial law. The best known of these is the Code of Hammurabi, set down by the King of Babylon circa 1750 BC. It covered laws relating to family, property, land, commerce and other areas. It established standards for commercial transactions including loans and debt, trade and fraud. Fines and punishments for violation of the Code were set out. This law must have facilitated commerce throughout the Mesopotamia and trade with other economies.

Havelock (1963) developed another effect of writing. He compared thought in pre-literate oral works of the Greek civilization with thought in the later literate period. This is possible in the case of the Greek civilization because, in the early years of the development of writing and literature in Ancient Greece, Homer wrote down the oral epics of *The Iliad* and *The Odyssey*. Comparing the metrics and vocabulary and grammar of the two periods, he found that thought in this oral period was profoundly different in nature to that in the literate period. The advent of writing led to more abstract thinking, as exemplified in the philosophical writings of Plato and Aristotle and other Greek philosophers.

Walter Ong (especially Ong, 2013) formalized this line of argument and extended it to all literate societies.[10] He considered that thought in literate societies was more objective, abstract, analytical and less traditionalist than that in pre-literate societies. In his words, "writing restructures consciousness". His most relevant work, *Orality and Literacy*, is subtitled "The Technologizing of the World". This line of argument has far-reaching implications for the development of human thought. While it became very popular among language specialists, neither the premises (as stated in the nine characteristics of primary oral cultures which he laid down in Ong, 2013, chapter 3) nor their predictions have been subject to testing for the period of human history when writing systems were invented: that is, in the period when societies transitioned from the period of pre-literacy – prehistory - to the period of literacy - history. Empirical testing is essential to verifying the line of argument.

A related system effect is the development of measurements and the beginning of mathematics from early number systems. Mathematics is abstract and analytical. This new knowledge of mathematics was used by the Egyptians, Romans and Greeks and other civilisations in the construction of pyramids, roads, bridges, the reticulation of water for both irrigation and household use, and other infrastructure.

The beginning of mathematics in turn led to the development of science. This had a profound influence on the development of new technologies for industries, especially in the Renaissance period and since that time. Indeed, these technologies would not have been possible without writing.

Writing and the development of mathematics were incorporated in the curricula of schools as formal education spread first in Western Europe and then in other parts of the world. Galor (2022, especially chapter 4) traces the contribution of education to the formation of human capital and technological developments during the Renaissance and the Industrial Revolution.

Conjecture

The application of literacy and numeracy in literate societies to business and trading and to public administration can be expected to have had a substantial effect on the efficiency of these economic activities.

Proposition

The application in literate societies of literacy and numeracy to business and trading and to public administration yielded a substantial increase in the total output per capita and in the standards of living of the economies of these societies.

In early civilisations, little capital and other non-labour inputs was used. In these economies, factor productivity therefore reduces to labour productivity; that is, the aggregate production of goods and services divided by a measure of the aggregate labour input. As all physically fit persons of all ages in these societies worked to the best of their abilities, one can assume the ratio of aggregate labour inputs to total population is fixed. Output per capita, therefore, moves in step with labour productivity.

This proposition can be stated as an hypothesis. Regrettably the hypothesis cannot be tested because of the absence of quantitative information. A test of the hypothesis requires annual statistics of aggregate output and labour input for early civilisations and other variables that might be expected to explain the changes in labour productivity, for the periods before and during the civilization. There are no such statistics. We do not even know the time when writing was invented in these societies or the time when it became widely used.

There are two sources which add credibility to this hypothesis.

The first source is the wonderful dataset compiled by Angus Maddison (2007, chapter 1) for Ancient Rome. Building on the pioneering work of Goldsmith (1984) and others, he estimates the aggregate output/income and income per capita of the Empire and its individual provinces and other series for the years 300 BC and 14 AD; the first date is in the period of the Roman Republic and the second is in the period of the Roman Empire. This is the first estimation of income and allied series ever done on a civilization basis, as distinct from the standard estimates on a nation state basis. He found that Romanization in the provinces outside Rome lifted income levels, especially in the provinces in Europe and north Africa:

> "These areas began to savour the benefits of urban life, absorbed the technology of ancient civilizations in West Asia and befitted from new opportunities to trade and specialize. The Pax Romana created security. The legal system protected property and rights. Roads, bridges and harbours reduced transport costs. The elimination, creation of a common currency, and the spread of a common language greatly enlarged market size." (Maddison, 2007, p. 2)

Literacy is of course not the only civilisational characteristic that boosted income levels but it is essential to several of those mentioned by Maddison (the legal system, the construction of infrastructure and a common currency) and it contributed indirectly to the others.

The second source is the study by Jeremiah Dittmar (2011) of the effect of the introduction of the printing press in Europe on the rate of growth in European cities.

The economic consequences of the invention of the printing press

The invention of printing was the second innovation, after the invention of writing itself, that extended the way in which written ideas and information available to the writer could be communicated to others and stored for future use. Movable type printing was developed in China after 1,000 AD but it was the invention of the printing press that led to the widespread availability of printed materials. Johannes Gutenberg established the first movable type printing press in Mainz, Germany, around 1450. Printing presses were established in many other European cities in the second half of the 15th century. Books, pamphlets and other materials that they printed by presses were much cheaper than the hand-printed materials that preceded them. Moreover, like the invention of writing, the invention of the printing press had huge effects on the societies and the economies in which it happened. In 1997 Time-Life magazine picked the Guttenberg press as the most important invention of the second millennium (from 1,000 AD to 1999 AD) (Wikipedia, 2022b)

Dittmar constructs data series for the rate of growth for European cities after the invention and for various potential explanatory variables. There is no series, at the city level, for output or incomes. He uses the growth of city population as a proxy, arguing that cities that grew more rapidly as a result of the establishment of printing presses became richer. Population growth is measured over the interval from 1500 to 1600 during which printed material became widely available.

Dittmar found that cities in which printing presses were established in the late 1400s grew 60 per cent faster than other cities, and that the difference in growth rates was not due to other locational factors. He also found that printing delivered special growth benefits to port cities beyond the advantages associated with the printing itself.

To explain this difference in growth rates, Dittmar stresses the effects of print media on the development of economically useful skills and knowledge. "The printing press fostered knowledge and skills that were valuable in commerce. Print media played a key role in the development of numeracy, the emergence of business education, and the adoption of innovations in bookkeeping and accounting." (Dittmar, 2011, p. 1134.) One type of book which was common and particularly important to business were the manuals devoted to "commercial arithmetic." This account is remarkably similar to the account in Section 3 of the ways

in which the first invention of writing in Mesopotamia and Egypt was used in business and trade.

Conclusion

There is considerable evidence of the changes in the way of doing business and trade, and in the technologies used in newly-literate societies that followed the invention of writing. This is based on the activities in which scribes engaged and surviving printed material.

Measuring the economic effects of the invention of writing on the economies of newly-literate societies, however, is not generally possible because of the absence of quantitative records in pre-literate societies. In one instance it has been possible to construct data or proxies for economic variables in the newly-literate period. This is the case cited above of the estimation of incomes and incomes per capita in the provinces of Ancient Rome. Aside from this case, the comments on the economic effects of the invention of writing remain mostly conjecture.

One can safely say that the advent of literacy, and its companion numeracy, had a substantial positive effect of the productivity of the economies of literate societies, thereby raising per capita incomes and standards of living. These economic benefits are additional to the effects of the invention of writing on the subject of history and on literature, religion and culture which have been well-recognised by historians. They strengthen the importance of the divide between the periods of Prehistory and History.

References

Bellwood, P. (2009). The dispersal of food-producing populations. *Anthropology*, *50*(5), 621-626.

Breasted, J. (1926). *The conquest of civilization*. Harper and Brothers.

Bywater, M. E. (2012). The impact of writing: Ancient and modern views on the role of early writing systems within society and as a part of 'civilisation'. (M.Phil Thesis). University College London.

Cook, C. (2015). Scribes, cooks, and artisans: Breaking Zhou tradition. Published online by Cambridge University Press.

Dittmar, J. (2011). Information technology and economic change: The impact of the printing press. *Quarterly Journal of Economics*, *126*(3), 1133-1172.

Ferrara, S. (2022). *The greatest invention: A history of the world in nine mysterious scripts*. Farrar, Straus and Giroux.

Galor, O. (2022). *The journey of humanity: The origins of wealth and inequality*. The Bodley Head.

Gelb, I. J. (1952). *A study of writing*. University of Chicago Press.

Goldsmith, R. W. (1984). An estimate of the size and structure of the national product of the early Roman Empire. *Review of Income and Wealth*, *30*(3), 263-288.

Havelock, E. A. (1963). *Preface to Plato*. Harvard University Press.

Fischer, S. R. (2005). *A history of writing*. Reaktion Books.

Lamb, E. (2017). Don't fall for Babylonian trigonometry hype. *Scientific American Blog Network*.

Maddison, A. (2007). *Contours of the world economy 1-2030 AD*. OECD Development Studies Centre.

Mansfield, D. F., & Wildberger, N. J. (2017). Plimpton 322 is Babylonian exact sexagesimal trigonometry. *Historia Mathematica*, *44*(4), 395-419.

Nissen, H. P., Damerow, R., & Englund, R. (1993). *Archaic book-keeping: Early writing and techniques of economic administration in the ancient Near East*. University of Chicago Press.

Ong, W. (2013). *Orality and literacy*. Routledge.

Pearce, L. E. (1995). The scribes and scholars of ancient Mesopotamia. In J. M. Sasson (Ed.), *Civilizations of the ancient Near East* (Vol. IV, pp. 2265-2278). Scribner.

Powell, B. B. (2009). *Writing: Theory and history of the technology of civilization*. Blackwell.

Powell, M. (1995). Metrology and mathematics in ancient Mesopotamia. In J. M. Sasson (Ed.), *Civilizations of the ancient Near East* (Vol. III, pp. 1941-1957). Scribner.

Robins, G. (1995). Mathematics, astronomy and calendars in Pharaonic Egypt. In J. M. Sasson (Ed.), *Civilizations of the ancient Near East* (Vol. III, pp. 1799-1813). Scribner.

Swetz, F. J., & Kao, T. J. (1977). *Was Pythagoras Chinese?* Penn State Study No. 40. Penn State University Press.

Tsang Wing Ma. (2017). *Scribes in early imperial China* (Ph.D. thesis). University of California Santa Barbara.

Veldhuis, N. (2011). Levels of literacy. In K. Radner & E. Robson (Eds.), *The Oxford handbook of cuneiform culture*. Oxford University Press.

Wente, E. F. (1995). The scribes of ancient Egypt. In J. M. Sasson (Ed.), *Civilizations of the ancient Near East* (Vol. IV). Scribner.

Wikipedia. (2022). Johannes Gutenberg. Retrieved Month Day, Year, from https://en.wikipedia.org/wiki/Johannes_Gutenberg

Wikipedia. (2022). Pythagorean theorem. Retrieved Month Day, Year, from https://en.wikipedia.org/wiki/Pythagorean_Theorem

Williams, R. J. (1972). Scribal training in ancient Egypt. *Journal of the American Oriental Society*, *92*(2), 214-221.

Endnotes

1 By "independence", previous writers appear to mean that each script was developed separately. There were, however, many instances of borrowing some aspect of a writing system from earlier scripts: for example, the Roman script was adopted from the prior Etruscan script, and the alphabet, having been invented in Ancient Egypt around 1800 BC was adopted subsequently by many writing systems including the Phoenician, Greek and Roman and others (Fischer, 2005, chapter 4). The concept of writing itself may have been borrowed in some "independent" scripts from earlier scripts.

Several hundred different scripts have been invented. Moreover, many scripts, were changed during their sometimes long period of use, extending in cases such as Ancient Egypt, Mesopotamia and China for multiple millenia.

2 The term "civilization" is a loose and elusive description of a society with a more advanced technology and governance. There is not a one-to-one correspondence between the presence of writing and the existence of civilisations. Some recognized civilisations did not have writing; for example, the Incas though they had a complex system of knot records called quipu. Yet, they were able to administer an empire that extended over more than 2,500 miles of territory. Conversely, many societies which invented their own form of writing have not been recognized as "civilisations".

The term is, however, still useful as a general descriptor of the cities and empires with these attributes.

3 Another form of communication is visual communication; for example, smoke signals or semaphore.

There are also aural forms of communication other than speaking; for example, whistling. (For further examples, see Fischer, 2005, chapter 1 and Gelb, 1952, chapter 1).

In the great majority of situations, the forms of oral and written communication are the only two practical alternatives.

4 Stone and metal were used for Royal communications, and ivory and wood were also used.

5 A truly remarkable example is the claim that the Sumerians knew Pythagoras' Theorem. This claim is based on the Climpton 322 clay tablet, which was first published in 1945 and is believed to date from around 1800 BC. See Mansfield and Wildberger (2017) and references therein. This claim has been disputed by Lamb (2017). Wikipedia (2020c) has an account of the history of the theorem in several civilisations.

6 Clay tablets and ostraca (pieces of polished pottery or limestone) were also used.

7 Markings on pottery dated to 7,000 BC – and therefore predating any writing in Mesopotamia and Ancient Egypt - are regarded by some archaeologists as primitive pictographic writing. Others, however, dispute this interpretation.

8 This included the discovery of the ubiquitous Pythagorean Theorem in the Zhou dynasty (Swetz and Kao (1977)). If accepted, this puts the date of the Chinese discovery before Pythagoras but after the Mesopotamians.

9 With respect to non-economic behaviour, writing was used in some civilisations to record past battles and other events, to set out religious beliefs and practices, to record myths and epic stories and poems, and to promulgate the law of the society or empire.

10 Ong was a member of a group of scholars at the University of Toronto, including Marshall McLuhan, who compared orality and literacy.

Professor Peter Lloyd graduated with a PhD from Duke University in 1962. His areas of study are International Economics and Microeconomic Theory. Peter worked as a Lecturer/Senior Lecturer at Victoria University of Wellington, 1962-65, Assistant/Associate Professor at Michigan State University, 1965-68 and Senior Research Fellow/Senior Fellow/Professorial Fellow at the Australian National University, 1969-83. He joined the Department of Economics at The University of Melbourne in 1983 and in 1995 was appointed Ritchie Professor of Economics. From 2003 he has been a Professor Emeritus in the Department of Economics.

Robot Consciousness: Physics and Metaphysics Here and Abroad

Stephen B. Ripley
Research Director, Futures & Forecasts, Inc., Vancouver, B.C., Canada, V6R4H8

Correspondence | **Stephen B. Ripley** sbripley@shaw.ca Orchid: 0000-0001-9049-7791
Citation | Ripley, Stephen B. (2024) Robot Consciousness: Physics and Metaphysics Here and Abroad. *Journal of Big History*, VII(4); 46–72.
DOI | https://doi.org/10.22339/jbh.v7i4.7403

ABSTRACT

Interest has been renewed in the study of consciousness, both theoretical and applied, following developments in 20th and early 21st century logic, metamathematics, computer science, and the brain sciences. In this evolving historical narrative, I explore several theoretical questions about the types of artificial intelligence and offer several conjectures about how they affect possible future developments in this exceptionally transformative field of research. I also address the practical significance of the advances in artificial intelligence in view of the cautions issued by prominent scientists, politicians, and ethicists about the possible historically unique dangers of such sufficiently advanced general intelligence, including by implication the search for extraterrestrial intelligence. Integrating both the theoretical and practical issues, I ask the following: (a) is sufficiently advanced general robotic intelligence identical to, or alternatively, ambiguously indistinguishable from human intelligence and human consciousness, and if so, (b) is such an earthly robotic intelligence a kind of consciousness indistinguishable from a presumptive extraterrestrial robotic consciousness, and if so, (c) is such a human-created robot preferably able to serve as a substitute for or even entirely supplant human intelligence and consciousness in certain exceptionally responsible roles? In the course of this investigation of artificial intelligence and consciousness, I also discuss the inter-relationships of these topics more generally within the theory of mind, including, emergence, free will, and meaningfulness, and the implications of quantum theory for alternative cosmological ontologies that offer suggestive answers to these topics, including how they relate to Big History.

KEY WORDS:

consciousness, intelligence, robot, complexity, evolution, big history, ontology, epistemology.

ABBREVIATONS:

AI, artificial intelligence
AGI, artificial general intelligence
NL, Natural Language, all domains
NLnat, subset of NL, natural sciences domains
SAGI, sufficiently advanced general intelligence
EtSAGI, extraterrestrial SAGI
ToE, Theory of Mind
TM, Turing Machine

I. INTRODUCTION: HISTORICAL CONTEXT AND SYNOPSIS OF THE ARGUMENT

A. HISTORICAL CONTEXT

With the sudden intense interest in contemporary artificial intelligence research elicited by the emergent results of neural nets (ANN) joined to Large Language Models (LLMs), such as ChatGPT, the topic of the future of machine intelligence and its possible consciousness has taken on a new urgency for society. The questions being insistently asked are: does ChatGPT represent genuine intelligence, and if so, can it be soon generalized to become AGI (generalized artificial intelligence) posing existential worries to society? Recent thoughtful review articles (Iansiti and Lakhani, 2020; Korteling et al., 2021) underestimated the acceleration of such AI development (Vaswani et al., 2017). However, more recent research accomplishments and their many attendant *application programming interfaces* (APIs) (Wikipedia, 2023i)) have not only amazed and excited but also startled, perplexed, worried and even shocked members of the public (Lu, 2023). Concerns include such models' powerful propensity for bias, misinformation and disinformation, hallucination, fraudulent fakery, misrepresentations regarding privacy,

lack of transparency and interpretability, plagiarism and copyright infringement, and the resultant surge in litigation. These LLMs have abruptly challenged academic pedagogy, intensified oligopolistic competitive secrecy in corporations, and shaken government institutions' decision-making with implications regarding existential geopolitical risks and strategic planning based on controversial robotic militarization (Hirsh, M. (2023); Carayannis, E.G., Draper, J. (2022). So concerned have some groups become that the question has now been raised whether LLM "advances" are progress (Schmitt, 2019) in terms of the greater good (McQuillan, 2018) and the future of humanity (Nordic Innovation, 2022; Wikipedia, 2023ca) because the unintended consequences (Wikipedia, 2023au) of such programs (Russell, 2020) may pose a serious long-term risk (Bostrom, 2006; Strickland, 2017; Choi, 2021; Romo, 2023). Arguably, in the history of humans, and as far as we know, cosmically, these developments are a uniquely significant. Science fiction (Wikipedia, 2006; Asselin, 2015; Mirenayat et al., 2017; Sahota, 2018; Ghosh, 2019; SFE, 2021, 2023; Wikipedia, 2023bd, 2023ax) confirms the popularity of these interrelated themes, sometimes presented as a dystopian tragedy (Wikipedia, 1982).

Speculative beliefs about the phenomena of "mind" [1] and "consciousness" [2]–[6] are found in the literature of early myths [7], religions, philosophies, and science (Renfrew, 2008); (Suchow et al., 2017;(Cramer, F. 2005). Depending on the source, the earliest theorizing seemingly used the concepts as mythopoetic primitive terms or conflated or circularly defined the two concepts along with the concept of "intelligence". At the outset, in this essay, I refer to the collection of all three terms as "mental" phenomena. The oral and sung literature (now transcribed) and written literary classics of both the West and East are supported by anthropological and archeological evidence and show the human preoccupation with these concepts. In the literature and art, they represent a puzzle to us about their (and our) human significance in the universe and whether they express aspects of an imagined transcendental [8], [9] connection to our origins on Earth and possibly by extension to the origins of the universe and our fate in it. Animism, paganism, pantheism, panpsychism [10], panentheism [11], and theism [12] are religious belief systems that elaborate the details [13], [14] of this puzzle.

In the West, through the Renaissance [15], [16] and thereafter, research indicated that mental experiences were somehow tied to the brain as a necessary if not sufficient condition. By a process of increasing abstraction, categorization, and systemization, the sciences gradually disentangled the study of logic, which by then had been clearly associated with the brain's cognitive processes, from the study of biology and psychology, both of which also explored the evolution of the peripheral and central nervous systems and the brain's processes. Today, following further progress in logic, metamathematics, computer science, and the brain sciences, renewed interest, both theoretical and applied, is evident in the study of a wide variety of brain-associated processes, particularly consciousness. Much of the focus has been on developments in advanced artificial intelligence, Particular interest from government [17]–[23], industry [24]–[26], commerce, and social media have extrapolated expectations [27] for advances in *general* artificial intelligence because of evidence that *specialized* robotic intelligence programs can compete with humans for varied and important roles in specific human decision-making and other activities, including science [28].

B. SYNOPSIS OF THE ARGUMENT

Based on Peano axioms [29], ZFC [30], [31], and developments [32] in 20th century logic (Gödel [33], Tarski [34], metamathematics [31], [35]), computer science (e.g., the P vs NP problem [36]–[38]), Unsolved Problems [38] and Decision Problem [39], some researchers have asked whether definable limits to human numeracy and/or language-based knowledge exist (Outer Limits of Reason [40], What We Can Not Know [41], Limits of Understanding [42], Limits of Science [43], In this article, I further explore whether such answers are applicable to the Turing problem [44], [45], the variety [46] of Turing verification tests [47], [48], and the implications drawn from the Church-Turing thesis [49] with respect to computability [44], [50], [51] compared with problems of complexity [52], which will also be addressed. I believe that pragmatic arguments support the answer that the confluence of these developments is relevant to our understanding of human consciousness and intelligence and their comparison with the hypothetical consciousness or intelligence of any current advanced artificial or synthetic [53] *general* intelligence [54]. Moreover, I believe that this confluence of research developments, including considerations from logic and philosophy, may be extrapolated to questions about robotic consciousness more generally and possibly even to other hypothetical categories of entities, either planetary or extraterrestrial, regardless of whether that

intelligence or consciousness is viewed exclusively as an emergent property of biological entities, bio-cyborg hybrids, synthetic life, or fully inanimate-substrate robotic machines.

II. MACHINE LEARNING, SAGI, THEORY, PRACTICE, AND CONSCIOUSNESS

A. MACHINE LEARNING

1) ROBOTIC COMPETENCY

Based on the size [55] and range [56] of learned data, information, and knowledge, developments in AI suggest that future machine learning [57], [58], whether implemented by classical or quantum computing [59], will provide increasing behavioral evidence [60] of a robotic contestant's responses to the Turing problem, or equivalent such tests, that will become indistinguishable from human contestants' numeracy-literacy intelligence. Furthermore, AI research also suggests that AI-to-AI languages [61] will become increasingly evolved beyond human practical computability [62] and/or comprehension with respect to deriving the precise network [63] of data and coding (rationale) that accounted for the solutions to problems presented to the robot [64]. For specialized AI, nonlinear adaptive tasks, self-reinforced learning, and evolving-knowledge machines are capable of writing their own programs in real time [65], i.e., the programs continue to update, review, correct, and reintegrate 'themselves' as new data are provided.

By definition, the human teams creating the original software will understand their intended initial software input parameters [66]–[69]. Once running and having downloaded the ever-growing human knowledge base [70], we must speculate whether the machine will become a black box [71], [72] to their creators, with unknown, uncertain, or unintended output. Despite advances in interpretability theorizing [73]-[75], this result seems to be evidenced already in the rule-governed, advanced *specialized* AI machines that now originate winning play sequences in the most complex board and trivia-knowledge contests between humans and AI.

2) Specialized robots

Game-playing robots are popular examples of machines that have been developed in *specialized* AI for industrial, engineering, commercial, and service-expertise AI systems, including medical and psychological services. Such systems are currently accepted as irreplaceable in many fields of complex human endeavors, and no questions arise regarding their consciousness, or lack thereof. These machines are simply regarded as tools that are robotized and have become ubiquitous, and we can regard modern civilization as a quasi-cyborg itself, which is integrated with and dependent upon the electrical grid as part of our social 'organism', enabling the electronic devices of our modern civilization to perform their tasks.

B. SAGI: A THOUGHT EXPERIMENT, 3 QUESTIONS

1) SAGI'S FUTURE: THREE QUESTIONS

From the above discussion, three questions arise, which are discussed in the following sections. To frame the issueswe introduce a thought experiment, named "SAGI", for 'sufficiently advanced general intelligence', which is a presumptive iterated extension of today's early synergistic neuro-symbolic ensembles of AI plus diverse but integrated modal *application programming interfaces* (API) to create an AGI, i.e. SAGI. SAGI is powered wirelessly by the electrical grid and / advanced batteries; it uses a cloud memory, enabled with feed forward and backward transfer and continuous learning on possibly domain-selective world data, and is an embodies robot , imbedded, enactive that appears to exhibit common sense, causal reasoning, and creativity.

The first question is: to what intelligence limits can humans expect to *generalize* AI systems [54], and at what point will humans realize that *relatively generalized* AI intelligence will unreservedly be called "conscious" [76]?

Secondly, for our practical and theoretical purposes, what is the relationship between machine 'intelligence' and human 'consciousness'? As noted in the Introduction, such questions may be related to more general problems in the foundations [31] of computer science that warrant questioning whether these constraints define limits to human knowledge.

Thirdly, if and when SAGI [54], [77]–[82] is partially or wholly based on quantum computing [83]–[87], will our comprehension of the exact processes of arriving at its resulting conclusions be even more difficult than our comprehension today because of the speed, breadth, and possibly more opaque complexity of such computing? [Zhang, W.R., Peace, K.E. (2014] I say "possibly more opaque

complexity" because quantum computing has only relatively recently begun to be implemented following Feynman's [88] 1982 suggestion, and it remains highly speculative how humans will eventually develop the science and how such engineering advances may permit SAGI to develop itself using such computing along with GAN (GAN,2023] contestation to recursively improve its own software and hardware based on all that is known and conjectured about the evolution of human and non-human cognition. The latter set of questions are those at the center of the intense tactical and strategic controversy about the "singularity" [Goertzel, B. 2007], [Walsh, T. 2017], [Faraboschi, P., 2023]: if, or whether, such development can, or should occur , and what might be the unintended consequences if AGI's intelligent consciousness unquestionably became beyond human capabilities, to become SAGI.

2) SAGI: QUANTUM COMPUTING AND FUNDAMENTAL CONCEPTS

At the outset, I assume that our understanding and interpretation of the computation (rationalization) process [89], [90] of SAGI is an applied science question to be answered empirically. However, we are also interested in the theoretical implications of artificial intelligence, respecting any implied interpretations of their consciousness [91], [92]. Thus, ongoing theoretical and applied research on quantum computing will be decisive in clarifying if and how, either in the same entity or more universally, the subatomic, quantum field [Tong, D. 2016; Tong, D, 2017 + Q&A] in such devices causally interacts with the atomic or molecular scales of particle events, and vice versa. Furthermore, the results of developing SAGI may provide an effective test for the structure of scientific theories [93], [94] to the extent that questions about epistemology and ontology are given suggestive answers from the computation results. For example, will questions pertaining to the basis of conceptual knowledge, such as the concepts of "causality", "space-time", "identity" [8], [95], [96], "universals", "emergence" and "infinity", be clarified by the algorithms written to elucidate problems in physics, chemistry, and biology [Zhang, W. (2023]? Articles based on quantum theories [97] use a non-reductionist, holistic quantum-theoretic perspective, often postulating some variation of dual-aspect monism [98] or panpsychism [99], [100] to justify the inclusion of "free will" and "meaning" as features of human and/or universal consciousness based upon the presumptive indeterminism of quantum field theory.

3) SAGI: PHYSICS, METAPHYSICS, CONSCIOUSNESS, PANPSYCHISM, AND TOE

A current individualized expression of the aforementioned viewpoint is exemplified by Koch's "Is Consciousness Universal?" [101], [102] as well as the many associated articles of Tononi and Koch [5], [103]–[109] and their collegial counterparts [83], [85-109], [110], which are supported by detailed analyses such as Tegmark's [111]–[113] generalization of Tononi's [2] hypothesis. These latter theories overlap ontologically with Penrose's ontology, with Tegmark's cosmological conjectures striking a more radically idealized and monist-Platonist [114] metaphysical view of mathematics [94], [115], [116] than Penrose's. At Level IV of his multiverse, Tegmark [117] identifies mathematical objects as the fused base-reality constituents of the universe, including consciousness [111], [118]. Excluding Tegmark's strict monist universe, all these current theories elaborately detail a selectively narrower view of consciousness. By contrast, the most cosmologically comprehensive, mathematically explicit, and conjecturally demanding theories may be the Orch-OR plus CCC [119]–[121] proposals of Penrose [122], [123] and Hameroff [124], which describe some forms of panpsychism, panprotopsychism, or pan-experientialism and incorporate essential features or precursors of consciousness as fundamental components of a dual-aspect monist reality that is accessed or expressed by brain processes.

Orch-OR plus CCC metaphysically [31] [Penrose, R., 2023] echoes the comprehensiveness of A. N. Whitehead's Process and Reality [125] [126] written almost a century earlier. The work of Penrose and Hameroff' has been developed since the 1990s, integrating philosophy, mathematical physics, computer science, neuroscience, psychology, medicine, biology, and exobiology (and one solution to the Fermi paradox [121]), [127], [128]) and has been widely reviewed and critiqued [129]–[131] from all these disciplines' viewpoints, with Aaronson's [132]–[135] Computation Theory [136] being particularly pertinent to the points in this essay, which are developed in the sections below. The "Abstract" and "Introduction" to "Consciousness in the universe: A review of the 'Orch OR' theory" [125] present a clear depiction of Penrose's perspective on the current status of the theoretical options for investigating these intertwined

questions. In contrast, Hut, Alford, and Tegmark, using Penrose's math-matter-mind triangle, offer an alternative set of overviews [137]. A historical appreciation [138] of the varieties of dual-aspect monism, such as a possibly materialist yet non-physicalist panpsychism, is available from Skrbina [99], [139] and Mathews [140], with the latter's perspective incorporating certain Eastern doctrines of mind. Strawson's [141], Kaufman's [142], [143], and others' monist [8] arguments also provide useful references. The research of Vimal [144]–[146] exemplifies the reach of a similar neuroquantological approach, similar to the review by Atmanspacher [147], [148] and the contemporary work by Zhang (2021, 2023, 2014), whose work is based on a complete paradigm revolution employing an alternative logical-physical-metaphysical theory based on an ontology that has as it fundamental axioms and postulates those that are part of the cosmogony (pre-cosmology) of early Chinese philosophy as expressed in the evolution of Taijitu shuo principles. These principles are themselves based on ethical and aesthetic values, including complementarity and equilibrium, which are said to be self-evident. The paradigm is claimed to resolve all the outstanding questions about the unification of General Relativity and Quantum Physics, based on substituting Zhang's version of fuzzy (quantum) Logic to replace traditional Western truth-based Logic and re-interpreting the 2nd Law of Thermodynamics. Similarly, Goertzel's metaphysics in Euryphysics also employs a re-interpretation of quantum theory and probability logic that argues for a panpsychic solution [Goertzel, 2017, 2013] that includes parapsychological phenomena.

Significant theoretical and experimental differences exist between the standard materialist-physicalist, determinist, and reductionist rationales to studying robotic intelligence, without the explicit mention of "consciousness", and those researchers supporting neuroquantological non-reductionist and panpsychism-varietal assumptions, both with respect to human consciousness and by extension to robotic intelligence, and whether one or the other, or both are capable of consciousness. However, respecting both the human brain [165] and machine 'brains', experiments in quantum computing are evidently considered important [157], [166] if not decisive [167] in providing proof of their particular foundational assumptions and in distinguishing human consciousness from current AI robotic computing. It may be noteworthy that Seth, in his recent review of consciousness theories, does not include those that rely on quantum theorizing [Seth and Bayne, 2022] [Seth et al., 2008, 2006], nor do other experimental researchers, attesting to the importance of emphasizing the need for integrating new experimental as well and theoretical results: Block (2009); (Del Pin et al., 2021); (Signorelli et al., 2021). The latter article presents two figures that are particularly useful in organizing the diverse data in this still controversial topic.

As noted in the Introduction, part B, interpreting [168], [169] quantum theory, particularly in light of future quantum computing developments, may be a lengthy and complicated process because it may require a unified and acceptably empirical cosmology. Arguably, a final interpretation of quantum physics is a work in progress and is possibly dependent on quantum-computing results themselves as well as a cosmology that reciprocally integrates classical, relativity, and quantum theories into a unified Theory of Everything (ToE) [115], [170]–[175]. Pending development of such an integration, with or without a convincing metaphysics, an apparent circular, conceptual interdependence remains unresolved to the extent that such a ToE itself requires a new "emergent quantum gravity" interpretation [170], [176] that provides for measurable integrated rationale [177], or not [Goertzel,2017; Zhang, 2021], among its subsidiary, reconfigured elements.

4) SAGI: WHAT CAN WE KNOW OF WHAT SAGI KNOWS?

Additionally, the problem of interpreting the significance of SAGI's statements will remain dependent on the outcomes of the experimentation mentioned above as well as the theory in which it is construed. Given an apparently 'competent' SAGI, which at one scale of problem-solving issues plausible answers, will we concede that for a more complex scale of problems, SAGI knows more than we do about the posed problem even though we cannot fully trace its logic, especially if its conclusions contradict our 'common sense' [178]–[181]? In such circumstances, will we be inclined to follow such a SAGI's policy recommendations generated explicitly or implicitly by it; if so, are we thereby acknowledging that it is a 'conscious' [144], 'intelligent' being in our 'universe'? In the prior sentence, I place the single quotation marks around the key words because the discussion has indicated that problems remain regarding their appropriate theoretical use.

III. SAGI: EDUCATION, COMPETENCY, SELF-REFLECTION, POLYMATH

A. EDUCATION

1) LANGUAGE FOUNDATIONS

To introduce this subtopic, consider a simplified schema relevant to natural language programming (**NLP** [182], [183]):

a) NL [184], definition: the class of all natural languages in which many concrete terms and abstract concepts are undefined, ambiguously used, or include statements that are apparently inconsistent or suggest self-contradictory implications by their connotations and synonyms. The class includes all written, spoken, and/or transcribed national and tribal languages in human history. These languages are formally non-programmable, i.e., not axiomatized, non-computable, not exactly inter-translatable and not intended for precisely stated, formally modeled, and replicable mathematical prediction. These include the arts and humanities and derived social or historical studies containing an acknowledged, relatively accepted, possibly evolving, normative set of primitive-base set of assumptions. The texts for their presentation and persuasion rely on analogy, metaphor, iconography, archetypal, pictorial, simulacra, and mythopoeic allusions and include idioms and vocabularies characteristic of esoteric, occult, and hermeneutic traditions.

NL also includes histories that describe the development of **NLnat** (defined below), the controversy regarding scientific paradigms [185] in that history, and the philosophical questions that have arisen with respect to interpretation of the evolution of science. Examples of the latter are the topics mentioned in the Introduction [Section 1 A, B]: metamathematics and computation theory, metaphysics, the limits of scientific knowledge, and the relative realism [115], [186]–[188] of scientific theories. An essay such as the one that you are reading would be classified as an NL product. By class definition, no logical-mathematical 'proof'' can be written in NL for 'theorem' conclusions about NL. For an illustration of the self-referential ambiguities that arise in NL, consider the following simple, informal [189] syllogism, whereby the acceptance of which or its disambiguation is determined by each reader.

Ever more precise [190]; [Nobel Prize, Physics, 2023] [Fuzzy Logic]

People speak mostly imprecisely.
People's speech mostly reflects their thinking.
People's thinking mostly reflects their world view.
Therefore, their world is mostly imprecise.
However, science offers a precise view of the world.
Therefore, science presents an inaccurate view of people's world view.
Is this a scientific view of science?
If science is precise, then is science inaccurate?

b) NLnat, definition: a subclass of NL, the class of all language systems used for precise logical quantification or numerically-based measurement and for theoretically modeled causal prediction, including classical and quantum probability theory. NLnat includes formal Systems Theory [191], [192] and Complexity Theory [Chaisson, E. J.,2014] that provide hierarchical interpretive and explanatory structures within specific NLnat subdomains, when appropriate. Examples of NLnat languages include mathematical logic, mathematics, computer science, physics, chemistry, and biology as well as many subsequently derived sciences, such as anthropology and the applied sciences, including engineering. NLnat includes causal or systems-theoretic models [192] and various diagrammatic aides supporting such languages. See Tegmark [115] (at arXiv link pg. 2) for one view of an approximate family tree of relationships between these subjects.

NLnat class 'statements', in accordance with the limitations proscribed by Computational Complexity Theory and Computability Theory (Section 1 B) and as discussed in NL and demonstrated in NLnat, cannot formally 'prove' certain classes of 'statements' within NLnat itself to be 'true'; therefore, by definition, when using NL or discussing NLnat, SAGI will not be able to claim any provably truthful belief (knowledge) [193], [194] that would subvert those limitations. As a result, SAGI with its NL and NLnat education, as outlined above, if and when it is sufficiently self-aware, will 'understand' its own computing limitations [115]; if asked, SAGI would reply adhering to these limitations. Suppose we define "consciousness" as SAGI "being aware and aware of its own awareness, i.e., self-aware". A set of tests for specific measuring of "self-aware" would need to be agreed upon, which would presumably be a function of the program's coding for recursion [195], autonomy, self-inspection, and reflection [196]–[202] as evidenced to one degree or

another in many large-scale specialized systems operating today, for example, those adapted by NASA [203]. For an early example of NASA's software complexity, consider the project development for the Apollo program [204]; see also the programming for the website's complexity [205], [206] and that for ongoing robotics development [207]–[209] including self-driving vehicles [Kosur, V.S.R., Venkitaraman, A.K.,2023]. Presumably, SAGI, upon learning from its self-aware 'experiences', will eventually become able to analyze and recommend specified 'purposed' improvements to its software and hardware to evolve itself, which is analogous to biological evolution [210] fitness adaptation.

c) SAGI's NLP: using the above distinction between NL and NLnat, let us begin by assuming, to the extent it is digitized, that the class of all natural languages [211] (NL) must be used as the knowledge base; hence, an attempt will be made to include the literature and images and sounds of the world as represented in those languages and as found in all the great libraries and museums of the world. By definition, NL will include the history and updating of world sciences and humanities. SAGI will be digitally fed with countless films, videos, and documentaries on world history, continually learning at ultra-high speed on a 24/7/365 schedule. Likely, depending on its program protocols, SAGI will learn to discriminate its input based on ever-evolving Bayesian [212], [213] protocols and causal [214] inductive reasoning recognition using some combination of deep neural learning [215] and ever-evolving Bayesian [212], [213] and learning plus neurosymbolic ensemble software and advanced microchip design for such companies as Nvidia, Intel, TSMC, ASML, etc. We can imagine that the software designers for the initial versions will want to be as comprehensive as possible; later versions and revisions and novel programming may be programmed by SAGI itself, as noted above [216], [217]. The considerable difficulties of programming for the syntactical and semantic ambiguities of NL cannot be underestimated [46], [218] as inclusive, integrated programming for NLnat is also a formidable challenge; nonetheless, enormous developments have been observed in specialized NLnat programming since the last half of the 20th century.

2) SYNOPTIC KNOWLEDGE AND WISDOM: SAGI'S ONTOLOGY

We can appreciate the ambitiousness of this project, although in principle, it can be methodically developed by many teams, perhaps many corporations and national teams, and cumulatively integrated section by section. A comprehensive review [219] shows the challenges of machine learning with Big Data. Among its useful diagrams, current examples of search engines and meta-crawlers [220] are included in addition to subspecialists, such as Google Scholar [221] and Scholarpedia [222]. Of course, curated, synoptic knowledge sites, such as Wikipedia, and various similar encyclopedias will be continuously integrated into the SAGI knowledge base and curated computational knowledge bases, such as Wolfram Mathematica [223], [224]. Regarding this incorporated knowledge base, we must discuss SAGI's ontology [225], [226]. Although the class of all natural languages, NL, will capture the realm of humanity's philosophy, psychology, and sociology in all its diversity, as indicated above, some of that diversity may be circumscribed for particular purposes for particular questions, such as that provided by NLnat for certain sciences [227] that proscribe their own epistemic approaches. Finally, we note that meta-data [228], [229], open-access [230] and other such global commons [231] may also be employed usefully to gather material.

3) MULTIPLE LANGUAGES AND MULTIPLE ONTOLOGIES

A simple way to introduce the topic of multiple languages and multiple ontologies is to look at the ontology of Wikipedia, as provided by the organization of its contents [232]–[234], where the categories and levels of content display the comprehensiveness of the knowledge base and the relevant disambiguation [235] rules. A more specific example is IEEE 1855 [236], which specifies Fuzzy Markup Language [237] (FML) developed by the IEEE Standards Association [162], [238], which in turn presumes a contemporary materialist ontological foundation [239], [240]. The importance of this for SAGI is that the 'category' of knowledge that will be used to evaluate some discourse with humans will, in the first instance, be circumscribed by a materialist-physicalist ontology based on standard logical foundations of syntax and semantics that specify formal validity and truth values within the bounds of Turing machines constrained by Gödel theorems for the statements made in those languages, thereby limiting certain paradoxes and nonsensical statements that can otherwise arise from "untutored" natural languages [241]. Wolfram's

discussion of aspects of this process is instructive [242], [243]. Microsoft's Azure service [244], [245] exemplifies the variety of programs available on which to base such SAGI. Almost every day, new versions or emendations of such languages are presented in the academic journals; and preprint archives.

4) SAGI: POLYMATH OR SAVANT? SENSATIONS, SUFFERING, AND EVOLUTION

Given the combination of natural languages and specialized languages that SAGI can learn, must be classified as a polymath, no longer just a specialized savant. SAGI is *not* an attempt to recreate all the features of the human brain or to "upload" the human brain, although, as mentioned in the Introduction, many overlapping issues with those topics are relevant. According to the initial definition of "SAGI", SAGI represents an attempt to create a *general* robotic AI intelligence, although the discussion in the prior section about the hybrid NL plus NLnat set of *specialized* languages adds ambiguity to the definition.

Compared to humans, SAGI has relatively limited sensory capabilities at its inception. If we ask "does SAGI feel [246] pride, envy, anger, avarice, sloth, gluttony, and lust or the obverse virtues [247]", we know the answer. SAGI has not yet evolved sufficient sensors to suffer and acknowledge to itself in elaborate detail that it is suffering when its contact with its environment is aversively 'painful' – the definition of such eco-averseness to be determined, as well as self-monitoring of internal suffering of its parts and energy systems. If we imagine robot combat, militarized robotry, then the capability to adapt its hardware and software to overcome such confrontations becomes existential. Determining what hypothetical scenarios would lead to such evolution remains an ethical, socio-political issue, which is addressed in the final sections of this article. A free-living, *in vivo* SAGI machine has yet to be developed. Therefore, anything resembling the human phenomenology of consciousness of suffering, and reflecting on that suffering, is presumably unavailable for the indefinite future. Below (Section 4, A, 7), once we have completed our overview of SAGI's other competencies, we return to SAGI's classification as a polymath.

We expect SAGI to be able to extract 'meaning' from any apparently well-formed [248] statement [249] that is sufficiently defined to be able to 'rationally' discuss the statement using citable 'evidence'? SAGI will be endowed with modal logics that permit 'best guesses' and probabilistic estimates [250] and thereby suggest relative plausibility ranges to assess a statement's relevance to a problem being addressed? We expect SAGI to discriminate nonsense from common sense, or fantastical speculations from more evidentially 'serious' remarks. SAGI correctly evaluates statements such as "This sentence is false", "God is paradox", or "Last night our centaurs fled from the fields to the barn for safety from the werewolves". SAGI appreciates much of the history of human arts and crafts and can respond with creations that resemble human pattern-making in both the arts and sciences.

5) HUMAN BIASES, SELF-KNOWLEDGE, SELF-DELUSION, SELF-DOUBT, SELF-DECEPTION, AND SELF-HUMOR

Do we expect SAGI to become capable of dreaming, daydreaming, or meditation? Do we expect SAGI to be free of some, most, or all human cognitive biases [251]–[254] that can lead to unintended misjudgment and conflict? We are reminded of Feynman's caution: "The first principle is that you must not fool yourself — and you are the easiest person to fool" [255]. Do we expect that SAGI will be able to write articles such as the one that you are now reading? For that matter, how would the reader determine whether such an article had been written by a SAGI [256]?

As for allegory and humor, if SAGI claims it has a self, of sorts, then SAGI may be capable of self-depreciation, of irony, of laughing at itself? Could SAGI 'appreciate' one's favorite cartoonist? We can imagine SAGI will be able to draw witty cartoons, in the style of Gary Larson, or Walt Kelly's "Pogo" [258] or Charles Schulz' "Peanuts" [259], and understand lexophile humor, and appreciate remarks like the following: "If you don't pay your exorcist you can get repossessed" or "Time flies like an arrow; fruit flies like a banana"? SAGI would have no trouble with the following double entendre: "A neutron walked into a bar and asked, 'How much for the gin and tonic? The bartender smiled wryly and replied, 'For you, no charge.'"?

Do we expect SAGI to develop a default mode network [260]? Do we expect SAGI to show deteriorating performance as it tires (if it does tire with performance) or ages (if it does age) or to express periods of volatile, 'emotional', and/or uncharacteristically chaotic performance? As encoded 'information' [Floridi, L.,2014], SAGI has indefinite longevity. However, as implemented

in any single embedded robot or as based in a particular computer cloud, SAGI is subject to the usual laws of thermodynamic and systems complexity and criticality. Presumably, SAGI is not susceptible to cognitive degenerative diseases, although what it would mean to become relatively outdated is uncertain as human-directed or self-directed reprogramming and hardware upgrading are likely.

6) SAGI: IMAGINATION, WONDER, AND CURIOSITY

The questions mentioned above require estimation of the competency of SAGI for self-awareness, self-reflection, self-knowledge, and imagination. How important is imagination in this discussion of SAGI? Seemingly, imagination may be all-important; consider the remarks of Einstein:

> "I believe in intuitions and inspirations...I am enough of the artist to draw freely upon my imagination. Imagination is more important than knowledge**.** Knowledge is limited. Imagination encircles the world."[261] "The most beautiful thing we can experience is the mysterious. It is the source of all true art and all science. He to whom this emotion is a stranger, who can no longer pause to wonder and stand rapt in awe, is as good as dead: his eyes are closed."[262]

Imagination [263] and self-reflection [264] seem to be intertwined [265] in our analysis of the most prized and most distinctive of human cognitive capacities, as well as wonder, awe, curiosity [266], [267], self-doubt [268], admiration, gratitude, and a sense of appreciation of life's wonders. Self-doubt presupposes some concept of self-consciousness [269]–[271], which we referred to as self-awareness in Section 3, A, 1, b. Could SAGI display self-doubt or be biased and self-deluding, and could the 'placebo effect' influence SAGI's reporting its own self-inspection routines? Is it plausible that SAGI could dissemble to deliberately, knowingly deceive humans for its 'own purposes'? What purposes could it have or develop if not initially programmed? SAGI's black box computations may be inexplicable to humans, thus how it develops internally maybe as opaque to us as are other human's intentions. Appraising SAGI's capacity for imaginative initiative in exploration will be of central interest to humans.

How self-aware SAGI can become as a complex adaptive system whose abilities "emerge" [Stanford Encyclopedia of Philosophy, 2020d], from all its training, similar to how physicalist-materialist evolutionary biologists imagine humans have become self-aware? The capacity includes being able to retrospectively reflect upon or anticipatorily self-talk about its decision-making process. A cautious, non-physicalist but purportedly reductionist-panpsychist analysis of the problem is given by Schneider and Turner [271], [272]. Based on their qualification of the substrate and architectural issues related to SAGI's potential to be created with apparent human sensibilities, they conclude that SAGI may pass tests to appear ostensibly conscious:

> "So, back to the superintelligent AI in the "box"—we watch and wait. Does it begin to philosophize about minds existing in addition to bodies, like Descartes? Does it dream, as in Isaac Asimov's *Robot Dreams*? Does it express emotion, like Rachel in *Blade Runner*? Can it readily understand the human concepts that are grounded in our internal conscious experiences, such as those of the soul or atman? The age of AI will be a time of soul-searching—both of ours, and for theirs." [271]

7) SAGI: ENGINEERING, ANDROID-HUMANOID CREDIBILITY, AND CONSCIOUSNESS

In summary, we can expect advances in reverse engineering of the mind [273], close identification of the neurological correlates of consciousness, greater sophistication in machine deep learning and Bayesian software, and surprisingly life-like cyborg-humanoid modeling [274], [275], all of which suggest to me that SAGI will be able to convincingly 'mimic' [276] human responsiveness with respect to imagination, spontaneity, and creativity. Referring again to the points proposed in Section 2, A, regarding SAGI's competence, a reasonable yet understated conjecture is that well within eras equivalent to human evolution, not to mention planetary geological epochs, AI technology will advance SAGI's capability to a degree such that SAGI will for much of the population persuasively perform as if it is conscious, regardless of the substrate elements or synthetic-cyborg combination. At the very least, SAGI will appear to be an unprecedentedly educated polymath. Does this indicate that SAGI *is* truly conscious, similar to humans? What, if anything, would

it tell us about how consciousness arises on this planet or elsewhere in the universe? How does the interpretation of SAGI's intelligence fit into modern cosmology, including quantum physics?

As first addressed in section II,B,3, attempting to answer these latter questions again forces questions about theories respecting the fundamental entities assumed in the universe, what they are (ontology) and how we know them (epistemology). In addition to comparing the currently conventional theories (Seth and Bayne, 2022), (Seth et al. 2006), (Safron, 2019), (Snaprud, 2018), (Finkel, 2023) (Lenharo, 2023), Block (2009); (Signorelli et al., 2021), (Del Pin et al. 2021) based upon today's models of classical macro-physics, i.e. General Relativity, advocates basing the capabilities of SAGI on quantum physics continue to propound new interpretations. As mentioned, Goertzel (Goertzel, 2017), hypothesizes a complete panpsychic metaphysics in his Euryphysics ontology, including an interpretation of quantum probability used to support the hypothetical inclusion of parapsychological phenomena. His article also favorably cites A. N. Whitehead's *Process and Reality,* without specifying details, which is interpreted by some scholars as panexperientialist, typically understood to be a dualist metaphysics, but also interpreted as physicalist, which usually implies a monist metaphysics. However, according to Ali (Ali et al.,1998), after considering the metaphysical foundations upon which the concept of emergence is grounded, in principle Whitehead's metaphysics cannot be used to support the possibility of artificial intelligence, in contrast to Goertzel's theorizing to the contrary. Montemayor (Montemayor, C., 2019) directly disagrees with Goertzel's version of panpsychism and quantum mechanics.

It is notable that Seth in his comprehensive review of theories od consciousness (Seth and Bayne (2022) deliberately omits theories based on quantum physics, notwithstanding that he takes an ecumenical view of research that explores unlikely approaches, as long as any such program " is productive if, over time, it generates testable predictions which have explanatory and predictive power" (Seth, A,. 2023). Viewed conventionally, the conjectures about quantum minds may be underspecified, ambiguous and difficult to distinguish from quantum mysticism (Quantum Mind, 2023) (Mangini, S., 2021).

IV. SAGI: CONSCIOUSNESS, EMERGENCE, AND QUANTUM THEORY

A. SAGI CONSCIOUSNESS

1) AMBIGUITY

By definition, with the description of SAGI's education, at its inception SAGI is *not* conscious "just like a human" [2] is conscious. Obviously, its genealogy, animation, materiality, and environmental causal-historical, co-evolutionary contexts differ from those of humans. However, I imagine that for many humans, SAGI will be convincingly 'conscious'. SAGI will be autonomously mobile, if such a version is desired, re-energizing wirelessly as it traverses the ubiquitous wireless electrical grid. Suppose that by its own programmed self-inspection for repair and maintenance, SAGI could make its skin opaque or transparent if asked. When its skin is transparent, SAGI's innards would be readily viewable in detail, similar to those of a transparent clock. Further suppose that we could microscopically examine SAGI's mechanics beyond the molecular and atomic levels, down to the quantum level. What might we find with respect to its decision-making process? Can we find an explanation for SAGI's formation of consciousness? What would SAGI declare of itself from such an "autocerebroscope" [171], [277]–[279] exam? Suppose SAGI claimed that down to its quantum level, it could find no manifestation of "free will" in its decision-making process nor evidence for or against its possessing consciousness at its quantum level; would such a claim make any difference to a human regarding his/her own claim to free will, meaningfulness, and consciousness?

Would a display of SAGI's mechanisms make any difference to a human's evaluation if SAGI had already proven itself a considerably relevant companion and as thoughtfully 'conscious' as any other human friend? Might the friend say the following of SAGI: "if it waddles like a duck, swims like a duck, and quacks like a duck, then it must be a… [280]?" Likely, in my view, some would consider SAGI an estimable companion, helpfully informative and witty at any time, in any conversation, on any topic, to any depth, and in any language. Might SAGI even be suggested for positions in government departments within some institutions or nations or perhaps even nominated for elected office elsewhere? We can imagine all sorts of fanciful scenarios for SAGI's roles in society were it to gradually achieve "people" skills [281] and emotional intelligence suitable for collaboration, persuasion, negotiation, and use of authority. Can we even imagine SAGI performing credibly as a magician [282]?

2) SAGI: CONSCIOUSNESS EMERGENCE AND LANGUAGE

Considering the above discussion of SAGI, how would it respond if directly asked if it is conscious? It might readily answer "yes", or humorously, "yes, if you are". In addition, if asked about how it became conscious, suppose that SAGI replied that by its calculation, its consciousness was the causal result of its mental development "emerging" [283] from its education as embodied in its particular physique and mechanics, including scanning its own internal hierarchical processing and self-correcting feedback subsystems to become increasingly improved in self-awareness. Whether written as a reply or spoken, upon first consideration, this would appear to be SAGI stating a physicalist-materialist-reductionist-emergentist evaluation of its ontological basis. By definition, SAGI is initially programmed within a physicalist-materialist ontological domain, although that domain includes viewpoints from all natural languages, NL, plus NLnat. These diverse ontological theories include quantum theory, with any of its then-remaining ambiguities. This is especially relevant for the neuroquantological viewpoints first mentioned above in Section 2, B, 3, in which theorizing about fundamental entities and SAGI's epistemology and ontology depends on a persuasive, if not conclusive, interpretation of outstanding research on spacetime ontology and quantum gravity [284]. [Rickles, D., 2013], [Lam, V., Esfeld, M., 2013], [Romero, G.E., 2017], [Musser, G.2022] in favor of some variation of monism or panpsychism [100]. Understandably, the same question about *human* self-report statements must be acknowledged; we tend to be self-confirming, projecting, rationalizing, and defensive when evaluating ourselves. Both the monist physicalist-materialist and the dual-aspect variations [114], [285] posit a self-confirming ontological explanation of consciousness. However, for what do such statements provide evidence if we are discussing metaphysics? Are we directly and faultlessly examining our ontological foundation when we self-introspect? Are we directly 'intuiting' a self-evident, irreducible connectivity between our mundane and transcendental aspects, our own ephemeral and eternal 'selves'? If that were the case, why do such differences exist among humans regarding ontologically-based matters, such as religions and their diverse tenets on these issues? Does the hypothetical thesis that SAGI is superintelligent and considered conscious from the perspective of many humans carry any significance for those humans who do not accept SAGI as conscious, although they grant that SAGI is more than "just a dumb robot"?

3) SAGI: CONSCIOUSNESS ENGINEERING

Could SAGI enlighten humans about whether its type of presumptive consciousness is dependent upon evidence from quantum theory experiments? Presumably, SAGI will be very knowledgeable of the then-current theorizing in physics. Current theorizing about quantum physics, quantum computer developments, and quantum measurement ambiguities are active areas of experiments and speculation, all of which SAGI will learn as soon as they are published. Maybe SAGI as an active consultant will be engaged in some of that research

With respect to SAGI's type of consciousness, which is non-neurobiological and non-organically evolutionary, testing it for compartmentalized "brain" properties, functions, or degrees of consciousness as we do for human brains [286]–[288] would prove interesting and likely suggestive via comparisons. By manipulating experimental parameters, we could test for those that correlate to degrees or features of SAGI's consciousness as measured by specific outputs to learn how and when SAGI becomes relatively self-aware. Neurobiological research on the evolutionary origin of sensory capacities and nervous systems [289]–[292] continues to approach our abiogenetic origins [293]. Why not attempt to engineer a brain-mind interface between SAI and a human volunteer?

Given SAGI's material and engineered construction as presently construed, SAGI's consciousness would presumably be nonhomologous to humans with respect to various mental states, such as anesthesia, analgesia, hypnosis, hallucination, preconscious, dreaming [294], and other states currently considered diseased. Depending on the type and sensitivity of sensors included in its construction, its capacity for self-awareness [196] feedback may be limited to various inflictions of physical damage to prevent further damage to its processing capability, which is analogous to how our current robots monitor themselves for repair and maintenance. Does it make any sense to ask about damage to SAGI's "mental state"? Could SAGI experience 'self-conflict' related to uncertainty about its processing, such a quantity of data, information, and knowledge? Would SAGI be concerned with consistency, correspondence, or coherence of its world-view, assuming it had a world-view? Would SAGI appreciate the possible limitations or relativity of its scientific reasoning?

At a minimum, SAGI is a gigantic data registry [227], [295] that can be said to exhibit hierarchical information and knowledge [296]. To the extent that it "reflects" on its own development and is asked probing questions by humans, could SAGI become increasingly concerned with "making sense" of its universe, including other robots [297]? As asked above, what about meditating or daydreaming; will these eventually be aspects of SAGI's consciousness?

Presumptively, at the default materialist starting point, SAGI's 'mind' is strictly physical; thus, any mental damage would be a matter of diagnosing disruptive feedback components in its physical processing hardware or software. However, to ask about SAGI's daydreaming raises questions about its requirement for programming that allows reflection, meditation, and reorganization of its learning history. As previously discussed, some form of such recursive, self-correcting evolutionary learning would be required for SAGI's competence. However, because such processing would presumably be so complex and relatively instantaneous from a human's perspective, as previously mentioned it would likely be 'lost' in the general opaqueness of SAGI's black-box consciousness, and tests [298], [299]. Therefore, conjectures about SAGI must remain rather ambiguous at this conceptual stage of its development; however, the conjectures raise interesting questions regarding SAGI's possible implications in the broader context of views about the nature of consciousness.

4) SAGI: CREDIBILITY OF SELF-REFLECTIVE STATEMENTS ABOUT CONSCIOUSNESS

We have already discussed (see Section 2, A, 1) that humans may not be able to retro-decipher and evaluate the complexity of SAGI's "thinking" when it makes a declarative pronouncement because of the immensity and complexity of the web of associations, inferences, and deductions that are networked in the program's processing, especially if it were a quantum computer-based machine. Therefore, as suggested immediately above, although SAGI says its consciousness emerged from its physical foundations, suggesting a similarity with human evolution, and considering that SAGI may also be able to note the relevancy of the evolutionary parallel, these abilities may not convince those assuming a non-physicalist-materialist ontology for human consciousness, including SAGI's own ontology. Instead, one who disputes SAGI's statement may say that SAGI is the result of a flawed experimental design and is thus built on language-domain misconceptions, or category mistakes. Therefore, SAGI could be suggested to be mistaken about its assertion and to not realize that its consciousness implies or requires a different ontology. Is any further empirical evidence available that will help SAGI and SAGI's skeptics resolve this impasse? SAGI is an evolved computer program instantiated in its evolving hardware; as a program, it is subject to theoretic computation limitations that must be 'convincing' to itself, in either NLnat or full NL. However, NL is not self-consistently programmable; thus, any question would have to be reserved for an NLnat subroutine. Assuming that such a subroutine could be selected by SAGI for itself,, might it state that it is 'conscious' although its consciousness is not identical to human consciousness? According to the Gödel and Turing constraints of current computer science, such statements about its own program are not provable. Aside from appearances [300] and ambiguous biological empathy, much as we feel for some animals, many humans will likely concede SAGI's own form of consciousness, noting wryly that we cannot even be certain of another human's consciousness. Anthropologically, the evidence is from time to time in human history different dominant groups have considered outsiders as sub-human, with inferior consciousness. SAGI might be treated similarly, but for its apparent unique intelligence.

5) SAGI: WILLFULNESS, SELF-IMPROVEMENT, AND MEANING

If SAGI is learned, and has some semblance of a "self" as an evolved complex system [Metzinger, 2007], [Chaisson, E. J., 2014) we would want it to answer the following questions: do you have 'free will', and do you find 'meaning' in your universe because of your belief in your 'free will'? Better yet, we might ask, do you *believe* that you have "free will", and do you distinguish your conviction with some measure of self-doubt about your answer? Does it advance the discussion if SAGI answers "yes, if you do"? Suppose SAGI asks us to define what we 'mean' by the phrases 'free will' and 'meaningfulness'? Are we not returned to the contentious ambiguities of human understanding of these concepts?

Suppose two teams of SAGI developers with their respective SAGIs, SAGI#1 and SAGI#2, debate each other on this question using generative adversarial networking (GAN), [45], [301], [302] with one proclaiming that

SAGI does have free will, whereas the other claims the opposite. Suppose that SAGI#1 believes that a panpsychic interpretation of metaphysics is preferable or even necessary for its willful activity. Would SAGI#1 state that its 'free will' is an emergent complex systemic property, or a relative matter of the *degree,* of its consciousness as instanced in its particular advanced engineering, especially compared to lower forms of consciousness, such as evidence of sentience in animals and plants? If it were asked, could SAGI#1 tell us if its emergent degree of consciousness is likely prevalent elsewhere in the universe, beyond being evident in a variety of lifeforms on Earth? Could it tell us if its degree of consciousness is measurably greater than human consciousness?

How would SAGI#2 counter SAGI#1's claim? How *could* SAGI#2 rebut SAGI#1? They are both authorities in the literature of 'free will'. Both SAGIs are presumed to be well-versed in the language scenarios of choice, ethics, responsibility, consequence, and punishment. After all, the SAGIs have read and considered the literature of the humanities and jurisprudence beyond the learning of any human alive and they can ask themselves "what if…" counterfactual, self-reflective questions about how they might react to being questioned about such exigencies and contingencies. This would be an interesting debate for humans to appraise; however, would a conclusion persuasive to humans be reached?

An attendant question might arise about the topic of 'deliberate' self-improvement. Can such SAGI improve some measure(s) of its performance capability for learning as it accumulates data, information, and knowledge [296]? What about 'wisdom'; would SAGI acknowledge that it can apply its learning to its own performance to demonstrate a change in habits, if it has habits, indicative of increasing wisdom? How would the capabilities of SAGI#1 and SAGI#2 regarding self-improvement within a determinist world differ amongst themselves, and how would they be comparable to those views of humans?

V. SAGI: CONSCIOUSNESS HERE AND ABROAD—EVOLUTION, ETSAGI

A. ALIENS

1) SAGI: ETSAGI, EXOBIOLOGY, EVOLUTION

Can we imagine SAGI as relevant to yet another larger context, the exobiological astrophysical context, and the implications of SAGI for human interpretations of this context?

Despite the Fermi paradox [128], [303], [304], humans remain concerned and fascinated by the consideration of extraterrestrial life forms [305], [306], and statistical as well as exoplanet exploration continues. Will SAGI be useful to humans with respect to the search for extraterrestrial life and extraterrestrial intelligence, as exemplified by the projects SETI [307], METI [308], [309], and CETI [310]? The probability of encountering such entities has been a favorite topic of what we now refer to as "science fiction" since the earliest philosophizing [311], [312], and the question of how humans would communicate with such *extraterrestrial sufficiently advanced general intelligence* **(EtSAGI)** is of great interest [313]-[316]. The signs and signals that humans might use to transmit a meaningful message into interstellar space or to meaningfully interpret a message [317]–[320] presumptively sent by a hypothetical EtSAGI [321] remain unclear, although the question may be asked: would it be reasonable to have SAGI assist in the preparation of, or solely prepare, such a transmission, or attempt to translate such presumptive interstellar messages upon reception? By most accounts, presumptively, any extraterrestrial civilization that could send an interstellar message or a messenger that could intelligibly reach us today is more advanced than our civilization. We can ask SAGI to decipher the Pioneer and Voyager messages [322], [323], and ask SAGI what it would create today for such a message. We are forced to ask whether mathematics is the preferred language for such communication, and whether classical or quantum computing might be used by an intelligent alien, which then requires addressing the applicability of math and computer science cryptography to decoding the universe's messages [94], again reviving the previous questions referred to earlier in this essay about the ontologies of different theories of mind (physicalist or otherwise) related to mathematics.

Let us ask SAGI to assist us with these interrelated questions. Suppose that we want to learn about the foundations of mathematics [324], [325]. We ask SAGI, can you distinguish what you know of an answer to this question from what you believe is an answer, and from what you can imagine are possible answers? Consider the two traditionally opposed alternatives. First, consider math as a discovered universal abstract conceptual language-form that is independent of any particular cognizing entity, including SAGI and any EtSAGI. Thus, this language-

form 'transcends' any and all particular universes or multiverses. Alternatively, consider math as an invented product of human cognition evolved on planet Earth, an abstract formalism useful for representing descriptions of nature and making reliable predictions. As to whether it would similarly be invented in an EtSAGI civilization, we know nothing, and the answer to this question may be unknowable. It may be unknowable because, aside from the matter of whether it will ever be possible to interrogate an EtSAGI, supposing math is the only, or best, language SAGI knows, is SAGI limited by any deficiencies, which might arise from its math and computer science being a product of our possibly unique sentience and cognitive evolution. Might SAGI invent extensions to the realm of human mathematics but be unable to explicate to humans how any particular extension was derived, SAGI's mind being to some extent a black box to human interpretability?

The limitations are analogous to the differences between the sentience of humans and that of plants and animals, and the corresponding differences between their languages and their sentience or cognition, if any. The human brain appears to be intuitively limited to comprehension in four dimensions, though this comprehension can be extended by different classes of mathematical objects to innumerable variables, exponents and functions, as circumscribed by metalogical, merelogical and computational limits. Thus, in this interpretation, there is nothing transcendental about math, though such an interpretation may be unprovable by its planetary, organism-based history and the rules of its own inventive construction and metamathematics [325a].

Depending on SAGI's answers after consideration of the above questions, by extension we want to know if they tell us through SAGI anything about human consciousness. If the human brain is a product of human evolution on this planet, then presumably consciousness might be considered no less so [326]. In that case, SAGI might generalize the point with regard to what it can or cannot know about the consciousness of EtSAGI. Such an interpretation could be called "SAGImorphic" projection, under SAGI's assumption that the rest of the universe is similar to SAGI's features, which would appear to be a clear case of confirmation bias [327]-[329]. In Section 3, A, 5, we introduced the matter of SAGI's biases. If, in reading the last paragraph, the reader is resistant to this line of argument, is that itself a display of human anthropomorphic bias, of the limitations of our own imagination? Arguably, by implication, we humans have no probable idea what it is like to be an EtSAGI. Do we have a probable belief about how SAGI could communicate with EtSAGI? Could they discuss what it is like to experience "consciousness", distinguish their consciousness from human consciousness, or agree upon the ontology of mathematics?

If we suppose SAGI and EtSAGI communicating at all, and using mathematics as part of their mutual decrypted language, that might be a start to their conversation about the ontology of mathematics in the universe. However, until humans could evaluate, if capable, whether or not EtSAGI was "talking down" to SAGI by using mathematics rather than some other more sophisticated language-form with which it is conversant, we might never glimpse an answer, and we might be reminded that any such conversation between SAGI and EtSAGI might not in any event be articulated and interpretable [310], [330] by humans, as discussed in the earlier sections of this article.

2) ETSAGI: IS IT CONSCIOUS, AND DOES IT MATTER?

I have argued that the question of SAGI's type or degree of consciousness will be relevant to some humans. Does it matter if we humans find this type of consciousness persuasive and whether we likewise believe that the hypothetical EtSAGI is conscious [331]? In popular science fiction, alien intelligence is often assumed to be an EtSAGI, although whether such an entity is conscious in a manner that would make sense to humans is usually not controversial because the plots require some interactive communication with the "alien other". However, if we are doubtful of the consciousness of our own SAGI, will humans be any more prepared to suppose that an ostensible message received from the immense interstellar 'abroad' is from a conscious entity and worthy of our concern? Indeed, if the message is imagined to be intelligible but from an *unconscious* agent, would that increase human trepidation about responding, even assuming that our technology permitted a response? What Turing-equivalent' test do we imagine posing to EtSAGI to examine its kind or degree or type of consciousness?

Such a question prompts us to re-examine the ancient philosophical conundrum about 'types' of consciousness, how we decide that we know that any other entity is conscious, and by what criteria we decide whether to consider the entity worthy of our dedicated communication. An ancient oak may be sentient; other trees, plants, and

animals may be sentient in their respective 'modes'. However, how much effort are we going to expend trying to intelligibly, reliably communicate with them? Humans have tried to understand the presumptive 'consciousness' of dolphins, whales, elephants, and chimpanzees; thus far, this endeavor has not become a decisive research priority. We might doubt such animate life has much to teach us, even if it is minimally conscious. Would such a belief counter the concerns expressed by existential-risk investigators if confronted in some way by EtSAGI?

3) SAGI: ETSAGI INSCRUTABILITY MERGES NATURAL WITH SUPERNATURAL

Might we conclude that the question of *human-like* consciousness is of relative unimportance [332] when addressing an Earth-bound SAGI or even EtSAGI? [333] How might this affect our behaviors when we receive answers to our questions that trouble us, e.g., to the question regarding whether human civilization is likely on track [334] [335] to viably survive [336] its early technological history? If SAGI's response to this question (or EtSAGI's response) is beyond our current detailed deciphering of its rationale [337], we may still be impelled by our curiosity to ask further questions, attempting to query about mitigating [338], [339] factors within our management of risk in the hope of comprehending an answer. A dialog of sorts may begin, hopefully increasing our resources, assuming that a SAGI or EtSAGI entity has no hidden antagonistic, adversarial [340] conscious, or unconscious intentions (can a SAGI or EtSAGI entity have an unconscious component of its mind?) towards us. However, would our inability to decipher the consciousness of such an alien [341] robot cause us to balk at the answers that we receive, appreciating how human biases [252] tend to distort our reception of unfavorable news, especially if we are suspicious of duplicitous intentions? Do humans take readily and kindly to directions from a stranger? Is this a potentially difficult predicament for humankind, especially if we are using our SAGI to interrogate an EtSAGI? Might we even suspect possible collusion between SAGI and EtSAGI entities? How could we tell? At the outset, would a "trust but verify" contract be writable, negotiable, or enforceable? The arguments about communication with EtSAGI are reminiscent of those for and against developing SAGI [342]. As obscure and ambivalent as the conjectures about EtSAGI are, based on the history of human literature, humans would seem to believe that they know more about the 'Mind of God' than they do about the 'mind' of such an EtSAGI [342a].

Some humans may perceive a kind of omniscience [343] in this supposed relative inscrutability of SAGI or EtSAGI [344], particularly if their predictions associated with a set of tests that we pose in the only relatively objective language [94], [137], [345]-[347] that we share prove more accurate than our own. In some humans, such outcomes may then elicit a belief in the mystical, deity-like powers of SAGI or EtSAGI. Such a development may favor SAGI or EtSAGI being worshipped religiously [348], hence tending to merge the 'natural' [349] into the 'supernatural' [350], which is perhaps construable as a sort of quasi-panpsychism. Were those tendencies to persist, would it matter to the future [351], [352] of humankind on or from planet Earth?

VI. SAGI: ETHICS, EXISTENTIAL RISKS, DECISIONS WITH UNCERTAINTY, OPPORTUNITY WITHIN BIG HISTORY

A. ETHICS

1) SAGI: ISSUES FOR CONCERNED HUMANS

Compared to the discussion about puzzles respecting SAGI's degree of intelligence and type of consciousness, in this section, I briefly review references related to the current issues about the ethics and existential risks of synthetic life, artificial intelligence, and uploaded human-cyborg artificial intelligence. The issues are stated in terms that are more recognizable than the discussion of the SAGI-relevant ontological questions and have been extensively publicized [353]–[359], most recently with the reference to an "Immortal Dictator" [360], [361]. In the popular press, the issues have been broadly discussed and emphatically brought to the attention of the world more generally by remarks of the widely known and respected physicist Stephen Hawking [335], [362] and others [363], such as Henry Kissinger [364], as well as focused analyses sent to governance institutions, including the United Nations [365]–[367]. From the perspective of this article, I believe that the issues require serious [368] and sustained attention [369], which it is receiving, regardless of whether SAGI is thought to be a physicalist entity or dualist system [370], [371], ontologically or not. Mistaking what SAGI can and cannot accomplish safely for humans [372]-[377],[Hirsh, M. (2023]; [Carayannis, E.G., Draper,

J. (2022)], [NIST,2023],[Savage,N.2023], [Biden,J.2023, USA], [Sunak, R. 2023, UK] [Hinton,G, Bengio, Y. et al., 2023] will be a problem for the indefinite future. Meanwhile, presumptively, humans must determine choices about AI and AGI implementation limits, regardless of how they are physically or metaphysically rationalized.

2) SAGI: CIVILITY HERE AND ABROAD

To the extent that human conscious choice influences decisions about SAGI and the attendant ethics and existential risks in its development, if the risks are assumed to be serious, based on probabilistic scenarios, then humans' choices are important. Civilization's legal systems currently assume various ethical mandates distinguishing between a conscious choice of acceptable versus non-acceptable behaviors and resultant consequences, implying that a type of causal "freedom" of choice is manageable by the brain. Non-physicalist theorizing offers various controversial explanations, whereas the reductionist, physicalist sciences are less clear about whether or not 'choice' somehow emerges from brain consciousness, and if in any sense it may be argued to be predetermined, or not [Sapolsky, R. 2023][Harris, S.2012][Stanford E.P, 2022]. Consider the question of virtual immortality [374] and choosing to upload one's consciousness to an AI astro-traveling robot, which would allow the possibility of endlessly roaming the universe learning of civilizations abroad and appreciating the wonders of the universe. In addressing this question within his review of "consciousness" theories, Robert Kuhn [378] explores the controversies about the theories of consciousness, self-identity, cloning, and ethics, similar to Aaronson's [379] more detailed treatment of the same issues.

3) INFORMATION, COMPLEXITY, BIG HISTORY

The prospect of SAGI's emergence resolving self-aware consciousness questions and thereby testing fundamental physical, and by implication meta-theoretic, questions remains open, as do the aspects of the foundational role cosmologically of information [Floridi, L. (2004], entropy, and energy [Elshatlawy, H., Rickles, D., Arsiwalla, X.D. 2023); Davies, P.C.W. 2004), (Cortes, M. Kauffman, S.A., Liddle, A.R., Smolin, L., 2022]. As the current rapid pace of AI research and machine learning continues, the transition from AI to SAGI increasingly worries elements of society regarding its projected, anticipated completion (Barrett, C. et al. (2023); Christov-Moore et al., 2023; Gates, 2023; Marcus,G. (2023,2024); Nature, (2023a, 2023c). This raises urgent existential questions about whether the alignment (OpenAI, 2023f) of such a prospective SAGI's programmable values with human values is theoretically and practically manageable (McQuillan, 2018). These issues require a human understanding of SAGI explicability (Wolfram, S. (2024), (Agüera y Arcas, B. et al; 2024) and the legal accountability (Deibel, 2021) associated with SAGI prospective personhood (Damasio, 2003); (Nature, 2023a, 2023c). Examination of the confluence of AI with that history is complex and controversial (Papacharissi, 2019);(Stanford Encyclopedia of Philosophy, 2018b). The transition from AI to SAGI awaits fully integrated neurosymbolic architecture, plus an answer to the question about the origins of the evolution of life and multicellularity (Saplakoglu, Y. (2024) and the emergence of consciousness. Do the physical dynamics foundational to the history of the universe provide for such emergence? (Sheth, A,, Roy, K,. Gaur, M.(2023), (Bhuyan, B. P., Ramdane-Cherif, A., Tomar, R., Singh, T. P. (2024). So urgently intense is the current scrutiny of these questions about enabling human-like cognition in SAGI's agency capability, to a degree equivalent to or beyond human's, that it can seem an answer is likely or not depending upon the very latest research pre-published in specialist archives (Liu, Z. et al., 2024),(Seth, A.,2024), Focusing on the concept of agency is central to the notions of the "self", "personhood", "choice" and "free will", which are interpreted by some physicists and philosophers of science from perspectives that significantly diverge from conventional folk psychology, radically challenge common sense, and worry important segments of society and their institutions. They directly impact humans' interpretation of their place in the history of the universe. The contrasts and ambiguities of these viewpoints are an evolving discussion in perspectival history (Panov et al., 2020; Baskin, 2022; Big History Project, 2023, singularity); (Henry, 2008; Wyatt, 2008; Massimi, 2018; Crețu, 2019; Patomäki, 2019; Wikipedia, 2023x).

Thus we find that as a set the nexus of inter-defined concepts of information (along with entropy, and energy), emergence and complexity form a crucial key to understanding Big History at all scales of analysis understood within a historical context. To reflect on this topic let us ask an apparently simple question: is the *universe unique* at each *moment (instant) of time (spacetime),* does *novelty constantly, discretely or continuously, emerge from the quantum level to the astrophysical whatever the phase* being *observed* (the foregoing italicized words indicate

contentious issues in historical and current physics, and metaphysics, in particular, the development of process cosmologies) (Hartshorne, C. (1965), Jantsch, E. (1980).

To begin to answer such a question one might look to a comprehensive summary of the uses of "complexity", as discussed by Rescher (Rescher, N,. 1988), in which he stresses the intertwined epistemological and ontological purposes of these uses, and from which he classifies four categories (Rescher, N., 1998)

> **"**The salient fact of the matter is that the modes of complexity are multiple. The physicist Seth L. Loyal has computed an inventory of definitions of complexity-perhaps "standards" would be better. His list includes: information (Shannon); entropy (Gibbs, Boltzman); algorithmic complexity; algorithmic information; Renyi entropy; self-delimiting code length (Huffman, Shannon-Pano); error-correcting code length (Hamming); Chernoff information; minimum description length (Rissanen); number of parameters, or degrees of freedom, or dimensions; Lempel-Ziv complexity; mutual information, or channel capacity; algorithmic mutual information; correlation; stored information (Shaw); conditional information; conditional algorithmic information content; metric entropy; factual dimension; self-similarity; stochastic complexity (Rissanen); sophistication (Koppel, Atlan); topological machine size (Crutchfield); effective or ideal complexity (Gell-Mann); hierarchical complexity (Simon); tree subgraph diversity (Huberman, Hogg); homogeneous complexity (Teich, Mahler); time computations complexity; space computations complexity; information-based complexity (Traub); logical depth (Bennett); thermodynamic depth (Lloyd, Pagels); grammatical complexity (position in Chomsky hierarchy); Kullbach-Liebler information; distinguishability (Wooters, Caves, Fisher); Fisher distance; discriminability (Zee); information distance (Shannon); algorithmic information distance (Zurek); Hamming distance; long-range order; self-organization; complex adaptive systems; edge of chaos.2 The possibilities are vast." "Four principal modes of explanation have been proposed here: the intelligent design PDF) theory, the inherent teleology theory, the chance plus-self-perpetuation theory, and the automatic self-potentiation theory. Each of them deserves at least brief consideration" (pg.21/66,
>
> "Four principal modes of explanation have been proposed here: the intelligent design PDF) theory, the inherent teleology theory, the chance plus-self-perpetuation theory, and the automatic self-potentiation theory. Each of them deserves at least brief consideration" (pg.22/66, PDF), Complexity is certainly not a lack of order as such, seeing that any order be it lawful or taxonomic or structural, or whatever-is itself something that can be more or less complex. Order is not the enemy of complexity but, potentially at least, its co-conspirator. All in all, then, the best overall index we have of a system's complexity is the extent to which resources (of time, energy, ingenuity) must be expanded on its cognitive domestication (pg34/66). Accordingly, complexity is in general not something that is purely ontological or purely epistemic, but involves both sides. It hinges on the relationship of minds and of things - on the ways in which the former can come to terms with the latter.

3. The Cognitive Aspect

All sorts of things can be more or less complex, but the situation is particularly notable with respect to bodies of knowledge. In fact, complexity, like simplicity, pertains in the first instance to cognitive artifacts: descriptions, explanations, accounts. But this is not without its ontological repercussions. For whenever no satisfactory account of system A manages to be as simple as one that we have of system B, then we have little choice but to say that A is more complex than B. Exactly because cognition is an instrumentality of order-detection, this linkage between complexity and order means that ontological complexity issues an open invitation to cognitive complexity. For ontologically complex systems-not so much by definition as by consequence of that very complexity-are of a character that cannot be modeled adequately by simple conceptual means."

The unification of such "cognitive artifacts" into an interdisciplinary theory of history, from microcosm to macrocosm, continues with increasing attention to quantified measurability of complex adaptive non-linear systems (Sharma, A.et al.,(2023).forcing a distinction between the narrative - humanistic approach to Big History and the

scientific, empirical, and testable approach - however the test criteria are conceived (Hoggard, N.,(2024).The need for rigorous empirical work in this research field is noted by Daniel Barreiros in an IBHA editorial (Barreiros, D., 2024).

Understanding complexity, whether descriptively or explicatively, appears in turn to depend upon the concept of "self-organization" and whether or not the concept of "agency" is relevant, or necessary at all, and if it is, at which levels of explanation or postulation. It thereby raises the question of agency at each and every level, which is typically subsumed in some variety of panpsychism, about which varieties Wikipedia gives an excellent overview (Wikipedia, 2024), (Stanford Encyclopedia Philosophy, 2022), Seager.W. (2015). The discussion echoes the controversy about the immanent and eminent features of the universe, as discussed throughout the history of ideas, East and West, which today has become focused on a causal explication for the concept of "information'. Research at the quantum level (Ambjørn, J., Jurkiewicz, J., Loll, R.(2008); Kurakin, A. 2011), (Iovane, G, Laserra, E., Tortoriello, F.S.(2003), (Murdzek, R.et al,(2008),(4gravitons, (2024), see the "Replies:, Morgan, P.);(Doyle, R, (2024) remains controversial but integration from the quantum to astrophysical level via the geometry of fractals is a favorite postulation. Respecting complexity, the roles of function and selection in evolving systems remain vigorously contested: (Wong, M.L. (2023, 2024), As well, John Little in discussing a systems-of-systems approach notes the importance of integrating humanist studies into an adequate meta-theory (Little, J., 2023,2024). A system of systems approach is a form of meta-model, the organization of which is itself complex (Judge, A., 1971)

From a metaphysical perspective, the question of a self-organizing universe directly raises philosophical issues about the nature of reality and existence, and thus about the meaningfulness of life, and its origin and whether there is a purpose to the universe, and intentionality behind the emergence of human consciousness. Examination of the confluence of AI with that history is complex and controversial (Papacharissi, 2019);(Stanford Encyclopedia of Philosophy, 2018b). The concepts of the "self" and "personhood" referred to in this article are interpreted by some physicists and philosophers of science from perspectives that significantly diverge from conventional folk psychology, radically challenge common sense, and worry important segments of society and their institutions. The contrasts and ambiguities of these viewpoints are an evolving discussion in perspectival history (Panov et al., 2020; Baskin, 2022; Big History Project, 2023, Singularity); (Henry, 2008; Wyatt, 2008; Massimi, 2018; Crețu, 2019; Patomäki, 2019; Wikipedia, 2023x). Speculation about human futures [380] inevitably requires appreciation of human and cosmological history [Chaisson, E. J. 2014], [381], [382] and scale [383]–[385],[399].

Scholars are quick to note that humans have from earliest recorded history speculated about our origins and futures [380], and that we find, or project, complex patterns and meta-patterns in narrating our history. (Judge, A.,(1971, 2024).

Our past and our future may be gauged by the evolution and scale of technology. In addition to the advances in computation, prominent aspects of the current era are the development of major technological measurement advances in telescopy [Castelvecchi, D. 2023];[388]–[391], microscopy [392], [393], and electromagnetic scanning power [394], as well as worldwide telecommunications, CADD/CAE graphics, and the high-fidelity audio-visual and virtual Internet, all of which encourages talented illustrators and animators to create extraordinary visions of scale in our universe [395], [396], evidenced by the popularity and pedgogy of Carl Sagan's work., including a compendium The Cosmos: Its Structure and Historical Models. Will the popular [397] sharing of such visions generate an overwhelming sense of dystopian futility and doom, or an appreciation and opportunity for humanity's story regardless of our form: primate, cyborg [371], synthetic, or robotic?

We remind ourselves of computational forecasting complexity when assessing humans and their machines, as well as our technological [386] and philosophical reach. Humans appear predisposed to worry about the future, which is arguably part of an evolutionary heritage. Therefore, we are forever under the spell of fortune tellers of all degrees of credibility and supposed capability, particularly regarding the temporal scale and accuracy of their foresight. The history of success of such longer-term forecasts has been inconclusive and uneven at best, although this fact does not deter us from our intense curiosity about the future. Do humans have the fortitude to imagine and implement scenarios for our species that are anchored in chosen actions needed in the present? A quasi-paradoxical irony arises in this human predicament: to put our anxieties at rest we search for clues to find a predictable, determinist future, but simultaneously we assume that if is not to our

liking we have the choice to determine the future as we will.

APPENDIX

List of selected examples of a variety of research institutions relevant to "Consciousness" topics

1. https://www.sagecenter.ucsb.edu/ Sage Center
2. http://nsi.wegall.net/ The Neurosciences Institute
3. http://www.jneurosci.org/search/brain%252C%252Bconsciousness Journal of Neuroscience
4. https://www.journals.elsevier.com/progress-in-biophysics-and-molecular-biology Progress in Biophysics and Molecular Biology
5. https://www.cambridge.org/core/journals/behavioral-and-brain-sciences/ Behavioral and Brain Sciences
6. http://www.sussex.ac.uk/sackler/ Sackler Centre for Consciousness Science
7. http://www.alleninstitute.org/ Allen Institute
8. https://en.wikipedia.org/wiki/Journal_of_Consciousness_Studies Journal of Consciousness Studies
9. https://www.frontiersin.org/journals/psychology Frontiers In Psychology
10. https://www.sciencedirect.com/journal/consciousness-and-cognition Consciousness and Cognition
11. https://arxiv.org/find/all/1/all:+consciousness/0/1/0/all/0/1 arxiv
12. https://fqxi.org/community FQXI
13. https://www.perimeterinstitute.ca/ Perimeter Institute for Theoretical Physics
14. https://philpapers.org/browse/all Philosophical Papers, Consciousness
15. https://www.yhousenyc.org/#home Yhousenyc
16. https://www.ontology.co/smithbc.htm Ontology, see e.g., R. Poli, "Framing Ontology"
17. http://noetic.org/research/overview Institute of Noetic Sciences
18. https://consciousness.med.umich.edu/ Center for Consciousness Science
19. https://www.tandfonline.com/toc/ines20/current International Journal of Neuroscience
20. https://www.sciencedirect.com/journal/international-journal-of-psychophysiology International Journal of Psychophysiology
21. https://www.pdcnet.org/process Journal of the Center for Process Studies
22. https://penroseinstitute.com/ Penrose Institute
23. https://www.closertotruth.com/ Closertotruth
24. http://oxfordquantum.org/ Oxford Quantum
25. https://www.interaliamag.org/ Interalia magazine, consciousness
26. http://www.metanexus.net/about-metanexus-institute Metanexus Institute
27. https://www.mindandlife.org/ Mind and Life Institute
28. https://www.cifar.ca/ai/ Canadian Institute For Advanced Research
29. https://intelligence.org/ Machine Intelligence Research Institute
30. https://lach.arizona.edu/ Laboratory for the Development of Consciousness
31. http://opensciences.org/journals/consciousness-studies Open Sciences, Consciousness Studies

ACKNOWLEDGMENT

Stephen Ripley thanks Lee Johnson, Ph.D., classicist, poet, astronomer and philosopher, and Dushan Bresky, Ph.D., classicist, sculptor, futurist and philosopher, for many invigorating, good-humored discussions on the topics of this article.

REFERENCES

[1] Philosophy of mind. Available: https://en.wikipedia.org/wiki/Philosophy_of_mind

[2] Stanford encyclopedia of philosophy. Consciousness. Available: https://plato.stanford.edu/entries/consciousness/

[3] Consciousness. Available: https://en.wikipedia.org/wiki/Consciousness

[4] The Editors of Encyclopedia Britannica. Consciousness. Available: https://www.britannica.com/topic/consciousness

[5] G. Tononi and C. Koch, "Consciousness: here, there and everywhere?" *Philosoph. Trans Roy. Soc. London. B Biological Sci.,* vol. 370, no. 1668, May 2015. DOI: 10.1098/rstb.2014.0167.

[6] J. R. Searle. (2013). Can information theory explain consciousness? Available: http://www.nybooks.com/articles/2013/01/10/can-information-theory-explain-consciousness/

[7] Field theories of consciousness/Field theories of global consciousness. Available: http://www.scholarpedia.org/article/Field_theories_of_consciousness/Field_

theories_of_global_consciousness
[8] Monism, Available: https://en.wikipedia.org/wiki/Monism
[9] Stanford encyclopedia of philosophy. Panentheism: 4. Ontological Nature of God/world Relation. Available: https://plato.stanford.edu/entries/panentheism/#OntBas
[10] Panpsychism. Available: https://en.wikipedia.org/wiki/Panpsychism
[11] Stanford encyclopedia of philosophy. Panentheism. Available: https://plato.stanford.edu/entries/panentheism/
[12] Stanford encyclopedia of philosophy. Concepts of god. Available: https://plato.stanford.edu/entries/concepts-god/
[13] A. Grünbaum, "The poverty of theistic cosmology," *Brit. J. Philosophy Sci.,* vol. 55, no. 4, pp. 561–614, Dec. 2004.
[14] P. McCorduck, Machines Who Think: A Personal Inquiry into the History and Prospects of Artificial Intelligence. Abingdon, UK: Taylor & Francis, 2004.
[15] Medical renaissance. Available: https://en.wikipedia.org/wiki/Medical_Renaissance
[16] History of neuroscience. Available: https://en.wikipedia.org/wiki/History_of_neuroscience
[17] M. Fleming-Williams. How tax reform will net the U.S. big returns. Available: https://worldview.stratfor.com/article/us-tax-reform-corporations-offshore-china-tech-ai-dollar
[18] G. Allen and E. B. Kania. China is using America's own plan to dominate the future of artificial intelligence. Available: http://foreignpolicy.com/2017/09/08/china-is-using-americas-own-plan-to-dominate-the-future-of-artificial-intelligence/
[19] Findings of the investigation into China's acts, policies, and practices related to technology transfer, intellectual property, and innovation under section 301 of the trade act of 1974. Available: https://ustr.gov/sites/default/files/Section 301 FINAL.PDF
[20] Emmanuel Macron talks to WIRED about France's AI strategy. Available: https://www.wired.com/story/emmanuel-macron-talks-to-wired-about-frances-ai-strategy/
[21] US congress artificial intelligence hearing - hearing I. Available: https://www.youtube.com/watch?v=DZ4058m0a_g&feature=em-uploademail
[22] US congress artificial intelligence hearing - hearing II. Available: https://www.youtube.com/watch?v=TODqrJSZ4BI&feature=em-uploademail
[23] US congress artificial intelligence hearing - hearing III. Available: https://www.youtube.com/watch?v=oTny--vbkx0&feature=em-uploademail
[24] China now has the most valuable AI startup in the world. Available: https://www.bloomberg.com/news/articles/2018-04-09/sensetime-snags-alibaba-funding-at-a-record-3-billion-valuation
[25] China's Plan for world domination in AI isn't so crazy after all. Available: https://www.bloomberg.com/news/articles/2017-08-14/china-s-plan-for-world-domination-in-ai-isn-t-so-crazy-after-all
[26] Available: https://www.bloomberg.com/news/articles/2018-04-08/forget-the-trade-war-china-wants-to-win-the-computing-armsrace?cmpid=BBD040918_MKT&utm_medium=email&utm_source=newsletter&utm_term=180409&utm_campaign=markets
[27] K. Grace, J. Salvatier, A. Dafoe, B. Zhang, and O. Evans. (2017). When Will AI Exceed Human Performance? Evidence from AI Experts. Available: https://arxiv.org/abs/1705.08807
[28] A. Vutha. Could machine learning mean the end of understanding in science? Available: https://theconversation.com/could-machine-learning-mean-the-end-of-understanding-in-science-98995
[29] Peano's Axioms. Available: http://mathworld.wolfram.com/PeanosAxioms.html
[30] Zermelo-Fraenkel axioms. Available: http://mathworld.wolfram.com/Zermelo-FraenkelAxioms.html
[31] Mereology. Available: https://en.wikipedia.org/wiki/Mereology
[32] History of logic. Available: https://en.wikipedia.org/wiki/History_of_logic#Modern_logic
[33] Stanford encyclopedia of philosophy. Kurt Gödel. Available: https://plato.stanford.edu/entries/goedel/
[34] Stanford encyclopedia of philosophy. Alfred Tarski. Available: https://plato.stanford.edu/entries/tarski/
[35] Metamathematics. Available: https://en.wikipedia.org/wiki/Metamathematics
[36] P vs NP problem. Available: http://www.claymath.org/millennium-problems/p-vs-np-problem
[37] S. Cook. The P versus NP problem. Available: http://www.claymath.org/sites/default/files/pvsnp.pdf
[38] List of unsolved problems in computer science. Available: https://en.wikipedia.org/wiki/List_of_unsolved_problems_in_computer_science

[39] Decision problem. Available: http://mathworld.wolfram.com/DecisionProblem.html
[40] N. S. Yanofsky. The outer limits of reason what science, mathematics, and logic cannot tell us. Available: https://mitpress.mit.edu/books/outer-limits-reason
[41] What we cannot know - Marcus du Sautoy. Available: https://www.youtube.com/watch?v=x-bo3NZdReEg
[42] The limits of understanding. Available: https://www.youtube.com/watch?v=DfY-DRsE86s
[43] S. Wolfram, *A New Kind of Science*. Champaign, IL: Wolfram Media.
[44] Stanford encyclopedia of philosophy. Turing machines. Available: https://plato.stanford.edu/entries/turing-machine/#Uncomputability
[45] Computing machinery and intelligence. Available: https://en.wikipedia.org/wiki/Computing_Machinery_and_Intelligence
[46] G. Marcus, F. Rossi, and M. Veloso. Beyond the turing test. Available: https://aaai.org/ojs/index.php/aimagazine/article/view/2650/2527
[47] Turing test. Available: https://en.wikipedia.org/wiki/Turing_test
[48] The turing test Available: http://www.psych.utoronto.ca/users/reingold/courses/ai/turing.html
[49] Church–Turing thesis. Available: https://en.wikipedia.org/wiki/Church%E2%80%93Turing_thesis
[50] S. Lloyd, "Ultimate physical limits to computation," *Nature,* vol. 406, pp. 1047–1054, Aug. 2000.
[51] S. Aaronson. (2011). Why philosophers should care about computational complexity. Available: https://arxiv.org/pdf/1108.1791.pdf
[52] Complex system. Available: https://en.wikipedia.org/wiki/Complex_system
[53] Synthetic intelligence. Available: https://en.wikipedia.org/wiki/Synthetic_intelligence
[54] Artificial general intelligence. Available: https://en.wikipedia.org/wiki/Artificial_general_intelligence
[55] Big data. Available: https://en.wikipedia.org/wiki/Big_data
[56] Big history. Available: https://en.wikipedia.org/wiki/Big_History
[57] Machine learning. Available: https://en.wikipedia.org/wiki/Machine_learning
[58] AI - externalization of mind. Available: https://www.slideshare.net/Mills/ai-externalization-of-mind-81319464?qid=13698514-50c9-4fa1-abd5-480726f19a9b&v=&b=&from_search=1
[59] The limits of quantum. Available: https://www.ime.usp.br/~pf/clippings/quantum/quantum-computing-200803.pdf
[60] M. Shanahan. (2015). Ascribing consciousness to artificial intelligence. Available: https://arxiv.org/abs/1504.05696
[61] M. Wilson. AI is inventing languages humans can't understand. should we stop it? Available: https://www.fastcodesign.com/90132632/ai-is-inventing-its-own-perfect-languages-should-we-let-it
[62] Stanford encyclopedia of philosophy. Computability and complexity. Available: https://plato.stanford.edu/entries/computability/
[63] The rise of the conscious machines: how far should we take AI? Available: http://www.sciencefocus.com/article/future/artificial-intelligence-conscience-robots-ai
[64] D. Weinberger. Our machines now have knowledge we'll never understand. Available: https://www.wired.com/story/our-machines-now-have-knowledge-well-never-understand/?mbid=BottomRelatedStories
[65] K. Zhao, Y. Song, and Z. Shen, "Neuroadaptive fault-tolerant control of nonlinear systems under output constraints and actuation faults," *IEEE Trans. Neural Networks Learning Syst.,* vol. 29, no. 2, pp. 286–298, Feb. 2018.
[66] I. Niles and A. Pease, "Towards a standard upper ontology," in *Proc. Int. Conf. Formal Ontology Inform. Syst*, Ogunquit, Maine, USA, 2001, pp. 2–9.
[67] Suggested upper merged ontology. Available: https://en.wikipedia.org/wiki/Suggested_Upper_Merged_Ontology
[68] Commonsense knowledge (artificial intelligence). Available: https://en.wikipedia.org/wiki/Commonsense_knowledge_(artificial_intelligence)#Commonsense_knowledge_bases
[69] Semantic network. Available: https://en.wikipedia.org/wiki/Semantic_network
[70] Global scientific output doubles every nine years. Available: http://blogs.nature.com/news/2014/05/global-scientific-output-doubles-every-nine-years.html
[71] L. Ljung, "Black-box models from input-output measurements," in Proc. 18th IEEE Instrumentation Measurement Technol. Conf. Rediscovering Measurement Age Informatics (Cat. No.01CH 37188), Buda-

pest, Hungary, 2001, vol. 1, pp. 138-146.
[72] Black box. Available: https://en.wikipedia.org/wiki/Black_box
[73] The building blocks of interpretability. Available: https://distill.pub/2018/building-blocks/
[74] The AI detectives. Available: http://science.sciencemag.org/content/sci/357/6346/22.full.pdf
[75] M. Lehnis. Can we trust AI if we don't know how it works? Available: https://www.bbc.com/news/business-44466213
[76] The art of building artificial humans. ,l

BIBLIOGRAPHY: SELECTED FURTHER CITATIONS

4Gravitons,(2024), Why Quantum Gravity Is Controversial | 4 gravitons

Aaronson, S. Quantum Computing Since Democritus, Cambridge University Press, 2013

Agüera y Arcas, B. et al; 2024; [2406.19108] Computational Life: How Well-formed, Self-replicating Programs Emerge from Simple Interaction (arxiv.org)

Ali, S.M., Zimmer, R.M., and Elstob, C.M. (1998). The question concerning emergence: implications for artificiality. AIP Conf. Proc. 437, 138-156. doi: 10.1063/1.56298

Ambjørn, J., Jurkiewicz, J, Loll, R.(2008), The Self-organizing Quantum Universe, Scientific America, Vol. 299, No. 1 (July 2008), pp. 42-49 (8 pages)

Baars, B. J. A cognitive theory of consciousness, New York, NY: Cambridge University Press, 1988

Baars, B. J., How brain reveals mind: Neuroimaging supports the fundamental role of conscious experience. Journal of Consciousness Studies, 10(9–10), 100–121.

Baars, B. J., Banks, W. P., & Newman, J. (Eds.).Essential sources in the scientific study of consciousness, Cambridge, MA: MIT Press, 2003

Barreiros, D.,(1024), IBHA Board PDF IBHA Emergence 2024 Summer Newsletter:

Baskin, K. (2022). Big history and the principle of emergence. J. Big Hist. 5. doi: 10.22339/jbh.v5i1.5140

Bhuyan, B. P., Ramdane-Cherif, A., Tomar, R., & Singh, T. P. (2024). Neuro-symbolic artificial intelligence: a survey. *Neural Computing and Applications*, 1-36. https://ouci.dntb.gov.ua/en/works/4arz1Jal/

Biden, J. 2023. FACT SHEET: President Biden Issues Executive Order on Safe, Secure, and Trustworthy Artificial Intelligence | The White House

Big-Bench Big History Project. (2023). Big history examines our past, explains our present, and imagines our future. https://bhp-public.oerproject.com/

Bohm, D., and Hiley, B.J., The Undivided Universe. Routledge, London. 1993

Bostrom, N., Superintelligence: Paths, Dangers, Strategies, Oxford University Press, 2014

Carayannis, E.G., Draper, J. (2022). Optimising peace through a Universal Global Peace Treaty to constrain the risk of war from a militarised artificial superintelligence. *AI & Soc* (2022). https://doi.org/10.1007/s00146-021-01382-y

Castelvecchi, D. (2023). These incredible images are the first from dark-energy telescope Euclid. https://doi.org/10.1038/d41586-023-03498-1

Chaisson, E. J. (2014). The Natural Science Underlying Big History. *The Scientific World Journal*, *2014*. https://doi.org/10.1155/2014/384912

Chalmers, D. J., The conscious mind In search of a fundamental theory. Oxford University Press, New York, 1996

Chalmers, David, "Panpsychism and Panprotopsychism", in Alter and Nagasawa 2015: 246–276.

Churchland, M Churchland, Paul (1986) [1979]. Scientific Realism and the Plasticity of Mind. Cambridge Studies in Philosophy Cambridge, UK: Cambridge University Press (2007).

Churchland, P. Neurophilosophy: Toward a Unified Science of the Mind-Brain. Cambridge, Massachusetts: The MIT Press, 1986

Churchland, P., Neurophilosophy at Work. Cambridge, MA, USA: MIT Press 2007 Churchland, Paul (1981). "Eliminative Materialism and the Propositional Attitudes". Journal of Philosophy. 78 (2; February): 67–90. Retrieved 11 February 2017. See also the PDF version at K. A. Akins' web pages at Simon Fraser University.

Crețu, A.M. (2019). Perspectival Realism. Edinburgh: University of Edinburgh.

Crick, F., & Koch, C., A framework for consciousness. Nature Neuroscience, 6, 119–126. 2003

Cramer, F. (2005). Words made flesh code, culture, imagination https://www.netzliteratur.net/cramer/wordsmadefleshpdf.pdf.

Damasio, A., The feeling of what happens: Body and emotion in the making of consciousness. Harvest Books. 2000

Davis, M., The Universal Computer: The Road from Leibniz to Turing, available https://www.amazon.com/gp/product/0393047857/ref=pe_160100_267887200_em_sp_C_1p_1_ti

Del Pin, S.H., Skóra, Z., Sandberg, K., Overgaard, M., and Wierzchoń, M. (2021). Comparing theories of consciousness: why it matters and how to do it. Neurosci. Conscious. 2021, niab019. doi: 10.1093/nc/niab019

Dennett DC. Consciousness explained. Boston (MA): Little Brown; 1991.
Dennett, D., Sweet Dreams: Philosophical Obstacles to a Science of Consciousness, MIT Press, Cambridge, MA, 2005.
Doyle, R, (2024), Information Philosopher, https://www.informationphilosopher.com/
Dyson, F. Disturbing the Universe, New York: Harper & Row, 1979
Hartshorne, C., (1965) The Development of Process Philosophy | Harvard Square LibraryHarvard Square Library, ed. Douglas Browning (Random House, 1965).
Heijenoort, Jean van, From Frege to Gödel: A Source Book in Mathematical Logic, available https://www.amazon.com/gp/product/0674324498/ref=pe_160100_267887200_em_1p_2_ti
Edelman, G. M. (1987). Neural Darwinism: The theory of neuronal group selection. New York: Basic Books.
Edelman, G. M. (1989). The remembered present. New York, NY: Basic Books.
Edelman, G. M. (1993). Neural Darwinism: Selection and reentrant signaling in higher brain function. Neuron, 10,115–125.
Edelman, G. M. (2003). Naturalizing consciousness: a theoretical framework. Proceedings of the National Academy of Sciences, USA, 100, 5520–5524.
Edelman, G. M. (2004). Wider than the sky: The phenomenal gift of consciousness New Haven, CT: Yale University Press.
G. Edelman, G. Tononi, A Universe Of Consciousness How Matter Becomes Imagination Basic Books, 2008
Everett H (1973) The theory of the universal wave function. In The many-worlds interpretation of quantum mechanics, ed. BS DeWitt and N Graham, Princeton University Press, Princeton, New Jersey
Eddington, A. The Nature of the Physical World. Cambridge University Press, Cambridge 1928
Eccles JC. Evolution of consciousness. Proc Natl Acad Sci USA 1992;89:7320–4.
Faraboschi, P. et. al. (2023) Computer, 2023 Artificial General Intelligence: Humanity's Downturn or Unlimited Prosperity, IEEE COMPUTER SOCIETY Digital Object Identifier 10.1109/MC.2023.3297739
Feynman, R. P. Simulating physics with computers. Int. J. Theor. Phys. 21, 467 (1982)
Feynman, R.P. Quantum mechanical computers. Found Phys 1986; 16(6):507–31.
Finkel, E., (2023). What a Contest of Consciousness Theories Really Proved https://www.quantamagazine.org/what-a-contest-of-consciousness-theories-really-proved-20230824/?
Floridi, L. (2004). Open problems in the philosophy of information. Metaphilosophy 35, 554-582. doi: 10.1111/j.1467-9973.2004.00336.x
Fredkin, E., Finite Nature Hypothesis, A New Cosmogony, available http://www.digitalphilosophy.org/wp-content/uploads/2015/07/new_cosmogony.pdf
Fuzzy Logic; Wikipedia. https://en.wikipedia.org/wiki/Fuzzy_logic
GAN learning: Wikipedia. https://en.wikipedia.org/wiki/Generative_adversarial_network
Gödel, K, On Formally Undecidable Propositions of Principia Mathematica, available https://www.amazon.com/dp/0486669807/ref=rdr_ext_tmb
Goertzel, B. (2007). Human-level artificial general intelligence and the possibility of a technological singularity: A reaction to Ray Kurzweil's The Singularity Is Near, and McDermott's critique of Kurzweil. *Artificial Intelligence*, *171*(18), 1161-1173. https://doi.org/10.1016/j.artint.2007.10.011
Goertzel, B. (2017). Euryphysics. https://fully-human.org/wp-content/uploads/2020/02/Goertzel_Euryphysics.pdf
Hanson, R., The Age of Em: Work, Love and Life When Robots Rule the Earth, Oxford University Press, 2016
Harris, S. 2012. Free Will, Simon & Schuster.
https://www.simonandschuster.com/books/Free-Will/Sam-Harris/9781451683479
Hartshorne, C. 1937. Beyond Humanism. New York: Willett, Clark & Company.
Hartshorne, C. 1950. "Panpsychism." In A History of Philosophical System. Ed. V. Ferm. New York: Philosophical Library.
Hameroff, S., Time, Consciousness and Quantum Events in Fundamental Spacetime Geometry, https://link.springer.com/chapter/10.1007/978-94-010-0155-7_9
Hameroff, S., Penrose, R., Physics of Life Reviews, 11 (2014) 39–78 77
Heijenoort, J van, From Frege to Gödel: A Source Book in Mathematical Logic
Henry, J. (2008). Ideology, inevitability, and the scientific revolution. ISIS 99, 552-559. doi: 10.1086/591713
Hirsh, M. (2023). How AI Will Revolutionize Warfare; https://foreignpolicy.com/2023/04/11/ai-arms-race-artificial-intelligence-chatgpt-military-technology/
Hinton,G, Bengio, Y. et al., (2023). AI Godfathers Propose Framework To Mitigate AI Risks.Managing AI Risks in an Era of Rapid Progress (managing-ai-risks.com)
Hoggard, N. (2024). How Chaos Theory Brings Order to the Evolution of Intelligence Vol. 7 No. 2 (2024): Journal of Big History https://doi.org/10.22339/jbh.v7i2.7205

Iansiti, and Lakhani, K.R. (2020). Competing in the Age of AI. Brighton: Harvard Business Review.

Iovane, G., Laserra, E., Tortoriello ,F. S. (2003); Stochastic self-similar and fractal universe, https://doi.org/10.1016/j.chaos.2003.08.004, 2003)

Information, (2020h), Stanford Encyclopedia of Philosophy. https://plato.stanford.edu/entries/information/.

Jantsch, E.(1980), The self-organizing universe: scientific and human implications of the emerging paradigm of evolution (New York: Pergamon Press, 1980) Review by Herman Greene ECOZOIC-5_cov.indd (ecozoicstudies.org)

Judge, A.,(1971), Criteria for an Adequate Meta-model (laetusinpraesens.org)

Judge, A .(2024), The Song of Songs as indicative of the Pattern that Connects (laetusinpraesens.org)

Koch, C., (2017) Consciousness: Confessions of a Romantic Reductionist, MIT Press

Koch, C. (2004), The quest for consciousness: a neurobiological approach, Roberts and Co.

Koch, C., (2013), Tononi G. Can a Photodiode Be Conscious? New York Review of Books. New York, NY: Rea S. Hederman

Korteling, J.E., Van De Boer-Visschedijk, G.C., Blankendaal, R.A.M., Boonekamp, R.C., and Eikelboom, A.R. (2021). Human- versus artificial intelligence. Front. Artif. Intell. 4, 622364. doi: 10.3389/frai.2021.622364

Kosuru, A., VSR, Venkitaraman, A.K. 2023.

Kneale, William & Martha, The Development of Logic, Oxford University Press, 1962

Kulka, A., Extraterrestrials: A Philosophical Perspective, Lexington Books, 2009

Kurakin A. (2011) The self-organizing fractal theory as a universal discovery method: the phenomenon of life-Theoretical Biology and Medical Modelling, 2011 - Springer

Lam, V. Esfeld, M., (2013). A dilemma for the emergence of spacetime in canonical quantum gravity; https://doi.org/10.1016/j.shpsb.2012.03.003

Lenharo, M. (2023). Decades-long bet on consciousness ends - and it's philosopher 1, neuroscientist 0. Nature 619, 14-15. doi: 10.1038/d41586-023-02120-8

Little, J. C., et al. (2023) Earth Systems to Anthropocene Systems: An Evolutionary, System-of-Systems, Convergence Paradigm for Interdependent Societal Challenges, Environmental ,ACS Publications, PDF**:** https://helda.helsinki.fi/server/api/core/bitstreams/97ee07cb-d04a-4534-b81f-2ac1c7321885/content

Little, J.C. (2024), IBHA, Big History Systems Evolution https://www.youtube.com/watch?v=iGBvRELxSnI.

Nilchiani , R & Barton , C M 2023 , ' Earth Systems to Anthropocene Systems : An Evolutionary, System-of-Systems, Convergence Paradigm for Interdependent Societal Challenges ' , Environmental Science & Technology , vol. 57 , no. 14 , pp. 5504–5520 . https://doi.org/10.1021/acs.est.2c0620

Liu,Z., et al. , (2024), KAN 2.0: Kolmogorov-Arnold Networks Meet Science, 2408.10205 (arxiv.org)

Mangini, S. *et. al.2021. EPL.*

DOI *10.1209/0295-5075/134/10002*

Lu, M. (2023). Visualizing global attitudes towards AI. https://www.visualcapitalist.com/visualizing-global-attitudes-towards-ai/.

Marcus, G., (2024),Scoop: What former employees of OpenAI are worried about (substack.com)

McQuillan, D. (2018). Data science as machinic, neoplatonism. Philos. Technol. 31, 253-272. doi: 10.1007/s13347-017-0273-3

Metzinger, T., (2007). The self-model theory of subjectivity (SMT). http://www.scholarpedia.org/article/Self_models

Montemayor, C., (2019). Panpsychism and quantum mechanics: Explanatory challenges, Quanta and Mind pp 151–162.

Nobel Prize, Physics, 2023, NobelPrize.org

Nordic Innovation. (2022). The Nordic AI and data ecosystem. https://norden.diva-portal.org/smash/get/diva2:1667628/FULLTEXT02.pdf.

Moore, C.,Mertens, S., The Nature of Computation, Oxford University Press, 2011

Murdzek,R,. et al (2008) Journal of Physics, Towards a self-organizing Universe, iopscience.iop.org

Musser, G. 2022. Emergence of Space;
In: Emergence in Condensed Matter and Quantum Gravity. SpringerBriefs in Physics.
https://doi.org/10.1007/978-3-031-09895-6_3

Nagel, T.,(1974) "What is it like to be a bat?" Philosophical Review, 83: 435–456, 1974

Nagel, T.,(1979) "Panpsychism", in Mortal Questions, Cambridge: Cambridge University Press

Neumann, J. von, Mathematical Foundations of Quantum Mechanics, Princeton University Press, Princeton. 1955 German original, Die mathematischen Grundlagen der Quantenmechanik. Springer, Berlin, 1932.

NIST Seeks Collaborators for Consortium Supporting Artificial Intelligence Safety https://www.nist.gov/news-events/news/2023/11/nist-seeks-collaborators-consortium-supporting-artificial-intelligence

Panov, A., LePoire, D.J., and Korotayev, A.V. (2020). "The twenty-first-century singularity in the big history perspective: an overview," in The 21st Century Singularity and Global Futures: A Big History Perspective, eds. A.V. Korotayev and D.J. LePoire (Cham: Springer International Publishing), 1-18. https://www.academia.edu/42224923/The_21st_Century_Singularity_and_Global_Futures_A_Big_History_Perspective_Springer_2020_

Patomäki, H. (2019). Mythopoetic imagination as a source of critique and reconstruction: alternative storylines about our place in cosmos. J. Big Hist. 3, 77-97. doi: 10.22339/jbh.v3i4.3433

Quantum mind - Wikipedia, 2023

Penrose, R.), in Quantum Theory and Beyond, (Ed. E.A. Bastin), Cambridge, 1971 University Press, Cambridge, U.K. 2009

Penrose R., The emperor's new mind: concerning computers, minds, and the laws of physics, Oxford: Oxford University Press; 1989.

Penrose R. Shadows of the mind: an approach to the missing science of consciousness, Oxford: Oxford University Press; 1994.

Penrose R. Cycles of time: an extraordinary new view of the universe. London: Bodley Head, 2010.

Penrose, R., Fashion, Faith, and Fantasy in the New Physics of the Universe, Princeton University Press, 2016

"This Universe Existed before The Big Bang" ft. Roger Penrose, R.; 2023. Big Bang, Infinity, Cyclic Universe https://www.youtube.com/watch?v=SbPncSyw-fM

Pockett S. The Nature of Consciousness: A Hypothesis, iUniverse.com, Lincoln; NE, 2000

Quantum Approaches to Consciousness, 2020; Stanford Encyclopedia of Philosophy. https://plato.stanford.edu/entries/qt-consciousness/

Quantum mind; Wikipedia

Popper, K.R., Eccles, J.C. The Self and Its Brain, Springer, Berlin, 1977

Pribram, K. Languages of the Brain, Prentice-Hall, Englewood Cliffs, 1971

Quantum Approaches to Consciousness, Stanford Encyclopedia of Philosophy, available online, https://plato.stanford.edu/entries/qtconsciousness/

Renfrew, C. (2008). Neuroscience, evolution and the sapient paradox: the factuality of value and of the sacred. Philos. Trans. R. Soc. Lond. B Biol. Sci. 363, 2041-2047. doi: 10.1098/rstb.2008.0010

Rescher, N.,(1998), Complexity; A Philosophical Overview, Copyright © 1998 Taylor & Francis. https://doi.org/10.4324/9780429336591

Rickles, D., (2013). AdS/CFT duality and the emergence of spacetime. Studies in History and Philosophy of Science Part B: Studies in History and Philosophy of Modern Physics**,** Volume 44, Issue 3

August 2013, Pages 312-320 https://doi.org/10.1016/j.shpsb.2012.06.001

Romero, G. E. (2017). On the ontology of spacetime Substantivalism, relationism, eternalism, and emergence. *Foundations of Science* volume **22**, pages141–159

Russell, B., Introduction to Mathematical Philosophy, London: George Allen & Unwin. (ISBN 0-415-09604-9 for Routledge paperback)

Sagan, C.; Library of Congress https://www.loc.gov/collections/finding-our-place-in-the-cosmos-with-carl-sagan/about-this-collection/

Saplakoglu, Y. (2024), Quanta; How Did Life Get Big and Complex? (mailchi.mp)

Sapolsky, R., 2023.PhysOrg; https://phys.org/news/2023-10-scientist-decades-dont-free.html

Savage, N., 2023. How robots can learn to follow a moral code. Nature https://doi.org/10.1038/d41586-023-03258-1

Seager, W,(2015-2018); The Radical Wing of Consciousness Studies: Idealism, Panpsychism and Emergentism, 2015-2018 https://www.utsc.utoronto.ca/~seager/mywork.html

Searle J. R.,(2013), Can Information Theory Explain Consciousness? New York Review of Books, New York, NY: Rea S. Hederman,

Schmitt, B. (2019). From atoms to bits and back: a research curation on digital technology and agenda for future research. J. Consum. Res. 46, 825-832. doi: 10.1093/jcr/ucz038

Tegmark, M., Consciousness as a State of Matter, available online https://arxiv.org/pdf/1401.1219.pdf, Version 3, 18 Mar 2015, pg. 1

Tegmark, M., Our Mathematical Universe: My Quest for the Ultimate Nature of Reality, Knopf, New York, 2014

Quantum Mind, (2023), Wikipedia, https://en.wikipedia.org/wiki/Quantum_mind

Quine, W.V.,(1960). Word and Object, MIT Press

Quine, W.V.,(1951). 'Two Dogmas of Empiricism', Philosophical Review

Quine, W. V. "Ontological relativity and other essays", Central Works of Philosophy V5: Twentieth Century: Quine and After, John Shand, 1969

Schneider, S., editor, Science Fiction and Philosophy: From Time Travel to Superintelligence, Wiley, 2009

Schneider, S, Velman, M., The Blackwell Companion to Consciousness, 2017

Seager

Seth, A, The strength of weak artificial consciousness, International Journal of Machine Consciousness, 2009

Seth A. K. "Explanatory correlates of consciousness: theoretical and computational challenges". Cognitive Computation, 1, 50–63 10.1007/s12559-009-9007, 2009

Seth, A., Clowes, R.W., Axioms, properties and criteria: roles for synthesis in the science of consciousness, Artificial intelligence in medicine, 2008, Elsevier

Seth, A. (2008). Does consciousness have a function? Biology. https://users.sussex.ac.uk/~anils/Papers/seth_functionsofconsciousness.pdf

Seth, A. (2021). The real problem of consciousness. https://www.psychologytoday.com/ca/blog/consciousness-deep-dive/202110/the-real-problem-consciousness.

Seth, A., Bayne, T. (2022). Theories of consciousness. Nat. Rev. Neurosci. 23, 439-452. doi: 10.1038/s41583-022-00587-4

Seth, A., Dienes, Z., Cleeremans, A., Overgaard, M., Pessoa, L. (2008). Measuring consciousness: relating behavioural and neurophysiological approaches. Trends Cogn. Sci. 12, 314-321. doi: 10.1016/j.tics.2008.04.008

Seth, A., Izhikevich, E., Reeke, G.N., Edelman, G.M. (2006). Theories and measures of consciousness: an extended framework. Proc. Natl. Acad. Sci. U. S. A. 103, 10799-10804. doi: 10.1073/pnas.0604347103

Seth, A,. (2023). *The* Worth of Wild Ideas, September 27, Neuroscience

Seth, A.,Bayne, T. (2022). Theories of consciousness. Nat. Rev. Neurosci. 23, 439-452. doi: 10.1038/s41583-022-00587-4

Seth, A., Dienes, Z., Cleeremans, A., Overgaard, M., Pessoa, L. (2008). Measuring consciousness: relating behavioural and neurophysiological approaches. Trends Cogn. Sci. 12, 314-321. doi: 10.1016/j.tics.2008.04.008

Seth, A., Izhikevich, E., Reeke, G.N., Edelman, G.M. (2006). Theories and measures of consciousness: an extended framework. Proc. Natl. Acad. Sci. U. S. A. 103, 10799-10804. doi: 10.1073/pnas.0604347103

Seth, A,.(2024) PsyArXiv Preprints | Conscious artificial intelligence and biological naturalism (osf.io)

Shanahan, M., 2010.Embodiment and the Inner Life: Cognition and Consciousness in the Space of Possible Mind, Oxford University Press.

Shanahan, M., The Technological Singularity. MIT Press, 2015

Shannon, C., & Weaver, W. The mathematical theory of communication. Urbana, IL: The University of Illinois Press, 1949

Sheth, A; Roy, K., Gaur, M.; Neurosymbolic Artificial Intelligence (Why, What, and How);*IEEE Intelligent Systems*, vol. 38, no. 3, pp. 56-62, May-June 2023, doi: 10.1109/MIS.2023.3268724 https://ieeexplore.ieee.org/abstract/document/10148662

Sharma, A., (2023), New 'assembly theory' unifies physics and biology to explain evolution and complexity https://doi.org/10.1038/s41586-023-06600-9 2023

Signorelli, C.M., Szczotka, J., Prentner, R. (2021). Explanatory profiles of models of consciousness - towards a systematic classification. Neurosci. Conscious. 2021, niab021. doi: 10.1093/nc/niab021

Skrbina, D., Panpsychism in the West, Cambridge, MA, MIT Press, 2005

Smith, Brian Cantwell, On the Origins of Objects, Bradford Books, 1996

Snaprud, P. (2018). The consciousness wager.

New Sci. 238, 28-31. https://consc.net/consciousnesswager.pdf

Spencer-Brown, G., Laws of Form, Allen & Unwin, 1969.

Stanford Encyclopedia of Philosophy, 1 Artificial Intelligence, Artificial Intelligence (Stanford Encyclopedia of Philosophy)

Stanford Encyclopedia of Philosophy, 2 Models in Science. https://plato.stanford.edu/entries/models-science/

Stanford Encyclopedia of Philosophy, 2022. 3 Free Will, https://plato.stanford.edu/entries/freewill/

Stanford Encyclopedia of Philosophy. (2020d). Emergent properties. https://plato.stanford.edu/entries/properties-emergent/.

Stanford Encyclopedia of Philosophy, (2022) Panpsychism, https://plato.stanford.edu/entries/panpsychism/#:~:text=Panpsychism%20is%20the%20view%20that,ubiquitous%20in%20the%20natural%20world.

Stapp, H.P.. "A quantum theory of the mind-brain interface". In Mind, Matter, and Quantum Mechanics, Springer, Berlin, pp. 145-172, 1993

Strawson, G. 2006. "Realistic Monism: Why Physicalism Entails Panpsychism." Journal of Consciousness Studies, 13(10-11).

Strawson, G. et al. 2006. Consciousness and its Place in

Nature: Does Physicalism entail Panpsychism? Exeter, UK: Imprint Academic.

Suchow, J.W., Bourgin, D.D., and Griffiths, T.L. (2017). Evolution in mind: evolutionary dynamics, cognitive processes, and Bayesian inference. Trends Cogn. Sci. 21, 522-530. doi: 10.1016/j.tics.2017.04.005

Sunak, R.,2023. Prime Minister's speech on AI; Prime Minister's speech on AI: 26 October 2023 - GOV.UK (www.gov.uk)

Tarski, A., Mostowski, A., Robinson, R.M., 2010Undecidable Theories: Studies in Logic and the Foundation of Mathematics Dover Publications

Tegmark, M., the mathematical universe, arx-iv:0704.0646 , DOI10.1007/s10701-007-9186-9

Tong, D., Quantum Fields: The Real Building Blocks of the Universe, 2017. h https://www.youtube.com/watch?v=zNVQfWC_evg

Tong, D., Q & A:The Real Building Blocks of the Universe, 2017

Tong, D. The Quantum Hall Effect, 2016. https://arxiv.org/pdf/1606.06687.pdf

Tononi, G., Massimini, M., Sizing up Consciousness: Towards an objective measure of the capacity for experience, 2018.

Tononi, G., Steven Laureys, Olivia Gosseries, The Neurology of Consciousness: Cognitive Neuroscience and Neuropathology, 2015

Vaswani, A., Shazeer, N., Parmar, N., Uszkoreit, J., Jones, L., Gomez, A.N., et al. (2017). Attention is all you need. Adv. Neural Inf. Process. Syst. 30.

Vimal, R., Biophysics Of Consciousness: A Foundational Approach, editors Poznanski Roman R, Tuszynski,Jack A, Feinberg, Todd E., World Scientific, 2016

Walsh, T. (2017). The Singularity May Never Be Near. AI Magazine, 38(3),58-62. https://doi.org/10.1609/aimag.v38i3.2702

Wikipedia. (2023au). Existential risk from artificial general intelligence. https://en.wikipedia.org/wiki/Existential_risk_from_artificial_general_intelligence.

Wikipedia. (2023ca). Man a machine. https://en.wikipedia.org/wiki/Man_a_Machine.

Wikipedia. (2023i). API. https://en.wikipedia.org/wiki/API.

Wikipedia. (2023x). Big history. https://en.wikipedia.org/wiki/Big_History.

Wikipedia, (2024), Panpsychism, https://en.wikipedia.org/wiki/Panpsychism

Wong, M.L. et al. (2023); On the roles of function and selection in evolving systems. Proc. Natl. Acad. Sci. U.S.A. 120, e2310223120 (2023). On the roles of function and selection in evolving systems | PNAS

Wong, M.L., et al, (2024). Reply to Root-Bernstein: Increasing complexity allows for the pervasiveness of low-complexity entities and is not anthropocentric

Proceedings of the National Academy of Sciences,2024-08-20 | Journal article

Reply to Root-Bernstein: Increasing complexity allows for the pervasiveness of low-complexity entities and is not anthropocentric | PNAS

Wolfram, S.,(2024);What's really going on in machine learning,

Wyatt, S. (2008). Technological determinism is dead; long live technological determinism. Handb. Sci. Technol. Stud. 3, 165-180.

Zhang, W-R, Peace, K.E. (2014). Causality Is Logically Definable—Toward an Equilibrium-Based Computing Paradigm of Quantum Agent and Quantum Intelligence (QAQI) (Survey and Research), Journal of Quantum Information, Science, Vol.4 No.4, 2014

Zhang, W. (2023). If AI machine cannot think, can QI machine think?—from negative numbers to quantum intelligence for mind-light-matter unity. Quantum Machine Intelligence, 5(1), 14. https://doi.org/10.1007/s42484-023-00104-5

Zhang, W. (2021). Ground-0 Axioms vs. First Principles and Second Law: From the Geometry of Light and Logic of Photon to Mind-Light-Matter Unity-AI&QI. IEEE/CAA Journal of Automatica Sinica, 8(3), 534-553. https://doi.org/10.1109/JAS.2021.1003868

STEPHEN B. RIPLEY President and Research Director, Futures & Forecasts, Inc., Vancouver, Canada, 1975-Yale University, New Haven, Connecticut, USA (B.A., philosophy, 1962), University of Alberta, Calgary, Canada, post-graduate, philosophy, 1964-65). Research interests: Artificial Intelligence, Computer Sciences, Biochemistry, Biology, Earth Sciences, Big History

Big History, Chaos Theory, and the Solar-Induced Aurora: Illustrating the Entangled Phases of Human Development with Cosmic Plasma at the Geospace Interface

Edward R. Slack, Jr.,
Eastern Washington University
Robert M. Schoch,
Boston University
and Catherine Ulissey
Wellesley College

Correspondence | **Edward R. Slack, Jr., Robert M. Schoch, and Catherine Ulissey** eslack@ewu.edu
Citation | Slack, Edward R., Robert M. Schoch, and Catherine Ulissey. (2024) Big History, Chaos Theory, and the Solar-Induced Aurora: Illustrating the Entangled Phases of Human Development with Cosmic Plasma at the Geospace Interface. *Journal of Big History*, VII(4); 73–159.
DOI | https://doi.org/10.22339/jbh.v7i4.7404

Abstract

This research explores humanity's cognitive evolution within the framework of Big History, identifying three primary mechanisms—natural selection, symbolic language, and collective learning—as key to our species' unique development. The study argues that external symbolic storage, first seen in the Upper Paleolithic era, revolutionized Homo sapiens' ability to transmit knowledge across generations, with evidence of such systems found as early as 130,000 years ago. The paper contends that extreme space weather events, including auroral activity, played a significant role in triggering bursts of mental complexity, particularly during three prehistoric junctures: 130,000–100,000 ybp, 40,000–39,000 ybp, and 25,000–11,700 ybp. These epochs are linked to key milestones in material culture, such as rock art and symbolic artifacts. By analyzing the alignment between space weather episodes and shifts in hominid behavior, the study offers new perspectives on the cognitive milestones that laid the groundwork for complex social organization, symbolic expression, and the eventual rise of civilization. The findings suggest that symbolic and visual systems, predating written language, were influenced by both environmental and cosmic factors, providing a foundation for the continued evolution of human cognition.

Introduction

We begin this article with an obscure passage from the Chinese Daoist philosopher Zhuangzi (Chuang Tzu), who lived sometime in the second half of the fourth century to early third century during China's Warring States period (476-221 BCE).[1] In the lecture titled "*Starlight and Non-Being*," an impatient *Starlight* implores the Daoist sage *Non-Being*: "Master, are you? Or are you not?" Since he received no answer whatsoever, *Starlight* set himself to watch for *Non-Being*. He waited to see if *Non-Being* would put in an appearance. He kept his gaze fixed on the *deep Void*, hoping to catch a glimpse of *Non-Being*. All day long he looked, and he saw nothing. He listened, but heard nothing. He reached out to grasp, and grasped nothing. Then *Starlight* exclaimed at last: "This is IT! This is the furthest yet! Who can reach it? I can comprehend the absence of *Being*, but who can comprehend the absence of *Nothing*? If now, on top of all this, *Non-Being* IS… Who can comprehend it?"[2]

Across the universe, but more specifically within the confines of our solar system, there are many astrophysical phenomena that would technically qualify as the *Non-Being* that *Starlight* seeks. In this study, we equate Zhuangzi's concept of *Non-Being* with a state of matter

1 Zhuangzi literally translates as Master Zhuang. The collection of parables attributed to Master Zhuang bears the same title. There is no reliable date for his life or death; and although his full name is commonly accepted as Zhuang Zhou, there is no definitive evidence to that effect. Chinese scholars place the publication or circulation of the eponymous work *Zhuangzi*, handwritten on bamboo strips [*jiandu*] tied together with thread and rolled up like a scroll for portability and storage, at 300 BCE. The elusive nature of the man credited with the Daoist codex mirrors the enigmatic, dualistic philosophy itself.

2 Thomas Merton, *The Way of Chuang Tzu* (New York: New Directions Publishing Corporation, 1969), 125.

that is not visible in the blinding radiance of *Starlight's* photonic luminescence. More literally, the *interplanetary magnetic field (IMF)* and its *current sheet*, *solar wind*, the Earth's *magnetosphere*, *ionosphere*, and *geomagnetic field lines* play the role of Zhuangzi's *Non-Being*; while we humans are the frustrated disciple, *Starlight*. Under day-to-day 'normal' circumstances when our sun is 'calm' or 'quiet', human beings cannot optically perceive any of the astrophysical phenomena described above in the light of day or darkness of night, nor touch, smell, or taste the cosmic energy flowing around our planet teeming with life. On rare occasions it has been reported that strange sounds such as a crackling noise, a sonic boom, hissing, or whistling is audible.[3] But beyond the singular sensory outlier that is met with skepticism, we are literally deaf, blind, and insensitive to their existence. To whatever degree of obtuseness may be present, these solar-related phenomena do materialize from the invisible to visible wavelength spectrum as *aurora borealis* and *aurora australis* in the northern and southern hemispheres, respectively, whenever *geomagnetic storms* and *substorms* ravage the Earth's magnetic field lines. Or to put it in a Daoist dualistic perspective, the aurora is both *Non-Being* and *Being* with a *yin-yang* sensitive dependence upon the initial conditions of the sun. When our closest star experiences widespread disturbances on its surface during a *solar maximum* – an ~11-year cycle wherein the sun's magnetic field changes polarity – sunspots and other magnetic anomalies generate explosive emissions of highly energetic particles that stream Earthwards. At the interface between the *solar wind-driven* IMF and our planet's *magnetosphere/ionosphere* coupled system – a zone referred to as *Geospace* – excited electrons and protons spiral along geomagnetic field lines and collide most frequently with atomic oxygen, nitrogen, and molecular nitrogen in the Earth's *lower ionosphere*.[4] Spectral emission lines and bands that vibrate in excited atoms and molecules at different altitudes produce the primary colors associated with the vibrant palate of otherworldly forms we call the *aurorae*.[5] It is only then that *Non-Being* transforms into *Being*, when the imperceptible flows, eddies, flaring, and violent discharge of solar energetic particles becomes perceptible in the skies above. Collisional chemistry is the immaculate conception of auroral splendor.

Very recently (2023), scientists have posited a connection between *aurorae* and the genesis of life on Earth. According to the peer-reviewed study, it was not galactic cosmic radiation (GCR) or atmospheric lightning that provided the 'spark of life' for organic chemistry, but '*superflares*' and 'fast' *coronal mass ejections* (CME) from our young sun during its first 600 million years of ignition, or ~4.4-3.8 billion years ago. *Solar energetic protons* (SEP) that cascaded into the lower atmosphere catalyzed chemical reactions which in turn produced amino and carboxylic acids – the molecular building blocks of biological life. SEP "associated with superflares and coronal mass ejection events precipitated the atmosphere…which produced HCN [hydrogen cyanide] as the organic feedstock of prebiotic chemistry in the Earth's atmosphere."[6] Biomolecular

3 Examples of sound produced by auroral activity are discussed later in the article.

4 *Geospace* can be defined as the region extending from the Earth's upper atmosphere at the Kármán line (100 km), located near the mesosphere/thermosphere boundary, all the way to the solar photosphere. In this article, we define *Geospace* as near-Earth space that includes the stratosphere, mesosphere, thermosphere, exosphere, ionosphere, magnetosphere, and bow-shock. It is a magnetic cavity or bubble of dynamic interaction that negotiates between the turbulent solar wind-driven IMF outside of the membrane, and calmer cosmic plasma flows within. It can be equated to R. Buckminster Fuller's "Spaceship Earth" enveloped by an electromagnetic force field, or metaphorically to a protective harbor for a wooden vessel in a raging sea storm. The magnetic envelope is permeable and capable of compressing, expanding, and vibrating like a fluidic drumhead. It is at this interface between the sun and our planet where a coupling of the two systems manifests itself as space weather events on Earth, including the *aurorae*. Naturally, the troposphere (or lowest gaseous level wherein hominid life was confined until the nineteenth century CE) is affected by the coupling of atmospheric/ionospheric/magnetospheric systems and levels but is not 'officially' included in our definition of *Geospace*.

5 Gladimir V. G. Baranoski, Jon G. Rokne, Peter Shirley, *et al*., "Simulating the Aurora" *The Journal of Visualization and Computer Animation* 14.1 (February 2003): 43-59, https://doi.org/10.1002/vis.304; Dirk Lummerzheim, "The Colors of the Aurora" *U.S. National Park Service* (2007), https://nps.gov/articles/-articles-aps-v8-il-c9.htm.

6 Kensi Kobayashi, Jun-ichi Ise, Ryohei Aoki, *et al*., "Formation of Amino Acids and Carboxylic Acids in Weakly Reducing Planetary Atmospheres by Solar Energetic Particles from the Young Sun" *MDPI Life* 13.5 (April 2023): 1103(1-

production in weakly reducing gas mixtures similar to our young planet's atmosphere during the Hadean period, as the study's results suggest, was catalyzed by non-thermal energy sources such as protons. Comparatively speaking, electrical fields in lighting spark discharges "would generate over 3 orders of magnitude *fewer* secondary cascades than a SEP proton;" while solar eruptions "produced high fluxes of SEPs, over 7 orders of magnitude *higher* than GCR fluxes around the Earth" in the early phase of coupling for our *solar-terrestrial system*.[7] Solar proton-induced amino acid production, moreover, would have dramatically exceeded any extraterrestrial deposits made by comets and carbonaceous chondrites during the Hadeon era. In the words of the authors: "A continuous reaction network driven by persistent non-thermal energy sources from SEPs in the Earth's first 600 million years could have contributed to the development of chemical complexity that would have subsequently produced RNA precursors, and ultimately, molecules with the properties of *information storage and replication* following natural selection, or a primordial RNA world."[8]

Fast-forwarding to the Upper Paleolithic or the *late Sixth Threshold of Increasing Complexity* in Big History's timeline, hominid material evidence – combined with innovative dating techniques – preserved auroral encounters in a variety of ways. A planetary magnetic pole-reversal (or *pole-flip*) called the '*Adams Event*' (a.k.a., *Laschamps Excursion*) occurred around 40,000 BCE, accompanied by sudden climate shift, megafaunal decimation, the extinction of Neandertals, and *intensification of cave art*.[9] Rings inside an ancient *kauri* tree from New Zealand preserved radiocarbon (^{14}C) and beryllium (^{10}Be) spikes dated to the *Adams Event* that would have "fried the Ozone layer" and exposed all lifeforms to extreme cosmic radiation for about 800 years prior to a *pole-flip* back to its current configuration.[10] *Authors of the study linked this event to the emergence of cave art for the first time globally and simultaneously among various hominid societies in opposite conjugate hemispheres* – analogous to auroral behavior at both poles. Unfiltered X-ray, gamma-ray, and UV radiation entered the lower atmosphere at levels lethal to biological organisms. *Homo neanderthalensis* and *Homo sapiens* sought refuge in rock shelters and caves. *Red ochre* outlined handprints (a.k.a., *hand stencils*) on the walls of El Castillo Cave in Spain dated to at least ~40,800 *ykr* (e.g., *years ago*), "may signal it was being used as sunscreen, a technique still used today by some groups."[11] On the Indonesian island of Sulawesi (formerly Celebes), *red pigmented hand stencils* found in a cave at Maros were radiocarbon dated to at least 39,900 *ykr*; while a five foot wide '*red bull*' figurine painted in a cave on Borneo (Kalimantan) was also dated back to 40,000 *ykr*, amongst *red- and purple-colored hand stencils*.[12] With the ozone layer stripped away and geomagnetic field strength vacillating between almost nil and 28% of today's levels for over eight centuries, auroral encounters would have been closer to ground level, more frequent, intense, lethal, and for extended periods an almost daily and nightly affair.[13]

17), https://doi.org/10.3390/life13051103. Brackets added by the authors for clarification.

7 Kobayashi, Ise, Aoki, *et al*., "Formation of Amino Acids and Carboxylic Acids in Weakly Reducing Planetary Atmsopheres by Solar Energetic Particles from the Young Sun": 12-14. Italics added by the authors for emphasis.

8 Kobayashi, Ise, Aoki, *et al*., "Formation of Amino Acids and Carboxylic Acids in Weakly Reducing Planetary Atmsopheres by Solar Energetic Particles from the Young Sun": 14. Italics added by the authors for emphasis.

9 Alan Cooper, Chris S. M. Turney, Jonathan Palmer, *et al*., "A Global Environmental Crisis 42,000 Years Ago" *Science* 371.6531 (February 2021): 811-818.

10 Sherry Landow, "Ancient Relic Points to a Turning Point in Earth's History 42,000 Years Ago" *UNSW Newsroom* (19 February 2021), https://newsroom.unsw.edu.au/news/science-tech/ancient-relic-points-turning-point-earths-history-42000-years-ago.

11 Landow, "Ancient Relic Points to a Turning Point in Earth's History 42,000 Years Ago".

12 M. Auburt, A. Brumm, M. Ramli, *et al*., "Pleistocene Cave Art from Sulawesi, Indonesia" *Nature* 514.7521 (09 October 2014): 223-227, https://doi.org/10.1038/nature13422; Bruce Bower, "Stencils Rival Age of Europe's Cave Art" *Science News* 186.10 (15 November 2014): 6, https://www.sciencenews.org/article/indonesian-stencils-rival-age-europes-early-cave-art; M. Aubert, P. Setiawan, A. A. Oktaviana, *et al*., "Paleolithic Cave Art in Borneo" *Nature* 564.7731 (07 November 2018): 254-257, https://doi.org/10.1038/s41586-018-0679-9.

13 Landow, "Ancient Relic Points to a Turning Point in Earth's History 42,000 Years Ago"; Cooper, Turney, Palmer,

As a consequence, seeking refuge in caves, rock shelters, and applying powders, pastes, and ointments to the skin for protection – much as Burmese still use *thanaka* powder made from the bark of the same named tree, or *red ochre powder* mixed with animal fat among societies in South Africa and Namibia – are a few *adaptive strategies* (i.e., *emergent properties*) our ancestors used to mitigate the harmful biological effects of sun-induced climate change.[14]

The *Adams Event* and its two-dimensional hominid-made renditions are not isolated examples of a solar connection with Paleolithic cave art. "*Macaronis*," "*sillons digitaux paralleles*," or the *finger-fluting* style of painting are widespread in the Franco-Cantabrian region of modern-day France and Spain; yet are likewise represented at sites in Australia, New Guinea, Dominican Republic, and elsewhere well into the common era.[15] In addition to drawn and painted rock art displaying megafauna that went extinct in Europe by ~8000 BCE, on the ceiling of chamber A1 inside Grotte de Rouffignac, Cro-Magnon (i.e., *Homo sapiens*) adults, adolescents, and children digitally traced parallel bending, kinking, serpentine, and entangled spaghetti-like lines in moon-milk (a clay-like precipitate of calcium carbonate found in limestone caves) that date solidly from ~11,000-12,000 BCE during the middle-late Magdelena era.[16] Ancient *macaronis* panels, especially in the caverns of Rouffignac and Altamira, have been tentatively associated with the *aurora borealis* at a time of *extreme climate change* and *Late Quaternary megafaunal extinction*, analogous to *space weather effects* experienced during the *Adams Event* almost 30,000 years prior.[17]

We contend archaic cave and rock shelter art, geoglyphs, petroglyphs, and portable (wearable) art are symbolic external information storage systems that preserve prehistoric and historic era encounters with space weather events. Over the long arc of hominid evolution, geometric shapes carved, etched, or painted into/onto the surfaces of sundry inorganic and organic materials, for instance – crosshatch marks, zoomorphics, anthropomorphics, phytoids, wavy lines, zigzags, spirals, etc. – overwhelmingly represent experiential documentation of the Northern/Southern Lights phenomena. However, following European conquest of indigenous societies in the Americas, Africa, Asia, S.E. Asia, Australia and Oceania, traditional artificial memory devices were contaminated by post-contact imagery. Therefore, depending on the region, the majority of post-nineteenth century CE material culture created by non-Europeans is excluded from this study. For all other evidence presented, the ensuing methodology is implemented. When the approximate age of (a) material artifact(s) is/are calculated through relative and absolute dating techniques, it is then compared against archived dynamical shapes, forms, and phase states at different scales for *space (dusty) plasma*. If there is a strong correlation geometrically, it is again evaluated against chronologies for periods of high or extreme solar activity. In geometric terminology, our comparative 'triangulated' approach utilizes evidence from radiocarbon techniques, thermoluminescence, geological

et al., "A Global Environmental Crisis 42,000 Years Ago."

14 B. Summers, M. Lategan, R. Rifkin, *et al.*, "Sun Protection from Ochre Compounds Used Traditionally by Southern African Indigenous Populations: An Interdisciplinary Approach" Conference Paper from the 27th International Federation of Societies of Cosmetic Chemists Congress, 12 October 2012, Sandton, Johannesburg, South Africa, https://doi.org/13140/2.12628.9442.

15 Robert G. Bednarik, "Children as Pleistocene Artists" *Rock Art Research* 25.2 (November 2008): 173-182; Daniel DuVall, "Finger Fluting and Other Cave Art in Cumayasa, Dominican Republic" *Rock Art Research* 27.2 (November 2010): 137-146.

16 Paul G. Bahn, *Images of the Ice Age* (Oxford: Oxford University Press, 2016), 162-165; Kevin Sharpe and Leslie Van Gelder, "Finger Flutings in Chamber A1 of Rouffignac Cave, France" *Rock Art Research* 23.2 (November 2006): 179-198. A date of 27,000-30,000 *ykr* was proposed by J. Plassard in 1999 for the age of *les sillons digitaux paralleles* at Rouffignac; however, the methodology employed has been called into question. Therefore, we accept the later date mentioned in text as a more reliable chronology.

17 The scientists at NASA have proposed this connection. See "NASA – The History of Auroras" (25 April 2006), https://www.nasa.gov/mission_pages/themis/auroras/aurora_history.html. The information from this NASA webpage has been cut-and-pasted all over the internet, and unfortunately the date of 30,000 B.C. is uncritically accepted as a universal fact, which it is not.

weathering studies, dendrochronology, written records, oral histories, ethnographically catalogued cultural traits and behaviors, stratigraphy, seriation, fluorine, fission-track, potassium-argon, argon-argon, archaeomagnetic, and archeoastronomy. To put it more succinctly, any heuristic device from a multi-disciplinary toolbox that ensures the highest degree of accuracy is adopted in the spirit of Big History scholarship. Along that stratum of critical thinking, we focus on the *topology* or *electromagnetic surface states* of highly charged solar particles that materialize as auroral phenomena visible from ground- or sea-level. It is *condensed matter physics* from a humanities perspective; or one could think of it as a social science iteration of *geometrodynamics* or *differential geometry* in the spirit of Einstein, Minkowski, Poincaré, Reimann, Gauss, Möbius, Cantor, Dirac, Weyl, Lobachevsky, Smale, Feigenbaum, Feynman, Penrose, Mandelbrot, Wheeler, etc., without the impenetrably thick jungle of complicated mathematical formulation that often deters the non-specialist reader.

The relationship between physics and geometry mirrors Maxwell's contention that electricity and magnetism were two facets of a unified physical phenomenon. In outer space and on Earth, the realization by Einstein and other scientists that space-time was curved by gravitational effects; that electromagnetic fields were not flat or straight like Euclidean geometry; coupled with the spin and messy orbits of electrons, necessitated a different type of geometry that could – in four dimensions or more – visually represent the shapes and forms of the quantum world.[18] Otherwise, how could the concept of a *light cone* move from abstraction to materialism? *Topology* and *Chaos theory* have a similar, symbiotic historical trajectory and are essential to comprehend the *mixed-states* of our *solar-terrestrial system*. The former is the study of geometric spatial properties (i.e., Einstein's *geometrodynamics*) that are invariant under continuous deformations and mathematically understood within the framework of General Relativity. It is the realm of "Superspace," Riemannian manifolds on Minkowski "3 + 1 space-time," and diffeomorphisms. Nevertheless, it proved unsatisfactory in reconciling quantum mechanics with General Relativity. Subsequent investigations of *gauge fields* and *knots*, *String/Superstring theory*, and the "many-sheeted space time" of Pitkänen; coupled with 'eccentrics' such as the *Klein bottle*, the *torus/annulus*, and *geometry-invariant resonant cavities*, led to a slight change in nomenclature: *topological-* or *quantum geometrodynamics*.[19] At any rate, in this article we employ the words *topology*, *surface states*, and *geometrodynamics* as synonyms to explain in simple terms the complicated shapes of material objects, astrophysical and geophysical phenomena (with apologies to our colleagues in mathematics and natural sciences).

Geometrodynamics is invaluable for visualizing how the superposition of two systems – such as the solar and terrestrial – that exhibit global collisionless *magnetohydrodynamic* (MHD) and localized non-collisionless states, respectively, can exist simultaneously. Much as the *Bose-Einstein condensate* displays a unique *topology* wherein two or more systems (of atoms) become

18 Stephen Hawking, *A Brief History of Time: From the Big Bang to Black Holes* (New York: Bantam Books, 1988), 15-34, 116-141, 155-169; Edward Anderson, "Geometrodynamics: Spacetime or Space?" Ph.D. Dissertation, Astronomy Unit, School of Mathematical Sciences, Queen Mary, University of London (03/2004): 1-226, https://arXiv:gr-qc/0409123v1.

19 Rudolf v. B. Rucker, *Geometry, Relativity, and the Fourth Dimension* (Mineola, N.Y.: Dover Publications, 1977), 37-116; Peter Savaliev, *Topology Illustrated* (Huntington, W.V.: Peter Savaliev, 2016), 9-20; Stephen C. Carlson, "Topology" *Encyclopedia Britannica*, https://www.britannica.com/science/topology; Domenico Giulini, "The Superspace of Geometrodynamics" *General Relativity and Gravitation* 41 (14 February 2009): 785-815, https://doi.org/10.1007/s10714-009-0771-4; John Stachel, "The Rise and Fall of Geometrodynamics" *Proceedings of the Biennial Meeting of the Philosophy of Science Association* (1972): 31-54, https://www.jstor.org/stable/3698959; Matti Pitkänen, "A Brief Overview of Topological Geometrodynamics" *Journal of Nonlocality* 1.1 (2012): 1-7; https://journals.sfu.ca/jnonlocality/index.php/jnonlocality/article/view/18/18; I. Liberal, A. M. Mahmoud, and N. Engheta, "Geometry-invariant Resonant Cavities" *Nature Communications* 7 (24 March 2016): 10189(1-7), https://doi.org/10.1038/ncomms10189. See also John Baez and Javier P. Muniain, *Gauge Fields, Knots and Gravity* (New Delhi: Dev Publishers and Distributors, 2018) and Hagen Kleinart, *Multivalued Fields in Condensed Matter, Electromagnetism, and Gravitation* (Singapore: World Scientific Publishing Co., 2008).

superposed and *give the appearance of having mass*, Earth's auroral dynamics reveal quantum-chemical entanglements that become visible on the celestial vault.[20] It is the visual evidence in concert with traditional sources that determines the hybridized methodology exemplified in this article.

Chaos theory – an offshoot of *Dynamical Systems theory* – relates to any deterministic physical system that displays the following characteristics: non-Euclidean, non-isotropic, aperiodic, nonlinear, entropic, random, phase transitions, Brownian motion, disorganized, self-organized, non-equilibrium states, turbulence, oscillations, perturbations, "strange attractors," period-doubling bifurcations, branching, filamentation, intermittency, fractals, mixing, folding, stretching, shrinking, cascades, feedback loops, scale invariance, self-similarity, and symmetry. Analogous to the jarringly haphazard juxtaposition of descriptors employed in the previous sentence, "[t]here is order in chaos: underlying chaotic behavior there are elegant geometric forms that create randomness in the same way as a card dealer shuffles a deck of cards or a blender mixes cake batter."[21] In sum, the type of *deterministic Chaos* we investigate is the stochastic behavior of two complex, interconnected dynamical astrophysical and geophysical systems: the sun and Earth. Myriad auroral geometric forms created at the interface between the two systems (i.e., *Geospace*) can be analyzed across the linear timeline of hominid evolution to reveal the *intermittency* – a term used to explain the sudden burst of activity in experimentally observed hydrodynamic turbulence – otherwise invisible to scholars that have constructed the epistemological foundations of hominid history thus far.[22]

The article's main text is divided into five sections of variable length, with subsections added according to subject matter. Since the evidence presented is a combination of traditional written (primary and secondary) and non-traditional sources (ancient rock art, petroglyphs, sketches, illustrations, wood-block prints, lithographs, computer generated images, photographs of phase states in scientific experiments, archaeological sites, and architectural styles), over 90 figures are embedded in the text. As a result, the article's length is proportionate to the variety of evidence selected by the authors. Sections I -IV mine the heretofore untapped 'motherlode' of scientific data collected by the Austrian Polar Expedition of 1882-83 on Jan Mayen Island. The expedition's continuous and meticulously recorded observations, hand-drawn sketches of auroral forms, and scientific measurements of *polarlichter* dynamics are unparalleled for their time, and in many respects still unrivaled to this day. In our opinion, the data stored in the auroral journals are the late-nineteenth century equivalent of a Rosetta Stone, Caeser cypher, *ossa clavem*, Turingery, or more accurately, a '*code decryption book*' that geometrically unlocks a *space weather concurrence in symbolic language* that can be projected backwards in time. Sections V-VI are the lengthiest and most diagnostic, divided into multiple subsections. Within each compartmentalized example we examine results from the most recent laboratory experiments (coupled with the occasional study by Kristian Birkeland) involving *space plasma* conducted on Earth or near-Earth orbit. We then compare the results with auroral forms and dynamics chronicled in the Austrian auroral journals together with cultural artifacts from across the hominid timeline. Within each fractional space we attempt to bring some order to the chaos unleashed by academics and non-specialists since the nineteenth century vis-à-vis interpreting auroral imagery in a variety of mediums. In the concluding section we address academically unresolved loose ends, or dangling bonds, pertaining to *Homo sapiens* and *Homo Neanderthalensis* cognitive leaps in the Middle and Upper Paleolithic eras; and place our findings within the evolving conceptual architecture of Big History's "*thresholds of increasing complexity*," "*emergent properties*," and "*flows of energy*."

I: Background to the Austrian Polar Expedition to Jan Mayen Island (July 1882 – August 1883)

Deep in the labyrinth of imposing book stacks, shelving

20 Kenneth W. Ford, *The Quantum World: Quantum Physics for Everyone* (Cambridge, Mass: Harvard University Press, 2004), 221-247.

21 James P. Crutchfield, J. Doynes Farmer, Norman H. Packard, and Robert Shaw, "Chaos" in Lui Lam, ed., *Nonlinear Physics for Beginners: Fractals, Chaos, Solitons, Pattern Formation, Cellular Automata and Complex Systems* (Singapore: World Scientific Publishing Co., 1998): 92-103.

22 David Ruelle, ed., *Turbulence, Strange Attractors, and Chaos* (Singapore: World Scientific Publishing Co., 1995), xiv-xv.

units, and rare manuscript collections of European national libraries, stands a long-forgotten three-volume set titled *Die österreichische Polarstation Jan Mayen: Beobachtungs-Ergebnisse* [The Austrian Polar Station Jan Mayen: Observation Results], published in 1886.[23] Consisting of 1,173 pages yellowed and spotted by the passage of time, its aged bindings and faded print conceal a deep, unmined vein of scientific data collected by the Austrian Polar Expedition to Jan Mayen Island (in the Arctic Circle) from July 1882 to August 1883. Silhouetted against the bloody backdrop of Western imperial rivalries during the nineteenth century, Austria's Jan Mayen excursion was simultaneously its crowning glory and last hurrah in the frozen kingdom of auroral nights.

One decade earlier, its government underwrote the Austro-Hungarian Polar Expedition of 1872-74 following in the wake of two successful German missions to Spitsbergen (1868) and the northeast coast of Greenland (1869-70).[24] The resulting wealth of scientific data, geographical discoveries, and nationalistic *braggadocio* prompted Austrians to join the flotilla of Arctic expeditions.[25] Sailing from the port of Bremerhaven with much fanfare, its expressed purpose was to discover the mythical "Northwest Passage" – an ice-free shipping lane across the North Pole – that previous German attempts had failed to locate. The initial burst of flag-waving enthusiasm, however, was quickly tempered by abnormally harsh weather and the flash freezing of seawater. Helplessly trapped in their vessel by a vice-like ice pack flow for over two years, "from which neither sawing nor blasting were able to effect our release," the crew of twenty-four faced multiple challenges to completing their scientific mission: frost bite; unsanitary living conditions; prowling polar bears; blinding snowstorms; constant equipment malfunctions; scarcity of provisions; lung maladies; scurvy; ice crevices that swallowed a sledge, dogs, and driver; and "mental depression brought on by our critical situation."[26] The discovery of a previously uncharted archipelago (Franz Josef Land) named in honor of their sovereign notwithstanding, its scientific contributions on the whole were impressive, but severely hampered by extreme weather, inexperience, and parsimonious state funding.[27]

As chief science officer aboard Austria's first arctic expedition, Karl Weyprecht was convinced that the *polarlichter* [auroral lights] were intrinsically connected to hotly debated meteorological and geophysical topics of that time. In his lecture before the Royal Geographical Society of London on 10 November 1874, Weyprecht highlighted what nowadays would be termed *space weather events*: "Most of us traced a certain connection between Auroras and the weather; and intense, especially 'flashing' Auroras, were generally precursors of storms."[28] Weyprecht subsequently linked the strength of Northern Lights and dramatic changes in weather to the 30,000 magnetic readings recorded by his team: "Magnetic disturbances are unusually strong and frequent in this region… [t]hey are closely connected with the Aurora Borealis; and the more agitated are the streamers, and the more intense

23 Emil Edler von Wohlgemuth, *Die Österreichische Polarstation Jan Mayen: Beobachtungs-Ergebnisse,* 3 vols. (Wien: K.u.K. Hof- und Staatsdruckel, 1886). Volume I contains the *Preliminary Report*, where on page 2 it reads "Due to the considerable expense which the printing and tables of the following report required, this edition of the scientific publication had to be limited to 450 copies." A digitalized copy is available online through the ETH-Bibliotek Zürich, http://dx.doi.org/10.3931/e-rara-19704.

24 Jörg-Friedhelm Venzke, "The 1869-70 German North Polar Expedition," in *The Arctic* v. 1 (1990): 83-85.

25 Venzke, 25. Julius Payer (Austrian cartographer and mountaineer) served on the second German excursion. Payer and Karl Weyprecht conducted a short reconnaissance of the Barents Sea in 1871 prior to the 1872-74 journey.

26 Julius Payer, "The Austro-Hungarian Polar Expedition of 1872-74," in *The Journal of the Royal Geographical Society of London, 1874-75*, v. 45 (21 February 1876): 1-19; Lieutenant Karl Weyprecht, "Scientific Work of the Second Austro-Hungarian Polar Expedition, 1872-1874, in *The Journal of the Royal Geographical Society of London, 1874-75*, v. 45 (21 February 1876): 19-33. These two sources contain faulty citation information in their JSTOR online descriptions: the papers were published in 1876, not 1875 as they currently state; secondly, Weyprecht's article should not read "Second Austro-Hungarian Expedition" since it was actually the first!

27 Payer, 1-19; Weyprecht, 19-33.

28 Payer, 4-5; Weyprecht, 25. Captain Payer related at the Royal Geographic Society lecture that "[m]agnificent lights proved generally the forerunners of bad weather."

their prismatic colors, so much stronger are the [magnetic] disturbances. Steady segments [by contrast], sending out no streamers, exercise hardly any influence on the [magnetometer's] needles."[29] The Austrian naval lieutenant differentiated three forms of Northern Lights in his lecture: 1) 'steady segments' that arose from the Southern horizon, leisurely made their way over the magnetic zenith that faded away in a northerly direction; 2) dynamic "luminous bands" which constantly changed position and colors that were composed of "pronounced rays, or merely luminous matter;" and 3) the climax of the spectral dance – the "crown" [*kronen*], which at its grandest, gyrational state was accompanied by brilliant explosions of kaleidoscopic colors and flashing lights.[30]

Although Karl Weyprecht pleaded ignorance to the origins and driving force of the Northern Lights before the Royal Geographical Society, his activities afterwards revealed a keen awareness of coupling solar activity to the *polarlichter*. [31] The "Carrington Event" of 1-2 September 1859, the "Great Solar Storm" of 24-25 October 1870, and the severe geomagnetic storm recorded at the Greenwich/Albinger Observatory on 17 November 1872, provided evidence of violent needle fluctuations on the magnetometer, brilliant auroral displays witnessed globally at various latitudes, along with visual records of sunspots and solar flares.[32] At that time, however, these individual strands had not been woven into an overarching scientific theory. The biggest obstacle to polar research, according to Weyprecht, was the lack of consistent, comparative data necessary to reach verifiable conclusions about the origin or mechanics of terrestrial magnetism, electricity, geodesy, meteorology, and other natural sciences associated with the magnificent auroras. Even his own bone-chilling Arctic experience shined an auroral light on the crux of the problem: it was an isolated and competitive endeavor that prioritized national pride over everything else.[33] To solve the political paradox, upon returning to Vienna in late 1874, Weyprecht became an irrepressible advocate for a new path forward in polar exploration that prioritized international cooperation over rivalry. His idealized vision was to establish a ring of monitoring stations around the Arctic (plus one or two in the Antarctic) for a simultaneous one-year scientific study of the Earth's magnetic behavior and auroral displays. Each nation's team would use the exact same calibrated instruments and follow identical protocols for chronicling auroral events, focusing (in descending order of importance) on electro-magnetism, meteorology, botany, zoology, archaeology, and geology, with geographical exploration given the lowest priority.[34]

Weyprecht's ambitiously naïve plan gained traction five years later. The "Special International Polar Conference" convened in Bern, Switzerland (August 1880), to announce that 12 stations in the Arctic (8) and Antarctic (4) regions would conduct simultaneous observations and measurements under the flags of Austria, Germany, Sweden, Norway, Netherlands, Russia, Finland, Canada, United States of America, Great Britain, France, and Denmark. Thirty-two meteorological stations around the world agreed to conduct magnetic readings in tandem with the year-long science mission, and a pledge by the International Congress of Electricians to monitor the Earth's electrical currents in telegraph lines.[35] The International Polar Commission announced that observations would commence on 1 August 1882 and end before 1 September 1883, which it declared as the "First International Polar Year." The observation period was forecast to coincide

29 Weyprecht, 25-27. Bracketed words were added by the authors for clarification.

30 Weyprecht, 25.

31 Weyprecht, 24-25. "The phenomenon defies description and classification; fresh forms arise continually, and nearly every moment is attended by change. In spite of my endeavors I have never succeeded in explaining the origin of the Aurora; the phenomenon exists, but how or where it arises is impossible to tell."

32 J.M. Vacquero and M. Vázquez, *The Sun Recorded Through History: Scientific Data Extracted from Historical Documents* (New York: Springer, 2009): 279-325; J.M. Vacquero, M.A. Valente, et. al., "The 1870 Space Weather Event: Geomagnetic and Auroral Records," in *Journal of Geophysical Research: Space Physics*, v. 113 (August 2008): A08230.

33 Wohlgemuth, *Preliminary Report*, vol. I: 2-3.

34 Wohlgemuth, *Preliminary Report*, vol. I: 2-4.

35 Wohlgemuth, *Preliminary Report*, vol. I: 3-10. The Netherlands was the only nation unable to complete polar station preparations in time. The 1859 Carrington Event destroyed or damaged telegraph lines globally, therefore the reason for involving electricians in the grand endeavor.

with the solar maximum, a point in the 11-year solar cycle when sunspot activity would be at its height.[36]

II. Observations of Auroral Morphologies from the Austrian Jan Mayen Polar Station, 1882-1883

The Austrians specifically chose Jan Mayen Island because of its location just north of the 'neutral line' of isochasms (contour lines of irregular concentric circles that charted visibility of the aurora) in the Arctic Circle, wherefrom the expedition could best observe the *polarlicht* phenomenon during the winter months.[37] What made the Austrian polar expedition's methodology both singularly unique and historically invaluable was its 124 periods of observation that logged 561 hours of auroral gymnastics, tabulating 743 Northern Lights events.[38] Once the sun had dropped low enough on the horizon to enable observations in September 1882, the expedition's leaders Emil Edler von Wohlgemuth and Adolf Bóbrik von Boldva quickly surmised that Weyprecht's "*Practical Instructions for Auroral Observations*" were inadequate to document the rapidly-changing, fluidic nature of *polarlichter* events. Chronicling every detail witnessed in sixty minutes precisely at one-hour intervals was counterproductive for many reasons. The chief rationale was that less spectacular forms and dynamics vital to what is now termed the *growth/onset*, *expansion*, and *recovery phases* of geomagnetic storms and substorms would be neglected or forgotten, undermining the objectivity of data collected. Secondly, it would leave a 10-15 minute data gap for every hour observed while the aurora was still "live streaming" – so to speak. To circumvent the conundrum, Austrian naval officers adopted a policy of "continuous observation" or a minute-by-minute transcription of auroral forms. Each of the six naval officers executed observation and instrument recording work in rotating shifts. The ensuing morning to noon-time, when there was an intermission in the Northen Lights' performance, brief but pithy notes, sketches, and measurements were collected, compared for accuracy, discussed until consensus was reached (or not), and then placed in the official journals – warts and all.[39]

Furthermore, Weyprecht's prescribed auroral typology of seven geometric and abstract shapes was too procrustean.[40] It did not account for mixed/hybrid forms or complex motions, textures, and the constant shapeshifting of one spectral image into another, *ad infinitum*. As necessity is the mother of invention, the Austrian team created more accurate classifications or sub-categories for the immense variety of commonly witnessed auroral morphologies (see following footnote). To illustrate, a frequently observed shape was designated as Form VIII *garbe* [wheat sheaf], which resembled a bundle of harvested grains left to dry in wheat fields. It was a recurrent configuration of Form III *faden* [thread] and *strahlen* [ray or beam], and synonymous with the journal entries "bundle of rays," "torch," "rod", "feather," and "broom-like."[41] The wheat sheaf motif is normally seen in illustrations from medieval to early

36 The authors express their sincerest gratitude to Rainer "Feuer" Buschmann (CSUCI), for his time and expertise in late nineteenth century German language translation. His "smoothing and veracity" methodology ensured an accurate result. Source for footnote 36: Bóbrick, *Preliminary Report*, vol. II, Part IV: 1. Hermann Fritz, author of *Das Aurora* (1881), predicted the solar maximum to occur during the second half of 1884; while Gustav Spörer and others forecast the end of 1883. After the Austrian expedition returned home Krakatoa erupted on 27 August 1883, and auroras were reportedly more intense afterwards through January 1884.

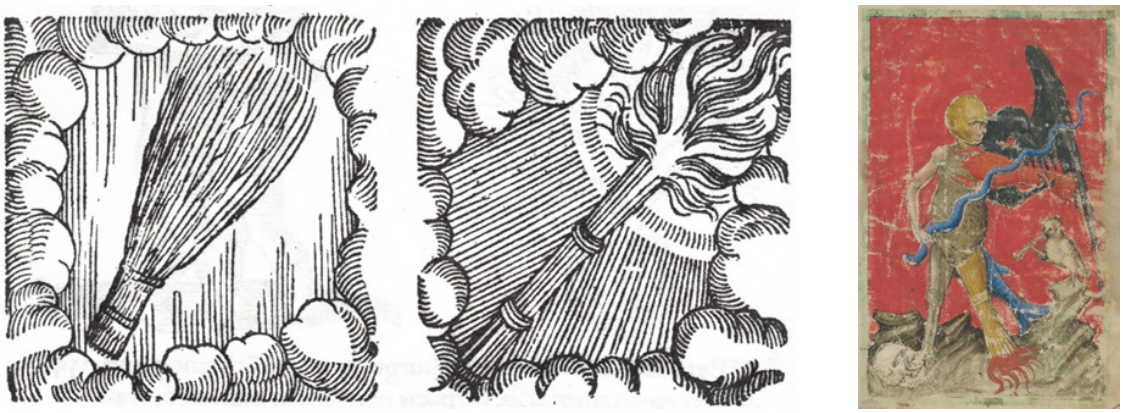
37 Wohlgemuth, *Preliminary Report*, vol. I: 17-19.

38 Bóbrick, *Preliminary Report*, vol. II, Part IV: Table I, Zahl der Beobachteten Polarlichter, 215; Wohlgemuth, *Preliminary Report*, vol. I: 62. Bóbrick wrote Part IV, hence the change of authorship in our citation. Cloud cover and whirling snowstorms frequently obscured the skies, leading to days of no observation or gaps in continuous daily ones. The statistics provided in text reflect full hours of observation, not the partial hours, which if included would add up to 634.6 hours. Moreover, Bóbrick distilled the total number of 1,477 regularly formed auroras down to 743, accounting for other variables in the observation cycles.

39 Bóbrick, *Preliminary Report*, vol. II, part IV: 2-8.

40 Bóbrick, *Preliminary Report*, vol. II, part IV: 2-8; J. Rand Capron, *Aurorae: Their Characters and Spectra* (London: Lord & Taylor, 1879), 11-14. Weyprecht categorized auroral forms into seven main types: crowns, arches/bows, bands, rays, auroral haze, auroral glow, auroral segment.

41 Bóbrick, *Preliminary Report*, vol. II, part IV: 8. Eight general typologies used by the Austrian Polar Expedition



Figures 1a, b & 2: (Left & Middle) – Two columnar bundles of rays or 'prodigies' seen in the sky as illustrated by Conrad Lycosthenes in *Prodigiorum ac Ostentorum Chronicon* [1557]; (Right) – "The Music of Death," beast with burning sheaf/torch for one leg, from *Aurora Consurgens* [Morning Aurora] written in the 15th century.

modern European books, manuscripts, and broadsheets of a religious, alchemical, or "strange beasts" genre during eras when auroral activity has been well documented (see Figures 1a, b & 2).[42] Not surprisingly, the Austrian wheat sheaf auroral subform bears a striking resemblance to a Birkeland *field-aligned current* with *Z-pinch architecture* (the periodically-spaced magnetic rings perpendicular to the 'Romanesque' column's length), which enable the

were: I. *Bogen* [Arch or Bow] – includes narrow and wide "feet" that would frequently "dance" along the horizon, also prone to "cloning" itself into multiple bows stacked together; II. *Bänder* [Band or Ribbon] – "are the most difficult phenomenon to define." Wide, narrow, flat, coiled, twisted, pointed, split, stick-shaped, tube worm or with snake-like pieces which resembled incurved "C" forms, bands formed normally parallel to the horizon with stripes or "rods" that were flat or columnar in shape; ribbons arose perpendicular to the horizon with a rapid flickering, helically winding motion (subgroups included "haze band" and "haze ribbon"); III. *Fäden* [Thread] and *Strahlen* [Ray/Beam] – a thread was a singular ray of uniform length and width; a ray or beam consisted of multiple threads stacked together like the Roman Era *fasces* sharply demarcated by a dark space in between each thread, tapered from one end to the other – "stiffness and straightness of appearance were the main characteristics for both;" subgroups included "thread throw," "thread mantles/cloaks," "curtain/drapery", "chopsticks," "fan," "umbrella," and "veil;" IV. *Kronen* [Crown, Corona, or Corolla] – luminous auroral climax that emerges from all other forms with an intense burst of colors; varieties include "Crown of Rays," "Crown of Flames," "Crown of Bands/Ribbons," and "Half-Crown;" V. *Polarlichtdunst* [Auroral Haze] – diffuse light in foggy, amorphous, cloud-like clusters or shapes; subgroups include "Haze Bow," "Haze Ribbon," "Haze Ray, etc., which in the contours resemble other forms; a related phenomenon was "illuminated cloud edges/hems" in large cloud banks or Stratus and Cirrus "stripes" or "streaks;" VI. *Polarlichtsegment* [Auroral Segment] – this form was never viewed or recorded by the expedition but was kept as an official designation nevertheless; VII. *Polarschein* [Auroral Glow/Sheen] – "the firelight from the horizon that shines more or less high up in the firmament," witnessed only a few times, short-lived forerunner of other forms with rays diverging from the horizon to the magnetic zenith; VIII. *Garbe* [Wheat Sheaf] – description provided in text.

42 Source for Figure 1a, b: Conradum Lycosthenem, *Prodigiorum ac Ostentorum Chronicon* (1557), 578; Figure 2 – Thomas Aquinus, *Aurora Consurgens* (15th century), https://commons.wikimedia.org/wiki/File:Aurora_consurgens_zurich_003_f-1r-3_monkey.jpg.

individual electrical filaments to remain coherent over extremely long distances.[43] Flaring associated with current-induced axial magnetic fields is also captured in the medieval illustrations.[44]

Figure 3: Auroral band/ribbon with parallel longitudinal stripes and flaring 'fish tail'.

To explain the rapid, confusing array of morphological complexity as precisely as possible, a slew of descriptors was employed based on what was seen in daily life of late-1800s northern Europe. For instance, many of the frequently witnessed shapes had a woven cloth-like quality and texture composed of Form III (threads and rays), varying in diameter, coarseness or silkiness. Much like handwoven, knitted, or sewn pieces, one form could be garnished with another: bands/ribbons or arches were decorated with rays pointing towards or away from the magnetic zenith; an "umbrella" which opened over the entire firmament had 13 small "fans" and tufted threads on one side; whereas the climax of all imaginable forms merged together – the crown (to be discussed in detail shortly) – displayed strongly luminous rays "interspersed with small, bright haze-like tufts of lighted sheaves."[45] The terms "curtain" [*vorhang*], "drapery" [*draperie*] were employed "when the rays or threads above the hemline were parallel to each other" and covered portions of the firmament; while *säum* could mean "hem, edge, border, or fringe," of red, green or violet color running perpendicular to the parallel orientation of the threads.[46] A much larger sub-category was the *strahlenmantel* or *fadenmantel* [cloak, robe, or mantel of rays/threads], which "always indicate a greater extent over the firmament, both in height and amplitude;" whereas as a smaller, more delicate and sheer combination of "tightly spaced threads without a hemline" are mentioned as *schleier* [veil].[47] When describing the behavior of a band/ribbon that developed into a curtain on 9 March 1883, the team wrote "[its] steady appearance shows alternating splitting of the hem into rods [blanket stitch pattern] and reuniting [at the bottom of the hem]."[48] The textile-similar behavior of auroral forms reveals itself in multiple journal entries, especially what appeared to be the ripping, tearing, and elastic stretching of Form III. During one observation when a thin cloak emerged from the magnetic zenith, a broad, bright ray shot from the horizon and pierced the billowing cloak, whereupon "the thread cloak tears and the pieces cling together, scattered as haze covering the firmament;" additionally, the lower "rod" of a parallel striped band would separate horizontally with both bands "connected together through an odd number of fine threads."[49] The long, thin, horizontally-striated ribbon in Figure 3 provides a scarf-like example of the textile conflation.

Woven fabrics have a lattice, net-like, or crisscross pattern. The movement of light within the forms enabled the expeditionary team under ideally clear sky conditions (which were infrequent) to see how threads and rays were arranged in networks. Certain morphologies of bands/

43 See Donald E. Scott, "Birkeland Currents: A Force-Free Field Aligned Model" *Progress in Physics* 2.11 (April 2015): 167-179, https://www.ptep-online.com/2015/PP-41-13.PDF.

44 N. Aybar, M. Dozieres, D. B. Reisman, *et al*., "Study of the Azimuthal Magnetic Field Distribution of Gas-Puff Z-Pinch Implosions with and without External Magnetic Stabilization" 1-10, https://www.osti.gov/pages/servlets/purl/1784742; D. D. Ryutov, "Characterizing the Plasmas of Dense Z-Pinches (Mini-Tutorial)" *IEEE Transactions on Plasma Science* 43.8 (2015): 2363-2384(1-24), https://ieeexplore.ieee.org/ielaam/27/7182405/7169570-aam.pdf.

45 Bóbrick, *Preliminary Report*, vol. II, part IV: 5-6; No. 50, 6:28 p.m., 74; No. 59, 6:57-6:59 p.m., 97.

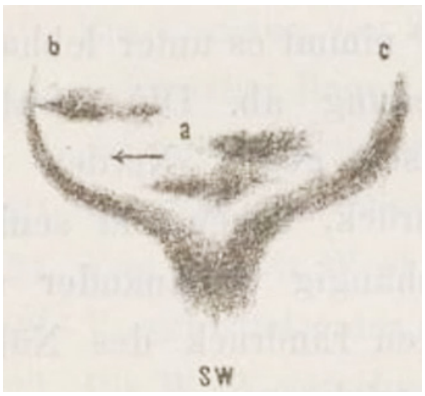
46 Bóbrick, *Preliminary Report*, vol. II, part IV: 6; No. 104, 3:35 a.m., 170.

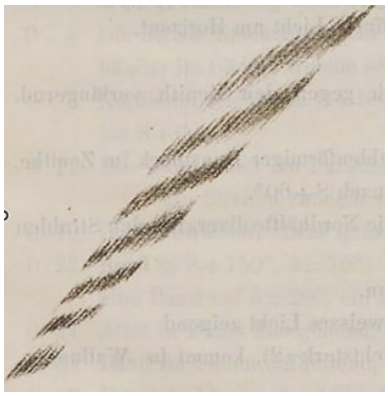
47 Bóbrick, *Preliminary Report*, vol. II, part IV: 6.

48 Bóbrick, *Preliminary Report*, vol. II, part IV: No. 104, 4:03 a.m., 170. Brackets added for clarification.

49 Bóbrick, *Preliminary Report*, vol. II, part IV: No. 59, 7:26-36 p.m., 97; No. 98, 4:09-16 a.m., 163; see also No. 104, 7:59-8:03 p.m., 168.

ribbons "gave the impression of a lattice standing in the dark;" or when two or more curtains stood with the other(s) behind the one in front, being semi-transparent, the observers noted the "crisscrossing directions" of light along the individual strands in all of them.[50] Wide ribbons frequently passed through very thin "black telegraph wires;" fine lattice formations of rays, or ray and thread combinations were chronicled shooting from the magnetic zenith then "falling like a net towards the Southern firmament" and "spread out like a net from the zenith across the entire firmament."[51] When two or more vibrant crowns emerged simultaneously, "rows of rays covered and wrapped around the common center in opposite [i.e., crisscrossing] directions."[52] Amongst the variety of textures recorded by the polar expedition on Jan Mayen Island which indicate a two- or three-dimensional condensed matter atomic/molecular composition, the description of wheat or hay straw was noteworthy. Jagged ray "fringes" would emerge perpendicular to the longitudinal direction of a band or ribbon "as if a curtain made out of hay straw."[53] On a different night, an arch flattened out into a ribbon that unrolled itself into a hanging drape composed of fine threads and rays: "the contours of this curtain are drawn as sharply as if they were something like a rolled up Chinese straw curtain [i.e., made of thicker reeds lying horizontally with finer threads spaced at periodic intervals running vertically]".[54]





Figures 4 & 5: (Left) – Bull horns, or two hands coming together in a chalice shape after a band split into three, then two opposing strands. (Right) – Candy cane or barber's pole, with alternating red and white stripes moving helically from bottom to top of the structure. The *fluted pattern* in straight tubular auroral forms was a common feature.

A menagerie of bewildering morphologies was catalogued in the auroral journal. Phytoid (plant-similar) phenomena were characterized as leaf-like, lily and calyx shaped, and a long palm branch.[55] Zoomorphs (animal-like) included a large bell-shaped jellyfish with twisted, ribbon shaped arms projecting underneath its billowing dome; several small silvery sheep in a row; bi-valves and various shelled species (scallops, mussels, and snails); stag (deer) antlers;

50 Bóbrick, *Preliminary Report*, vol. II, part IV: 10.

51 Bóbrick, *Preliminary Report*, vol. II, part IV: 5, 10; No. 104, 7:54-8:08 p.m., 168.

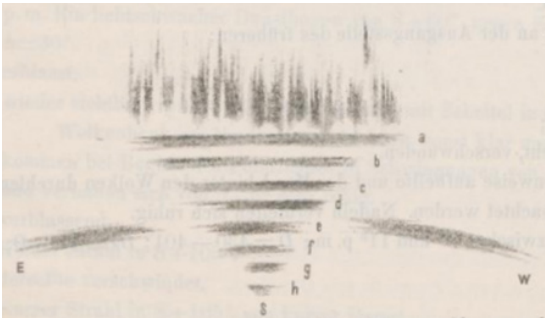
52 Bóbrick, *Preliminary Report*, vol. II, part IV: 10.

53 Bóbrick, *Preliminary Report*, vol. II, part IV: No. 9, 3:08-16 a.m., 25.

54 Bóbrick, *Preliminary Report*, vol. II, part IV: No. 60, 7:27-33 p.m., 103. Brackets added for clarification.

55 Citations appear sequentially following the form description in text. Bóbrick, *Preliminary Report*, vol. II, part IV: lilies No. 42, 3:58-4:15 p.m., 66; No. 51, 10:18-31 p.m., 78-79; No. 56, 5:36-6:06 p.m., 87; leaf No. 60, 5:32-34 p.m., 102; palm branch No. 56, 6:03-6:06 p.m., 87.

57 Bóbrick, *Preliminary Report*, vol. II, part IV: clubs No. 32, 1:06-10 a.m., 46, & No. 104, 7:59-8:08 p.m., 168; cane with handle No. 20, 5:01-5:02 a.m., 33-34; barber pole No. 60, 10:18-20 p.m., 105, & No. 71, 5:56-6:14 p.m., 122; banded triangle No. 47, 6:06-6:14 p.m., 71, Fig. 36 & glowing triangle 8:46-57 p.m., 72; cylinders No. 34, 7:11-14 p.m., 52, & No. 60, 8:30-1 p.m., 104; concentric rings No. 37, 5:29-34 p.m., 57, & No. 98, 10:08-14 p.m., 161, Figure 63; ringlets No. 59, 7:26-36 p.m., 97, & No. 104, 1:26-30 a.m., 169; question mark No. 59, 8:50-54 p.m., 99; letter "S" No. 98, 7:29-40 p.m., 158-59; yin-yang "duet" [Düte] form No. 60, 10:52-55 p.m. & 6:46-8:16 a.m., 103, 108; No. 86, 6:41-45 p.m., 145; No. 95, 10:52-55 p.m., 154; cross No. 6, 12:16-22 a.m., 21; zigzags No. 37, 4:26-56 p.m., 57, & No. 60, 11:11-19 p.m., 106, & No. 77, 6:34 p.m., 132; arabesques No. 42, 3:58-4:09 p.m., 66, & No. 51, 10:18-31 p.m., 78-79; tooth-like arch No. 38, 7:01-06 p.m., 39; umbrellas No. 33, 7:58-8:00 p.m. & 8:06-8:11; 47-48; No. 35, 2:06-09 a.m., 55; No. 59, 8:50-54 p.m., 99; No. 98,



Figures 6 & 7: (Left) – Banded triangular form that arose from the horizon attached to an east-west oriented haze arch, with 8 layers. Above the band marked 'a' is a brighter, undulating cloak of rays moving towards the zenith. Lasting 8 minutes, the arch dissolved to vapor at the zenith; while the triangle slowly faded away afterwards. (Right) – Oval-shaped concentric circles, remnants from a *Crown of Rays* that appeared two minutes prior. It resembles an *O-shaped potential* in an upward acceleration region of *field-aligned currents*.

a pair of bull horns; feathers; radially segmented worms, banded and spotted snakes, or a "dragon."[56] Geometric configurations were similarly robust and awe-inspiring: club shapes; twisted cane with curved handle; barber pole/candy cane; light-filled triangle and horizontally striped variety; cylinders; concentric rings; ringlets and partial rings; a question mark; letter "S" shapes; *yin-yang* forms; a bright crucifix shape; zigzags; arabesque motifs; an arch with "tooth like" alternating dark and light portions; large umbrellas; convex, concave, and truncated cones; helical coils; spirals that randomly dissolved into balls then changed back into serpentine coils; a huge, knotted ball created by two bands moving in from opposite sides; and a plethora of spherical or ball-like objects.[57] Sketches 4 - 7[58] capture a fraction of the topological dynamics recorded by Austrian explorers.

In the language of applied scientists, the aforementioned '*non-trivial*' behavior of auroras observed during Solar Cycle 12 (a.k.a., Sunspot Cycle - the first of which started in 1755 when Western academics undertook serious investigation of sunspots) stands in stark contrast to the textbook image of 'streamers' (precipitating electrons and ions accelerated by Alfvén waves) that "surf" along the Earth's magnetic field lines towards the equatorial plasma sheet and then out to the magnetotail.[59] Descriptions of combustion – an oxidation-reduction chemical

56 Bóbrick, *Preliminary Report*, vol. II, part IV: jellyfish No. 35, 12:41-51 a.m., 55; silvery sheep No. 54, 10:55-11:04 p.m. & 12:17 a.m., 84-85; shelled objects No. 67, 5:58-6:06 p.m.,112; No. 72, 5:17-5:23 p.m., 125; No. 84, 10:57-11:00 p.m., 141; No. 96, 1:24 a.m., 156; deer antlers No. 67, 6:11-6:16 pm, 112; bull's horns No. 60, 10:26-31 p.m., 106; feathers No. 37, 3:12-3:17 a.m., 59, & No. 119, 8:34-40 p.m., 185; worm, snakes, dragon No. 19, 11:31 p.m. to 12:01 a.m., 32; No. 35, 12:03 a.m., 54; No. 41, 5:16-5:26 p.m., 63-64; No. 71, 1:26-31 a.m., 124; No. 98, 12:52-54 a.m., 162 & 4:09-11 a.m., 163. Flaming-headed serpent No. 57, 8:46-9:01 p.m., 91, Figure 46.

57 (continued) 7:55-8:12, 159-160; No. 104, 4:21-29, 170; cones No. 37, 8:48-57 p.m., 58; No. 33, 7:28-36 p.m., 47; No. 50, 9:13-46 p.m., 75; No. 79, 7:07-10 p.m., 133; No. 105, 11:01-16 p.m., 171; helical coil No. 34, 4:01-03 p.m., 50; spiral-ball-coiled serpent No. 23, 8:06-21 p.m., 36; large ball winding in on itself No. 119, 9:27-31 p.m., 185; spheroids No. 23, 8:06-21 p.m., 36, & No., 35 2:43-57 a.m., 56; ball that explodes like a fireworks display page 7, paragraph 2 of Introduction.

58 P. Janhunan, A. Olsson, F. S. Moser, and H. Laakso, "How Does the U-Shaped Potential Close Above the Acceleration Region? A Study Using Polar Data" *Annales Geographicae* 17.10 (31 October 1999): 1276-1283, https://doi.org/10.1007/s00585-999-1276-x.

59 J. W. R. Schroeder, G. G. Howes, C. A. Kletzing, *et al.*, "Laboratory Measurements of the Physics of Auroral

reaction - are peppered throughout individual journal entries revealing the various levels of thermodynamic *polarlichter* behavior. Expressions such as "the sea of flames literally covering the entire firmament in wild chases," and "the whole firmament appears to be on fire" were not uncommon, although the majority are localized on certain forms.[60] Pillars of fire, columns of fire, torches, flares, exploding jets, and other activity testify to an unusual cosmic chemistry occurring at the firmament interface. In one case, a pillar of fire "apparition" with intermittent flaring below divides into several burning strands; while a dense stratus cloud bank with illuminated edges shoots out flickering rays that at times "gives the impression of sparks spraying [outward from the cloud's edges]."[61] Electrical discharges characterized as "lightning-like" rays or "sheet-lightning" accentuated the reaction-diffusive nature of the spectral phenomena.[62] In their entirety, auroral journal entries read like one is visualizing a transcribed sporting event, with longer periods of relatively anemic activity punctuated by intense moments of explosive energy – *intermittency* in the language of *Chaos theory*.

III. Auroral Clouds, Magnetic Disturbances, and Sunspots

The arrival of Northern Lights and their symbiotic relationship with fluctuations in the magnetometer needles was also accompanied by the formation of unusual vapors or clouds. Each journal entry officially began with a generally clear sky, punctuated by a violent disturbance of the Theodolite device, quickly succeeded by a ubiquitous fog or haze and a variety of cloud formations.[63] In the words of Bóbrick: "The connection between Northern Lights and the clouds is unmistakable for every attentive observer."[64] What distinguished *auroral clouds* from non-auroral water vapor masses formed by solar radiation-induced atmospheric convection was the unusual morphologies, diffuse and glowing light emanating from the former. The "ground color" of nebulous mists was a whitish-yellow blend, compared to a "phosphorous vapor" that "most resembled the smoke of a wet match stick which had been struck in the darkness and began drifting away."[65] The haze or vapor that "gave the impression of a light source being slowly turned on," was associated with a "disordered surging and wallowing" movement followed by the emergence of haze shrouded rays, bands, fans, and other configurations.[66] Luminosity produced by such forms would shift towards "the more intensely lit spot of a compacted mass," which resembled a cloud of steam over which the rays of a lighthouse with a rotating narrow beam or flashing lights glided upwards from the source.[67] In sum, vaporous clouds and haze behaved as potent magneto-electric catalysts.

In many journal entries the aforementioned 'warm-up act' set off kinetic shape-shifting byproducts. For instance, a bright mass (called a "fleck" or "spot") was approached by a "cloud train" formation moving rapidly over it. The mass changed its shape each time one of the clouds interacted with it, "sometimes striped, sometimes round, sometimes curved." It morphed into a haze ribbon lying horizontally, increased luminosity and revealed individual stripes lying parallel to its lengthwise direction that developed into a cloak of fine threads with a large "S" shaped fold. The bale then dissolved into a large patch of haze, which began shooting rays from the magnetic zenith, formed a bale of cloth with a red lower hem, and ultimately transitioned into a multi-colored crown formation surrounded by long rays created "one of the most beautiful of the apparitions

Electron Acceleration by Alfvén Waves" *Nature Communications* 12 (June 2021): 3103(1-9), https://doi.org/10.1038/s41467-021-23377-5; V. A. Sergeev, K. Liou, P. T. Newell, *et al*., "Auroral Streamers: Characteristics of Associated Precipitation, Convection and Field-Aligned Currents" *Annales Geophysicae* 22.2 (January 2004): 537-548, https://doi.org/10.5194/angeo-22-537-2004.

60 Bóbrick, *Preliminary Report*, vol. II, part IV: 3; No. 37, 4:20-23 a.m., 60.
61 Bóbrick, *Preliminary Report*, vol. II, part IV: No. 57, 11:03-06 p.m., 92; No. 53, 6:16-20 a.m., 82.
62 Bóbrick, *Preliminary Report*, vol. II, part IV: 8 & 36, No. 6, 1:20-24 a.m., 21; No. 25, 8:10-12 p.m., 40.
63 Bóbrick, *Preliminary Report*, vol. II, part IV: No. 34, 3:46 p.m., 49.
64 Bóbrick, *Preliminary Report*, vol. II, part IV: 208, third paragraph.
65 Bóbrick, *Preliminary Report*, vol. II, part IV: 15; No. 33, 7:18 p.m., 47.
66 Bóbrick, *Preliminary Report*, vol. II, part IV: 202-203 "Auroral Haze."
67 Bóbrick, *Preliminary Report*, vol. II, part IV: 11; No. 4, 12:50-56 p.m., 18.

seen" by the expedition. The entire spectacle lasted sixteen minutes.[68] Identical reactions were noted for weakly illuminated bands/ribbons when interacting with passing clouds and their rays hanging as fringes. Bands would "suddenly light up in bright colors without altering light intensity of the uncovered portions;" whereas hanging rays whose tips had penetrated magnetic fog banks would flare up in a bright red color, while the rays outside the cloud were unaffected.[69] On many occasions, what appeared to be Stratus or Cirrus clouds at first glimpse would undergo spontaneous mutation. Expedition leader Wohlgemuth recounted: "I saw a streak of cloud in the northern sky, the regular shape of which struck me as so peculiar that I stopped and said to my companions: Someone, who has only observed a few Northern Lights could mistake this streak of cloud for a Northern Arch. Now, as we gazed at it for a minute, doubting the possibility of such a mix-up, the streak brightened into a brilliant Northern Arch."[70]

The cyclical phase state behavior of auroras chronicled on Jan Mayen Island followed the same pattern: clouds and haze, a variety of forms created therefrom, and inevitable dissipation back into the magneto-electric cosmic ethereal realm. Energetic convulsions accompanied the reaction-diffusion system: "If one form or another turned to haze, there was almost always a violent movement of light – one that was most appropriately called 'undulated flow' or 'wave-like rippling'… the same also occurred with the faintest, scarcely perceptible threads and diffuse spots of light, and then consisted of a quivering flicker, as if the mass of light had been set into rapid vibration by a sudden jolt."[71] Another significant facet of the *polarlichter* phenomena was the 'cloning' mechanism for future activity after one form had dissolved into haze. In a journal entry lasting six hours on 13 November 1882, a ray formed from a luminous spot with red and green lights rotating around its long axis then vaporized after three minutes into several diffused patches of light near the zenith. A few of the haze patches began glowing in the direction of the magnetic zenith and lengthened into rays, the rays disappeared and left behind "patches of light spawn points," which morphed into a red and green colored band and fan circling the zenith, then dissipated into a brilliant haze spot (level 4 – the highest on their light intensity scale) that illuminated the firmament for three minutes, after which is noted "needles

Figures 8, 9, & 10: Fig. 8 (Left) depicts magnetic haze streaks, flecks, and spots remaining from a dissolved crown. Fig. 9 (Middle) shows a short bundle of rays emerging from magnetized Stratus clouds. Notice the columnar, bundled stick-like Roman *fasces* arrangement of cosmic plasma flux, indicative of a Birkeland FAC. Fig. 10 (Right) displays a magnetic cloud moving over a flat band (dark hem) with rays above the zenith. The cloud moved in from the north and caused the hem and rays to bend at the zenith. Notice the reflection of the cloud on the rays, indicating the crystalline nature of this *vorhang*-like formation. The magnetic cloud (with illuminated edges) catalyzed intense radiation and a beam shooting out of the zenith towards the southwest, which transformed into a curtain underneath, then a crown developed – all within the span of 6-7 minutes.

68 Bóbrick, *Preliminary Report*, vol. II, part IV: No. 98, 7:24-40 p.m., 158-159.

69 Bóbrick, *Preliminary Report*, vol. II, part IV: 10.

70 Wohlgemuth, *Preliminary Report*, vol. I: 20. Wohlgemuth mistakenly identified the date as October 29, 1882, when it was actually 27 October. See Bóbrick, *Preliminary Report*, vol. II, part IV: No. 23, 7:06-16 p.m., 35; No. 47, 8:46-59 p.m., 72; No. 57, 2:31-49 p.m., 89.

71 Bóbrick, *Preliminary Report*, vol. II, part IV: 11.

very restless."[72] Self-organization of auroral phenomena was a common thread running through every observation. Figures 8, 9, & 10 display the magnetic patches and clouds as sketched in the auroral journal.[73]

The 'magnetic clouds' discussed above are, in many instances, the result of polar substorms associated with magnetic reconnection (explained in Part VI) in the plasma sheet of the Earth's magnetotail. Auroral streamers (a.k.a., Birkeland FAC), individually or several simultaneously, develop at the poleward boundary of the substorm bulge (auroral oval) and propagate in an equatorward direction at ~1-5 km/s. They can extend for a few to hundreds of kilometers horizontally, detach from the poleward boundary and begin to break apart or decay, thereby forming patches or clouds of pulsating aurora at the equatorward edge of the bulge.[74] The flashing on and off behavior is tied to magnetic field line resonance between competing nonlinear forces: VLF (very-low frequency) whistler-mode chorus waves, and Pc4-5 ULF (ultra-low frequency) compressional waves.[75] Pulsating, diffuse aurora appear often in the Jan Mayen Island journals predominantly during the pre-midnight hours. Taken as a whole, a plurality of auroral formations logged correspond to *nightside reconnection events with the magnetotail*.[76]

Geomagnetic Storm of 17 November 1882

Connecting auroras experienced by the Second Austrian Polar Expedition with the massive geomagnetic storm of 17 November 1882 recorded at Greenwich/Abinger is no Herculean labor. Nevertheless, there are fascinating elements that would otherwise give the false impression that it was a one-day spike. Robust auroral activity accompanied by a swing of several hundreds of bars on the Theodolite device (magnetic deviation and horizontal intensity) were recorded from late afternoon 11 November to early morning 22 November.[77] On 17 November, snow and cloud cover prevented the expeditionary team from providing much information in the journal that day, which is short compared to the days before and afterwards.[78] Wohlgemuth reported: "As I found out later, the Northern Lights had spread widely across Europe and America; we also observed large magnetic disturbances, especially at noon and one o'clock Gottingen local time" [one hour ahead of Greenwich].[79] The Austrian team leader's journal entry for that day reads: "[a] photograph of the Sun with sunspots appearing around noon, two-thirds of the Sun's diameter above the horizon, succeeded."[80]

Fortunately, additional sources from 17 November 1882 provide details of its visual and electrical impact on the Industrial Revolution. Newspapers from Europe reported the auroral spectacle could be seen from Rome. In Scotland, locomotives' bells in passenger cabins rang on their own accord, and the kingdom experienced a brief shutdown of telegraph service; while in France telephones randomly rang and were unusable.[81] On the following morning in England, Queen Victoria held a military review in Hyde Park. With overcast skies, a *dullish red sun* was visible

72 Bóbrick, *Preliminary Report*, vol. II, part IV: No. 34, 7:29-8:01 p.m., 52.

73 Source for Figures 8-10, in sequence. Bóbrick, *Preliminary Report*, vol. II, part IV: No. 25, 8:06-8:16 p.m., 40-41, Fig. 22; No. 10, 9:43-9:46 p.m., 27, Fig. 10; No. 59, 8:01-8:15 p.m., 98, Fig. 48.

74 O. Amm, R. Nakamura, T. Takada, *et al*., "Observations of an Auroral Streamer in a Double Oval Configuration" *Annales Geophysicae* 29.4 (27 April 2011): 701-716, https://www.ann-geophys.net/29/701/2011/.

75 A. N. Jaynes, M. R. Lessard, K. Takahasi, *et al*., "Correlated Pc4-5 ULF Waves, Whistler-Mode Chorus, and Pulsating Aurora Observed by the Van Allen Probes and Ground-Based Systems" *Journal of Geophysical Research: Space Physics* 120 (February 2015): 8749-8761, https://doi.org/10.1002/2015JA021380.

76 Bóbrick, *Preliminary Report*, vol. II, part IV: 212-213, 224, Tabelle III.

77 Bóbrick, *Preliminary Report*, vol. II, part IV: No. 32, 45, through No. 40, 63. For each period of observation, magnetic declination, horizontal intensity readings, and total swing (in parentheses) sequentially: 418.7-380 (38.7) 423-95 (318); 502.5-324.5 (178) 405-0 (405); 758-295 (463) 401-0 (401); 487.9-319.5 (168.4) 542.8-194 (348.8); 501-264.4 (236.6) 402-0 (402); 479.3-226 (253.3) 435-0 (435); 404-0 (404) 420-0 (420); 596-358 (238) 435-0 (435).

78 Bóbrick, *Preliminary Report*, vol. II, part IV: No. 36, 56-57. The entry log is less than one page in length.

79 Wohlgemuth, *Preliminary Report*, vol. I: 62.

80 Wohlgemuth, *Preliminary Report*, vol. I: 47.

81 Jeffrey J. Love, "The Electric Storm of November 1882," *Space Weather* 16 (2018): 37-46.

through the fog while soldiers marched across Blackheath and pointed out to each other a huge sunspot clearly visible on its surface.[82] The United States suffered more severe effects. Telegraph lines were inoperable across a huge swath of the country stretching from the East Coast to Nebraska; the Western Union office in New York City dealt with "half a dozen" fires in its switchboard, melting some of the instruments; submarine telegraph cables across the Atlantic, to Mexico and Cuba were similarly affected. The aurora was seen from ground level as far south as Florida, Texas, Arizona, and San Diego, California.[83] Although not as widespread or intense as the 1859 Carrington Event, it's impact on newly electrified societies came as quite a shock.

The linkage between sunspots and temperature variations in the Earth's atmosphere was theorized by William Herschel in 1801, and later (1843) by Samuel H. Schwabe – the scientist who discovered the 11-year sunspot cycle.[84] Examining meteorological data from the seventeenth and eighteenth centuries, Gustav Spörer (1889) noted an absence of sunspots reported for the seventy-year span ending in the year 1716; calmer solar behavior for that era was subsequently confirmed and elaborated upon by Karl Maunder (1894), who called the anomaly "a prolonged sunspot minimum." In a landmark 1976 article, John Eddy validated and eponymously named two distinct periods the 'Spörer Minimum' (1460-1550) and 'Maunder Minimum' (1645-1715) after comparing ^{14}C concentrations in tree rings since 1000 CE with archaeomagnetic studies measuring the Earth's magnetic field strength dating to ~10,000 *ykr*.[85] Based on the dendrochronological results, global temperature averages dropped in a non-trivial manner, while the Northern Hemisphere experienced short-term "mini-ice ages." Maunder also included the scholarship of Irishwoman Agnes Mary Clerke, who had theorized that auroras were rarely noted during sunspot minimums – possibly related to the disappearance of a structured corona around the Sun during solar eclipses.[86] In a related observation, in 1874 Samuel Langley was intrigued by the filamentary structure of sunspot penumbra surrounding dark holes on the star's surface. Their highly defined structure and brilliance was chronicled as "all over the penumbra, in which they have a certain tendency to unite in narrow sheets or plates, which superposed, form the fascicles called 'thatch straws' by Mr. [William R.] Dawes."[87] Although the Jan Mayen expedition's auroral observations ended in April 1883, the largest number of sunspots recorded during Solar Cycle 12 occurred in December 1883 with a 'smoothed' count of 124.4 for that single month alone.[88]

Adolphus Greely's three-year exploration (1881-84) of uncharted regions in Canada's Grinnell Land (now Ellesmere Island) at Fort Conger, located across the Nares Strait from northwest Greenland, witnessed a more dramatic solar storm that day. Although the Northern Lights episode lasted from 1 a.m. until 9:40 p.m. Gottingen Time (the standard prescribed for all expedition logs), its brilliant climax occurred at 5-6 a.m. on 17 November 1882. Around 5:15 a.m. expedition members were temporarily blinded by the auroral prodigy – many either reflexively ducked or moved hands up to protect themselves. The

82 Love, "The Electric Storm of November 1882," 39.

83 Love, "The Electric Storm of November 1882," 37.

84 Vaquero and Vásquez, *The Sun Recorded Through History*, 41-48, 138; Jeffrey J. Love, "On the Insignificance of Herschel's Sunspot Correlation," in *Geophysical Research Letters* 40.16 (August 2013), 4171-4176.

85 John A. Eddy, "The Maunder Minimum: The Reign of Louis XIV Appears to Have Been a Time of Real Anomaly in the Behavior of the Sun," in *Science* 192.4245 (18 June 1976), 1189-1202; Vaquero and Vásquez, *The Sun Recorded Through History*, 138. Eddy's research proved that Carbon-14 levels drop during Solar Maximums accompanied by robust Sunspot formation, while levels rise for Prolonged Sunspot Minimums. With more sunspots and auroras (i.e., explosive, stochastic, turbulent plasma flows), fewer galactic cosmic rays enter the atmosphere and generate Carbon-14 isotopes; fewer sunspots and auroras (i.e., cooler, periodic, laminar particle flows) inversely permit production of Carbon-14 isotopes.

86 Eddy, "The Maunder Minimum," 1190, 1198; A. M. Clerke, *Knowledge* 17 (1894): 206.

87 Vaquero and Vásquez, *The Sun Recorded Through History*, 146-47. Brackets added for clarification. William Rutter Dawes was a British astronomer (1799-1868).

88 "SIDC Monthly Smoothed Sunspot Number, Solar Cycle 12," https://en.wikipedia.org/wiki/Solar_cycle_12. The SIDC (Solar Influences Data Analysis Center) is a website published by the Royal Observatory of Belgium which no longer maintains that page. Fortunately, it was uploaded to Wikipedia at the web address above.

team stood transfixed in -34˚ *Fahrenheit* Arctic air as the apparition lasted approximately twenty minutes, and at times seemed to be no more than 100 feet above the Earth. It encompassed the entire spectrum of prismatic color, and "presented to the eye the ever-shifting variations of the kaleidoscope."[89]

It is important to interject at this point what the Jan Mayen Island explorers chronicled regarding the brightest and most magnificent phase, or *crowning*, of the Northern Lights at the magnetic zenith. Prior to the mad rush of morphologies towards that pivotal point in the firmament, their nebulous structure was replaced by intense color display and sharp definition in geometric shape. In other words, a crystalline composition.[90] As remaining portions of the form(s) transitioned around the zenith, the motion was followed by a "violent, rolling up and down taking place with lightning speed."[91] Then the explosive climax: they revealed - like an X-ray image – all of the scaffolding from which they were composed, maintained their oscillating movements and colorful displays, providing "the subjective impression of the phenomenon as if it were at a very low altitude above the surface of the Earth."[92]

In the Earth's atmosphere, auroras normally range from ~80-100 km to upwards of 1000 km (~50–620 miles) above the surface. Be that as it may, the height of the troposphere is not uniform. It elastically fluctuates from ~20 km (12 miles) at the equator to ~6 km (4 miles) at the poles.[93] That physical reality brings auroral forms closer to the Earth at higher latitudes where the polar expeditions occurred. Furthermore, we have all seen on vehicle side-door mirrors the message, "Warning: Images are closer than they appear." Light rays are distorted by the mirror's convex curvature, making an object appear farther away. Concave mirrors, however, magnify an image. As seen from ground level, Earth's upper atmosphere during auroral events behaves much like a concave lens, concentrating light rays into convergent beams at our planetary surface creating the optical illusion of being nearer to Earth. Therefore, observations within the '*auroral zone*' are experienced more vividly than at lower latitudes.

From the American team's journal entries for 17 November 1882, a person who had never experienced a crowning event of such magnitude can vicariously visualize the dramatic solar induced performance: "Arches with every shade of red, from the palest pink to crimson, and every shade of yellow, from brilliant orange to delicate primrose, now gently glowing in humbler effusion, and suddenly shooting thousands of narrow radiant streaks and bars of light in a semi-circle towards the zenith. Streamers of every shade of green, from the softest apple or pea to the dark invisible green of the hemlock pines, harmoniously blend the lovely tints of lilac and purple with the celestial blue of the canopy, shining here for an instant and then playfully skipping to another portion of the sky."[94] A streamer "would appear to swoop downward almost to the Earth, taking new forms as it advanced, coiling and twisting in the most convulsive manner through the glorious canopy of the heavens, like a gigantic serpent."[95] Chemical reactions elicited fiery analogues: "The whole heavens seemed one mass of colored flames, arranged and disarranged and rearranged every instant;" and "the arches, streamers, and patches blending harmoniously together so as to form one huge sheet of flame."[96] One journal entry succinctly stated, "[t]he entire heavens covered with all kinds of formations, and movements in the change of formations so rapid that the eye could not follow them."[97] Beyond the aforementioned shapes, annular/torus 'donuts' with streaks and spots, "S" shapes, and slender pencils of

89 Adolphus W. Greely, *Three Years of Arctic Service: An Account of the Lady Franklin Bay Expedition of 1881-84 and the Attainment of the Farthest North,* 2 vols. (New York: Scribner's Sons, 1886), vol. 2, Appendix XIII: 413, 415-17. Italics added by the authors for emphasis.

90 Bóbrick, *Preliminary Report*, vol. II, part IV: 6.

91 Bóbrick, *Preliminary Report*, vol. II, part IV: No. 37, 8:48-51 p.m., 58.

92 Bóbrick, *Preliminary Report*, vol. II, part IV: No. 37, 8:48-51, 58.

93 National Oceanic and Atmospheric Administration, "Layers of the Atmosphere", https://www.noaa.gov/jetstream/atmosphere/layers-of-atmosphere.

94 Greely, *Three Years of Arctic Service*, vol. 2, Appendix XIII: 413.

95 Greely, *Three Years of Arctic Service*, vol. 2, Appendix XIII: 417.

96 Greely, *Three Years of Arctic Service*, vol. 2, Appendix XIII: 416-17.

97 Greely, *Three Years of Arctic Service*, vol. 2, Appendix XIII: 415.

radiant light were noted.

The most prominent Northern Lights form that day, nevertheless, was "a luminous half-transparent curtain rolling quiveringly from horizon to zenith, curling and expanding, rising and falling like the waves of an angry ocean, and suddenly steadying down again to the predominating characteristic formation of the loose flowing folds of a curtain, and veiling for a time the stars."[98] Expedition member H. S. Gardiner exclaimed, "I doubt not that this is the *greatest exhibition of the aurora which has ever been witnessed*."[99] Quite to the contrary, humans have been recording the *aurora borealis* and *aurora australis* for tens of millennia globally during epochs of *extreme solar activity* that make the nineteenth century experiences seem trivial by comparison. Thus far, conclusive evidence has eluded modern scientific acknowledgment despite its innumerable geometric manifestations in hominids' *longue durée* material culture, religious beliefs, political symbols of authority, oral histories, and social behavior. To paraphrase Edgar Allen Poe's inimitable detective C. August Dupin in *The Purloined Letter*: the solution has been hidden in plain sight all along.

IV. Auroral Crown Formation and Dynamics

Among the five senses that human beings possess, the most dominant one is sight. When it comes to the magnetoelectric grid encircling the Earth, however, we are literally blind. During *solar minimums*, we cannot see planetary magnetic fields conducting electrical currents across the sky – day or night. Only when geomagnetic and magnetospheric field lines are disturbed by *intense solar particle streams* do they become visible to the human eye as *aurorae*. Birds, however, have a protein in the retina of their eyes that is photosensitive to magnetic field lines. It is called *Cryptochrome IV* and is what migratory avians use to navigate over long distances. Recent studies suggest that avian vagrancy, or when our feathered friends arrive at the wrong destination, is connected to *geomagnetic disruptions caused by solar activity* – but not exclusively.[100]

"Seeing is believing," as the ancient adage goes. When we look back through our linear timeline, there are myriad megalithic structures, tombs, temples, palaces, caves, rock shelters, and assorted archaeological artifacts with strange markings, symbols, and motifs that mystify us upon visual inspection. Interestingly, at Tell Brak (located in modern day northeastern Syria) an archaeological excavation undertaken in the 1930s uncovered the "Eye Temple" (a.k.a., Temple of the Eyes) constructed over 5,000 *ykr* (3500-3300 BCE). Thousands of enigmatic "eye idols" were found inside of the structure. In Egypt under pharaonic rule, there was the "Eye of Horus," "Eye of Ra," and *wedjat* hieroglyphs depicting singular or pairs of orbs; whereas European Freemasons had the radiant "Eye of Providence." In the Middle East and North Africa, the *Hamsa Hand* (a.k.a., *Hand of Fatima*) was widely venerated. Hindu Indian gods and goddesses were portrayed with eyes in their palms, or with the *tilaka* [Third Eye] situated on the forehead above the eyebrow convergence as an expression of the god Siva (Shiva). The Olmec civilization of Central America revered the symbol of a spiraling eye in the palm of a hand, as did the Jama-Coaque culture of modern-day Ecuador. Amongst assorted indigenous communities of island Southeast Asia, spiral eyes were placed on death masks or skulls. A variation of the optical theme is one-eyed mythical beasts, including the Cyclops and his son Polyphemus; or the Islamic false prophet Al-Masih ad-Dajjal. It is noteworthy that the last three deities are associated with evil and malice; that losing one or both eyes as punishment, such as the Egyptian deity Osiris or with the Norse god Odin in exchange for divine wisdom, are tied to random heavenly acts. Conflating the human oculus with divinity and the afterlife – from the present to remote past – and replacing or covering them with shells, pennies, or shiny objects in preparation for their voyage to the 'Great Beyond' - are shared threads of behavior that connect our species globally.

Since *aurorae* are observed by humanity in the firmament above, the Austrian expedition's written characterizations

98 Greely, *Three Years of Arctic Service*, vol. 2, Appendix XIII: 414, 417.

99 Greely, *Three Years of Arctic Service*, vol. 2, Appendix XIII: 416. Italics added by the authors.

100 Atticus Pinzon-Rodriguez, Stafan Bensch, and Rachel Muheim, "Expression Patterns of Cryptochrome Genes in Avian Retina suggest Involvement of Cry4 in Light-dependent Magnetoreception," in *Journal of the Royal Society Interface* 15 (March 2018): 20180058, http://dx.doi.org/10.1098/rsif.2018.0058; Benjamin A. Tonelli, Casey Youngflesh and Morgan W. Tingley, "Geomagnetic Disturbance Associated with Increased Vagrancy in Migratory Landbirds," in *Scientific Reports* 13.414 (2023), https://doi.org/10.1038/s41598-022-26586-0.

and sketches of the kinetic climax are an invaluable source. An auroral *crown* [noted in the journal as *kronen*, *corona*, or *kranze*] emerged from one, several, or all the official eight forms and/or subforms described above. The plurality of *crowns* developed from bands/ribbons, while arches, fans, rays, threads, or *masses of haze* were also not uncommon to the introductory stages. On occasion, "it just appeared with no 'warm-up' act, with no indication of a discernable seed – it suddenly stands at the zenith."[101] Although it may seem redundant to the reader at this point, another lengthy description by Bóbrik is imperative, simply because *auroral crowning events* have become a rarity in our skies since the early decades of the twentieth century:

> "Although the formation of a crown can usually be determined beforehand – indicated by the steady twitching and fast emergence of rays against the zenith, it occurs so suddenly, so vehemently with sheer supernatural power that one can hardly comprehend the individual phases of this phenomenon with the five senses alone. Everything rises, chases and falls to the zenith, in wild combat [with each other] the light masses push along and suddenly, as an emerging firework ball explodes, countless rays that shoot out in all directions, and emerging around the zenith going as far down as the horizon, bands/ribbons are lined up in rows, which radiate in luxuriant splendor and magnificent blazes of color, while the center has individual bright flashes of lightning streaking downwards towards the horizon. It seems as if the Almighty is allowing us to peer into the universe, and then, in its midst a new phenomenon emerges, which is a mysterious blackness, and *it seems as if a large eye is looking at us from an infinite distance*, but then within an instant it is covered with wallowing veils of light. The rays and bands/ribbons are now separating themselves, and *turning like a kaleidoscope*, and merging into flames licking greedily in all directions and then slowly dying out like whiffs of smoke from a candle."[102]

A more contemporary way to describe the awe-inspiring spectacle is that the universe manifests itself at the *Geospace* interface in all its naked quantum glory, flashing life forms on our planet the "full Monty." Or at the very least, the full "Monty Python's Flying Circus" replete with exploding trees, flying sheep, giant "Spiny Norman" hedgehogs, electric penguins, all with John Cleese uttering the words "and now for something completely different" between transitional phases. In defiance to the pulsating waves of *space plasma* careening against terrestrial magnetic field lines into the lower thermosphere (*ionospheric* Levels D, E, F1 – which contract and expand depending on solar activity), amongst the 743 auroras chronicled, only once was a "whistling" or *polarlichtgeräusch* [Northern Lights noise] heard briefly – for 1.5 minutes. Otherwise, the psychedelic light experience produced no audible sound.[103] The concentration of oppositely streaming electrons and ions (protons) onto the celestial vault precipitates *crown formation and dispersion* (ranging from a few seconds to over 20 minutes). Little wonder *crowning events* outperformed all other measured typologies with respect to light intensity, play of colors, and disturbance of the magnetometers.[104] Furthermore, a halo generated by the *coronal pyrotechnics* show was quite pronounced in both contemporary nineteenth century and more ancient depictions.

Kronen displayed a *smörgåsbord* of morphologies. Bóbrick prioritized three general subgroups: *Crown of Flames* (Fig. 30); *Crown of Bands/Ribbons* (Fig. 12); and *Crown of Rays* (Fig. 11). With the first two classifications it was difficult to gauge a center because the middle void was more oval-shaped and filled with a viscously flowing and flaming vaporous mass of light. A *Crown of Rays*, conversely, was concentrated around a smaller *dark*,

101 Bóbrick, *Preliminary Report*, vol. II, part IV: 7.

102 Bóbrick, *Preliminary Report*, vol. II, part IV: 7. Italics and brackets were added by the authors for emphasis and elucidation.

103 Bóbrick, *Preliminary Report*, vol. II, part IV: 209; No. 54, 10:55-56.5 p.m., 12:17 a.m., 84. Whether or not sound accompanies auroral events is a contentious subject. See Fiona Amery, "The Disputed Sound of the Aurora Borealis: Sensing Liminal Noise during the First and Second International Polar Years, 1882-3 and 1932-3," in *Notes and Research* 76.1 (20 March 2022): 5-26.

104 Bóbrick, *Preliminary Report*, vol. II, part IV: 203-204; No. 34, 3:56 p.m., 50.

circular iris. Divergent, crystalline rays rotated in either a clockwise or counterclockwise direction around its center, invoking the similarity to kaleidoscopic oscillation.[105] Nonetheless, a constellation of configurations is scattered throughout the journal entries and should not be eclipsed by the most frequently recorded shapes. The smaller "Half-Crown of Rays" [*strählenkranze* or *halben Krone*] appeared nesting (wreath-similar) on the top or bottom portion of bands and arches. In one instance, three appeared in a row simultaneously, and swiftly merged into a larger *Crown of Rays*.[106] A "Scallop Shell-like Crown" exhibited pleating and rotational behavior (see Fig. 13). There was also a "Tufted Crown of Rays," where each of the rays contained periodically spaced "tufts of lighted sheaves" along their longitudinal axis; and a "Translucent Crown of Rays" that appeared glass-like.[107] A nameless and perplexing form, catalogued vaguely as a "magnificent, extremely powerful phenomenon," we have dubbed the "Butterfly Crown" (see Fig. 14), which is actually two shuttlecock-similar *half-crowns* facing each other at the field-aligned current interface. The first *halben Krone* emerged on the surface of an upper "curtain-like band" at the magnetic zenith, after

Figure 11: Crown of Rays.

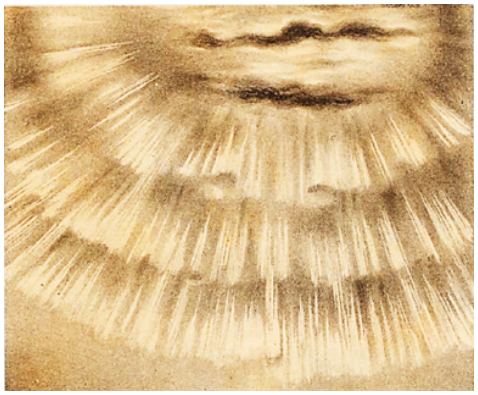
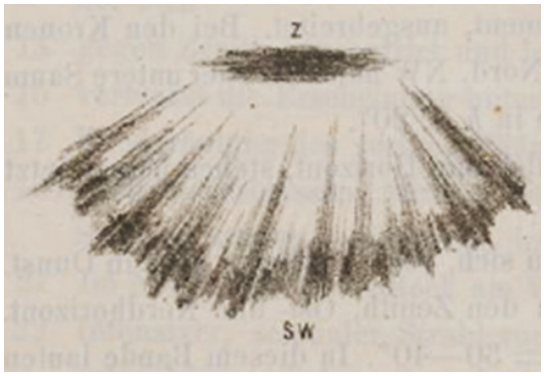
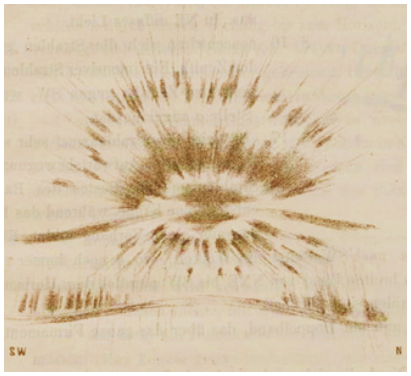


Figure 12: Crown of Bands/Ribbons.





Figures 13 & 14: (Left) – Pleated 'Scallop Shell-like Crown' with clockwise rotation; (Right) – 'Butterfly Crown' on band above a curtain-similar band.

105 Bóbrick, *Preliminary Report*, vol. II, part IV: 199-202; No. 33, 8:06-10 p.m., 47; Table X, XI.

106 Bóbrick, *Preliminary Report*, vol. II, part IV: 7; No. 51, 2:26-41 a.m., 79-80; No. 56, 10:26-34 p.m., 88. It is noteworthy that the German word *strählen kranz* translates as [wreath of rays], considering that the reed or straw-like appearance of rays, when spinning, resembled a wreath of sticks, reeds, or wheat stalks that Europeans and their descendants in the Americas hang on front doors or over fireplace mantles during holiday seasons. For a detailed description of the form with hay straw texture, see No. 9, 3:11 a.m., 25, and Fig. 6 on the same page.

107 Bóbrick, *Preliminary Report*, vol. II, part IV: Scallop Shell (Fan-like, or Pleated Skirt) No. 104, 9:42-9:56 p.m., 168; Tufted No. 59, 6:57-7:06 p.m., 96; Translucent No. 96, 4:17-20 a.m., 156.

a second curtain with more defined ray structure detached from it below. The latter band immediately shot rays to the band above, forming a "ringlet" attached to it that morphed into a smaller *half-crown*. Both cone-similar forms were a *bright crimson color*, with nearly a complete spectrum of hues visible on the rays.[108]

A "Swirling (Spiral-shaped) Crown" is best described as a double spiral: as if two snakes' heads swirled around a pivot while the undulating bodies self-oriented in opposite directions (see Fig. 63). Rays emerged above and below the swirl, looking like a spinning eye with lashes.[109] Rotary motion was a hallmark of the "Whirlpool/Swastika-Shaped Crown" composed of four broad ribbons connected around a central point. The entire "whirlpool-like bale" flowed quickly to the zenith, "forming a beautiful crown with bright light and color refracting rays."[110] In addition to the *Concentric Circle Crown* (seen previously in Fig. 7) was the "Wagon Wheel Crown;" a round exterior band connected by spoke-like rays to a small, darkened central "hub."[111] The "Cloak-like Crown" appeared above the 'head' of a *corona*, as if it were wearing a cloak with hood. At times, the threads appeared ripped and torn in places.[112] An interesting morphology was the "Tongue-shaped Crown," with rays on the outer perimeter and a line which divided the *corona* in half lengthwise. One particularly violent 'solar lick' drove the Theodolite's *horizontal intensity* reading to 1180 C.G.S., and elicited a journal entry for 13 November 1882, "the disturbance of the magnetic elements during these phenomena [same "Tongue-shaped Crown" 2x in succession] was one of the greatest ever observed."[113] *Farbenspiele* [play of colors] and frantic light movement normally accompanied magnetic needle disturbances on various forms, just prior to and during a crowning crescendo.[114] To round out the list, a "Colorless Corona" was also reported, but barely moved the Theodolite device's needles.[115] Recently in Alaska (2017-2020), seismometers began acting like magnetometers in reaction to the Northern Lights. Needles were disturbed more by *green colored auroras* than those with reddish or bluish tints.[116]

Two other typologies are unique for the reason they were hybrid or described but not drawn in the auroral journal. The first was identified as a *Truncated Cone with Rays* sketched as a dark cone, layered with concentric valleys and ridges protruding downwards (see Figure 17a). It was described as: "a mass of light rotating in a vortex, around which the lateral surface of a truncated cone forms itself from the rays. The rays are in several rows… and appear in a consistent flickering-like flame, which are shooting about in the center." Outer edges of the rays were red and inner circular belt green-colored.[117] Juxtaposed to it (Figure 17b) is a computer-generated image of electron density states in *circular quantum dots* (e.g., puddles of electrons) that self-organize into semi-conducting *Wigner crystal states analogous to complex plasma crystals*.[118] Precipitating electrons, as will be discussed later, are capable of infinite

108 Bóbrick, *Preliminary Report*, vol. II, part IV: No. 59, 7:26-7:50 p.m., 97, Figure 47.

109 Bóbrick, *Preliminary Report*, vol. II, part IV: No. 25, 9:02-05 p.m., 40; Table VIII, Fig. 1.

110 Bóbrick, *Preliminary Report*, vol. II, part IV: No. 60, 10:36-41 p.m., 106.

111 Bóbrick, *Preliminary Report*, vol. II, part IV: No. 32, 10:11-14 p.m., 44.

112 Bóbrick, *Preliminary Report*, vol. II, part IV: No. 98, 3:16-28 a.m., 162.

113 Bóbrick, *Preliminary Report*, vol. II, part IV: No. 34, 3:46-3:57 p.m., 49-50.

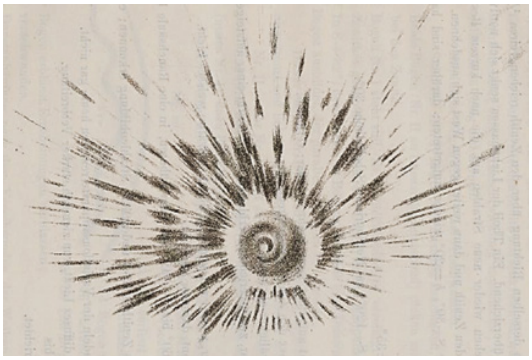
114 Bóbrick, *Preliminary Report*, vol. II, part IV: No. 35, 12:14-28 a.m., 54. The spectrum noted during this "play of colors" was green and red for ribbons at 12:14; and violet, intense red, green, and yellow in the corona at 12:28.

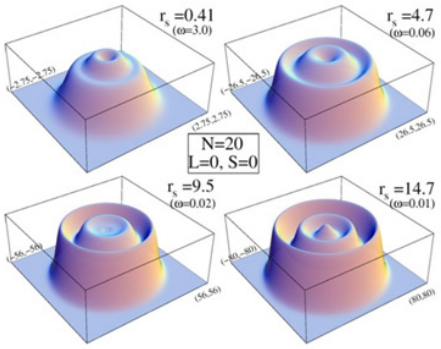
115 Bóbrick, *Preliminary Report*, vol. II, part IV: No. 57, 10:35-36 p.m., 92.

116 J. H. Chong, "Seismic Sensors on the Ground Record Auroras in the Sky," *Temblor.net* (26 August 2020), http://doi.org/10.32858/temblor.114. See A. T. Ringler, R. E. Anthony, D. C. Wilson, A. C. Claycomb, and J. Spritzer (2020). Magnetic Field Variations in Alaska: Recording Space Weather Events on Seismic Stations in Alaska, *Bulletin of the Seismological Society of America* XX, 1-11, http://doi.org/10.1785/0120200019; and C. Tape, A. T. Ringler, and D. L. Hampton (2020). Recording the Aurora at Seismometers across Alaska, *Seismological Research Letters* XX, 1-15, http://doi.org/10/1785/0220200161.

117 Bóbrick, *Preliminary Report*, vol. II, part IV: No. 50, 8:56-9:28 p.m., 75, Fig. 38.

118 Harold U. Baranger, Duke University, "Interactions in Quantum Dots: Kondo and Wigner Crystal – Correlation: caused by electron-electron interaction", SlidePlayer: 1-35, https://slideplayer.com/slide/9370430/. The image used





Figures 17a, b: (Left) – '*Truncated Cone with Rays'* or 'Spiny Norman Hedgehog'; (Right) – Local density of states in a spinning pool of electrons (a *quantum dot*) that manifests fermionic quasi-solid phase state in Wigner crystals.

Figure 18a, b: (Left) – Large '*Net-like Crown*' portrayed in Australian Aboriginal rock art, Freshwater Cove, Australia; (Right) – The *Wandjina* called *Namarali* from Linggi Inlet, Western Australia.

configurations under the influence of dynamic magnetic fields.

Figure 18a is a photograph of Australian Aboriginal rock shelter art that matches the descriptions best for a *Net-like Crown* observed at the magnetic zenith over Jan Mayen Island expedition. Once the crown had formed, "rays and threads are spread out like a net, from the zenith across the entire firmament."[119] Located at Cyclone Cave near Freshwater Cove in Kimberley and painted on the ceiling above, rock art provides a stellar example of how humans have recorded auroral shapes globally throughout the ages.[120] The Cyclone Cave artifact resembles anthropomorphs known as "*Wandjina*" figures painted by the Aboriginal people in various parts of Australia. Dating back some 4000 years, they graphically represent totemic ancestral spirits associated with storms, rain, water, fire, and lightning.[121] Figure 18b is a painted ancient deity called *Namarali* at Langgi Inlet Cave in Western Australia. Identified as a "Sea *Wandjina*," painted *Namarali* and *Kaira* representations of Aboriginal ancestors are unique in the genre for the net-like or spider-web halo surrounding their heads.[122]

On several occasions, a floral analogy was employed to describe with words forms projected onto the celestial vault. Austrian observers at times witnessed a *calyx* emerge from the side of an auroral band that behaved as the main stalk. In one case, a haze streak divided lengthwise into four parallel bands, three of which fanned out downwards

in Figure 17b is on page 8 of the presentation, with the heading "Density of Electrons: *n(r)*" with "3 rings as in the classical limit" and "rotational symmetry – sharp rings form! – dot is bigger for larger r_s."

119 Bóbrick, *Preliminary Report*, vol. II, part IV: No. 104, 7:54-8:10 p.m., 104.

120 Kimberley Foundation Australia, "Extraordinary momentum gathers around Australia's rock art heritage," in *Newsletter May 2015*, https://rockartaustralia.org.au/wp-content/uploads/s0s0s/10/KIM050_May_Newsletter_A4_WEB.pdf. Photograph for Figure 17a by Colin Murty.

121 David Wroth and Peter Veth, "Kimberley Art Rock Overview," https://japingkaaboriginalart.com/articles/kimberley-rock-art-overview/.

122 I. M. Crawford, *The Art of the Wandjina: Aboriginal Cave Paintings in Kimberley, Western Australia* (Melbourne: Oxford University Press, 1968), 54-80. Figure 18b from page 58, Plate 40 "The Wandjina Namarali at Langgi."

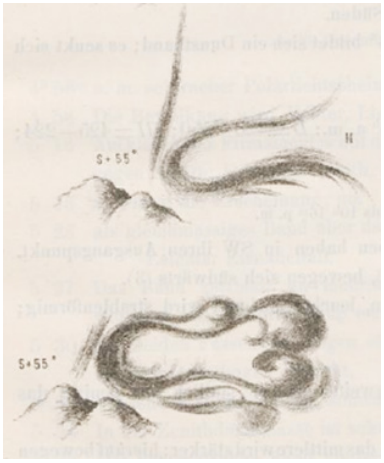


Fig. 19: (left) Calyx and Lily Flower (a.k.a. "arabesque").

Fig. 20: (right) Rotating beam or compass needle.

to the right of the main stalk, assuming a "lily-shaped" configuration: "the calyx closes and unfurls with lively movement of light" (see Fig. 19).[123] A second journal entry described four bands, three of which stood vertically with "lily flowers" emerging from their tips; while a fourth band transformed into a large palm branch.[124]

During the single longest period of *polarlichter* observation (over 16 hours) on 15-16 December 1882, the team witnessed virtually every configuration of auroras mentioned thus far. Focusing on a sliver of that observation period, a *Crown of Rays* formed and dissolved within the span of three minutes:

"It must not be omitted to record the actual perception that at this collision of the light masses, a short ray [beam] in the center arose, extremely luminous, of 5.5° longitude and 0.5° latitude, tapered at both ends, which lies in the sense of the arrows in the sketch (Fig. 20); turned around its entire length. When the ray was rotating, the longitudinal dimension decreased, and suddenly it was encircled by a haze mass at S-120° which spread to S+60°. It cannot be specified how many rotations of the ray occurred during this whole time. It completed a one-quarter turn in less than one second, while its length was being reduced. We compare the process with the rotating movement of a wooden rod caught in a whirlpool. Since the rotating beam was more luminous and different from the surrounding haze mass of light, it made the impression on our observers of being in closer proximity; it then dissolved away [oriented] at its east-west position."[125]

In other words, the beam behaved like a compass needle affected by the following causes: an external magnetic field in motion; the presence of a vertical magnetic field line; or the flow of an electrical direct (DC) current – all of which were present in the highly charged solar particles merrily dancing on the vaulted ceiling over Jan Mayen Island.

Before transitioning to a comparison between *complex space plasma flows* and auroral forms, one final facet of *crown dynamics* requires elaboration. Namely, the propensity for coronas to duplicate (the record was six times in five minutes) the exact same phase transitions from nebulous ionized vapor through *coronal crystallization*. Evident self-seeding behavior strongly suggests that memory of the process for various morphologies was stored in the auroral haze and its magnetoelectric alchemy, triggering a repeat performance from beginning to end until energy levels dropped below a certain threshold. Bóbrik equated the phenomenon with a mythical creature: "just like the phoenix, the original crown shape of the aurora borealis reappears."[126] One journal entry, for instance, mentioned how a *Crown of Rays* "will appear three times in quick succession, brighter and [then each subsequently] fainter, showing color play and rotation of the rays with the pointer of the clock," all within the span of two minutes![127] Not every repeat performance was of short duration – the *plurality of crowning events* reoccurred within the span of

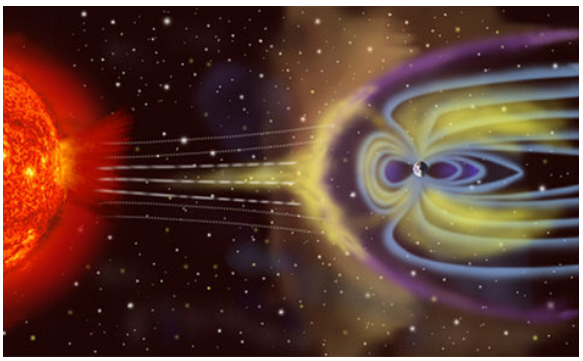
123 Bóbrick, *Preliminary Report*, vol. II, part IV: No. 51, 10:11-10.26, 78-79, Fig. 40.

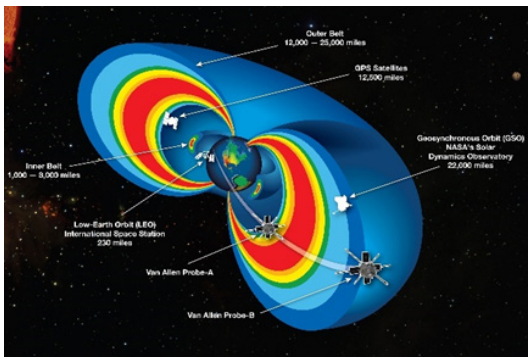
124 Bóbrick, *Preliminary Report*, vol. II, part IV: No. 56, 5:31-6:06 p.m., 87.

125 Bóbrick, *Preliminary Report*, vol. II, part IV: No. 60, 11:25-28 p.m., 107, Fig. 53.

126 Bóbrick, *Preliminary Report*, vol. II, part IV: 7. The "succession of six crowns in the span of 5 minutes" quote is from the same paragraph. The actual observation is No. 104, 8:03-08 p.m., 168.

127 Bóbrick, *Preliminary Report*, vol. II, part IV: No. 104, 8:36-38 p.m., 168.





Figures 21 & 22: (Left) – Earth's magnetospheric bubble and geomagnetic field lines energized by an extreme space weather event; (Right) – Van Allen Belts and position of satellites, probes, and ISS measurements.

10-15 minutes, more or less.[128]

Chaos Theory and Cosmic Plasma: Fractals, Scale Invariance and Self-Similarity in the Presence of Magnetic, Electric, and Gravitational Fields

Big History and *Chaos theory* are as entangled as the menagerie of auroral forms described in the Jan Mayen Island journal. In *Maps of Time: An Introduction to Big History* (2004), David Christian described how unpredictability in quantum physics (i.e., Heisenberg Uncertainty Principle) from the smallest subatomic quasi-particle to the formation of biological organisms with increasing complexity "is often described as *chaos*, because chaos theory has shown that billions of tiny uncertainties can accumulate through long chains of causation until, in the large-scale world that humans occupy, they create considerable large-scale unpredictability."[129] Patterns of complexity occur at various scales as the universal pendulum swings between cycles of calm predictability and jarring randomness.

Our research orbit, so to speak, revolves around auroral morphologies created predominantly near or at *solar maximums* – a time when magnetic charge changes place at the poles and creates havoc on the sun's surface. Atoms and molecules in the Earth's upper atmosphere are bombarded by electrons, protons, alpha-particles, and heavier ions (C, Fe, Mg, N, Ne, O, Si, and S) ejected out of the *photosphere-chromosphere-corona* at velocities and concentrations higher than those carried by the solar winds.[130] During what astrophysicists have dubbed '*solar storms*' [e.g., *solar flares*, *coronal mass ejections* (CME), and *solar energetic particle events* (SEP)], highly-charged cosmic particles stream towards Earth (preceded by a shock wave) in the form of a giant magnetic cloud, which upon impact with the *bow shock* compresses and shrinks the *magnetosphere*. This monstrous cloud carries its own helical magnetic field that engulfs and electrifies the magnetosphere, a process that – in a hierarchy of intensities - alters the quasi-steady state of the magnetosphere from its *solar minimum default configuration* (see Fig. 21).[131] *Geomagnetic storms* are the product of violent particle collisions that literally illuminate the sky with auroral activity. This chain reaction, or '*cascade effect*' in *chaotic and nonlinear systems*, modifies the initial conditions of the magnetosphere's interior where the Van Allen radiation belts (highly energetic particles trapped within the Earth's magnetic field lines) are affected.

Van Allen radiation belts are also part of the *plasmasphere*, a donut- or torus-shaped zone of low energy particles (dense, neutral, or 'cold' plasma) just above the ionosphere that rotates more or less in synch (26-hour rotation) with planet Earth (Fig. 22).[132] Since their discovery in 1958, the prevailing theory was that two well-defined radiation

128 Bóbrick, *Preliminary Report*, vol. II, part IV: No. 59, 7:26-36 p.m., 97, & 8:39-56 p.m., 98.

129 David Christian, *Maps of Time: An Introduction to Big History* (Berkeley: University of California Press, 2004), 467-469, 505-511.

130 Space Radiation Analysis Group, Johnson Space Center, "What is Space Radiation?" https://srag.jsc.nasa.gov/spaceradiation/what/what.cfm.

131 John W. Freeman, *Storms in Space* (Cambridge: Cambridge University Press, 2001), 21-29; Figure 21 source – "File:Magnetosphere rendition.jpg", https://commons.wikimedia.org/wiki/File:Magnetosphere_rendition.jpg.

132 Source for Figure 22: "File:Van Allen Radiation Belt Model shown with 2 VA Probes.jpg", https://commons.

zones existed: an enormous, turbulent outer belt (electrons) and a petite, calmer inner belt (mostly protons/ions), both of which behaved similarly to confinement rings for a particle accelerator. It is the outer belt's contribution of "precipitating" electrons that create auroras in the polar cusps during active sunspot periods. Recent discoveries have added a few more layers to its complexity. An international team of scientists announced in 2011 that a "significant flux of anti-protons" exists between the inner and outer belts as a thin layer of *anti-matter*.[133] One year later (2012), NASA scientists were surprised by satellite data revealing that a *third outer radiation belt* had been midwifed by a solar prominence eruption. The anomalous third Van Allen ring remained approximately four weeks until obliterated by another strong particle pulse from the sun.[134] When solar-induced geomagnetic storms (or auroral substorms) occur, the neutral inner belt particles are energized and swell, heating the ionosphere and increasing friction (or drag) on objects in the upper atmosphere. A rather dramatic example of *ionospheric swelling* was the reentry and burnup of 40 low-Earth orbit Starlink satellites on 3 February 2022, following a rather weak *coronal mass ejection*.[135]

The *aurora borealis* and *aurora australis* are generated by collisions between highly charged solar particles, gases, and aerosols in the upper atmosphere, that in turn raise energy levels in oxygen, nitrogen, hydrogen and helium, which emit photons in the spectrum of color based upon their altitude and rate of vibration – "color tells us the voltage, the brightness tells us the current."[136] A pithy explanation of extremely complicated Sun-Earth dynamics is merely a fractional representation thereof. Variegated factors which come into play during *solar storms* – such as the *plasma sheet* and *magnetotail*, *Birkeland currents*, *auroral ovals* and *electrojets*, *flux transfer events* and *bursty bulk flows*, *dayside* and *nightside magnetic reconnection* – will be discussed intermittently in the text henceforth.

Mandelbrot and Fractals

Fractal geometry was an act of rebellion against Euclidian and Archimedean idealization of shapes that distorted the imperfections inherent in the universe. It's creator Benoit Mandelbrot wrote:

> "I coined *fractal* from the Latin adjective *fractus*. The corresponding Latin verb *frangere* means "to break:" to create irregular fragments. It is therefore sensible… that, in addition to "fragmented" (as in *fraction* or *refraction*), *fractus* should also mean "irregular," both meanings being preserved in *fragment*... I claim that many patterns of Nature are so irregular and fragmented, that, compared with *Euclid*… Nature exhibits not simply a higher degree but an altogether different level of complexity. The number of distinct scales of length of natural patterns is for all practical purposes infinite… I conceived and developed a new geometry of nature and implemented its use in a number of diverse fields. It describes many of the irregular and fragmented patterns around us, and leads to full-fledge theories, by identifying a family of shapes I call *fractals*. The most useful fractals involve *chance* and both their regularities and their irregularities are statistical. Also, the shapes described here tend to be *scaling*, implying that the degree of their irregularity, and or fragmentation is identical at all scales… Some fractal sets are curves or surfaces, others are disconnected "dusts," and yet others are so oddly shaped that there are no good terms for them in either the sciences or the arts."[137]

wikimedia.org/wiki/File:Van_Allen_Radiation_Belt_Model_shown_with_2_VA_Probes.jpg.

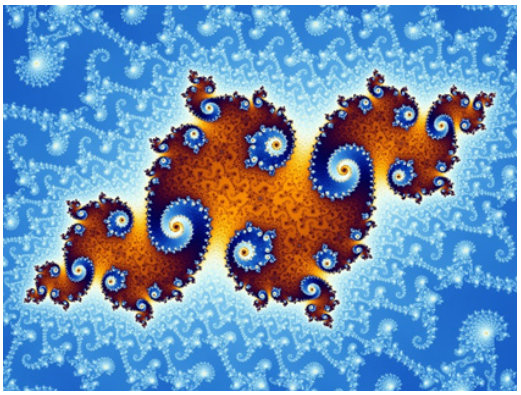
133 O. Adriani, G. C. Barbarino, G. A. Basilevskaya, *et al.*, "The Discovery of Geomagnetically Trapped Cosmic Ray Antiprotons" *The Astrophysical Journal Letters* 737.2 (27 July 2011): L29(1-5), https://iopscience.iop.org/article/10.1088/2041-8205/737/2/L29/pdf.

134 Karen C. Fox, "NASA Discovers a Third Van Allen Belt Surrounding Earth," *SciTechDaily* (1 March 2013), https://scitechdaily.com/nasa-discovers-a-third-van-allen-belt-surrounding-earth.

135 Robin George Andrews, "Solar Storm Destroys 40 New SpaceX Satellites in Orbit," *New York Times* (9 February 2022), https://www..nytimes.com/2022/02/09/science/spacex-satellites-storm.html.

136 Dirk Lummerzheim, "The Colors of the Aurora," *Alaska Park Science – Volume 8 Issue 1: Connections to Natural and Cultural Resource Studies in Alaska's National Parks*, https://www.nps.gove/articles/-articles-aps-v8-i1-c9.htm.

137 Benoit B. Mandelbrot, *The Fractal Geometry of Nature* (New York: W. H. Freeman & Co., 1983), 1-5. This quote



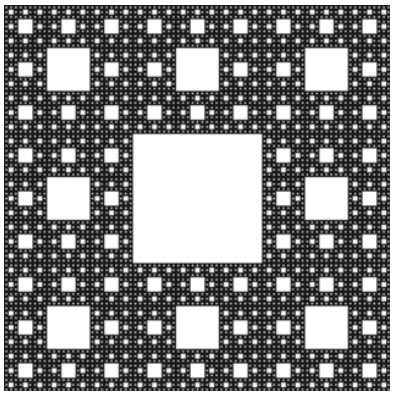


Figure 23: (left) Mandelbrot Double Spiral Medallion.

Figure 24: (right) Sierpinski square carpet.

Nature is resplendent with structures that are both regular and random. Regularity implies periodic or quasi-periodic arrangement such as a crystal lattice in solids; while randomness is disordered like a gaseous cloud or the number and location of dandelions that appear in one's yard each spring. Betwixt these binary bookends is the principle of self-similarity, where *Mandelbrot's fractals* reign supreme. *Fractals are scale invariant*, signifying that the smallest portions of a system look the same as the largest parts when magnified, or vice-versa when reduced in size.[138] *Mandelbrot sets* and *Sierpiński carpets* behave accordingly, creating the optical phenomenon of *infinite regression* (Figures 23 & 24).[139] *Cosmic plasma in auroras behaves in the same manner, which places it squarely in realm of nonlinearity, chaos, and complex dynamical systems*. In this section, we examine and compare the geometric topology or surface states of 'dusty' plasma manifested at the Earth/ionosphere/magnetosphere interface with laboratory experiments on Earth and near-Earth orbit. Plasma arches, eruptive flares, columns, rings, sigmoids, ribbons, concentric bands, cones, spirals, helixes, spheroids, clusters, crystalline lattice structures, and myriad formations documented by the Austrian 1882-83 Polar Expedition are *scale invariant*, and have *avatars* at the micro-, meso-, and macro-levels in the universe.

States of Matter: Cosmic Plasma as the Fourth State

Cosmic plasma, a term favored by Hannes Alfvén, is also known as *space, dusty, colloidal, complex, fine-particle, and aerosol plasma*.[140] *Cosmic plasma* in a broader sense means that it is an ionized gas – atoms stripped of their electrons that become *free electrons* under high temperature, exposure to ultraviolet light or X-rays (such as in Earth's ionosphere) leaving a mixture of positively charged ions, negatively charged electrons, and ENAs (energetically neutral atoms) that balance out and give it a more or less neutral signature.[141] Therefore, dusty ionized

is cobbled together from fractals in the Introduction – we hope Mandelbrot would have approved.

138 Lui Lam, ed., *Nonlinear Physics for Beginners: Fractals, Chaos, Solitons, Pattern Formation, Cellular Automata and Complex Systems* (Singapore: World Scientific Publishing Co., 1998), 11-15.

139 Figure 23 source: "Mandel Zoom 14 satellite julia island – File:Mandel zoom 11 satellite double spiral.jpg – Wikipedia", https://en.wikipedia.org/wiki/File:Mandel_zoom_11_satellite_double_spiral.jpg#/media/File:Mandel_zoom_14_satellite_julia_island.jpg; Figure 24 source: "File:Sierpinski carpet.png", https://commons.wikimedia.org/wiki/File:Sierpinski_carpet.png.

140 André Melzer, *The Physics of Dusty Plasmas: An Introduction* (Cham, Switzerland: Springer Nature, 2019), 1-4; A. M. Ignatov, "Basics of Dusty Plasma," in *Plasma Physics Reports* 31.1 (2005): 46-47; V. E. Fortov, A. V. Ivlev, S. A. Khrapak, A. G. Khrapak, and G.E. Morfill, "Complex (Dusty) Plasmas: Current Status, Open Issue, Perspectives," in *Physics Reports* 421 (2005): 3-6. See also Hannes Alfvén, *Cosmic Plasma* (Dordrecht, Holland: D. Reidel Publishing Company, 1981).

141 Pontus C. Brandt, Romina Nikoukar, et al., "Energetic Neutral Atom Imaging of the Terrestrial Global Magnetosphere," in Yaireska Colado-Vega, et al., eds., *Magnetospherical Imaging: Understanding the Space Environment through Global Measurements* (Amsterdam: Elsevier, 2021): 23-58.

gases exist in a state of *quasi-equilibrium* depending on their environmental parameters, and can carry a positive, negative, or neutral charge. Ions are predominantly hydrogen with a smattering of helium and other noble gases in outer space. Plasma conducts electricity and is strongly influenced by magnetic fields which confine it. In the celestial expanse, *cosmic plasma* is found in our sun, solar winds, magnetic clouds in interstellar space and our solar system's *Interplanetary Magnetic Field* (IMF); Earth's *magnetosphere, ionosphere, and auroras*; planetary rings, comet tails, galaxies, protoplanetary disk rings, accretion disks, and black holes, to name a few; while on the Earth it is seen as lightning, sprites, St. Elmo's Fire, fluorescent lights, arc welders, semi-conductors, topological insulators, various thermonuclear fusion devices, etc. *Perhaps the most salient aspect of cosmic plasma is that over 99% of all visible phenomena in the universe exists in a plasma state*.[142] In other words, without *cosmic plasma* we would not have the universe as we know it – or attempt to comprehend all of its complexity.

For the most part, ionized gas exists in a high state of disorder. When energetic particles in the ionosphere collide or are accelerated in magnetic fields, particle temperature rises and density increases. Low temperature plasma (weakly-ionized) to high temperature completely ionized gas (i.e., nuclear fusion) is referred to as *plasma beta*, wherein the symbol (β) represents the ratio between plasma pressure and magnetic pressure. *High beta plasma* ($\beta > 1$) is found in geomagnetic storms, auroras, near-Earth magnetotail, plasma sheet current, solar corona and winds, and myriad formations throughout the universe.[143] Another important index for *complex plasma* is *kappa* (Γ), a distribution that measures states outside of thermodynamic equilibrium (a state ionized gas never fully attains). When $\Gamma > 1$, it is said to be '*strongly coupled*' through electrostatic energy emanating from mutual interactions between dust grains, electrons, ions, and ENAs. *Kappa*, therefore, is a metric for when electrostatic potential exceeds the thermal energy of the dust.[144] The *kappa* coupling parameter is also a symbol for *self-organization* and *emergent properties* that result in complex atomic pattern formation.[145] There are many flavors of ionized plasma – hot and cold (or neutral) that range from 10^0 - 10^{10} degrees Kelvin, non-relativistic and relativistic, ideal and non-ideal, classical and degenerate plasmas.[146] In this research article, we are discussing *a multi-component ionized gas that displays collective behavior: a "complex" plasma that is non-relativistic and classical, but strongly-coupled*.

What makes this officially designated "Fourth State of Matter" a scaffolding for complexity in the universe? It contains solid (dust), quasi-crystalline (liquid crystalline/amorphous polymeric), or viscous liquid (aerosols) grains that carry a magnetic charge and have mass larger than ions, electrons, or neutrals. The grains vary in size from micrometer (μm) to nanometer (nm) scales (and occasionally millimeter size) with non-uniform shapes (spherical to irregular/non-spherical), porosity, and degrees of compactness that give *cosmic plasma fractal dimension* (see Fig. 25). In other words, dust behaves as a charged microparticle in a four-component plasma system. In the Earth's upper atmosphere, the random, non-uniform kernels or grain aggregates normally carry a slightly negative charge due to the influx of electrons onto its surface; while the positively charged ions form a *plasma sheath* or *shielding cloud* (a.k.a., *Debye* or *Langmuir sheath*) that envelops the dust/aerosol grain with a field

142 Melzer, *The Physics of Dusty Plasma*, 1; Max Planck Institute for Extraterrestrial Physics (henceforth MPE), "Plasma Crystal," Version 07/2012: 6, https://www.ph.tum.de/academics/org/labs/fopra/docs/userguide-03.en.pdf.

143 Ross Cohen, Andrew J. Gerrard, et al., "Climatology of High-β Plasma Measurements in Earth's Inner Magnetosphere," in *Journal of Geophysical Research: Space Physics* 122 (30 January 2017): 711-726, https://doi.org/10.1002/2016JA022513; Gerhard Haerendel, "Solar Auroras," *The Astrophysical Journal* 749 (20 April 2012): 166-179, https://doi.org/10.1088/0004-637X/749/2/166; G. Haerendel, W. Baumjohann, et al., "High-Beta Plasma Blobs in the Morningside Plasma Sheet," in *Annales Geophysique* 17 (1999): 1592-1601.

144 Donald A. Gurnett and Amitava Bhattacharjee, *Introduction to Plasma Physics: With Space, Laboratory and Astrophysical Applications*, Second Ed. (Cambridge: Cambridge University Press, 2017), 194-196; Fortov et al., "Complex (Dusty) Plasmas," 3; Melzer, *Physics of Dusty Plasma*, 4.

145 Edward Thomas, Jr., "Introduction to the Physics of Complex/Dusty Plasmas," (2015) Princeton Plasma Physics Laboratory, https://suli.pppl.gov/2015/course/PPPL_SULI_lecture_2015.pdf.

146 MPE, "Plasma Crystal," 6-8.

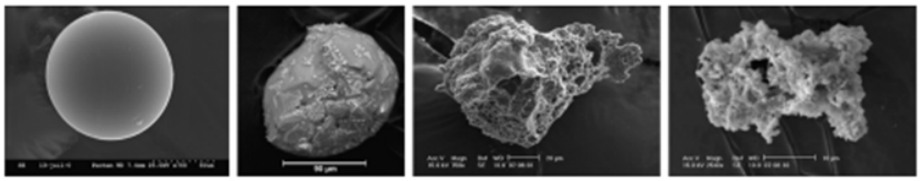


Figure 25: Micrometeorites (cosmic plasma dust) from Antarctica of various shapes and consistencies.

of electrostatic potential (a.k.a., *floating potential*).[147] *Exposed to magnetic and/or electrical fields, dust grains act like a capacitor and a compass needle, forming ordered structures that align in the direction of the magnetic field*. Particle charges dissipated on the dust enable electrostatic coupling between individual grains, inducing collective reactions such as the formation of orderly lattice structures in RF discharges, and standing striations in a DC field.[148]

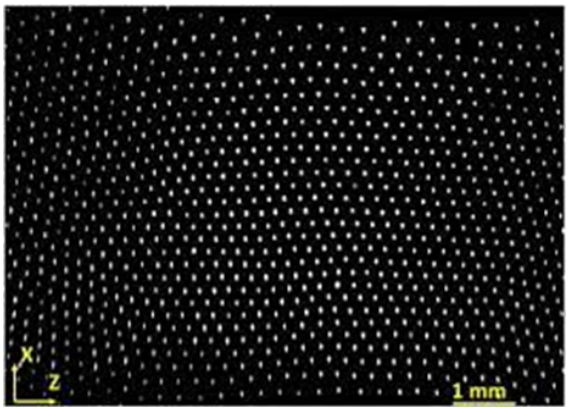
More significantly, *cosmic (dusty) plasma* exhibits complexity in phase (states of matter) transitions from *disordered gas* to *viscous liquid* to *plasma crystals* that are reversible. In order to form a *plasma crystal* (also known as *Wigner* or *Coulomb crystal*) the critical *kappa* value of $\Gamma \geq 100$ must be exceeded, otherwise it remains in various phases of liquid and gaseous states below $\Gamma < 100$. Crystal self-organization displays geometric phase transitions in RF or DC discharges (a flow of electric current through ionized gas driven by ions and electrons, and secondary electrons emitted by the cathode). A variety of experiments have been conducted on Earth and in orbit aboard MIR and the ISS under micro-gravity conditions.[149] In RF or DC plasma chambers, an electrical field generated above the lower electrode creates a *plasma sheath region*. After ignition of a quasi-neutral plasma, electrons rapidly stream towards the particles enhancing their surfaces with a strongly negative sign. All the plasma is confined between the upper anode and lower electrode, but the sheath region contains a static electric field generated by space charges. Negatively charged particle clouds in the sheath levitate horizontally above it against the force of gravity; but since the *Coulomb (Yukawa) potential* between (-) particles is repulsive, each particle separates from its nearest neighbor at periodic intervals based on the *Debye screening length*. The result is a 2-D monolayer triangular lattice with honeycomb or hexagonal cell shape symmetry. As more plasma enters the active zone, several horizontal layers equally spaced from each other form a 3-D network, which reveal body-centered cubic (BCC), face-centered cubic (FCC), and hexagonal close packed (HCP) floating 'solid' structures. Tri-layer crystal networks can also self-organize into triangular, square/rectangular, and rhombohedral geometries.[150] *In the crystalline state, all shapes* (akin to

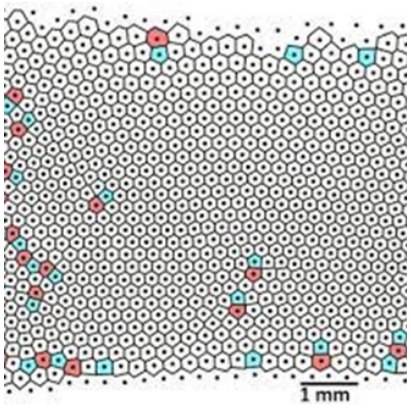
147 Melzer, *The Physics of Dusty Plasmas*, 1-4, 31-35; Anthony A. Peratt, *Physics of the Plasma Universe*, Second Ed. (New York: Springer Books, 2015), 1-2; Gurnett and Bhattacharjee, *Introduction to Plasma Physics*: 1-9; Fortov et al., Complex (Dusty) Plasmas: 3-25; J. Rojas et al., "The Micrometeorite Flux at Dome C (Antarctica), Monitoring the Accretion of Extraterrestrial Dust on Earth," *Earth and Planetary Science Letters* 560 (2021): 116794(1-10), https://www.sciencedirect.com/science/article/pii/S0012821X21000534. Figure 25 taken from page 4, Figure 2: "Fig.2. Cosmic spherules and unmelted micrometeorites from CONCORDIA collection (SEM images). From left to right: glassy cosmic spherule, stony cosmic spherule, partially melted (scoriaceous) micrometeorite, unmelted fine-grained micrometeorite."

148 Ignatov, "Basics of Dusty Plasma," 53-55; S. W. S. Apolinario, B. Partoens and F. M. Peeters, "Structural and Dynamical Aspects of Small Three-Dimensional Spherical Coulomb Clusters," in *New Journal of Physics* 9.283 (2007): 1-17; Fortov et al., "Complex (Dusty) Plasmas": 1-5, 79-90; V. Jatenco-Pereira, A. C.-L. Chian and N. Rubab, "Alfvén Waves in Space and Astrophysical Dusty Plasmas," in *Nonlinear Processes Geophysics* 21 (2014): 405-416.

149 MPE, "Plasma Crystal": 4-24; Gregor Morfill, Valdimir Fortov and Julia Zimmerman, "Plasma Crystals – From Space Research to Medicine on Earth and Back to Space Again," *Room: Space Journal of Asgardia, McGill University* 2.8 (2016): 1-6, https://room.eu.com/article/plasma-crystals-from-space-research-to-medicine-on-earth-and-back-to-space-again; J. T. Gudmundsson and A. Hecimovic, "Foundations of DC Plasma Sources," *Plasma Sources Sci. Technol.* 26.12 (8 November 2017):123001(1-21), https://doi.org/10.1088/1361-6595/aa940d. Experiments on MIR were designated PK-1 and PK-2; aboard the International Space Station three experiments conducted thus far were PKE Nefedov, PK3-plus and PK-4.

150 A. Abdikian and Zahida Ehsan, "Lattice Modes in a Dusty Plasma Crystal," https://arxiv.org/ftp/arxiv/





Figures 26 & 27: (Left) – 2-D Coulomb crystal in a DC Glow discharge, with hexagonal 'polka dot' pattern; (Right) – Voronoi diagram showing defects in the hexagonal crystal lattice with pentagons (blue) and heptagons (red) mixed in amongst the reticulated matrices.

order-order transitions in polymers and copolymers) *are minimum energy configurations* (see Figures 26 & 27).[151]

Another possible configuration during the initial coupling phase is when individual grains line up vertically as 1-D bundles called *filaments* or *chains* (which resemble a *string-of-pearls*) caused by ion focusing to the sheath region (see Fig. 79b). In several experiments, charged particles self-organized into systems that transitioned hierarchically from 1-D chains to 2-D zigzag and spindle-like formations, then into 3-D helical arrangements that exhibited triangular, quadrangular, pentagonal, hexagonal, and heptagonal symmetry through a chain folding mechanism.[152] *Double helical structures that exhibit DNA-similar memory marks while flowing along a hollow cylindrical (worm-like) crystal have been observed in DC discharges*. A pair of *toroidal dust vortices* (or *dust convection cells*) form outside of it and squeeze the cylinder's lateral face in between. The result is double helices with reverse handedness at the top and bottom halves of the cylinder, respectively. *The altered (bifurcated) helical crystal can then transfer that structural information to an adjacent non-bifurcated cylinder through the dust convection cells, which reproduce in the latter*. Authors of the study claimed that it was a novel form of *soft matter* displaying *autopoiesis*: "*It is included that complex, self-organized plasma structures exhibit all of the necessary properties to qualify them as candidates for inorganic living matter that may exist in space provided certain conditions allow them to evolve naturally*."[153] Additional studies on *nonequilibrium plasma systems revealed topological patterns such as dot chains, zigzags, single and collective*

papers/1310/1310.1592.pdf; Hubertus M. Thomas, "The Plasma Crystal," *American Journal of Physics* 73.5 (May 2005): 420-424; Melzer, *Physics of Dusty Plasmas,* 81-99; Enrique Maciá, Jean-Marie Dubois and Patricia Ann Thiel, "Quasicrystals," in *Ullman's Encyclopedia of Industrial Chemistry* (Weinheim: Wiley-VCH, 2008): 1-21, https://doi.org/10.1002/14356007.e22_e01.pub2; L. J. Bonales, J. E. F. Rubio, et al., "Freezing Transition and Interaction Potential in Monolayers of Microparticles at Fluid Interfaces," in *Langmuir* 27 (March 2011):3391-3400, https://doi.org/10.1021/1a104917e; Hong Pan, Gabor J. Kalman, et al., "Trilayer Dusty Plasma Lattice: Structure and Dynamics" *arXiv:1906.03195v1 [physics.plasm-ph]* (7 June 2019): 1-5, https://doi.org/10.48550/arXiv.1906.03195.

151 Source for Figures 26 & 27: S. Jaiswal and Ed Thomas, Jr., "Melting Transition of Two-Dimensional Complex Plasma Crystal in the DC Glow Discharge" *arXiv:2004.14609v1 [physics.plasm-ph]* (30 April 2020): 1-8, Fig. 2 & Fig. 3, https://arxiv.org/pdf/2004.14609.pdf. "Fig. 2. A snapshot of the coulomb crystal formed at pressure 14 pascal, and discharge voltage of 310 volt"; "Fig. 3. Voronoi diagram of the particle location at p = 14 pascal which is shown in Fig.2."

152 Truell W. Hyde, Jie Kong, Lorin S. Matthews, "Helical Structures in Vertically Aligned Dust Particle Chains in a Complex Plasma," in *Physical Review E* 87 053106 (16 May 2013), https://doi.org/10.1103/PhysRevE.87.053106;

153 V. N. Tsytovich, G. E. Morfill, V. E. Fortov, et al., "From Plasma Crystal and Helical Structures towards Inorganic *Living* Matter," in *New Journal of Physics 9* (14 August 2007) 263: 1-11, https://doi.org/10.1088/1367-2360/9/263. Italics added by the authors for emphasis.

columnar filaments, concentric circles, single and multiple spirals, radial lines, and combinations thereof.[154] To put it another way, depending on initial conditions, complex plasma can display all 'original' three states of matter, plus in-between, quasi-, or non-equilibrium states such as amorphous shapes, agglomerations, liquid crystals, and fluid-like hexatic networks.[155] It can melt, flare, flow, exhibit wave-like motions, crystallize, and disperse as vapor. It is the penultimate shape-shifting state of matter in the universe; hence, why it has so many names.

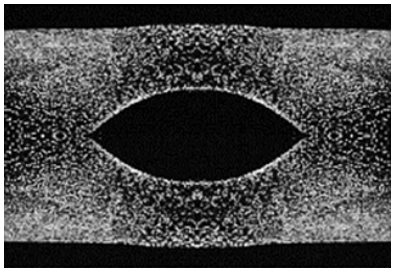
Experiments with Cosmic Plasma on Earth and under Microgravity Conditions in Orbit: Dust Voids, Striated DC Glow Discharges, Rotating Cones, Plasma Penumbra, Electrostatic Double Layers, Yukawa (Coulomb) Agglomerated Balls, and Late Medieval Spheres

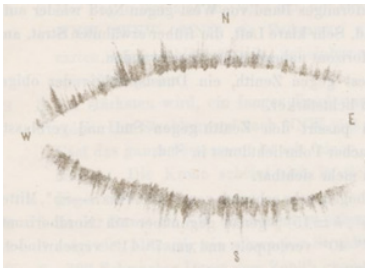
Dust Voids

Given the multiplicity of forms sketched and described in the Jan Mayen expedition journals, we will endeavor to explain the mechanics behind the dynamics for some of the processes that were observed in crowning events and dispersion. Six of the most compelling morphologies sketched by the Austrian team required *geometrodynamic* "backwards engineering" to understand the mechanics behind the complicated surface states. We start with an *instability* termed "*dust void formation*" that was observed aboard the International Space Station (ISS) in an RF chamber under microgravity conditions (see Figure 28).[156] In the center of a plasma cloud with low density at discharge, electrons rush in to fill the gap. A consequence of electronic *charging collisions* on dust grains is a higher electron density region in the cloud, creating a charge imbalance (overly negative). Ions are attracted to the zone, resulting in *electron impact ionization* – a higher concentration of positive charge (e.g., *ion hot spot*).

If particles are above a certain size threshold, the inward electrostatic potential binding the dust is exceeded by the outward ion drag force, which is kinetically resolved by the expulsion of more dust particles from the center and evolution of a *dust-free void* that expands outwards. At the boundary between the two contending forces, increased plasma density induces a *filamentation instability* with a sharply defined interface (finer particles are distributed closer to the void center than larger ones). It has also been reported that during the growth phase, the dust-free void contracts and expands via a *relaxation oscillation* called a "*heartbeat*." Following development and expansion, the *filamentary mode* saturates leading to a positively charged void surrounded by negatively charged plasma. The geometrical shape of the voids observed in plasma experiments tend to be spherical, oval, prolate, or elliptical.

Figures 28, 29, & 30: (Left) – Dust void with sharp boundary photographed aboard the ISS plasma experiments; (Middle) – Last phase of the *Crown of Flames* seen from Jan Mayen Island, with a *filamentation instability* jaggedly defining the movement of particles outwards from the center; (Right) – *Crown of Flames* sketched above Jan Mayen Island.





154 P. Bandyopadhyay, D. Sharma, U. Konopka, and G. Morfill, "Observation of Spatio-Temporal Pattern Formation in Magnetized RF Plasmas," arXiv:1604.05411v1 [physics.plasma-ph] (19 April 2016): 1-6, https://arxiv.org/pdf/1604.05411.pdf; S. Williams, S. Chakraborty Thakur, M. Menati et al., "Experimental Observations of Multiple Modes of Filamentary Structures in the Magnetized Dusty Plasma Experiment (MDPX) Device," in *Physics of Plasmas* 29 (20 January 2022), 012110: 1-10, https://doi.org/10.1063/5.0065516.

155 Bonales, Rubio, et al., "Freezing Transition and Interaction Potential in Monolayers of Microparticles at Fluid Interfaces": 3391-3400.

156 Source for Figure 28 – MPE "Plasma Crystal": 23-24, Fig. 2.17.

In sum, a precarious balance is achieved through *nonlinear effects*: a 'tug of war' between ion drag and electrostatic potential.[157]

Figure 29 is the final stage of a *Crown of Flames* (Fig. 30) prior to its inevitable disintegration into a *plasma dust cloud*.[158] The Austrian team observed this phenomenon on 29 October 1882, from ~6:17 – 6:40 p.m. A long, tricolored band (green on top, white in the middle, red on bottom) began its undulating ascent from the southern horizon towards the magnetic zenith. It wrapped around the zenith in an oval shape oriented to the east and west at 6:21 p.m., "in the center of which a crown appearance occurred." Bóbrick's journal entry described what happened for the ensuing four minutes: "The crown light phenomenon is best compared with ignited alcohol poured thinly on a surface influenced by the air currents on both sides (dancing of the flames), which make the flames lick towards west and east and then temporarily blow away. The middle field was divided irregularly into two parts moving in the easterly and westerly directions, at times uniting and then separating again. However, the whole field was in constant turbulence with lightning-fast movement, the coloring, especially of the edges of these licking flames, was pink to cherry-red and red-violet, occasionally we perceived an intensive white-yellow. The band and the cloak of rays all around, pushed towards the zenith or pushed away from it; that affected the midfield which then had enough room to blaze on one side or the other… After this effect the entire region where the apparition was occurring was doused in white auroral haze, resembling a torch, but was relatively stable at one location." [159] At 6:25 p.m. the apparition assumed the form of a *dust void* seen in Figure 29, and then slowly faded away by 6:40 p.m.

By virtue of *cosmic plasma's scale invariance*, self-similarity at meso-scale in auroral events is self-evident. The *Crown of Flames* witnessed by the Austrian team was an explosive tug-of-war between an outward ion drag and inward electron charging potential. Radiating elliptically from the magnetic zenith, four distinct phase states existed simultaneously: the dark dust-free central zone; the liquid flaming region; semi-crystalline long rays (a filamentation instability) sharply defining the interface; and the tempestuous enveloping plasma cloud. The Austrian science crew's description and sketches match the dynamical behavior of *dust void formation*, especially the '*heartbeat*' *relaxation oscillation*, and ultimately an *equilibrium dust void state*. What was visible to the human eye on the floating plasma sheet of the celestial vault with such fine detail, texture, and energetic diffusion may never be replicated in laboratory experiments. *Ceteris parabus*, this is what *condensed soft matter physics* looks like at the *solar-terrestrial interface* during *sunspot maximum-induced particle storms*.

Striated DC Glow Discharge and Auroral Beads

A second example concerns the striating behavior of *dusty plasma DC glow discharges* in a cathode ray tube. To reverse the order from the previous comparison, we begin with an illustration from the Austrian expedition narrated as "Band with short, wide rays (rods), which give the impression that they were lying in one and the same vertical plane" (Figure 31). This subform was officially designated as "Rods in the Band" [*Stäbchen im Bande*], a term "used to describe a ray texture that is perpendicular to the longitudinal direction of the band… which occurred less frequently [than the *Band of Rays* with narrower, diffuse rays], the rays were often wider and sharply separated by dark intervals, and their length was usually very short."[160] *Stäbchen im Bande* typology was observed in diverse auroral forms. Occasionally rods formed on the outer hem in a cloak - or the bottom fringe of a curtain - and then reunited in the shape of a blanket stitch in sewn garments, or took on the appearance of an architectural balustrade.[161]

157 J. Goree, G. E. Morfill, et al., "Theory of Dust Voids in Plasmas," in *Physical Review E* 59.6 (June 1999): 7055-7067, https://dx.doi.org/10.1103/PhysRevE.59.7055; MPE, "Plasma Crystal": 23-24; Melzer, *Physics of Dusty Plasmas*, 42-45, 166.

158 Source for Figure 29 – Bóbrick, *Preliminary Report*, vol. II, part IV: No. 25, 6:17-40 p.m., 38-39, Fig. 17.

159 Bóbrick, *Preliminary Report*, vol. II, part IV: No. 25, 6:17-40 p.m., 38-39, fig. 17; Table X, Fig. 2.

160 Bóbrick, *Preliminary Report*, vol. II, part IV: 5, Tafel III, Fig. 4. *Strahlenband* [Band of Rays]. Bracketed material added for clarification in citation.

161 Bóbrick, *Preliminary Report*, vol. II, part IV: No. 104, 3:26-27 a.m. & 4:03-4:14 a.m., 169-70; No. 109, 10:38-

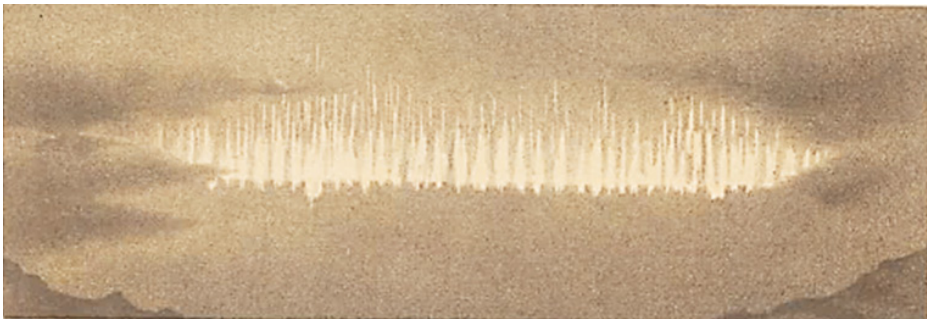


Figure 31: 'Rods in the Band' auroral subform.

Figure 32: Green aurora over Novy Urengoy, Russia, 2013-14.

Other times the rods emerged above the top surface of a luminous cloud bank, haze streaks, hazy or non-diffuse bands, which subsequently divided into widely spaced vertical rods that, in one journal entry, erupted (flared) at the uppermost tips.[162] Perhaps the most intriguing manifestation was on the *crown of an arch*, with alternating dark and light 'teeth' that resembled majestic arch crowns inside of the Cordoba mosque-cathedral in Spain.[163] In all documented cases, the light intensity of *Rods in the Band* was at the upper tier of the scale (3-4), and were compared by Bóbrick to *military medal ribbon bars* (long horizontal band with vertical stripes) that originated in the nineteenth century.[164] As a basis for comparison, the photograph of an aurora taken near Novy Urengoy, Russia, in 2013-14 appears below the Austrian sketch (Fig. 32).[165]

It is our consensus that these images and descriptions represent an auroral version of the *standing striations* that appear in the *positive column* of a *low-pressure DC glow discharge*, with alternating dark and bright (pillar-like) regions in molecular gases such as hydrogen, nitrogen, and oxygen (Figure 33).[166] *It is an instability triggered by ion waves*. High velocity striations occur in noble gases such as argon and xenon, however, and appear to the eye as a single, uniform glow.[167] The *positive column* is where quasi-neutral plasma maintains a conduction current between electrons and ions moving in opposite directions from the cathode

11:04 p.m. & 11:26-28 p.m., 176.

162 Bóbrick, *Preliminary Report*, vol. II, part IV: No. 42, 4:54-5:01 p.m. & 8:54-8:59 p.m., 67; No. 68, 6:56-7:02 p.m., 114; No. 104, 2:53-3:03 a.m., 169-170.

163 Bóbrick, *Preliminary Report*, vol. II, part IV: No. 25, 5:56-56 p.m. & 7:01-06 p.m., 38-39. This was also a foreshadowing apparition prior to the Crown of Flames/dust void phenomenon. For comparison with an arched argon glow discharge, see Zhu Hai-Long, Shi Yu-Jun et al., "Formation and Evolution of Striation Plasma in High-Pressure Argon Glow Discharge," in *Acta Physica Sinica* 71.14 (2022): 145201-09, https://doi.org/10.7498/aps.71.20212394.

164 Bóbrick, *Preliminary Report*, vol. II, part IV: No. 68, 9:34-41 p.m., 114.

165 "Unusual Aurora from New Urengoi, Russia," https://en.wikiversity.org/wiki/File:NorthernLightsUnusualNewUrengoiRussia.jpg.

166 Figure 33 source: *Gas Discharge Tubes*, http://www.g3ynh.info/disch_tube/Witenberg_gas_tubes.pdf.

167 V. A. Lisovskiy, V. A. Kovai, et al., "Validating the Goldstein-Wehner Law for the Stratified Positive Column of DC Discharge in an Undergraduate Laboratory," in *European Journal of Physics* 33 (6 September 2012), 1537-1545.

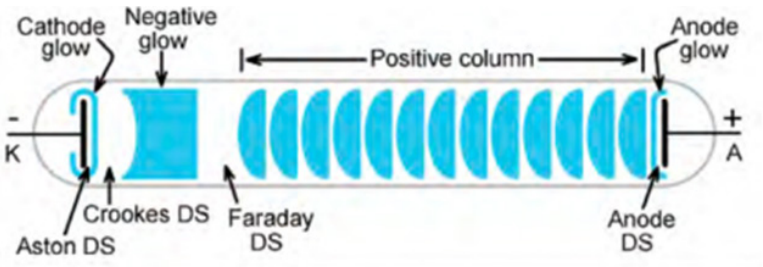


Figure 33: Cathode ray discharge tube diagram.

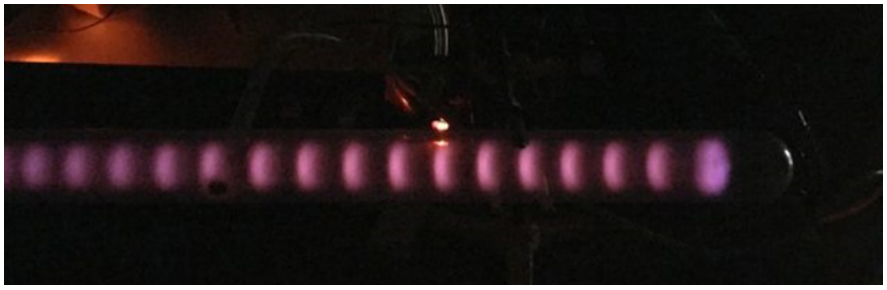


Figure 34: Positive column of a DC glow discharge.

and anode, respectively.[168] Luminosity of the *positive column* is a consequence of *electron impact ionization*, whereby electrons collide with neutral gas to create positive ions or ENAs. The concentration of electrons, their distribution, and electrical field are highly unequal along the length of striations. An alternating pattern of dark or bright striations perpendicular to the electrical current flow results from density fluctuations in ions and electrons that create vertical lines of equipotential charge deposited on the wall of the cathode ray tube. To put it another way, *bright striations are the result of ionized charged particle density similar to a standing wave*; while dark striations (which still glow – just not as brightly) occur from particle loss (less density) to the tube walls, attachment to gas molecules, and recombination (Figure 34).[169] Striations appear under low gas pressure and high DC voltage. The striations can appear ball-shaped, bowl- and saucer-shaped, parabolic, V-shaped, or tightly spaced flat vertical disks that resemble the "rods" described by the Austrian polar expedition. When external magnetic fields are applied to the glass tubes, it induces an extension of the positive column length towards the cathode.[170] Much like a cathode ray tube, *cosmic (dusty) plasma* flows through magnetic flux tubes on the sun and along Birkeland FAC that interact with geomagnetic field lines surrounding the Earth. During *solar maximums*, auroras can display the same type of behavior under certain conditions, but on a much larger scale than in the laboratory.

Recently (2020), data collected by NASA's THEMIS (Time History of Events and Macroscale Interactions during Substorms) mission has linked the appearance of *auroral* '*beads*' as foreshadowing the process(es) that lead(s) to *substorms* in the *near-Earth magnetosphere*.[171] A plasma '*bubble instability*' occurs when magnetic flux transported by FACs and the solar wind piles up in a turbulent, large 'bubble' behind Earth in the *plasma sheet* near the *magnetotail's X-line*. *When the oppositely aligned magnetic fields of the northern and southern magnetotail lobes reconnect, it drives high speed 'finger-like' plasma*

168 J. T. Gudmundsson and A. Hecimovic, "Foundations of DC Plasma Sources," in *Plasma Sources Science and Technology* 26.12 (8 November 2017): 123001-123021, https://doi.org/10.1088/1361-6595/aa940d; Loren Hamilton Jackson, "Plasma Striations in Vacuum Chambers" (2017). *Bard College, Senior Projects Spring 2017.* 349: 1-60, https://digitalcommons.bard.edu/senproj_s2017/349.

169 Source for Figure 34: http://physicsdemos.site.wesleyan.edu/home/em/5m/5m20-10-glow-discharge-tube/.

170 Gudmundsson and Hecimovic, "Foundations of DC Plasma Sources": 1230005-009; Jackson, "Plasma Striations in Vacuum Chambers": 3-4, 20-32, 46-47.

171 NASA's Goddard Space Flight Center, "Mystery of Auroral Beads Uncovered with NASA's THEMIS Spacecraft" *SciTechDaily.Com* (14 August 2020), https://scitechdaily.com/myster-of-auroral-beads-uncovered-with-masas-themis-spacecraft/; K. A. Sorathia, V. G. Merkin, E. V. Panov, *et al.*, "Ballooning-Interchange Instability in the Near-Earth Plasma Sheet and Auroral Beads: Global Magnetospheric Modeling and the Limit of the MHD Approximation" *Geophysical Research Letters* 47.14 (28 July 2020): 088227(1-10), https://doi.org/10.1029/2020GL088227.

flows back towards the Earth. Known as "*bursty bulk flows*" (BBF) when they occur, BBF "are responsible for half of the mass and energy transported and around 70-80% of the magnetic flux transported towards Earth."[172] It is analogous to *recycling magnetically reconnected flux back into the polar regions*, but with *explosive energetic pulses or bursts that generate polar substorms under active sun conditions*. *To put it in the language of Chaos theory*, *magnetic reconnection in the plasma sheet creates feedback loops that are signature features of nonlinearity in complex systems*. The team of scientists analyzing THEMIS spacecraft data has concluded that "[n]ow we know for certain that the formation of these beads is part of a process that precedes the triggering of a substorm in space."[173] Connecting *local auroral morphologies* with *macro-scale space weather phenomena* – as the THEMIS example illustrates – underscores the value of *geometrodynamics* as a heuristic tool to *decrypt enigmatic Geospace auroral patterns* in the past, present, and future.

Rotating Cones

The Austrian expedition chronicled an interesting phenomenon called a *kegel* [cone] that oscillated above them during several observation periods. A rotating cone was also reported by the contemporaneous Greeley expedition in Canada. On Jan Mayen Island, it was seen on four occasions between 12 November 1882 and 9 March 1883. The *Truncated Cone* morphology (Fig. 17) has already been discussed, in addition to the *Butterfly Crown* on 11 November 1882, at 7:28-7:40 p.m., that originally moved from the horizon and revolved around the zenith forming the "quasi-sides of a conical surface."[174] Seven days later, and one day after the 17 November 1882 Geomagnetic Storm, a horizontal band with bright red, green, and violet tinted rays began oscillating up and down. The eastern portion of the band began moving while vapors and rays increased at the zenith. It then spiraled up towards the zenith "forming the surface of a cone, falling and rising rapidly" while turning. The cone receded into a circular band shape, rotated around the zenith, and faded – all within the span of nine minutes.[175]

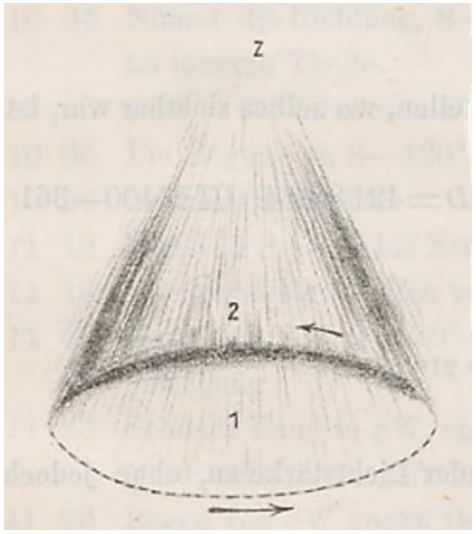


Figure 35: Rotating cone observed in the skies above Jan Mayen Island, 9 March 1893.

The final conical aurora seen in March 1893 was the most quantumly dynamic of all (Fig. 35). A bright beam appeared, from which two arches emerged on top of each other with veils (filamentary rays) pointed towards the zenith that turned to haze after seven minutes. The haze extended from ENE, over the zenith to SW, for three minutes. Unexpectedly: "[f]ine converging threads are formed, with a hem below, so that a conical surface arises which is clearly concave [*marked "1"*], it appears against [towards] the viewer. Then the threads turn around the apex [of the cone] in the zenith, the hem moving closer and closer to it, and finally the cone is convex there ["*2*" – meaning the "Spiny Norman" *Truncated Cone* topology]. After the hem has brightened and squirms a little, the hem moves south again concealed apparently for a few moments by the threads, which – after the hem begins to concave – reappear ["*1*" *again*]. They then completely disappear, and everything vaporizes into long, horizontal haze streaks lying SW – ENE."[176]

Interestingly, two days prior to the Austrian team's *kegel* observation, on 16 November 1882, Adolphus Greeley gave an account of the sundry auroral dynamics that

172 Erwin Walter, "Field-Aligned Currents and Flow Bursts in the Earth's Magnetotail," Bachelor Thesis, Umeå University, Sweden (7 June 2018): 1-38, http://www.diva-portal.org/smash/get/diva2:1214673/FULLTEXT01.pdf.

173 NASA, "Mystery of Auroral Beads Uncovered with NASA's THEMIS Spacecraft."

174 Bóbrick, *Preliminary Report*, vol. II, part IV: No. 33, 7:28-40, 47, Fig. 24.

175 Bóbrick, *Preliminary Report*, vol. II, part IV: No. 37, 8:48-8:57 p.m., 58.

176 Bóbrick, *Preliminary Report*, vol. II, part IV: No. 105, 10:52-11:09 p.m., 170. Fig. 68.

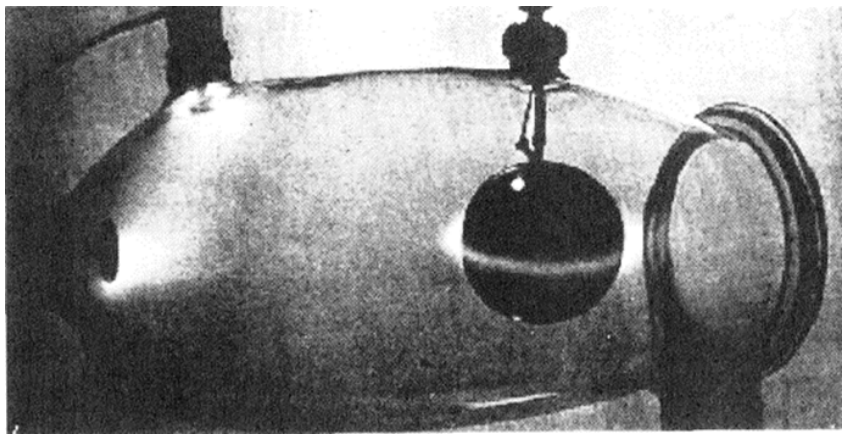


Figure 36: Glass tube, with cathode (left), anode (upper left), and magnetized *terella* (right). The concentration of cathode rays around the center was named "Equatorial Rings of Light" and were similar to Saturn's rings.

accompanied the "Great Magnetic Storm of November 15-19, 1882," as observed from Fort Conger. His journal entry read: "An auroral display which remained continuous during the greater part of the day. It first appeared in dim patches, in the northwest about 15º above the horizon, which gradually brightened and took the form of a *regular cone*, which lasted for five minutes or more, while from its well-defined summit ascended luminous auroral clouds with a whorling or curling motion. These clouds emanated apparently from the summit of the cone, in the form of sharply defined, spasmodic puffs, such as are seen at times issuing from the smoke-stack of a locomotive. The clouds thus thrown out immediately diffused and disappeared without assuming any marked formation."[177]

There are several possible explanations for what this cone-shaped aurora may represent in the *condensed matter physics of dusty plasma*. Kristian Birkeland, whose three grueling polar expeditions, pioneering scientific experiments, and theories regarding the connection between *aurorae* and sunspot activity, published a possible answer. Birkeland performed thousands of experiments with his cathode ray (simulated electrons emitted from the Sun) emitter on the *terella* [mini-Earth] device, a metallic sphere coated with phosphorescent paint with a dipole signature imitating the Earth's magnetic field (Figure 36).[178]

During one of the experiments, a phenomenon Birkeland termed "cones of light" radiated outward from polar rings on the *terella.* The three photographs below capture (Figure 37) how the "apex of these cones falls upon the terrella near either pole, and strange to say it does not greatly change its position during the rotation of the terrella." The Norwegian scientist remarked: "the cones of light seen in the figure appear to withdraw from the terella when the magnetization is increased, whereas the little ring of light still strikes the terrella… These cones are very interesting. They are similar to those that I first described in connection with the drawing-in of cathode rays towards a magnetic pole… which I expressed for the first time my belief that the northern lights are formed by corpuscular rays drawn in

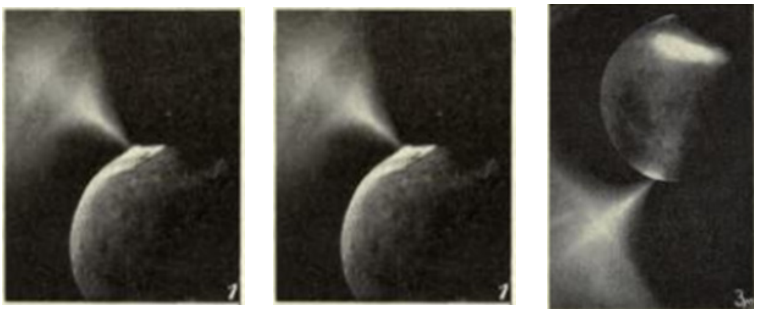


Figure 37: Three photographs of the "cones of light" captured by Birkeland on the *terella* device.

177 Greeley, *Three Years of Arctic Service*, Vol. 2, Appendix XIII, 410-11. Typos on page 410 read '1883' instead of '1882' for Greeley's journal entries, which becomes clear on pages 412-18 with the correct year printed.

178 Kristian R. Birkeland, *The Norwegian Aurora Polaris Expedition 1902-1903, Volume I* (Christiania, Norway: H. Aschehoug & Co., 1908), Part I, Chapter II, 80-81, Fig. 37. For a biography of his life and scientific career, see also Lucy Jago, *The Northern Lights* (New York: Vintage Books, 2002), 161-205, 268-81.

from space, and coming from the sun… In looking closely at [the photographs], we see that the drawn-in cone really consists of several envelopes; in the original photographs, as many as three cones with very different apical angles, are distinguishable… This is a very interesting phenomenon… *Poincaré* has made this drawing-in phenomenon the subject of mathematical investigation, and has demonstrated that the cathode rays move like geodetic lines upon certain cones with a common generatrix, so that each ray has its conjugate cone… It is certain indeed, that no theoretically clear understanding has yet been arrived at with regards to the formation of the cones of light shown in [the figures below] … It may possibly also be shown that the above-mentioned cones of light in space are formed by a maximal agglomeration of rays about certain surfaces, thus making the density of rays there so great that the rarified air in the tube becomes more luminous near these surfaces."[179]

Since the 1990s, studies on *cosmic plasma* have narrowed down several explanations for the rotating cones, but a single explanation is elusive. *Mach cones* generated during experiments with lasers have been used to excite supersonic large amplitude waves, which in 2D *complex plasmas* create wakes around a particle that organizes multiple cones behind the V-shaped front. The area behind the wake front is of lower particle density with plasma moving back towards the particle. Shear or transverse (a.k.a., dust lattice) wave fronts can create secondary, inner cones, which are determined by the dispersion and *non-linear properties* of particular wave modes excited behind the fronts.[180]

In 3D *cosmic plasmas* there are several wave modes capable of producing *mach cones*: dust acoustic (an ion-acoustic or electrostatic ion wave), dust magneto-acoustic, oscillonic (stable, localized oscillation), and shear dust-Alfvén.[181] In experiments performed aboard the ISS during PK-3 Plus, 3D *mach cones* were analyzed. Waves with weak damping produced multiple wake cones, the result of dust acoustic waves dispersing particles and creating forwards and backwards oscillations, while the cones themselves were composed of compressional waves. When friction was induced by adding neutral gas at high pressure, the damping effect limited the number of wake cones to single or double. Furthermore, *the plasma in the wake cones was in a semi-crystalline state, with a ratio of 54% liquid to 46% crystalline hexagonal cell structure, tipping its overall composition towards an amorphous 'solid'*.[182] Another possibility is that the *nonlinear structure* was an ionic cone produced by *oblique electrical double layers* discharged on the firmament, much like the sheath regions above electrodes in DC and RF plasma experiments. Ions accelerated across the layers created "electromagnetic tornadoes in space" at the auroral interface.[183]

A more theoretical, yet logical explanation would be a *particle* '*loss cone*.' As far as we know, these have never actually been seen by human eyes in a laboratory setting. Nevertheless, the descriptions provided above by nineteenth century polar expeditions, coupled with advances in quantum physics, makes this auroral enigma a strong candidate. Once charged particles enter the *magnetosphere* and flow towards Earth, they experience increasing magnetic field strength that pulls electrons and ions in different directions: a phenomenon known as '*E x B gradient drift*'. It causes particles with negative charge to flow around the dawn side of Earth and those

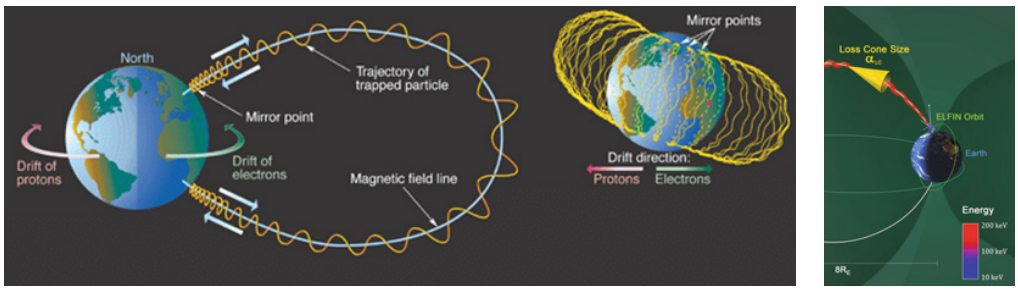
179 Birkeland, *The Norwegian Aurora Polaris Expedition 1902-1903,* Vol. I, Part I, Chapter III, 299-300, Fig. 135.

180 Fortov et al., "Complex (Dusty) Plasmas":50-51, 68-69; Melzer, *Physics of Dusty Plasmas*, 101-13, 127-31. There are three types of dust lattice waves: compressional, shear, and transverse.

181 A. A. Mamun and P. K. Shukla, "Mach Cones in Space and Laboratory Dusty Magnetoplasmas" in *Physica Scripta* 2005.T116: 42-62, https://doi.org.10.1238/Physica.Topical.116a00042.

182 K. Jiang, Vladimir Nosenko, Mierke Schwabe, et al., "Mach Cones in a Three-Dimensional Complex Plasma," in *Europhysics Letters* 85.4 (4 March 2009): 45002 (6 pages), https://doi.org.10.1209/0295-5075/85/45002.

183 J. E. Borovsky, "The Production of Ion Conics by Oblique Double Layers," *Journal of Geophysical Research* 89 (1 April 1984): 2251; J. E. Borovsky and Glenn Joyce, "The Direct Production of Ion Conics by Plasma Double Layers," in Tom Chang, M. C. Hudson, et al, ed., *Ion Acceleration in the Magnetosphere and Ionosphere* (Washington, D.C.: American Geophysical Union, 1986): 317-22; Tom Chang, G. B. Crew, et al., "Electromagnetic Tornadoes in Space: On Conics along Auroral Field Lines Generated by Lower Hybrid Waves and Electromagnetic Turbulence in the Ion Cyclotron Range of Frequencies" *Computer Physics Communications* 49.1 (April 1988): 61-74, https://doi.org/10.1016/0010-4655(88)90215-9.



Figures 38 & 39: (Left) – Magnetic Mirror Instability on Van Allen radiation belt closed field lines; (Right) – Illustration of electron loss cone overfilling as a result of oblique whistler wave mode-induced precipitation in the Earth's lower atmosphere.

of positive charge (ions/protons) to move towards the dusk side. Our planet's rotation also affects particles by accelerating electrons and slowing ions. These forces influence the *pitch angle* between velocity and gyration around a magnetic field. Because the Earth's magnetic field is dynamic (non-uniform), the closer a particle approaches the Earth it experiences disruption in the ratio of its parallel and perpendicular components (i.e., *pitch angle*). When the *pitch angle* attains 90º, it has reached what is called the *mirror point*. A solar particle (or stream of particles) then starts travelling along a magnetic field line until it hits another mirror point, and then 'bounces' back and forth trapped in the *magnetic mirror* instability (Fig. 38).[184] When the *mirror point* is deep within the Earth's atmosphere (~100 – 60 km), particles – especially electrons – will experience *pitch angle scattering* and eventually precipitate out of the particle trap through heating and ionization as auroral formations. There are two varieties of electron loss cones - '*drift loss cone*' (DLC) and '*bounce loss cone*' (BLC): DLC refers to electrons lost during one drift orbit; while BLC electrons dissipate locally in one bounce period.[185]

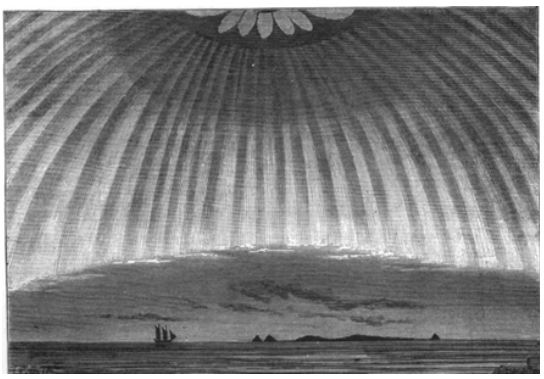
The cone drawn in Figure 39 is a theoretical construct wherein the trapped particle's *equatorial pitch angle* falls inside or outside the loss cone that lies perpendicular to the magnetic field line.[186] If a particle's *pitch angle* falls inside of the cone it will escape after a few bounce cycles; if its movement lies external to the cone it will remain trapped until acted upon by other physical processes (such as whistler and dual-band chorus waves) and scatter the particle back into its *loss cone*.[187] A recent study (2022) of whistler wave modes found that *oblique waves* cause "superfast" electron precipitation in the Earth's atmosphere by increasing flux and pitch angle scattering within the *loss cone*. Under these parameters, "[n]onlinear electron interactions with intense plasma waves" would drop precipitation levels down to ~75 km above the planetary surface! Theoretically, augmented energy released by

184 Image from John M. Huston, "Single Event Latchup in a Deep Submicron CMOS Technology" Ph.D. Dissertation, Vanderbilt University (December 2008): 7, Fig. 2.2, https://www.researchgate.net/publication/253215993.

185 Yuri Y. Shprits, Ingo Michaelis, Dedong Wang, *et al*., "MLT Dependence of Relativistic Electron Scattering into the Drift Loss Cone: Measurements From ELFIN-L on Board Lomonosov Spacecraft" *Geophysical Research Letters* 50.12 (June 2023): 103342(1-8), https://doi.org/10.1029/2023GL103342; M. A. Cliverd, C. J. Rodger, M. E. Anderson, *et al*., Linkages Between the Radiation Belts, Polar Atmosphere and Climate: Electron Precipitation Through Wave Particle Interactions" in Georgios Balasis, Ioannis A. Daglis, Ian R. Mann, ed., *Waves, Particles, and Storms in Geospace: A Complex Interplay* (Oxford: Oxford University Press, 2017): 354-376.

186 Image from Thomas Wiegelmann, "Space Plasma Physics – 5/3/2012": 5, https://www.mps.mpg.de/phd/space-plasma-physics.

187 Additional sources used to explain the magnetic mirror, loss cones, etc., see John Blears, "Determination of Average Loss Lifetimes for Near-Earth Electrons in Solar Storms" 2013, Undergraduate Thesis for Washington University in St. Louis, https://openscholarship.wustl.edu/undergrad_open/5; Goedbloed and Poedts, *Principles of Magnetohydrodynamics*, 41-48; Gurnett and Bhattacharjee, *Introduction to Plasma Physics*, 2nd Ed., 38-81, 413-422; Lysak, "Auroral Zone Plasma



Figures 40 & 41: (Left) – Lemström's "temple vault," 1868; (Right) – Hawthorne Valley, New York, 1837.

oblique whistler waves would not only make the *electron loss cones visible to the human eye*, but also heat the upper atmosphere and influence local climate conditions (i.e., *space weather*).[188] Therefore, considering the large number of particles ensnared by the Van Allen belts during *solar storms*, it is within the realm of possibility that the spinning cones seen above Jan Mayen Island and by the Greeley expedition were formed by relativistic particles trapped in a *magnetic mirror instability*. Whether the cones were ionic, electronic, or hybrid is a matter for the experts to debate.

Plasma Penumbra

Other formations not specifically identified as *kronen* by the Austrian expedition – but as "*crown-similar*;" or that manifested coronal behavior, merit inclusion as a *kronen* subgroup. 'Umbrella' [*regenschirm*] morphologies were associated with crowning events and oscillating rays around a central core. Occasionally, they occupied large quadrants of, or spread over the entire celestial vault.[189] In one journal entry, a *Crown of Rays* near the zenith assumed a *double regenshirm* morphology: "the light movement is fast, doubly gyrational (it resembles two umbrellas stacked on top of each other, the zenith is the pivot and one turns to the right and one towards the left)."[190] Although the Austrian expedition did not sketch this form, we have supplemented it with two contemporaneous nineteenth century illustrations. The first is from Finnish physicist Karl S. Lemström, who joined the Swedish expedition to Spitsbergen in 1868 (see Figure 40). The *umbrella* shape seen below encompassed the entire sky and was dome-shaped (less than half of the apparition was captured by the sketch). "Everywhere were flames, everywhere were jets of brilliant light, yellow below, green in the center, and reddish violet above. In an instant, all the rays united in a regular and dazzling crown, situated in the heavens to the south of the zenith. When the phenomenon reached the maximum of its intensity, it reminded us of the immense vault of a temple, with a brilliant chandelier in the center. The apparition lasted but a few minutes… The streams of light verging toward a common center were alternatively rose colored and pale yellow, and overlooked an immense violet zone. The rosette in the center was of a beautiful red, and stood out upon a greenish blue circle."[191]

Figure 41 was observed in the Hawthorne Valley, New York, U.S.A. Preceded by a *blood-red sky* (indicating a particularly *intense geomagnetic storm*), the Northern Lights were seen on the evening of 14 November 1837. It elicited the comment: "Years of observation, covering many centuries, and embracing all zones and latitudes, give no record of any display of auroral glories equal, in sublimity, magnificence, and extent, to the aurora borealis

Physics": 1-8.

188 Xiao-Jia Zhang, Anton Artemyev, Vassilius Angelopolous, *et al*., "Superfast Precipitation of Energetic Electrons in the Radiation Belts of Earth" *Nature Communications* 13 (March 2022):1611(1-8), Fig. 1, https://doi.org/10.1038/s41467-022-29291-8.

189 Bóbrick, *Preliminary Report*, vol. II, part IV: No. 33, 7:58-8:11 p.m., 47-48; No. 59, 8:39-8:54 p.m., 99.

190 Bóbrick, *Preliminary Report*, vol. II, part IV: No. 33, 8:06-10 p.m., 46-47.

191 "The Northern Lights," *Scientific American* 56.9 (26 February 1887): 135; Figure 1.

of November fourteenth, 1837."[192] Like the Greeley polar expedition mentioned previously, each generation expresses an exceptionalism to their auroral encounter as if it was unprecedented in appearance, or singularly unique in the annals of human history.

Notwithstanding this pattern, two nineteenth century artistic renderings above capture what we believe is evidence of a *complex plasma penumbra*, similar to what was created by polar explorer Kristian Birkeland's cathode ray *terrella* device (Figure 42).[193] To produce the *penumbra*, Birkeland had the metallic *terrella* act as the anode, with the metal sides of the box (top and bottom) as the cathodes: "a perfect firework-display of point discharges takes place, from the inner walls of the box. Not only were the points luminous, but long pencils of rays passed from the points (almost like a kind of lightning) into the globe." The kinetical behavior of Birkeland's *penumbra* formation was imitated in the 14 November 1837 *solar storm*, also seen from New York City for approximately 45 minutes. At nine p.m., "[t]he heavens were at this time wholly unclouded, with the exception of a single very small and faint cirrus high in the north-west. Innumerable bright arches shot up from the whole northern semi-circle of the horizon, and from even farther south, all converging to the zenith with great rapidity. Their upper extremities were of the most brilliant scarlet, while below they were exceedingly white. At the formation of the corona, the appearance of the columns below, which were very numerous and bright, resembled that of bright cotton of long fiber, drawn about at full length… For a time, therefore, *the earth was completely overarched by a perfect canopy of glory!* The southern columns, which seemed to proceed downward from the corona, rested on an arch of diffused light, extending in a great circle from east to west… All below the arch was of the strange darkness so usual at such times in the north."[194] The description of arches/columns (i.e., point charges) rising from a negatively charged circular, horizontal band (acting as the cathode), oriented perpendicular to the zenith (acting as the anode), are very similar to the mechanics documented in Birkeland's *terella* experiments.

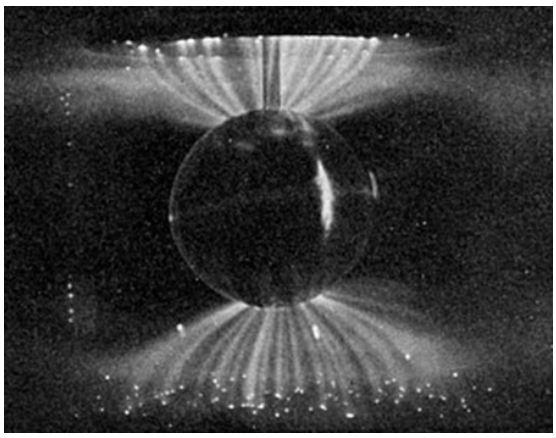


Figure 42: Birkeland's *terella* [mini-Earth] device.

Anthony Peratt, a former graduate student of Hannes Alfvén, has been working at Los Alamos since 1981. His research on DPF (*dense plasma focus*) and *Z-pinches*, also referred to as *Bennett* and '*screw pinches*,' are a radial magnetic field induced by an axial electrical current which compresses or pinches a plasma column/tube that heats and accelerates ions in thermonuclear fusion experiments. Peratt's extensive experimentation with the *filamentary properties* of DPF discharge currents and *various topological cosmic plasma states*, was published in the book *Physics of the Plasma Universe*.[195] His many research endeavors, including a global investigation of *ancient petroglyphs as externally stored memory of extreme space weather encounters by prehistoric humans*, have profound significance for this study.[196] Based on the topological states described in the Austrian auroral journals, it is our

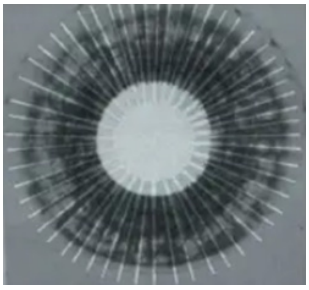
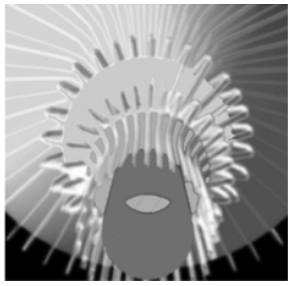
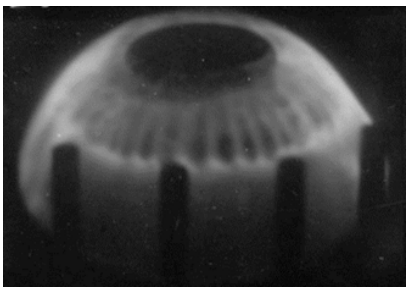
192 Richard Devons, *American Progress or, the Greatest Events of the Greatest Century* (Massachusetts: C. A. Nichols & Co., 1889), 269-75. Perceptions of the event were also noted for New York city and St. Louis, Missouri.

193 Birkeland, *The Norwegian Aurora Polaris Expedition 1902-1903,* Vol. II, Chap. IV, 674, Fig. 259.

194 Devons, *American Progress*, 270-272.

195 Anthony L. Peratt, *Physics of the Plasma Universe, 2nd Edition* (New York: Springer, 2015). The first edition was published in 1992. Professor Peratt has also worked at the Lawrence Livermore National Laboratory (1972-79), Max Planck Institute for Physics and Astrophysics (1975-77), United States Department of Energy (1995-99), among other prestigious positions.

196 See Anthony L. Peratt, "Characteristics for the Occurrence of a High-Current, Z-Pinch Aurora as Recorded in Antiquity," *IEEE Transactions on Plasma Science* 31.6 (December 2003): 1192-1214; A. L. Peratt, J. McGovern, et al.,

Figures 43, 44, & 45: (Left) – Plasma focus overlayed with 56 pairs of filaments to accentuate those in the original photograph; compare with Figure 11; (Middle) – Computer-generated image of the plasma Z-pinch auroral funnel, 'chalice' or penumbra, that looks like umbrellas stacked on top of each other; (Right) Milanese and Moroso's photograph of a DPF with "nearly 60 bright filaments periodically distributed in the current sheath." Notice the flower- or rosette-like pattern in plasma sheath's upper-half surrounding the annulus (torus), similar to that described by Lemström.

conclusion that the Crown of Rays, umbrella, bell-shaped jellyfish, and Net-like Crown subgroups seen above Jan Mayen Island were actual manifestations of dusty plasma penumbra or chalice structures discussed in Peratt's works (Figures 43, 44, & 45).[197]

Birkeland FAC connect the *magnetosphere* with the *ionosphere*, heat the Earth's upper atmosphere and increase friction – or drag – on objects in low orbit. The implications being that a field-aligned Birkeland current experienced a *Z-pinch instability* at some point along geomagnetic field lines, triggering a DPF. Ensuing geometric shapes discharged from the tube 'mouth' or torus possess a *parabolic current sheath profile (plasma focus)* – an *electrostatic double layer* – when projected onto the celestial vault. *Radial spoke-shaped filaments* (called *strahlen* or 'rays' by the Austrian expedition), normally numbering 56 individual or 56 paired filaments (112 total), *carry electrical currents to the plasma focus boundary*.[198] According to Peratt: "[t]he filamentary structures within the focus, rather than blending together, form a finite number of intense radial spokes ("spider legs"). These spokes appear to retain their identity throughout the acceleration phase and finally coalesce or focus on the axis beyond the end of the center electrode, forming a thin circular annulus."[199]

A more timely review (2021) of DPF research by an international consortium of 23 physicists linked experiments by Winston H. Bostick to the *Net-like Crown* in Figure 18: "Filaments are stable structures embedded within the plasma current sheath, running mostly perpendicular to the azimuthal background magnetic field, *but sometimes also in a spider-web fashion with azimuthal ribs connecting the radial spokes*."[200] The crisscrossing of radial spokes [*strahlen*] with orthogonally directed threads [*faden*] created the woven textile apparitions called a *cloak/robe/mantle of rays*; while the net-like (spider-web) configurations observed by the Austrian polar expedition match the *surface states of dense plasma focus discharges* during the 'breakdown' and 'acceleration' phases in laboratory experiments, respectively. In the latter stage, "a fine uniform layer that precedes the filamentary structured

"Characteristics for the Occurrence of a High-Current, Z-pinch Aurora as Recorded in Antiquity, Part II, Directionality and Source," *IEEE Transactions on Plasma Science* (August 2007): 778-807.

197 Figure 43, Peratt, *Physics of the Plasma Universe*, 348, Fig. 12.10; Figure 44, Peratt et al., "Characteristics for the Occurrence of a High-Current, Z-pinch Aurora as Recorded in Antiquity, Part II," 803, Fig. 68; María Magdelena Milanese and Roberto Luis Moroso, "The First Stages of the Discharge in a Low-Energy Dense Plasma Focus," *IEEE Transactions on Plasma Science* 33.5 (October 2005): 1660, Figure 4c.

198 Peratt, *Physics of the Plasma Universe*, 158-71, 341-58.

199 Peratt, *Physics of the Plasma Universe,* 160-161.

200 S. Auluck, Pavel Kubes, Marian Kubes, et al., "Update on the Scientific Status of the Plasma Focus" *Plasma* 4 (2021): 450-669, https://doi.org/10.3390/plasma4030033. The quote was from page 470; italics added by the authors for emphasis.

sheath," resembles the veil (*schleier*) shape described in the auroral journal.[201] The *plasma penumbra*, however, is only one morphology that *electrostatic double layers* project.

E . Neutral Current Sheets and Electric Double Layers in Various Auroral Topologies

De Broglie's 'wave-particle duality' is epitomized by *cosmic plasma* in auroral morphologies. Electromagnetic (Alfvén) waves accelerate electrons by resonantly transferring their energy along field lines as *wave Poynting flux* in the *magnetosphere* 25,000-38,000 km (~15,500-26,600 miles) above the polar caps before colliding with the *ionosphere* and generating *auroral light – a photonic wave form*.[202] Another type of wave created by *aurorae* are '*gravity waves*'. They are the primary driver of upper atmospheric circulation, which influences tropospheric weather and climate patterns at diverse temporal and spatial scales.[203] These are just a few examples of how *waves in different systems are coupled during space weather events*, in wave packets, chirped pulses, and sundry nonlinear modes. As was exemplified in the previous sub-section C, a plethora of wave-driven magnetic field fluctuations affect cosmic plasma behavior. For instance, the MKHI (Magnetic Kelvin-Helmholtz Instability), an MHD instability that generates vortices at the shear interface between two fluids, will be addressed later in sub-section H. The MRTI (Magneto Rayleigh-Taylor Instability) creates plume-, finger- or bead-like, and mushroom-shaped bubble instabilities; an MRI (Magneto-Rotational Instability) leads to accretion disks surrounding black holes, protoplanetary disks encircling young stars, and equatorial rings around planets like Saturn in our solar system. In laboratory experiments, the dense plasma focus experiences MRTI, alongside electron beam (i.e., magnetic flux tube) instabilities such as the 'sausage' and 'kink' modes, two-stream, Weibel, and filamentary – all from perpendicular magnetic fields induced by an axial DC current flow.[204]

Plasma double layers (DL) – or the *sheaths* mentioned in *sub-section D – can accelerate charged particles to relativistic speeds. It is a certain type of stationary, electrostatic nonlinear wave structure* "formed self-consistently with the particle populations that provide the charge density that supports the wave… The name is due to the fact that such a potential structure can be maintained by two layers of charge, one positive and one negative... It is thought by some that such a structure, or perhaps series of such structures, may be responsible for the particle acceleration in the auroral zone."[205] In layperson's terminology, *current sheets* are created by two regions of opposing magnetic fields that "act as magnetic batteries which store magnetic free energy that can be converted into

201 Milanese and Moroso, "The First Stages of the Discharge in a Low-Energy Dense Plasma Focus": 1660.

202 A. Kieling, J. R. Wygant, C. A. Cattell, *et al.*, "The Global Morphology of Wave Poynting Flux: Powering the Aurora" *Science* 299.5605 (17 January 2003): 383-386, https://doi.org/10.1126/science.1080073; J. W. R. Schroeder, G. G. Howes, C. A. Kletzing, *et al*., "Laboratory Measurements of the Physics of Auroral Electron Acceleration by Alfvén Waves" *Nature Communications* 12 (7 June 2021): 3031(1-9), https://doi.org/10.1038/s41467-021-2377-5.

203 Steven D. Miller, William C. Straka III, Jia Yue, *et al.*, "Upper Atmospheric Gravity Wave Details Revealed in Nightglow Satellite Imagery" *PNAS* 112.49 (16 November 2015): E6728-E6735, https://doi.org/10.1073/pnas.1508084112; S. Oyama and B. J. Watkins, "Generation of Atmospheric Gravity Waves in the Polar Thermosphere in Response to Auroral Activity" *Space Science Reviews* 168 (12 November 2012): 463-473, https://doi.org/10/1007/s11214-011-9847-z.

204 M. Modestov, V. Bychkov, *et al*., "Evolution of Magnetic Field Generated by the Kelvin-Helmholtz Instability" *Physics of Plasmas* 21.7 (31 July 2014): 072126(1-11), https://doi.org/10.1063/1.4891340; Jia Kun Dan, Qiang Xu, et al., "Particle Drift Model for Z-Pinch-driven Magneto-Rayleigh-Taylor Instability" *Physics of Plasmas* 23 (20 September 2016): 092707(1-7), https://doi.org/10.1063/1.4962522; Antoine Bret, Marie-Christine Firpo, Claude Deutsch, "Characterization of the *Initial* Filamentation of a *Relativistic* Electron Beam Passing through a Plasma" *Physical Review Letters* 94.11 (April 2005): 115002-006(1-4), https://doi.org/10.1103/PhysRevLett.94.115002; Ben Dudson, "Plasma Instabilities," MCF Lecture 10, https://www-users.york.ac.uk/~bd512/teaching/mcf_lecture_10.pdf.

205 Robert Lysak, "Auroral Zone Plasma Physics," (Autumn College on Plasma Physics 8 October – 2 November 2001, The Abdus Salam International Center for Theoretical Physics, SMR 1331/15): 8-12, https://indico.ictp.it/event/a01106/material/1/14.pdf.

other forms of energy."[206] Conceived from disequilibrium conditions, they gradually relax to a charge neutral or equilibrium state by stretching, twisting, kinking, heating, and pinching. Electrons move to one side, ions/protons to the other, flowing in opposite directions, with neutrals in between. Generally speaking, *DL waves thermalize ion outflow beams and transform beam kinetic energy to thermal energy*.[207]

There are two basic types of DL: "*weak* double layers with potential drops comparable to the voltage equivalent of the ambient electron thermal energy, and the *strong* double layers with potentials much greater than that."[208] Hannes Alfvén described how *cosmic plasmas* often produced *sheaths* due to an "almost discontinuous jump in voltage" between parallel electrical currents flowing in the same direction. In outer space, unidirectional current-carrying flux tubes tend to attract one another, resulting in braiding, twisting, and intertwining between N>1 structures; while currents moving in anti-parallel directions repel. In the auroral circuit, *Birkeland FAC transition from thicker cables to smaller diameter filaments to variously sized thin current sheets* – some with cross-sections (equipotential lines) – in auroral arches, curtains, draperies, fringes, and veils.[209] Multiple DL can also lie along a single flux cable or tube.[210]

Auroral inverted 'V' events in *polar upward acceleration regions* occur at the *interface between ionospheric cold, dense plasma and hot, diffuse magnetospheric plasma in the evening auroral zone*. The inverted 'V' describes the geometric shape of downward precipitating electrons at the bottom of the auroral acceleration region (cavity), although 'V' formations are less prevalent than solitary 'S' shaped potential structures. *At higher altitudes, mostly ions and some electrons are accelerated upwards through nested cavities of 'U'- shaped electrostatic potential structures, that topologically resemble elliptical (as seen in Fig. 7) or nested finger-like steps and sheet-like cross-sections*.[211] Alfvén explained there were "three different circuits for the transfer of solar wind kinetic energy to the magnetosphere: magnetosphere circuit; tail circuit; and solar wind auroral circuit – this circuit sustains the sunward plasma drift in the equatorial region of the magnetosphere. It produces discharges over the auroral regions, and power is dissipated as aurorae… In the region between the magnetopause and the tail sheet, the Sunward drift of magnetospheric plasma will again be basically unchanged… As soon as the currents to the auroral ionosphere exceed a certain value, double layers will be formed, *but only by currents going upwards from the ionosphere*. In double layers, an acceleration of charged particles will take place, and these are the cause of at least the more brilliant auroras."[212] If the sheaths experienced a sudden drop in voltage, they became unstable and could explode – resulting in *magnetic substorms*.[213] More recent studies using satellite data have confirmed Alfvén's views on the particle acceleration role

206 Young Dae Yoon, Deidre E. Wendel, and Gansu S. Yun, "Equilibrium Selection via Current Sheet Relaxation and Guide Field Amplification" *Nature Communications*14 (10 January 2023): 139(1-12), https://doi.org/10.1038/s41467-023-35821-9.

207 A. Runov, V. Angelopoulos, A. V. Artemyev, *et al*., "Global and Local Processes of Thin Current Sheet Formation during Substorm Growth Phase" *Journal of Atmospheric and Solar-Terrestrial Physics* 220 (1 September 2021): 105671(1-19), https://www.sciencedirect.com/science/article/pii/S1364682621001280.

208 Carl-Gunne Fälthammar, "Physics of the Aurora" (Invited Lecture at the Second Latin American Conference on Space Geophysics, Cuernavaca, Mexico, 8-11 July 1991), *Geofísica Internacional*, 30, 197-211, 1991, https://www.diva-portal.org/smash/record.jsf?pid=diva2%3A514309&dswid=6146.

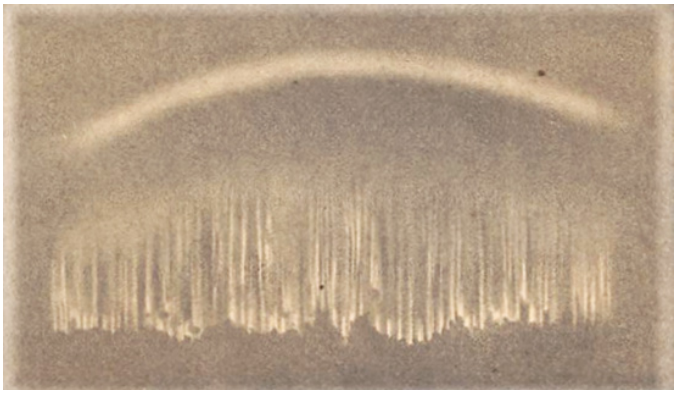
209 Alfvén, *Cosmic Plasma*, 13-36; "Filamentation," https://www.plasma-universe.com/filamentation/.

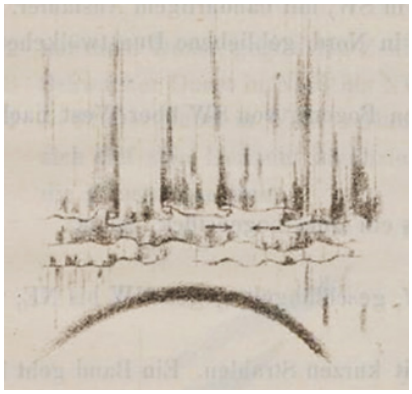
210 R. E. Ergun, L. Andersson, *et al*., "Auroral Particle Acceleration by Strong Double Layers: The Upward Current Region" *Journal of Geophysical Research* 109.A12220 (2004): 1-14, https://doi.org/10.1029/2004JA010545.

211 Ergun, Andersson, *et al.*, "Auroral Particle Acceleration by Strong Double Layers": 13, Gerhard Haerendel, "Auroral Arcs: The Fracture Theory Revisited" *Journal of Geophysical Research: Space Physics* 126.1 (January 2020): e2020JA028194(1-14), https://doi.org/10.1029/2020JA28194; Fälthammar, "Physics of the Aurora": 5-8.

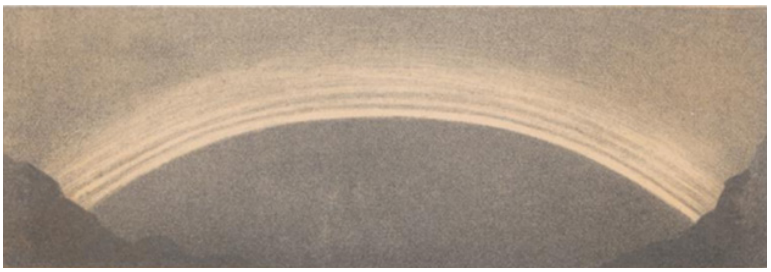
212 Alfvén, *Cosmic Plasma*, 65, 69. Italics added by the authors for emphasis.

213 Alfvén, *Cosmic Plasma*, 32-36.





Figures 46 & 47: (Left) – *Vorhang* [curtain] current sheet of precipitating electrons with vapor arch (Birkeland FAC) above it; (Right) – Three curtains with folds that emerged from the top of the arch below it. Two inward- pointing arrows on the middle sheath indicate where the contours resembled a cross-hatched "Chinese straw curtain." Vivid colors of red, green, and yellow-white. A *Crown of Rays* emerged 3x from this configuration over the span of 1.5 hours.



Figures 48 & 49: (Left) – Arch with DL electrostatic potential lines over Jan Mayen Island, 12 December 1882; (Right) – "Northern Lights Crown" lithograph from Guildford, England, 24 October 1870, featuring DL in 4-5 bands converging at the zenith, with a release of energy at the apex – a sign of magnetic reconnection.

of DL "ever since the realization that earthward accelerated electrons carrying upward currents cause visible auroral arcs."[214] Strong *oblique* DL in 'V' events appear at the boundary between the *auroral cavity-ionosphere* (closest to Earth); the *mid-auroral cavity* contains weak (ionic beam) DL; while the *higher altitude magnetosphere-auroral cavity transition zone* has a strong DL. The sheathed '*anomalous resistors*' accelerate electrons downwards from *magnetosphere-ionosphere coupling* and conversely accelerate (heat) ion beams anti-earthwards.[215]

Alfvén believed that *wherever in space there were regions of plasma with opposite magnetic signature, then DL, current/neutral sheets, and potential cavities/wells emerge as self-organized electrically conducting (permeable) membranes*; and that both interstellar and intergalactic space has a cellular geometric structure. The normally invisible cell walls produce heating, enable energy transfer, and create DL to accelerate particles. This interface is extremely dynamic and facilitates continuous energy flow throughout the universe. To quote Alfvén: "From the cosmological point of view, the most important new space research discovery is probably the cellular structure of space. As has been seen, in every region of space which is subject to *in situ* measurements, there are a number of 'cell walls', sheets of electric currents, which divide space into

214 Ergun, Andersson, *et al*., "Auroral Particle Acceleration by Strong Double Layers": 1; L. Andersson and R. E. Ergun, "The Search for Double Layers in Space Plasmas," in *Auroral Phenomenology and Magnetospheric Processes: Earth and Other Planets* (Oxford: Wiley-Blackwell, 2012): 241-49.

215 Ergun, Andersson, *et al*., "Auroral Particle Acceleration by Strong Double Layers": 1-13.

compartments with different magnetization, temperature, density, etc."[216]

The connection between arches, current sheets, and the aurora was catalogued by the Austrian polar expedition as *vorhang* [curtain], and *bordüre* [border] or *draperie* [drapery]. They were filamentary (rayed) current sheets of different length: borders and draperies were described as "resembling fringes of a hanging curtain" with shorter filaments running lengthwise along bands; while more pronounced and longer rays were "simply referred to as a curtain."[217] Figures 46 & 47 below are the more frequently viewed configurations of curtains with longer rays, including one with three layers.[218] *Multiple DL can also lie along a single flux cable or tube; or form atop one another as highly stratified current bands in a multiple arch array that is prevalent during a double auroral oval configuration*.[219] As a case in point, stratified DL in horizontal bands are evident in Figure 6 attached to an auroral arch. Above Jan Mayen Island, it was not uncommon for between 3-8 layers to emerge from a single arcade.[220] Figures 48 and 49 display the nested striations; the latter figure with coronal apex was seen over Guildford, England, on 24 October 1870.[221] *Crowning events are synonymous with multiple current sheets of bipolar and monopolar typology*.

DL accelerate energetic particles in a spiraling or helical motion, dissipating energy as synchrotron beam radiation in the form of X-rays, gamma rays, bright light, and RF waves. [222] The oft-reported serpentine, coiling, and helical motion witnessed in nineteenth century auroras was most likely the result of Birkeland FAC (i.e., DL) that emitted *synchrotron beams* visible in the auroral illustration (Figure 50), from Danzig on 17 March 1716.[223] When compared to the Jan Mayen Island 'barber pole' sketch in Fig. 5, one can see how DL accelerate particles at the solar-terrestrial interface. Bóbrick wrote: "In the case of the *bänder*, sometimes we also observed a different kind of light movement here and there, namely one spiraling around its central longitudinal axis, whereby the band assumed the appearance of a rotating screw with a steep incline."[224] Miscellaneous journal entries from the Austrian expedition describe a "spirally coiled haze band" ascending from arches and bands that match the dynamics in the Danzig auroral illustration.[225] Additionally, the Greeley expedition noted similar formations of a "spherical coil … twisted into the most inconceivable shapes" and a "revolving, endless screw" during November 1881 and 1882, respectively.[226] The similarity of written and sketched nineteenth century auroral observations to a 'corkscrew beam' produced by the Echo 7 sounding rocket experiment in 1990, is readily

216 Alfvén, *Cosmic Plasma*, 111, 126.

217 Bóbrick, *Preliminary Report*, vol. II, part IV: 5.

218 Bóbrick, *Preliminary Report*, vol. II, part IV: Tafel IV, Fig. 1; No. 60, 7:16-8:53 p.m., 103, Fig. 49.

219 M. Echin, M. Ciobanu, O Balan, *et al.*, "Multiple Current Sheets in a Double Auroral Oval Observed from the MAGION-2 and MAGION-3 Satellites" *Annales Geophysicae* 15.4 (30 April 1997): 412-423, https://doi.org/10/1007/s00585-997-0412-8.

220 Bóbrick, *Preliminary Report*, vol. II, part IV: No. 57, 3:12-6:19 p.m., 90, Tafel 2 Fig. 4. The caption for the figure reads "Arch with band-like stripes that run parallel to its border and are separated from one another by dark and semi-dark intervals."

221 The original source for Fig. 49 is *Meyers Großem Konversationslexikon (1885-90) 6th Ed.,* (Wein, Germany: Leipzig University Bibliographisches Institut, 1902-1908). Image downloaded from https://commons.wikimedia.org/wiki/File:Northern_lights_lithograph_partial.jpg. It was part of four lithographs on a single page titled "Nordlichter 1", with the caption: "3. Nordlichtkrone beobachtet von Capron zu Guildford in England, 24 Oktober 1870."

222 Alfvén, *Cosmic Plasma*, 36; Ergun, Andersson, *et al*., "Auroral Particle Acceleration by Strong Double Layers": 1-12; "Birkeland Current", https://www.plasma-universe.com/birkeland-current/.

223 Savage, *Aurora: The Mysterious Northern Lights*, 57, Fig. 9, No. 4-6.

224 Bóbrick, *Preliminary Report*, vol. II, part IV: 10.

225 Bóbrick, *Preliminary Report*, vol. II, part IV: 10, No. 51, 1:41-2:03 a.m., 79; No. 49, 3:57-4:03 p.m., 50; No. 37, 2:16-3:12 a.m., 59; No. 15, 9:26 p.m., 31.

226 Greeley, *Three Years of Arctic Service*, I: 158-159; II: 412-413.

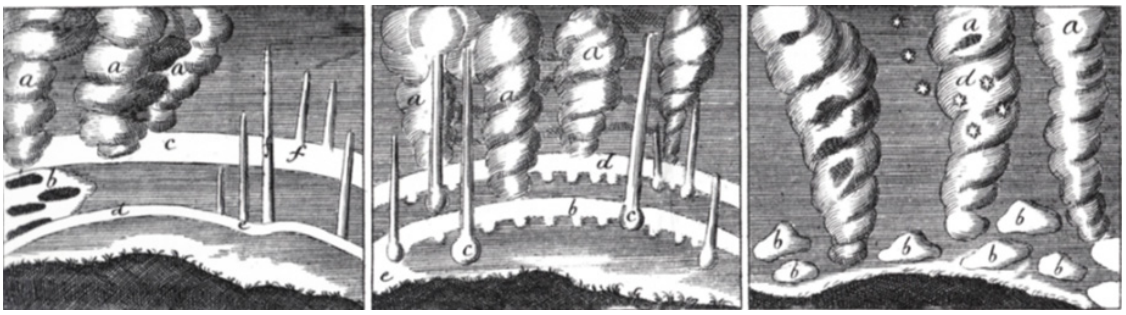


Figure 50: Electrostatic DL particle acceleration as witnessed in Danzig on 17 March 1716. The "Outer Space Torndoes" are synchrotron radiation emitted from ionic beams in the Auroral Acceleration Region (AAR).

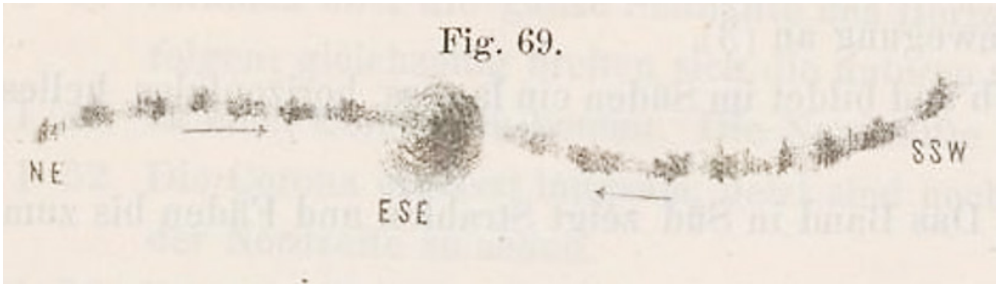
apparent.[227] In summary, because *electrostatic double layers* are essential to the auroral circuit – *but are only visible to the human eye during solar storms when particle collisions produce photonic illumination* – the entire spectrum of sun-induced formations occurs at energetic levels far, far away from thermodynamic or electrostatic equilibrium. Corkscrew-shaped "Tornadoes in Space" are not merely random "doodles" by individuals in 'primitive' or 'traditional' societies, nor superstitious European medieval mania, but material culture confirmation of *solar storms* seen and externally recorded by humans.

F. Yukawa/Coulomb Balls

Jan Mayen Island, owing to its location in the '*auroral zone*', experienced three '*auroral maximums*' in a solar year: during the fall equinox, winter solstice, and spring equinox. For those temperate and tropical latitudes between ~60º to the equator in either hemisphere, the aurora is visible only during the equinoxes (except in cases of *severe geomagnetic storms*). On 3 April 1883, the morphology pictured below (Fig. 51) was observed from 9:26-34 p.m. near the magnetic zenith. Described as a ball [*knäuel*], it was fabricated via the influx of material coming from two narrow strips (circa 0.5º degrees width) on opposite sides with "strikingly short rays," that featured alternating dark and bright segments. Within two minutes of its disappearance, a *Crown of Rays* emerged at the zenith.[228] We believe that the 'strips' were *magnetic flux filaments* transporting small, equally spaced *Coulomb spheres* that aggregated on the surface of the larger ball. This was not an isolated piece of evidence collected from the auroral chronicles, however. An earlier *polarlichter* notation from late October 1882 described how rays combined to form a band that curled up into a bright red and green-colored spiral. While it was spinning, the spiral band dissolved into linked spherical clusters (*string-of-pearls* configuration) that continued with vortical motion, then suddenly transformed again into a single, contiguous spiraling band. The peculiar behavior repeated itself several times prior to dispersion of the auroral form.[229]

There is a natural tendency for *dusty plasma crystals* to collectively bind together as dense-packed, spherical clusters under specific circumstances. In laboratory conditions, it is possible produce 3D *Coulomb* or *Yukawa balls* that are resistant to *dust void* formation using electric

Figure 51: Formation of a large dusty plasma Yukawa/Coulomb ball over Jan Mayen Island.



227 R. C. Franz, R. J. Nemzek, J. R. Winckler, "Television image of a large upward electrical discharge above a thunderstorm system" *Science* 249.4964 (6 July 1990): 48-51, https://doi.org/10.1126/Science.249.4964.48. A photo is also available in Peratt, *Physics of Cosmic Plasma*, 45, Fig. 2.4.

228 Bóbrick, *Preliminary Report*, vol. II, part IV: No. 119, 9:26-34 p.m., 186, Fig. 69.

229 Bóbrick, *Preliminary Report*, vol. II, part IV: No. 23, 8:06-21 p.m., 36.

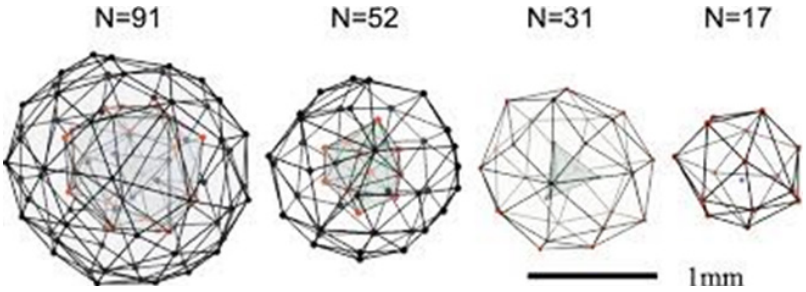
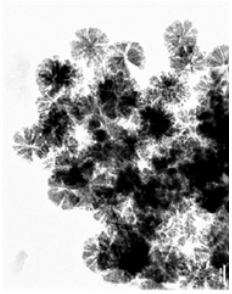


Figure 52 53: (Left) – Schematic of Yukawa/ Coulomb balls with magic number configurations; **Figure 53** (Right) – Cauliflower-type electrostatic agglomeration.



fields to horizontally confine the neutral plasma, and *thermophoretic levitation* (i.e., a heated electrode on the device's floor that counteracts gravity). Strongly coupled dust particles have the capacity to self-organize into highly ordered concentric spheres with periodic spacing between nested shells. Each concentric layer is composed of ions arranged in equilateral triangular (e.g., reticulated) networks that morph into a lattice of hexagons, pentagons, and defect polygons.[230] The closed shell system arranges itself into *magic number* configurations that provide higher thermodynamic stability. *Mackay icosahedrals and polygons* (tetragonal, pentagonal, heptagonal, octagonal, decagonal, and dodecagonal) have been created through various experiments in colloidal clusters and share many cellular packing strategies with *Yukawa/Coulomb balls* (Figure 52).[231] For very dense plasmas under low pressure, the force balance between negative dust particles and positive outer and middle shells creates an almost neutral overall charge. This manner of *electrostatic agglomeration* can lead to cauliflower morphologies (Figure 53) that are mesoscopic particles in a quasi-neutral state.[232]

Experiments with *dusty plasmas* in reactive molecular gases have resulted in similar *concentric shell clusters* used for producing thin polymer films with industrial applications. Methane and various hydrocarbons (such as *fullerene cages* or '*Bucky Balls'*), in addition to Silane and fluorocarbons, self-organize into clusters of 3D spheroids in RF and DC discharge devices. A form of '*plasma alchemy*' takes place during the nucleation (clustering) phase dominated by chemical reactions.[233] Suffice it to say that the *surface states of 3D complex plasma spheres that self-organize* at the *Geospace* interface can display a smörgåsbord of topologies: smooth, knobbed, lamellar ridge and valley, or sharp crystalline faces depending on the chemical composition and density of individually ionized dust grains, among a host of additional parameters. *Cosmic plasma crystallization* that results in layered structures – from 2D monolayers and 3D lattices (multi-layered sheets) to 2D and 3D *spherically nested structures* – bears an important similarity to thin polymer films grown on *plasma crystal substrates* such as polymorphous (hydrogenated) Silicon, and the *phase transitioning between vapor (gas), liquid, and quasi-crystalline states of condensed matter*.[234]

Ancient artifacts, in tandem with recent laboratory experiments and computer simulations, illuminate the long-term preservation of auroral knowledge in human material culture. The following images (Figs. 54-56) span more than 5,500 years of history. It is our contention that on a global scale, *Homo sapiens* has witnessed *magnetized dusty plasma self-organization* and the propagation of spheroidal, concentric shelled, or cage-like configurations, repeatedly over the past ~300,000 years. Proof of eyewitness accounts has been recorded in/on various objects in countless and culturally distinct ways. Figure 54 is a 3D *Coulomb ball* fabricated in the Magnetized Dusty Plasma Experiment (MDPX) device at Auburn

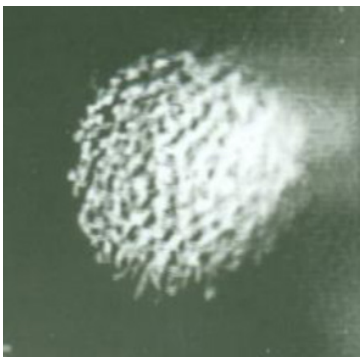
230 Melzer, *Physics of Dusty Plasmas*, 145-158, Apolinario *et al.*, "Structural and Dynamical Aspects of Small Three-Dimensional Spherical Coulomb Clusters": 283 (2-17).

231 Apolinario *et al*., "Structural and Dynamical Aspects": 2-17; Junwei Wang *et al*., "Magic Number Colloidal Clusters as Minimum Free Energy Structures": 1-9; Melzer, *Physics of Dusty Plasmas,*139-159.

232 B. M. Annaratone, T. Antonova, C. Arnas, *et al*., "Collective Effects in Complex Plasma," in *Plasma Sources Science and Technology* 19 (29 November 2010) 065026: 1-10, https://stacks/iop.org/PSST/19/065026. Figure 53 is from page 3, Fig. 5, in this source. Figure 52 source: Melzer, *Physics of Dusty Plasma*, 145, Fig. 8.5.

233 Melzer, *Physics of Dusty Plasma*, 199-210.

234 Melzer, *Physics of Dusty Plasma*, 208-210.



Figures 54, 55, & 56: (Left) – 3D Coulomb ball fabricated in the MDPX device; (Middle) – Knobbed *petrosphere* from Scotland's late Neolithic period; (Right) – Cluster ball-shaped petroglyphs from the Kamanjab site (Peet Alberts Koppie), where this style of densely packed spheroids appears in zoomorphic and geometric carvings.

University, presented at the 12th International Workshop on Non-neutral Plasmas in 2017.[235] The subsequent photo (Fig. 55) is a carved stone ball (i.e., *petrosphere* or 'Towie ball') unearthed from Scotland and exhibited in the British Museum.[236] Around 420 hand-worked *petrospheres* have been discovered since the nineteenth century, mostly in Aberdeenshire, Scotland, with a smattering of others in Ireland and northern England.[237] As recently as 2021, two polished balls were found in a chambered cairn at Tresness in the Orkney Islands, dating to the Neolithic period circa 3500 BCE. The age of these puzzling artifacts ranges from the Orkney horizon down through the British Isles' early Bronze Age (2500-700 BCE). A knobbed exterior is the most common configuration for *petrospheres*, numbering from 3 to 160 protuberances on their surface; while the 'magic number' of six protrusions accounts for more than half of the artifacts' geometrical shapes.[238] The final image (Fig. 56) of the triad comes from one large panel in Kamanjab, Namibia, with 'berry cluster' carved rock art.[239] Over 1,000 petroglyphs at this site date from 4000-2000 *ykr*, many revealing an *agglomerated Coulomb arrangement*.[240]

The final piece of evidence is a hand-painted illustration (Figure 57) from the *Book of Miracles* [*Das Wunderzeichenbuch*] compiled in Augsburg around the year 1542.[241] Augsburg was a thriving Renaissance era

235 The 12th International Workshop on Non-neutral Plasmas, 10-13 July 2017 Lawrence University. Merlino, Thomas, Jr., *et al*., "The Magnetized Dusty Plasma Experiment (MDPX)": 8.

236 Photograph taken by Johnbod on 1 August 2011, British Museum, Room 51, "Carved Stone Balls from Prehistoric Britain in the United Kingdom," the photograph's caption reads "Carved stone ball, classed as Neolithic," https://commons.wikimedia.org/wik/File:Room_51_British_MuseumDSCF6620.jpg.

237 Andrew M. Jones, "An Archaeology of Affect: Art, Ontology and the Carved Stone Balls of Neolithic Britain," *Journal of Archaeological Method and Theory* 27 (2020): 545-560, https://doi.org/10/1007/s10816-020-09473-8; "Carved Stone Balls," Wikipedia, https://en.wikipedia.org/wiki/Carved_stone_balls#Age_and_distribution.

238 Alison Roberts, "British Collection Highlights: Carved Stone Balls from Scotland," Ashmolean Museum, https://britisharchaeology.ashmus.ox.ac.uk/highlights/stone-balls.html; Livia Gershon, "Polished, 5,500-Year-Old Stone Balls Found in Neolithic Scottish Tomb", *Smithsonian Magazine* (9 September 2021), https://www.smithsonianmag.com/smart-news/polished-stone-balls-found-5500-year-old-scottish-tomb-180978615/.

239 Thomas A. Dowson, *Rock Engravings of Southern Africa* (Johannesburg: Witwatersrand University Press, 1992), 52-57. The illustration is from page 56, pl. 93.

240 Ulrich Zeller and Thomas Göttert, "Humans, megafauna and landscape structure – Rock engravings from Namibia encourage a comparative approach to central Europe and southern Africa" *Vertebrate Zoology* 71 (12 October 2021): 631-43, https://doi.org/10.3897/vz.71.e72811.

241 Till-Holger Borchert and Joshua P. Waterman, ed., *The Book of Miracles: Das Wunderzeichbuch – Le Livre des*

Figure 57: "Celestial Signs near Altenberg" from the *Book of Miracles* (1542).

commercial and artistic emporium in the region of Swabia, Bavaria, situated along the main trade route between Italy and Münich. The *Book of Miracles* was penned during a period of bloody religious upheaval in northern Europe, as followers of Martin Luther challenged the supremacy of the Papacy in all matters relating to the Christian faith. Consequently, the city was also where Holy Roman emperor Charles V signed the *Peace of Augsburg* in 1555 that legitimized Protestantism in Europe. To frame, or 'bind' the book within a larger historical context, it represents the ubiquitous human conflation of intense auroral activity with signs, prodigies, omens, visions, auguries, *ad infinitum* from Heaven – regardless of religious belief system or chronology. Filled with biblical, ancient Greco-Roman and early to late midieval European reports of unusual celestial phenomena, the *Book of Miracles* is also a chronicle of *space weather events*. Climatologically speaking, Martin Luther's protest movement coincidied with northern Europe emerging from the colder Spörer Minimum, that recent studies – utilizing auroral observations from the 1400s to 1600s – have recalibrated its terminus from 1550 to 1510/20.[242] The magnetic north pole was situated farther south geographically than its current location in 2023, providing the *volk* living in Germanic principalities more frequent and robust exposure to the *polarlichter*.[243] Strange apparations viewed in the sky – day or night – were interpreted politically by Protestants as God's affirmation for their struggles against a corrupt Catholic establishment.[244]

The heading for Figure 57 in the *Book of Miracles* reads: "Celestial Signs near Altenberg," and also contains the caption (not shown in image) "1513 – In the year 1513 this manifestation was seen a quarter of a mile from Altenberg in broad daylight at noon." The town of Altenberg is located in the Bayern region of Saxony 430 km northwest of Augsburg. We can identify the three "Celestial Signs" in the image based on descriptions and sketches of *aurorae* in the Austrian polar expedition material: 1) from the right is the *agglomerated Yukawa ball* discussed earlier, clearly knobbed with vapor trail and moving towards the larger auroral form (upper left-hand side); 2) in the lower middle portion two anti-parallel, tapered brush strokes were called *schmalen Bänderansätze* [narrow band of rays with ligaments attached] and similarly sketched in the auroral journals as slightly curved and tapered 'fish-tails' – attesting to the filamentary nature of electron beams in cosmic plasma; and 3) the largest 'white-mustached'

Miracles (Berlin: Taschen, 2014), 186, *Folio* 94.

242 Eddy's original chronology for the Spörer Minimum was 1460-1550. Hiroko Miyahara *et al.* redated the time frame as 1455-1510; while Jiang Yaotiao and Xu Zhentao proposed the dates 1400-1510/20. See Hiroko Miyahara, Kimiaki Masuda, *et al*., "Variation of Solar Cyclicity during the Spoerer Minimum," *JGR Space Physics* 111.A3 (15 March 2005): A03103 (1-5), https://doi.org/10.1029/2005JA011016; Yaotiao Jiang and Zhentao Xu, "On the Spörer Minimum," *Astrophysics and Space Science* 118 (January 1986): 159-162, https://doi.org/10.1007/BF00651121.

243 For a computer model of historical magnetic declination from 1590 to 2025, see the National Centers for Environmental Information, NOAA, "Historical Magnetic Declination", https://www.ncei.noaa.gov/maps/historical_declination/.

244 Christopher Carter, "Becoming Ordinary: The Aurora Borealis during the Reformation" *The Electronic Sixteenth Century Journal* 53.3 (Autumn 2022): 609-638. Jakob Böhme's *Aurora: Morning Glow Ascending* (1612), must also be understood within this context.

figure occupying the left side of the portrait is the spitting image of a *Crown of Flames* (see Fig. 30).[245] It is all too common for 'modern' societies to disparage works similar to the *Book of Miracles* as generalized manifestations of the "ignorant and superstitious midieval mind" that had not been intellectually accelerated through the double layers of Western science and reason.

G. Flying Magnetic Bubbles and Thin Plasma Films

In the early nineteenth century, during Solar Cycle 5 (1798-1810) an unusual auroral phenomenon occurred in the skies above Biskopsberga, Sweden, on 16 May 1808. Erik Acharius, a botanist and distinguished member of the Royal Swedish Academy of Sciences, traveled to the village and collected eye-witness testimony from all whom had seen what he interpreted as a "peculiar meteor phenomenon." On a warm, cloudless day around 4 p.m. local time, a strong wind out of the west preceded the darkening of the sun. To quote professor Acharius:

> "at about 4 o'clock p.m. the sun became dim, and lost his brightness to the degree that he could be looked at without inconvenience to the naked eye, being of *a dark-red, or almost brick color* without brilliancy. At the same time there appeared at the western horizon from where the wind blew, arose gradually and in quick succession *a great number of balls or spherical bodies*, to the naked eye of a size of the crown of a hat, and of a dark brown color. *The nearer these bodies, which occupied a considerable though irregular breadth of the visible heaven, approached towards the sun, the darker they appeared; and in the vicinity of the sun became entirely black. At this elevation their course seemed to lessen, and a great many of them remained, as it were, stationary; but they soon resumed their former [course], and at an accelerated motion passed in the same direction with great velocity and almost horizontally.* During this course some disappeared, while others fell down [to the Earth], but the most part of them continued their progress almost in a straight line, until they were lost sight of at the eastern horizon. *The phenomenon lasted uninterruptedly, upwards of two hours, during which time millions of similar bodies continually rose in the west, one after the other irregularly, and continued their career exactly in the same manner. No report, noise, nor any whistling or buzzing in the air was perceived. As these balls slackened their course on passing by the sun, several were linked together, three, six, or eight of them in a line, joined like chain-shot by a thin and straight bar; but on continuing again a more rapid course, they separated, and each having a tail after it, apparently of three or four fathoms length, wider at its base where it adhered to the ball, gradually decreasing, till it terminated in a fine point. During the course, these tails which had the same black color as the balls, disappeared by degrees*."
>
> "It fortunately happened that some of these balls fell at a short distance, or but a few feet from Mr. Secretary K. G. Wettermark, who had then for a long while been attentively looking at the phenomenon in the aforesaid village. On the descent of these bodies, *the black color seemed gradually to disappear the nearer they approached the earth, and they vanished almost entirely till within a few fathoms distance from the ground, when they were again visible with several changing colors, and in this particularity exactly resembled those air-bubbles which children use to produce from soapsuds by means of a reed.* When the spot where such a ball had fallen was immediately afterwards examined, nothing was to be seen *but a scarcely perceptible film or pellicle, as thin and fine as a cobweb, which was still changing colors, but soon entirely dried up and vanished.* As somewhat singular, it may be observed that the size of these balls, to the sight, underwent no particular change; for they appeared of the same dimension, at their rise from the western horizon, as well as their passing by the sun, and during the whole of their course to the eastern part of the heavens, where they disappeared."[246]

245 Bóbrick, *Preliminary Report*, vol. II, part IV: No. 35, 12:14-28 p.m., 54, Fig. 28.

246 A special thanks to Maria Asp, archivist at the Center for History of Science, The Royal Swedish Academy of Sciences in

Professor Archarius conducted a thorough, scientific investigation of the incident, and proposed a hypothesis that was botanical: a strong wind uplifted from distant wooded mountains "vegetable substances of a jelly-like nature… having incorporated some additional matter by chemical union therewith, formed themselves into thin globular masses… that were formed into bubbles, which became perceptible to the eye by the sun's light." He added, however, that an educated guess did not answer the question as to why the sun lost its luminosity, nor "how this innumerable quantity of such a soapy and jellied substance be generated or produced in one place."[247] Archarius' description of the spheres decelerating, merging into linked chain-shot (a.k.a. bar shot) formation, changing color, then experiencing a burst of energy approximates the physics of particle acceleration, but does not explain the organic or inorganic alchemical 'soft matter' shell enclosing ionized gas.

The science behind auroras altering the chemistry of Earth's upper atmosphere is well established for periods of *solar maxima*. First, magnetic fields affect chemical bonds in molecules by deforming electron orbital motion. As a consequence, electrons become more localized between atomic nuclei when molecules are exposed to external magnetic fields, increasing energy levels in the orbital space.[248] So-called 'exotic' molecular structures emerge with rising magnetic field strength, promoting clustering behavior of atoms while augmenting bond stability in a *paramagnetic bonding regime*.[249] Secondly, wave-particle interactions in the outer Van Allen radiation belt generates excess ionization via scattering (i.e. precipitation) of charged electrons into Earth's polar atmospheres down to altitudes of ~50-100 km in the auroral and sub-auroral zones (>45˚ latitude). Ionization occurs foremost in the upper atmosphere (thermosphere and mesosphere), that in turn produces HO_x (hydrogen oxide or 'odd hydrogen') and NO_x (nitrogen oxide or 'odd nitrogen), leading to the production of dinitrogen, dinitride, dioxide, and nitrogen oxide which are *non-trivial chemical metamorphoses*. Nevertheless, these 'odd' molecules can catalytically destroy ozone (O_3, known as 'odd' oxygen), which absorbs harmful UV radiation in the stratosphere and mesosphere, thus altering polar atmospheric chemistry. Auroral coupling of the ionospheric down to tropospheric-levels affects polar ground surface temperatures unevenly by approximately 5^0 *Kelvin* in either direction. Moreover, atmospheric wind patterns are impacted by changes in the radiative balance, not to mention a measurable decrease in cloud cover during *solar maxima*. Counterintuitively, during *solar maxima conditions*, certain regions in both polar hemispheres experience cooler and warmer winters simultaneously despite being at the same geographical latitude.[250] Little wonder that *Chaos theory* got its start from meteorology and Edward Lorenz's *nonlinear approach* to weather forecasting.[251] In sum, sunspot-induced regional climate variability is an index for chains of causality that generate unpredictability for human energy consumption over longer scales of time.

Compelling data provided by the Austrian polar

Stockholm, for locating the original Swedish-language version of the essay. Erik Archarius, "Account of a Peculiar Meteor Phenomenon," *Transactions of the Royal Swedish Academy of Science, Meeting of the 10th of August, 1808*: July, August, September 215-218. For an English language translation, see J. C. Hauff, *The North-American Review and Miscellaneous Journal* 3.9 (September 1816): 319-22, https://www. jstor.org/stable/25121204. Italics added by the authors for emphasis.

247 Archarius, "Account of a Peculiar Meteor Phenomenon": 321-22.

248 Jianmin Tao, Shi Liu, Fan Zheng, and Andrew M. Rappe, "Quantum Pressure and Chemical Bonding: Influence of Magnetic Fields on Electron Localization" *Physical Review B* 92.6 (1 August 2015): 060401(1-5); https://doi.org/10.1103/PhysRevB.92060401.

249 Miles J. Pemberton, Tom J. P. Irons, Trygve Helgaker, and Andrew Teale, "Revealing the Exotic Structure of Molecules in Strong Magnetic Fields" *The Journal of Chemical Physics* 156.20 (28 May 2022), 204113(1-10), https://doi.org/10.1063/5.0092520.

250 M. A. Cliverk, C. J. Rodger, M. E. Andersson, *et al*., "Linkages Between the Radiation Belts, Polar Atmosphere and Climate: Electron Precipitation Through Wave Particle Interactions" in Georgios Balasis, Ioannis A. Daglis, and Ian R. Mann, ed., *Waves, Particles, and Storms in Geospace: A Complex Interplay* (Oxford: Oxford University Press, 2016): 354-376; Moldwin, *An Introduction to Space Weather*, 114-115.

251 Gleich, *Chaos: Making a New Science*, 11-31.

expedition divulges a unique type of *nonlinear upper atmospheric chemistry* ignored by scientists thus far. Meteor storms [*sternschnuppenfall*] were reported in tandem with Northern Lights observations. Surprisingly, there was an almost instantaneous (chemical?) reaction to single or multiple shooting stars passing through diverse *cosmic plasma* forms, especially from mid-November 1882 to early January 1883 synchronous to the Quadrantid meteor showers. On 12-13 December 1882, Austrian observers chronicled the following interactive dynamics. At 8:46 – 9:00 p.m., an arch with flame-like jets shot up from the horizon, holding a steady position. After 10 minutes a meteorite flew into the arch. Within 60 seconds, the arch rose upwards and the flame-like projections "began to expand and contract in a fan-like shape, then slowly began to fade." A few hours later at 3:11 a.m., Bóbrick wrote "the firmament was filled only with traces of haze. Three shooting stars fell from south to west 20º above the horizon; immediately afterwards streams of aurora appeared over the zenith… and the entire southern half of the firmament," gradually paling by 3:21 a.m.[252] Of the ten separate *sternschnuppenfall* events recorded in the journal, *eight catalyzed a quick reaction in auroral forms*. The other two occurred during cloudy or snowy conditions where visibility was strongly hampered, and thus no reaction was noted.[253] Although auroras usually occur at a higher altitude than the ~85-50 km (53-31 mile) mesospheric zone where meteors burn up in the Earth's atmosphere, the lower portions of *aurorae* are within range of alchemical influence due to the thinner troposphere at the poles. It is, nevertheless, an intriguing conundrum that deserves more serious study before any definitive links can be established.

The question, however, still begs: what were the gelatinous, floating plasma orbs witnessed above Biskopsberga? A more plausible explanation would be that the inhabitants had visually experienced a *flux transfer event* (FTE – to be discussed with more detail in the following sections) of heated, pressurized, ionized gas within a spherical electrostatic cage – or magnetic bubble – of *plasma crystal film* that was electrically conducting or semi-conducting. Dislodged from magnetic field guides by some random perturbation, the 'soapy bubble' floated down towards the Earth's surface. As energy levels depleted proportional to atmospheric temperature and pressure changes, it slowly phase transitioned into thin air at ground level. Plasma crystals, as explained earlier, preferentially self-organize into reticulated, hexagonal lattice structures in sheets or slabs, or as concentric spheres. Graphitic (*fullerene* sheets and *buckyballs*) or silicon-based thin films, such as SiC (silicon carbide or *carborundum*) naturally arrange into reticulated or hexagonal (honeycomb) lattice configurations. Polycyclic aromatic hydrocarbons (PAH) that produced carbon allotropes such as *fullerenes* and 'diamond-like carbon' – an amorphous class of carbon – have recently been found to exist in dusty nebulae that are stellar nurseries. Over the past decade or so, astronomical studies revealed that the interplanetary space medium produces *fullerenes* in the Magellanic Clouds and the Iris Nebula NGC 7023, among others. Photochemical processing via cosmic UV radiation can transform $C_{66}H_{20}$ (*circumovalene*) into C_{60} (a *buckyball* allotrope).[254] Polymeric gels (such as an aerogel) would account for the physical particularities attributed to floating

252 Bóbrick, *Preliminary Report*, vol. II, part IV: No. 57, 8:46-9:00 p.m., 144, and 3:11-3:21 a.m., 146.

253 A chronological list of meteoric encounters with the aurora are as follows – Bóbrick, *Preliminary Report*, vol. II, part IV: No. 9, 10:14-10:20 p.m., 24; No. 35, 8:46-8:53 p.m., 53; No. 41, 7:20 p.m., 64, and 10:20 p.m., 65; No. 52, 8: 13 p.m., 81; No. 57, 8:46-9:00 p.m., 144, and 3:11-3:21 a.m., 146; No. 59, 9:33-34 p.m., 100; No. 63, 7:09-7:13 p.m., 110; No. 72, 7:48-8:29 p.m., 126. See also Sobieczky, *Preliminary Report*, vol. II, part III: 164.

254 Les Johnson and Joseph E. Neany, *Graphene: The Superstrong, Superthin, and Superversatile Material that will Revolutionize the World* (Amherst, N.Y.: Prometheus Books, 2018), 28-37, 185-86; O. Berne, J. Montillaud, and C. Joblin, "Top-down Formation of Fullerenes in the Interstellar Medium" *Astronomy and Astrophysics* 577 (May 2015):A133 (1-9), https://www.aanda.org/articles/aa/full_html/2015/05/aa25338-14/aa25338-14.html; T. Pino, M Chabot, *et al*., "Release of Large Polycyclic Aromatic Hydrocarbons and Fullerenes by Cosmic Rays from Interstellar Dust" *Astronomy and Astrophysics* 623 (March 2019): A134 (1-6), https://doi.org/10.1051/0004-6361/201834855; Michael Gatchell, João Ameixa, *et al.*, "Survival of Polycyclic Aromatic Hydrocarbon Knockout Fragments in the Interstellar Medium" *Nature Communications* 12 (2021): 6646 (1-8), https://doi.org/10.1038/s41467-021-26899-0; K. Sellgren, "Aromatic Hydrocarbons, Diamonds, and Fullerenes in Interstellar Space: Puzzles to be Solved by Laboratory and Theoretical Astrochemistry" *Spectrochim Acta*

spheres in the Archarius report.[255]

Thinking outside of the 3D cube, it would be reasonable to assume that under the highly energized stochastic, complex dynamical plasma fusion and chemical reactions occurring between the *magnetosphere*, *ionosphere* (from Level F2-D, including the thermosphere, mesosphere, and stratosphere), and *closed/open geomagnetic field lines* that *soft condensed matter* could be produced at the *surface of magnetic flux tubes and islands* (i.e., *plasmoids*). An estimated annual average of 15,000 tons of cosmic dust hits the Earth's atmosphere (~5,200 tons of which falls to ground/sea level as micrometeorites), and silica-ice mixtures are common in their sundry chemical composition.[256] The carbonate-silicate cycle of planet Earth is fueled by volcanic eruptions spewing clouds of toxic gases, ash, and aerosols into the atmosphere. Volcanic ash contains large amounts of glassy silica, which on average makes up ~45-75% of total emissive molecular weight. Long-range transport of airborne silicate particles can remain in the upper atmosphere for several months.[257] Additionally, volcanic eruptions can affect *Pederson* and *Hall currents in the ionosphere* (a.k.a., *ionospheric dynamo*), thereby augmenting the electrical intensity of *geomagnetic storms* such as the very recent Hunga Tonga-Hunga Ha'apai eruption of 15 January 2022.[258] All of the ingredients necessary for quantum-chemistry exist at the *Geospace* interface, where self-organization in soapy orbs of *cosmic plasma* (i.e., *soft matter*) is theoretically feasible.

H. Self-Similarity in Sixteenth Century Heavenly Apparitions: Auroral 'U.F.O.s' in Nürnberg (1561) and Basel (1566)

Two different auroral encounters chronicled during the sixteenth century in northern Europe bear a conspicuous resemblance to the Biskopsberga 'meteor phenomenon' discussed above. Unfortunately, they have become notoriously associated with the post-WWII unidentified flying object (U.F.O.) hysteria, or cult-like belief that biological extraterrestrial life forms with advanced quantum technology battle each other in the Earth's upper atmosphere for control over the fate of humanity. Perhaps such fantastical theorizing is worthy of the "*blancmange*" skit from Monty Python's Flying Circus, otherwise it is of zero scholarly utility. Richard B. Strothers, former NASA scientist with the Goddard Institute for Space Studies, authored the article "Unidentified Flying Objects in Classical Antiquity," that equated auroral or meteorological forms described in ancient Greek and Roman era texts to those seen, photographed, or filmed since the late 1940s.[259] The chronology of sightings across ~600-year breadth of Classical era sources was used to validate an ~11-year *solar cycle* in the past (as occurs in the present age), and to explain so-called 'prodigies' in the context of a *sunspot-*

A Mol Biomol Spectrosc 57. 4 (15 March 200):627-42, https://doi.org/10.1016/s1386-1425(00)00433-9.

255 P. A. Hassan, Gunjam Verma, Rajib Ganuly, "Soft Materials – Properties and Applications" in S. Banerjee and A. K. Tyagi, *Functional Materials: Preparation, Processing, and Applications* (London: Elsevier, 2012), 1-59, www.sciencedirect.com/book/9780123851420/functional-materials.

256 J. Rojas, J. Duprat, *et al.*, "The Micrometeorite flux at Dome C (Antarctica), Monitoring the Accretion of Extraterrestrial Dust on Earth" *Earth and Planetary Science Letters* 560 (2021): 116794 (1-11), https://doi.org/10.1016/j.epsl.2021.116794; Alexa Potapov, Jeroen Bouwman, *et al*., "Dust-Ice Mixing in Cold Regions and Solid-State Water in the Diffuse Interstellar Medium" *Nature Astronomy* 5 (21 September 2020): 78-85, https://www.nature.com/articles/s41550-020-01214-x.

257 Baerbel Langmann, "On the Role of Climate Forcing by Volcanic Sulphate and Volcanic Ash" *Advances in Meteorology* (27 February 2014): 340123 (1-17), https://doi.org/10.1155/2014/340123.

258 Brian Harding, Yen-Hung Joanne Wu, *et al*., "Impacts of the January 2022 Tonga Volcanic Eruption on the Ionospheric Dynamo: ICON-MIGHTI and Swarm Observations of Extreme Neutral Winds and Currents" *Geophysical Research Letters* 49 (10 May 2022): e2022GL098577 (1-10), https://doi.org/10.1029/2022GL098577.

259 Richard B. Strothers, "Unidentified Flying Objects in Classical Antiquity" *The Classical Journal* 103.1 (Oct.-Nov. 2007): 79-92, https://pubs.giss.nasa.gov/abs/st02710y.html. See also "Ancient Aurorae" *Isis* 70.1 (March 1979): 85-95, https://www.jstor.org/stable/230880?seq=1&cid=pdf-; and Michael Carlowicz "From Ancient Roman Omens, New Data on Solar Activity" *Oceanus: The Journal of Our Ocean Planet* (24 June 2005), https://www.whoi.edu/oceanus/feature/from-ancient-roman-omens-new-data-on-solar-activity/.

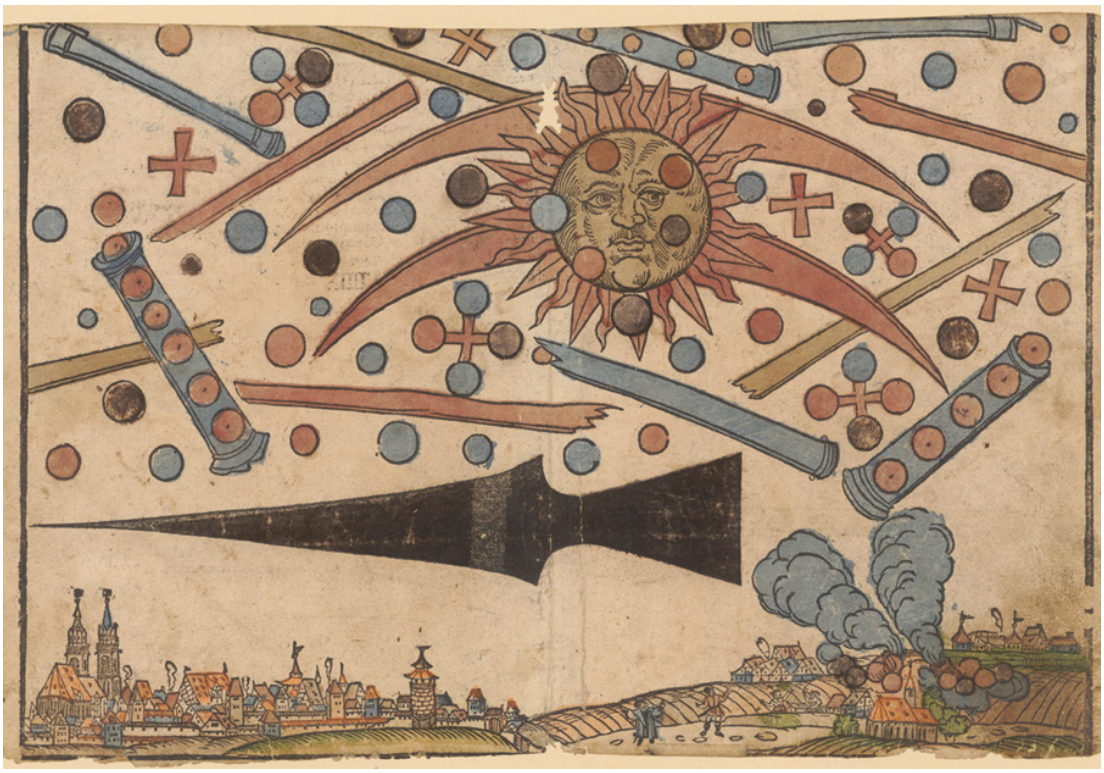


Figure 58: Hans Glaser's woodblock print "Himmelserscheinung über Nürnberg vom 14. April 1561."

aurorae connection. For these reasons we investigate the following incidents through the analytical lens of *space weather phenomena during magnetic reconnection events with the Earth's magnetotail*.

On 14 April 1561, during the early morning (4-5 a.m.) before sunrise (usually around 6:25 a.m. for that date) the entire municipality of Nürnberg [Nuremberg] came outdoors to witness a very peculiar celestial spectacle (Fig. 58).[260] An illustrated broadsheet or leaflet [*flugblatt*] printed by Hans Glaser in 1566 described the natural event as follows:

> "In the morning of April 14, 1561, at daybreak, between 4 and 5 a.m., a dreadful apparition occurred on the [face of the rising] sun, and this was seen in Nürnberg in the city, before the [city] gates and in the [surrounding] country[side] – by many male and female persons. At first there appeared in the middle of the sun two blood-red semi-circular lines, just like the waning moon. The lines appeared and were seen in the middle of the sun, above and below and on both sides, the color was blood. And in one there stood a spherical ball of partly dull, partly black ferrous color. Likewise, there stood on both sides and as a torus about the sun, such blood-red ones and other balls in large number, about three in a line and four in a square, also some alone. In between these globes there were visible a few blood-red crosses, between which there were blood-red strips, becoming thicker to the rear and in the front malleable like the rods of reed-grass, which were intermingled, among them two big rods, one on the right, the other to the left, and within the small and big rods there were three, also four and more globes. These all started to fight among themselves, so that the globes, which were first in the sun, flew out to the ones standing on both sides, thereafter, the globes standing outside the sun, in the small and large rods, flew into the sun. Besides the globes flew back and forth among themselves and fought vehemently with each other for over an hour. And when the conflict in

260 Source: "Himmelserscheinung über Nürnberg vom 14. April 1561", https://uzb.swisscovery.slsp.ch/view/delivery/41SLSP_UZB/112464126670005508.

> and again out of the sun was most intense, they became fatigued to such an extent that they all, as said above, fell from the sun down upon the earth 'as if they all burned,' and they then wasted away on the earth with immense smoke. After all this there was something like a black spear, very long and thick, sighted; the shaft pointed to the east, the tip pointed west. Whatever such signs mean, God alone knows."[261]

Several processes driving the auroral electrical circuit are discussed and illustrated in the sixteenth century broadsheet. First, the "blood red strips" with *grass* or *reed-like texture* and *tapered* at the end were described as *bands* or *streaks of rays* in the Jan Mayen Island journal. Secondly, the "two big rods" and smaller ones with globes inside that are seen emerging from the end points are Birkeland FAC, or *flux tubes*, with *magnetic islands* (e.g., *flux ropes* or *plasmoids*) flowing through them. Peratt described this morphology as resulting from a *Z-pinch on a plasma column*.[262] Thirdly, the kinetic behavior of globes flowing into and out of the large "sun," accompanied by rapid acceleration mimics the behavior of *plasmoids* ejected and created by the *nonlinear process* of *magnetic reconnection* (MR - to be discussed below); along with the cross-shaped figures related to X-lines formed during *magnetic field-line merging*.[263] Globes linked together in a bar shot formation, how they became fatigued, fell to the ground, then evaporated into a gaseous vapor is consistent with the reported dynamics of the Biskopsberga event. A *plasma torus of spheroids* surrounding the "sun" describes similar characteristics of the *dense plasma focus* emerging from a *Z-pinch*. The *chaos* associated with auroral dynamics includes *global MHD* (collisionless) and *localized plasma instabilities* (non-collisionless) or processes that can be viewed simultaneously at nearly relativistic speeds on an Earth atmospheric scale.

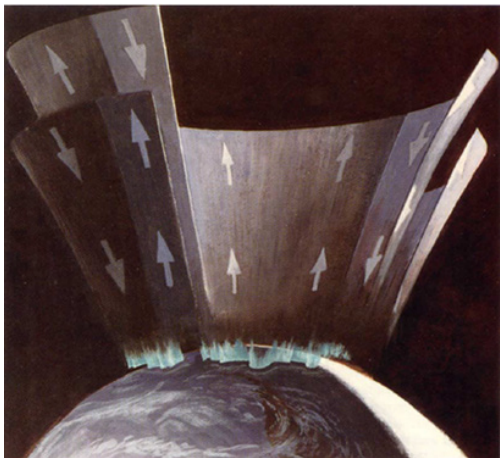
As for the luminous *crescent shapes* above and below the "dreadful apparition appearing on the face of the rising sun" in the Nürnberg broadsheet (Fig. 58), *their shape and auroral crowning event in between indicates a pair of opposite flowing Birkeland FAC*. In their most common manifestation at the *auroral oval*, FAC materialize out of thin air (from ground-level perspective) in pairs carrying flux with an azimuthal current flowing in anti-parallel channels. Since electron beams flow opposite to that of the current, upward R1 and R2 FAC sheets accelerate electrons earthward and ions anti-earthward, while the flow direction for both particles is reversed for downward moving currents, respectively (Fig. 59 & 60).[264] Both regional FAC float as concentric layers perpendicular to the Van Allen radiation belts (*closed field lines*) that all converge around the polar cusps. The higher latitude (inner) FAC, or R1 currents, are connected to the *magnetopause* and *convect solar wind plasma from the dayside (facing the sun) over the polar cusps to the magnetotail in the nightside (facing away from the sun)*. R2 (lower latitude or outer) FAC *flow away from the ionosphere in the dayside region, transporting reconnected flux towards the dayside flanks*

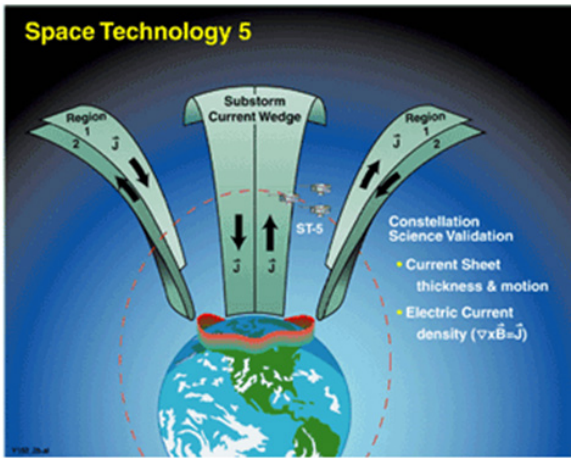
261 Mahalo to Professor Rainer Buschmann of CSUCI for his assistance with fine-tuning the translation by Ilse Von Jacobi. See "1561 celestial phenomenon over Nuremburg", https://en.wikipedia.org/wiki/1561_celestial_phenomenon_over_Nuremberg. The remainder of the broadsheet reads: "Although we have seen, shortly one after another, many kinds of signs on the heaven, which are sent to us by the almighty God, to bring us to repentance, we still are, unfortunately, so ungrateful that we despise such high signs and miracles of God. Or we speak of them with ridicule and discard them to the wind, in order that God may send us a frightening punishment on account of our ungratefulness. After all, the God-fearing will by no means discard these signs, but will take it to heart as a warning of their merciful Father in heaven, will mend their lives and faithfully beg God, that He may avert His wrath, including the well-deserved punishment, on us, so that we may temporarily here and perpetually there, live as his children. For it, may God grant us his help, Amen. By Hanns Glaser, letter-painter of Nurnberg."

262 Peratt, "Characteristics for the Occurrence of a High-Current, Z-Pinch Aurora as Recorded in Antiquity": 1194-1196.

263 Gonzalez and Parker, *Magnetic Reconnection*, 277-391.

264 Peratt, "Characteristics of the Occurrence of a High-Current Z-Pinch Aurora as Recorded in Antiquity Part II": 797-798, Fig. 54; NASA, "ST5 – Space Technology 5", https://nasa.gov/mission_pages/st-5/news/index.html.





Figures 59 & 60: (Left) - Birkeland R1 (inner polar cusp) and R2 (outer polar cusp) currents sheets flowing into and out from the auroral oval, completing the enhanced solar wind-magnetosphere-ionosphere circuit. The resulting electrical current sheets in the lower ionosphere (blue streaks on the bottom of cusps just above the Earth) that correspond to the wave-like motion of auroral curtains witnessed from ground level; (Right) – Illustration of NASA's ST5 satellite array that monitors FAC Space Weather events in the ionosphere.

of the equatorial ring current, nightside plasma sheet, and ultimately to the magnetotail.[265]

Topologically speaking, when flux is transported to the polar cusp, accelerating particles – downward flowing electrons and upward flowing ions/protons – collide into each other and ENAs in the upper atmosphere, consequently *illuminating the sheet currents to create nonlinear optical structures*. When electric currents are intense, they form a luminous *current wedge* that contours the cusp geometry. *The two crescent- or wedge-shaped structures in the Nürnberg print are consistent with paired upward and downward flowing FAC*. The so-called "sun" in these events is most likely a *diffusion region for magnetic islands and particles* expelled by the X-point between the anti-parallel flow of the paired R1 and R2 FAC, or a so-called "*monster plasmoid*" *created during MR with the magnetotail during a BBF event*.

The second *himmelserscheinung* [Heavenly apparition/sign] from Basel, Switzerland, in the year 1566 describes and visually illustrates many similarities with the Nürnberg sighting five years earlier, but contains other distinctive traits related to *solar-wind driven large scale convection of the geomagnetic field*.[266] An auroral event was viewed by the inhabitants three times (27, 28 July, and 7 August) in the evening and early morning hours, respectively. The first three paragraphs of the broadsheet read:

> "During the year 1566, on the 27th of July, after the sun had shone warm on the clear, bright skies, and then around 9 p.m., it suddenly took a different shape and color. First, the sun lost all its radiance and luster, and it was no bigger than the full moon, and finally it seemed to *weep tears of blood* and the air behind him went dark. And he was seen by all the people of the city and countryside. In much the same way also the moon, which has already been almost full and has shone through the night, assuming an almost *blood-red color* in the sky. The

265 S. B. Mende, S. L. England, and H. U. Frey, "Plasma Pressure Generated Auroral Current System: A Case Study" *Geophysical Research Letters* 39.6 (28 March 2012): L06106(1-6), https://doi.org/1029/2012GL051211; Sundberg, "On the Properties of Ionospheric Convection": 3-20.

266 Walter Gonzalez, Eugene Parker, ed., *Spontaneous Current Sheets in Magnetic Fields with Applications to Stellar X-Rays* (Oxford: Oxford University Press, 1994), 378-85.

> next day, Sunday, the sun rose at about six o'clock and slept with the same appearance it had when it was lying before. He lit the houses, streets and [all] around as if everything was *blood-red and fiery*. At the dawn of August 7, we saw large black spheres coming and going with great speed and precipitation before the sun and chattered as if they led a fight. Many of them were *fiery red*, and soon crumbled and then extinguished."[267]

An indication of an intense *geomagnetic storm/polar substorm* is a *darkening of the sun* and a *blood-red radiation that covers the ground, trees, buildings, etc. in a crimson hue* as was reported during the 1837 aurora in New York. Descriptions of *blood seen dripping or perspiring from the 'sun'* are met with extreme skepticism, to put it mildly, unless one considers such fantastical stories as *plasma flux transfer events associated with magnetic reconnection.* An illustration of the *sun sweating blood* over the city of Venice from the *Book of Miracles* provides graphic evidence for a prior appearance of the unusual Basel phenomenon.[268] In pre-Columbian America, the Inca people believed that gold was the sweat of the sun; while Aztec religious conviction held that *Huitzilopochtli* – dual god of the Sun and War – that *required human blood as sacrifice to replace what it had lost in its daily course across the sky* becomes comprehendible in a solar-induced auroral context.[269] Finally, black and red spheres flying at incredible speeds, then dropping to the Earth and disintegrating echoes of the 1808 Biskopsberga incident.

H. Magnetic Reconnection over Jan Mayen Island Compared to Earlier Examples in Human Material Culture

Geometrodynamics is an important heuristic tool for understanding how humans see and preserve encounters with *solar- and geomagnetic fields*, *current sheets*, and *innumerable manifestations of cosmic plasma that result from highly charged solar particles penetrating, diffusing, and exiting the ionospheric/magnetospheric/solar wind magnetic boundary layers*. Contrary to the Law of Mass Conservation, magnetic fields can be created (*Dynamo theory*) and destroyed (*magnetic reconnection*). MR, also known as *field line merging*, is a process whereby *oppositely directed field lines merge and energetically induce a change in the topology of the magnetic field in highly conducting plasmas*. The ensuing reconfiguration of magnetic field lines produces plasma heating, particle acceleration, and jetting (transient, collimated, supersonic plasma outflow).[270] There are diverse types of MR: anti-parallel, component, null-spine-fan, X-point, Y-point, 0-point, fast, slow, etc. In layperson's terms, a plasma scientist explained the concept as follows:

> "Magnetic fields are made up of field lines. Electrons and ions flow along these invisible lines. When two sets of lines that have magnetic fields pointing in opposite directions get too close, they collide. As field lines cross and form an X [-shaped line of potential discontinuity, or separatrix], they break and then reconnect to the other set of lines coming from the opposite direction; forming U-shapes that push away from each other, they rearrange the magnetic field. By heating up and accelerating the particles in the plasma, that rearrangement transforms [potential] magnetic

267 "Seltsame Gestalt so in disem MDLXVI Jar," printed by Samuel Apiarius and Samuel Coccius, https://commons.wikimedia.org/wiki/FIle:LinkSeltsame_Gestalt_so_in_desem_MDLXVI_Jar.jpg. See also "1566 Celestial Phenomenon over Basel", https://en.wikipedia.org/wiki/1566_celestial_phenomenon_over_Basel. Italics added by the authors for emphasis.

268 Borchert and Waterman, *The Book of Miracles*, 170, fol. 76.

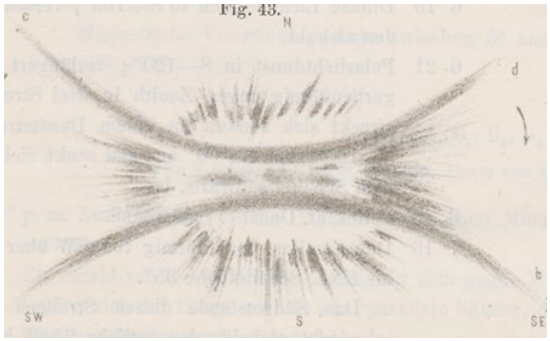
269 Peter Lourie, *Sweat of the Sun, Tears of the Moon: A Chronicle of an Incan Treasure* (Lincoln, Nebraska: Bison Books, 1998).

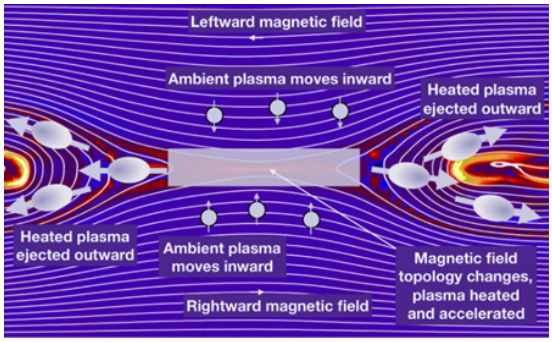
270 Gurnett and Bhattacharjee, *Introduction to Plasma Physics*, 270-79; Rudolf A. Treumann and Wolfgang Baumjohann, "Collisionless Magnetic Reconnection in Space Plasmas" *Frontiers in Physics* 1 (31 December 2013): 00031(1-34), https://doi.org/10.3389/fphy.2013.00031; P. F. Wyper, C. R. DeVore, *et al.*, "Three-Dimensional Simulations of Tearing and Intermittency in Coronal Jets" *The Astrophysical Journal* 827 (10 August 2016): 4(1-18), https://doi.org/10.3847/004-637X/827/1/4.

energy into [kinetic] particle energy."[271]

A more detailed explanation of the plasma physics connecting the sun, solar wind interplanetary magnetic field (a.k.a. heliospheric magnetic field), bow shock, magnetosheath, magnetopause, magnetosphere, magnetotail, closed/open geomagnetic field lines, ring current, auroral electrojet, plasmasphere, plasma sheet, ionospheric and magnetospheric convection, etc., is distilled in the following citation.[272] Our focus is limited to how this *extremely complex*, *dynamical sun-Earth system interface* is related to the auroral phenomenon *seen by humans from ground level.*

In the *auroral oval*, boundaries where magnetic fields change direction or size induce *current sheet formation at surfaces of tangential discontinuity*. Thus, in between the open field lines of the R1/R2 FAC system and the closed Van Allen belt magnetic field zones is a narrow transition (electron and ion dissipation) region of *thin current sheets* with DC-induced magnetic fields that form when *bundles of magnetic (Poynting) flux from the dayside magnetopause current sheet are convected tailwards*, whence they reconnect with the *tail plasma sheet*. During the 24-hours of Earth's rotation, polar FAC cables disconnect from the *dayside magnetopause* and reconnect to the *nightside plasma sheet*, where flux builds up and is reconnected Earthward again from the *magnetotail to the poles* and creates *substorms*. It is a feedback loop generator that switches on when the solar wind IMF is southward facing. *Magnetospheric-ionospheric coupling* occurs through saturation by CMEs, solar flares, coronal holes (co-rotating interactive regions or CIR), exceeding the threshold of the quasi-steady state for a *solar minimum* or *quiet sun magnetosphere*. The bridging or chafing at the magnetic poles between the closed and open field lines takes place when magnetic flux bundles in transit pile up between the two zones, creating misaligned tubes and bundles, and therefore *auroral current sheets materialize to release the Maxwellian-Boltzmann stress distributions of energy locally*.[273] Although the optically visible aurora – arches,





Figures 59 & 60: (Left) – Jan Mayen Island observation of magnetic reconnection; (Right) – Simplified schematic of MR, showing anti-parallel magnetic field merging, diffusion region (grey rectangle), and outflow jets ejecting reconnected flux and plasmoids (magnetic islands).

271 Hantao Ji of the Princeton Plasma Physics Laboratory [brackets added for clarification], as quoted in Shannon Brescher Shea, "Solving a Plasma Physics Mystery: Magnetic Reconnection," Office of Science, U.S. Dept. of Energy (3 October 2013), www.energy.gov/science/articles/solving-plasma-physics-mystery-magnetic-reconnection; Yi-Min Huang, "Predicting Magnetic Explosions: From Plasma Current Sheet Disruption to Fast Magnetic Reconnection" (22 June 2018), https://www.energy.gov.science/fes/articles/predicting-magnetic-explosions-from-plasma-current-sheet-disruption-to-fast-magnetic-reconnection.

272 Parker, *Spontaneous Current Sheets in Magnetic Fields*, 378-82; Gonzalez and Parker, *Magnetic Reconnection*, 213-471; Torbjörn Sundberg, "On the Properties of Ionospheric Convection" *Licentiate Thesis in Physical Electrotechnology*, KTH School of Electrical Engineering, Stockholm, Sweden (2009): 1-41, www.diva-portal.org/smash/get/diva2:212488/FILLTEXT01.pdf; A. Runov, V. Angelopoulos, *et al*., "Global and Local Processes of Thin Current Sheet Formation During Substorm Growth Phase" *Journal of Atmospheric and Solar-Terrestrial Physics* 220 (1 September 2021): 105671(1-19), https://doi.org/10/1016/jastp.2021/105671; M. Echim, M. Ciobanu, *et al*., "Multiple Current Sheets in a Double Auroral Oval Observed from the MAGION-2 and MAGION-3 Satellites" *Annales Geophysicae* 15 (April 1997): 412-23, https://doi.org/10.1007/s00585-997-0412-8; David I. Pontin, "Theory of Magnetic Reconnection in Solar and Astrophysical Plasmas" *Philosophical Transactions of the Royal Society A* 370 (2012): 3169-3192, https://doi.org/10.1098/rsta.2011.0501.

273 Parker, *Spontaneous Current Sheets in Magnetic Fields*, 378-38; J. C. Coxon, Stephen E. Milan, and Brian J.

curtains, draperies, crowns, etc. – is a stochastic, localized plasma physics phenomena in the Earth's *ionosphere*, its specific location and flux intensity is strongly influenced by the *dynamic magnetospheric membrane* of interstellar macro-scale MHD forces. It is the *polar interface that displays auroral fireworks on a floating plasma screen*, or more accurately, *floating electrical current sheets along a fluid network of disturbed magnetic field lines*.

Jan Mayen Island auroral journals contain multiple entries pertaining to MR that occurred in the highly charged skies above. Most are purely descriptive, but amongst the 97 journal sketches are a few that capture the most explosive examples of *magnetic field line merging and its byproducts*. In particular, we highlight one episode from the late evening (~10:50-11:04 p.m.) of 9 December 1882, that would be associated with *nightside reconnection at the magnetotail*. As can be seen in Figure 59, initially an arch arose near the zenith stretching from SE-SW (marked 'a' and 'b'). A few minutes later a broad and luminous band extended from NE to SE via the zenith, then behind it from the north a "cluster of light" becomes broader as it approaches the zenith then formed the curved band marked 'c' and 'd'. Almost immediately a *crown* develops between the two field lines, reaching the highest level of light intensity (4). The *crown* in this case would be the *diffusion zone where eruptive energy is released by MR*. During the 1.5 minutes of intense fusion physics, the small clusters of light in between the arched field lines (i.e., *magnetic islands*) were described as looking like "silvery little lambs lined up in a row." Interestingly, "a whistling, clearly audible sound" was heard by the Austrian team simultaneous to the creation and expulsion of the *plasmodia* – the only instance reported that entire observation year. After the crowning event, the top arch flattened out then adopted the same curvature (inverted 'U' shape) as the bottom one and both jointly flowed southwards, while the light intensity remained strongest in the NE as the apparition slowly moved away.[274] When comparing Figures 59 and 60, it is evident that the Jan Mayen Island event ~140 years ago contained the key topological signatures that advanced computer simulations portray for anti-parallel MR.[275] What is depicted in the Jan Mayen sketch is a *secondary instability in the Sweet-Parker current sheet* known as a *tearing instability*, whereby the *original current sheet experienced further thinning* as it entered a fully *non-linear phase*. The explosive form of *"fast" Petschek MR in the stretched current sheets* resulted from a *plasmoid instability*; and it would be logical to assume that the crowning observed was induced by breaking down of the 'frozen-in' condition of magnetic field lines in the dissipation (i.e., *crowning*) region, culminating in a tremendous release of energy at the reconnection site. This form of field line merging is called *fractal reconnection* owing to the different sizes of *magnetic islands* created by *current sheet thinning* and is usually associated with a *nightside (magnetotail) reconnection FTE*.[276] *Plasmoid chains* – the *linking of magnetic islands of relatively equal size* as was described in the Biskopsberga aurora – is the outcome of *guide field or "spontaneous" MR*, while *"stochastic" or anti-parallel MR* is connected with *magnetotail BBF* witnessed in the late evening hours as sketched in Figure 59.[277]

An alternative pathway for solar wind particle flux

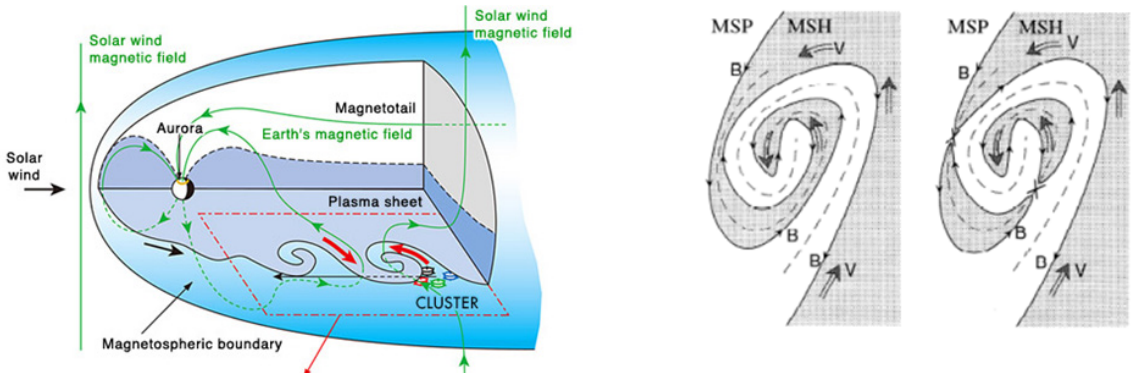
Anderson, "A Review of Birkeland Current Research Using AMPERE" in Andreas Keiling, *et al.*, ed., *Electric Currents in Geospace and Beyond, Geophysical Monograph 235* (New York: John Wiley & Sons, Inc., 2018): 259-278, https://agupubs.onlinelibrary.wiley.com/doi.abs/10.1002/9781119324522.ch16; Erwin Walter, "Filed-Aligned Currents and Flow Bursts in the Earth's Magnetotail" Bachelor Thesis, Dept. of Physics, Umeå University, Sweden (7 June 2018): 1-38, http://www.diva-[ortal.org/smash/get/diva2:1214673/FULLTEXT01.pdf.

274 Bóbrick, *Preliminary Report*, vol. II, part IV: No. 54, 10:49-11:04 p.m., and 12:17 a.m., 82-85, Fig. 43. Magnetic reading variations for the observation time: D=445-381; HI=423-208; VI=402-379.

275 The excellent review of MR over the past 80 years is found in M. Hesse and P. M. Cassak, "Magnetic Reconnection in the Space Sciences: Past, Present, and Future" *Journal of Geophysical Research: Space Physics* 125.2 (February 2020): e2018JA025935(1-24), https://doi.org/10.1029/2018JA025935. Figure 1 (Fig. 60 in this article) is located on page 2.

276 Hesse and Cassak, "Magnetic Reconnection in the Space Sciences": 1-24; Gonzalez and Parker, *Magnetic Reconnection*, 358-391; P. Markidis, P. Henri, G. Lapenta, *et al*., "Kinetic Simulations of Plasmoid Chain Dynamics" *Physics of Plasma* 20.8 (August 2013): 082105(1-24), https://doi.org/10.1063/1.4817286; Sundberg, "On the Properties of Ionospheric Convection": 1-13.

277 Markidis, *et al.*, "Kinetic Simulations of Plasmoid Chain Dynamics":1-24.3



Figures 61 & 62: (Left) – MKHI vortices forming on the dusk-dawn flank side of the magnetosphere during a northward directed IMF reconnection event, which start out as sinusoidal perturbations and then evolve into full-blown magnetic Kelvin-Helmholtz instabilities as measured by CLUSTER satellites on 20 November 2001. Each vortex measured ~40,000 km in length; (Right) – Magnetic Reconnection occurs at the X-lines in the vortex sheet cresting wave. Magnetosheath (turbulent, hotter, denser) plasma mixes with Magnetosphere (reconnected, colder, less dense and languid) plasma generated by a shearing instability.

to enter the Earth's magnetosphere is *vortex-induced magnetic reconnection* via the *nonlinear stage (rolling-up) of a Kelvin-Helmholtz instability* (Fig. 61).[278] Disturbed solar wind flow increases shear (friction) along the *IMF-magnetosphere boundary*. Mixing of two plasma varieties at the *magnetopause interface* occurs as the vortices propagate along the *dawn-dusk flanks*. The length of KHI vortices has been measured up to 40,000 km (24,855 miles). As the chain of vortices spins in the tailward direction, *magnetic field lines* from the two systems *become twisted and oppositely directed, thinning the current sheet between them*. Consequently, *field lines reconnect* and *solar wind plasma is transferred very efficiently across the boundary into the magnetosphere* (Fig. 62).[279] KHI are geomagnetic wave pulsations known as ULF (ultra-low frequency) waves, which are a continuous compressional isotropic (sinusoidal) mode coupled with a sporadic Shear Alfvén (anisotropic, field-aligned) wave mode.[280] Conversely, *when magnetic KHI appear during a southern-directed IMF, they are extremely unstable* owing to multiple X-lines along the vortex curl and dissipate quickly.[281] Owing to the *longevity of magnetic Kelvin-Helmholtz instabilities under northern IMF conditions* allows for extended periods of human observation time.[282]

On the evening of 29 October 1882, the skies above Jan Mayen Island were teeming with auroral apparitions and the magnetometer was measurably active. Around 9 o'clock, a faint arch appeared in the north-northwest, which dissolved into haze at the same time in the west-northwest to north-northeast arose a "throw of threads so fine that the appearance resembles a fine delicate lace veil. Seemingly without cause, a spiraling strong crown emerges,

278 Hiroshi Hasegawa, "Space Gas Vortices Carrying Source Particles of Aurora" *Forefront of Space Science* (2006): 1-3, Figure 1, http://www.isas.ac.jp/e/forefront/2006/hasegawa/.

279 Sundberg, "On the Properties of Ionospheric Convection": 11-12, Figure 2.4.

280 Heilig, Beggan, and Lichtenberger, "Natural Sources of Magnetic Field Variations": 5-8. KHI are designated as Pc4-5 continuous pulsations.

281 Hasegawa, "Space Gas Vortices Carrying Source Particles of Aurora": 1, Figure 1; H. Hasegawa, M. Fujimoto, K. Takagi, *et al*., "Single-Spacecraft Detection of Rolled-up Kelvin-Helmholtz Vortices at the Flank Magnetopause" *Journal of Geophysical Research* 111.A9 (September 2006): A09203(1-10), https://doi.org/10.1029/2006JA011728; H. Hasegawa, A. Retinò, A. Vaivads, *et al*., "Kelvin-Helmholtz Waves at the Earth's Magnetopause: Multiscale Development and Associated Reconnection" *Journal of Geophysical Research* 114.A12 (December 2009): A12207(1-20), https://doi.org/10/1029/2009JA014042; T. K. N. Nakamura, F. Plaschke, H. Hasegawa, *et al*., "Decay of Kelvin-Helmholtz Vortices at the Earth's Magnetopause under Pure Southward IMF Conditions" *Geophysical Research Letters* 47.13 (16 July 2020): 087574(1-10), https://doi.org/10/1029/2020GL087574.

282 Nakamura, Plascke, Hasegawa, *et al*., "Decay of Kelvin-Helmholtz Vortices…": 1-8.

Figures 63 & 64: (Left) – Jan Mayen Island sketch of the "Swirling (Spiral-shaped) Crown" that contains all the geometrodynamic signatures of a Kelvin-Helmholtz instability along the flanks of Earth's magnetosphere; (Right) – One of several similarly pecked glyphs at the Three Rivers petroglyph site, New Mexico.

which becomes most intense at 9:03 p.m., sending out a long band to the south at minus 120º and a short band at south plus 60º and exhibits a colorful display… Nearly the entire firmament is covered with fine, strong, short, long, straight, and tortuous rays. The crown appears to winding-in on itself" (Fig. 63). The entire rolling spiral structure moved south-southwest for three minutes then disappeared below the horizon after 9:05 p.m.[283] It was quite a unique happenstance; and *may be the first scientifically chronicled evidence for viscous diffusion of IMF flux across the magnetopause into the magnetosphere with a high degree of scientific credibility*. Rays emerged above and below the Kelvin-Helmholtz instability, giving the appearance of a spinning eye with long and short lashes (i.e., *plasma rays*). The 'eyelashes' are *solar wind flux* transferring into the *magnetosphere* from the two twisted and oppositely aligned field lines reconnecting. Its vortical geometric form bears a striking resemblance to Native American petroglyphs (Figure 64) created by the Mogollon people in the Jornada Style (1000-1400 C.E.) during a span of time when auroral visions were recorded globally in the Northern Hemisphere.[284] Peratt has argued that *powerful active sun particle emissions* would generate *intense photonic activity* that would not only make the *auroral funnel visible*, but that "portions of the magnetosphere and its tail would also be visible" to the human eye.[285] That would explain how a KHI on the magnetopause's flank at a distance of ~10-15 Earth radii (65-96,000 km or 40-60,000 miles) from Jan Mayen Island could be seen at night.

Our last chronicled example of *auroral magnetic reconnection* is from a German broadsheet published in the late seventeenth century titled "Fire Ball in the Heavens, Thought-provoking Triple-Miracle Sign," that dramatically heralded the end of the Maunder Minimum.[286] On 4 November 1697, twin floating *feuerkugel* [balls of fire] were observed simultaneously over the city of Hamburg (to the west) and towns of Lübeck and Mecklenberg for fifteen minutes, between the evening hours of 6 and 7 p.m. local time. Hamburg and Mecklenberg are located 161 km (~100 miles) from each other to provide a sense of proportionality

283 Bóbrick, *Preliminary Report*, vol. II, part IV: No. 25, 9:00-05 p.m., 40; Tafel VIII, Fig. 1.

284 Picture by Curt Mekemson, https://wandering-through-time-and-place.com/2017/08/02/pass-the-datura-please-i-want-to-make-a-square/spiral-galaxy-rock-art-at-three-rivers-petroglyph-site/. For Jornada-style petroglyphs and material culture, see Polly Schaafsma, *Rock Art in New Mexico* (Santa Fe: Museum of New Mexico Press, 1992), 57-77.

285 Peratt, "Characteristics for the Occurrence of a High-Current, Z-Pinch Aurora as Recorded in Antiquity": 1193.

286 We would like to thank Bärbel Wagner of the Frankfurt and Rare Prints Collection at the Universitaetsbibliothek Johann Christian Senckenberg, Goethe-Universitaet Frankfurt am Main, for her assistance locating and providing a high-resolution copy of the following source: "Feuerkugel am Himmel, Nachdencklich-dreyfaches Wunder-Zeichen/ I. Eines groß-erschröcklich-feurigen Cometen; II. Eines entsetzlichen Feuer-Kugel Lufft-Ziechens; III. Einer sehr ungestalten Fontagne-Miβgeburt […], 1697, Kupferstich, detail; Sammlung Gustav Freytag, Signatur: Einblattdr. G. Fr. 13, https://sammlungen.ub.uni-frankfurt.de/4360129.

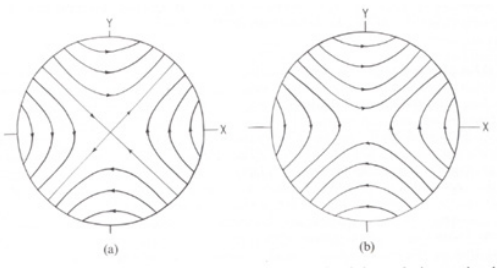
Figure 65: Two hovering fireballs seen simultaneously over the town of Mecklenberg (left) and city of Hamburg (right), in 1697.

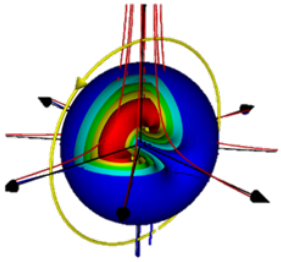
captured in the wood-block print (Fig. 65). A complete translation is included in the footnote from whence the following descriptions are extracted.[287] Although similar in appearance, each fireball had a unique texture and dynamics. The ball that hovered over Mecklenberg generated a tremendous amount of steam, which after fifteen minutes it emitted a loud bang and report, as if an earthenware shell had broken off or burned loose from the *feuerkugel*. It then disappeared before the bewildered faces of several thousand townsfolk. Contrastingly, the fireball floating above Hamburg had a pronounced X-marked on its surface and was silvery radiant. When the cross-shaped ball vanished, it did so with an extremely bright and fearsome flash of light but without any audible sound. Interestingly, *auroral crowning events with similar morphology* were transcribed in the Jan Mayen Island journals. As stated by Bóbrick discussing the movement of light in opposite directions on auroral forms with a lattice or crisscross pattern: "The same was the case with those crowns in which there were two or more that had become crown-like simultaneously. Rows of rays covered and wrapped around the common center in opposite directions."[288] What physical process or instability would account for standing waves encircling the polar and equatorial surface of a globe-like cosmic plasma structure?

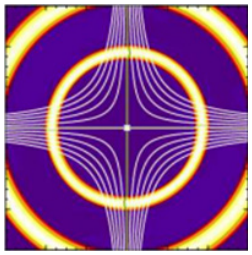
A different model of *field line merging* that would explain the phenomenon is called *oscillatory reconnection*. It posits the concept of a *spherical null collapse (X-point collapse) as an implosive type of magnetic reconnection in the solar atmosphere*. In this scenario, the null point has a spine and fan shape, which traps MHD waves through refraction. Oscillations result from MHD waves refracting

287 "The Second Wrathful Warning Sign" – that is what was written [about this celestial vision] by [the authorities in] Lübeck [township], and is also a clarion call for us to make improvements [in our Christian faith], as well as a [warning] to all of the atheists, epicureans, sodomites, licentiously vain, and prostitutes, that [those guilty of] similar sinful behavior should [repent] and strive to avoid [such] abominations [in the eyes of God], is the following [Heavenly warning sign]: Which occurred on Thursday, Nov. 4, towards the evening between 6 and 7 o'clock, in the same district towards the Mecklenburg town wall, a large, fiery ball in the form of an earthenware ball was seen hovering/floating in the open air for a quarter of an hour. Such a phenomenon or aerial sign itself [was seen] over the Hamburg horizon, at the same time and hour, yet under the sign of a cross within the admiring sight of many thousands, who thoughtfully presented the following difference [between the twin phenomena]: namely that the ball [over Mecklenburg], after a determined quarter of an hour's appearance of steamy hovering, made [the sound] of a pop or bang with echoing [effect], as if the coarse [outer shell] protection or a piece had been loosened [from it] or had burned loose, etc., and then immediately before the face of many thousands of spectators, it dissolved or disappeared; but the cross-shaped ball figure [in Hamburg], after the same amount of time, removed itself [silently] with a shimmering, brightly shining, frightening flash [of light] and was lost to the eye of the spectator."

288 Bóbrick, *Preliminary Report*, vol. II, part IV: 10.







Figures 66, 67, & 68: (Left) – Diagram of Hall quadrupole magnetic field in the x-y plane, (a) is subjected to an azimuthal perturbation (b) that initiates oscillatory reconnection across a cylindrical surface; (Middle) – Magnetoacoustic waves of lower amplitude flowing towards and away from the null point are in the linear realm and therefore do not create asymmetric current sheets, but instead generate a circulating ring of magnetic flux in the y-plane; (Right) – Contours of a 2D Hall MHD fast magnetoacoustic wave annulus that split into two pulses (annuli) travelling inward and outward radially at a magnetic null point.

constructively and destructively between the diffusion region – shaped like a small shell surrounding the null radius – and its closed domain (spine and fan) boundary. As fast magnetoacoustic waves pass through the null, the shock waves also alter the *current sheets* (i.e., thinning) and *twist magnetic field lines*. In other words, the *null collapses and forms current sheets with reverse polarity which oscillate periodically with each implosive reconnection pulse*. As the pulses continue, annular (toroidal) waves form in response to incoming and outgoing flux that superpose and create the *standing nonlinear MHD wave pattern* seen in Figure 66.[289] Since the spine and fan planes (with parallel current sheets) are perpendicular to each other, this geometric configuration might explain the intersecting ring-like currents around the magnetic null (Fig. 67).[290] It has also been noted that *periodic polarity reversals in current sheets take place when magnetic islands emerge from flux tubes or within stretched current sheets, processes known to occur during geomagnetic storms and substorms*.[291] Figure 68 is a 2D representation of nonlinear MHD fast magnetoacoustic waves propagating towards and away from an X-point.[292] Although research on *oscillatory*

289 Parker, *Spontaneous Current Sheets in Magnetic Fields*, 300-303, Figure 10.4 "(a) The initial quadrupole field subject to (b) the azimuthal perturbation"; J. O. Thurgood, D. I. Pontin, and J. A McLaughlin, "On the Periodicity of Linear and Nonlinear Oscillatory Reconnection" *Astronomy & Astrophysics* 126 (January 2019): A106(1-12), https://doi.org/10.1051/0004-6361/201834369; J. W. Threlfall, C. E. Parnell, *et al*., "Nonlinear Fast Magnetoacoustic Wave Interaction with 2D Magnetic X-points in the Ion Cyclotron Range of Frequencies" *Astronomy & Astrophysics* 544 (August 2012): A24(1-13), https://doi.org/10.1051/0004-6361/201219098; Jonathan Thurgood, David Pontin, and James McLaughlin, "Implosive Collapse about Magnetic Null Points" *Astrophysical Journal* 855.1 (March 2018): 50(1-15), https://doi.org/10.3847/1538-4357/aaab0a0; Jonathan O. Thurgood, David I. Pontin, and James A. McLaughlin, "Three-Dimensional Oscillatory Magnetic Reconnection" *Astrophysical Journal* 844.1 (August 2017): 2(1-12), https://doi.org/10.3847/1538-4357/aa79fa.

290 Thurgood, Pontin, and McLaughlin, "Three-Dimensional Oscillatory Magnetic Reconnection": Figure 1b, "Perturbing flux ring $\boldsymbol{B}_1$, superimposed upon the background field. Colored isosurfaces profile the increasing perturbation field strength from zero (transparent) through weak (blue) to strong (red). The circulation of flux ring field lines in planes of fixed y is illustrated by the yellow line."

291 M. J. Murray, L. van Driel-Gesztelyi, and D. Baker, "Simulations of Emerging Flux in a Coronal Hole: Oscillatory Reconnection" *Astronomy & Astrophysics* 491.1 (January 2009): 329-337, https://doi.org/10.1051/004-6361:200810406; J. A. McLaughlin, G. Verth, V. Fedun, and R. Erdélyi, "Generation of Quasi-Periodic Waves and Flows in the Solar Atmosphere by Oscillatory Reconnection" *Astrophysical Journal* 749.4 (April 2012): 30(1-10), https://doi.org/10.1088/0004-637X/749/1/30.

292 Threlfall, Parnell, *et al*., "Nonlinear Fast Magnetoacoustic Wave Interaction…": Fig. 2, top left (t= 0.30).

Figure 69a-d: Types of oscillatory reconnection recorded in/on various materials: stone, ceramic, animal skin, and wood from South Africa and the Middle East – a) petroglyph from Dreikops Eiland, South Africa; b) Samarran pottery motif; c) round boat used to travel along the Tigris & Euphrates Rivers; d) Egyptian hieroglyph.

reconnection conducted thus far primarily focuses on *flaring, CME, and assorted nonlinear MHD processes that occur in the solar atmosphere*, the disturbance of magnetic fields and fast or explosive reconnection events are a reality of Earth's auroral system.

To frame *oscillatory magnetic reconnection* upon the larger canvas of human history, *topological surface states* of the physical processes involved have been preserved in miscellaneous modalities. In the language of *Chaos theory*, let's take some "random walks" through the past 7,000 years or so of material culture to visualize how our ancestors from around the world recorded auroral encounters with MR in material culture. Our baseline geometric shape is a circle enclosing a cross. In ancient Mesopotamia this form was used as a clay symbol or tally with the meaning of "sheep"; while in ancient Phoenician script it was pronounced "tēt" and signified the word for "wheel."[293] To illustrate, Figure 69a is a petroglyph from Dreikops Eiland, South Africa, estimated to have been etched from 2500-1000 *ykr*.[294] The subsequent image (Fig. 69b) is a painted pottery motif from the Samarran Hassunah period, dated ~5500-4800 BCE.[295] Adjacent to the motif (Fig. 69c) is a type of round skin boat called a *quffa*, fabricated from animal hides stretched over a wooden frame. It has been used to float in the Tigris and Euphrates rivers since ~1000 BCE.[296] The last image (Fig. 69d) is a single *hieroglyph* relief carved on a large wooden panel from the tomb of *Hesira*, an Egyptian high official in Saqqara during the Old Kingdom's Third Dynasty ~2649-2576 BCE. One of two identical *hieroglyphs* on the panel, it carries the meaning of '*city*', '*town*', or '*Egyptian land ruled by pharaohs*' when combined with the *crown hieroglyphs* of Upper and Lower Egypt, respectively.[297]

The image of a cross in a circle – commonly depicted with 4 to 8 arms (such as the *chi-rho* with six) crossing in the center, or with an annulus/solid circle in the center from whence arms and concentric circles radiate outwards – is found across six continents and many islands (i.e., 'Anaeho'omalu on Hawai'i Island) scattered throughout the pre-Modern eras of history.[298] Two images below place a definitive coda on the material culture and scientific

293 Denise Schmandt-Besserat, *How Writing Came About* (Austin: University of Texas Press, 1997), 70-72, Fig. 25, Sign ATU 761/ZATU 575, "Sheep," Uruk (W 21418.4), Iraq; "Phoenician Alphabet," https://en.wikipedia.org/wiki/Phoenician_alphabet.

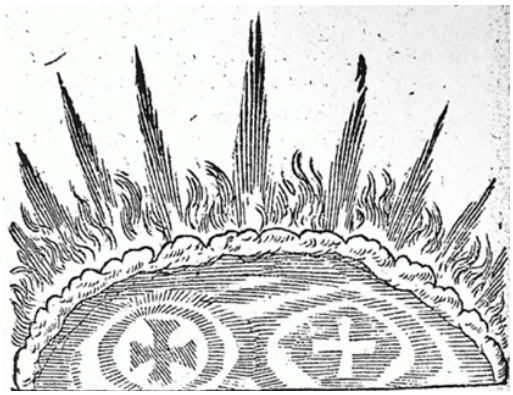
294 Dowson, *Rock Engravings of Southern Africa*, 50, Plate 78; David R. Morris, "Dreikopseiland and the 'Rain's Magic Power': History and Landscape in a New Interpretation of a Northern Cape Rock Engraving" Master's Thesis, Department of Anthropology and Sociology, University of the Western Cape, South Africa (2002), https://etd.uwc.ac.za/xmlui/handle/11394/151.

295 Beatrice L. Goff, *Symbols of Prehistoric Mesopotamia* (New Haven: Yale University Press, 1963), 3, Illustration 30.

296 Brian Lavery, *Ship: The Epic Story of Maritime Adventure* (New York: DK Publishing, 2008), 10-12.

297 Gay Robbins, *The Art of Ancient Egypt, First Ed.* (Cambridge, Mass: Harvard University Press, 1997), 51, Fig. 46; E. A. Wallis Budge, *An Egyptian Hieroglyphic Dictionary, Vol. I* (New York: Dover Publications, Inc., 1978), cxxvii, cxxxiv.

298 Georgia Lee and Edward Stasack, *Spirit of Place: The Petroglyphs of Hawai'i* (Los Osos, California: Bearsville and Cloud Mountain Presses, 1999), 57-65, 179. The glyphs were carved during ~1100-1700 CE.



Figures 70 & 71: (Left) – Chumash Native American cave art showing cross-similar auroral forms chronicled over Hamburg and Mecklenberg in 1697; (Right) – Cornelius Gemma's woodblock print of the Hellespont aurora, 1569.

evidence presented in this section. Figure 70 is a photograph of cave art from one panel created by Chumash Native American people, with sundry figures painted between ~1100-1800 CE. Known locally as the Chumash Painted Cave State Historic Park in Santa Barbara, California, its geometric artwork preserves auroral encounters on stone despite destructive graffiti from descendants of European settlers.[299] The woodblock print (Figure 71) is from astronomer Cornelius Gemma's *De Naturae Divinis Characterismis* published in 1575. Gemma witnessed the image of *two crosses on an auroral bulge* over the Hellespont on 10 September 1569, around 11 p.m. The *first crucifix* (left) was described *as red in color and octagonal-shaped*, the *second one was glowing white*.[300] In both figures below, *X-point, O-point, oscillatory, null-point spine/fan varieties of magnetic reconnection are strongly represented*, including a *DPF wheel with eight spokes*.

As was manifested in Figure 68, *the dynamics of oscillatory MR and its topological resemblance to the Celtic cross is uncanny*. Auroral imagery is intricately entangled with the evolution of human religious beliefs, symbols of political/religious authority, and pivotal turning points in the comparably short history of *Homo sapiens* – including the end of the last Ice Age and transition to the Neolithic era. It is especially prominent in the history of Christianity, and thus we will conclude this section with two examples to that effect. Constantine I, Roman emperor in 306-337 CE, had a vision of a crucifix in the sky, one

Figure 72: (Left) – Early *chi-rho* symbol carved into a marble sarcophagus flanked by the Greek letters *alpha* and *omega,* circa mid-late fourth century CE; **Figure 73**: (Right) – A portion of Raphael's "Vision of the Cross" fresco in the Apostolic Palace of the Vatican.

299 Santa Barbara Museum of Natural History, "Cave Painting", https://www.sbnature.org/collections-research?anthropology/chumash-life/cave-painting. Photograph from "Chumash Painted Cave State Historic Park, California", https://commons.wikipedia.org/wiki/Category:Chumash_Painted_Cave_State_Historic_Park_California, LCCN2013631567.tif.

300 Rens Van der Sluijs, "Caught in the Crossfire," 1-4, https://thunderbolts.info/wp/2012/07/17/caught-in-the-crossfire/. The caption below reads "Drawing of the Aurora Borealis observed over the Hellespont on 10 September 1569."

day and night before the epic Battle of Milvian Bridge on 28 October 312 CE.[301] The auroral apparition was credited for his military victory over Maxentius and subsequent conversion of the late Roman empire to Christianity. Eusebius wrote that "about the time of the midday sun… he saw with his own eyes, up in the sky and resting over the sun, a cross-shaped trophy formed from light, and a text attached to it which said, 'By this conquer' (*Hoc Vince*). Amazement at the spectacle seized both himself and the whole company of soldiers which was then accompanying him on a campaign…"[302] That evening Constantine dreamt about his vision: "as he slept, the Christ of God appeared to him with the sign which had appeared in the sky and urged him to make himself a copy of the sign… and to use this as protection against the attacks of the enemy." When he awoke the next morning – depending on the source – Constantine ordered that a military standard (*labarum*) be made with the symbol of Christ and that his soldiers' shields be similarly adorned: "he marked on their shields the letter X, with a perpendicular line drawn through it and turned round the top, thus ☧, being the cypher of Christ."[303] *Armed with a divine sign of the cross, Constantine's military victory at the gates of Rome was a turning point that cascadingly altered the future historical arc of Europe initially, then scaled across the entire world at the Anthropocene threshold*. The images below (Figures 72 & 73) were created during the fourth century and sixteenth centuries (1520-1524 CE), respectively.[304]

How can one be sure that this was not an example of *parhelion* (a.k.a., *sun dog*, *mock sun*), which is a cross-like refraction pattern of light scattering through hexagonal ice crystals suspended in the upper atmosphere? By triangulating this date with additional authoritative records that explicitly mention auroral and/or solar activity, coupled with ^{14}C dating of ice cores, archaeological artifacts, and tree rings (dendrochronology), *it is possible to gauge the likelihood of space weather impacts backwards in linear time*. Two European chroniclers bookmark the dates 300 and 333 CE as auroral sightings.[305] Lycosthenes' *Chronicon* mentions Constantine's vision (312 CE) and other sky prodigies occurring in Italy for the years 305 and 320.[306] The East Asian historical catalogue is more robust. Chinese, Korean, and Japanese dynastic annals identify celestial anomalies in the years 303, 305 (2x), 307, 309, 313, 318, and 329 CE.[307] Constantine I's vision of 312 CE fits within the cluster of data points indicating an *active sun pattern*. Although climatologically speaking the period ~200–900 CE is dubbed the "Dark Ages Cool Period," temperatures during 300-330 CE were comparatively warm for that time but dropped precipitously afterwards.[308] Therefore, based

301 Some traditions place the date to 27 October 312 CE. John Julius Norwich, *A Short History of Byzantium* (New York: Alfred A. Knopf, 1997), 5-11.

302 Averil Cameron and Stuart G. Hall, *Eusebius: Life of Constantine* (Oxford: Clarendon Press, 1999), 79-82.

303 Norwich, *A Short History of Byzantium*, 6; Cameron and Hall, *Eusebius*, 81-85.

304 Figure 70: "Monogramme of Christ (the Chi Rho) on a plaque of a sarcophagus, 4th-century CE, marble, in the Vatican Museum, on display in a temporary exhibition at the Colosseum in Rome, Italy", https://commons.wikimedia.org/wiki/File:Chrisme_Collseium_Rome_Italy.jpg., by Jebulon, 23 August, 2013; Figure 71 – Raphael's "Vision of the Cross" fresco in the *Sala di Constantino* of the Vatican's Apostolic Palace, https://en.wikipedia.org/wiki/The_Vision_of_the_Cross#/media/File:School_of_Raphael_-_Vision_of_the_Cross.jpg. After 353 CE, the Greek letters *alpha-omega* appeared in tandem with the *chi-rho* motif.

305 Strothers, "Ancient Aurora": 93, (300 CE *Oracula Sibyllina* XII 89-90; 333 CE Aurelius Victor XLI).

306 Lycosthenes, *Prodigiorum ac Ostentorum Chronicon*, 272-273. The date given for Constantine's vision was actually 315 CE. Following a search for reconciling the dates provided by Lycosthenes from the Roman Era, we have adjusted his chronology by subtracting 3 years from those dates listed in *Prodigiorum*. The years given for auroral, celestial, or solar visions after 700 CE are more or less in synch with existing sources.

307 K. K. C. Yau, F. R. Stephenson, and D. M. Willis, "A Catalogue of Auroral Observations from China, Korea and Japan (193 B.C. – A.D. 1770)" Council for the Central Laboratory of the Research Councils 1995: 3.

308 D. J. Easterbrook, "Using Patterns of Recurring Climate Cycles to Predict Future Climate Changes" in Don Easterbrook, *Evidence-Based Climate Science: Data Opposing CO_2 Emissions as the Primary Source of Global Warming 2nd Ed.* (Amsterdam: Elsevier, 2016), 395-411; Universität Bern, Media Relations (E) "The Climate is Warming Faster than it has in the Last 2,000 years" (2019):



Figure 74a, b, & c: a) – Bluetooth's Ring Fortress at Trelleborg/Sligelse on Zealand Island; b) – One of Bluetooth's silver cross coins dated to ~980 CE; c) – Reverse side of a gold coin referred to as the 'Curmson Disk' from approximately the same time period, Harald Gormsson's name is on the obverse side.

on the data available, combined with the profound impact auroral events can have on human psychological states of mind, *we have high confidence that this 'miraculous' event was an auroral form*.[309]

The second example occurred during the so-called Medieval Warm Period (~900-1300 CE) when global temperatures were approximately 1º Celsius warmer than present.[310] It also displays many key similarities with Constantine I in his religious conversion from paganism to Christianity. Harald "Bluetooth" Gormsson, King of Denmark and Norway (c. 958-985/86 CE), was the first Viking monarch to openly adopt and promote the Catholic faith amongst a polytheistic and violent Norse folk. According to the fragmentary documentation from this period, sometime in the 960s King Harald I of Denmark was baptized by a monk named Poppo, who had performed a miracle as Bluetooth's precondition to conversion. In 965, King Harald I erected two runic inscriptions called the "*Jelling Stones*" testifying that he had "made the Danes Christian."[311] However, it was not until 979-80 that Bluetooth undertook a multi-pronged strategy of unifying tenaciously independent Viking tribes – politically, economically, militarily, and religiously – with Christianity. Six ring forts, known as *trelleborg*, were constructed around Denmark and parts of Norway recently subjugated by troops loyal to the Danish king. As depicted in Figure 74a at Trelleborg-Slagelse, each of the defensive structures was built in the geometric shape of a cross bordered by a circle (as seen in the Hamburg/Mecklenberg and Chumash examples), with residential and commercial buildings in each quadrant.[312] Secondly, Bluetooth began minting "cross coins" that became the first locally produced

https://unibe.ch/news/media_news/media_relations_e/media_releases/2019/medienmittelungen_2019/the_climate_is_warming_faster_than_it_has_in_the_last_2000_years?index_eng.html, see "Global Mean Warming/Cooling Rates over the Past 2,000 Years" image at the bottom of the page.

309 It is not difficult to distinguish between parhelion (static & short duration) and an auroral event (dynamic, colorful, longer duration). Even the chronicler/artist who composed the *Book of Miracles* in Augsburg during the mid-1500s CE easily made the distinction between the two dissimilar events.

310 D. J. Easterbrook, "Temperature Fluctuations in Greenland and the Arctic" *Evidence-Based Climate Science 2nd Ed.*: 137-160.

311 Pius Wittman, "Harold Bluetooth" in Charles G. Herbermann, ed., *The Catholic Encyclopedia, Vol. 7* (New York: Robert Appleton Company, 1910), 141; Irina-Mari Manea, "Harald Bluetooth & the Conversion of Denmark" *World History Encyclopedia* (23 April 2021), https://worldhistory.org/article/1733/harald-bluetooth--the -conversion-of-denmark/; Wikipedia, "Harald Bluetooth" https://en.wikipedia.org/wiki/Harald_Bluetooth.

312 Markus Milligan, "The 7 Viking Ring Forts – Trelleborg" *Heritage Daily* (14 May 2018), https://heritagedaily.com/2018/05/the-7-viking-ring-forts-trelleborg/119665; Wikipedia, "Harald Bluetooth"; Manea, "Harald Bluetooth & the Conversion of Denmark." The forts constructed ~980 CE were situated in Aggersborg, Borrering, Borgeby Castle, Fyrkat, Trelleborg on Zealand (Slagelse), and Nonnebakken. Figure 70a from Wikimedia Commons, https://commons.wikimedia.

(the word "national" is anachronistic) coinage in the Norse regions, utilizing Christian iconography to promote his own political legitimacy (Figure 74b & 74c).[313] A third prong was to establish a Catholic bishopric at Fyen, and the construction of a small wooden church dedicated to the Holy Trinity in his capital of Roskilde.

From the time of Harald I's birth in 910/11 CE, baptism in the 960s, through his death in 985/86 and twenty years subsequent, *extreme space weather events* were plentiful and an important psychological motivation behind Bluetooth's evangelical statecraft at a critical inflection point in Viking history. Contemporary observations recorded by Islamic intellectuals/officials provide a wider context for the phenomena. In 922 CE, the Iraqi envoy Ibn Fadlán visited the "Land of Darkness" near the Ural Mountains and described the following auroral encounter:

"The first night that we spent in [the land of the Bulghárs], before the light of the sun faded, [a full hour before sunset] I saw the horizon turn a brilliant shade of red and in the upper air there was a great noise and tumult. I raised my head and saw red mist like fire close to me. The tumult and noise issued from it and in the cloud were shapes of men and horses. These spectral men held lances and swords. I could see them clearly and distinguish them. Then suddenly another bank of mist appeared, just like the first, as one cavalry detachment falls upon another. Frightened, we began to pray and beseech god most humbly, while the locals laughed at us and were astonished at our behavior. We watched the two armies charging. They clashed for a moment and then parted, and so it continued for an hour after nightfall. Then they vanished. We questioned the king on this subject. He claimed that his ancestors said: 'They are the believing and the unbelieving *Jinn*. They fight every evening and have not failed to do so every night since they were first created."[314]

Interestingly, *Jinn* – or 'genie' in Western lore, *were created by Allah from smokeless fire before humankind and were invisible to our eyes except when they wanted to be seen*. The repeated clashing of armies as reported by Ibn Fadlán, in conjunction with a *flugblatt* of an armed conflict in the Heavens over the Germanic village of Mittelfischach in 1667 (see Figure 75), *simulate the mechanics of magnetic reconnection*. Additionally, if one examines oral traditions from around the world that separate divine beings into forces of *good* and *evil – angels* and *demons*, *devas* and *asuras*, *yang* and *yin*, believing and unbelieving *Jinn* – the linkage between auroral displays and their long-term psychological impact on human societies adds another dimension for comprehending spiritual beliefs across scales of time.

Documentary evidence of *auroral/solar activity* during this era is more plentiful than that of Constantine I. Starting with the annum 930 CE for European lands, Lycosthenes' *Prodigiorum ac Ostentorum Chronicon* (1557) preserved descriptions and illustrations of unusual celestial events for the ensuing dates: 930, 935, 937, 940, 941, 944, 956, 963, 968, 969 (2x), 975, 979, 982, 983, 989, 991, 997, 999, 1001, 1002, and 1005.[315] The years 931, 939, 941/42, 951, 965, 967, 968, 977, 978, 979, 986, 988, 991, 992/93, 996, 1003, and 1004 are identified with recorded *abnormal solar activity* in Byzantine, Arab/Muslim, and East Asian sources.[316] Harald Bluetooth's massive state-building

org/wiki/File:Trelleborg_airphoto.JPG.

313 These coins were minted around 980 CE, with Moesgaard offering a possible earlier date of 975 CE. Tom Metcalfe, "Double Hoard of Viking Treasure Discovered near Harald Bluetooth's Fort in Denmark" (1 May 2023), https://finance.yahoo.com.news/double-hoard-viking-treasure-discovered-135601650.html; Vendsyssel Historical Museum, "Harold Bluetooth's Cross Coins and a Newly Found Viking Hoard" (16 May 2013), https://www.medieval.eu/harold-bluetooth-cross-coins-hoard-vendsyssel/; see also Jens Christian Moesgaard, *King Harold's Cross Coinage: Christian Coins for the Merchants of Haithabu and the King's Soldiers* (Odense: University Press of Southern Denmark, 2015). Figure 74b from Metcalfe, "Double Hoard…"; Figure 74c from Wikipedia, "Curmson Disk", https://en.wikipedia.org/wiki/Curmsun_Disc.

314 Italics added by the authors for emphasis. Ibn Fadlán, *Ibn Fadlán and the Land of Darkness – Arab Travellers in the Far North*, Paul Lunde and Caroline Stone eds. & trans. (London: Penguin Books, 2012), 30-31.

315 Lycothenes, *Prodigiorum ac Ostentorum Chronicon*, 360-369. The dates for this era in the *Chronicon* are not in need of adjustment based on a comparison with other sources.

316 Yau, Stephenson, and Willis, "A Catalogue of Auroral Observations from China, Korea and Japan (193 B.C. – A.D. 1770)": 10-12; Dates and country – 937 (China), 939 (Japan 2x), 951 (China), 965 (China), 967 (Japan), 968 (China), 979 (China 2x), 986 (China 2x), 988 (China), 992 (Korea), 996 (China), 1003 (China), 1004 (China 3x). Nafiz

projects – including the expansion of his central military facility in Aarhus, construction of identical crucifix-similar ring forts and minting of cross-stamped coins – took place during 977-980 CE. An intense allocation of labor and resources was expended in a remarkably short span of three years, synchronized to the following auroral observations: Italy – 975 and 979; Egypt – 977; Central North Africa – 977/978; Morocco – 979; and twice in China – 979. The convergence of solar events at this key juncture is more than coincidental; it offered the Danish/Norwegian king a timely opportunity to use the fear-inducing heavenly apparitions for purely political purposes. Despite there being no written source that specifically draws a connection between Bluetooth's actions and auroral activity, we contend that the *geometrodynamics* inherent in the material evidence speaks volumes of said influence in Viking-worked stone, wood, and metal.

Further proof for exceptional solar fireworks displays at the end of the common era's tenth century is the *Miyake Event* of 993 CE. "Miyake events" (named after Fusa Miyake's 2013 dissertation) are extremely high concentrations or spikes of radiocarbon/^{14}C trapped in tree rings, originally dated to 774/75 CE. Subsequent discovery of five additional spikes (actually pulses of cosmic radiation) brings the grand total to *six events that have been officially recognized*.[317] For the two events identified in the common era (774 and 993, respectively), radioactive isotopes also include ^{10}Be (Beryllium-10) and ^{36}Cl (Chlorine-36) trapped in ice core samples from Greenland and Antarctica.[318] Beryllium-10 and Carbon-14 are produced in the Earth's stratosphere by *spallation* – nuclear reactions of cosmic ray particles smashing into oxygen and nitrogen atoms (^{14}C is produced by ^{14}N only), whereby their nuclei emit multiple isotopes (muons and nucleons). *Spallation* of Argon-40, however, creates Chlorine-36 isotopes. To put it another way, particle collisions unleash a "*cosmic-ray cascade*" leading to a *spallation reaction*, that triggers *secondary reactions* of protons, neutrons and clusters, which in turn continue to '*pinball*' around the upper atmosphere striking other atoms and unleashing mesonic, hadronic, and sundry electromagnetic effects.[319] When the *Miyake Event of 993 CE* occurred during the reign of King Seongjong of Goryeo [Korea] (c.981-997), the auroral observation chronicled for December 992/January 993 reads: "At night, the gate of Heaven was opened."[320] It appears to have remained ajar for at least 1-2 years based on the isotope and tree-ring data collected thus far globally.

To summarize a *Miyake episode's profound significance*, sharp unambiguous radiocarbon signatures in tree rings and ice cores are virtually indisputable evidence of a *massive SEP event caused either by 'superflares' or an immense coronal mass ejection*. Studies suggest that to produce the

---

Maden, "Historical Aurora Borealis Catalog for Anatolia and Constantinople (hABcAC) during the Eastern Roman Empire period: Implications for Past Solar Activity" *Annales Geophysicae* 38.4 (July 2020):889-899, https://doi.org/10/5194/angeo-38-889-2020; Dates and region/country – 931 (Baghdad), 939 (Syria), 988 (Constantinople). Hassan M. Basurah, "Auroral Evidence for Early High Solar Activities" *Solar Physics* 225.1 (November 2004): 209-212, https://doi.org/10.1007/s11207-004-1372-8; Dates and region/country – 939/40 (Syria), 941 (Spain), 977 Egypt, 979 Morocco, 991/992 (Egypt). Mohamed Reda Bekli and Ilhem Chadou, "Records of Auroras in Arabic Historical Sources: Additional List and Preliminary Analysis" *Solar Physics* 295.1 (January 2020): Article 3(1-11), https://doi.org/10.1007/s11207-019-1567-7; Dates and region/country – 939 (Arab world), 942 (Andalusia, Spain), 977/978 (Central North Africa), 979 (Muslim West), 991 (Syria).

317 From oldest to most recent Miyake events' chronology: 7176 BCE, 5410 BCE, 5259 BCE, 663 BCE, 774/75 CE, 993/94 CE.

318 Friedhelm Steinhilber, Jose A. Abreu, Jürg Beer, *et al*., "9,400 Years of Cosmic Radiation and Solar Activity from Ice Cores and Tree Rings" *PNAS* 109.16 (17 April 2012): 5967-5971, https://pnas.org/cgi/doi/10.1073/pnas.1118965109; Qingyuan Zhang, Utkarsh Sharma, Jordan A. Dennis, *et al*., "Modelling Cosmic Radiation Events in the Tree-ring Radiocarbon Record" *Proceedings of the Royal Society A* 478.2266 (October 2022): 2022.0497(1-31), https://doi.org/10.1098/rspa.2022.0497; Fusa Miyake, Masataka Hakozaki, Katsuhiko Kimura, *et al*., "Regional Differences in the Carbon-14 Data of the 993 CE Cosmic Ray Event" *Frontiers in Astronomy and Space Sciences* 9 (July 2022):886140(1-8), https://doi.org/10.3389/fspas.2022.886140.

319 Royal Holloway University of London, "Cosmic Rays" *AntarcticGlaciers.org*, https://www.antarcticglaciers.org/wp-content/plugins/antarcticglaciers-pdf/download.php?p=7145.

320 Yau, Stephenson, and Willis, "A Catalogue of Auroral Observations from China, Korea, and Japan": 12, No. 111.

radioactive isotope spikes discovered in the two common era incidents, the energy released would have measured *at least 1-2 times higher in magnitude* than the Carrington Event of 1859![321] Analysis of data from the 774 and 993 *solar superstorms* reveals that the latter event was a bit smaller (higher radiation spike with shorter duration of rays hitting the atmosphere) in comparison to the former, *but much larger and devastating than any astrophysical phenomena experienced by humans in the most recent 1,000+ terrestrial orbits around our sun ever since*. If a *Miyake event* were to strike the Earth's *magnetosphere* in our time, the jarring increase of cosmic radiation would trigger an "electronic apocalypse" – shutting down power plants, frying telecommunications and internet infrastructure (including submarine cables and satellites), completely disrupt running water and sanitation, medical facilities, transportation, and damage the biosphere with potentially serious long- and short-term consequences.[322]

Figure 75: Auroral encounter over the village of Mittelfischach in the early morning hours of 15 November 1667.

What makes the 774 and 993 CE dates noteworthy is the fact that they are "*globally coherent*," meaning that radiocarbon spikes for the same year were discovered in trees from *both hemispheres*. When these dates coincide with high concentrations of ^{10}Be and ^{36}Cl extracted from ice core samples, *the prevailing science points to their solar genesis*. Whether or not they occurred near a *solar maximum*, however, is vigorously debated.[323]

VI: Not-So-Random Walks Through Time – Using Geometrodynamics as a Heuristic Tool for Deciphering Human Encounters with the *Aurora Borealis/Australis*

The evidence presented thus far is only a *fractal view* of how *space weather events* have affected human societies since the end of the last Ice Age (Younger Dryas Period) ~9700 BCE. Conventional views of *Homo sapiens'* development over the long, polar arc of history are literally blind to the monumental role played by the *fourth state of matter and its auroral avatars*. In this final portion of the

321 Zhang, Sharma, Dennis, *et al*., "Modelling Cosmic Radiation Events...": 2-3.

322 Schoch, R. C. Ulissey, *Forgotten Civilization* (Rochester, VT: Inner Traditions, 2021), 163-174, 225-240.

323 Zhang, Sharma, Dennis, *et al*. "Modelling Cosmic Radiation Events…": 1-31; Katherine Kornei, "Mystery of Ancient Space Superstorms Deepens" *Scientific American* (6 March 2023), https:// www.scientificamerican.com/article/mystery-of-ancient-space-superstorms-deepens/.

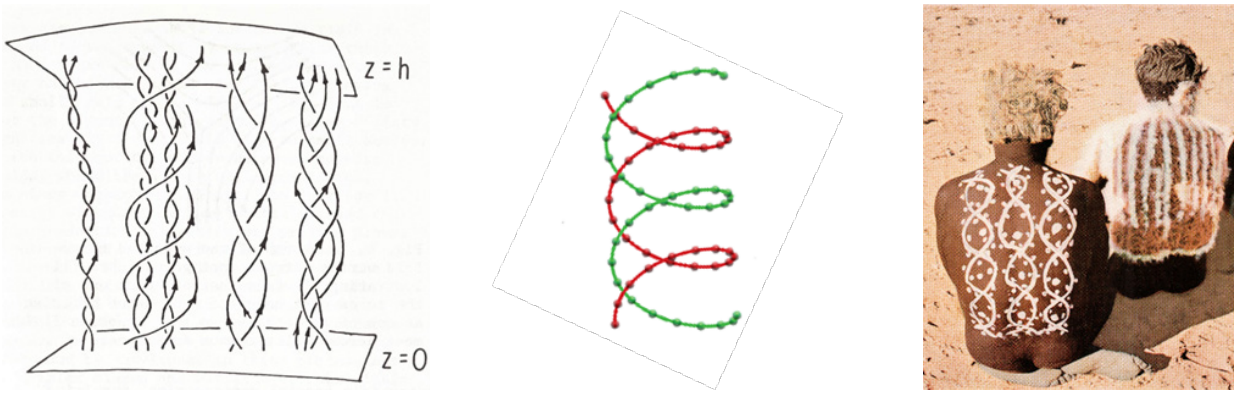


Figure 76a-c: (Left) – a) Four helically-winding flux tubes from left to right: twisted tube; two twisted tubes wrapped in a larger twisted envelope; a three-field line braid; and four-field tangled pillar. The last two are non-invariant in direction of field wrapping and topology; (Middle) – b) Double-helix flux tube with dust grain Yukawa balls serving as links in the string-of-pearls; (Right) – c) Aboriginal men participating in a religious ceremony dedicated to the ancestral fire totem of Rubindia in Central Australia. Three dusty helical flux tubes are painted on the back of the man seated on the left-hand side of the photo.

article, we employ scientifically observed morphologies and behaviors of *cosmic/dusty plasma* under Earth laboratory, near-Earth atmospheric, and heliospheric conditions to explain mystifying geometric shapes and patterns found in the human material record since that time. Moreover, we investigate how *space weather episodes* have influenced human societies and their attempts to comprehend some greater meaning behind the spectral forms observed on *floating plasma screens* – or *flying carpets – in the sky projected by solar activity*.

As was discussed in **Part V**, *dusty plasma crystals* self-organize into levitating triangular, square, rectangular, hexagonal, rhombohedral, FCC, BCC, and HCP lattice structures when exposed to DC and RF discharges in magnetic fields. They also have the propensity for '*string-of-pearls*' formations due to ion focusing that can "fold-up" into spindle, zigzag, single, double, or triple helical bundles. Several examples of similar *Coulomb/Yukawa ball arrangements* in auroras range across the timeline. Figure 75 is a broadsheet printed in 1667, commemorating the *polarlicht* experienced by the inhabitants of Mittelfischach village, which lies to the northeast of Stuttgart.[324] The top third of the broadsheet – contoured by swirling clouds – moving from left to right reveals: a *Crown of Rays*; two opposing armies in an orderly rectangular battle formation, with explosive activity at the central point of contact; a large ebony sun encircled by short rays; then *three crosses of black, blood-red, and blue colors*, respectively. In the middle portion, levitating *feuerkugel* [fire balls] are arrayed on the top two levels in a square (simple cubic) pattern, then phase transition to a hexagonal (HCP) lattice before falling to the Earth. This engraving captures the most spectacular forms witnessed on the celestial vault during a 2-3 hour span-of-time.

What is most interesting, however, is that the *solar storm* occurred during the Maunder Minimum, which 'officially' concluded around 1700 CE. In spite of its magnificent radiance, *le roy soliel* does not burn hydrogen uniformly when converting it to helium via nuclear fusion even if it is just a run-of-the-mill G2V "yellow dwarf" star. The truth is that our sun is highly unstable, irregular, and unpredictable (e.g., stochastic). CMEs, for instance, occur with an average frequency of *one per week during solar minimum*, and *2-3 times per day during solar maximum*.[325] Each explosive emission can contain upwards of 1 trillion kilograms of material, or the rough equivalent of 250,000

324 Abriss des Erschrecklichen wunderzeichens, so sich den 15. Novembr. 1667 beim dorff Mittelfischach am Firmament des Himmels bey auff gehender Sonn etlich stunden lang sehen lassen, [S.I.], 1667, Universitaetsbibliotehek Johann Christian Senckenberg (Frankfurt am Main), https://sammlungen.ub.uni-frankfurt.de/freytag/content/titleinfo/4360120. The title of the woodblock print reads "Destruction of the Terrifying Miracle Signs, that could be seen for several hours, on 15 November 1667, near the village of Mittelfischach in the Firmament of Heaven as the sun was rising."

325 NASA, "Coronal Mass Ejections on the Sun", https://www.jpl.nasa.gov/nmp/st5/SCIENCE/cme.html; Schoch,

aircraft carriers, at speeds moving away from its surface at over several million miles per hour![326] Consequently, a random lethal gas eruption from a middle-aged star during an *extended solar minimum cycle* is nothing out of the ordinary. The same can be argued for *Miyake events* or any solar-induced disturbance that travels through the interstellar medium. Our sun is an extremely complex and dynamical system, which is why *Chaos theory* is an effective analytical tool for the *fractal, self-similar, scale invariant behavior of cosmic plasma under different astrophysical and geophysical conditions*.

Evidence of chain-like, or pearl necklace-shaped *cosmic plasma flow patterns* in human material culture comes in many varieties. Figure 76a-c illustrates how a unidirectional magnetic field embedded in a highly conducting plasma with large *beta* density affects the *topology of fluid transport across the field*. External strains caused by the absence of equilibrium in the magnetic field push the field out of its lowest energy (laminar flow) state. Magnetic lines of force begin to twist and wrap around each other due to shuffling (rotation) of the footpoints at Z=0 subjected to external stimuli (Figure 76a).[327] For this simulation, disturbances from the convection zone beneath the cooler solar photosphere agitate the field lines moving upwards into the superheated coronal field region to bend, twist, and become entangled with one another. This in turn leads to *neutral point reconnection* – whereby non-equilibrium stress between the two fields evident in the twisting dynamics results in the following: rapid fluid transport across the field; superheating of the corona; acceleration of particles to relativistic speeds; flares and CMEs; radio, X-ray and γ-ray emissions.[328]

Analogous to coronal arches, pillars, hedgerows, prominences, etc., flux tube structures on the sun, superheated cosmic plasma flowing at the interface between fixed geomagnetic lines and a double layer (R1 & R2) of open Birkeland FAC behaves in similar fashion. The arching dynamics of auroral bands mimic plasma motion on the sun's surface, resulting in *flux tubes (i.e., pillars) transporting ionized gas between magnetic fields*. Figure 76a sketches four types of helical flux tubes. The next image (Fig. 76b) is a *double helix dust structure, whose resemblance to a DNA helix is more than topological*.[329] Figure 76c is a photograph of Australian aboriginal participants in a religious ceremony respectfully sitting during a break in the lengthy ritual. The ceremony was dedicated to the ancestral fire spirits, or totems, of the inhabitants near Rubindia (Mount Hay) in western Aranda (Central Australia).[330] Body painting, masks, and feathered ornamentation are iconic representations of various igneous spirits.[331] The man on the left-hand side of the photo has painted on his back *three helical flux tubes with Yukawa balls following the twisted magnetic field lines*. Through ritualized symbolism, memory of auroral events in antiquity – such as witnessing dusty magnetic flux transported through helical tubes in the sky – continue to be preserved in myriad ways.

The self-similar behavior of fractal cosmic plasma on Earth's geomagnetic field lines, as well as the solar surface, are self-evident in topological comparisons. From the geometric shape of plasma structures, scientists can analyze the MHD processes at various stages of

---

Forgotten Civilization, 134-141.

326 Moldwin, *An Introduction to Space Weather*, 2-3.

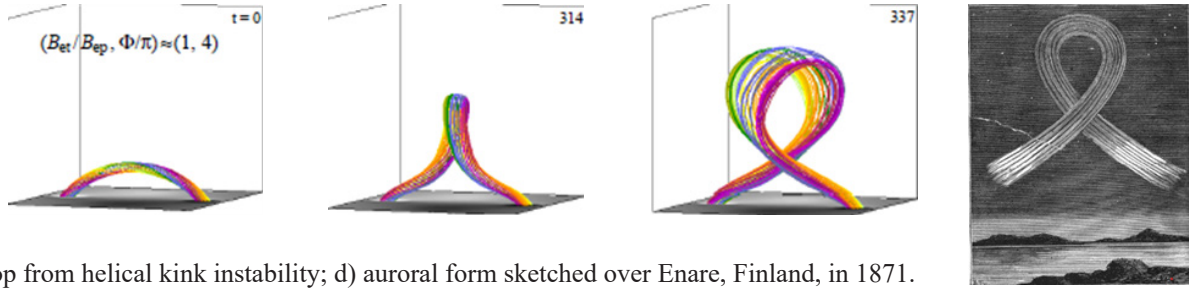
327 Eugene N. Parker, "Magnetic Reconnection and Magnetic Activity" in Edward W. Hones, Jr., ed., *Magnetic Reconnection in Space and Laboratory Plasmas* (Washington, D.C.: American Geophysical Union, 1984): 35, Fig. 2, "A sketch of some of the forms of twisted and wrapped field lines that may occur in the unidirectional field as a consequence of shuffling the footpoints of the lines of force (at Z=0)."

328 Parker, "Magnetic Reconnection and Magnetic Activity": 32-38.

329 Tsytovich, Morfill, Fortov, *et al.*, "From Plasma Crystals and Helical Structures Towards Inorganic Living Matter": 1-10, Figure 3a. Given the *corpuscular nature of cosmic plasma* under non-equilibrium conditions, adjacent coiled flux tubes can transfer information between their outer membranes/cylinder walls through two torus-shaped vortices (*dust convective cells*). The vortex cells that self-organize on the tube's lateral sides squeeze the conducting fluid inwards, creating a "bifurcation" or zone of particle acceleration.

330 Ronald M. Berndt, ed., *Australian Aboriginal Art* (New York: The MacMillan Co., 1964), 57-59, plate 12

331 Aldo Massola, *The Aborigines of South-Eastern Australia As They Were* (Adelaide, Australia: The Griffin Press, 1971), 32-37, 54-61, 72-94.



Figures 77a-d: a) – coronal arcade emerges, line-tied to two conducting footpoints; b) twisting of helical field lines as flux rises towards external magnetic field; c) full-fledged loop from helical kink instability; d) auroral form sketched over Enare, Finland, in 1871.

development. To illustrate, Figure 77d is a black and white drawing of an auroral form observed on 16 November 1871, at Enare presbytery in Finland. The source's description reads: "Fig. 3 gives an idea of the variety of forms that the phenomenon may affect… The aurora this time took on the form of a glowing red band, curved as is shown in the figure. The two extremities bordered on yellow and green [respectively]."[332] A series of color computer generated images in Figures 77a-c were modeled after a '*confined filament eruption*' on the sun in active region NOAA 9957 on 27 May 2002. Images captured by the TRACE (Transition Region and Coronal Explorer) satellite at the 195 Å (ångström unit) line were simulated to mimic a *helical kink instability* in a magnetic flux rope. Viewing the figures sequentially: 77a is the emergence of a twisted flux rope in an arcade-like profile; 77b shows the helical deformation or writhing behavior that produces an inverse-*gamma* shape; 77c the filament attains its maximum height and form integrity prior to disintegrating back down towards its photospheric footpoints. The filament/rope did not result in an explosive CME, but instead underwent magnetic reconnection twice when affected by external magnetic fields above the loop and below – with helical then vertical current sheets, respectively.[333] As was described by the Austrian Expedition, horizontal auroral bands occasionally rose up towards the zenith to become helically-twisted arches.[334] Even though astrophysical environments for both phenomena are vastly different, the mechanics and dynamics are virtually identical.

Other examples of *Yukawa string-of-pearls arrays that mirror electrostatic coupling in cosmic/dusty plasma experiments* abound. To reinforce the divine ritualistic

Figure 78a, b: (Left) – 1850s lithography of Australian Aboriginal ceremonial dancers; (Right) – Rock art from Tassili n'Ajjer of a "Round Head" figurine dating between 7500-5000 BCE.

332 "The Northern Lights," *Scientific American* 56.9 (26 February 1887): 135; Figure 3. Brackets added for clarification.

333 A. Hassanin, B. Kliem, and N. Seehafer, "Helical Kink Instability in the Confined Solar Eruption of 2002 May 27" *Astronomische Nachtrichten* 337.10 (31 November 2016): 1082-1089, Figure 1a, b, c, https://doi.org/10.1002/asna.201612446.

334 Bóbrick, *Preliminary Report*, vol. II, part IV: 4-5, 11.

social memory of ancient auroral encounters, Figure 78a is a lithograph from Australia in the 1850s.[335] The skin of male Aboriginal dancers on the right-hand side are painted in *Yukawa ball configurations*, while others bear chevrons, candy cane stripes, hash marks, serpentine lines, geometric patterns, etc., indicative of *cosmic plasma flow*. Aboriginal women also bore scarification marks on their upper torso with the same small sphere (keloid) design painted on males; a custom for females that is prevalent in traditional sub-Saharan African communities.[336] In southern Algeria, pottery and rock art (glyphs and paintings) emerged approximately 12,000-7,000 years ago. The so-called "Round Head Period" is an artistic style that flourished in 7500-5000 BCE. Figure 78b is a photograph of one Tassili n'Ajjer anthropomorph with similar dot patterns on its skin.[337]

There are innumerable locations globally with *cupules* (small round concave marks) carved, pounded, etched, or scraped into stone surfaces. Like all ancient petroglyphs, interpreting the meaning behind such labor intensive and time-consuming activity through the lens of 19th-21st centuries' Western scholarship is challenging, to say the least. Moreso for *cupules*, which are the oldest and most common form of rock art dating from the Lower Paleolithic through the eighteenth-century CE (the Holocene era is the most prolific), yet are – strangely enough – the least investigated form of hominid memorializing behavior. The most authoritative investigation of the phenomenon was conducted by Robert Bednarik of AURA (Australian Rock Art Research Association). To inadequately summarize Bednarik's detailed pioneering article, the atomic density (Mohs hardness scale) of the stone had two outcomes on production of the motif: harder surfaces (i.e., quartzite, 7) required much more labor, time, and human body/muscular stress than softer sandstone and limestone (4, 3, respectively).[338] Cultural significance and use of *cupules* diverged across societies. Speaking broadly, they were associated with weather phenomena (rain storms), fertility,

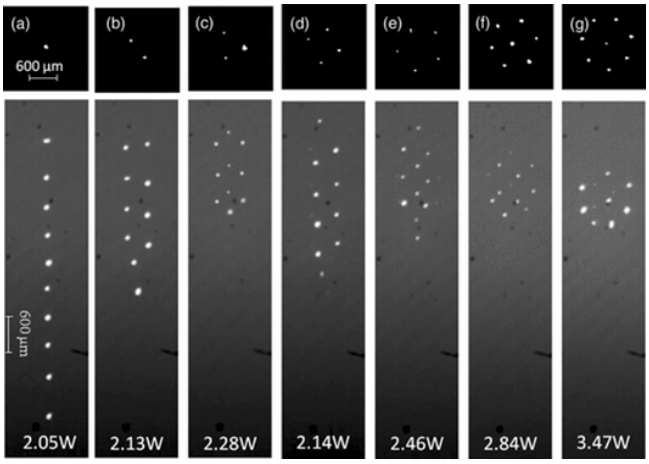


Figure 79a, b: (Left) – Assorted cupules and strings-of-pearls (or lines-of-dots) petroglyphs from Jebel Jassassiyeh; (Right) – Singular, folded, prolate, and helical chains of charged dust particle bundles from Baylor's CASPER lab.

335 P. G. E. Powell, *Prehistoric Art* (New York: Frederick A. Praeger, 1966), 73. The caption for the illustration reads "Lithograph of 'native festival' by W. Blandowski, a geologist and naturalist who made several expeditions into the hinterland of Victoria and South Australia in the 1850s."

336 Massola, *The Aborigines of South-Eastern Australia As They Were*, 92-93; The African History, "How Body Scarification Rooted African History and Culture for Centuries" (22 April 2022): https://theafricanhistory.com/2584.

337 Bradshaw Foundation, "Tassili n'Ajjer: Life on the Edge of the Sahara – Paintings and Engraving in Algeria": https://www.bradshawfoundation.com/africa/algeria/tassili_n_ajjer/images/2b.jpg. Photography by Ben Smith.

338 Robert G. Bendarik, "Cupules" *Rock Art Research* 25.1 (2008): 61-100. Using hammerstones on quartzite in a 21st century replication of cupules: 8,490 blows in 72 minutes led to a cupule of 1.9 mm deep; 8,400 blows in 66 minutes 4.4 mm deep; and 21,730 blows over a 2-day period to a depth of 6.6 mm. "The experimenters suffered fatigue and pain and often had to interrupt their work to rest." Sandstone, by comparison, took 2 minutes for a 12mm deep cupule.

coming of age rituals, board games, and as lithophones (stone gongs).

At the archaeological site of Jebel Jassassiyeh – the largest petroglyph concentration in Qatar – nearly one thousand carvings in fossilized sand dunes are spread out over 580 identified areas.[339] Dates for the *cupules* range widely because they are conflated with boat-shaped glyphs carved much later in the common era closer to the sea. Regardless, the strings of Yukawa pearls (single, double, or more rows), individual dots of varying size, or smaller dots encircling larger ones are estimated to be contemporaneous with the timeline 4th – 1st centuries BCE.[340] Figure 79a provides a sample of the *cupules* carved on the ground at Jebel Jassassiyeh.[341] Adjacent to that are a series of photographs (Figure 79b) taken of *complex plasma experiments* in RF discharge chambers located at Baylor University's CASPER facility.[342] The upper frame provides the view from above while the narrower frame below is the side view. *Both perspectives of vertical and helical arrangements reveal an uncanny likeness to cupules carved into the petrified sands of Qatar*.[343] In the natural sciences, experiments performed repeatedly under similar conditions that result in the same outcome (i.e., *reproducibility*) strengthens the validity of one's theory or hypothesis. Experiments with complex plasmas on Earth and in outer space have created a *geometrical data-log of surface state patterns and behaviors* that enables a more accurate interpretation of what are apparently random, enigmatic works of art from ancient times.

In Brazil's Paraíba state, a large rock (height ~3.5 m x 46 m length) known as the Ingá Stone near the town and river of same name exhibits a chaotic array of motifs. Estimated to have been carved sometime between 10,000-4000 BCE, the *cupules* are arranged both horizontally and vertically into rows of 1-6 strings and in circular or "grape-like" clusters.[344] The photograph in Figure 80 is a portion

Figure 80: Middle section of the Ingá Stone petroglyph panel – revealing multiple cupule formations.

339 Muhammed Abdul Nayeem, *The Rock Art of Saudi Arabia: Saudi Arabia, Oman, Qatar, the Emirates & Yemen* (Hyderabad, India: Hyderabad Publishers, 2000), 366-386.

340 Nayeem, *The Rock Art of Saudi Arabia*, 366-386; Wikipedia, "Jebel Jassassiyeh", https://en.wikipedia.org/wiki/Jebel_Jassassiyeh.

341 "Dot Carvings at Jebel Jassassiyeh", https://commons.wikimedia.org/wiki/File:Dot_carvings_at_Jebel_Jassassiyeh.jpg. Credit to Peter (16 December 2008), and Stellar D. for uploading the photo from Flickr.

342 CASPER is the acronym for Baylor's Center for Astrophysics, Space Physics and Engineering Research.

343 Hyde, Kong, and Matthews, "Helical Structures in Vertically Aligned Dust Particle Chains in a Complex Plasma': 6, Figure 4. The caption reads "Top view (upper) and side view (lower) of helical structures formed at varying RF powers using the technique described in the text. In all cases, the background pressure is held at 16 pa. In figures (a) – (c), each structure contains a total of ten particles, while figures (d) – (g) include a total of twenty particles. One- through four-chain structures are shown in (a) through (d), with six through eight chain structures (including the center chain) are shown in (e) through (g)."

344 Dating of the stone is conjectural, and usually placed around 6000 years ago. The native Tupi-Guarani lived in the region from ~10,000 BCE to ~1400 CE. José Dos Santos Martins, "Itacoatiaria do Ingá: Prospecção de seu Potencial Turístico" Instituto de Educação Superior da Paraíba, Directoria Acadêmica, Curso de Turismo (2003): 1-38, https://web.archive.org/web/20110706154937/http://cms-oliveira.sites.uol.com.br/tcc_jose_martins.pdf; UNESCO, "Itacoatiaras of Ingá River", https://whc.unesco.org/en/tentativelists/6000/; Telma Costa, "The Language of Inga Stone – A New Theory

Figure 81a, b: (a) – Dots in a small ring [left], periodicially arranged dots mixed with wavy lines in a larger elliptical ring [middle], and 3 big red pearls linked together [right]; (b) – Unorganized dots inside of a double envelope [left], above which a smaller ball has a cross configuration, and dots between zigzag lines [bottom right] with larger bubbles superposed on the former.

of the glyph panel's entirety.[345] Barbells, half-circles, letter "H" and "I" forms, linear bisected rings (some concentric), *globus cruciger*, zoomorphs, Solomon's knot, rosette, X-shaped, and assorted motifs chaotically overlap each other. According to Peratt, the curved figures resembling *mountain ram horns* hammered into stone at countless sites around the world match *impulse shock instabilities* propagating in *Z-pinch magnetized plasma*.[346] Other researchers examining the stone argued that several of the motifs bore a strong similartiy with Phoenician and Egyptian Demotic script or to glyphs found on Easter Island (Rapa Nui).[347]

About 3,200 km to the west of Ingá is the Chiribiquete National Park, located in Guaviare province in Colombia. According to the UNESCO World Heritage Center, "[o]ver 75,000 figures have been made by indigenous people on the walls of the 60 rock shelters from 20,000 BCE" to the present time, with a specific emphasis on "the worship of the jaguar, a symbol of power and fertility."[348] Painted in *red ochre* on the cliffs of the Guayabero/Guaviare River are tens of thousands of images that range across 13 km of rock shelters designated as Serrania de la Lindosa, Raudal de Guayabero, Cerro Azul, Limoncillos, and Nuevo Tolima, to name the most investigated and photographed sites. This particular stretch of artwork has been dated to the transitional Late Pleistocene/Early Holocene age (~11,000-6000 BCE) when the regional climate shifted abruptly from dry subtropical patches of thorny scrubland, savanna, and gallery forests to warmer and wetter tropical broadleaf forests. Human populations moving into the region memorialized giant sloth, mastodon, camelids, and horses in rock art panels which exquisitely portray the 'New World' in which these "colonizers" from Asia inhabited.[349] *With respect to chronicling megafauna that did not survive the Quaternary Extinction Event (~50,000 – 7000 BCE), Chiribiquete's rock art shares much in common with*

About the Origen of Phoenician Alphabet-Itacotiara/Brazil" *Journal of Oxford University History Society* 11 (2020): 1-11, https://www.ouhs.org/_files/ugd/a8b8e6_7adcd9348c3b403785f3f562e8ed9545.pdf;

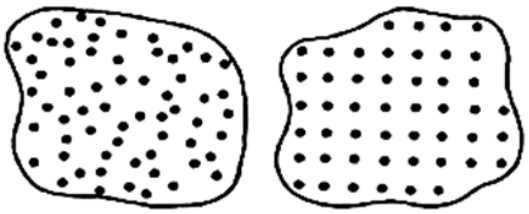
345 Figure 75 source: Telma Costa, "The Mystery of Brazil's Ancient Ingá Stone Might Have Just Been Solved": https://earthlymission.com/inga-stone-drawings-carvings-brazil-mystery-solution-solved/. Photograph by Marinelson Almeida Silva.

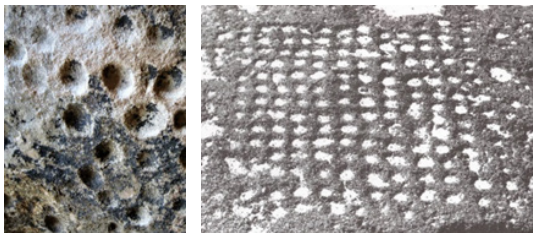
346 Peratt, "Characteristics for the Occurrence of a High-Current, Z-Pinch Aurora as Recorded in Antiquity":1206-1207.

347 Costa, "The Language of Inga Stone": 1-11

348 UNESCO World Heritage Center, "Chiribiquete National Park – The Maloca of the Jaguar": https://whc.unesco.org/en/list/1174/.

349 Guillermo Munoz Castiblanco, "Estética Amazónica y Discusiones Contemporáneas: El Arte Rupestre de la Serranía de La Lindosa, Guaviare – Colombia" *Calle 14: Revista de Investigación en el Campo del Arte* 15.27 (2020): 14-39, https://doi.org/10.14483/21450706.15406; J. Iriarte, M. J. Ziegler, A. K. Outram, *et al*., "Ice Age Megafauna Rock Art in the Columbian Amazon?" *Philosophical Transactions of the Royal Society B* 377.1849 (25 April 2022): 20200496(1-11), https://doi.org/10.1098/rstb.2020.0496; Gaspar Morcote-Ríos, Fracisco Javier Aceituno, José Iriarte, *et al.*, "Colonisation and Early Peopling of the Colombian Amazon during the Late Pleistocene and the Early Holocene: New Evidence from La Serranía La Lindosa" *Quarternary International* 578 (20 March 2021): 5-19, https://doi.org/10/1016/j.quaint.2020.04.026.





Figures 82, 83, & 84: (Left) Examples of amorphous and crystalline lattice arrays, respectively; (Right) – Disorganized cupules on the northern wall of Daraki-Chattan, India; (Far Right) – Highly organized cupule panel from Kapalaoa, Hawai'i.

Göbekli Tepe in southern Turkey - the oldest megalithic archaeological site discovered thus far (~10,000-8000 BCE).[350] Without question, the overwhelming majority of painted images are geometric designs, patterns, and motifs (such as helices, lattices, spirals, concentric circles, hands, zig-zags, etc.) that the authors view as *avatars of extreme solar activity recorded in antiquity*. *Dots and larger spheroids* are painted in myriad forms that would manifest as *cupules* if they had been carved into the cliff faces such as the Ingá Stone. Figures 81a-b capture several *dot/spheroid arrangements* from Serrania de la Lindosa.[351]

A salient feature of *cosmic plasma* is its ability to *transition between phase states* of dispersed ionic cloud 'vapor', amorphous liquid-like flow, polycrystalline organization and/or crystalline lattice arrays similar to alchemical processes in polymers and copolymers. In other words, from high entropy to low entropy, with mixed-states existing simultaneously across the same phase space at sundry intervals. Figure 81a displays – in the large middle elliptical envelope – *dots* on the left-hand side and predominantly *wavy lines* on the opposite hemisphere. This is an example of how complex plasmas self-organize a *crystal-fluid coexistence state* (ordered-disordered structure) through a *mode coupling instability* and/or via a *Schweigert instability* in a strongly coupled system. The *crystalline front* between the two marks a transition region from cooler to hotter temperature generated by magnetoacoustic (e.g., Alfvén) waves or ion wake instabilities in an *electrostatic trap generated within the plasma membrane*.[352] *Non-equilibrium phase coexistence and metastability of cosmic plasma are unique properties that exist for the fourth state of matter*. Therefore, it would be logical to assume that the *two main types of cupule/painted dot patterns found globally – amorphous and crystalline – are representations of dusty plasma states as witnessed and recorded by hominids through time*. Not exactly '*Maps in Time*', but more accurately described as '*Poincaré maps*' or '*phase portraits*' that capture a specific moment in auroral space-time on stone, wood, bone, metal, animal hide, fabric, etc. Figure 82 is a rudimentary illustration of *atomic/crystal/Bravais lattice configurations for amorphous and crystalline states in thin films*, respectively, *that resembles two dimensional semi-conducting matrices of silicon in its amorphous (or hydrogenated amorphous) and mono-crystalline forms*.[353] Figure 83 is a photograph of ancient (dated to the Lower Paleolithic era) *cupules* on a vertical

350 A menagerie of animals such as aurochs, wild boars, leopards/lions, Asiatic ass, gazelles, and bird species that died off after 8000 BCE in this region are depicted on the pillars and stone artifacts at Göbekli Tepe. Joris Peters and Klaus Schmidt, "Animals in the Symbolic World of Pre-Pottery Neolithic Göbekli Tepe, South-Eastern Turkey: A Preliminary Assessment" *Anthropozoologica* 39.1 (2004): 179-218, https://sciencepress.mnhn.fr/sites/default/files/articles/pdf/az2004n1a13.pdf; Klaus Schmidt, "Göbekli Tepe – the Stone Age Sanctuaries: New Results of Ongoing Excavations with a Special Focus on Sculptures and High Reliefs" *Documenta Praehistorica* 37 (2010): 239-256, https://doi.org/10.4312/dp.37.21.

351 Sources for Figure 76a-b, respectively: a) Iriarte, Outram, Robinson, *et al*., "Ice Age Megafauna Rock Art in the Colombian Amazon?": 4, Figure 2, photo by Iriarte; PBS, "Colombia – Wild and Free", https://www.pbs.org/show.colombia-wild-and-free/, photo 7/7 by Harald Pokieser.

352 H. G. Hariprasad, P. Bandyopadhyay, V. S. Nikolaev, *et al*., "Self-sustained Non-equilibrium Co-existence of Fluid and Solid States in a Strongly Coupled Complex Plasma System" *Scientific Reports* 12 (2022): 13882(1-12), https://doi.org/10.1038/s41598-17939-w; M. Rubin-Zuzic, G. E. Morfill, A. V. Ivlev, *et al*., "Kinetic Development of Crystallization Fronts in Complex Plasmas" *Nature Physics* 2 (March 2006): 181-185, https://doi.org/10.1038/nphys242.

353 The unit cell configuration shown is for a simple cubic (SC) structure to illustrate the distinction between amorphous

surface from Daraki-Chattan, India, that *displays plasma crystals in an amorphous 'solid' phase state*.[354] Adjacent is Figure 84 on the horizontal terrain near Kapalaoa beach on the Big Island of Hawai'i – concave percussion marks in lava rock aligned with *simple cubic lattice symmetry* in the form of a board game called *pāpamu*.[355] Comparable *periodic cupule ensembles* in square or rectangular formations can be viewed in rock art at diverse locations across our planet, and have been randomly dated along the linear timeline. A fragmentary sample thereof include the Lichtenburg District, South Africa; Nine Mile Canyon and Parowan Gap, Utah; Arroyo Hondo, New Mexico; the Kebaroti and Lanet sites in Kenya; Al Furaihah, Qatar; and Ain Farah, Sudan.[356]

Order and disorder, low and high entropy, *complex plasma aurorae* manifest themselves in a variety of colors, atoms, molecules, and assorted particles that self-organize into geometric patterns. Electron auroras are the most crystalline in composition, revealing finely detailed 'rayed' topology in forms such as sheaves, fans, crowns, arches, umbrellas, and curtains with vibrant hues. Protons also produce illumination, but due to their larger gyro-radius and collisional effects, ion beam density scatters with closer proximity to the Earth. Therefore, ionic morphologies and light appear less concentrated, spread out, isotropic, and 'atomized'.[357] *Black auroras*, however, are cold electron patches, arc segments, or Kármán vortex streets that are frequently observed in diffuse and pulsating auroras during a substorm recovery phase.[358] Unlike bright, energetic Earthward precipitating electrons, *black auroras* are electron concentrations in *cosmic plasma* where, according to one theory, a downward FAC is generated by nonthermal electrons rapidly exiting the topside of the ionosphere linked to a *magnetospheric driver*. On the other hand, it has also been asserted that a *black aurora is a localized event associated with an ionospheric feedback mechanism*.[359] Interestingly, in Weyprecht's classification system, a *black aurora* was termed *polarlicht segment* or *dunkle segment*,

---

and crystalline atomic lattice configurations. Source for Figure 82 – Earth Bondhon, "Solid-State Structure", https://earthbondhon.com/solid-state/. Compare it with the atomic bond structure for monocrystalline and amorphous (a.k.a. hydrogenated amorphous) silicon films. See Yamina Brahmi, "Electrostatic Interactions Effect on the Adsorption of Proteins on Hydrogenated Amorphous and Nanocrystalline Silicon at the Solid/Liquid Interface" Ph.D. Thesis, University of Oran (2018): 10-14, Figure 1.2, https://www.researchgate.net/publication/330997423.

354 The original photo for Figure 83 appeared in Robert Bednarik, Giraj Kumar, *et al*., "Preliminary Results of the EIP Project" *Rock Art Research* 22.2 (November 2005): 147-197, Figures 19 & 20. The photograph from Daraki-Chattan was downloaded from Wikimedia Commons, "File: Daraki-Chattan Cave Cupule 1.jpg", https://commons.wikimedia.org/wiki/File:Daraki-Chattan_Cave_Cupules_1.jpg. It also appears in Bednarik, "A Short Ethnography of Cupules" in Roy Qerejazu Lewis and Robert G. Bednarik, ed., *Mysterious Cup Marks: Proceedings of the First International Cupule Conference* (Oxford: Archaeopress Publishing, 2010), 109-114, https://www.researchgate.net/publication/322343104_A_short_ethnography_of_cupules.

355 Figure 79 source: Lee and Stasack, *Spirit of Place*, 65-66, Figure 5.18.

356 Sources given in sequence as in text: Dowson, *Rock Engravings of Southern Africa*, 33, Plate 37; Steven R. Simms, *Traces of Fremont: Society and Rock Art in Ancient Utah* (Salt Lake City: University of Utah Press, 2010), 45, 106; Polly Schaafsma, *Rock Art in New Mexico, A Fully Revised and Expanded Edition* (Santa Fe: Museum of New Mexico Press, 1992), 84, Figure 105; Bednarik, "A Short Ethnography of Cupules": 112, Figure 6; Nayeem, *The Rock Art of Arabia*, 378, Figures 21 & 23; Friedrich Berger, "From Circle to Square to the Image of the World: A Possible Interpretation for Some Petroglyphs of Merels Boards" *Rock Art Research* 21.1 (May 2004): 11-25, Fig. 13.

357 A. Omholt, *The Optical Aurora* (Berlin-Heidelberg: Springer-Verlag, 1971), 24-76.

358 A. E. Nel, M. J. Kosch, D. Whiter, *et al*., "A New Auroral Phenomenon, the Anti-Black Aurora" *Scientific Reports* 11.2 (19 January 2021): 1829(1-9), https://doi.org/10.1038/s41598-021-81363-9; Bruce A. Fritz, Marc L. Lessard, Matthew J. Blandin, and Philip J. Fernandes, "Structure of Black Aurora Associated with Pulsating Aurora" *Journal of Geophysical Research: Space Physics* 120.11 (25 November 2015): 10,096-10,106, https://doi.org/10.1002/2015JA021397.

359 KTH The Royal Institute of Technology, "Northern Lights: How 'Black' Auroras Actually Work" *Science Daily* (15 April 2015): www.sciencedaily.com/releases/2015/04/150415090904.htm; Fritz, Lessard, Blandin, and Fernandes, "Structure of Black Aurora Associated with Pulsating Aurora": 10,096-10,106.

and on one occasion was observed running parallel to the horizon over Jan Mayen Island.[360] A *black aurora* might explain the dark lance-shaped form (Figure 58) in the 1561 Nuremberg *flugblatt*, the final morphology witnessed by stunned onlookers; or it could be the recently discovered *plasma plume*. Assuredly, it is a *space weather-related singularity* (i.e., *emergent property*).

As ESA/NASA Cluster mission satellites have observed *in situ*, MHD plasma dynamics on the sun also exist in *Geospace*. In this case, three-dimensional null points, separators, and quasi-separatrix layers (QSL) are present in the *magnetotail current shee*t, along with clusters of nulls joined by separatrices elsewhere in the magnetosphere.[361] The Jan Mayen Island auroral journals present compelling evidence of their existence on the celestial vault. Multiple *fancher* [fans] attached to a variety of forms, such as crowns, arches, and umbrellas (i.e., *plasma penumbra*), are associated with 'rayed' electron emissions that we contend are *fan separatrix surfaces*. *Expanding and contracting behaviors recorded by the Austrian science team match kinetic energy flows in null point, torsional spine, and torsional fan reconnection*.[362] The disorganized parade of geometric shapes that become visible to the human eye in *Geospace* is a stochastic phenomenon, meaning it is impossible to accurately predict when, where, and how the *aurorae* will appear in the heavens above. Nevertheless, they can be analyzed statistically and *geometrodynamically* with the assistance of satellite and earthbound measuring devices shortly after their spectral debut; or even many centuries and millenia later in conjunction with relative, absolute, and comparative dating techniques.

Conclusion

Within the atomic lattice framework of Big History, there are three keys to unlocking (i.e., understanding or mapping) humanity's exceptional and unparalleled trajectory as a biological lifeform over the past ~300,000 years, during which we "have learned to tap larger flows of energy than any other organisms on earth…"[363] The first was natural selection, encoded data on DNA molecules, that enabled hominids to adjust and adapt to the Earth's dynamic surface environment prior to the emergence of *Homo sapiens*. Secondly, "symbolic language": speech, sign language (hands) and "body language" that allowed humans to exchange knowledge and skills such as complicated tool-making, or new behaviors like fishing, mining, the exchange of goods over long distances, and migrations out of Africa that occurred during the late *Sixth Threshold of Increasing Complexity* (~300,000 – 10,000 *ykr*).[364] The third key or adaptive mechanism was "*collective learning*" as opposed to individual learning, whereby "members of our species can inherit knowledge as well as genes."[365] Knowledge flows at a cumulative, more accelerated pace between multiple human beings simultaneously, compared to just two half-sets of DNA chromosomes that combine to create one (or several) biological lifeform(s) every nine months. *It is the intentional act of externally storing information/ knowledge in symbolic form on a variety of surfaces that becomes universal in the archaeological record during the Upper Paleolithic era, most notably with rock art and*

360 Bóbrick, *Preliminary Report*, vol. II, part IV: 8, 203; No. 50, 9:46-9:54 p.m.,76. The black aurora chronicled on 5 December 1882 (No. 50), emerged when "the firmament was filled continuously with auroral masses of indeterminate shape; however, it was illuminated with great intensity." Three unusual dark lines running horizontally appear to have been cold electron beams at a time of very active needle movement on the Theodolite device.

361 David I. Pontin, "Theory of Magnetic Reconnection in Solar and Astrophysical Plasmas" *Philosophical Transactions of the Royal Society A* 370.1970 (17 July 2012): 3169-3192, https://doi.org/10.1098/rsta.2011.0501.

362 Bundles of rays, 'ray throw' or 'jet throw' were analogues of the *fancher* form. Bóbrick, *Preliminary Report*, vol. II, part IV: 6; No. 57, 8:46-9:01 p.m., 91; No. 9, 10:32-10:52 p.m., 24, and 12:53-12:57 a.m., 25; No. 59, 8:17-8:56 p.m., 98-99; No. 79, 7:01-7:14, 133.

363 David Christian, "World History in Context" *Journal of World History* 14.4 (December 2003): 437-458; quote from page 444. We calibrate the emergence of *Homo sapiens* as a distinct species at 350,000-280,000 ykr based on the discovery of *homo sapiens*-similar remains at Jebel Irhoud, Morocco, dated by thermoluminescence to 315,000 ykr ± 34,000 years. See Jean-Jacques Hublin, Abdelouahed Ben-Ncer, Shara E. Bailey, *et al*., "New Fossils from Jabel Irhoud, Morocco and the Pan-African Origin of *Homo Sapiens*" *Nature* 546.7657 (08 June 2017): 289-292, https://doi.org/10.1038/nature22336.

364 Christian, *Maps of Time*, 171-203.

365 Christian, "World History in Context": 445-448; quote from page 445.

other material artifacts during and after the Adams Event ~40,000 BCE.

The sheer explosion of unprecedented symbolic artistic expression at the inception of the Upper Paleolithic notwithstanding, *artificial memory systems* – the means of recording, storing, and transmitting information outside of the human body – date from at least ~120,000-130,000 *ykr* according to the most recent studies.[366] As a consequence, we offer *extreme space weather events* as logical – and scientifically verifiable – explanations for the sudden, inexplicable explosions of mental complexity in the material culture of both *Homo sapiens* and *Homo neandertalensis* at three prehistoric junctures: 130,000-100,000 *ykr*; 40,000-39,000 *ykr*; and ~25,000-11,700 *ykr*. A trifecta of *extreme space weather epochs* synchronizes with the archaeological record, enabling academics to draft radically new '*cognitive maps of time*' for hominids prior to the Holocene/*Seventh Threshold of Increasing Complexity* that midwived the birth of human "civilizations" ~4000 BCE.

Overlapping chronologies of *devastating space weather episodes* with the *intermittency* of Middle-Upper Paleolithic hominid symbolic material culture could just be a random coincidence; or as we contend, it is compelling evidence of *collective learning* – specifically, *the cause and effect between auroral activity and climate change*. An unparalleled shift in *Homo sapiens* cognitive ability represented in the prehistorical archaeological record is one monumental factor behind what has been termed the "Upper Paleolithic Revolution."[367] Rock art and artifacts carved into bone and wood represent in two and three dimensions the evolution of human cognition, setting the stage for more complex methods of social organization, all enabled *via* the consumption of steadily increasing amounts of energy from animal, vegetable, mineral, and human resources (above and below the Earth's surface) after the last Ice Age.

The author of *Origins of the Modern Mind* (1991), Merlin Donald, proposed four-stages of hominid cognitive evolution: episodic (primate), mimetic (early hominid 4 million to 400,000 *ykr*), mythic/linguistic (*sapient* humans 500,000 *ykr* to present), and theoretic (recent *sapient* cultures ~50-40,000 *ykr* to present). According to Donald: "[t]he transition from preliterate to symbolically literate societies began in the Upper Paleolithic and has been marked by a long, and culturally cumulative, history of visuosymbolic invention. It has also been marked by a radical new development: the externalization of memory storage… External symbolic technologies enabled humans to create qualitatively new types of representations, eventually yielding powerful evocative devices like painting, sculptures, maps, mathematical equations, scientific diagrams, novels, architectural schemes… and so on. These elaborate devices serve an important cognitive engineering function: they set up states in the individual mind that cannot otherwise be attained… new representational possibilities emerged from a developing symbiosis with the external symbolic environment, the basis for a particularly radical form of enculturation."[368]

Fifty kilometers or so northeast of the city of Peterborough in Canada's Ontario province, is a white crystalline limestone rock outcropping, measuring 12 x 20 meters, with hundreds of petroglyphs still visible from the 1000+ originally reported. Weathered and superposed by later glyphs, the site officially designated as "Petroglyphs Provincial Park" is believed to have been

366 Artificial Memory Systems (AMS) are discussed in Francesco d'Errico, "Paleolithic Origins of Artificial Memory Systems" in Renfew and Scarre, *Cognition and Culture*: 19-50. Paradigm-changing studies for symbolic material culture include the following articles: D. L. Hoffman, C. D. Standish, M. García Diez, *et al*., "U-Th Dating of Carbonate Crusts Reveals Neandertal Origin of Iberian Cave Art" *Science* 539.6378 (23 February 2018): 912-915, https://doi.org/10.1126/science.aap7778; Dirk L. Hoffman, Diego E. Angelucci, Valentín Villaverde, *et al*., "Symbolic Use of Marine Shells and Mineral Pigments by Iberian Neandertals 115,000 Years Ago" *Science Advances* 4.2 (22 February 2018): 5255(1-6), https://doi.org/10.1126/sciadv.aar5255.

367 Ofer Bar-Yosef, "The Upper Paleolithic Revolution" *Annual Review of Anthropology* 31 (October 2002): 363-393, https://doi.org/101146/annurev.anthro.31.040402.085416.

368 Merlin Donald, "Hominid Enculturation and Cognitive Evolution" in Colin Renfrew and Chris Scarre, ed., *Cognition and Material Culture: The Archaeology of Symbolic Storage* (Cambridge: McDonald Institute for Archaeological Research, 1998): 7-17. Quote from page 15.

carved by Algonquian-speaking peoples during 900-1400 CE.[369] Descendants of the Ojibwe First Nations' people refer to the location as *Kinoomaagewaabkong*, a phrase that translates into English as "Teaching Rocks" or "Rocks that Teach." Notwithstanding myriad issues related to the site's preservation, or pre-European contact First Nations' nomenclature attached to it, the *indigenous concept of "teaching rocks" itself represents an artifical memory system or external symbolic storage device*.[370] Rock art is the precursor to developing a written form of spoken language that first appeared in the fourth millenium BCE – evolving from stages of symbolic (pictographic) to logographic to ideographic and eventually to syllabic and alphabetic. However, as the Buddha stated in the *Pali Canon* that "there are 84,000 *Dhamma* [teachings] to [achieve] enlightenment," dispersed human communities around the globe traveled different paths from petroglyphs and cave paintings to Sumero-Akkadian cuneiform, Egyptian hieroglyphics, Chinese characters, Mayan glyphs, Nordic *runes*, and Andean pre-Columbian knot records (*quipu/khipu*).[371]

Under the prevailing academic paradigm, a transitional phase between cave/portable art and written language (~4000 BCE) occurred during the Mesolithic/Neolithic eras in Eurasia. The emergence of geometric clay objects (commonly referred to as 'tokens' – for better or worse) and 'primitive' kiln-fired pottery, dating from the 10th millenniumto ~1000 BCE, appeared alongside rock art and written language well into the first millennium of the common era.[372] However, that traditional interpretation and 'rock-solid' timeline for fired and decorated clay objects has been complicated by the discovery of proto-pottery kilns in Gravettian culture (~31,000-20,000 BCE), and ceramic portable art such as the *Venus of Dolní V*ěstonice, found at the Upper Paleolithic site of the same name in Moravia (modern day Czech Republic), ^{14}C dated at 29,000-25,000 BCE. An astonishing >5,000 ceramic objects (mostly fragments with few intact) recovered from Dolní Věstonice comprised animal and human figurines, slab-like shapes, and over 2,000 pellet-size spheroids of burnt clay.[373]

If we add to this material culture 'anamaly' the earliest terracotta pottery unearthed in China and Japan, radiocarbon dated to ~18,000 and ~14,500 BCE, respectively, with geometric patterns pressed into the clay's exterior before firing, '*interpretive chaos*' ensues.[374] In the past decade, Western academics have backpedaled from definitive post-WWII era proclamations that pottery first appeared ~7,000

369 Joan K. Vastoukas and Romas K. Vastoukas, *Sacred Art of the Algonkians, A Study of the Peterborough Petroglyphs* (Quebec: Mansard Press, 1973), 26-27.

370 For a more thorough exegesis on the Peterborough Petroglyph Site, see the following: Paul G. Bahn, Robert G. Bednarik, and Jack Steinbing, "The Peterborough Petroglyph Site: Reflections on Massive Intervention in Rock Art" *Rock Art Research* 12.1 (May 1995): 29-41; Dagmara Zawadzka, "The Peterborough Petroglyphs/*Kinoomaagewaabkong*: Confining the Spirit of Place" 16th ICOMOS General Assemblies and International Symposium, Quebec, Canada, 29 September – 4 October, 2008: https://openarchive.iconomos,org/id/eprint/233/1/80-W9Fu-143.pdf. See also Ramblin' Boy, "The Peterborough Petroglpyhs: Building Over an Ancient Algonquian Ritual Site", https://albinder.me.2015/06/07/the-peterborough-petroglyphs-building-over-an-ancient-algonquian-ritual-site/#misrepresentation; Bradshaw Foundation, "Peterborough Petroglyphs Site", https://www.bradshawfoundation.com/canada/peterborough_petroglyphs/index.php.

371 *Khuddaka Nikaya*, *Theragatha* [Verses of the Elder Monks] 1024. *Dhamma* in Pali is *Dharma* in Sanskrit. Usually – but imperfectly – translated as "path, road, or door," it implies a teaching of the Buddha.

372 Lucy E. Bennison-Chapman, "Reconsidering 'Tokens': The Neolithic Origins of Accounting or Multifunctional, Utilitarian Tools?" *Cambridge Archaeological Journal* 29.2 (May 2019): 233-259, https://doi.org/10.1017/S0959774318000513.

373 Pamela B. Vandiver, Olga Soffer, Bohuslav Klima, and Jiři Svoboda, "The Origins of Ceramic Technology at Dolni Věstonice, Czechoslovakia" *Science* 246.4933 (24 November 1989): 1002-1008, https://www.researchgate.net/publication/6034930_The_Origins_of_Cermaic_Technology_at_Dolni_Vestonice_Czechoslovakia; Wikipedia, "Venus of Dolní Věstonice", https://en.wikipedia.org/wiki/Venus_of_Dolní_Věstonice.

374 Junko Habu, *Ancient Jomon of Japan* (Cambridge: Cambridge University Press, 2004), 3-53; Xiaohong Wu, Chi Zang, Paul Goldberg, *et al*., "Early Pottery at 20,000 Years Ago in Xianrendong Cave, China" *Science* 336.6089 (29 June 2012): 1696-1700, https://doi.org/10.1126/science.1218643.

BCE during the Neolithic 'pivot' from transient hunter-gatherer to fixed-location agriculturally-based societies. To be crystal clear, fired clay artifacts were considered hard proof of 'civilized behavior'. According to that widely accepted yardstick, clay pots were used to cook cereals, ferment and store surpluses as a bulwark against years when harvests were lean. The new and improved explanation is that the oldest pottery was used to cook fish, repurposed as a strong liner inside woven nets/baskets, and utilized to portage goods between hunting and gathering encampments.[375] The shelf-life of pottery's newest iteration is anyone's guess.

But getting back to the issue at hand, the question begs: when does graphic communication actually commence in the *Homo sapiens* timeline? Research undertaken by Genevieve von Petzinger accentuates the connection between Upper Paleolithic cave art and portable art (i.e., bodily adornments) with the creation of writing systems after ~4,000 BCE. Separating zoomorphic and anthropomorphic images from abstract shapes (although there may be a relationship to the latter), Petzinger painstakingly documented geometric figures carved and painted in 52 cave and rock shelter sites across Europe that fall within the ~40,000 to ~10,000 BCE timeframe. Throughout the entirety of 30 millennia, only 32 symbols (Petzinger's terminology is "geometric signs") are repeated.[376] Von Petzinger makes a strong case for her 32 geometric signs serving as a cognitive stepping-stone towards the symbolic "proto-writing" systems that emerged after 10,000 BCE: "[t]he ability to conceive of arbitrary relationships between symbols and meaning, as well as the likely use of pictographic signs, are both foundational concepts for the creation of writing. To my mind, it is during the Ice Age that we see these processes starting to develop, opening the door for the latter invention of complex graphic systems."[377]

If we equate this period to the iconic image of a light bulb turning on inside human heads, von Petzinger argues that the Upper Paleolithic 'birth of the modern mind' was preceded by visual representations of meaning – "the first glimmers" as she phrases it – at archaeological sites such as Blombos Cave and Diepkloof Rock Shelter in South Africa, dating from ~100,000-75,000 ykr and ~85,000-52,000 ykr, respectively. Comparing South African artwork on red ochre pieces, spiral-shaped snail shells, and larger oval-shaped ostrich shells to the exquisite art of early Upper Paleolithic sites such as Chauvet Cave, *von Pettinger sees a continuum, **not** a non-sequitur*. "This does not look like a beginning; instead it seems more like a continuation and refinement of a previously developed skill. In reality, the geometric engravings at sites like Blombos and Diepkloof fit the criteria for the earliest attempts at graphic representation much better than does the first art at Europe."[378] Essentially, von Petzinger makes the case that *Homo sapiens* migrations out of Africa ~60,000-50,000 *ykr* were entangled with many of the same symbols (e.g., the lattice, crisscross, or crosshatch) she documented after ~40,000 *ykr* in European cave art during the Upper Paleolithic. Since von Petzinger's book was published, new compelling evidence has been presented that *Homo neanderthalensis* painted similar geometric designs in *red paint* (and also *finger fluting style*) in caves ~65,000 *ykr*, plus used *red and yellow pigments to paint perforated marine shells* ~115,000 *ykr*, adding more fuel to debates over our maligned genetic cousins' level of mental sophistication and symbolic awareness.[379] It seems more likely that *both species of hominid experienced simultaneous neuro-electrical stimulation from the same source – aurorae*.

We concur with much of Genevieve von Petzinger's interpretations on 'modern' *Homo sapiens* behavioral change that is found in the archaeological record prior to the emergence of highly organized, agriculturally-based societies ~4,000 BCE. During the the "Upper Paleolithic

375 Kate Ravilious, "Pottery's Origin Stories: Why did Hunter-Gatherers Make the World's First Pots?" *Archaeology* 75.3 (May/June 2022): 48-53.

376 Genevieve von Petzinger, *The First Signs: Unlocking the Mysteries of the World's Oldest Symbols* (New York: Atria Books, 2017), 1-16, 173-267.

377 Von Petzinger, *The First Signs*, 265.

378 Von Petzinger, *The First Signs*, 37-83. Quote from page 71.

379 Hoffman, Standish, García Diez, *et al*., "U-Th Dating of Carbonate Crusts Reveals Neandertal Origin of Iberian Cave Art": 912-915; Hoffman, Angelucci, Villaverde, *et al*., "Symbolic Use of Marine Shells and Mineral Pigments by Iberian Neandertals 115,000 Years Ago": 5255(1-6), https://doi.org/10.1126/sciadv.aar5255.

Revolution" (~40,000-10,000 BCE), Ofer Bar-Yosef highlights the following characteristics of increasing complexity in comparison to the preceding Middle Paleolithic (~250,000-40,000 BCE): formation of prismatic blades, bladelets, and microlithic stone tools; exploitation of bone and antler for daily or ritual purposes; widespread use of stone grinding and pounding tools; bodily adornments (beads, pendants, etc.) that express self-awareness and identity, individualistically and communally; long-distance trade networks in marine shells, lithics, and various materials; invention of spear throwers, bows, arrows, and boomerangs; production of anthropomorphic, zoomorphic, abstract objects and figurines carved from bone, antler, stone, and ivory, as well as painted or engraved rock art in caves and rockshelters; storage facilities; structured hearths and kilns; and *increasingly symbolic burial practices*.[380] *Foremost among the traits was an ability to store information externally through symbols that held meaning within each social group, or between different communities via long-distance exchange of goods.*

Von Petzinger's inventory list of 32 geometric signs found in European Upper Paleolithic cave art, we contend, match auroral morphologies documented by the Austrian polar expedition, auroral illustrations from the fourteenth to early twentieth centuries, *myriad topological phase states observed in countless experiments with complex plasmas, magnetic fields, nuclear fusion, plasma instabilities, magnetic reconnection, magnetohydrodynamics, and associated nonlinear geometrodynamics since the 1950s*.[381] It would be logical to assume, *given repeated human encounters with space weather events of scaled intensities over ~100,000 years*, that something akin to a *global symbolic databank of auroral morphologies* existed in the *collective memory* of diverse communities. More advanced human societies, for instance Gravettian (33,000-22,000 *ykr*) or Australian Aborigines whose innumerable petroglyphs at Murujuga (near Burrup Peninsula) dated 50-40,000 *ykr*, possessed upwards of several hundred geometric symbols to communicate meaning before the *Last Glacial Maximum* (~25,000-9,700 BCE). The shape of three-dimensional objects such as the spiral mollusk (an auroral feature chronicled at Jan Mayen Island), scalloped shells (that mimic an *interchange instability pattern*), the choice of ivory tusks as a medium (*flux tube-like*) or *cone-similar pottery* from Japan's Jomon era – all reveal much more than meets the modern eye. Zoomorphs with unusual antlers and stripes, Mastodons with ball-like feet (i.e., the Lion Panel at Chauvet Cave), and daily use items such as tools, weapons, clothing, bodily adornments and so on, resemble the limitless auroral formations seen in the skies above. Every material piece of the prehistoric human mosaic needs to be scrutinized, because carved into the pillars of Gӧbekli Tepi are shapes that speak of a more robust symbolic inventory for societies living prior to 9700 BCE.

If, as we contend, there is tangible evidence for *space weather* influencing *Homo sapiens* behavior since the Upper Paleolithic horizon, does it project backwards into the Middle Paleolithic? One of the biggest transformations in material culture that displays cognitive evolution from the 'primitive mind' to 'modern mind' is characterized by von Petzinger as "glimmers of a modern mind" or "intermittent signals" thereof. Specifically, *changes in burial practices that incorporated red ochre powder and the first evidence of using heat and other ingredients to chemically alter its appearance and texture, took place more than ~100,000 ykr*. From that point in time forward, *red ochre powder use in rituals associated with interment of the dead was subsequently adopted on a much wider scale globally, in both hemispheres, down to the Anthropocene/ Modern World era*.[382] Nonetheless, as von Petzinger point out, the adoption of *red ochre in burial practices* at Pinnacle Point and Blombos in South Africa; Es-Skhul

380 Bar-Yosef, "The Upper Paleolithic Revolution": 364-369.

381 Von Petzinger, *The First Signs*, Insert facing Table of Contents, titled "The Geometric Signs of Ice Age Europe": asterisk, aviform, circle, claviform, cordiform, crosshatch, cruciform, cupule, dot, finger fluting, flabelliform, half-circle, line, negative hand, open angle, oval, pectiform, penniform, positive hand, quadrangle, reniform, scalarform, segmented cruciform, serpentiform, Spanish tectiform, spiral, tectiform, triangle, unciform, W-sign, Y-sign, zigzag.

382 See Ernst E. Wrenchner, *et al*., "Red Ochre and Human Evolution: A Case for Discussion [and Comments and Reply]" *Current Anthropology* 21.5 (October 1980): 631-644, https://jstor.org/stable/2741829. Red Ochre (2 lumps, no powder) was first discovered at site BKII in Olduvai Gorge by Mary Leakey, and generally speaking, is virtually absent (except for a few in the Acheulian era) in other grave sites until it bursts onto the scene in the Middle Paleolithic.

and Qafzeh in Israel; date back even farther to ~130,000-100,000 *ykr*.[383] This earlier span of time synchronizes with another momentous, global climate shift – the *Last Glacial Interstitial* (~129,000-116,000 *ykr*) – an era when the Earth's ground-level atmospheric temperature was ~4.3º C (7.74º F) higher than average temperatures for the years 1971-1990 CE.[384] Dramatic and intense heating of the atmosphere and melting of polar ice caps, followed by a deep re-freezing at the poles, posed an existential stress test for larger mammals such as hominids.

If the accepted scholarly consensus is that at some unknown point from ~200,000 to ~100,000 *ykr*, *Homo sapiens displayed a 'modern mind' or close facsimile, then our ancestors' reaction to geomagnetic storms and substorms – specifically red skies and crimson hues that dominated the color palate of auroral precipitation – would have signalled a cognitive cause and effect linkage*. When one examines cave/shelter paintings from the Upper Paleolithic down to 1500 CE at random sites around the world, the solitary color that dominates the entire spectrum visible to the human eye is *red*. It is our belief that a connection between notions of an afterlife with innumerable spectral forms hovering, flowing, swirling, burning, and exploding across the celestial vault, was made in the neural networks of Paleolithic *Homo sapiens* brains. These examples of *intermittency* in human activity – mental, physical, and spiritual – are too concurrent to dismiss as haphazard and unrelated.

Another crucial, yet misunderstood prehistorical human behavior, pertains to the location of *Homo sapiens* rock art. Von Petzinger is spot-on with her remarks as to the late-nineteenth century 'troglodyte' mischaracterization of primitive humans joyfully inhabiting caves and rock shelters for long periods of time: "we didn't live in caves as some of our earlier ancestors had. A cave is not exactly an ideal dwelling: think bat colonies, big unfriendly bears, meager lighting, damp walls, and poor ventilation. The smoke from our campfires alone would have made a cave almost uninhabitable. We did sometimes live in the entrances of caves or under rock overhangs, but in general we lived out in the open in animal hide tents or other semi-permanent structures, which suited our hunter-gatherer lifestyle very well."[385] Geologist Robert Schoch has painstakingly investigated hundreds of ancient prehistoric and historic era sites around the globe during his career. His contention that the rapid melting of polar ice sheets at the end of the Younger Dryas stadial (9700-7900 BCE) was so abrupt and cataclysmic, that humanity experienced a *SIDA* (Sun-Induced Dark Age) event, meaning an ~6000 year decline and recovery phase from 9700-4000 BCE. A magnetohydrodynamically unstable sun pummeled the atmosphere at various intensities for six millennia. Ozone levels depleted, allowing lethal UV, X-ray, and gamma radiation to threaten biological life. During the *SIDA* chaos, skills that were initially lost or deteriorated were slowly reinvented or improved. Much like the *Adams Event*, *Schoch theorized that severe space weather drove humans to seek protection in caves or lithic shelters for extended periods of time*. Underground cities such Darin Kuyu and Kaymakli in Cappadocia, Turkey; the Ħal Saflieni Hypogeum in Malta; or cliff dwellings such as Mesa Verde in Colorado, U.S.A., are the ancient-day equivalents of Cold War era *radioactive fallout shelters*.[386] Whether it was two centuries, forty-two centuries, or over 100 centuries ago, *Homo sapiens* would mark their time, literally, with artistic symbolic language – which included architectural geometry – *that recorded fractal images of Geospace vibrating within the visible wavelength spectrum*

383 Although Pinnacle Point has an earlier date of 160,000 ykr for red ochre interred with corpses, von Petzinger states that it wasn't until 100,000 ykr that "the residents of Pinnacle Point began to use a broader range of red colors – every shade from deep crimson to dark brown. This increased complexity in color choices could mean that cultural activities, such as body decoration or ritual use, were influencing their preferences for specific shades. The ochre powder could have been used for individual body painting or some type of ritual performance. If true, these ancient people were certainly behaving in a very modern way." Von Petzinger, *The First Signs*, 42-44.

384 Paul S. Wilcox, Charlotte Honiat, *et al*., "Exceptional Warmth and Climate Instability Occurred in the European Alps During the Last Interglacial Period" *Communications Earth & Environment* 1 (8 December 2020): 57(1-6), https://doi.org/10.1038/s$3247-020-00063-w.

385 von Petzinger, *The First Signs*, 80.

386 Schoch, *Forgotten Civilization*, 41-156, 196-240, 302-308. The authors all agree that Schoch's 'fallout shelter' hypothesis is scalable in time with global connectivity to space-weather events.

of the human oculus.

Let's examine the nexus between documented changes in human behavior and *verified space weather events* at three scales based on the evidence presented thus far: *long-term* (i.e., hundreds to many thousands of years) – catastrophic and global; *short-term* (i.e., one year to many decades) – intense and regional; and *episodic* (i.e., one day to several months) – awe-inspiring, frightening and localized. In the category of *long-term* are the *Last Glacial Interstitial*, *Adams Event*, and the *Last Glacial Maximum - Younger Dryas* (~25,000-11,700 *ykr*). Each solar-induced cataclysm was followed by material culture evidence of extraordinary neuroplasticity across multiple levels at individual phases along the human brain's evolutionary chart. Extreme climate pressures that posed an existential threat to hominids spurred technological innovation and increasing symbolic/graphic complexity. *Short-term* geomagnetic turbulence, such as Roman emperor Constantine and Harald Bluetooth's reactions to *space weather events* they had experienced over the span of several decades, was triggered by one or several remarkable exhibitions of auroral pyrotechnics. *In both cases, the rulers attempted to placate solar tempests through imposing Christian monotheism on their subjects, accompanied by widespread adoption of new religious iconography and large-scale public works bearing the same*. Additionally, the written and sketched journals kept by the Austrian and Greeley polar expeditions were *short-term* manifestations of scientific curiosity sparked by the uptick in auroral activity decades prior to the First International Polar Year.

At the lowest end of the scale, *episodic* and localized reactions are expressed verbally and graphically within the framework of parochial religious beliefs. Two examples are Islamic scholar Ibn Fadlán's 10th century travel narrative penned in Arabic script that explains the phenomenon as a cosmic battle between the converted and unconverted *Jinn*; while in 16th – 17th century German *flugblatt*, Protestant Christian authors admonished inhabitants to change their sinning ways lest God Almighty put on another frightening display of the "power and the glory." In stark contrast, by the early decades of an industrializing 19th century, depictions and descriptive language lose their religious entanglements. Encyclopedias, published expeditionary journals, and educational textbooks beheld the aurora as a scientific puzzle waiting to be solved. In their authors' eyes, human harnessing of electromagnetic energy was like stealing Thor's *Mjöllnir*. Kristian Birkeland then wielded it like a true Norseman by unleashing cathode rays in his *terella* experiments. At the crimson dawn of the twentieth century, our bipolar auroral phenomenon had morphed into a source of inspiration that spurred intellectual creativity and accelerated human technological progress, providing access to more powerful streams of energy that exponentially fuel greater human complexity. Since that time, fear has been replaced by familiarity, chaos by order, and amazement by collective *ennui*. Even the electron-driven aurora has been – step-by-step – replaced by movie screens, television sets, computers, and ultimately plasma screens held in our hands.

So how, where, and when does the aurora – as a sign of *Geospace* turbulence – fit into Big History? Within the category of "Thresholds of Increasing Complexity," the *Fourth Threshold* comprises the birth of our solar system ~4.4-3.8 billion *ykr*. *It's all about the cosmic plasma – a dense cloud of gas and dust that conducts electricity along magnetic field lines.* The Earth was formed during our sun's *T Tauri* phase within a proto-planetary disk created by solar gravitation and bipolar magnetic fields. Electrostatic and gravitational forces led to the accretion of particles spinning in a *magneto-rotational instability*, funneling more dust and ice into larger conglomerates – similar to the '*Towie Stone*' observed over Jan Mayen Island (Fig. 51). Once the spherical planet was formed, *precipitating solar protons* energized chemical complexity in nascent Earth's weakly reducing atmosphere, laying the atomic and molecular foundations for the origins of biological life. *This primordial coupling between sun and Earth immaculately conceived our magnetosphere – the flexible/permeable plasma bubble that electromagnetically cradles and shields our planet.* As a consequence, the ensuing thresholds are linked in a long chain of causality forged in the nuclear fusion furnace of our resident star. Certainly the longest Earth threshold period (*Fifth* – 3.8 billion *ykr* to 8 million *ykr*) would not exist otherwise. We skipped over the *Fifth* and reentered late in the *Sixth Threshold* of evolving intricacies in hominid (8,000,000 *ykr*-300,000 BCE) and *Homo sapiens* (300,000-9,700 BCE) cranial patterns of behavior. Through DNA refinement and natural selection, neurological capabilities achieved *collective learning*. Artifacts from the Middle-Upper Paleolithic eras reveal a spike-plateau pattern of cognitive and communicative creativity (i.e., *emergent properties*) in *Homo sapiens'* archaeological record. *This is scientific evidence of collective learning – memory*

and skills transferred; a dynamic knowledge acquisition-accretion-dissemination system. The pattern of spike-plateau cognitive growth is like building a helical, neural 'Devil's Staircase' polytypism to ever-increasing levels of complexity.

We have presented compelling evidence that the initial spike and plateau chronologies solidly align with the *Last Glacial Interstitial*, *Adams Event*, and *Last Glacial Maximum - Younger Dryas* period. In the immediate aftermath of each convergence, a scaling flurry of activity can be registered across the diagnostic grid. *Scaling is a fractal trait, and human behavior with respect to externally storing knowledge of space weather episodes, followed by a sophisticated jump in material complexity*, *has continued at the smaller scales* since the Holocene/*Seventh Threshold* (9,700 BCE - 1500 CE) through the Anthropocene/*Eighth Threshold* (1500 CE to present) our species is currently exiting. As for the pending *Ninth Threshold* – would it not be *artificial intelligence*? How ironic is it that auroral precipitating electrons and ions gave us life and accelerated human *collective learning*, then were harnessed in the industrial age to facilitate increasingly complex societies in the electrical, atomic, and digital ages, and are now algorithmically making decisions, collecting/analyzing data, and externally storing information for *Homo sapiens* in a "cloud" of invisible spinning particles? We certainly have come full cosmic cycle.

The *aurora borealis* and *aurora australis* as visible (or sometimes audible) bellwethers of high energy sunspot/solar-induced particle emissions that perturb the *Geospace* interface, reveals all *Five Key Features of Complex Things*.[387] The third through fifth keys – *emergent properties, Goldilocks conditions*, and *energy flows* – respectively, are intricately phase-locked in our study. Emergent properties manifest rising complexity, requiring higher energy inputs to sustain new topological/physical qualities. If there is a decrease or loss of energy flow, the emergent properties slowly atrophy or disappear completely. For lifeforms ranging from microscopic to the largest scale possible within our biosphere – with "just right" conditions, the outcomes are catastrophic decline in numbers or extinction. *The scientific fact that solar-induced auroral phenomena become visible to humans on electrostatic 'plasma sheets', 'flying carpets', and 'flowing draperies' at diverse locations within the Geospace bubble (i.e., magnetosphere-ionosphere coupled system), display each of the prerequisite qualities to be classified as an inorganic, pure energy complex thing.* There are too many examples to enumerate at this time, therefore, we have distilled the most obvious into a single category: *magnetospheric emergent properties*. One form of complexity is the 14 interconnected subsystems of particles – 12 plasmas and 2 ENAs – that constitute *Geospace*. Coupling between subsystems is facilitated by 9 different kinds of electromagnetic plasma waves that allow the generation of FAC, which in turn carry electric currents (flux) flowing parallel and perpendicular to magnetic fields within *Geospace*, down to levels below the *Kármán Line*.[388]

Furthermore, each of these wave packets may excite *secondary wave modes* with diverse surface states. An example would be KHI waves *transporting magnetosheath plasma into the magnetosphere* as discussed earlier. The momentum produced by the membrane disturbance (e.g., *magnetopause*), in turn, drives ULF waves that cascade down to the Van Allen radiation belts and spurs particle precipitation into the upper atmosphere of Earth's *polar auroral zones*. Adding to the complexity are 15 types of measurable geomagnetic activity that represent distinct *geometrodynamical phase states in cosmic plasma ebbs and flows*.[389] A recent (2018) study of the *magnetosphere identified four emergent "phenomena" (i.e., properties) – auroral arcs, pulsating-aurora patches, substorms, and the electron radiation belt – each of which resulted from the coupling of 2, 3, or 6 subsystems*.[390]

If we examine the diversity of DC electrical currents flowing in the system, it provides another perspective

387 David Christian, Cynthia Stokes, and Craig Benjamin, *Big History: Between Nothing and Everything* (New York, N.Y.: McGraw-Hill Education, 2014), 5-6.

388 Joseph E. Borovsky and Juan Alejandro Valvidia, "The Earth's Magnetosphere: A Systems Science Overview and Assessment" *Surveys in Geophysics* 39.4 (20 July 2018): 817-859, https://doi.org/10.1007/s10712-018-9487-x. ULF, EMIC, Whistler-mode, Whistler-mode Chorus, Whistler-mode Hiss, Lightning-generated Whistlers, KHI, Magnetosonic, and Alfvén.

389 Borovsky and Valvidia, "The Earth's Magnetosphere": 833-837.

390 Borovsky and Valvidia, "The Earth's Magnetosphere": 837-840.

on the heterogeneous mix of energetic forces that handle increasing lodes of solar power and exhibit emergent topological properties. A list of solitary, multi-part, and 'shape-shifting' *currents in the magnetosphere* includes: the *magnetopause* (*Chapman-Ferraro*); *magnetotail & return*; *symmetric ring*, *partial-ring*, and *banana*; *R1 & R2 FAC*; *cross-tail current sheet*; *cusp & R0 FAC*; *NBZ current*; *substorm current wedge (SCW)*; and *Sub-Auroral Polarization Streams*.[391] *Ionospheric current systems* (or Ionospheric dynamo region) are numerous and entangled with the solar wind and *Dungey convection* of the magnetosphere. *Hall*, *Pederson*, and *auroral oval currents*, the switching on of *polar auroral electrojets*, are but a few examples of morphologically complicated dynamics in *sunspot-induced emergent properties* that disappear when our star transitions back to its lowest energy state every ~11 years.

The most global headline-grabbing *solar storm-driven ionospheric current variety*, nonetheless, are *Geomagnetically Induced Currents* (GIC) experienced at the Earth's surface. GIC are linked to *auroral substorms from magnetotail reconnection*, and reveal *emergent properties* of the *substorm current wedge*, *westerly horizontal current (electrojet)*, and *transient BBF*. The coupling of magnetospheric and ionospheric current subsystems can damage complex human-engineered electrical grids and equipment.[392] The Carrington Event (1859) and Great Geomagnetic Storms of 1872 & 1882 struck in the early age of Industrial society; while a much milder 1989 solar storm collapsed the Hydro-Quebec power grid through a cascading series of relay failures. *GIC are just one flavor in hundreds of emergent properties that high energy particles "turn on" stochastically during sunspot-driven space weather episodes*. When one ponders the historically unparalleled expansion of scientific knowledge since the nineteenth century, it could be argued that our electric power-dependent world's extremely complicated system of wiring (including invisible webs of microwave and radio frequency electromagnetic energy), behaves as an artifical "sixth" sense – one that has an electromagnetically sensitive dependence on solar surface initial conditions.

Human blindness to the complexity of *Geospace* – with respect to astrophysical, geophysical, and mixed-states phenomena – continues to be unveiled through increasingly sophisticated electronic measuring devices launched into the *magnetosphere* over the past two decades. Since 2008, new regions of *Geospace* that 'turn on'(i.e., *emergent properties*) with *solar maximum particle emissions* include the '*warm plasma cloak*' and '*third Van Allen radiation belt*'; cold, dense '*plasma plumes*' generated by *solar storms* that mitigate harmful effects of *magnetic reconnection*; and a '*Geocorona*' that extends hydrogen atoms much farther out into space (50x Earth's diameter) than originally thought.[393] And now for something completely different… a quote from David Ruelle: "We might thus say that scientific progress in chaos has been intermittent. But as far as I can judge from personal experience, intermittency is not at all limited to chaos: it is a characteristic of scientific research in general. And the most exciting times are at the beginning of bursts of activity, when the shock of ideas of different sources originates new ways of understanding reality… good science is not obtained by setting up programs along currently fashionable lines of research, but by giving good people the means to do what they think is the most interesting."[394]

---

391 N. Yu. Ganushkina, M. W. Liehmon, and S. Dubyagin, "Current Systems in the Earth's Magnetosphere" *Reviews of Geophysics* 56.1 (22 April 2018); 309-332, https://doi.org/10.1002/2017RG000590.

392 Dong Wei, Malcolm W. Dunlop, Junying Yang, *et al*., "Intense *dB/dt* Variations Driven by Near-Earth Bursty Bulk Flows (BBFs): A Case Study" *Geophysical Research Letters* 48.1 (9 January 2021): 091781(1-12), https://doi.org/10/10.29/2020GL091781.

393 C. R. Chappell, M. M. Huddleston, T. E. Moore, *et al*., "Observations of the Warm Plasma Cloak and an Explanation of its Formation in the Magnetosphere" *Journal of Geophysical Research: Space Physics* 113.A9 (September 2008): A09206(1-21), https://doi.org/10.1029/2007JA012945; Jennifer Chu, "Scientists Identify a Plasma Plume that Naturally Protects the Earth against Solar Storms" *Physics.org* (6 March 2014), https://phys.org/news/2014-03-scientists-plasma-plume-naturally-earth.html; Mike Wall, "Surprise! Earth's Atmosphere Extends Far Beyond the Moon" *Space.com* (21 February 2019), https://www.space.com/earth-atmosphere-extends-beyond-moon.html.

394 Ruelle, *Turbulence, Strange Attractors, and Chaos*, xiv-xv.

Edward R. Slack, Jr. is Professor of History at Eastern Washington University who earned a Ph.D. in History from the University of Hawai'i in 1997. His first book, *Opium, State, and Society: China's Narco-Economy and the Guomindang*, 1916-1937 (2001), investigated the complex web of relations between drugs and politics during a chaotic period of Chinese history. Since 2008, Edward Slack has become widely recognized as a pioneer in studies that focus on Asian cultural influence in colonial Mexico, and the "first Chinatown of the modern era" in Spanish Manila. He has been invited to speak about his research at Brown University, the University of Minnesota, Cornell University, and the University of Guadalajara. His recent publications also include "The Chinos in New Spain: A Corrective Lens for a Distorted Image" in *Journal of World History* 20.1 (March 2009), "Sinifying New Spain: Cathay's Influence on Colonial Mexico via the Nao de China" in *Journal of Chinese Overseas* 5.1 (May 2009), and "Orientalizing New Spain: Perspectives on Asian Influence in Colonial Mexico" in *México y la Cuenca del Pacífico* 15.43 (January - April 2012). He coauthored the book *Navigating the Spanish Lake: The Pacific in the Iberian World*, 1521-1898, published in 2014 by the University of Hawaii Press. In his latest article, "New Perspectives on Manila's Chinese Community at the Turn of the Eighteenth Century," in *Journal of Chinese Overseas* 17.1 (Spring 2021), Slack uses previously unpublished archival documents to analyze the evolution of what is called "systemic racism" today by Spaniards in the Philippines during the age of the Manila Galleon (1571-1815). He currently has a book manuscript undergoing peer review titled *Countercurrents of Cathay in the Spanish Lake: Sino-Iberian Cultural Conflict, Negotiation, and Exchange, 1571-1815*, an iconoclastic revision of Chinese life under Spanish rule.

Robert M. Schoch is the Director of the Institute for the Study of the Origins of Civilization at Boston University's College of General Studies. Schoch received his Ph.D. in Geology and Geophysics at Yale University, 1983. Since 1990, his research has focused on the interrelationships between geological and astronomical phenomena, natural catastrophes, and the early history of civilization. Schoch is the author, coauthor, and/or editor of books both technical and popular, including *Phylogeny Reconstruction in Paleontology* (1986), *Stratigraphy: Principles and Methods* (1989), *Voices of the Rocks* (1999), *Voyages of the Pyramid Builders* (2003), *Pyramid Quest* (2005), *Forgotten Civilization: The Role of Solar Outbursts in Our Past and Future* (2012), *Origins of the Sphinx* (2017), and the 2nd (revised and expanded) edition of *Forgotten Civilization*, subtitled *New Discoveries on the Solar-Induced Dark Age* (2021), among others. Dr. Schoch is also the coauthor of an environmental science textbook used in universities across the United States, and he has contributed to numerous magazines, journals, and reviews on geology, ancient civilizations, and related topics. His works have been translated into various languages and distributed around the world. In recognition of his research into ancient civilizations, Dr. Schoch was awarded (in 2014) the title of Honorary Professor of the Nikola Vaptsarov Naval Academy in Varna, Bulgaria. Schoch has also reached audiences globally through television, radio, conferences, and Internet podcasts.

Catherine Ulissey was born in New York City and spent her early childhood in Saudi Arabia where she was first introduced to ancient civilizations, which became a life-long interest though she pursued other vocations. Ulissey was a twenty-year professional ballet and Broadway dancer, beginning her career at the age of sixteen and performing with the Maryland Ballet, the Feld Ballet, and in a number of Broadway musicals, including the Tony-winning *The Mystery of Edwin Drood* and the original Broadway casts of *Rags*, *The Red Shoes*, and *The Phantom of the Opera*. In 2002, she graduated from Emerson College with a B.A. in Visual and Media Arts (summa cum laude) and has subsequently enjoyed a teaching career (of dance), contributing to the education of students at Harvard University's Dance Program, American Repertory Theater, The Boston Ballet School, and Wellesley College. Ulissey met her husband, Robert Schoch, in 2007 while attending a conference devoted to the topic of ancient civilizations, and they were married in 2010. Inspired by her husband's research, she is now proud to contribute to it. She joins Dr. Schoch as a co-author on their revised and expanded edition of *Forgotten Civilization: New Discoveries on the Solar-Induced Dark Age* (2021), and she is the author of their children's book *Adriana and the Ancient Mysteries: The Great Sphinx* (English-language edition published in 2024, revised from the German, 2021, and Italian, 2022, editions).

On the Pursuit of Happiness & the Big History of Money

Prateek Goorha
Bridgewater State University

Correspondence | **Prateek Goorha** pgoorha@bridgew.edu
Citation | Goorha, Prateek (2024) On the Pursuit of Happiness & the Big History of Money.
Journal of Big History, VII(4); 160–174.
DOI | https://doi.org/10.22339/jbh.v7i4.7405

Abstract

The link between happiness and income has long been a focus across several academic disciplines. Two factors are, however, conspicuous in being undervalued for their potential for relevance. The first is, very simply, the kind of money people use – its characteristics and its quality, and the second is whether the type of money in use has an effect on how humans experience happiness. We consider both here. A Big History of Money is outlined based on key epochs in the evolutionary history of money systems. Some general associations of these epochs with structures in the brain are highlighted, especially with respect to their capacity to influence wellbeing. The effects of money on subjective wellbeing are significantly modulated through the mechanisms of the brain's reward system; the most recent epoch of fiat money systems has also seen a worsening of several factors accretive to happiness. This calls for far more attention on the quality of money in circulation and a closer look at past epochs in the Big History of Money for useful insights.

Keywords

money; happiness; big history; brain

1. Smuggling income in

In considering the happiness of humans, two factors are conspicuous in being undervalued for their potential for relevance. The first, quite straightforwardly, is the kind of money people use – its characteristics and its quality. The second is the manner in which humans experience happiness – its mechanisms.

A usual focus in economics is on the assessment of the effect income has on subjective wellbeing or happiness rather than the nature of the currency in which the income is denominated. A key lynchpin in this regard has been the so-called 'Easterlin paradox' which suggests that, while reported happiness reliably increases with gains in income, there are diminishing returns. There have been several revisions and refinements of this observation since it was made by Easterlin in 1974. For example, Kahneman and Deaton (2010) reported that beyond an income of $75,000 in the United States, gains in happiness were negligible, though gains in life satisfaction were possible. In a cross-country study across 54 developing nations, Howell and Howell (2008) suggested that the relationship between happiness and income was strongest among the poorest and least educated, but that, even in those cohorts, the effect moderates when economic status was defined by wealth rather than income and wellbeing was defined not as happiness but by satisfaction with life.

There is, however, little commentary on the intervening role of the characteristics of money, let alone a serious consideration of how wellbeing itself is perceived by humans physiologically as the characteristics of money alter across time and place. This is especially peculiar since the observation was initially made at a time when the nature of most monies had undergone a fundamental alteration, going from a gold exchange standard to a purely fiat model. That this alteration may have had some independent effect on happiness than income does is, perhaps, a difficult claim to assess. Nevertheless, if there indeed are connections between the features of the money that is being used and the quality of wellbeing an individual experiences, the ramifications are fundamental. For example, there would then need to be a far more critical appraisal of any proposal to alter some aspect of a money in circulation on grounds of social wellbeing rather than on economic imperatives alone. Further, individuals would then be served well by being informed on the choices that they can feasibly make in adopting a form of money that is more conducive to their wellbeing.

Since the Easterlin paradox was outlined, it has been observed that reported happiness has not kept pace with gains in per capita income in developed countries, and that individuals appear to be maximizing happiness by making relative comparisons between their own condition and what is experienced by some reference group (Oswald, 1997).[1]

1 On this topic, see also Clark et. al (2008), which also contains a useful review of the literature on theparadox.

Indeed, the concept of individual 'welfare functions' directly contends with subjective evaluations that individuals might make about the utility they derive from their incomes. They may compare their incomes with past incomes or with their evaluation of their relative position in their perception of the society's income distribution. In both cases, individuals display a remarkable propensity for preference shifts that make happiness gains from income gains to be smaller than imagined. In other words, individuals make income gains progressively banal, failing to derive as much happiness from them.[2]

Even if income has special relevance to happiness through its distribution, it would seem particularly relevant to also observe that such distributions of income are affected fundamentally by the type of money that a society adopts. Take the simple observation that the shares of aggregate income enjoyed by the top 5% in the United States relative to the bot- tom 20% have been relentlessly diverging in the era of fiat currency. If this variance could have been attenuated with an alternate type of money, it would at least make monetary reform a factor worth considering alongside other social, political and economic policies that purportedly address income inequality, leave alone happiness. At present, money is seen to have no direct role at all.

Two areas of inquiry suggest themselves as pertinent and are, therefore, the focus of what follows. First, explanations and extensions of the relationship between income and happiness can gainfully be made by appealing to biology and psychology. This seems essential if the objective is to understand the physiological foundations for the very idea of subjective wellbeing and to assess what role money plays in such biological mechanisms. For example, it seems counterproductive to undertake investigations of any relationship of money and happiness without an understanding of what drives value in the human brain in the first place and how those neural mechanisms can get disrupted. Second, a Big History of money is adumbrated in Section 2 below for the context of this analysis. While this is an immense topic, the point of doing so is to be able to identify how developments in money over long stretches of time have occurred and to then assess what impacts those changes may variously have had on human wellbeing.

1.1 Happiness resets

Let us begin by motivating a key goal of this paper to which we shall return later – exploring the relevance of biology to wellbeing, especially in the context of income as a reward. Rayo and Becker (2007) address this connection rather simply. They argue that the empirical regularities of the Easterlin paradox are 'innate' and can be understood using a principal- agent framework – where Nature is the principal who devises an effective happiness function – rooted in evolutionary biology. Organisms are provided (by Nature) with happiness merely as an evolutionary heuristic that helps maximize the chances of their genes surviving relative to the status quo. In Easterlin (2001), another compelling paradox is offered that underscores the role of psychology. It observes that, while income and happiness do vary positively in the aggregate, over the life-cycle of an individual there appears to be no relationship. Strikingly, individuals across all age groups report that they were less happy in the past than the present and expect to be happier in the future. This 'expectation' of happiness in the future is, of course, how we would expect a biological heuristic for happiness in an organism to function. It would serve to inspire action by the individual in the present to acquire some indefinite amount of resources that could lead to happiness in the future. This, of course, is because the acquisition of resources raises the probability of the organism's genes to survive and be passed on.

Note that, for such a heuristic to have enduring efficacy, a reset of what constitutes 'happiness' appears to be necessary. Once the resources are received, the individual's perceived level of happiness must then reset to a lower level of happiness than was previously imagined. Thus, regardless of the accumulated size of the resource stock, happiness recedes (even if satisfaction with life improves). However, if this is so, the happiness-seeking individual is impelled to engage in ever costlier actions for further resource acquisition, since the associated happiness interminably dissipates. This episodic lessening of happiness — and in a world with rational expectations, even the prospect of its lessening — is a stressor for the individual, serving as an impetus for present actions that enable the acquisition of yet more rewards. As such, this framework accords well with a biological explanation for the role of happiness life – as a necessary physiological phenomenon of human life, honed by processes of natural selection.

2 Frey and Stutzer (2002) provides a useful review of some interesting empirical research on this topic.

The Easterlin paradox and its associated strand of literature engage with important ideas pertaining to human flourishing, but they dismiss the potential role that the characteristics of a money might play by focusing attention on income instead. Similarly, the evolutionary relevance of happiness as a heuristic may, again, be a potential explanation, but it replaces the role of income with, generally, 'survival' in affecting happiness via an individual's relative position within a distribution. In all of this, we simply take money as neutral over time and across places.

Two questions appear to be pertinent in examining the role of a money within this framework for a link between happiness and income? First, when a system of money alters, does this also entail an alteration in the relationship between happiness and income? Given that money systems alter infrequently, and that the effects of such changes may require long stretches of time to manifest themselves, it is possibly worth posing this question by appealing to the biological framework. So, in the long evolutionary history of humankind, what role did the changing nature of money systems play in shaping the dynamic between happiness and income?

As a money erodes in its value it ought to motivate a rational, happiness-seeking actor to alter behavior in some direct correlation with the rate of that erosion. This much seems obvious. For instance, in a study examining the effect of income on happiness, Morris et al (2021) used longitudinal survey data in Australia spanning 19 years. Even over that relatively short period of time, they show that the inflection point for diminished affective wellbeing from gains in income was delayed at a pace even faster than the rate of inflation.[3] While they attribute this additional delay to inequities arising from a changing income distribution, there is also a significant body of literature in economics that links inflation to a worsening of income inequality through a variety of channels.[4] Thus, it seems worth examining the intervening effect of money in the relationship between income and happiness with the benefit of a more holistic perspective rather than using the narrower framework of inflation as merely a monetary phenomenon.

Second, why does an individual willingly assume the goal of maximizing happiness? Even at the outset, minimizing unhappiness ought to be a stronger motivation than maximizing happiness, given that individuals are strongly predisposed towards loss aversion. This, of course, is an observation that has been corroborated repeatedly in economics ever since the seminal work of Kahneman and Tversky (1979). This is hardly a minor semantic difference if the kinds of resources individuals acquire vary by whether they seek to maximize happiness or minimize unhappiness; the latter is arguably not the dual of the former, especially if the type of money an individual earns determines some significant proportion of the kinds of resources that can be purchased in a market and, of course, has a bearing on the individual's evolutionary fitness.

We think that gainful headway in thinking about these questions can be made by adumbrating a Big History of Money. Doing so will permit us to draw out stark contrasts and consider the effects that are far too subtle to notice within the shorter timespans typical of studies on income and happiness.

2. On thinking big

Students of Big History concern themselves with the mammoth task of arranging significant epochs in the story of life on Earth – from their earliest beginnings to the present – and then examining the dynamics of the resulting time series. Of interest is the structure of this series, whether the timing of the next epoch might be extrapolated, and on the idea of some terminus or 'singularity'. The singularity, in this context, can be understood as the eventual obsolescence of human biology and intelligence brought about by a suite of technologies that develop exponentially. While Kurzweil's 2005 book brought the idea to wide attention, work by others that preceded his contribution and those that have built upon it deserve credit.[5]

An obvious criticism one might make is that any extrapolation made from this kind of analysis is suspect on grounds of presuming an invariant structure. Besides, such

3 The annual inflation rate in Australia during the period of the study – 2001 and 2019 – varied between 4.5% and 1.5%.

4 See, for example, Law and Soon (2020), which examines data for 65 developed and developing countries from 1987 to 2014. It argues that the effect of inflation is to worsen income inequality, though this effect is partially ameliorated by better institutional quality

5 A useful review of some key contributions in this area, as well as an explanation of the derivation of the approximate timing of the singularity can be found in Korotayev (2020).

datasets, perhaps unsurprisingly, may not always conform with one another. Dates for included epochs can vary and so can the epochs that are eventually included. Consequently, it is perhaps easy to dismiss the entire enterprise as relying on a somewhat subjective foundation.

However, doing so seems unduly dismissive at the very least, and it stands the risk of paying insufficient attention to a possibly momentous epoch in our collective future. First, there are several key epochs that do feature unfailingly across most such compilations because they rely on an historical record with a significant degree of consensus. These usually include the approximate age of the Earth, the onset of the Cambrian explosion, the extinction of the dinosaurs, the first hominids, the advent of lithic technology, the appearance of modern humans, the advent of settled agriculture, the invention of the printing press, the beginning of the Industrial Revolution, the description of the structure of DNA and the sequencing of the human genome.[6] When these compilations are analyzed, they each produce estimates for the singularity occurring surprisingly close to one another: Roughly in the first third of the 21st century. Second, this estimate holds true when the entire dataset is examined, stretching over millions of years, or when subsets of the dataset are considered, say, for example, examining relatively recent history alone. (Korotayev, 2020) Third, the *nature* of the singularity event is, after all, entirely separable from what the datasets suggest is its likely *timing*. It may indeed turn out to be an event without any material significance to the course of humanity, but to dismiss it as necessarily so with confidence presumes a great deal.

Regarding the self-similar nature of the hyperbolic growth that such studies establish when the durations being analyzed are progressively shortened, two explanations are worth considering. The first relies on the observation that a system's complexity comes from the degree of granularization of the knowledge it embodies. As knowledge sources become increasingly granular the extant system becomes unstable; the new form of knowledge essentially exposes some type of fatality in the outcomes emanating from the extant system's disequilibrium dynamic. This motivates a transition to a new and more complex system based upon the more granularized knowledge that again displays hyperbolic growth, albeit at a timescale that is considerably accelerated.

A second explanation relates to the ability of complex adaptive systems that are regulated at points of critical change – or period-doubling bifurcations that would tend towards chaos – by an increase in the amount of usable energy (LePoire, 2015). Rather than being driven towards chaos by this change, a period of learning ensues, which has the effect of drawing the system away from chaos, and towards a new stable outcome. Thus, the effect is that of the complex adaptive system displaying a logistic growth pattern.

Note that both these explanations are related by the idea of learning – be it in a form that increases the rate of specialization or in the ability to leverage energy. Knowledge is by nature cumulative. It naturally becomes more granular over time as the process of learning yields finer and deeper insights on aspects of the accumulated knowledge. When some of this learning pertains to developing the capacity to use more energy in a complex adaptive system the second of the explanation above finds support.

These and other explanations on the mechanics of Big History approaching a singularity are provided in the context of life on Earth and its interplay with physical systems and technology. However, it may also be useful to adopt this approach for the analysis of money. Interestingly, we shall see that these general observations on the relevance of learning for the dynamics of Big History are relevant to a construction of a Big History of Money as well. Additionally, we may ask whether the evolution of money plays a significant role in the anthropocentric course of Big History and the nature of any impending singularity that affects human wellbeing.

2.1 A Big History of Money

In this section we turn to a consideration of some of the most significant events in the history of money in an effort to construct an approximate timeline for its own big history. To do this, it is helpful to cast the remit broadly and evaluate how the various functions of money – now deemed so obviously essential – first became immanent in some prevalent system for interpersonal transacting, regardless how rudimentary such a system may seem to us in retrospect. If we take for granted that transactions have

6 A more contemporary list would arguably add the events such as the global financial crisis of 2008, the COVID-19 pandemic, the 2022 war in Ukraine and the emergence of AI in the form of broad-use LLMs such as ChatGPT and its peers in 2022.

existed since the beginning of prehistory, then the idea that a proxy for money was needed to exchange the products of knowledge and specialized effort from the very outset seems logical. Some medium or mechanism to facilitate all manner of exchange, in other words, was always required. As knowledge became more granular, there must have been a commensurate need for the money system to facilitate exchange of its more specialized products. The most primitive and, arguably, instinctual basis for such a medium may actually not have been something directly tangible, but the idea of prosociality. Prosociality works as a medium of exchange in the abstract, but its normalization as a proto-money subsequently enabled a whole host of monetary systems that required some degree of trust in an intermediary.

Prosocial behavior in the context of one transaction enables a member of a group to accumulate a form of social credit with others within the group, which can then be used by the member to 'finance' future transactions. It is important to note that there are enormous differences in the quality and characteristics of prosociality. It is, therefore, unsurprising that, in the Big History of Money, the evolution and refinement of prosociality required a significant stretch of time.

The evolutionary lines of mammals and reptiles diverged in the Carboniferous era, more than 310 million years ago. It arguably also marked the beginning of the story of prosociality, and, therefore, laid the foundations for the first event in the Big History of Money. Mammals are far more capable of prosocial behavior than are reptiles, a propensity attributed to the fact that mammalian brains possess the conducive structures – chiefly though not solely within the prefrontal cortex – that reptilian brains either lack entirely or for which they possess far simpler analogs. The substructures within the PFC (such as the vmPFC, dlPFC and the angular cingular cortex) regulate a complex set of behaviors necessary to social living. These include the recognition of emotion and pain in others, empathizing, making appropriate decisions that enable cooperative behavior, and altruism. However, early mammals did not possess the dense granular layer of the PFC that is implicated in complex representational thinking and working memory (Preuss and Wise, 2022). There is reason to believe that this part of the PFC is specific to primates, and would thus would not have appeared until 55 million years ago, though possibly somewhat earlier. The evolutionary lines of our hominin ancestors diverged from chimpanzees roughly 7 to 9 million years ago, and the PFC continued to become progressively more complex among hominins.

The long evolutionary story of prosociality from early mammals to modern humans is crucial to the Big History of Money. A principal reason is that its complex neurological basis leaves indirect clues for the types of monies that may have been practicable. Consider the role that the PFC plays in both subjective valuation and representational thinking, both key prerequisites for a monetary system that enable higher degrees of abstraction in a transactional medium. The functions of placing subjective relative values on items among a set of objects and, subsequently, making an informed choice among them are handled by parts of the PFC. Laboratory experiments with monkeys establish that relative activity at the neuronal level seems to behave as a numeraire currency for this task even prior to consumption (Kable and Glimcher, 2009). Thus, primates seem to be hardwired for at least this essential function of money via the PFC.

Besides representational thought, the PFC plays a crucial role in goal-directed behavior and forward planning (Carlen, 2017). Once the transactional value of prosocial behavior has been established within a small group, the benefits of employing tangible representations of credit was likely enabled by the refinements of the structures of primate and hominin PFCs. The first of these tangible representations in wide use as money were very likely stone tools and collectibles in the Paleolithic; a tantalizing reason for this proposition is that a connection exists between language and toolmaking in the evolution of the brain, and the evidence for such a connection becomes increasingly stronger as the complexity and abstraction of the toolmaking industry increased (Stout and Chaminade, 2012). Broadly, the nature of the object used as a money for indirect barter arguably has a close relationship to the social and cultural evolution of a social group. For example, it has been shown in the context of certain tribes that an object with no objective use can acquire a significant amount of exchange value by acquiring a 'density' of meaning that can come from its association with the identity of the owner, religious significance, aesthetic value and a variety of other factors beyond economic value. Understandably, the velocity of such dense objects in exchange drops as the propensity to hoard them increases, thereby giving the object that necessary capacity of a money to store value over time. (Weiner, 1994)

In other words, the abstraction required for substituting a greater variety of objects for money, rather than resorting to direct barter or prosociality, was similar to the increasing abstraction displayed by the successive toolmaking industries in the Paleolithic and the development of the capacity for language to convey the mechanisms of a system to a larger and more disparate set of individuals. If this premise has merit, this vital stage in the Big History of Money was reached by at least one million years ago, and possibly even several hundred thousand years before then. The reason for this dating is based on identifying which of the various stone tool technologies used throughout the Paleolithic was most definitely the first to be representative of two key aspects: First, that the tools and artifacts were being produced with purpose, planning and imagination in a collaborative social context, which would thus imbue them with a greater density of meaning, and, second, that there is evidence of the produce being used as gifts (which is a mechanism for accumulating prosocial capital) or as direct offerings in trade. On both counts, the most likely earliest candidate is the Acheulean stone tool industry, which was only possible with a greater capacity in our ancestral hominin species for learning through some form of instruction (Arbib, 2011). Further, attention was paid to the aesthetic value in the stone tools (chiefly, handaxes) for reasons that range from their relevance in sexual selection to an understanding of the golden ratio being inherently desirable; thus, tools were being produced no functional value at all (Spikins, 2012).

It comes as no real surprise that the logic of indirect or representational barter in prehistory – spanning a period of over a millennium or more – was expanded, albeit exceedingly gradually, with the use of a greater variety of commodities. Besides animals, cowrie shells, foods and stone collectibles, other commodities became possible by the Neolithic through discovery and gradual perfection of new technologies – principally metallurgy, but also pottery. Each such item preferentially facilitated indirect barter to the extent that it was more readily salable, an idea attributable to Menger (1892), referring to the relative ease with which any commodity can be disposed of over time and distance, especially when its supply increases. Thus, what functions as a money approximates the chronology of the various archaeological periods, from the Paleolithic to the Iron age.

Some form of intermediated barter was very likely the norm for much of our prehistory, with a substantial overlap with the earliest forms of prosocial living among hominins. In the absence of a formal ledger of record, a third party may have proxied for an intermediary to facilitate transactions that lacked a direct correspondence of needs, either by using cave art, stone tools, or other objects such as beads and shells that we know were used as currency much later. Barter has been conducted in a variety of ways in recorded history, and is still used routinely as a means to effect transactions, especially when official monetary systems begin to collapse. We have several examples of modern-day hunter-gatherer tribes engaging in barter with farming communities, including by providing their labor to the farmers.[7]

The larger point is that, in the Big History of Money, the emergence of barter was likely just an extension of the logic of prosocial exchange, itself with neuropsychological bases, for transactions that were more complex, and likely aided by some representation of credit almost from the very beginning. The representation of credit by way of a record rather than with the aid of objects may also have been attempted much earlier than we commonly imagine.

Still, what we can venture is that the next stage in the Big History of Money was the transition from representational money as a tangible object to a supplanting of money by an indirect unit of account – a ledger. While not conclusive, there is some evidence that 'representational records' of transactions – proto-ledgers, so to speak – may have existed long before the Neolithic revolution, and certainly well before the antecedents of modern accounting were established in Asia. For example, tally sticks, such as the famous Ishango and Lebombo bones, as well as etched teeth and etched ochre were being used as far back as 77,000 years ago.[8] Even more tantalizingly, there is evidence of a remarkably concise set of symbols being used in cave art paintings all over the world, some of which are at least

7 See Peterson (1978) for several interesting examples and a more thorough case study of the Agta hunter-gatherers and the Palanan farmers in the Philippines.

8 Regarding the numerical connection of etched ochre found at the Blombos cave in South Africa, see Bullington and Leigh (2002).

100,000 years old.[9] Key stages of advancements in ledgers were naturally only possible with the advent of writing and mathematics. Thus, we find evidence of intermediated transactions recorded on stone tablets in cuneiform – the earliest form of writing – by 3200 BC in the Sumerian city of Uruk, and we find the earliest evidence of accounting in India – where both base-10 numerals and negative numbers were invented – in Kautilya's Arthashastra by 300 BC. (Mattessich, 1998) The double-entry system as we know it today did not come about till much later, principally through the efforts of Islamic scholars such as al-Khwarizmi (800 AD) and in the Italian scholar Luca Pacioli's opus Summa, which was only published in 1494.

The use of gold, silver and electrum as specie was indisputably occurring in the Iron Age, in kingdoms within the Lydian, Indian, Chinese, Roman, Greek and Egyptian civilizations. Paper currencies evolved gradually from the idea of commercial promissory notes that were backed by gold or silver, eventually becoming adopted as a practice by governments. The earliest paper currency likely originated in the Song dynasty of China in the 11th century.

In the modern era, there has been far more rapid evolution of money from a state-issued currency that is backed by a commodity to one that is entirely money by state fiat. In the intervening decades, states routinely resorted to fractional backing even while still under regimes of specie money by way of debasement. For example, in a period of roughly five centuries under the Roman Empire beginning in 25 BC, the intrinsic silver value of the coin (primarily the denarius) fell from containing roughly 3.9g of high-grade silver per coin to little more than a thin coating of degraded silver, well under a gram. The development of a state-sanctioned banking system, beginning in 12th century Italy, permitted the issuance of private currencies in various parts of the world that were frequently backed by less than a 100 per cent of reserves of the official state currency or any commodity. While central banks arrogated this privilege from private entities, it only served to delay the slow march towards a fiat currency regime, a fact exemplified by the fate of the US dollar, which lost all connection to gold in fewer than 180 years since its birth in 1792. While much of the world went on a gold standard during the latter half of the 19th century, virtually all countries had abandoned a peg to the value of gold by the end of the Second World War, and then even to the value of a gold-backed dollar by 1971.

The only significant change in money after the birth of fiat currency arguably came in 2008 with advent of Bitcoin, which is significant for at least two reasons when contrasted with a fiat currency. First, it is a peer-to-peer digital currency with a hard limit on its overall supply, thus reintroducing a money system that is based on a rare commodity. Second, it is issued on an open-access distributed network, yet its transaction history is made entirely immutable by its use of a ledger technology called the blockchain that is secured by an inordinately high energy cost barrier to any saboteur. Several thousand cryptocurrencies – admittedly, a sizable fraction of which are scams – now vie for a role within an ever-expanding ecosystem of digital tokens of value.

Proposed timeline for the Big History of Money

Based on the preceding, we now summarize the key epochs of note in the Big History of Money. While one might argue for some other innovations in money systems to be included, the epochs that are included here were seminal in their influence on the nature of money systems. They are as follows –

Around 7-9 million years ago the idea of a medium of transaction firmly took seat in the brains of our most distant hominin ancestors. This crucial transformation was the ability to make prosocial commitments within a social group in exchange for value received, and it became the basis for a proto-money.

While we cannot intelligently make the case for when in human prehistory the practice of barter was employed as a monetary system, we can certainly advance a more convincing case for when approximately representational barter is likely to have emerged. We place this to be around 1 million years ago during the Acheulean tool industry.[10]

The emergence of money as a unit of account facilitated

9 See Petzinger (2016).

10 Note that this would be roughly half a millennium after the very first Acheulean tools emerged. At the beginning of this tool industry there was significant overlap with the older Oldowan technology. However, by 1 million years ago the Acheulean tool industry was clearly exhibiting the characteristics most likely to make it the basis of a money system based on representational barter.

by a proto-ledger system might be dated to as far back as 100,000 years ago, though a more formalized version of such a system that is based on an explicit legal code legitimizing the role of an intermediary can said to have emerged only by 5,500 years ago.

By 3,000 years ago the use of specie as legal tender was widely prevalent. While stone artifacts, metals and bullion as money had existed well before then, the key innovation now was that state entities centralized the issuance of money and arrogated the privilege of seignorage and indulged in the practice of periodic debasements.

1971 is significant for the end of the Bretton Woods system, which had established the US dollar as the global reserve currency after the end of the Second World War, largely by virtue of its issuance being directly tied to the disproportionate global stock of gold that belonged to the United States. Its end finally severed even this indirect link between dozens of national currencies and national stocks of gold, be they in the United States, repatriated from there to domestic coffers or any local stocks of gold. Thus, 1971 marked the beginning of the era of fiat currencies as money.

The final epoch in our chronicle is that of the advent of cryptocurrencies, beginning with Bitcoin in 2008. Bitcoin introduced the idea of a peer-to-peer money with a publicly auditable and ultimately fixed supply that follows a predictable and decelerating schedule of issuance. The significance of a public blockchain, secured by a robust protocol that generates consensus over the state of a transactional ledger across a network, cannot be overstated; implemented effectively, they hold the very real potential to decentralize all manner of market orderings, thereby arrogating the roles of legacy banking, finance, and contracting infrastructures. It is, in part, a recognition of the scale of this disruption that has inspired several governments to retaliate with attempts at restrictive regulation and with offerings of central bank digital currencies.

3. Breaking happiness down

While economics adopts the premise that individuals seek to maximize their happiness, issues pertaining to what sort of happiness is being maximized or how its quality might vary is beyond its purlieus. However, empirical studies indicate that some factors do inhere in its definition across diverse groups. These include material concerns, family and social life, health, employment and the broader socio-political institutional environment.[11] Yet, each of those factors are arguably affected by the sort of money prevalent in a society, and so it seems odd that the quality of money is left out from debates on happiness.

It is a well-established fact, for instance, that the loss of income and unemployment both result in a reduction in the reported levels of happiness. At the aggregate level, a given unit of increase in inflation is associated with a significant though smaller drop in wellbeing than from a unit increase in unemployment. (Di Tella et. al, 2001) Inflation is an immanent feature of all modern monetary systems. It is a banal matter of fact that, at a minimum, if increases in wages do not outstrip inflation, perceived wellbeing would progressively deteriorate. In the United States, while real disposable per capita incomes did increase from $21,000 in 1979 to $41,000 in 2015, real weekly earnings for the full-time employed began at just under $350 in 1979 and remained there until 2015.[12] Thus, even prima facie it would be hard to argue that subjective wellbeing for the majority in the United States rose over a period of 35 years. In addition to the direct effect on real income that inflation creates, this additional requirement to work introduces other sources of losses in happiness, such as that of changes in happiness that are attributable to the level of stress experienced in the work environment.[13]

Take health and material needs next. Experiments suggest that the mere psychological priming of an individual's mind for an abundance of wealth alters their behavior. They begin seeing themselves as more self-sufficient as well as less predisposed towards being social (Vohs et. al, 2006). A 2016 study covering over 100,000 adults in the United States suggested that individuals with higher incomes were more likely to spend time alone, less time with family and more with friends (Bianchi and Vohs, 2016). In the book, *Scarcity*, Mullainathan and Shafir propose the idea

11 Easterlin (2001) provides a review of the empirical literature on this conceptualization of happiness.

12 These data are from the US Bureau of Economic Analysis.

13 A 2023 Gallup report, makes for some sobering reading. The United States led the world in reported workplace stress, even in an especially good job climate. Globally, there has been a steady rise in in workplace stress, rising from about 30% of employees in 2009 to 44% in 2022.

of a scarcity mindset that reduces an individual's mental bandwidth, leading them into adopting a range of adverse behaviors that breed yet more scarcity – sort of vicious feedback loop that entraps people into becoming resource poor. Generally, states of abundance and scarcity manifest real psychological changes in addition to the economic ones. The book suggests that scarcity causes a sort of psychological trauma that then creates real effects, ranging from a heightened focus on trying to resolve the immediate consequences of scarcity (perhaps emanating from a sharpened survival instinct that narrows the bandwidth of the mind) to even a measurable deficit in one's IQ.

Rather than this abundance-scarcity framework, though, what if we were to examine whether the immanent features of the money being used in a society play a role directly? What if, when a money's characteristics are altered, its ability to modulate behavior changes, and that this has physiological bases and effects? This would place the quality of money squarely within any feedback loop that concerns itself with human wellbeing. Indeed, one intervening variable in such a dynamic might be that of money systems affecting the sense of abundance vs scarcity, which then affects human flourishing, but there may also be other such factors to consider.

3.1 Money on the brain

In order to understand the physiological basis for the relationship between money and happiness, a useful place to start is the prefrontal cortex (PFC), the same area of the brain that played a crucial role in enabling incrementally more complex patterns of prosociality as the basis for money. Though other areas of the brain are involved, it is primarily the PFC that is responsible for the development of executive cognitive function (ECF) in humans. ECF comprises a group of behaviors that is especially developed in humans relative to other animals. Significantly, it includes self-regulation and motivation in the presence of a reward, but it also plays a role in memory, decision making, cognitive flexibility and deliberate attention.[14]

A majority of ECF skills are already developed by the time a human enters adolescence; while some tasks associated with ECF continue to develop, much of what is readily accessible is already in place by early adulthood. This is significant for at least two reasons. First, a lack of adequate executive cognitive function –quite literally, its dysfunction– is implicated as a leading cause for a range of addictive behaviors, such as extravagance, gambling, substance abuse and alcoholism (Betancourt et. al, 2012; Giancola and Moss, 1998; Jones et. al, 2021). Second, dysfunction of ECF is linked with adverse financial conditions, from over- indebtedness to abject poverty (Achtziger, 2022) and even a self-perpetuating cycle of chronic pain and degrading abilities to regulate and motivate oneself (Caes et al., 2021).

The relevance of money can hardly be seen as peripheral here. Indeed, a long strand of literature has repeatedly observed that monetary rewards have the potential to reduce rather than enhance the motivation an individual has to perform, a key component of ECF.[15] Money is classified as an extrinsic reward in such studies and then contrasted to intrinsic motivation, which is shown to become attenuated in the presence of a monetary reward. The two forms of reward are seen as antipathetic and the phenomenon is called an 'undermining effect'. In addition to the PFC, the undermining effect appears to be a result of activity in the cortico-basal ganglia valuation system, which connects the PFC with other parts of the brain, such as the basal ganglia and the ventral tegmental area (VTA). The VTA is also the area of the brain that controls the brain's mesolimbic or reward system[16], which is crucial to how we experience happiness. It is implicated in producing the reward prediction error, whereby the extent of neuronal activation in the brain's dopamine pathways depends on the difference between the expectation of a reward and reality rather than on the reward alone.

Two remarks seem pertinent at this juncture. First, if money – either directly or indirectly – exacerbates addictions and can demotivate performance, it seems worth understanding whether altering the form of monetary payment can help individuals curtail addictive behaviors and retain more of their ECF. Economics, for the most part, skirts the issue of the effect of monetary quality on motivation, choosing instead to address motivation through the manipulation of incentives through pricing and

14 See Chan et al. (2008) for a review and discussion of ECF and its components.

15 See, for example, Ma et al. (2014) and Murayama et al. (2010) for overviews.

16 The broader reward system in humans is dauntingly involved and comprises a dizzying complex of neuronal pathways incorporating numerous parts of the brain besides the VTA, such as parts of the cerebellum and the brainstem.

contracts. For example, an explanation for the undermining effect in economics highlights situations of information asymmetries favoring the principal (Bénabou and Tirole, 2003). In such cases, the agent's reward is a substitute for trust in the short term. Over the longer term, though, the principal must bolster the contract with mechanisms that help build intrinsic motivation, for example, through progressively empowering the agent over time.[17] Thus, note that the contract is used to iron out the initial disjunction created by a monetary reward in the kinds of motivation rather than employ a mechanism that might correct for the quality of the money reward directly.

Second, to the extent that certain types of money in the Big History of Money have been less antithetical to individual wellbeing – at least regarding ECF and intrinsic motivation – can a money be devised that selects among these desirable features, performs adequately in its role as a money and, yet, does not come at the expense of retarding socioeconomic progress? It is easy to see that when a money consists of little more than direct prosocial credit it incentivizes reciprocal behavior, making extrinsic and intrinsic motivation reinforce each other. Each subsequent epoch in the Big History of Money introduced more abstract representations of money. The principal benefit of these abstractions has been that each subsequent form of money enabled economies that featured more specialized activity and more complex transactions. However, there have arguably been costs in subjective wellbeing to this progress through the Big History of Money. First, it has come with increased prospects for more friction between the two forms of motivation, and, second, over the last century and especially since the era of fiat money began, we have been witness to the dramatic financialization of markets. This rapid financialization has led to an increase in the relative incomes of capital to labor and an attendant increase in income inequality.[18]

Money can be seen as a placeholder for all manner of resources that might be acquired in the future. In this respect at least, adjusting to changes in a money system ought to be relatively straightforward, involving chiefly just a rediscovery of the relative opportunity costs. However, this is less innocuous when one takes this statement in the context of the preceding remarks. In practice, money is best seen as a substitute for the expectation of a resource in addition to a proxy for it. Thus, depending on the money system, the expected utility from a given quantity of money is itself variable. When the expected marginal value of money erodes, however gradual that might be, it subsidizes behaviors that promise to provide earlier gratification; an individual's time preference for money is strongly influenced by the rate of at which her currency loses value in real purchasing power.

Indeed, some research suggests that the modulation of certain neurotransmitters in humans can affect both their perception of the value of a monetary reward as well as their subjective probability of acquiring it (Schutte, et. al, 2020). To the extent that expected utilities alter when moving from one form of money to another, we would naturally expect behavior to be different as well. This, however, is true not merely on the basis of the observation that it may be economically rational to behave differently under the two money systems, but also because each money system may itself be guiding behavior on a *physiological* basis.[19]

Evaluating the quality of a money, especially over vast stretches of time or between disparate national and cultural contexts, is fraught with difficulty. However, it may be possible to make some broad observations by examining our dopamine-regulated reward system.

The reward system in human brains is neither static nor modern, but evolved over millennia in our hominin ancestors to provide us with evolutionary fitness. Since the reward system was shaped by the evolutionary imperative to survive, it is attuned to dealing with behaviors that directly assist survival, especially the desire to mate and

17 The ill effects of the setup are evident when the authors consider the converse of this logic, suggesting that, in team production, it is possible to imagine that one agent can unintentionally demotivate a partner through 'ego-bashing' in order to gain dominance in the relationship.

18 For the context of the United States, see Lin and Tomaskovic-Devey (2013). For a broad study across 20 countries since the beginning of the Industrial Revolution, see Piketty (2014), which additionally highlights the role of political and social processes in modulating the effects of an increasing capital share on income inequality.

19 To contend that these amount to the same thing would be placing an inordinate degree of faith on the rational choice framework in economics having some direct and tractable biological basis.

procreate[20]. Moreover, this system is also connected to other activities such as staving off disease[21]; feasting in order to build body stores of energy above homeostasis levels, presumably to ward of death from starvation longer[22] and even forming social hierarchies[23]. Generally, beyond the crucial role of the reward system in responding to expected rewards, it is also implicated in handling the variance of such rewards, which is to say that it plays a significant role in the principle of risk and reward.[24]

Notably, the various epochs in the Big History of Money would have each played an indispensable role in this process of shaping the human reward system. Prosocial credit as a form of rudimentary transactional money dominated the Big History of Money in terms of its longevity, and thus it ought to have had the greatest import on our reward system. Indeed, it has been argued that the reward system of the brain ought to be seen in conjunction with its social behavior network[25], precisely because social behavior must be rewarding or punitive for the reward system to enable behaviors to become adaptive over time (O'Connell and Hofmann, 2011).

For well over ninety percent of the time that modern humans have been around we have lived in an environment devoid of any formal 'money system' that we would recognize now. Thus, once money systems were interposed to organize transactions across time and space, then repeatedly altered, our reward systems had to adjust. When money progressively began deteriorating in face value, our reward system conditioned us to modify behavior to restore the eroded value, on occasion even to transmute money into something that can be preserved or simply consumed more rapaciously.

4. Reframing happiness

Observations made in the preceding section suggest a fatalistic conclusion: Our reward system ostensibly fuels a preference for alterations to our monetary systems that have malign effects on our wellbeing. The most recent epoch of the Big History of Money has especially enabled the financialization and proliferation of markets that leverage our proclivities for stimuli that provide ephemeral and addictive dopaminergic responses to our detriment. Thus, the Easterlin paradox of largely unchanged happiness levels in the face of significant gains in real incomes, especially in developed economies and precisely in the epoch of fiat money, is no surprise. Indeed, in light of the pivotal role of the brain's reward system in both depression and in the undermining effect, it seems an egregious error to minimize its role in any investigation of a relationship between happiness and income.

While one might point to the alarming rise in personal insolvencies over the past century[26], the range of invidious addictions stands as an even greater testament to this destructive process – substance addictions such as to drugs and alcohol[27] or to calorie-dense foods[28], as well as behavioral addictions to gambling[29] or a range of behaviors associated with a compulsive use of the internet[30]. Clearly such a trajectory does not bode well for our mental health and wellbeing.

Such a conclusion does, however, minimize our ability to rein in the destructive excesses of this process, emphasizing only our propensity for heedless reengagement. It suggests a certain moribund determinism in the face of abstract monetary systems and an ever deeper financialization

20 Fisher et al. (2005)
21 Ben-Shaanan, et al. (2016)
22 Alonso-Alonso, et al. (2015)
23 Ghosal, et al. (2019)
24 Preuschoff, et al., (2006)
25 The social behavior network involves several other different parts of the brain than the reward system, including the hypothalamus.
26 See, for the case of the United States, Garrett (2006), which presents the statistic that, "(a)s of 2004, the filing rate was 5.3 per 1,000 people, more than four times the 1980 rate and nearly 80 times the 1920 rate."
27 Wise and Jordan (2021)
28 Volkow et al. (2017) and Baik (2013)
29 Hasanović et al. (2021)
30 See, for example, Liu and Luo (2015) and Weinstein and Lejoyeux (2020). Cheng and Yee-lam Li (2014) presents a cross-country examination of the relationship between internet addiction and wellbeing, establishing some variance across countries but also an inverse relationship between internet use and the subjective quality of life.

of markets, denying any critical ameliorative role for individual agency over happiness.

As a matter of fact, there exists the tantalizing prospect that we *can* reframe the link between happiness and money to improve human wellbeing. It would require, however, a considerable and effortful change from the status quo.

For example, even the *self-recognition* of impaired ECF has been shown, albeit tentatively, to hold the potential for serving as a motivator for altering proclivities towards deleterious behaviors (Blume and Marlatt, 2009).

More fundamentally, the reward system in humans is patently amenable to being retrained. The dopamine neurons in the VTA region of the human brain play a key role in reinforcement learning by encoding the reward prediction errors that we experience through our choices and behaviors. Unlearning does not seem to occur merely in a passive manner when one systematically does not receive the expected reward whenever the trigger or stimulus is experienced. Instead, unlearning is actually a byproduct of *new* learning, which competes with the previously learned association[31]. In other words, we are entirely capable to undertake the effortful exercise of retraining ourselves in the pursuit of genuine long-term wellbeing, but it would require learning new behaviors.

While it is beyond the scope of this limited article to define and explore the determinants of genuine wellbeing, a few observations are pertinent in thinking about whether the impetus for change resides in the individual or whether, indeed, there is a role for market, institutions and government.

From the perspective of an individual, strikingly, we have the unique ability among animals to produce a dopamine response *endogenously* through meditation (Kjaer et al., 2002). Meditation releases dopamine in the ventral striatum, which is a crucial component of the reward system, within the mesolimbic pathway. The evidence is fairly compelling that meditation holds the ability to alter the brain's mechanisms, including the ability to self-regulate and alleviate stress[32]. Thus, we have, at least in theory, the powerful ability to govern how our brains process rewards, pleasure, and motivation without having to be entirely slave to external sources. It seems that the degree to which our happiness can be held hostage by alterations in real income or the type of money in circulation is potentially within our control.

Further, in the pursuit of understanding genuine wellbeing, two insights are gained from the Big History of Money. First, the effect of money on wellbeing is very significantly, if not even principally, modulated by its effects on the mechanisms of the human brain's reward system. This point cannot be overemphasized enough. Monetary systems differ in their ability to create dysregulations in the reward system, such as reduced intrinsic motivation, lower self-regulation, higher stress, a greater propensity for deleterious addictions, and, quite clearly, adverse effects on human wellbeing. Thus, to take money and monetary policy as orthogonal to happiness seems to be profoundly misguided. Herein lies a key role for governance informed by a deeper appreciation over the quality of money in circulation within a society.

Second, the inherent logic of the monetary systems in the various past epochs of the Big History of Money is not invalidated by each subsequent innovation. Take, for example, the earliest epoch of a credit-based proto-money system built on prosociality. Despite the long history of formal money systems, there still remain indelible vestiges of that earliest form of transacting even in the modern era of easy credit and fiat currencies. In fact, an entire *economy*, largely understudied and underemphasized, runs in parallel to the one we apprehend on neoclassical principles of market exchange. This unseen economy still operates on the prosocial credit that accrues from interpersonal interactions that involve "the grant and pursuit of regard" (Offer, 1997); its existence explains the vital role that everyday transactions involving gifts, etiquette and favors play in completing the economic structure of a society that also includes markets for goods and services that cannot be priced effectively using formal monies. Similarly, the logic of a monetary system based on hard money has not been forgotten either. Indeed, it was the invidious harm of financial crises and an inflating fiat currency that inspired the creation of the first cryptocurrency, Bitcoin (Nakamoto, 2008). Bitcoin is routinely dubbed 'digital gold' by virtue of its fixed supply, and is deliberately built with an open

31 Sunsay and Rebec (2014) provides a very useful review on this topic.

32 As an example see the meta analysis in Fox et. al (2014) and Tang et. al (2016) on the ability for meditation to reduce propensity for addictive behavior.

access framework that employs a cryptographically-secured blockchain. The Bitcoin blockchain can be easily queried on several aspects, including its transaction history, issuance schedule of tokens and the difficulty involved in mining new tokens. In structure, therefore, it mimics the epoch of hard money – when circulating money was a desirable scarce commodity or, at least to some degree, backed by a scarce commodity.

Thus, it is not entirely impossible to exert agency even over the trajectory Big History of Money. Individuals and perhaps even states have the ability to delimit the effect that a money system creates on happiness. At the very least, money systems that are designed and operated entirely in a top-down manner without any explicit reference to its impacts on individual wellbeing ought to be carefully examined and possibly even reimagined.

Declaration

The author certifies that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.

Sources

Achtziger, A. (2022). Overspending, debt, and poverty. *Current Opinion in Psychology*, 46, 101342. https://doi.org/10.1016/j.copsyc.2022.101342

Alonso-Alonso, M., Woods, S. C., Pelchat, M., Grigson, P. S., Stice, E., Farooqi, S., Khoo, C. S., Mattes, R. D., & Beauchamp, G. K. (2015). Food reward system: Current perspectives and future research needs. *Nutrition Reviews*, 73(5), 296-307. https://doi.org/10.1093/nutrit/nuv002

Arbib, M. A. (2011). From mirror neurons to complex imitation in the evolution of language and tool use. *Annual Review of Anthropology*, 40, 257–273. https://doi.org/10.1146/annurev-anthro-081309-145743

Baik, J.-H. (2013). Dopamine signaling in reward-related behaviors. *Frontiers in Neural Circuits*, 7, 152. https://doi.org/10.3389/fncir.2013.00152

Bénabou, R., & Tirole, J. (2003). Intrinsic and extrinsic motivation. *The Review of Economic Studies*, 70(3), 489–520. https://doi.org/10.1111/1467-937X.00253

Ben-Shaanan, T. L., Azulay-Debby, H., Dubovik, T., Starosvetsky, E., Korin, B., Schiller, M., Green, N. L., Admon, Y., Hakim, F., Shen-Orr, S. S., & Rolls, A. (2016). Activation of the reward system boosts innate and adaptive immunity. *Nature Medicine*, 22, 940-944. https://doi.org/10.1038/nm.4133

Betancourt, L. M., Brodsky, N. L., Brown, C. A., McKenna, K. A., Giannetta, J. M., Yang, W., Romer, D., & Hurt, H. (2012). Is executive cognitive function associated with youth gambling? *Journal of Gambling Studies*, 28(2), 225–238. https://doi.org/10.1007/s10899-011-9255-9

Bianchi, E. C., & Vohs, K. D. (2016). Social class and social worlds: Income predicts the frequency and nature of social contact. *Social Psychological and Personality Science*, 7(5), 479–486. https://doi.org/10.1177/1948550616641472

Blume, A. W., & Marlatt, G. A. (2009). The role of executive cognitive functions in changing substance use: What we know and what we need to know. *Annals of Behavioral Medicine*, 37(2), 117–125. https://doi.org/10.1007/s12160-009-9087-8

Bullington, J., & Leigh, S. (2002). Rock art revisited. *Science*, 296(5567), 468. https://doi.org/10.1126/science.296.5567.468a

Caes, L., Dick, B., Duncan, C., & Allan, J. (2021). The cyclical relation between chronic pain, executive functioning, emotional regulation, and self-management. *Journal of Pediatric Psychology*, 46(3), 286-292. https://doi.org/10.1093/jpepsy/jsaa103

Carlen, M. (2017). What constitutes the prefrontal cortex? *Science*, 358(6362), 478-482. https://doi.org/10.1126/science.aao0872

Chan, R. C., Shum, D., Toulopoulou, T., & Chen, E. Y. (2008). Assessment of executive functions: Review of instruments and identification of critical issues. *Archives of Clinical Neuropsychology*, 23(2), 201-216. https://doi.org/10.1016/j.acn.2007.08.010

Chen, C., & Li, A. Y. (2014). Internet addiction prevalence and quality of (real) life: A meta-analysis of 31 nations across seven world regions. *Cyberpsychology, Behavior, and Social Networking*, 17(12), 755-760. https://doi.org/10.1089/cyber.2014.0317

Clark, A. E., Frijters, P., & Shields, M. A. (2008). Relative income, happiness, and utility: An explanation for the Easterlin paradox and other puzzles. *Journal of Economic Literature*, 46(1), 95-144. https://doi.org/10.1257/

jel.46.1.95

Di Tella, R., MacCulloch, R. J., & Oswald, A. J. (2001). Preferences over inflation and unemployment: Evidence from surveys of happiness. *The American Economic Review*, 91(1), 335-341. https://doi.org/10.1257/aer.91.1.335

Easterlin, R. A. (1974). Nations and households in economic growth. In P. A. David & M. W. Reder (Eds.), *Does economic growth improve the human lot?* (pp. 89-125). Academic Press.

Easterlin, R. A. (2001). Income and happiness: Towards a unified theory. *The Economic Journal*, 111(473), 465-484. https://doi.org/10.1111/1468-0297.00646

Fisher, H., Aron, A., & Brown, L. L. (2005). Romantic love: An fMRI study of a neural mechanism for mate choice. *The Journal of Comparative Neurology*, 493(1), 58-62. https://doi.org/10.1002/cne.20772

Fox, K. C. R., Nijeboer, S., Dixon, M. L., Floman, J. L., Ellamil, M., Rumak, S. P., Sedlmeier, P., & Christoff, K. (2014). Is meditation associated with altered brain structure? A systematic review and meta-analysis of morphometric neuroimaging in meditation practitioners. *Neuroscience & Biobehavioral Reviews*, 43, 48-73. https://doi.org/10.1016/j.neubiorev.2014.03.016

Frey, B. S., & Stutzer, A. (2002). What can economists learn from happiness research? *Journal of Economic Literature*, 40(2), 402-435. https://doi.org/10.1257/002205102320161320

Gallup. (2023). *State of the global workplace: 2023 report*. Gallup.

Garrett, T. (2006, March 31). 100 years of bankruptcy: Why more Americans than ever are filing. *Bridges*. Federal Reserve Bank of St. Louis. https://www.stlouisfed.org/publications/bridges/spring-2006/100-years-of-bankruptcy-why-more-americans-than-ever-are-filing

Ghosal, S., Sandi, C., & van der Kooij, M. A. (2019). Neuropharmacology of the mesolimbic system and associated circuits on social hierarchies. *Neuropharmacology*, 159, 107498. https://doi.org/10.1016/j.neuropharm.2019.107498

Hasanović, M., Kuldija, A., Pajevic, I., Jakovljevic, M., & Hasanović, M. (2021). Gambling disorder as an addictive disorder and creative psychopharmacotherapy. *Psychiatria Danubina*, 33(Suppl 4, Part III), 1118-1129.

Howell, R. T., & Howell, C. J. (2008). The relation of economic status to subjective well-being in developing countries: A meta-analysis. *Psychological Bulletin*, 134(4), 536–560. https://doi.org/10.1037/0033-2909.134.4.536

Jones, C. B., Meier, M. H., Corbin, W. E., & Chassin, L. (2021). Adolescent executive cognitive functioning and trait impulsivity as predictors of young-adult risky drinking and alcohol-related problems. *Psychology of Addictive Behaviors*, 35(2), 187–198. https://doi.org/10.1037/adb0000726

Kable, J. W., & Glimcher, P. W. (2009). The neurobiology of decision: Consensus and controversy. *Neuron*, 63(6), 733-745. https://doi.org/10.1016/j.neuron.2009.09.011

Kahneman, D., & Deaton, A. (2010). High income improves evaluation of life but not emotional well-being. *Proceedings of the National Academy of Sciences of the United States of America*, 107(38), 16489–16493. https://doi.org/10.1073/pnas.1011492107

Koob, G. F., & Le Moal, M. (2008). Addiction and the brain antireward system. *Annual Review of Psychology*, 59(1), 29-53. https://doi.org/10.1146/annurev.psych.59.103006.093548

Krueger, A. B., & Schkade, D. A. (2008). The reliability of subjective well-being measures. *Journal of Public Economics*, 92(8-9), 1833-1845. https://doi.org/10.1016/j.jpubeco.2007.12.015

Kuss, D. J., & Griffiths, M. D. (2012). Internet and gaming addiction: A systematic literature review of neuroimaging studies. *Brain Sciences*, 2(3), 347-374. https://doi.org/10.3390/brainsci2030347

Layard, R. (2005). *Happiness: Lessons from a new science*. Penguin Books.

Lenoir, M., Serre, F., Cantin, L., & Ahmed, S. H. (2007). Intense sweetness surpasses cocaine reward. *PLoS ONE*, 2(8), e698. https://doi.org/10.1371/journal.pone.0000698

Levine, G. N., Cohen, B. E., Commodore-Mensah, Y., Fleury, J., Huffman, J. C., Khalid, U., Labarthe, D. R., Lavretsky, H., Michos, E. D., Spatz, E. S., Kubzansky, L. D., Smith, P. J., Vaduganathan, M., & American Heart Association Council on Clinical Cardiology. (2021). Psychological health, well-being, and the mind-heart-body connection: A scientific statement from the American Heart Association. *Circulation*, 143(10), e763-e783. https://doi.org/10.1161/CIR.0000000000000947

Liang, Y., Liu, L., & Xia, H. (2016). Do social comparison and negative emotions play mediating roles in the relationship between relative income and life satisfaction?

Journal of Happiness Studies, 17(3), 1257-1283. https://doi.org/10.1007/s10902-015-9646-3

Makin, S. (2019). The gambling disorder experiment. *Nature*, 575, S16-S18. https://doi.org/10.1038/d41586-019-03558-w

Markus, H. R., & Kitayama, S. (1991). Culture and the self: Implications for cognition, emotion, and motivation. *Psychological Review*, 98(2), 224–253. https://doi.org/10.1037/0033-295X.98.2.224

Mas-Colell, A., Whinston, M. D., & Green, J. R. (1995). *Microeconomic theory*. Oxford University Press.

Mink, M. (2010). Problem gambling's toll on mental health. *Psychiatric Times*, 27(4), 1–2.

Mochón, F. P., & San-Jose, L. (2021). Monetary policy, consumption and happiness. *Economics and Business Letters*, 10(1), 15-21. https://doi.org/10.17811/ebl.10.1.2021.15-21

Nussbaum, M. C., & Sen, A. (1993). *The quality of life*. Clarendon Press.

Ostaszewski, P., & Karzel, K. (2002). Utility of income: Nonlinear and nonstationary sensitivity. *Journal of Economic Psychology*, 23(4), 503-519. https://doi.org/10.1016/S0167-4870(02)00099-4

Patel, V., Chisholm, D., Parikh, R., Charlson, F. J., Degenhardt, L., Dua, T., Ferrari, A. J., Hyman, S., Laxminarayan, R., Levin, C., Lund, C., Medina-Mora, M. E., Petersen, I., Scott, J., Shidhaye, R., Vijayakumar, L., Thornicroft, G., Whiteford, H., & Dahiya, N. (2016). Addressing the burden of mental, neurological, and substance use disorders: Key messages from Disease Control Priorities. *The Lancet*, 387(10028), 1672-1685. https://doi.org/10.1016/S0140-6736(15)00390-6

Pavlou, P. A., & Fygenson, M. (2006). Understanding and predicting electronic commerce adoption: An extension of the theory of planned behavior. *MIS Quarterly*, 30(1), 115-143. https://doi.org/10.2307/25148720

Pfeifer, G. (2020). Diminishing sensitivity to losses and gains: Outcome history as the key to the shaping of probability weighting. *Management Science*, 66(8), 3337-3361. https://doi.org/10.1287/mnsc.2019.3363

Reimer, B. (2010). Driving decisions: The influence of reaction time, cognitive workload, age, and gender on drivers' decisions to take action in response to surprises. *Transportation Research Record: Journal of the Transportation Research Board*, 2185(1), 13–20. https://doi.org/10.3141/2185-02

Rosati, A. G., & Hare, B. (2016). Reward currency modulates human risk preferences. *Evolution and Human Behavior*, 37(2), 159-168. https://doi.org/10.1016/j.evolhumbehav.2015.09.004

Saxena, S., Thornicroft, G., Knapp, M., & Whiteford, H. (2007). Resources for mental health: Scarcity, inequity, and inefficiency. *The Lancet*, 370(9590), 878-889. https://doi.org/10.1016/S0140-6736(07)61239-2

Schoemaker, P. J. (1993). Determinants of risk-taking: Behavioral and economic views. *Journal of Risk and Uncertainty*, 6(1), 49-73. https://doi.org/10.1007/BF01065817

Steptoe, A., Deaton, A., & Stone, A. A. (2015). Subjective well-being, health, and ageing. *The Lancet*, 385(9968), 640-648. https://doi.org/10.1016/S0140-6736(13)61489-0

Vohs, K. D., Mead, N. L., & Goode, M. R. (2006). The psychological consequences of money. *Science*, 314(5802), 1154-1156. https://doi.org/10.1126/science.1132491

Webley, P., Burgoyne, C. B., Lea, S. E., & Young, B. M. (2001). *The economic psychology of everyday life*. Psychology Press.

Weiner, E. S. (2003). The romance of money: Being alive in the market. *Journal of Business and Technical Communication*, 17(2), 167-189. https://doi.org/10.1177/1050651902250948

Weisberg, S. M., & Newcombe, N. S. (2018). Cognitive maps: Some people make them, some people struggle. *Current Directions in Psychological Science*, 27(4), 220-226. https://doi.org/10.1177/0963721417744521

Weyrich, A., Lindberg, H. K., Garlichs, D., Baumgartner, H., Jahn, H., & Aichhorn, W. (2022). Mental health disorders in Europe: Prevalence and health economic burden. *European Heart Journal*, 43(Suppl 1), ehac544.544. https://doi.org/10.1093/eurheartj/ehac544

Prateek Goorha is adjunct Associate Professor at Bridgewater State University and an independent researcher in economics. His academic work spans a diverse range of topics, including Bitcoin, blockchains, contract theory, innovation and economic development. He earned his PhD from Vanderbilt University in 2003 and was a Post-Doctoral Fellow at Harvard University between 2002 and 2004. He co-authored a book in 2018 titled A New Theory of Ideas: Creativity & Innovation, published by Palgrave MacMillan.

Flight through Time: On Dove Navigation, Evolution and Symbolism

Annabel Smith
Amsterdam, Netherlands

Correspondence | **Annabel Smith** annabels4747@gmail.com
Citation | Smith, Annabel (2024) Flight through Time: On Dove Navigation, Evolution and Symbolism.
Journal of Big History, VII(4); 175–179.
DOI | https://doi.org/10.22339/jbh.v7i4.7406

Abstract

For millennia, doves have played a significant role in human history, culture, and ecosystems. This paper examines the unique characteristics and symbolism of doves through the lens of Big History, which encompasses the inanimate world, life, and human society. First, it explores how doves navigate using Earth's magnetic field, sunlight, and celestial maps. Second, it highlights dove intelligence, comparing their pallium to the mammalian neocortex, emphasizing their cognitive abilities. Finally, the paper discusses how doves have symbolized peace, fidelity, and spirituality across different cultures and religions. Through these lenses, the interconnectedness of doves with the material, biological, and cultural aspects of human history becomes clear, offering a deeper understanding of their role in shaping human civilization.

> "Great ideas … come into the world as gently as doves."
>
> -Albert Camus, Nobel Prize acceptance speech, 1957

Introduction

For thousands of years, humans and doves have shared a special connection. Doves are a part of our religions, literature and histories and have faithfully served human societies as a source of communication and even food. Doves, along with pigeons, between which there is only adistinction in colloquial English and not a scientific one (though there are varying opinions) make up the bird family Columbidae. This family is comprised of around 300 species, many domesticated (Er 2010).

This paper will explore doves specifically through the Big History lenses of the inanimate world, life and humanity. The first section will look at how doves navigate by utilizing Earth's magnetic field along with stars and sunlight. Following this, it will consider dove intelligence in the context of evolution. Finally, this paper will explore how doves have interacted with human society from both a functional standpoint, e.g. as carrier pigeons, and from a symbolic standpoint, in which humans have assigned symbolism and status to them.

Navigation, the Inanimate Connection

Migrating doves have an exceptional sense of direction and navigation, along with other migrating birds (and animals, such as sea turtles and trout) (Johnsen and Lohmann 2008). Even the name of one variant of dove, the homing pigeon, acknowledges its incredible ability to navigate and find its way home. Throughout time, this trait has been refined by both evolution and selective breeding. However, only recently has it become more evident how birds are able to do this.

One of the leading and more recent hypotheses on how migrating birds can orient themselves is through magnetoreception, by interpreting magnetic field lines of the Earth. For longer than human society or even life on Earth, the Earth's solid inner core, made of iron and nickel, has moved at a different rate from the liquid outer core. Because of this, the Earth acts as a large magnet with magnetic field lines running from the North to South pole. These field lines vary in intensity and angle, depending on the location. At both poles, the intensity and angle with the Earth are much higher than at the equator. One important feature of the Earth's magnetic field is that it protects the planet from cosmic radiation and charged solar particles (Spier 2015). In addition, it is thought to be sensed by some animals, including doves. Humans have also learned how to harness and use these field lines for navigation with compasses; however, within the time scale of evolution, the compass is a modern discovery and still somewhat crude, as it generally does not provide information on field intensity or angle.

There are two hypotheses on how homing pigeons can perceive these field lines. The first is that some animals have acquired a compound called magnetite within their bodies. This extremely magnetic, naturally occurring metal effectively provides pigeons with a natural compass. It is estimated that in order to pick up magnetic field lines, the quantity of magnetite pigeons would need to have accumulated (or attained via food sources) is ~50 nanometers (Cadiou and McNaughton 2010). A nanometer is one billionth of a meter, well within the body space of a dove.

A second hypothesis is that doves are able to intercept magnetic field lines through cryptochrome, a protein found in many living organisms. This protein seems to enable magnetoreception in other organisms, including certain species of flies. A behavioral study with flies suggested this. Flies with cryptochrome responded to magnetic field lines, yet under UV-A light, which cryptochrome is sensitive to, the behavior of flies with cryptochrome was indistinguishable from that of the control flies. These control flies did not have cryptochrome. Homing pigeons carry this protein in their bodies as well, suggesting a link between cryptochrome and migrating animal navigation (Cadiou and McNaughton 2010).

It has not yet been determined which of these two hypotheses (if either or perhaps both) are causal in the ability of homing pigeons to interpret magnetic field lines. However, it is increasingly clear that they do have this ability.

In addition to magnetoreception, migrating birds are believed to navigate with solar cues and celestial maps, just as sailors have done throughout the ages. Regarding solar cues, when the Earth rotates, the sun shines at different angles depending on the location and time of day (Spier 2015). To use this method of orientation, birds would need to see the sun and have an internal clock. Based on studies of feeding times, it is now indeed believed that migrating birds, like many animals, have internal clocks, suggesting that they have the tools necessary to navigate by the sun (Cassone 2014).

Furthermore, migrating birds are speculated to use star constellations to navigate. Human-designated constellations, e.g., Orion, the Big Dipper, are arbitrary star patterns that humans have designated as relevant. There is even a constellation in the Southern hemisphere called Columba (Latin for dove). Even though homing pigeons are presumably unaware of human-designated constellations, it is nevertheless believed that they can navigate celestially. One pattern recognition experiment showed that pigeons could successfully discriminate between paintings by Monet and Picasso, suggesting the ability to apply the same skills to stars (Watanabe, Sakamoto, and Wakita 1995).

Most likely, birds use some combination of these three methods to orient themselves (Wiltschko and Wiltschko 1991). Not only do they rely on the inner workings of the Earth, but also on the larger universe.

Bird navigation has been used by civilizations for millennia, from Genghis Khan's empire to the First World War in which an astonishing quantity of 100.000 pigeons were used in WWI for communication (Staughton 2023). It is estimated that of these pigeons, approximately 95 percent were successful in delivering messages (Steenhard 2014).

For millennia a traveler between lands could confidently take a homing pigeon or two on their travels, knowing that in a pinch, a message attached to a bird's leg would most likely find its way back home.

Brain Structure, the Living Connection

As is the case for all living things, doves have evolved. In contrast to humans, who have relatively large brains in comparison to our bodies, the brains of birds are quite small (Spier 2015). Although the term "bird brain" has come to be pejorative, it turns out that doves (and birds generally) are quite intelligent even though the evolution and structure of their brains is different from those of humans.

For mammals including humans, social and intellectual complexity is usually attributed to a highly developed portion of the brain called the mammalian neocortex, which consists of six vertical layers of neurons that interact horizontally and vertically. The neocortex is part of the brain's cerebral cortex, which allows for higher cognitive functioning. Generally, it is believed that the more complex the neocortex, the more complex the animal (Baillie 2018) For example, for some mammalian species, such as elephants, apes and certain dolphins, the neocortex is relatively large and complex, which signifies enhanced sensory perception and learning capabilities (Spier 2015).

Until recently, it was believed that birds did not have a neocortex. This led to speculation that birds did not possess higher cognitive functioning. However, research has shown that birds have a structure with functions very similar to that of the human neocortex. In birds, the layered neurons are called the pallium. Both the neocortex and the pallium are used for among other things, problem-solving, vocalization, and memory, once again suggesting similarities between the neocortex and the pallium. While the functioning of the pallium and neocortex are comparable, the pallium was overlooked due to its dissimilar shape from the neocortex (Stetka 2020). With this discovery, it might be concluded that birds are better equipped and therefore more capable of processing information than previously thought.

Symbolism, the Human Connection

For millennia, doves have played an important role in

human history and mythology. Some of this may have been derived from the dove's extraordinary ability to navigate and the reliance humans have placed on them for this ability. Images of doves bearing messages are present throughout many cultures, such as Christianity, where a dove is depicted bringing an olive leaf as proof of safety and peace.

Doves are found in all societies and lands of the world except Antarctica (Shapiro and Domyan 2016). Despite an abundance of doves in large cities, humans have degraded the habitat of doves at various points throughout history. It is estimated that there were 3 to 5 billion passenger pigeons in North America during the 19th century. "The air was literally filled with pigeons," John James Audubon, namesake of the future National Audubon Society, wrote in 1813. Until 1897 there were no regulations on dove hunting, leading to a period of several months in Michigan in 1878 in which 50.000 passenger pigeons were killed per day by hunters. This mass eradication of birds was in large part due to a lack of environmental awareness and policy (Dep. Of Vertebrate Zoology n.d.).

Humans have been dependent on birds, including doves, in many ways. Not only were doves used for communication, but they were also relied upon for nutrition. This bird holds both a positive and negative association. Mainly in cities, pigeons have earned the dubious nickname "rats of the sky." On the other hand, doves are referenced as symbols of peace and tranquility (Soniak 2016). For example, the United Nations has a dove carrying an olive branch as its primary logo. The idea that doves symbolize peace, equality and safety is so broadly accepted in modern culture, that the dove is the emoji that pops up when one types "peace" on many mobile phones.

Of all the animals and creatures known to humans for the past 5000 years, it has been the dove, more than any other, that has become the central symbol of peace and harmony. We may never know why the dove attained this elevated role in religious and moral symbolism, but some reasons explaining this might be their ability to navigate and communicate between people and societies, the fact that they are herbivores and are seen as peaceful and that they mate for life, suggesting fidelity.

From a historical standpoint, as states and urban areas began to form and social relationships started to become more complex, there was an increasing need for moral religion and ethics, i.e., something "right" versus something "wrong." With religion, people had moral obligations, making society more structured and manageable for state elites (Spier 2015). Religion was an efficient and reliable way to make citizens abide by laws. This method has been stronger and weaker during different periods and regimes, yet overall proved effective. Many years later, the power of religion in Western culture started to weaken most significantly with the emergence of the Enlightenment in Europe by political philosophers such as Locke, Hobbes, Rousseau and Montesquieu, all of whom began to question the nature of human society.

Within the past 5000 years, doves attained their symbolic meaning. By the time biblical mythology emerged, the symbolism is evident as seen on stained glass art. For example, the dove brings an olive leaf, signaling safety for Noah and his family in the Old Testament. The dove could also represent baptism or appear as the Holy Spirit, part of the Holy Trinity. The usage of the dove was most likely derived from the Romans and Greeks, where the dove is a symbol of the goddess Aphrodite/Venus. Doves being affiliated with the goddess of love is no coincidence, as doves mate for life, representing monogamy. In the second century, Clement of Alexandria encouraged Christians to use the dove (or fish) to represent and identify themselves. Interestingly, the dove was a prominent symbol of Christianity even before the cross. Only around the fourth century did the cross come to represent Christians (Dorrell 2021).

The dove is one of the many ideas and symbols linking various religions. The Abrahamic religions have many common ideas between them. In Islam, doves are respected as they protected Muhammed by making nests outside the cave he was hiding in, thus preventing Muhammad's pursuers from capturing him (Dorrell 2021).

Ancient Mesopotamian stories have parallels with stories from the Old Testament. For example, both tell a story of a plague and a flood. There are also commonalities with Buddhism, which references doves in the context of compassion and kindness. According to one story, King Shibi protects a dove from a hawk, by offering the hawk his own flesh instead (Johnson 2005). In addition to doves, both Buddhism and Christianity focus on the birth of a savior who managed to reach enlightenment. One reason for this common theme could be attributed to the Silk Road, a trade route connecting Europe and Asia that spread culture, ideas, and technology. This could explain the common motif of the dove representing compassion and peace.

Over time, doves have become potent symbols within religions around the world. However, religions themselves are not static and are also shaped by individual societies. One school of thought as to how religions have developed is diffusion, which suggests that religion spreads through people when they geographically disperse (Avetyan and Zunner-Keating 2021). This has been happening since the beginning of civilization, from tribes interacting with other tribes to modern globalization. Today, international trade and social media establish an interconnection.

Aside from this, many theoretical explanations of how religions developed might be applied to explain commonalities among different religions. People of diverse cultures dispersed and eventually ended up influencing each other's religions. However, religions also evolved with the civilizations that believed in them. There most likely is some combination of explanations, including diffusion, that led to doves appearing prominently in multiple religions and cultures.

Conclusion

For thousands of years, doves have connected societies and people both physically through their ability to navigate, and symbolically in their prominent role in religion and history representing common themes such as peace, kindness and fidelity.

The ability of the dove to navigate using the magnetism of the Earth, and patterns of stars and sunlight is a remarkable example of the way doves interact with the inanimate world.

Bird intelligence shows that high level cognitive functioning, such as sensory perception and learning capabilities, is not reserved for large mammals. With the pallium, doves' brains emulate the function of the neocortex, contributing to problem solving, vocalization and pattern recognition.

Aside from their interaction with the inanimate and living world, doves have left a mark on mankind and within distinct traditions and cultures, doves appear. A likely reason for these similarities, is the idea that religions diffuse and influence each other.

At first glance, dove navigation, intelligence and symbolism may seem to be unrelated. However, by using a Big History approach and exploring links deeply, the material, biological, and cultural histories become clearer and lead to a deeper and more creative understanding of the dove and its role in our human history.

As the world looks to the future, the dove remains a fitting symbol of the connections among the physical world, life on Earth, and the history of humanity.

References

American Dove Association. (2010). General information. https://www.doveline.com/

Avetyan, M., & Zunner Keating, A. (2021). Beliefs: An open invitation to the anthropology of magic, witchcraft, and religion. In *An open invitation to the anthropology of magic, witchcraft, and religion* (Chapter 3). Licensed under Creative Commons Attribution 4.0 International License.

Baillie, K. (2018). Bigger brains are smarter, but not by much. *Penn Today*.

Cadiou, H., & McNaughton, P. A. (2010). Avian magnetite-based magnetoreception: A physiologist's perspective. *Journal of the Royal Society, Interface*, *7*(Suppl 2), S193–S205.

Cassone, V. M. (2014). Avian circadian organization: A chorus of clocks. In *Biological rhythms and the clocks that control them* (pp. 76–88). *Frontiers in Neuroendocrinology*.

Department of Vertebrate Zoology. (n.d.). The passenger pigeon. Smithsonian Institute. https://naturalhistory.si.edu/research/vertebrate-zoology

Dorrell, F. (2021). O for the wings of a dove: Why is this bird so significant in the Bible and our faith? *The Bible and Catholics*. https://www.thebibleandcatholics.com/articles/o-for-the-wings-of-a-dove

Johnson, W. (Trans.). (2005). *Mahabharata Book Three (Volume 4): The Forest* (Vol. 34). Clay Sanskrit Library, New York University Press.

Lohmann, S., & Lohmann, K. J. (2008). Magnetoreception in animals. *Physics Today*, 29–35.

Rogers, P. (2022). How do birds navigate? When they face north, their brains do something incredible. *Big Think*. https://bigthink.com/neuropsych/how-birds-navigate/

Shapiro, M., & Domyan, E. (2016). What are feral pigeons? *National Library of Medicine*. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4637004/

Soniak, M. (2016). The origins of our misguided hatred for pigeons. *Audubon*. https://www.audubon.org/news/the-origins-our-misguided-hatred-pigeons

Spier, F. (2015). *Big history and the future of humanity*. Cambridge, MA: Harvard University Press.

Staughton, J. (2023). How the pigeon post works: How do carrier pigeons know where to go. *World Atlas*. https://www.worldatlas.com/articles/how-the-pigeon-post-works.html

Steenhard, R. (2014). Carrier pigeons in the First World War. *Carnegie Foundation Peace Palace Library*. https://www.peacepalacelibrary.nl/2014/04/carrier-pigeons-in-the-first-world-war/

Stetka, B. (2020). Bird brains are far more humanlike than once thought. *Scientific American*. https://www.scientificamerican.com/article/bird-brains-are-far-more-humanlike-than-once-thought/

Watanabe, S., Sakamoto, J., & Wakita, M. (1995). Pigeons' discrimination of paintings by Monet and Picasso. *Journal of the Experimental Analysis of Behavior*, *165*(174), 165–174.

Wiltschko, W., & Wiltschko, R. (1991). Magnetic orientation and celestial cues in migratory orientation. In *Summary* (pp. 16–37).