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.

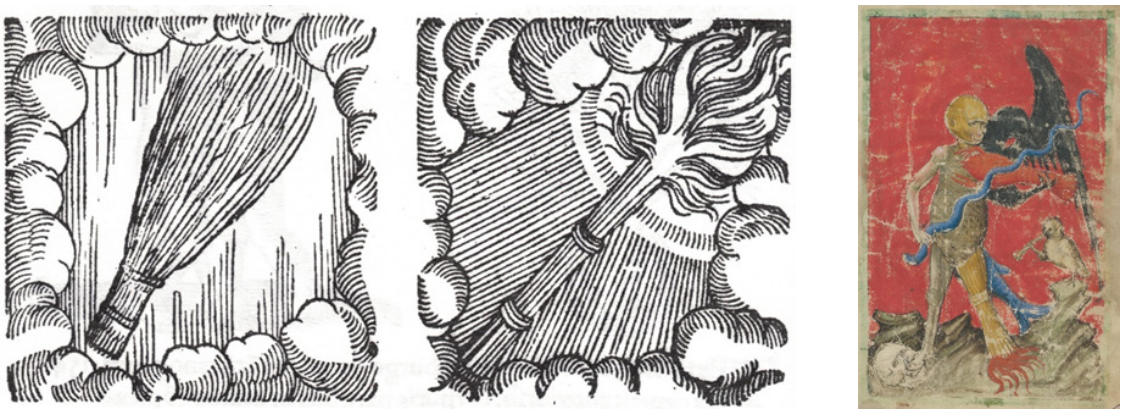
37 Wohlgemuth, *Preliminary Report*, vol. I: 17-19.

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.

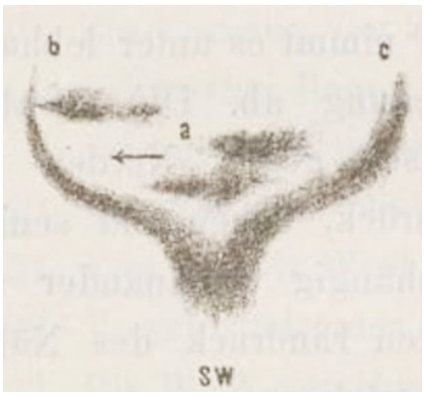
46 Bóbrick, *Preliminary Report*, vol. II, part IV: 6; No. 104, 3:35 a.m., 170.

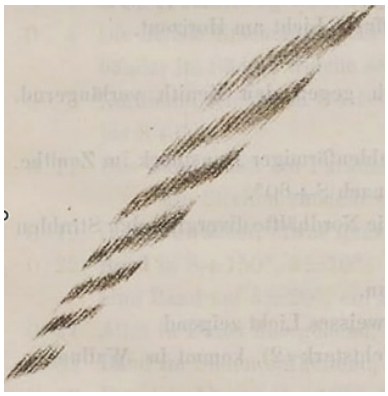
47 Bóbrick, *Preliminary Report*, vol. II, part IV: 6.

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.

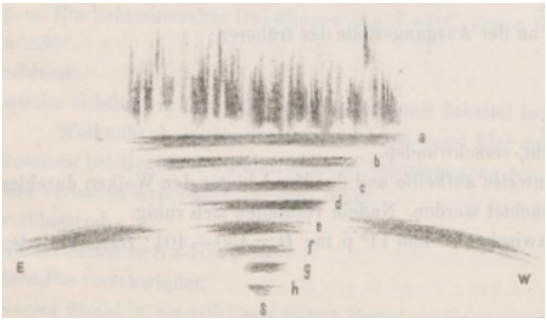
52 Bóbrick, *Preliminary Report*, vol. II, part IV: 10.

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.

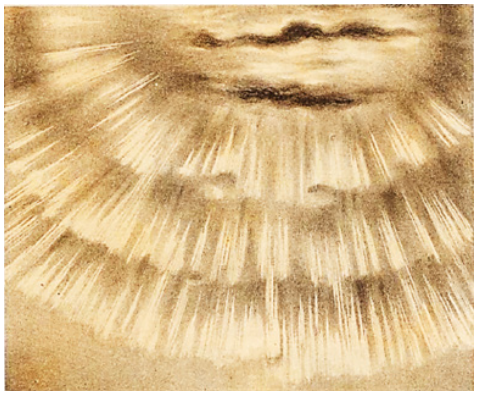
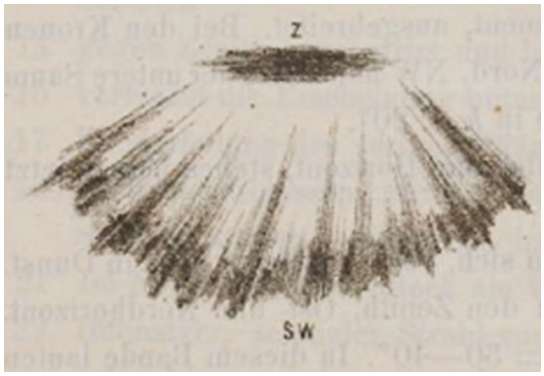
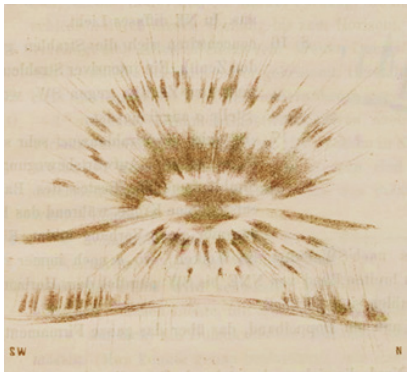


Figure 12: Crown of Bands/Ribbons.





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.

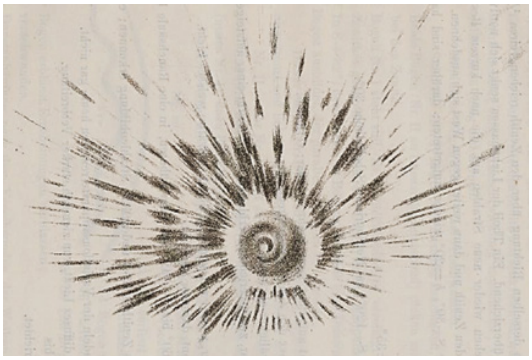
114 Bóbrick, *Preliminary Report*, vol. II, part IV: No. 35, 12:14-28 a.m., 54. The spectrum noted during this "play of colors" was green and red for ribbons at 12:14; and violet, intense red, green, and yellow in the corona at 12:28.

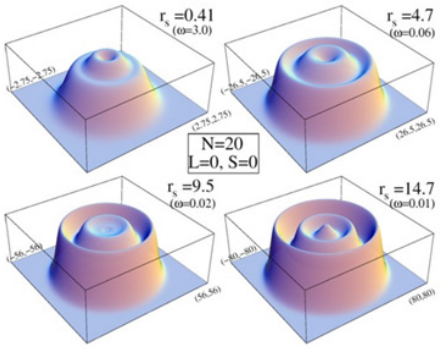
115 Bóbrick, *Preliminary Report*, vol. II, part IV: No. 57, 10:35-36 p.m., 92.

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."

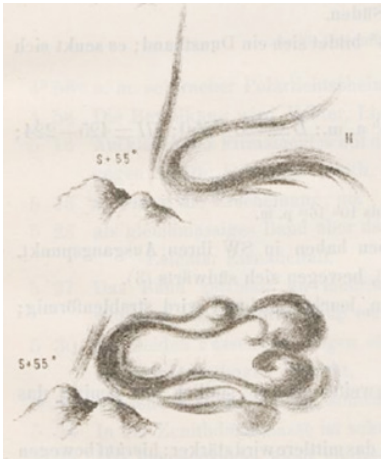


Fig. 19: (left) Calyx and Lily Flower (a.k.a. "arabesque").

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

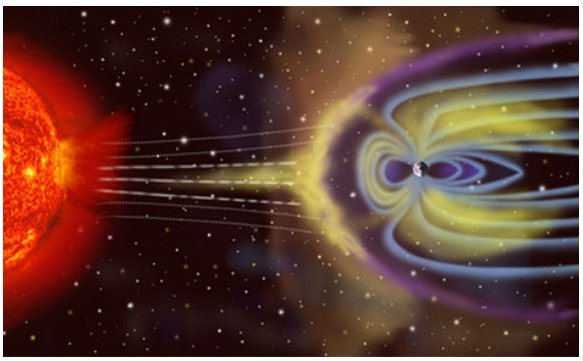
123 Bóbrick, *Preliminary Report*, vol. II, part IV: No. 51, 10:11-10.26, 78-79, Fig. 40.

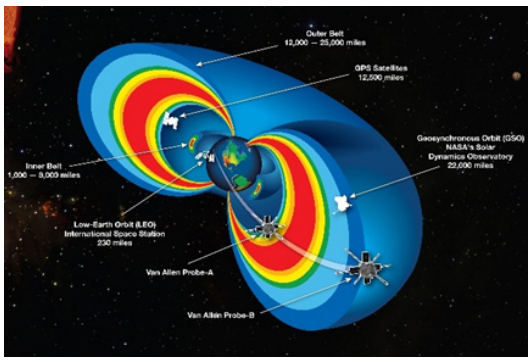
124 Bóbrick, *Preliminary Report*, vol. II, part IV: No. 56, 5:31-6:06 p.m., 87.

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.

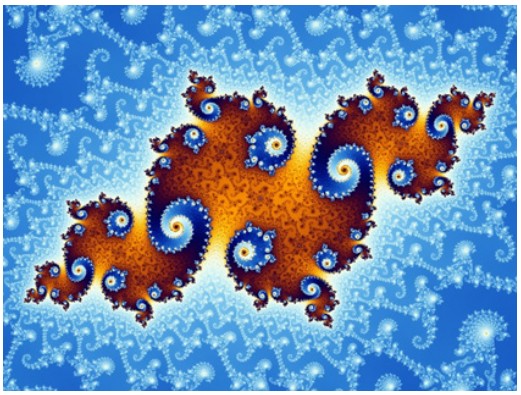
133 O. Adriani, G. C. Barbarino, G. A. Basilevskaya, *et al.*, "The Discovery of Geomagnetically Trapped Cosmic Ray Antiprotons" *The Astrophysical Journal Letters* 737.2 (27 July 2011): L29(1-5), https://iopscience.iop.org/article/10.1088/2041-8205/737/2/L29/pdf.

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



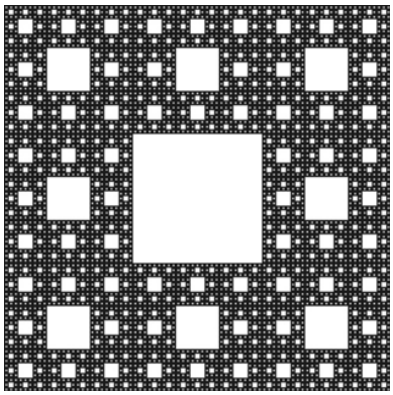


Figure 23: (left) Mandelbrot Double Spiral Medallion.

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.

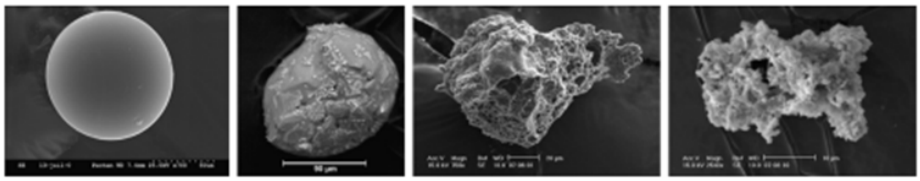


Figure 25: Micrometeorites (cosmic plasma dust) from Antarctica of various shapes and consistencies.

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]

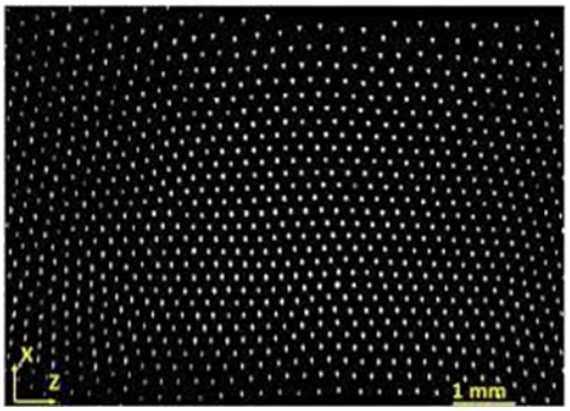
More significantly, *cosmic (dusty) plasma* exhibits complexity in phase (states of matter) transitions from *disordered gas* to *viscous liquid* to *plasma crystals* that are reversible. In order to form a *plasma crystal* (also known as *Wigner* or *Coulomb crystal*) the critical *kappa* value of $\Gamma \geq 100$ 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

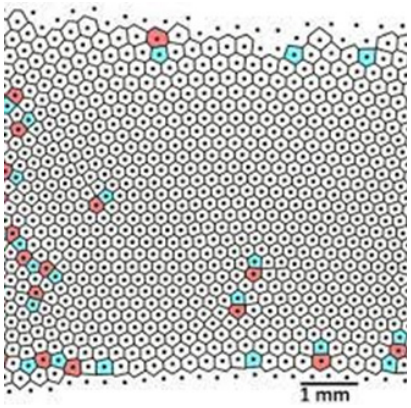
147 Melzer, *The Physics of Dusty Plasmas*, 1-4, 31-35; Anthony A. Peratt, *Physics of the Plasma Universe*, Second Ed. (New York: Springer Books, 2015), 1-2; Gurnett and Bhattacharjee, *Introduction to Plasma Physics*: 1-9; Fortov et al., Complex (Dusty) Plasmas: 3-25; J. Rojas et al., "The Micrometeorite 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.

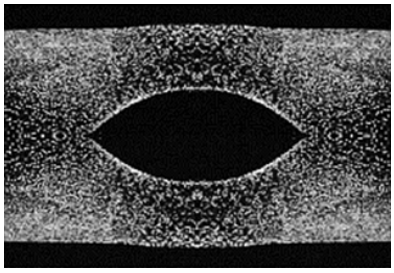
Experiments with Cosmic Plasma on Earth and under Microgravity Conditions in Orbit: Dust Voids, Striated DC Glow Discharges, Rotating Cones, Plasma Penumbra, Electrostatic Double Layers, Yukawa (Coulomb) Agglomerated Balls, and Late Medieval Spheres

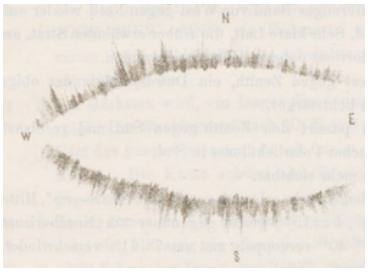
Dust Voids

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-

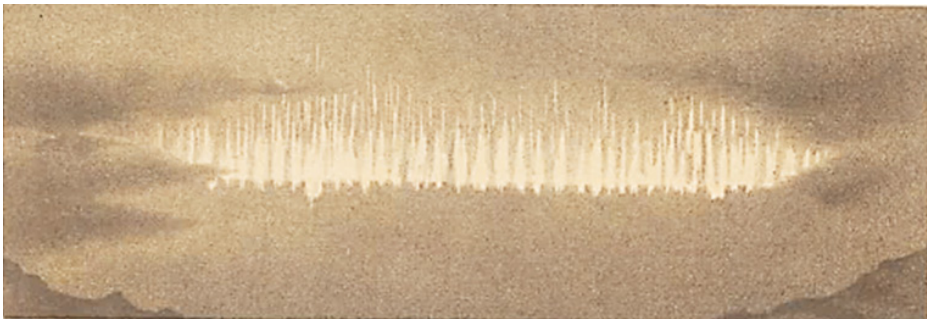


Figure 31: 'Rods in the Band' auroral subform.

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.

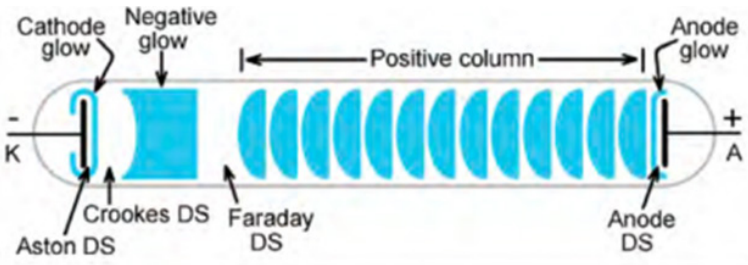


Figure 33: Cathode ray discharge tube diagram.

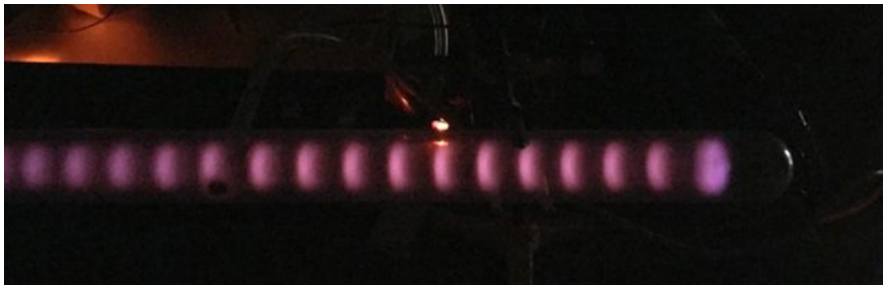


Figure 34: Positive column of a DC glow discharge.

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]

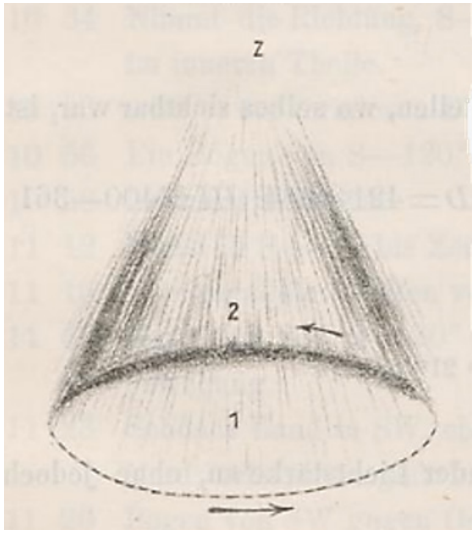


Figure 35: Rotating cone observed in the skies above Jan Mayen Island, 9 March 1893.

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.

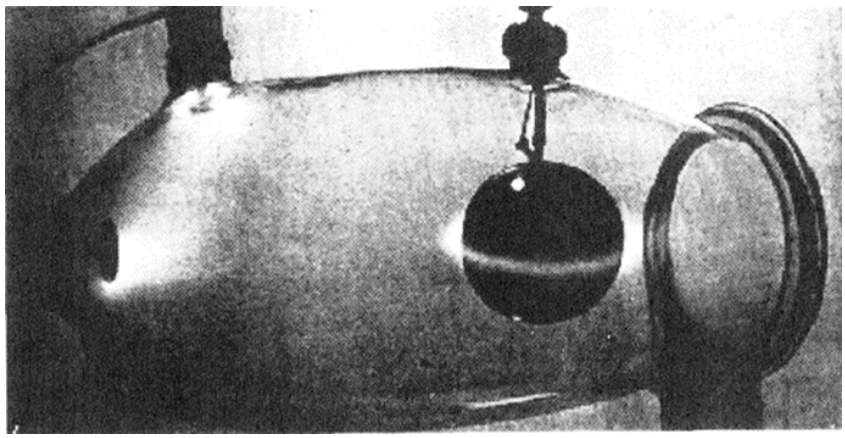


Figure 36: Glass tube, with cathode (left), anode (upper left), and magnetized *terella* (right). The concentration of cathode rays around the center was named "Equatorial Rings of Light" and were similar to Saturn's rings.

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

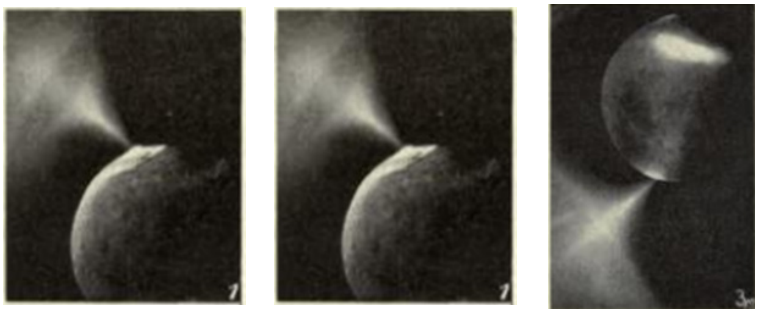


Figure 37: Three photographs of the "cones of light" captured by Birkeland on the *terella* device.

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

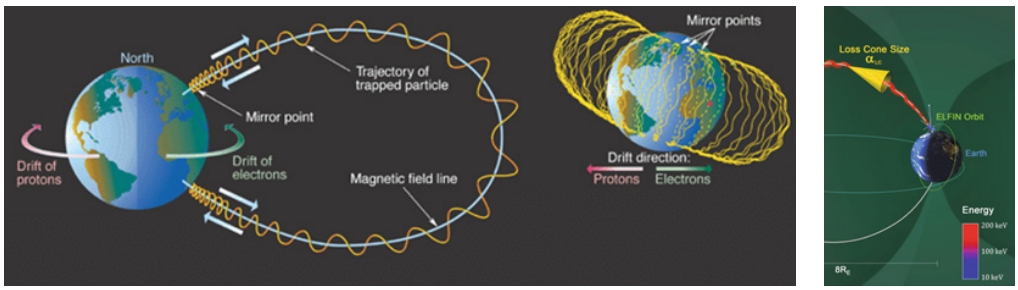
179 Birkeland, *The Norwegian Aurora Polaris Expedition 1902-1903,* Vol. I, Part I, Chapter III, 299-300, Fig. 135.

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]

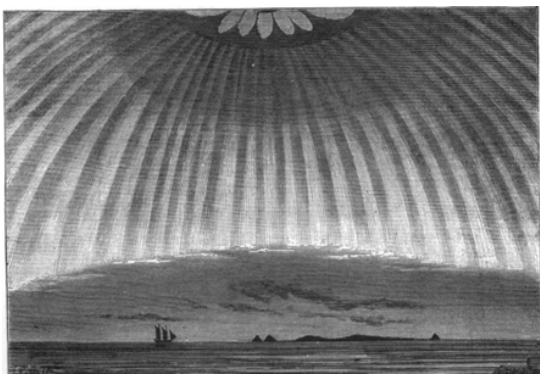
The cone drawn in Figure 39 is a theoretical construct wherein the trapped particle's *equatorial pitch angle* falls inside or outside the loss cone that lies perpendicular to the magnetic field line.[186] If a particle's *pitch angle* falls inside of the cone it will escape after a few bounce cycles; 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.

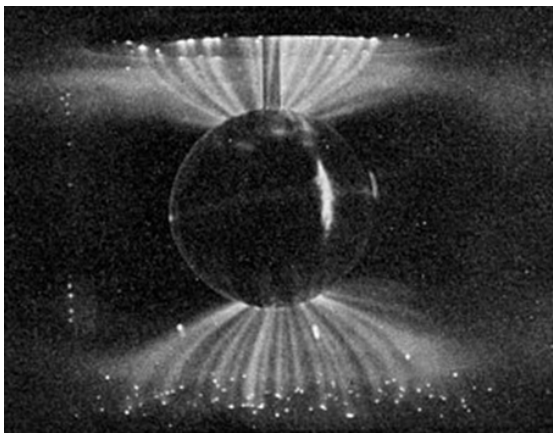


Figure 42: Birkeland's *terella* [mini-Earth] device.

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

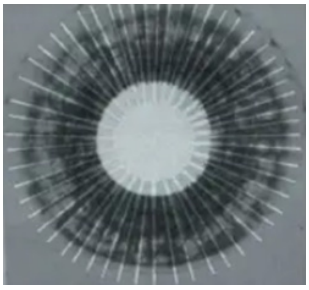
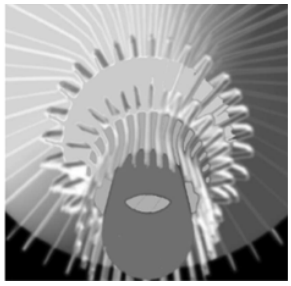
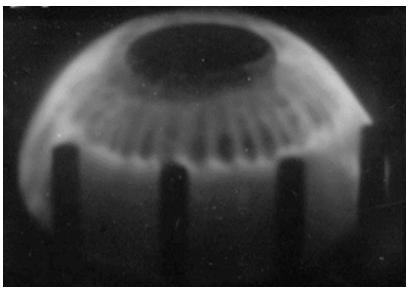
192 Richard Devons, *American Progress or, the Greatest Events of the Greatest Century* (Massachusetts: C. A. Nichols & Co., 1889), 269-75. Perceptions of the event were also noted for New York city and St. Louis, Missouri.

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.

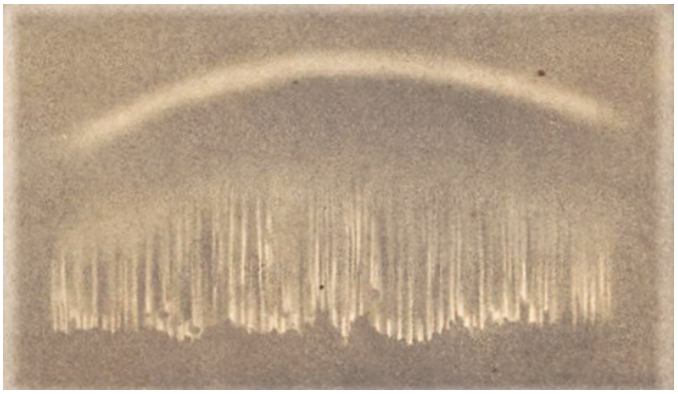
209 Alfvén, *Cosmic Plasma*, 13-36; "Filamentation," https://www.plasma-universe.com/filamentation/.

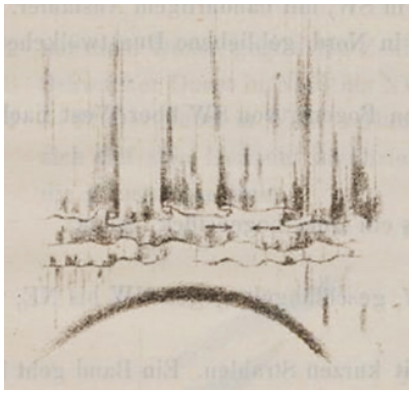
210 R. E. Ergun, L. Andersson, *et al*., "Auroral Particle Acceleration by Strong Double Layers: The Upward Current Region" *Journal of Geophysical Research* 109.A12220 (2004): 1-14, https://doi.org/10.1029/2004JA010545.

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.

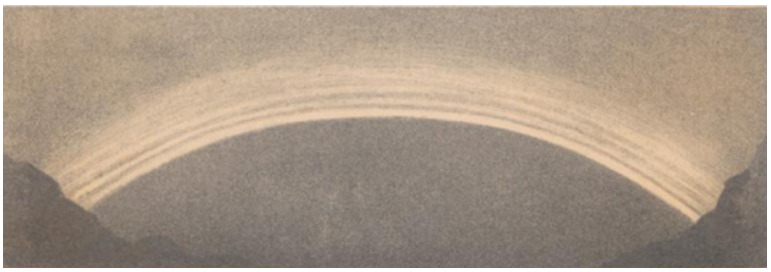
212 Alfvén, *Cosmic Plasma*, 65, 69. Italics added by the authors for emphasis.

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.

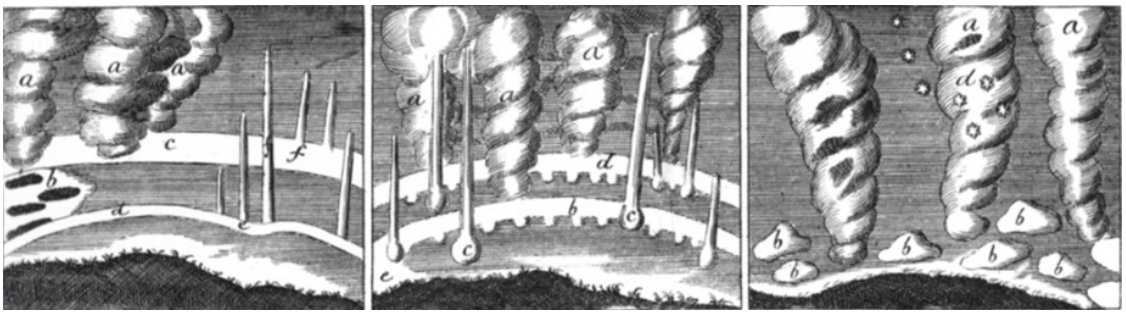


Figure 50: Electrostatic DL particle acceleration as witnessed in Danzig on 17 March 1716. The "Outer Space Torndoes" are synchrotron radiation emitted from ionic beams in the Auroral Acceleration Region (AAR).

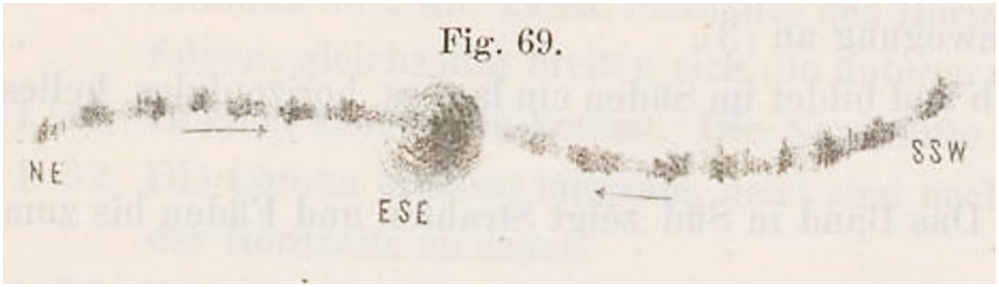
apparent.[227] In summary, because *electrostatic double layers* are essential to the auroral circuit – *but are only visible to the human eye during solar storms when particle collisions produce photonic illumination* – the entire spectrum of sun-induced formations occurs at energetic levels far, far 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.

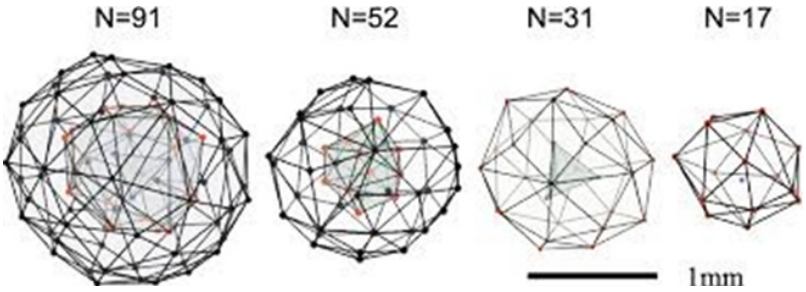
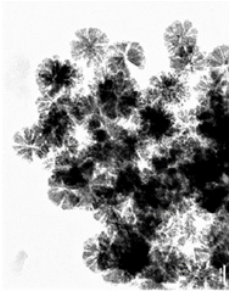


Figure 52 53: (Left) – Schematic of Yukawa/ Coulomb balls with magic number configurations; **Figure 53** (Right) – Cauliflower-type electrostatic agglomeration.



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

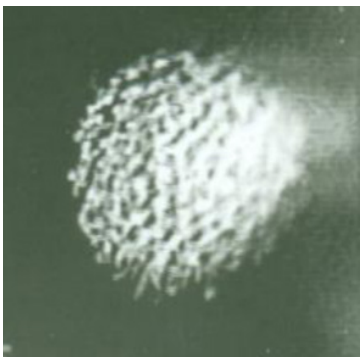
230 Melzer, *Physics of Dusty Plasmas*, 145-158, Apolinario *et al.*, "Structural and Dynamical Aspects of Small Three-Dimensional Spherical Coulomb Clusters": 283 (2-17).

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/.

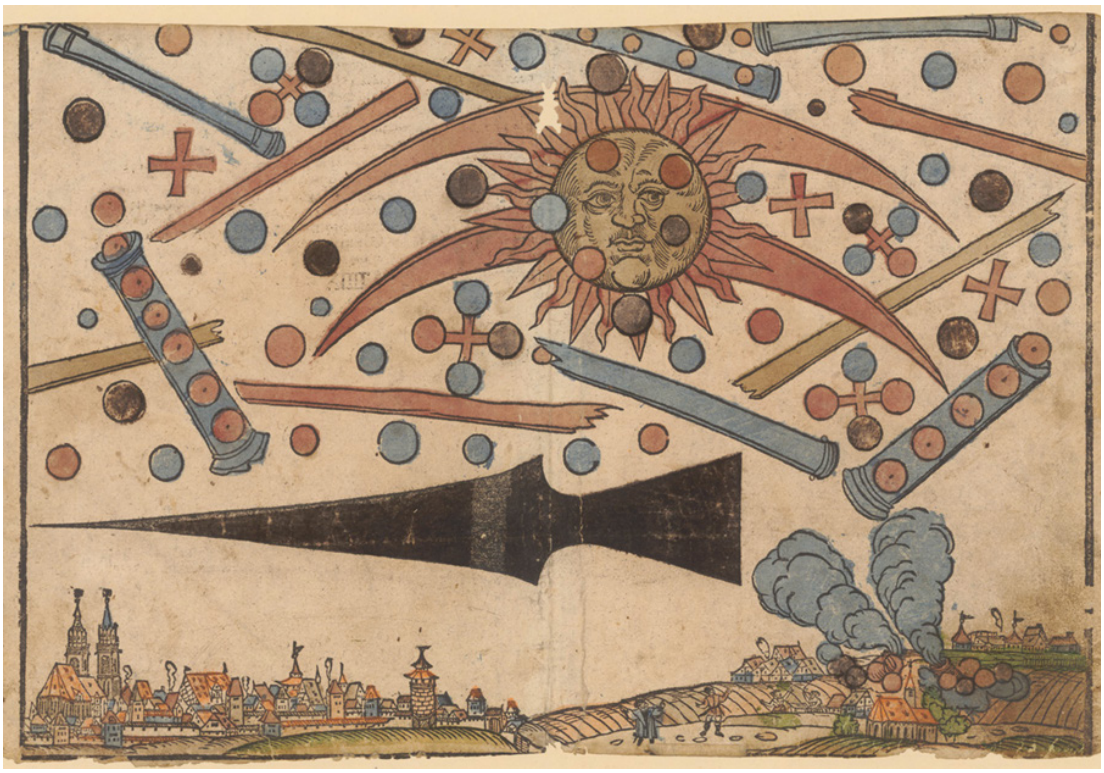


Figure 58: Hans Glaser's woodblock print "Himmelserscheinung über Nürnberg vom 14. April 1561."

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.

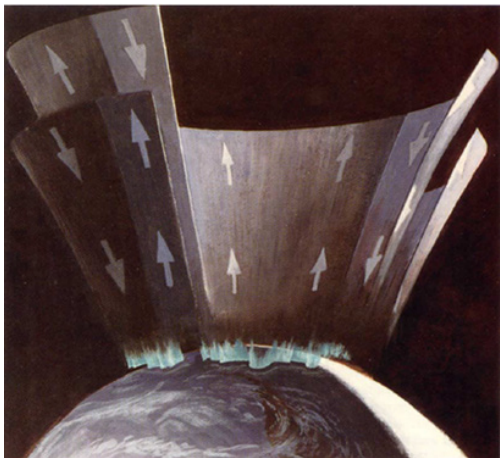
As for the luminous *crescent shapes* above and below the "dreadful apparition appearing on the face of the rising sun" in the Nürnberg broadsheet (Fig. 58), *their shape and auroral crowning event in between indicates a pair of opposite flowing Birkeland FAC*. In their most common manifestation at the *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*

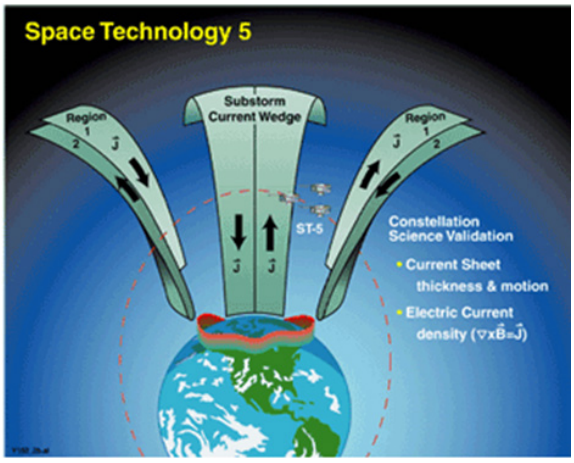
261 Mahalo to Professor Rainer Buschmann of CSUCI for his assistance with fine-tuning the translation by Ilse Von Jacobi. See "1561 celestial phenomenon over Nuremburg", https://en.wikipedia.org/wiki/1561_celestial_phenomenon_over_Nuremberg. The remainder of the broadsheet reads: "Although we have seen, 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.

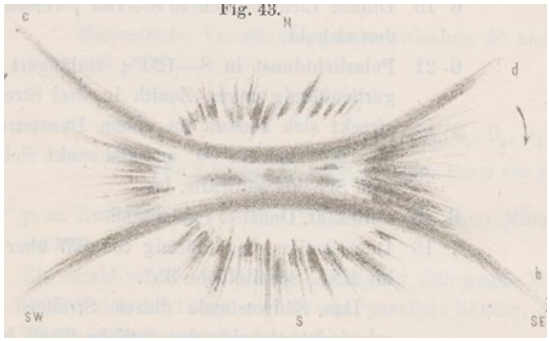
269 Peter Lourie, *Sweat of the Sun, Tears of the Moon: A Chronicle of an Incan Treasure* (Lincoln, Nebraska: Bison Books, 1998).

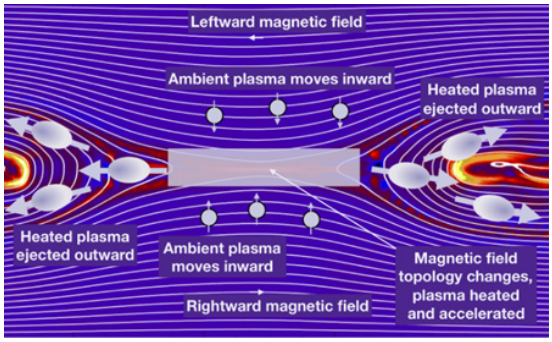
270 Gurnett and Bhattacharjee, *Introduction to Plasma Physics*, 270-79; Rudolf A. Treumann and Wolfgang Baumjohann, "Collisionless Magnetic Reconnection in Space Plasmas" *Frontiers in Physics* 1 (31 December 2013): 00031(1-34), https://doi.org/10.3389/fphy.2013.00031; P. F. Wyper, C. R. DeVore, *et 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

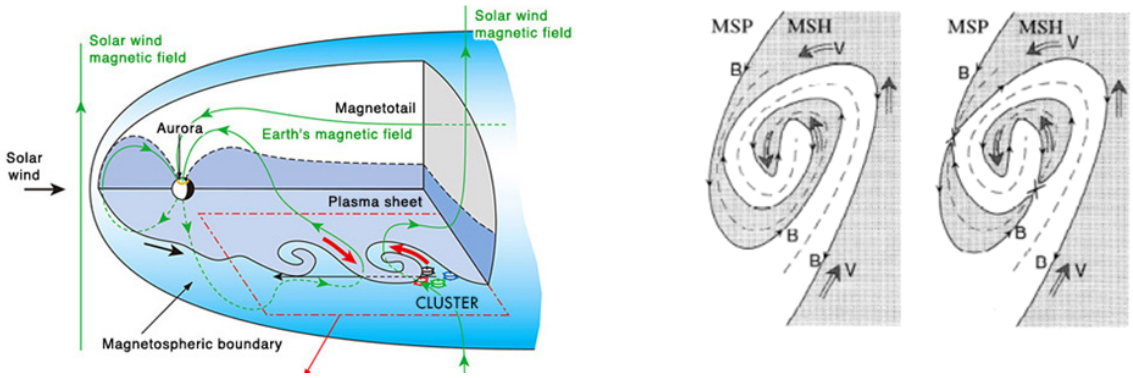
Anderson, "A Review of Birkeland Current Research Using AMPERE" in Andreas Keiling, *et al.*, ed., *Electric Currents in Geospace and Beyond, Geophysical Monograph 235* (New York: John Wiley & Sons, Inc., 2018): 259-278, https://agupubs.onlinelibrary.wiley.com/doi.abs/10.1002/9781119324522.ch16; Erwin 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.

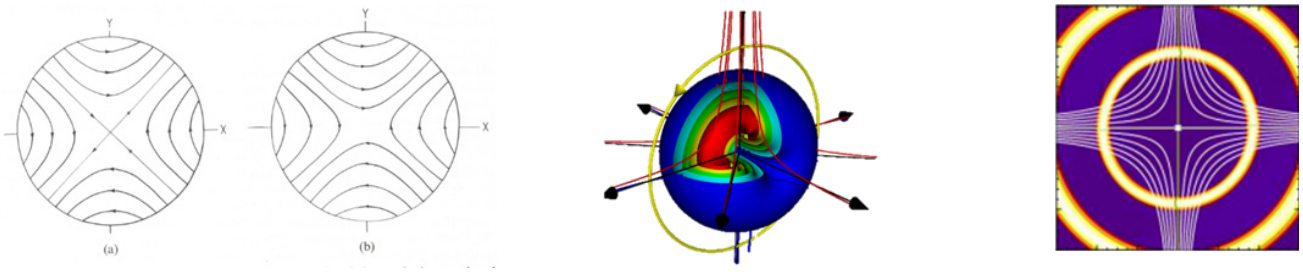
Figure 65: Two hovering fireballs seen simultaneously over the town of Mecklenberg (left) and city of Hamburg (right), in 1697.

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.

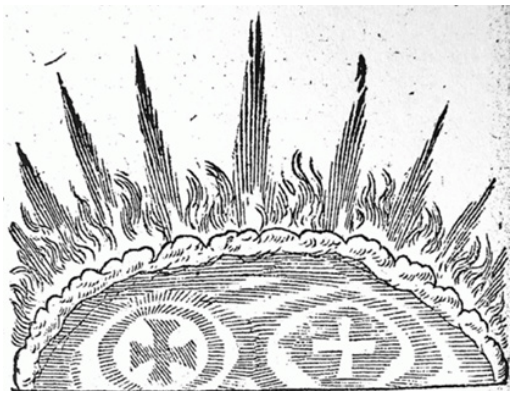
294 Dowson, *Rock Engravings of Southern Africa*, 50, Plate 78; David R. Morris, "Dreikopseiland and the 'Rain's Magic Power': History and Landscape in a New Interpretation of a Northern Cape Rock Engraving" Master's Thesis, Department of Anthropology and Sociology, University of the Western Cape, South 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/.

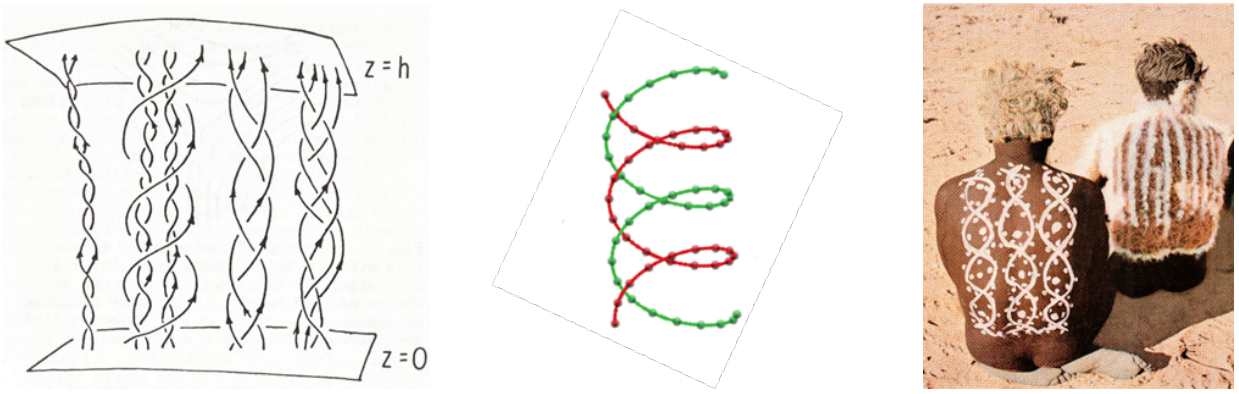


Figure 76a-c: (Left) – a) Four helically-winding flux tubes from left to right: twisted tube; two twisted tubes wrapped in a larger twisted envelope; a three-field line braid; and four-field tangled pillar. The last two are non-invariant in direction of field wrapping and topology; (Middle) – b) Double-helix 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.

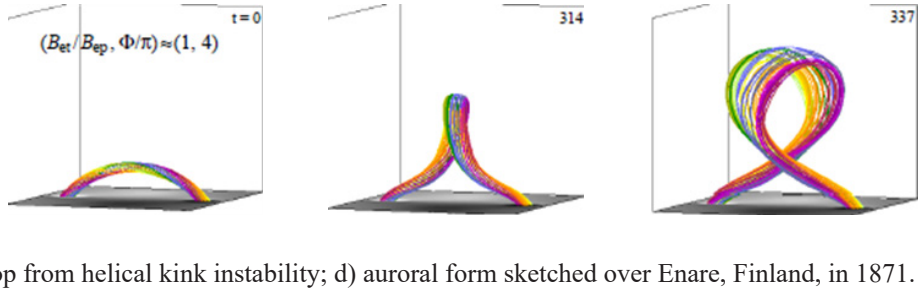
327 Eugene N. Parker, "Magnetic Reconnection and Magnetic Activity" in Edward W. Hones, Jr., ed., *Magnetic Reconnection in Space and Laboratory Plasmas* (Washington, D.C.: American Geophysical Union, 1984): 35, Fig. 2, "A sketch of some of the forms of twisted and wrapped field lines that may occur 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,

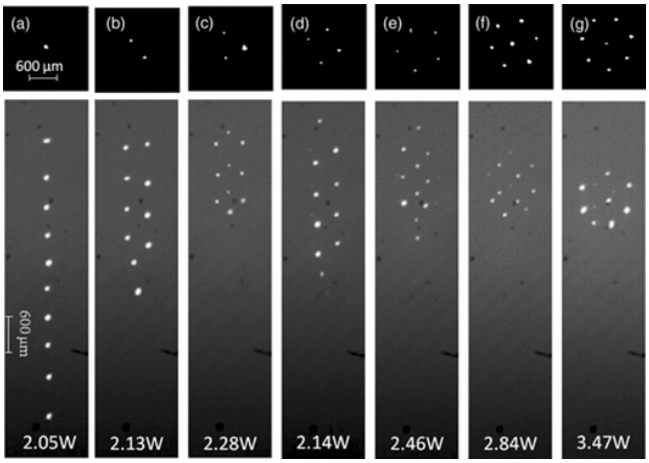


Figure 79a, b: (Left) – Assorted cupules and strings-of-pearls (or lines-of-dots) petroglyphs from Jebel Jassassiyeh; (Right) – Singular, folded, prolate, and helical chains of charged dust particle bundles from Baylor's CASPER lab.

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;

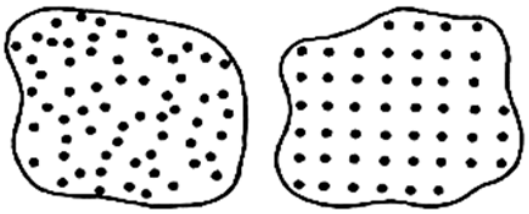
345 Figure 75 source: Telma Costa, "The Mystery of Brazil's Ancient Ingá Stone Might Have Just Been Solved": https://earthlymission.com/inga-stone-drawings-carvings-brazil-mystery-solution-solved/. Photograph by Marinelson Almeida Silva.

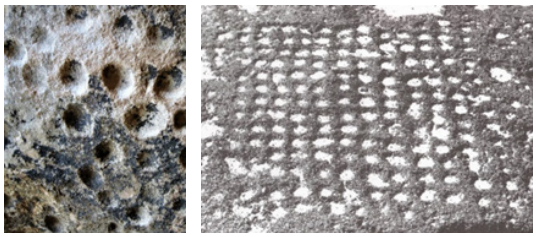
346 Peratt, "Characteristics for the Occurrence of a High-Current, Z-Pinch Aurora as Recorded in Antiquity":1206-1207.

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).