Review and Analysis of Big History Periodization Approaches

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Citation | Solis, K. & LePoire, D. J. (2023) Review and Analysis of Big History Periodization Approaches. *Journal of Big History*, VI(3); 22–34.
DOI | https://doi.org/10.22339/jbh.v6i3.6303

Keywords: Big History, evolution, complexity, thresholds,

Abstract: Big history may in fact be one very long "one damn thing after another,"* but even if we experience time as a continuum, dividing its expanse makes our discipline more "manageable" for psychological, teaching, research, discourse, and other reasons. Big history related books, like David Christian, Cynthia Stokes Brown, and Craig Benjamin's 2014 textbook, *Big History: Between Nothing and Everything*, and several papers also often divide the time continuum into periods, but unlike other disciplines such as geology, we have no broadly agreed upon conventions for doing so. Big history pioneer, Fred Spier, in a recent *JBH* paper, "Thresholds of Big History – A Critical Review" (Vol 5, No. 1), criticized Christian's "thresholds" schema for periodization and seemed skeptical of the very idea of periodization. As noted above, we believe that periodization is a worthwhile project to be undertaken, preferably by an ad hoc IBHA "working group." We then suggest a general framework for how big history might be divided into time periods, and then anticipate some of the major challenges to developing any coherent periodization schema. So that we can better illustrate some of these challenges, we will end by taking deeper analyses of three possible big history "events" that might be used for demarcating one time period from another.

1. Introduction – Thresholds to Big History?

Big history is, well. . . BIG! 13.8 billion years of events, processes, and "things" are a lot to wrap our minds around. Consider – the thickness of a sheet of paper sitting on top of the Prudential skyscraper in Boston, or the top floor of the Eiffel Tower represents the relative length of time covered by traditional histories compared to big history. Geologic history is much longer than traditional history, of course, but still is only about 1/3 as long as big history. We seem to have an inborn tendency, even need, to divide large "things," probably so that we can better apprehend and comprehend them. This tendency to divide large pieces of information is called "chunking" in psychology (Gobert, 2012). The division of human areas of study is , of course, one example, and one that big historians often rail against: physics, biology, ethics, chemistry, astronomy, music, literature, and history are in the end just different aspects of the universe that are all interconnected. For example, Pythagoras, the ancient Greek philosopher, discovered that the harmonics in music have a physical basis in "nature" – not just our minds (Stewart, 2015). Despite the ultimate unity of knowledge, our mind begs to parse it into manageable chunks, and so we also have a strong tendency to do the same with the universe's 13.8 billion years of time.

Personal communication with David Christian confirmed that he periodized big history into 9 "thresholds" in his *Great Courses* lectures series "*Maps of Time: An Introduction to Big History* (2011), and the text book *Big History: Between Nothing and Everything* (2014) only for pedagogical purposes. Regardless, dividing time by some type of periodization schema might make sense at face value to the great majority of those interested in some aspect of "deep time." After all, geology divides time by several levels like "eons," "epochs," and "eras." Paleontology has the paleolithic, and neolithic as well as other time divisions. Traditional history divides time in a myriad number of ways (Kisak, 2022).

Hence, at first blush, Fred Spier's objections to big history periodization in his paper (Spier, 2022), "Threshold of Increasing Complexity in Big History: A Critical Review," in JBH Volume 5, number 1, seems surprising. Furthermore, David Christian is generally considered the founder

*An apocryphal quote often attributed, likely mistakenly, to the historian, Arnold Toynbee.

of contemporary big history, and Fred Spier is amongst its earlier pioneers as well. Hence, given the status of those with opposing views only "adds fuel to the fire" and begs for further examination:

Spier's major contentions against Christian's "thresholds of increasing complexity" include the following:

- The periodization scheme and its terms are Earth-centric once the Solar system forms and fails to acknowledge that advanced complexities likely occurred earlier elsewhere in the universe.
- Similarly, the scheme and its terms are also anthropocentric beginning about 7 million years ago when the evolutionary lines split between the great apes and the line that led to Homo sapiens.
- Christian's "thresholds" lack precision in defining or characterizing what qualifies as a significant advancement in complexity so that they warrant being markers for a new period in big history.
- Thresholds also fails to identify processes and conditions that favor increases in complexity, i.e., "Goldilocks" circumstances,"
- It ignores other advances in complexity that occurred, or conversely, declines in complexity that occurred.

The first two objections can be readily and briefly addressed: At this time, big history is *necessarily* Earth-centric and anthropocentric. First, while we are progressively detecting evermore planets, including solid ones, with more advanced telescopes and other detection strategies, our knowledge of them is small compared to what we know about Earth, e.g., primarily their approximate size, mass, and year length. We know much more about the planets and moons of the Solar system, and Earth is arguably its most complex member. It is the solar system's only solid heavenly body with plate tectonics, Van Allen belts, a liquid hydrosphere, and a relatively large moon that causes secondary phenomena that help it support complex life. The Solar system's gas giants have complex weather systems, many moons, and Van Allen belts, but they almost definitely lack a biosphere because their gaseous nature would not allow for the Goldilocks circumstances that promote life as we know it. Life in turn rapidly advances the complexity of systems in a myriad of ways that even the most complex physical systems like planets, stars, black holes and galaxies do not.

Big history is also necessarily anthropocentric if only because we cannot ask even advanced Earth species like chimpanzees and dolphins about their perspectives because they lack grammatical language. Of course, humans are more advanced complex life forms compared to Earth's other species in many more ways than we can recount here. Life on other planets outside of Earth is likely, even very likely, but it remains a point of conjecture until there is demonstrative empirical evidence of its existence. In short, once the Solar system forms, we are left with only our own perspective to examine and contemplate. If and once we can gain much more information about other exoplanets, and perspectives from other communicative, sentient beings, big history will likely have to adjust.

In his book, *Big History and the Future of Humanity*, Spier (2015) also acknowledges that big history is necessarily Earth and anthropocentric (p8). His book does proceed to list different events from the Big Bang to contemporary "emergences" in chronological order. Apparently, however, he feels that a *periodization* scheme like Christian's "thresholds of increasing complexity" implies a cosmic reach in its application. We believe that semantics aside, there is little difference in proposing a periodization scheme versus more simply a chronological listing of events (that typically give rise to greater complexity) over the expanse of time. An author *still* must decide *which* events are significant enough to warrant them being described, even if just being the heading for a chapter, e.g., "Chapter 5. Life on Earth: The Widening Range of Complexity," and the included subchapters, e.g., "The Emergence of Multicellular Organisms." Note that we are not criticizing the listing of events in a chronological or hierarchical manner, and in fact, we endorse it. However, there is not a great distinction between a mere listing of important events and a somewhat more formal periodization of time based on important events.

Spier's other objections to Christian's thresholds of increasing complexity do deserve much more discussion, however.

2 Why Should We Periodize Big History?

Perhaps the most immediate reason for periodization is to accommodate the human mind's tendency to divide large entities so that we can better apprehend and comprehend them – as mentioned earlier, psychology refers to this tendency as "chunking." (Gobert, 2012). Big history periodization is but one example. We also divide the living organisms into clades, the electromagnetic spectrum according to ranges of wavelengths, and areas of human knowledge into various disciplines – even if the matter at hand is a continuum.

Another pragmatic purpose is to facilitate the teaching of big history in discrete modules according to the most relevant scientific discipline for a time period, e.g., astronomy, geology, paleontology, traditional history, and so on (Kisak, 2022). As David Christian did at his big history course at Macquarie University, inviting different lecturers from different disciplines to teach the how and why their subject matter varied over time was undoubtedly beneficial for both him and his students. For example, while most historical professors can learn to recite the events that occurred in the three minutes after the Big Bang, an astronomer would be able to better articulate the deeper reasons of *why these* events occurred as they did, or other questions relevant to astrophysics like the formation of higher chemical elements. Students will also benefit by being able to better compartmentalize how different types of processes and entities drive change depending on the time being studied, e.g., physical processes before life appeared on Earth, then various genetic and epigenetic processes, leading eventually to the many factors at work in the modern age.

Big history research and academic discourse would benefit from a widely agreed upon periodization scheme by helping to crystallize certain concepts or prompt various research agendas – perhaps one of most direct being the exploration of various characteristics, processes, "Goldilocks" (i.e., optimum) conditions, and other parameters that make the very periods of time distinct. Such projects help to make big history "deeper" than the mere compiling of events. These concerns are already demonstrated in books by David Christian (2008, 2011), Eric Chaisson (1996, 2001), Tyler Volk (2017), Fred Spier (2015), and many others.

Finally, assigning names to different periods of big history serves as an informational heuristic – a shortened or condensed way of including a lot of information with a brief word or phrase. For example, if someone tells you that animals with a nervous system first appeared during the "Cambrian explosion," you would know to place that occurrence to about 540 million years ago. Nevertheless, even if a big historian had to look up the exact date of the Cambrian explosion, they would already know basic information, such as: life had been established on Earth for a long time; there was a high concentration of oxygen in the air; multicellular life and sexual reproduction had already developed; dinosaurs had not yet appeared; etc. A short phrase can encompass a lot of information!

This list of reasons for purposefully and thoughtfully periodizing big history is unlikely exhaustive, but illuminates some of the key reasons of why it is a goal worthy of the needed creativity, rigor, energy, and consensus for this academic discipline.

3 How Has Big History Been Divided by Others?

David Christian is not the first to divide the expanse of time from the Big Bang to present. Table 1 includes an overview of just a few authors that have periodized big history in the past, even if their primary intention might have been to illustrate another thesis such as the apparent mechanics or dynamics of evolution. Because Christian is widely recognized as contemporary big history's founder and was the inspiration for Spier's polemic to such a schema, we will look briefly at his method first.

In his 2018 book *Origin Story: A Big History of Everything*, Christian (2018) divides big history into 8 "thresholds," with a future projected 9th threshold: "A sustainable world order?" (p13-14). The 8 thresholds in chronological order include: 1. Big Bang, 2. The first stars, 3, New elements forged in dying stars, 4. Our sun and solar system forms, 5. Earliest life on Earth, 6. First evidence of our species, *Homo sapiens,*7. End of the last ice age, and 8. Fossil fuel revolution begins. He notes that each threshold "highlights major turning points when already existing things were rearranged or otherwise altered to create something with new, "emergent" properties, qualities that had never existed before."

We should note that Christian also offers a number of events that occur between some of the thresholds (e.g., "The first large organisms on Earth"), but does not state if he used any particular criteria for deciding which ones to include. The listing of events such as "an asteroid wipes out the dinosaurs," (and even the "threshold" of "End of the last ice age") indicates that he is not exclusively noting new levels of complexity emergences to periodize big history, but sometimes a major geologic event that might have made a new level of complexity possible, or at least more likely.

However, Christian is not the only one who lacks rigorously defined criteria for identifying big historical events or defining new time periods. In Eric Chaisson's (1996) book, *Epic of evolution: Seven Ages of the Cosmos,* the astrophysicist and fellow big history pioneer, includes seven "epochs:" 1. Particle, 2. Galactic, 3. Stellar, 4. Planetary,

5. Chemical, 6. Biological, and 7. Cultural. The criteria he used to arrive at these divisions are not made clear and the term "epoch" is not defined. Admittedly, he notes that the principal epochs he lists are overlapping (p248) and his focus is on "the story of cosmic evolution" rather than an attempt to periodize this evolution in some rigorous manner.

On the other hand, Robert Aunger, a professor of evolutionary public health, wrote "A rigorous periodization of 'big' history," in 2007. Hence, his paper anticipated the topic at hand (Aunger, 2007). He proposed dividing big history into "eons," "eras" and "periods," the former being longer in time duration than the latter. Time "periods" include 16 divisions that are determined by the appearance of a new non-equilibrium steady-state transition (NESST) that is also persistent through history (i.e., does not become extinct). Each successive NESST is a novel system that uses a new energy source to maintain a structure's "work cycle." Hence, during the "Atomic period," atoms capture electrons, as controlled by the electro-magnetic force. During "Cell period," living cells use metabolism to maintain themselves, and the control mechanism is found in the genetic code, and so on.

Aunger's four "eras" - a longer duration of time that spans over several time periods - are determined by the *kinds* of energy source used to maintain a system. For the "material" era, systems are driven by nuclear fusion, the "biological" era by metabolism, the "cultural" era by new kinds of human-made tools, and the "technological" era by machines like windmills and watermills. Finally, Aunger names two long eons that span over several eras: the "cosmological eon" and the "terrestrial eon" Aunger notes that during the span of time from the Big Bang until the origin of terrestrial life, the duration of time between the appearances of new systems using a novel energy source, *and* the time duration it took for new type of system to become "mature" was increasing. In other words, the rate of the appearance of new types of physical bodies like galaxies, stars, and planets, was slowing. Once life appeared on Earth, at least, new systems (i.e., living organisms) began to appear much more quickly due to their inheritable and alterable genetic material.

Admittedly, the foregoing is a brief description of Aunger's significantly more profound proposal. Although Aunger's schema for big history periodization is subject to criticism (e.g., many systems of the "material era" are not driven by nuclear fusion, and arguably many important "epochal" events during Earth's history are ignored), his general approach has great merit. Like geologic time scales, he not only has different resolutions of time durations as indicated by his eons, eras, and periods, but he also strives to be rigorous and consistent in defining and applying his criteria.

Theodore Modis, a physicist and futurist, periodized big history by collating important events from 12 different sources to arrive at his list of 25 major "milestones" (2002). He also assumes that each of these milestones has similar importance and plotted them on a semi-logarithmic graph to demonstrate what appears to be a geometric rate of progression of complexity across the expanse of time. This is similar to the events constructed by Panov (2019). He also analyzed the apparent dynamics of evolutionary change to argue that the overall rate of complexity progression had embedded "S" shaped logistic curves that portended a slower rate of complexity progression in the near future, rather than the increasingly vertical curve predicted by the futurist, Ray Kurzweil (2005), of "technological singularity" fame. Regardless of the paper's primary intent to demonstrate the logistic progression of complexity, his collated milestones periodize big history in yet another manner.

David LePoire (2015, 2023) concurs with Modis' that complexity progression's dynamics follows a modified logistic curve. To determine a key new complexity progression, he considers not only a consensus of other authors in this area of research, but also their increase in rates of energy flows, informational processing, and organizational stages (an" integrative approach"). His "cumulative learning acceleration" schema includes 17 historical events, and like Aunger and the "geologic time scale," (see below) he also believes that it is desirable to have different resolutions of time periodization.

The numbering of new major events in the range of 20-30 seems to be a common occurrence. The biophysicist Harold Morowitz lists 28 new emergent events (an equivalent to the progression of complexity) in his book, *The Emergence of Everything* (Morowitz, 2002). Similar to Christian's "thresholds," Morowitz focuses on the intuitive importance of a new emergent phenomenon itself rather than looking for a deeper underlying thermodynamic, evolutionary, or other mechanistic thread.

Volk (2017) cites 12 hierarchical evolutionary "levels" that have been attained over the expanse of time. Like many other authors cited in this paper, his primary intent is to explain a major mechanism that drives evolution: the combi-

Approx Time	Cumulative Learning Acceleration	Christian (2014) "Thresholds"	Aunger (2007) "Eons/Eras/Periods"	Modis (2002) "Milestones"	Morowitz (2002)	Chaisson (1996) "Epochs"	Volk (2017) "Levels"	ICS Geologic Time Scale (2022) "Eons/Eras/Periods/ Epochs
13.8 BYA	Cosmic/ BB	Universe (1)	Cosmological/ Material/ Atomic	Big Bang(1)	Primordium(1)	Particulate (Chaos, Hadron, Lepton, Nuclear, Atom) [Radiation]	Fundamental Quanta(1), Nucleons(2), Atomic Nuclei(3),	Early Universe
	Cosmic/ structure	Stars(2)/ Elements(3) Sun(4)	Stellar Galaxy	Origin of the Mily Way(2)	Large-Scale Structure (2),Stars(3), Elements(4), Solar system(5), Planets(6), Geosphere(7)	Galactic, Stellar, Planetary [Matter]	Atoms(4)	Stelliferous Era (1MY from BB)
5 BYA	Life/ Chem & Prokayotes	Life (5)	Terrestrial/ Biological/Cell	Origin of Life(3)	Biosphere(8), Prokaryotes (9)	Chemical, Biological [Life]	Molecules(5) Prokaryotes(6)	HADEON(4.6BYA) ARCHEON(2.8BYA)
1.5 BYA	Life/ Eukaryotes		Complex Cell	Eukaryotes	Eukaryotes(10)		Eukaryotes(7)	PROTEROZOIC (2.5-0.539 BYA)
500 MYA	Life/ Multicellular		Multicell	Multicellular Life(5) Cambiran explosion(6)	multicellularity (11) neurons (12), bilateral(13), vertebrate(14), fish(15)		Multicellular(8)	PALEOZOIC , MESOZOIC [Triasic (251MYA) Jurasic (201MYA)
150 MYA	Life/ Land			First Mammals(7) First Flowering Plants(8)	Amphibians (16), Reptiles(17)			Cretaceous(145MYA)]
50 MYA	Life/ Mammals			Asteroid Collision(9) First Hominids(10)	Mammals(18)		Animal Social Groups(9)	CENOZOIC [Paleogene(66MYA)
15MYA	Life/ Primates		Tool	First Orangutans(11)	Arboreal mammals(19), primates(20), Great Apes(21)			Miocene(23MYA)
5MYA	Humans/ Bipedal	Hominines, Humans(6)	Fire	Chimps & Humans Diverge/ Bipedalism (12)	Hominids(22)			Pliocene(5.3MYA) {Lower Paleolithic}
1.5 MYA	Humans/ Tools			Stone Tools/ Language(13)	Toolmakers(23)			Pleistocene(2.6MYA)
500 KYA	Humans/ Fire			Homo Sapiens (14) Fire(15) Human DNA types(16)				{Middle Paleolithic}
150 KYA	Humans/ Language		Neanderthal Culture Revolustion(11) from 150 KYA	Modern Humans (17)	Language(24)		Tribal Metagroups(10)	
50 KYA	Humans/ Migration		Upper Paleolithic(12) from 40KYA	Rock Art(18)				{Upper Paleolithic}
15 KYA	Humans/ Agriculture	Agriculture (7)	Neolithic Revolution(13) 12-9 KYA	Agriculture(19) Techniques for starting Fire / First Cities(20)	Agriculture (25)		Agrovillages(11)	Holocene Mesolithic Neolithic Copper Age
5 KYA	Civ/ Ancient & Classical	Cities (7.25)	Ancient Urban Revolution (14) from 6-5KYA; Imperial Antiquity, Iron Age, Axial Age(15) from 2.800-2.500 KYA	Wheel/Writing (21) Democracy(22)	Technology and Urbanization(26), Philosophy(27)	Cultural		Ancient & Classical History (Bronze & Iron Age)
1.5 KYA	Civ/ Trade		Middle Ages(16)	Zero and Decimals(23)				Middle Ages
500 YA	Civ/ Commercial	Brink (7.5)	Modern Period (17)	Renaissance & press(24)				Early Modern
150 YA	Civ/ Industrial	Modernity (8)	Industrial Revolution(18)	Industrial Revolution(25) Modern Physics(26)			Geopolitical States(12)	Late Modern
50 YA	Civ/ Information	Anthropocene (8.25)	Information Revolution (19)	DNA, Transistor, nuclear energy (27) Internet, human genome (28)				(Anthropocence) {Contemporary}
	Future Cone	Future(9)		Predicted slow down	Spiritual(28)			

Table 1. *Comparison of major events or periods in various big history frameworks.*

nation of an ever greater number and hierarchy of components to arrive at larger, more complex systems. Hence, the Big Bang begins materially with the formation of quarks. Quarks combine to make nucleons, nucleons combine to form atomic nuclei, and so on to arrive eventually to living cells and even later to our contemporary geopolitical states. Volk's primary aim does not appear to be to periodize big history, which is true of many authors in this area, but rather to primarily explain an important facet of evolutionary mechanics.

The international geologic time scale (GTS) standards are set and maintained by the International Commission on Stratigraphy – a standing committee in the International Union of Geological Sciences (IUGS). Table 1 includes a greatly condensed version of their complete chart (International Commission on Stratigraphy, 2023; Cohen, 2013). Importantly, GTS is actively "maintained" or updated periodically by this committee as the relevant sciences make new discoveries that can alter the timing or explanation of relevant events. To its credit nearly everyone interested in a discipline that involves deep geologic time is familiar with GTS. Even young children who love dinosaurs might tell you that dinosaurs lived during the Mesozoic era, or at least be familiar with the movie called "Jurassic Park." Like Aunger's and LePoire's schemata, time is divided by different gradations with the addition of "epochs'' and sometimes, "ages." At present, we are in the Phanerozoic eon, Cenozoic era, Quaternary period, Holocene epoch, and Meghalayan age (Geological Society of America, 2023). Some geologists and others argue that we have recently left the Holocene era and entered the "Anthropocene" epoch (Crutzen & Stoermer, 2000).

GTS is not concerned with citing significant progressions in the complexity of systems, although correlations often occur. Instead, GTS divides time periods according to different geological and paleontological events that have occurred as evidenced by changes that can be detected in Earth's rock layers or strata. Those changes can be indicated by differences in rock qualities (lithology), magnetism, and embedded fossils. For example, the Cretaceous period ended, and the Tertiary period began when a large asteroid struck Earth and left a layer of Iridium in rock strata around the globe. As a correlation, dinosaur fossils are no longer present in rock strata after the Cretaceous period as well. Of course, GTS does not and cannot be extended to time periods before the formation of Earth.

4 How Should We Periodize Big History (broadly considered)?

The foregoing noncomprehensive list of formal and informal big history divisions of time strongly suggests that it is unlikely that there will be only one reasonable periodization scheme. Differences in perspectives, goals, metrics, and other factors will in turn make varying ways to divide big history reasonable and even necessary for the task at hand. Nevertheless, it would be desirable to have one periodization scheme for one large group of people and purpose: the teaching or review of big history for the layperson and undergraduate audience. Having general consistency for those with an initial or more casual interest in big history would be desirable so that we make teaching and learning it more coherent, lessen confusion should the interested person consult different sources, and even facilitate communication amongst big history's more dedicated scholars. The actual work of developing such a periodization scheme would be best accomplished by a "working group" of big historians from several nations and disciplines to better ensure that different perspectives are included in the scheme. Furthermore, any such scheme, like GTS, would be considered a "work in progress" that should be periodically updated to include new findings as the sciences and humanities advance.

Regardless of which periodization schemes might eventually be created, the following factors should be considered during its development:

- As with GTS and Aunger's proposal (2007), there should be **different levels of resolution** such as "eons," "eras," and "periods" and the like. Varying the resolution better allows us to accommodate the fact that after the momentous Big Bang, changes and variations in processes and systems occurred slowly for the first 10 billion years. However, once life began on Earth, as David Christian, Ray Kurzweil (the futurist) and many others have observed, changes have subsequently occurred ever more quickly. Indeed, even GST's time duration of "ages," which lasts a few thousand years, does not have the resolution needed to demarcate the substantial change that has occurred on Earth contemporaneously due to our rapid rate of cultural and technological innovations.

- It is likely that periodization will be based on **some aspect(s) of increasing complexity**. Christian, Chaisson, Spier, and most other big historians have all noted implicitly or explicitly that the increase in complexity of systems over time is big history's most intriguing overarching theme. The increase in complexity to the level of "life," even if it occurred in only one miniscule corner of the universe, is also the most intriguing phenomenon that spans time. Other varied, but yet somehow coherent phenomena that span the breadth of time since the Big Bang might exist, but none seem to have generated the level of interest as provoked by increasing complexity. The interest is due at least in great part because complexity offers a rich fount of inquiry with its multidisciplinary roots in thermodynamics, information theory, general systems theory, and, of course, complexity science to name a few. With a broad, but still reasonable conceptual characterization, complexity can also span the disciplines from cosmology and physics to history and sociology. Adoption of increasing complexity by big history for periodization would also set it apart from geologic time scales that use a variety of terrestrial events to demarcate time rather than a deeper, binding universal theme. Of note, traditional history lacks any widely agreed upon method of periodization that spans its past approximately 5,000 years.
- Spier's contention that complexity does not just progress, but also declines should be noted. However, the apparent surprisingly nearly perfect geometric rise in complexity since the Big Bang has been noted by several disparate authors (LePoire) despite decreases in local complexity (e.g., viruses devolving from bacteria, the Greek "dark age") and mass extinction events. Of note, after each mass extinction event, renewed diversification occurred relatively quickly from surviving species, some of which (fortunately) were as complex or nearly as complex as any that preceded these cataclysmic events (Jablonski, 1994; Kaplan 2016). For example, the Cretaceous-Tertiary (a.k.a., Cretaceous-Paleogene) extinction event witnessed the loss of about 75% of all species on Earth (Jablonski, 1994). Within 3-5 million years, however, the number of species is believed to have recovered to that which preceded it - a brief time in geologic terms (Renne, 2013; Kaplan 2016). Furthermore, birds and mammals were equivalent or near equivalent to even the most complex dinosaurs, so that the "thread" of the central nervous system's advancing complexity remained intact.
- Aunger's big history periodization proposal is based on examining different aspects of system energy flows. More important than what he attempted to base periodization on, was his attempt to be consistent and rigorous in its application. Besides energy sources or energy flows (Chaisson, 2001; Niele, 2005; Fox, 1988; Smil, 2010), other candidates for being markers for periodization include the appearance of new emergent phenomena (Kauffman, 1995; Christian, 2011; Morowicz, 2002), information processing, storage, or transmission (e.g., Sagan, 1977; Kurzweil, 2005), organization (Gunderson & Holling, 2002; Volk, 2017), and an integration of the above (Jantsch, 1980). Admittedly, these and other authors who describe a variety of changes or dynamics of change, are not usually attempting to periodize big history as their primary or even secondary goal. Still, their analyses offer a variety of other potential ways to demarcate periods of time.
- **Clear definitions or characterizations** of key terms need to be given to minimize ambiguity and confusion. This goal often requires more than a "cut and paste" from a dictionary because some terms like "energy" and "time" are so fundamental that their more basic nature is still actively debated even in theoretical physics. Others like "complexity" and "life" are perhaps best defined by a list of characteristics rather than a seminal core feature. The definition and nature of terms like "emergence" and "consciousness" are debated actively in both science and philosophy with

> no consensus regarding how the terms should be fully understood. Despite these challenges, a periodization schema should be accompanied by the best and most relevant definition or characterization that we can formulate.

Opining further on how to periodize big history could be interpreted as usurpation of a task that would be better undertaken by a qualified working group, preferably under the auspices of IBHA. Nevertheless, it might be worthwhile to anticipate some of the other challenges that anyone or any group will face when working to periodize big history.

5 Some Other Challenges to Periodizing Big History

Indeterminacy**.** It seems that you only need to pick up the latest National Geographic or any science magazine that covers the latest in paleoanthropology to learn that the dates and branches of hominid evolution have been changed yet again – usually with origin dates being pushed back further in time, or another species being identified. Hence, many time periods that are defined by dynamic areas of inquiry like human evolution will need to be adjusted. This challenge can be easily addressed by simply noting that periodization is a "work in progress" as it is with GTS.

A few temporal demarcations lend themselves to ready consensus amongst big historians as well as a more definitive time period for their occurrence – at least relative to the time scales of the period in question. For about a decade now, the Big Bang dates to 13.8 billion years ago – perhaps *the* seminal event in big history, which astrophysicists state unfolded over seconds to a few minutes. Future discoveries might alter the date or make its occurrence more and more precise – as of 2018, the date was set at 13.787 +/- 0.020 billion years ago (Planck Collaboration 2020). A similar argument can be made for the end of the Cretaceous period, which concluded with the rapid strike of a massive asteroid 66.043 +/- 0.011 years ago (Renne et al., 2013).

Many, if not most seminal big history "events," however, are actually prolonged processes as Spier pointed out (Spier, 2022). Deciding which date should be chosen for periodization purposes is not immediately clear for many events that would be candidates for demarcating time periods. The origination of "humans" provides a salient example as will be discussed below. The same kind of challenge will be present regarding the onset of multicellular life (e.g., differentiated versus undifferentiated multicellular organisms), or the appearance of "consciousness" – at face value a truly remarkable development in big history even if it is not typically acknowledged with a few exceptions like Henriques et al's "Tree of Knowledge" schema (Henriques et al., 2019).

Perspective(s)? Deciding on a single definitive schema for periodization will also be difficult because different disciplines and researchers with different purposes will likely base a schema on different criteria. For example, someone teaching big history at a non-graduate level especially, or writing for a mass audience, will likely want to avoid abstractive criteria like free energy flow rates or negative entropy (~syntactical information), and base periodization criteria on more easily understood and memorized criteria like major "interesting" events. Although conjectural on our part, perhaps this was Christian's primary motivation in creating his particular "thresholds" for big history.

Those who study and research big history and other related disciplines, however, will likely desire some binding thread for major event through cosmic time to determine if there is a discernible pattern, and if so, what factor(s) might be responsible for that pattern. A physicist might wish to focus on complexities' free energy flow rates which they not only well understand but can also often be quantitatively measured or at least approximated (Chaisson), a biologist might prefer one based on information content and transmission because DNA provides a glaring example of information's role in biotic system diversification and progression. The traditional historian might prefer a schemata that focuses on events for the "simple" sake of their glaring importance. This option might have more merit than it first seems. Schemas that rely on complexity progression due first and foremost to some aspect of information or organization, might diminish the role of aerobic metabolism, control of fire, or even agriculture. Each of these "events" are arguably most important primarily for increasing the availability of energy. Conversely, if events are chosen because of novel energy sources or increase in energy flow rates, a schema might then ignore the origination of multicellular organisms (organization primary) or grammatical language (information primary).

Differences in the desired focus due to varied purposes or disciplinary backgrounds can be viewed as perspectives occurring across a horizontal plane. Another orientation is "levels of abstraction" (LOA's) that looks at perspectives on a vertical plane with low levels of abstractions being more detailed and higher levels being less detailed but more of something's entirety. There is no set number of levels of

LOA for any one issue. If we look just at the LOA's of a living organism, we can readily (and coarsely) discern 5 or more LOA's according to a few relevant scientific disciplines: from lowest to highest LOA we can proceed to examine its: physics, chemistry, physiology, general biology, on "up" to the study of the organism or class of organisms itself (e.g. ornithology).

6 Examples of Analyses for Choosing Events for Big History Periodization

We offer three events below that would likely serve as markers for big history periodization, and some of the reasons that might or might not be relevant to them being chosen by those who might undertake such a project. Admittedly, we are choosing events that demonstrate a new, significant emergent phenomenon or progression in complexity, with the caveat that such changes likely have occurred elsewhere in the cosmos before they did on Earth. We are also not carefully defining terms below, but a "common sense" understanding of them will work for these brief illustrations.

<u>The Origin of Life</u>**.** Life began ~ 3.7 billion years ago (Bya) (Ricardo, 2009) . The date is likely to have a high confidence level (+/- 3%) because the preceding Hadean eon made life unlikely due to frequent meteorite bombardment which made Earth inhospitable. The details of how life began remains a mystery. Nevertheless, it is likely to be a major and widely recognized event that will separate, , a "prebiotic" and "postbiotic" epoch because the onset of life demonstrates an entire new host of changes compared to the physics, chemistry and range of the purely "physical" phenomena that preceded it. For example, as Chaisson points out, the free energy rate density (FERD) increased through living systems compared to "stable" physical systems like stars. Living systems also derive their energy from metabolism, and ultimately from high energy ATP molecular bonds rather than gravitation, radiation, and nuclear fusion. Authors who are proponents of an information theory approach, however, would point out that living systems contain the information required for their formation, sustenance, reproduction, and variation in their genome which is typically composed of DNA molecules. Those in favor of a hierarchy of combinations approach would likely favor analysis that explains how the organic molecules constitute these systems instead of the non-organic molecules, atoms, and ions that predominate in the structures of preceding physical systems. Finally, but certainly not comprehensively, a biologist might be most impressed with life's extensive and varied evolutionary potential while a philosopher might note the beginnings of "agency," (e.g., an entity that has purposes and identity).

All these and other profoundly new and emergent phenomena will likely prompt anyone deciding on a periodization schema to consider making it a major demarcation, or the equivalent of GTS's "eon" – their broadest time scale. Furthermore, the date of life's origination Earth is not likely to change to any significant degree which makes it reliable temporally as well.

<u>The Origin of "Humans."</u> If the origin of life is Earth-centric, then demarcating the origin of humans would obviously make big history periodization anthropocentric. Besides self-interest, a periodization schema that shifts to being anthropocentric is arguably warranted for several other reasons. From a thermodynamics perspective, humans have likely used a greater amount of energy per unit mass (and simultaneously created more entropy) than any other species, especially once we began to use fire (Niele, 2005). The continued increase in FERD of the modern era in turn dwarves that of our primitive fire toting ancestors to a remarkable degree.

From an information perspective, humans convey more information across space (e.g. via speech, music, mass media, the internet), and across time by oral traditions, rock art, books, and now many forms of electronic media. These abilities prompted David Christian to note that "collective learning" vaulted our species beyond others that were sharper of tooth and law, faster, stronger, or otherwise could have eaten us more than we eat them. More profoundly we process information in a way that no other known organism does with a high degree of self and other-awareness, abstract thought, art, future projections, and so on. Notably, we have also extended our information gathering abilities by microscopes, telescopes, sound amplifiers, x-rays, and the "large hadron collider" at CERN. In short, we have mastered more aspects of information than any other living organisms by many degrees of magnitude. This ability in turn has led us, for better and for worse, to (perhaps temporarily) dominate this planet.

Other justifications for the relevance of human origins being worth consideration for periodization include our ability to create composite tools and machines, abstract based interconnected social groups like "nations," religions, or ideology, and our marked adaptability to different environments and circumstances. Hence, it seems to be easy to objectively cite many reasons for our origins to be worthy of note in any periodization schema.

The imposing challenge, however, is fixing a date for our emergence. As Spier pointed out, human origination is actually the result of a prolonged process perhaps spanning millions of years rather than an actual event. The following are just a few candidates that might vie for the date for the origin of "humans" (Handwerk 2021)– a term which needs to be more precisely defined itself, i.e., ~hominin, hominid? *Homo habilis* onwards? *H. erectus* onwards*? H. sapiens? H. sapiens sapiens?*

- 7 million years ago (mya) – Proconsul last common ancestor between great apes and humans (White et al., 2009)
- 3.9 mya – Australopithecus afarensis the first hominid to walk upright (McNutt, 2021). The unique combination of having free dexterous hands due to an upright gait, and possibly being social might have been what was needed to begin the evolution of our large brains. Also, it was once believed that stone tool use did not begin until Homo habilis arrived about 2 mya. More recent discoveries, however, date to 3.3 mya (Krier, 2023). Therefore, the potential for dexterity might have been exercised by the earlier A. afarensis. This last point also demonstrates the lability in dating many paleoanthropological "firsts."
- 0.4 -1.6 mya – the first purposeful use of fire, usually attributed to H. erectus (Dance, 2017). The former date is more certain at this time, but some evidence supports ever earlier dates (Cowie, 2020) which exemplifies the frequent discoveries, and associated controversies in the field of paleoanthropology.
- 0.2-0.3 mya – the origination of archaic H. sapiens. H. sapiens might have been morphologically indistinguishable from later human beings, but is this our cardinal feature (Callaway, 2017)?
- 40-77,000 years ago – the beginning of abstract thought. H. sapiens were fully anatomically modern by about 100 thousand years ago (kya). Cave art depicting abstract representations of the world were drawn by about 40 kya which was the first proposed date for the origin of abstract thought (Marchant, 2016). Later discoveries in South Africa, however, indicate that it might have begun much closer to the time when our species became morphologically indistinguishable from contemporary human beings.

Other dates might certainly be considered as candidates for the origin of humans. However, the point is that it will likely be challenging for any one person or any group of people to settle on both a characteristic and a date that cemented our origin.

<u>The "Anthropocene"</u> Biologist Eugene Stoermer and chemist Paul Crutzen coined the term "Anthropocene" (Crutzen & Stoermer, 2000) to "describe the most recent period in Earth's history when human activity started to have a significant impact on the planet's climate and ecosystems". While noting that this time period has not been officially recognized by the IUGS, several different demarcations for its onset (and the end of the Holocene) have been proposed: 1. The onset of industrialization about 1750-1800, which would coincide with Christian's proposal that it also marks the beginning of the modern age, 2. The detonation of the first atomic bombs in 1945, and 3. In 1950 when "The Great Acceleration" began (when human activity affecting the Earth greatly increased). Each of these candidates would likely leave a change in global rock strata that could be detected by hypothetical future geologists – to be consistent with GTS criterion.

If big history were to adopt the idea of the Anthropocene, even if not the term itself, determining a fairly exact demarcation date might not pose a great challenge (once a criterium was proposed) because our records of recent history are extensive (Stromberg, 2013). Similarly, we would likely be able to discern the core process(es) that prompted the change, such as the increase in burning of coal that left its soot, the dropping of a bomb that left new radioactive isotopes, or the manufacture of "forever chemicals."

A bigger challenge might be in remaining consistent with prior periodization nomenclature and criteria standards. For example, if we decided that informational aspects were most relevant to a periodization schema, then it might be more important to cite 1948, when both information theory and the transistor were developed. If new combinations of more fundamental "components" are determined to be the binding thread, then perhaps the rise of nation-states in the 1800's or the founding of the United Nations in 1945. (Note the repeated citing for the mid to late 1940's!) The richness of changes that coincide with the Anthropocene will likely make it easy to make its inclusion in a periodization schema both rigorous and consistent. The bigger problem might be in choosing *which* event or process makes periodization in recent times most worthy of being a new age by future big historians who might eschew our choices in favor of another event whose future portent "we did not see coming."

7 "Selling It"

Even a "job well done" is no guarantee of success. For example, Robert Aunger's work (2007) is arguably one of the most careful efforts at big history periodization developed thus far. He also bases his schema on aspects of thermodynamics which is favored by some big history notables like Eric Chaisson and Fred Spier. Nevertheless, his work is not cited by these authors to our knowledge, and his approach does not seem to be well-known in big history circles. Hence, another reason to periodize big history by an IBHA working group is that it would subsequently likely be known by more big historians. Whether it is subsequently accepted and used, however, will depend on how well it meets the objectives noted above and likely several other factors as well. Certainly, the wide acceptance of geologic time scales by multiple disciplines concerned with terrestrial deep time, and some familiarity by even the public (e.g., the movie "*Jurassic* Park") would indeed be a lofty goal for us to achieve.

8 Conclusion

David Christian deserves tremendous credit, not just for founding contemporary big history as a formal area of study, but also for promoting - even if others have preceded him at times - some of its key concepts like increasing complexity, collective learning, and others. Several of Fred Spier's objections to Christian's "thresholds" for the periodization of big history have merit as we discussed above and should be addressed by anyone seeking to periodize the vastness of the universe's time continuum. The propensity for humans to make divisions of "something" large ("chunking") before them should not be ignored even if many are content with leaving big history "whole." We also believe that it is not necessary to be strident in our criticisms of the work of any originator or other author that has good intent and diligence. If such a large project like big history "sprang forth fully formed like Minerva from the head of Jupiter," it would leave us with little to research, contemplate, or advance.

In that spirit, we have suggested a rough framework of possible criteria, along with a variety of challenges, to consider when formulating more rigorous periodization schemes for big history. Hopefully, the resulting schemes would be pragmatic and thought provoking for psychological, pedagogical, research, and even conversational concerns. Any such schema should be made amenable as the sciences and humanities make progress in their understanding of how, when, and why big history unfolded as it did. We suggest that the next step to take forward is for IBHA leadership to set the seeds for the formation of an international, multidisciplinary working group to develop and perhaps occasionally adjust a periodization scheme for the primary purpose of presenting a coherent and consistent way to better parse the expanse of big history for the general and undergraduate audience.

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