Peer Emergent Complexity during the Stelliferous Era

Historical Periodization and Emergent Complexity Thresholds

David Christian's eight thresholds of emergent complexity in Big History.

1. Big bang
2. Stars and galaxies
3. New chemical elements
4. Earth and the solar system
5. Life on Earth
6. Collective learning
7. Agricultural
8. Modern revolution/anthropocene

Adams and Laughlin's five ages of the universe:

1. **Primordial Era**—radiation dominated era from the big bang through recombination.
2. **Stelliferous Era**—dominated by stars and galaxies
3. **Degenerate Era**—dominated by degenerate stellar remains (brown dwarfs, white dwarfs, neutron stars, and black holes), ending with proton decay
4. **Black Hole Era**—dominated by black holes
5. **Dark Era**—after the last black holes evaporate, the universe converges on thermodynamic equilibrium and heat death

The scale of time employed in big history is a small fragment of the scale of time of cosmological history.

The Stelliferous Era

- The period in the history of the universe populated by stars carrying out nucleosynthesis and organized in galaxies
- From one million (1 Ma.) to ten quadrillion (10,000 Ga.) years after the big bang
- Characterized by galactic ecology, hence increasing metallicity and increasing availability of heavier chemical elements
- Expansion of the universe will result in gravitationally bound structures becoming isolated
- Presence of water: The greatest mass of water in the observable universe is at a quasar 12 billion light years away in the Lynx constellation.
  - Bradford, C. M., Bolatto, A. D., Maloney, P. R., Aguirre, J. E., Bock, J. J., Glenn, J., … Zmuidzinas, J. (2011). THE WATER VAPOR SPECTRUM OF APM 08279+5255: X-RAY HEATING AND INFRARED PUMPING OVER HUNDREDS OF PARSECS. The Astrophysical Journal, 741(2), L37.
- Presence of Polyatomic organic molecules including polycyclic aromatic hydrocarbons (PAH)
  - Kwok, S., & Zhang, Y. (2011). Mixed aromatic–aliphatic organic nanoparticles as carriers of unidentified infrared

emission features. Nature, 479(7371), 80–83. https://doi.org/10.1038/nature10542

- Planets with polycyclic aromatic hydrocarbons (PAH) form between the soot line and the frost line.

Terrestrial Emergent Complexities Arising from Chemical and Minerological Complexity

1. Life (biochemistry)
2. Sensation (central nervous system)
3. Consciousness
4. Technology
5. Art
6. Agriculturalism and the urban revolution (V. Gordon Childe)
7. Industrialized civilization

These terrestrial emergent complexities can be understood as exemplifying Planetary endemism

- Terrestrial emergent complexities are characterized by planetary endemism
- Planetary surfaces are ideal locations for Stelliferous Era emergent complexity
  - Energy flows driven by stellar insolation
  - Interfaces between land surfaces, atmospheres, and liquid bodies (lakes, oceans, etc.)

    - Large number of geochemical processes (rock cycle, water cycle); life adds biogeochemical processes, all of which produce more mineralogical compounds.
- Planetary endemism entails emergent complexities at the bottom of a gravity well

The first four of David Christian's thresholds of emergent complexity—big bang, stars, chemical elements, and complex planets like Earth—are observed on cosmological scales; the last four of David Christian's thresholds of emergent complexity—life, collective learning, agriculture, and modernity—are observed only locally, limited to Earth, thus only in the context of planetary endemism.

Peer emergent complexity (post-astrochemical complexity) branches out (or would branch out, if there are peers to known post-astrochemical emergent complexity) from the point of the last common emergent complexity ancestor.

The primordial soup of the cosmos may come in distinct flavors.

The Narrow Peer Emergent Complexity Concept

1. Civilization is the missing piece of the SETI puzzle.
    a. Any artifact or signature detectable on interstellar distances would have to be product of industry at the scale of civilization

   b. SETI presupposes civilization and often mentions civilization, but has not theory of civilization to explain exactly what it is we are looking for; SETI conceptions of civilization are non-falsifiable.
2. Narrowly conceived peers are indistinguishable at cosmological scales of magnification
   a. At a low resolution, broadly construed peers may appear identical
   b. The squint test: step back and squint, and things previously distinguishable become indistinguishable
3. There is a scale of magnification at which indistinguishable peers are distinguishable, but this is not the scale here under consideration—the scale of cosmological visibility and interstellar interaction.
4. Post-astrochemical peers may appear identical at a low level of resolution (low-resolution identity).

The Wide Peer Emergent Complexity Concept

1. Branches away from an astrochemical point of origin (post-astrochemical emergent complexity)
2. Serves as a point of origin for further emergents
3. Planetary-scale behavior (emergent complexities that conform to the planetary endemism thesis)
4. Planetary system-scale behavior (emergent complexities *not* exemplifying planetary endemism)
5. Producing detectable signatures over interstellar distances

At each threshold of emergent complexity there will be peers in the sense of belonging to the same wide peer class but which would be identical at a low level of resolution, i.e., over interstellar distances.

We are probably mediocre in regard to our planetary endemism.

1. Life (biochemistry)	biochemical peers
2. Sensation (central nervous system)	sentient peers
3. Consciousness	conscious peers
4. Technology	technological peers
5. Art	artistic peers
6. Agriculturalism and the urban revolution (V. Gordon Childe)	
7. Industrialized civilization	Industrial peers

Projecting indistinguishable peers at a cosmological scale implies re-tracing this sequence of emergent complexity without branching off into alternative peers.

Some alternative or peer emergent complexities

- Life early in the history of the universe
  - Loeb, A. (2014). *The habitable epoch of the early Universe. International Journal of Astrobiology, 13(04), 337–339.*
- Atmospheric Habitable Zones (AHZ)
  - "Particles, environments and possible ecologies in the Jovian atmosphere" Sagan & Salpeter
  - "Atmospheric Habitable Zones in Y Dwarf Atmospheres" by Jack S. Yates, et al.

  - “Brown Dwarf Atmospheres As The Potentially Most Detectable And Abundant Sites For Life” by Manasvi Lingam and Abraham Loeb
- Stellivores
  - Vidal, C. (2016). *Stellivore extraterrestrials? Binary stars as living systems. Acta Astronautica, 128, 251–256.* doi:10.1016/j.actaastro.2016.06.038
  - There is some resemblance between Vidal’s stellivores and John Smart’s Transcension Hypothesis.
- Crystalline Life
  - “Brandstetter, T. (2012). *Life Beyond the Limits of Knowledge: Crystalline Life in the Popular Science of Desiderius Papp (1895–1993). Astrobiology, 12(10), 951–957.* doi:10.1089/ast.2011.0779

A Scenario for Peer Emergent Complexity without Life, Consciousness, Intelligence, Technology, or Civilization—lifelike, but not life as we know it…

- “We have created a dynamic material powered by artificial metabolism using simultaneous processes of biochemical synthesis and dissipative assembly... We succeeded in constructing machines from this novel dynamic biomaterial with emergent regeneration, locomotion, and racing behaviors…” Hamada, et al., 2019
- “If radiation pressure is the accelerating force, then ‘Oumuamua represents a new class of thin interstellar material, either produced naturally, through a yet unknown

process in the ISM or in protoplanetary disks, or is of an artificial origin." Bialy and Loeb, 2018

A thought experiment in peer emergent complexity:

- Non-biological metabolism emergent from the chemical complexity of comets (not bound by planetary endemism)
- Selection pressure for locomotion by means of thin membranes
- Non-biological (post-astrochemical) equivalent of bioelectricity
- Coordination of system-wide activity by radio signals
  - "…the ingredients for effective radio communication are clearly available in the animal world and it may only be a matter of time until true radio communication is discovered in our own biosphere." Raup, D. M. (1992)

"Although radio communication has not evolved among animals on earth, as far as we know now, the fact that many animals can detect radio signals and/or generate strong electrical pulses suggests that radio communication in non-intelligent animals is possible. Therefore, organisms on other planets may use natural radio communication and detection from space is a possibility."

To this we could add that non-living forms of emergent complexity might also converge upon radio communication

How we (and our peers) exemplify the principle of Mediocrity

- This thought experiment should not be seen as anything unusual, but rather as exemplifying the principle of mediocrity
- Terrestrial emergent complexities may be mediocre in the sense of having many peers (belonging to a wide peer class)
- Once a set of post-astrochemical peers is defined, we can define subsets of peers, the frequency of each of which will constitute a bell curve

- Terrestrial emergent complexity may be mediocre in the sense of exemplifying the planetary endemism paradigm
- Compared to other peers filling out the bell curve of emergent complexity, we may be an outlier in some respects

An example of a wide peer class: peer mammalian intelligence

- Mammals share a common brain and central nervous system architecture
- Mammalian brain/CNS complexity entails the complexity of mammalian behavior
- While high-end mammalian intelligence is noticeably greater than low-end mammalian intelligence, the average mammal is more intelligent that the average reptile, and the average reptile is more intelligent than the average arthropod.

The wide peer class of emergent complexity

- Rare: endemic to a single planet
- Common: visible on a cosmological scale
- Rare: cosmological-scale distribution

Populating the conceptual space of peer emergent complexity

- We cannot yet determine our standing among post-astrochemical peer emergent complexity
- Our conception of the universe has involved projecting indistinguishable peers on a cosmological scale

- More thought experiments are necessary to populate the concept of peer emergent complexity
- Given the branching bush of emergent complexity, the distinction between biosignatures and technosignatures is ambiguous

Lingam, M., & Loeb, A. (2018). *Relative Likelihood of Success in the Search for Primitive versus Intelligent Extraterrestrial Life. Astrobiology.* doi:10.1089/ast.2018.1936

"While the search for biosignatures is primarily oriented towards confirming the existence of 'primitive' life, the detection of technosignatures would indicate the presence of 'intelligent' life. In reality, it must be observed that this classification is somewhat facile because certain biosignatures could end up being conflated with technosignatures. An interesting example in this context was pointed out by Raup (1992), who suggested that certain species can naturally evolve communication in the radiofrequencies without necessarily being technologically advanced and may therefore be mistaken for signatures of technological intelligence. Hence, the possibility that the boundaries between biosignatures and technosignatures could become blurred must be borne in mind."

"Persistence of Technosignatures: A Comment on Lingam and Loeb" by Milan M. Ćirković, Branislav Vukotić, Milan Stojanović (Submitted on 8 May 2019) https://arxiv.org/abs/1905.03146

"…we have fully accepted the tacit premise of LL18 (universally accepted in the current astrobiology/SETI discourse) that biosignatures are clearly and unambiguously distinguishable from technosignatures. One interesting speculative possibility which perhaps deserves more attention – and is anyway necessary for the logical closure of discussions of detectability – is that the distinction between biological and technological might eventually be erased."

Questioning the biosignature and technosignature distinction:

- Biological complexity can converge upon signatures indistinguishable from technology.
- Astrochemical peers, less familiar to us than biology, could also be indistinguishable from technology.
- Cosmological-scale communications and signaling would select for appropriate mechanisms
- Communications and signaling over interstellar distances may involve mechanisms that we interpret in terms of technology, but may not be produced by artificial means.

On the one hand, the foregoing makes an even stronger formulation of the Fermi paradox possible:

Not only is there no sign of any communicating ETI (no detection of an indistinguishable peer by way of a technosignature), there is no sign of any post-astrochemical peer of any kind.

Even if technological civilizations (indistinguishable peers) are rare, the universe could be densely populated with post-astrochemical peers, but it does not appear to be so populated.

On the other hand…

Given the range of possibilities for post-astrochemical peer emergent complexities, and the ambiguity of the biosignature/technosignature distinction, we could live in a universe densely populated with peer emergent complexity and not know it…

If complexities are uniquely determined, then emergent complexity is not a branching bush.

To test the uniqueness of emergent complexity at a given threshold of complexity, we can look at prior threshold of emergent complexity.

There is a range of stellar peers defined by the Hertzsprung–Russell diagram

There appears to be a range of planetary peers, though we cannot yet determine this with certainty

"…the reactants that produce carbonylated heterocycles and potentially PNA monomers form in a wide variety of environments. In consequence, the chemical evolution of N-heterocycles to carbonylated adducts in Miller-Urey mixtures, as described here, may be a common phenomenon in the Solar System, potentially extending the formation of PNA precursors from early Earth environments to meteorites and other planetary bodies."

Rodriguez, L. E., House, C. H., Smith, K. E., Roberts, M. R., & Callahan, M. P. (2019). Nitrogen heterocycles form peptide nucleic acid precursors in complex prebiotic mixtures. Scientific Reports, 9(1). doi:10.1038/s41598-019-45310-z

Raup, D. M. (1992) Nonconscious intelligence in the Universe. Acta Astronautica. 26:257–261.

"…the ingredients for effective radio communication are clearly available in the animal world and it may only be a matter of time until true radio communication is discovered in our own biosphere."