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Gaia *versus* the Anthropocene: Untimely Thoughts on the Current Eco-Catastrophe

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Abstract

Embracing science but suggesting an alternate explanation for global warming, the essay provides a thermodynamic and historical perspective on eco-destruction. From a long-term evolutionary perspective, caution is raised about the repetition of human exceptionalism implied by the popular term "Anthropocene," which hyperbolically frames humankind as the first organism in evolutionary history, and uniquely dangerous at that, to threaten global life. In fact, cyanobacteria preceded technological humanity, altering Earth's atmospheric composition orders of magnitude more than humanity has. The extreme resilience of Gaia, planetary life taken as an open thermodynamic system with environmentally regulative tendencies, has undergone dramatic changes in the past, such as the production of an oxygen-rich atmosphere. Genetically nimble life, recycling matter on a planetary level, has evolved means of tempering the tendency of organisms to exponentially reproduce. Ironically, these means, some which appear to have evolved to titrate hypergrowth in animal clades via senescence, have so far escaped ecologically rapacious humans. Thermodynamically, modern technological humanity, for all its self-regard as an intelligent life form, resembles a ravaging fire or intrinsically short-lived storm system. Long-term human persistence in the global ecosystem will require changes in our epistemology, economics, and ecology.

Keywords: Thermodynamics, gradient, geoengineering, Gaia, cyanobacteria, symbiogenesis, aging

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About the Author

Writer, theorist, and independent scholar Dorion Sagan is author or coauthor of twenty-five books translated into fifteen languages, including several with biologist Lynn Margulis on planetary biology and evolution by symbiosis. He has also collaborated with Eric D. Schneider on the thermodynamics of life, and theoretical biologist Josh Mitteldorf on the evolution of aging. With his parents Carl Sagan and Lynn Margulis, he is the first author of the entries for both "Life" and "Extraterrestrial Life" in the Encyclopædia Britannica. *His work in progress explores the scientific romance and romantic sciences of his parents at the dawn of America's Space Age.*

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Just as politics is too important to be left to the politicians, science is too important to be the left to the scientists. "Scientists," wrote Samuel Butler in the 19th century, "are the priests of the modern age, and must be watched very closely." When we consider this comment in the light of horrific excesses in the following, twentieth century—for example Nazi eugenics made in the name of science, or the development and deployment of nuclear weapons—it seems more timely now than when it was written. And we are not out of the woods—a revealing ecological metaphor I have consciously chosen: going back to, or at least re-growing the woods is part of what we need to do!—yet. Extinction-level dangers loom both from ecological destruction and hasty proposals to address it. As urgency increases so do dangers of ecofascism, greenwashing, manufactured unanimity of scientific views, and geoengineering that exacerbates rather than ameliorates environmental problems. Nonetheless, scientific analysis is crucial. Ripple *et al.* (2017) in their "World Scientists' Warning to Humanity: A Second Notice," give an important update, showing both ecological improvements (e.g., decrease in ozone depletors, associated with repair of the ozone hole), and looming problems (increase in temperatures, exponential increase in human population, decrease in the world's forests, and decrease in the abundance of vertebrate species, as well as of supply of freshwater and ruminant food *per capita*). There is also the widely reported increase (albeit of a fraction of a percent) of carbon dioxide, although some scientists have argued that the increase is the result of warming rather than its main cause. In this paper, I provide evidence for a distinct cause of global warming which has so far escaped the attention of both scientists and the public. The philosopher Henri Bergson talks of a woman who is about to open the gate of an old-fashioned elevator—and plunge into the shaft to her death, because there is no elevator at that floor. Before she does so, however, a man appears and pushes her to the floor, saving her life. However, there was no man—it was a hallucination. Nonetheless, the hallucination saves her life. Similarly, the consensus view that the rise of CO_2 is the greatest ecological problem facing the human species may also be wrong—but also draws needed attention to humanity's increasing destruction of its own and other species' habitats. Science, wrote quantum physicist David Bohm, is about finding the truth, whether we like it or not. Few people, scientists and other authorities included, like to find out that they may have been wrong, especially when they are considered experts and matters of our collective survival are at stake. Nonetheless, it behooves us in the face of new evidence to periodically examine our most ardent beliefs and examine the possibility that we may have been wrong.

I would argue that just as we are inhabited by the bodies of other organisms, we inhabit the shared living spaces unto bodies of ecosystems that produce our food and recycle our wastes without our help and using metabolic skills of which we are incapable, either in our bodies or by our technology. This suggests that we must better understand and respect the fellow beings upon whom both the quality of our lives and our lives themselves depend. Both as individual animals and as a planetary civilization we depend upon the bodies and bodily knowledge of our nonhuman planetmates. The ethical and aesthetic stakes could hardly be higher.

Toxic masculinity checked by bloody warfare fomenting technology may be the secret of hu*man*ity's recent "success," especially in spreading across this planet, if not "conquering" space. Of course, we have not conquered space; we have tentatively and gingerly brought a few people there, and quite a few more machines. Nonetheless, the push to explore space that began in the Cold War has led to the unsought discovery that Earth's ecological surface is actually a planetary-level nonequilibrium thermodynamic system, Gaia. This discovery is, I contend, the greatest discovery of NASA's space program.

Methanogens, including in communities of archaea and bacteria and protists inside animals such as cattle and termites, produce methane on a global scale, in principle detectable on Earth by Martians with equivalent tech to Earth astronomers during the time of the Viking mission. Methane, unstable in the presence of oxygen, is produced by microbes on a massive scale. The same is true of other gases by other microbes and their symbiotic progeny. For Lynn Margulis (1994), the co-developer of the mature Gaia hypothesis, bacteria don't go extinct. Although given species names, prokaryotes don't obey the biological species concept; they trade their genes rampantly and can quickly adapt to multiple environments. Crucially, from a thermodynamic perspective, they are able to completely recycle metabolic wastes, allowing Gaia, which reuses limited atoms, to continue to produce entropy as temporary pollution and unrecapturable heat waste without destroying itself. It has done so for billions of years. The largely closed nature of the Earth system sharply distinguishes Gaia from the problematic idea that Gaia is in any way an ordinary organism. Mere organisms—such as we—cannot thrive on their own waste matter. Recycling is something done by ecosystems, not monocultures, including our technological monoculture.

Nonetheless, while we worry in an apocalyptic register about raising the CO_2 level about one-hundredth of a percent,[1] our oxygen-producing cyanobacterial ancestors increased another gas, O_2, originally a dangerous waste, from virtually nonexistent to 20 percent of the atmosphere—many orders of magnitude greater change, and one from which we directly benefit (Sagan 2017).

It is nonetheless true that our pollution is endangering life, including ourselves. We are thus put in the position of trying to rectify the damage caused by our population growth and industrial activities. It is not clear that we are up to the task: "Can you imagine yourself with the task of overseeing your body's physical processes?" Lynn Margulis (1994, 76) provokes:

> Can you make your kidneys function? . . . Are you conscious of the blood flow through your arteries? . . . We are unconscious of most of our body's processes, thank goodness, because we'd screw it up if we weren't. The human body is so complex, with so many parts. . . . The idea that we are consciously caretaking such a large and mysterious system is ludicrous. The idea that we are 'stewards of the earth' is another symptom of human arrogance. (Margulis 1994, 76)

That said, population control, which can prevent organisms from growing too fast and then running out of food all at once, has evolved many times but never consciously. The biological tendency for exponential growth is a direct consequence of life's dependence upon energy, which is available and tends to be dissipated, and life's nature as a complex system requiring energy sources to run its metabolism. Organisms without the wisdom or know-how to control their own rampant growth risk not only mass starvation, but also destroying their environment and themselves in their polluted wake, as well as being destroyed by infectious diseases. In the present climate situation we are at risk from a major natural form of waste—heat—which is being produced too near life's sensitive surfaces.

Gaia is really a far more than human being slightly reducing the gradient between cold space and the concentrated energy of the sun. Matter at our scale has a tendency to organize itself to reduce gradients. A gradient is a difference across a distance (of temperature, pressure, or electron potential) and represents available energy. Even very simple nonequilibrium thermodynamic systems can be impressive in their mind-like *attempts* to reduce ambient gradients, using energy and sometimes using it up, and spreading it (producing entropy) in the process. Consider a heated log cabin on a snowy mountain. Wherever there is an opening or *space*, say by a window or beneath a door, heat will *attempt*—I use this word advisedly—to escape (Examples of this type must account for some reports of ghosts—for example a wisp of heat that seems to slip and shapeshift, genie-like, through a keyhole and out of a reclining person's room). Available energy has a tendency to be used up, reducing temperature and other differences. Life is involved in this sort of operation, although the main difference it lives off of is the larger-than-Earth one between the hot sun and surrounding space.

The teleology of even simple thermodynamic systems, let alone a four-billion-year-old one like Gaia, is profound. In 1957 astrophysicist Subrahmanyan Chandrasekhar, a 1983 Nobel laureate for his work on the physics and evolution of stars, described convection, a non-living process that dissipates heat:

> The simplest example of thermally induced convection arises when a horizontal layer of fluid is heated from below and an adverse temperature gradient is maintained. The adjective 'adverse' is used to qualify the prevailing temperature gradient, since, on account of thermal expansion, the fluid at the bottom becomes lighter than the fluid at the top; and this is a top-heavy arrangement which is potentially unstable. Under these circumstances the fluid will *try* to redistribute itself to redress this weakness in its arrangement. This is how thermal convection originates: It represents *the efforts* of the fluid to restore to itself some degree of stability (323; emphasis added).

Examples of gradient-reducing systems include whirlpools, convection cells, Belousov-Zhabotinski and other autocatalytic chemical reactions, Taylor vortices, and bacteria swimming up a sugar gradient.[2] Indeed, for all its complexity, Gaia is also a gradient-reducing, entropy-producing system organizing itself internally and pushing heat away from its sensitive surfaces. Far from violating the second law of thermodynamics, complex systems enable the dissipation of energy the second law describes. Like heated cabins, and those whirling fluid dynamic systems, convection cells, Gaian Earth life finds concentrated available energy and dissipates it within an energetic cosmos (Sagan and Whiteside 2004).

Even nonliving aspects of the Earth system are organized to get rid of thermodynamic heat waste. Convection cells, as exemplified by Bénard cells, hexagonal fluid systems that reduce a temperature gradient, are one example. Peter Sloterdijk (2017) writes that in

> the most propulsive idea outside of the religious domain, the most ingenious and dangerous notion ever conceived by modern Europeans, Portuguese sailors became engaged, in a metaphorical and real sense, to the prevailing winds. They devoted themselves—first in thoughts, then in actual ships—to the breezes that continually blow out from Europe's western coast to the ocean, a clockwise . . . whirling of air masses that produces in more southern latitudes a relatively constant current from the northeast and elicits in more northern latitudes a continuous, often stormy western current. The European television viewer today sees this structure in their so-called weather reports on almost a daily basis from the perspective of satellites, without suspecting that they have the same climatic-political secret of globalization before their eyes. In order for the wind to air their sails, the *marinheiros* of the fifteenth century had to plummet into the invisible whirling vortex and expose themselves to its motion, come what may . . . It was their idea, which gradually became clear, to drift out to sea for as long as it took until, vertiginously far afloat after a tenaciously adhered to western course before the northeastern trade wind, they pushed forward into the western wind zones of the Atlantic, from which the wind's propulsion would allow them to return home again. (46)

This bold maneuver, Sloterdijk avers, "which was soon so common that hardly anyone noticed it except for captains, received a sonorous name from the Portuguese sailors: *volta do mar*, the sea's about-face" (46). These trade winds, as well as jet streams and tropical rain-belts are driven by the Hadley cells, a form of atmospheric convection which consists of equator-heated air flowing poleward at around 15 kilometers above the earth's surface, descending in the subtropics, and then returning in an organized heat-dissipating circulation. The Americas were obviously already inhabited, and not just by humans, when Europeans *discovered* them. But even to do so the Europeans had to advantage themselves of a process of orderly entropy production.

In Margulis's view (1994) tenacious bacteria and archaea, able to thrive in anoxic and oxic atmospheres, never going extinct, in effect run *our* global thermodynamic system; humanity, indeed all speciating animal life, are heterotrophic epiphenomena. The cyanobacteria from their dominant role in multilevel stromatolite communities billions of years ago to their afterlife as platformed plastids in the leaves of tropical forests, are primary producers making themselves from water, sunlight, and air. They own the means of production. Other bacteria and their descendants do the actual recycling. More than us, cyanobacteria are star beings, not looking for themselves there in outer space but finding themselves, here, alive and well and grokking the energy of a local star, our sun. They, and their comrades, have long since found ways to use energy sustainably without polluting themselves to death.

The roots of the tendency for exponential growth can be found in the tendency for concentrated energy to be dispersed, a tendency which is enabled and accelerated by complex thermodynamic systems, from bacteria soon-to-be-expelled from a sick person's gut to stately Gaia *herself*, keeping life's sensitive surfaces relatively cool for billions of years. Measurements taken by global thermal satellites over the Amazon and Borneo tropical forests at the height of the summer are equivalent to those taken over Siberia in mid-winter. Low-flying aircraft show a continuum of increasing coolness going from urban heat islands to newly planted to old growth Douglas fir forests. Clouds reflect as well as trap heat, with a probable net effect of cooling, as the thermal satellite imagery suggest. Indeed, most of the solar energy trapped by trees is used not for growing but for evapotranspiration, which exports heat and helps form clouds (Schneider and Sagan 2006).

This inability to sufficiently dissipate heat and other wastes has long been a problem for life's distributed, gradient-reducing, genetically underlain, potentially exponentially reproducing systems. We can see it in our own bodies. I extrapolated the growth of my newborn son. He'd doubled his weight in the first six weeks. With 8.66 periods of such doubling in his first year, he would, by age three, weigh over two thousand tons. Such growth doesn't happen though. The early exponential growth of the zygote inevitably abates. Indeed, it looks like an evolutionary freeze frame of a population that has learned the hard way when to grow and when to say no. Entropy production *per* unit mass for embryos and young animals falls off, giving rise to adults with higher overall entropy production but who are no longer growing so fast, or at all (Zotin 1969). So too, mature, biodiverse ecosystems enjoy greater overall entropy production than early phase ecosystems, but their size remains constant, avoiding exponential reproduction (Schneider and Sagan 2006).

Perhaps the most fascinating case of avoiding hyper-entropy production is that associated with animal populations and their aging individuals. Aging, in the precise statistical sense of being more likely to die next year than this year, varies widely and is not found in all animals. Sharks, whales, turtles in our own phylum show few or no signs of aging. Clams can live hundreds of years, trees thousands. Lobsters, although they eventually die of something, become stronger and more fertile as they age. Meanwhile mayflies live a day, and some salmon begin to rapidly deteriorate immediately after reproduction. Aging seems to have evolved in eukaryotic clades whose ancestral populations and species were winnowed, often but not always by mass starvation following natural but unsustainable bursts of hypergrowth.[3]

Today a new form of killing pollution looms. Convection may have helped an earlier Europe expand, but new evidence suggests that global warming—literally, thermodynamic dysfunction of Gaia's gradient-reducing systems—is blocking normal Gaian convection. Like a ceramic plate put over a beaker of convection-surfing celery seeds in a high school lab experiment, heat near Earth's surface, preventing a sufficient temperature gradient, has the potential to stop convection at multiple scales.

Science is about the open-minded search for truth, and facing evidence, whether we like it or not. There were many hotter times in Earth's history including four times since humans came out of Africa some 200 thousand years ago. Nonetheless, the present heating seems largely human-caused. To the best of my knowledge early work on Gaia was in part an extension of the puzzle of the temperature of the early Earth. The composition of the early atmosphere was deliberated as part of the puzzle of what was called the Faint Early Sun Paradox. According to nuclear models of the life of stars, our early sun was up to 70% less luminous. But then how did Earth life survive without freezing early on or burning up now? Carl Sagan with George Mullen initially suggested that the greenhouse gas methane could have done it. Saved from photodissociation by a layer of organic compounds, the gas could have warmed Earth early on. Similar thinking suggested that as the sun increased its luminosity, photosynthetic organisms could have taken progressively more carbon out of the atmosphere, cooling Earth. This part of the speculative prehistory of the Gaia hypothesis—how did Earth stay warm enough for life early on?—seems to have found new life in the now-consensus idea that CO_2 is uncontestably the main cause of anthropogenic global warming.

However, there is more than one scientific view about what is causing the current phase of warning. Looking closely at a temperature profile on the front page of the *New York Times* on January 19, 2017, Bernard Gottschalk (2018) noticed a thermal peak coincident with World War II. The *Times* graph was based on NOAA's 1880–2020 global temperature data. The mid-century spike tops out at the height of WWII, and then drops to 1949. Then the slower rise in temperature resumes.

A recent peer-reviewed paper plots Gottschalk's fitted curves for eight NOAA data sets showing relative temperature profiles over time next to proxies for particulate pollution (Herndon and Whiteside 2019). The century-plus worth of data shows a steady—except for the steeper bump Gottschalk noticed—rise of about two degrees Celsius, over both land and sea. The rise is coincident with increases in global aviation pollution, global crude oil pollution, and global coal production. The striking Gottschalk bump takes off about 1940, flying high until it reaches its peak about 1945, and doesn't settle back to join the main curve until the end of the decade.

The authors analyze various aerosol particles—black carbon, brown carbon, coal fly ash-containing iron oxides that covert into even more absorptive magnetite in forest fires and so on—that absorb solar radiation and heat the troposphere. These particles, they contend, by putting too much heat at the surface, destroy the normal tropospheric gradient, blocking convection. Among the strong supporting evidence is an analysis (not the authors') of the Mount St. Helens volcanic plume (Mass and Robock 1982). Although the eruption led to cooler temperatures in daytime as particulate matter blocked sunlight, the nighttime temperatures were warmer, as particulates reradiated heat before settling to the ground. In another reference it was shown that heat-trapping Saharan-blown dust appears to block convection over the north Atlantic. Direct measurements in clouds from airborne instruments—radiosonde and aethalometer readings—up to three kilometers off Earth's surface show greater increases from particulates (including water vapor) than from CO_2. The picture they draw is of convection, blocked by the production of too much heat from particulates close to Earth's surface.

Such direct evidence, which must be considered, contrasts with the prevailing views of CO_2 as the main cause for warming, which depend on supercomputer-run GCMs, giant global circulation models that do not take into account convection. The GCMs are also poor at modeling evapotranspiration and cloud cover and may miss Gaian feedbacks. Major contributors to particulate pollution according to the authors are 1) fine coal fly ash not trapped in coal plants (in China and India, and soon the US, under current energy policy); 2) widespread but undisclosed military and civilian geoengineering; and 3) particulate-forming additives to gasoline. To this we may also add bombing in military operations. Of particular note is the short residence time of aerosols in the troposphere. They fall out in a matter of days to weeks, and so, if particulate pollution rather than CO_2, which has a much longer residence time in the atmosphere, is the main culprit of warming, then trapping or, better, preventing aerosol emissions may have a dramatic short-term effect on global warming.

Near the end of his life Carl Sagan quite publicly worried about nuclear winter-like effects from the burning of Iraqi Oil wells. Now we worry about the exact opposite. We might speak of Gaia *versus* the Anthropocene. The first is essentially a microbe-based system that has come roaring back after several mass extinctions and appears to be able to take care of itself through complex feedbacks. We are not so lucky. As the self-appointed most intelligent beings on the planet we humans have reproduced ourselves and technology to near the carrying capacity of the environments we are destroying. Mutating, gene-trading, symbiogenetic, prototactic life includes metabolically diverse bacteria and archaea as well as an estimated 30 million extant species representing less than a percent of all species that have existed on or in Earth's surface. Clearly most of these organisms did not require human-style cranial intelligence to subsist, and expand, or titrate their potentially destructive growth to continue to function within metabolically diverse ecosystems tapping sustainably into local energy sources.

And at the precipice what do we do? Continue to do what we have done, in both our lifestyles and our lack of humility regarding the living system which supports us.

There are alternatives. Bronx-based ecologist Paul Mankiewicz who shows for example the amazing ability of mussels and oysters to purify water, writes that "a thermodynamic boon comes from elevating shoots, branches and leaves into the fluid atmosphere to capture sunlight and carbon dioxide. In this vertical lift, land plants can process, move, a hundred-fold more heat, but mainly as water vapor, so thereby cooling the surface in the process. Integrating flows of water and radiation, terrestrial plants dramatically drop the body temperature of the world around them" (Sagan and Mankiewicz 2017, 454). We need to experiment with multispecies cultures, re-finding our place in more diverse ecosystems.

Both the moderated exponential growth of embryos and variable and flexible senescence suggest that even and especially in human beings the autonomous physiology of our bodies may be "smarter" than technical civilization in its expansionist growth phase. The same is true of Gaia.

In Gaia, we are not alone, not even in our bodies. Our wise elders may or may not be out there, but they are certainly here, in and around us. Like the djinn in medieval Islam whose bodies are made of fire but often manifest as whirlpools, nonliving thermodynamic systems often organize rapaciously around gradients, quickly using all available energy, and then disappearing. Living gradient-reducing systems may know better, having evolved anticipatory modes to moderate their energy use, safeguarding their ability to do so in the future. Let us join them.

Notes

[1] From about .03 to .04 percent of the air.

[2] See e.g., Chapter 9, "Physics' Own 'Organisms,'" in Schneider and Sagan (2006).

[3] See e.g., Josh Mitteldorf's *Aging is a Group-Selected Adaptation: Theory, Evidence, and Medical Implications* (2016). For a more accessible account, see Josh Mitteldorf and Dorion Sagan's *Cracking the Aging Code* (2016).

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