REIMAGINING THE HUMAN-ENVIRONMENT RELATIONSHIP

Our Copernican Revolution: Climate Change and the Astrobiology of the Anthropocene

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This paper forms part of the volume *Reimagining the Human-Environment Relationship* for Stockholm+50. This curated collection of ideas captures, interrogates, and elevates alternative paradigms of the human-nature relationship – existing and new, and from various disciplines and societies – creating a space to recast our relationship with the environment and inform future policymaking.

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You can't solve a problem until you understand it and you can't understand it until you know how to tell its story.

Introduction: Finding the Right Story

It has been said that the first human technology was the story. When we meet someone for the first time, we do not ask for their scientific metrics – their height, weight, blood type or DNA profile. Instead, we ask for their story. Where did they grow up? How long have they lived in the neighbourhood? What do they do for work? As individuals and as cultures, we human beings have always understood ourselves and our place in the world through the stories we tell. Thus, it is critical to recognize that when it comes to climate change, we have been telling ourselves the wrong story.[1]

In spite of decades of intense effort, we still lack the global response needed to deal with the global climate crisis. This paper will highlight that beneath many of the reasons for this inaction[2] lies a fundamental misunderstanding about exactly what is at play in climate change. It is a misunderstanding which is, however, eminently understandable. The new story we need to tell about the Earth and our place on it, especially in the context of climate change, is just that…*new*. Revealed through a series of recent and profound scientific transformations, this narrative has emerged from a novel field of research known as ***astrobiology***: the study of life in its full cosmic and planetary context.

Five centuries ago, European cultures experienced a radical intellectual upheaval in what has been called the Copernican Revolution. Before Copernicus wrote his famous treatise *On the Revolutions of the Heavenly Spheres*, both common and expert opinion "knew" the Earth was the centre of the Universe, just as everyone also "knew" that the Sun rose and set each day because it circled the Earth in the sky. But within a century or two, common and expert opinion would pivot. The Earth was dethroned to became just another sibling world in the solar system's family of planets. Even the Sun stopped rising in the morning. Instead, it was the Earth's horizon that dropped away as the planet spun on its axis.[3]

The Copernican Revolution was, however, much more than just the discovery of a new set of astronomical facts. Instead, it was the foundation of a new grand narrative about the world and our place in it. For better or worse, the cosmic story would be implicated in all the other revolutions that followed. The Copernican Revolution was the beginning of the Scientific Revolution with all that implied from emerging market economies to the religious upheavals of the Reformation to the spread of colonial empires.[4] It is noteworthy that even our broad use of the word "revolution" comes from the title of Copernicus' work.

The central premise of this paper is that seeing climate change in its proper *astrobiological perspective* represents our era's Copernican Revolution. It is a reframing of our planetary view that can also rewire the human conception of itself as we enter the human-dominated geological epoch called the Anthropocene. Astrobiology shows us the Earth as a world that has co-evolved with its life for more than 3 billion years. Again and again, life has transformed the planet only to find itself transformed in turn *by the planet*. There has never been, and there never can be, any separation between the living and non-living realms (a perspective many indigenous cultures already understood).[5] Looking outward, astrobiology shows us a solar system with planets that have already experienced profound episodes of climate change. Mars, Venus, and Saturn's moon Titan: each world tells us a story about planetary climate and planetary dynamics we can learn from. Looking even further outward, astrobiologists have only recently discovered that the Universe is teeming with trillions upon trillions of worlds – "exoplanets" – that we are just learning to observe and that may have their own stories to teach us about of life and civilizations.

Building a long-term, sustainable version of global human civilization will require working out a wide range of details ranging from diplomacy to governance to technology. But to be successful – *to stick* and not crash against the walls of reaction and inaction – this work must occur within a larger frame. It requires a new story of Earth, life, and the human prospect. The astrobiological perspective – our Copernican Revolution – can deliver that new story. We begin with the defining characteristics of this new science.

The 3 Revolutions of Astrobiology

The question of life on other worlds is an ancient one. The Hellenistic Greeks argued vociferously over this very question 2,500 years ago. Aristotle, for example, was firm in his belief that Earth was unique. There could not be more than one world he claimed. Epicurus held a more optimistic view: "There are infinite worlds both like and unlike our own... Furthermore, we must believe that in all worlds there are living creatures and plants and other things we see in this world."[6]

This dichotomy between optimists and pessimists about other planets and other life would echo across the millennia. Only within the last century however – and really only in the last few decades – has humanity moved from arguing over *opinions* about life elsewhere to finally starting to gain data. This is critical because only data can take us beyond mere opinion. In the process, the new scientific field of astrobiology was created. NASA defines astrobiology as: "the study of the origins, evolution, distribution, and future of life in the universe." It is a field that cuts across disciplinary boundaries, drawing on geochemistry, genetics, anthropology, information theory, astrophysics, and more.[7] To understand how this field gives us a new story about climate change and the Anthropocene, we must first understand the story of astrobiology itself and the three revolutions that accompanied its birth.

The Solar System: What the Robot Ambassadors Say

The Space Age began with the launch of Sputnik in 1957. Since then, every class of solar system body from planets, comets, to asteroids has been explored by robot probes.[8] Through these missions, the entire 4.5 billion year history of the Sun and its satellite worlds has been explicated. Perhaps the most important scientific boon that came from these explorations has been a universal understanding of planetary climate.

The principal discovery of humanity's first mission to another planet was finding a world wrecked by the greenhouse effect. In 1962, the Mariner 2 probe, an ungainly box of electronics, made the perilous forty million kilometer journey to Venus.[9] There it found a world much like Earth in terms of mass and size, but entirely unlike our world in terms of climate. Mariner found Venus had surface temperatures of almost 500 Celsius and surface pressures high enough to crush a nuclear submarine.[10] Mariner 2 and the subsequent missions to Venus have shown scientists a planet that may have once hosted oceans but which, some 100 million years ago, experienced a catastrophic build-up of carbon dioxide (CO_2) and a “runaway” greenhouse effect. Thus, Venus may have once been a garden world, but now looks as close to hell as we can imagine.

Then there is the case of Mars. From H.G. Wells’ *War of the Worlds* onward, the red planet was long believed to be a world that might host life. When Mariner 6 visited in 1969, however, the pictures it returned showed cratered empty landscapes reminiscent of the Moon.[11] Subsequent missions however, revealed the presence of what appeared to be dry riverbeds, broad deltas, and empty lakes. While Mars today is frigid and covered by a thin atmosphere, these ancient features hint at the possibility that the red planet was once warm with a dense blanket of air allowing liquid water to exist on its surface. Since the 1990s (the beginning of the modern age of astrobiology), a series of robot rovers has trundled across the Martian surface and provided conclusive evidence that the red planet was once blue. Deep in its past, Mars thus had significant quantiles of water streaming from highlands to lowlands and collecting perhaps into shallow continent-spanning oceans.[12] But, just as with Venus, something terrible happened. Mars’ climate changed and it was left a cold, desiccated world.

Our interplanetary robot ambassadors have proven that climate change has happened on other worlds too. But just as important, they have also given us the tools to understand the universal principles of climate that must apply to *any world* including Earth. They have shown us how the interplay of solar energy, atmospheric gases, and planetary rotation will *always* create features like jet streams, equator to pole circulation, and greenhouse warming.[13] The key point is that we would not understand the anthropogenic climate change being driven by humanity today without the study of these other worlds. The computer models we use to project Earth’s climate future were developed and tuned in tandem with models that have been successfully applied to Venus and Mars. It is noteworthy, for example, that the first models of a Nuclear Winter, which proved so pervasive in getting Russia and the US to disarmament talks in the 1980s, relied on an understanding of atmospheric dust gained from Martian climate models (Mars often experiences planetary scale dust storms).[14]

The Exoplanet Revolution: A Universe of Worlds

Life most likely needs a planetary surface or ocean to get started. Thus, even before one can ask about life elsewhere in the Universe, we must first deal with the question of other planets beyond the solar system. For millennia, humans did not know if there were any planets orbiting any other stars and many astronomical careers were ruined by claims, later disproven, of “exoplanet” discoveries. In 1995, however, researchers revealed conclusive evidence of a Jupiter-sized world orbiting its star on a 4.5-day orbit.[15]

This first discovery of a planet orbiting a sun-like star initiated an avalanche of exoplanet science.[16] An astonishing variety of worlds were quickly discovered. Some planets were found to be so dense they must be made of diamond. Others were found to be so hot they must host a continuous rain of lava. Other planets appeared to be ocean worlds covered by water stretching down hundreds of miles. Astronomers even found that the most common type of planet in the Universe was one which we did not have in our solar system: “Super Earths” with masses between our world and that of Neptune (equivalent to 14 Earth masses). What is important to understand is that each of these planets is a place just like Earth, a location where things happen just like they do anywhere on any day on our world. We can say with some certainty that there will be snow-capped mountains on some of these worlds while others will host valleys where rain falls softly as their sun rises over the horizon. In this sense, Earth is most definitely not unique.

By 2020, astronomers had found more than 4,000 alien worlds. This was enough for them to carry out detailed statistical analysis revealing that every star we see in the sky is likely to host a family of worlds.[17] Even more importantly, one in five of those stars will be orbited by an Earth-like planet at a distance that allows liquid water to exist on its surface (this is believed to be the first requirement of life). With this new data, it became possible to calculate the total number of potentially habitable planets in the Universe. That calculation reveals a cosmos with approximately *ten billion trillion* worlds where life and technological civilizations like ours may have formed.[18] This number has important implications for thinking about human uniqueness in the cosmos. Each habitable world represents an experiment that nature has run in the possible formation of life, intelligence, and technology. Thus, the only way humans and our experience on Earth could be unique would be if all those 10 billion trillion experiments failed. But having all those experiments fail would mean that nature is, somehow, remarkably biased against forming what has clearly formed here on Earth. From that perspective, it seems unlikely that the human experience on Earth is the first time in cosmic history that a world has evolved life that went on to create the kind of social, tool-building species we represent.

Even more importantly, as we will explore, the existence of 10 billion trillion planets where technological civilizations may have formed also implies that we might not be the first species to inadvertently trigger climate change on its world. In other words, Anthropocenes might not be uncommon. Thus, only those species that are smart enough to understand what is happening once their planet's climate change begins and take appropriate action will be those that endure.

Our Planet's History: The Many Masks of Earth

While it is true that astrobiology has only one example of life to work with, to think that this limits the field's reach misses a key point about its approach. Astrobiology is the study of life and planets together. It understands life as a planetary phenomenon. In other words, life is not something that happens *on a planet* but *to a planet*. This key insight has come to astrobiological studies through its recognition that Earth has been a version of many planets over its long history.

The Earth formed 4.5 billion years ago with the Sun and rest of the solar system. Life is known to have appeared a billion years later, though that may be a conservative appraisal.[19] No matter the exact date of life's formation, very soon after its appearance, a process called co-evolution began in which life and the Earth began changing together.[20] The biosphere, which is the sum-total of living organisms, began exerting strong feedback forces on the other "geospheres" of air (atmosphere), water (hydrosphere), ice (cryosphere), and land (lithosphere). Together, the bio and geospheres formed a "coupled Earth system" that has evolved as a single entity taking on many forms over time. There were, for example, *Snowball Earth* phases of near total planetary glaciation. There were also "thermal maxima" *Jungle Earth* phases with ice and snow existing only on the highest mountains. Life was often the driver of these planetary transitions as new species emerged with new functions and capacities that altered the geophysical/geochemical behaviour of atmosphere, oceans, etc. Perhaps the most dramatic example of this co-evolution is what is called The Great Oxidation Event (GOE).

For almost half of its existence, Earth's atmosphere contained only minute quantities of oxygen. If human time travellers appeared on the planet 3 billion years ago, a period when life was already flourishing, they would have instantly died of asphyxiation. So where did the oxygen, which now accounts for 23 per cent of the atmosphere, come from? The answer is life. More than 2.5 billion years ago, evolution invented a new form of photosynthesis in which microbes could take energy directly from sunlight by splitting apart water molecules (H_2O).[21]

The oxygen which was released in this process soon began to build up in the Earth's rocks, oceans, and finally air. It was the greatest revolution in the history of the planet.[22] Molecular oxygen (O_2) is an energetically potent chemical. Once it became widely available, new kinds of super-charged biochemistries become possible including eventually the evolution of big-brained thinking animals like humans. But the GOE was a disaster for the life that existed at the time. Oxygen is also a poison for some kinds of biochemistry and the GOE represented a mass extinction event for much of the microbial species that were present then. Today, those species that made it through the GOE must live in oxygen-free environments like underground warrens, sulfurous pools or even inside our stomachs.

The importance of the GOE is that it shows how profoundly life has been a key player in planetary evolution. The emergence of a novel species changed the chemistry of the entire atmosphere and, in the process, put its own existence at risk. This situation should seem all too familiar to we human beings standing at the beginning of the Anthropocene.

From Holocene to Anthropocene

The three revolutions of astrobiological science provide a unique vantage point from which to view the Earth's current state. To understand this perspective and what new insights it can yield, we must first review where the planet, its life, and the global civilization we have built stands now.

Geologists divide Earth's history into eons, eras, periods, and epochs. Loosely speaking, eons are the longest divisions and tend to last billions to hundreds of millions of years. Eras subdivide the eons and are measured in hundreds to tens of million years. Then come periods, which clock in at tens to millions of years. Finally, there are epochs, which are of order millions of years or less. For the last few million years, the Earth has been in the Quaternary Period, characterized by a series of ice ages when glaciers extend from the poles to mid-latitudes for a hundred thousand years only to retreat again in short "inter-glacial" periods.[23] During these ice ages, much of the Earth's water is locked in ice. The planetary climate state is cold and dry. When the last ice age ended approximately 12,000 years ago, climate again shifted to become relatively warm and moist. This marked Earth's entry into the current epoch known as the Holocene.

The Holocene has been a positive epoch for humans at least in terms of human invention, creativity and population growth. The whole of what we will call the "project of civilization"[24] occurred during the Holocene as humans explored different kinds of social organization, invented farming, created diverse systems of knowledge, and developed worldwide circuits of trade.[25] This project of civilization also allowed humanity to understand the natural world in new ways. Our sciences grew in complexity and reach during this epoch, a key moment being a few centuries ago when we discovered new ways of harvesting energy in the form fossil-fuel driven combustion engines. The discovery of this energy source had profound consequences, giving humans enormous productive capacities. It also gave humans enormous destructive capacities, driving significant changes in the ecological systems making up the biosphere. By the end of the 20th century, it was becoming clear to many scientists that human activity was driving the Earth out of the Holocene epoch.

Climate change is only the most apparent marker of this oncoming shift in planetary state. Another aspect included the fact that humans were also moving more material from one place to another than all other natural forces. Also, our use of nitrogen and phosphorous, elements key to the biosphere, outstripped their natural deployment.[26] Taken together, these and other metrics showed that human activity had become the dominant source of "forcings" on the coupled Earth systems. A "forcing" can be thought of as an effect that changes the state of the planet. Since it is the state of the coupled Earth system which, in part, defines geological eons, eras, and epochs, it thus became clear that our project of civilization was driving the Earth into a new geological epoch which was given the name the Anthropocene.[27]

The Anthropocene can be seen from many perspectives and concerns i.e., politics, economics, legal, social justice, etc. For our purposes, however, the Anthropocene will be strictly viewed in terms of planetary state changes, which is fundamentally an astrobiological perspective. In light of Earth's long history of life and evolution, the Anthropocene represents another instance of co-evolution. As has happened many times before, it is the initiation of a state change that is driven by life and takes the Earth from one kind of planet to another. As we will now see, it is from the multibillion year astrobiological view that our place, and our choices in the Anthropocene, can be significantly reframed.

The Astrobiology of the Anthropocene

Since the first UN Conference on the Human Environment fifty years ago, the world's diplomatic community has worked tirelessly to create a sustainable version of human civilization. From the astrobiological point of view, however, this effort raises a particular kind of question: How do we know such a thing is possible?

The question is particular because of the way it must be framed. We know that the natural processes that govern the Universe allow many different forms and structures to evolve. The Universe contains many galaxies, stars, black holes, interstellar gas clouds, planets, asteroids, and comets. It is clear, then, that the Universe "knows" how to make these kinds of things, but does the Universe and its laws also allow for the existence of long-term, sustainable technological planetary-scale civilizations? Are these kinds of planetary phenomena also something the Universe makes? Given our exploration of astrobiology, this is not a trivial or facetious question. We have seen that there exist laws (or at least repeating patterns) in the evolution of planets in terms of their climate states. We have also seen from Earth's long history that life and planets co-evolve. Once biospheres become robust, they exert strong feedbacks on their planet's geophysical systems that, in turn, exert equally strong feedbacks on the biosphere. Thus, we can ask two pointed questions relevant to our situation today.

First, will any species that develops intensive energy-harvesting technologies like those that humans now possess push their world into significant climate change? In other words, will any technological species appearing on any world drive their own version of an Anthropocene? Second, are these exoplanet versions of an Anthropocene (an "exo-Anthropocene") always fatal to the species that drive them? This is just another version of the question we asked earlier, does the Universe allow for long-term technological energy-intensive civilizations?

Over the last decade, our astrobiology group at the University of Rochester, along with biosphere scientists from the Max Planck Institute in Jena and the University of Washington Urban Studies Department, began looking at these questions by modelling the co-evolution of a planet and an energy-harvesting civilization.[28] The model coupled population dynamics equations to a generic global climate model that could be applied to any kind of planet. The goal was to understand how typical the generation of detrimental climate change was in the history of a large ensemble of planets with civilizations. The answers we found were instructive.[29]

Our most striking conclusion was that once a species begins harvesting energy from their planet (as humans have done on Earth via combustion of fossil fuels), it is difficult to keep that world from being pushed into new climate states. Every mode of energy use has consequences. This comes via the second law of thermodynamics that demands that some fraction of energy used to do useful work always ends up as waste heat.[30] The second law tells us that using energy to do work always produces feedback on the system, either in terms of heat or decay or pollution. Thus, in the process of building a planetary-scale civilization there can be no “free lunch.” Even the large-scale use of renewables will have some impact on the planetary environment.[31] But while all of our model civilizations triggered an Anthropocene, not all Anthropocenes were equal.

The best news emerging from our models was that some worlds experienced “soft landings” where the planet and civilization came to new steady states. Population growth stopped and temperatures became steady and manageable. In this way, we were able to answer our second question. In our models, at least, the Universe *does* allow for sustainable technological civilizations. But the models had a warning as well. In numerous cases, we saw changes in the planetary state becoming so severe that the civilization experienced extreme reductions in its population. Since a technological civilization is a complex social system, it is not clear that one could persist after losing 90 per cent of its population (as occurred in some cases). Worse still, in some model instantiations, the civilization experienced total collapse with populations essentially disappearing as the climate was driven into a dynamic state of runaway change.

These studies offer a new way of understanding our entry into the Anthropocene.[32] From the astrobiological perspective, a species that creates a technological energy-harvesting civilization is not apart or “other” from its biosphere. Instead, it is simply another evolutionary innovation in a long series of such innovations. It is part of its biosphere’s ongoing experimentation. Grasslands were once a novel biospheric innovation as were conifer forests and giant dinosaurs. Each arose, drove their global impacts and, in some cases, disappeared. A global civilization is, in this sense, simply *what the biosphere is doing now*. But that does not mean it will be what the biosphere is doing 1,000 or 10,000 years from now. That is our sustainability dilemma.

By seeing technological civilizations as a novel form of biospheric activity in which energy is harvested from the planet to accomplish the work of growth and organization, our models showed that triggering climate change may be difficult to avoid. This perspective subverts a question that is often used to blunt climate action. Climate denialists have long been successful in casting doubt on the reality of climate change.[33] They continue to ask the question “Is Earth’s climate really changing?” even though the science has long since established the answer. From the astrobiological point of view, however, this question gets turned on its head to become a statement. "We built a planet-girdling civilization. Of course, we changed the climate. What else did you expect to happen?"

This view is equally potent in blunting a kind of defeatist "anti-human" narrative that appears around discussions of climate change and the Anthropocene. In this telling of the human story, we become something like a disease or a virus infecting the planet. The sooner the Earth gets rid of us the better. But from an astrobiological perspective, we did not trigger climate change because we are inherently evil. Instead, it was an unintended consequence of activities we had engaged in for tens of thousands of years, which have been amplified by our growing technological capacities.

The next step, however, is equally important. While triggering climate change might not have been our "fault," once we recognized the planetary consequences of our activity, not responding to those consequences would indeed be our fault or, or to put it more accurately, our failing. In terms of responses, our models included the possibility for a civilization to switch from high impact energy resources (in terms of climate response) to lower impact ones. It was clear that those civilizations that made the switch early had a higher probability of achieving the soft landing (a "good Anthropocene", discussed earlier). Thus, those who continue to deliberately blunt the world community's efforts to switch to carbon-free energy systems[34] run the risk of dooming human civilization to the junk heap of cosmic history. They will be the reason that the biosphere moves on without us.

Towards Planetary Intelligence

The astrobiological perspective is useful because it allows us to see more deeply into how we, and the Earth, got ourselves into the Anthropocene. It tells us a new story about planets, life, and civilizations that we would not otherwise know how to tell. Even more importantly, however, it can also offer a new perspective on the task at hand by showing us key features of sustainability in terms of the co-evolution of planets and life. It is in particular only from an astrobiological viewpoint that we can recognize the role of Planetary Intelligence in shaping planetary history.

The *biosphere* was a revolutionary idea when it was first introduced into science by Russian geophysicist Vladimir Vernadsky in 1926.[35] It took some time before researchers accepted that the collective activity of life – all the microbes, plants, and animals – could dominate the evolution of an entire world. But, as we have seen, recognizing the biosphere's vast capacities eventually showed us that once life does appear on a planet, that planet can take on a life of its own.[36] Based on recent studies about the nature of cognitive activity in the biosphere, a new question has emerged about Earth and its evolution that is equally revolutionary. Simply put, if a planet with life has a life of its own, can it also have a mind of its own? If the collective activity of life can change the behaviour of an entire world, what about the collective activity of cognition? Can there be anything like Planetary Intelligence and, if so, can it work for the good of a world?

Intelligence is usually a property we ascribe to mammals with large brains (dolphins, apes, humans). Over the last few decades, however, evidence for collective, distributed intelligence has appeared in a wide array of creatures and a staggering variety of scales. For instance, a single bee holds only a small amount of the colony's total cognitive load, the information it has about the world. But it is the colony *as a whole* that knows and responds to the environment.[37] Such collective knowing appears in entirely different kinds of living systems as well. For example, the root systems of individual trees in forests spanning hundreds of miles are connected via underground strands of fungus to create a kind of forest nervous system. These "mycorrizorial" networks have been shown to channel nutrients and water to regions of a forest stressed by drought.[38] In this way, some have posited a kind of "green mind" in forests distributed across space and time that is utterly different from our usual conception of intelligence. Finally, even microbes have been shown to act collectively and cognitively. Rather than blindly bumping into their environments, microbial colonies respond to their surroundings in surprising ways such as "quorum sensing" where colonies of bacteria adapt to adverse environmental conditions through collective changes in their behaviour.[39]

These examples show that when intelligence is more broadly defined, it can extend beyond individuals and be effective over remarkable distances. Just as important, in all these cases, collective intelligence has acted for a collective purpose: self-maintenance. More than reproduction, some scholars see the ability of organisms to "self-produce" themselves in changing conditions as the hallmark of life.[40] A good example of self-production/self-maintenance is the membrane of a cell that must continually be rebuilt. The membrane is both a process and product that allows the cell to go on living and create more processes and products that maintain the membrane. It is a strange loop that makes life possible.

In a recent study, our group used these results to explore the idea that cognitive activity – in terms of knowing the environmental state and responding to it – can act across planetary scales.[41] When properly functioning, such Planetary Intelligence allows life (i.e., the biosphere) to shape planetary conditions and maintain them in a habitable state. Our principal goal was to show how a civilization, in the form a "technosphere," could do the same.

Coined by researcher Peter Haff, the technosphere is "*the interlinked set of communication, transportation, bureaucratic and other systems that act to metabolize … energy resources.*"[42] From trucks on highways carrying manufactured goods to packets of information riding the aether of wireless internet connections, the technosphere is a potent example of what scientists call a Complex Adaptive System. Composed of many smaller subsystems and agents, complex adaptive systems emerge to form integrated wholes with behaviours that could not be predicted from knowledge of just the subsystems. Over the last century, the human technosphere has emerged as a complex adaptive system from the biosphere (that itself emerged from the geospheres) to become its own planetary power.

Looking at the history of the Earth, one can see how the biosphere moved through evolutionary stages in terms of its the ability to exert influence on the other geophysical systems. The development of dense networks of feedback between living systems (like microbes) and the planet was the mechanism by which the biosphere exerted this influence. For example, the feedback loops between global populations of methane-breathing microbes and the atmospheric greenhouse effect can keep changes in planetary temperature from getting out of hand.[43] And just as in the forest networks discussed earlier, such feedbacks are the agents allowing something like cognition to act on global scales.

Thus, as these feedbacks evolve and become more numerous, we can speak of the biosphere going from an *immature* to a *mature* stage. Once the network of feedbacks becomes dense enough, the biosphere will become self-maintaining and self-producing over long periods. At this point, we can call it a mature biosphere that exhibits Planetary Intelligence. It has become a global system of living and non-living networks that responds to global changes (like the slow increase in solar radiation) and continue to be self-sustaining.

This transition between a mature and immature biosphere becomes a model for the next step. The question we humans need to understand is *what has to happen* on any planet that develops a long-term, sustainable technological civilization because that is the step we must take. We have already developed a technosphere that exerts considerable influence on the rest of the planet. The failed efforts to respond to the Anthropocene, however, demonstrate that our technosphere is still immature. It lacks the hallmarks of Planetary Intelligence. The biosphere became mature when it integrated into the other planetary systems in such a way that, at the very least, it did not actively degrade the Earth's habitability. But the current version of technosphere has it backwards. It is not integrated at all into the other Earth systems. It simply draws matter and energy from them in ways that will drive the whole into a new state that likely does not include a technosphere. There is no self-production and no self-maintenance. Our technosphere is, in the long run, working against itself. In terms of a theory of planetary intelligence, it is formally immature and stupid. It leaves the entire planet unguided, careening into new and uncharted territory.

So, what would a mature technosphere look like? First of all, it would be rooted in the biosphere, which itself is rooted in the other planetary systems. In its organization and operation, a mature technosphere would be part of the self-maintenance of the entire Earth system including all forms of non-human life on which it depends. Just as in the biosphere, this would occur through feedbacks built into the various systems that comprise the technosphere. Consider for example the world's financial system, a business cannot go to a bank for a loan to build a nuclear weapon. The financial system has feedbacks that would not allow the loan to proceed. A business, however, can get a loan to build coal-fired power plant. Even though the power plant will act to degrade the planetary conditions that allow the technosphere to exist, there are not feedbacks within the financial system to prevent its construction. Thus, we can imagine that long-term, sustainable civilizations develop technospheres that fully integrate into the other planetary systems and, thereby, become mature in their own right. Through the addition of their additional self-maintaining feedbacks, they would drive their planet to new and higher states of Planetary Intelligence.

Our Copernican Revolution

The Earth and its life stand at a unique moment in its many billion year history. While, as we have seen, there have been many examples of co-evolution between the living and non-living domains in its long past, what is happening now is unique. With the emergence of the technosphere, a new kind of sentience has appeared and, with it, new possibilities.

Some of these extend beyond Earth's domain as we might bring the vast creative capacities of life to other worlds in our solar system (or further). Others have to do with the preservation and maintenance of life here on our own world. If the dinosaurs had a technosphere, they might have been able to deflect the asteroid that ended their reign long before it reached Earth (developing "planetary protection" from asteroids and comet impacts is currently an active part of the world's space programs). The development of a mature technosphere would also create the possibility for human culture to extend indefinitely into the future via what astrobiologist David Grinspoon calls a Sapieozoic Eon where wisdom guides the action of a planetary-scale civilization.

None of this can happen, however, without humanity figuring out a way to emerge from its current, dangerous state of "cosmic adolescence." We have gained so much power over ourselves and the world we inhabit and yet we lack the maturity to use that power with wisdom, grace, and compassion. But, like all teenagers, we need stories to guide us. We need stories of possibility and hope, danger and courage, love and redemption. Because of its broad view of planets and life, the astrobiological perspective can offer us those stories. Recognizing our place in a Universe teeming with worlds and possibilities, its scientific narrative of co-evolution, and the possibilities of integration between biosphere and technosphere can be one fulcrum that allows us to get past polarization and support the heavy lifting required to build the first iteration of a sustainable, just, equitable, free, and fully inclusive human civilization.

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