*Special Report:*

# Our Fate in the Stars: How a Universe Rich with Alien Worlds Can Help Us Save Our Own

### Editor's Note

*Anthropogenic climate change has become a matter of intense debate in the public sphere, not only regarding how human civilization can respond to this threat, but even whether or not it is happening at all. University of Rochester astrophysicist Dr. Adam Frank describes a new, astrobiological framework for thinking about climate change that broadens our perspective on humanity's place on Earth. By considering current environmental dilemmas in a wider context — how life on Earth impacts physical planetary processes, and how civilizations throughout the universe might naturally induce climate change on their planets — Frank argues that we are better positioned to solve the compelling, existential problem of climate change.*

*This report is adapted from a lecture of the same name that Frank presented at Dartmouth College in May 2017. His book* Light of the Stars*, published July 2018, provides further reading on astrobiology and climate change.*

### What is the Problem?

The premise of Frank's argument is: **You can't solve a problem until you can understand it, and you can't understand it until you can tell its story**. What, then, is the real story behind climate change?

There is broad scientific consensus that humans are driving changes in the Earth's current climate state by burning fossil fuels. Problems associated with climate change, such as ocean acidification, shifting weather patterns and melting ice caps, are further compounded by general resource depletion across the world's biomes. While the science surrounding the topic is well established, political debate has lagged behind, and many people do not think climate change is happening or do not believe it is a threat to civilization.

This was not always the case, however. High-level political rhetoric surrounding climate change goes at least as far back as 1964, with an address by President Lyndon Johnson to Congress:

"This generation has altered the composition of the atmosphere on a global scale through radioactive materials and a steady increase in carbon dioxide from the burning of fossil fuels."

Over fifty years after LBJ's address, debate in the public sphere has become extremely polarized, and political gridlock has limited the options of how to tackle the climate change problem. A new framework for thinking about climate change could move the conversation in a more productive direction.

### Think Like a Planet

Much of the social misconceptions about climate change could be attributed to a problem in perspective. Fundamentally, climate change is thought of as a one-time phenomenon — that it has never happened before — and many people unfamiliar with climate science concepts simply don't believe that that human beings are capable of drastically altering the planet's atmosphere. In order to tackle these misunderstandings, Frank argued the perspective on climate change needs to move beyond just human beings in this moment in history.

To do this he suggested "thinking like a planet." Scientific understanding of planets has seen rapid advancements in recent decades. Frank noted that the idea of planets as a general, universal, cosmic phenomenon is very new, as are ideas suggesting that planets, their biospheres, and even their civilizations are broadly governed by knowable rules. Studying these rules and thinking about how planets and civilizations occur as a natural phenomenon can help us "think like a planet."

### Many Earths

Earth at one time had a magma ocean. Earth was also a continent-less water world. There was a later time when the Earth was seven degrees warmer than it is now — a jungle world. Later, the Earth was completely glaciated. In the distant future, as the sun heats up, Earth will be a desert world. There have been many different versions of Earth throughout the planet's long history, and there will continue to be many more in the future.

Geologists have demarcated epochs in the Earth's history that represent the planet's wildly different conditions. Currently, we are in the Holocene, a period of warm, moist, conditions that has only started since the last Ice Age about 10,000 years ago. Generally speaking, sophisticated human civilizations began and flourished in the Holocene.

Because civilization has thrived within the Holocene, it is unclear what would happen to human civilization outside of the Holocene. Frank stated that this point is particularly important to understand, because when we say we are worried about the climate, what we *really* mean is that we are worried about the Holocene. The word "sustainability" is often used to describe solutions to climate change. But what, exactly, do we want to sustain? We want to sustain is Earth as it currently is — comfortable for human civilization. Specifically, a civilization that maximizes human well-being, is technological and energy intensive, and has a high enough population to support a functioning, complex, technologically advanced society. To do this, we need to keep the Holocene. But by sustaining the Holocene in perpetuity, we are altering the planet's evolution. A perspective encompassing a long history of Earth shows that humans are far from the first species to do this.

### Biosphere Affecting the Planet/Co-Evolution

Life and Earth have been evolving together for billions of years. Physical processes on the planet affect life, and biological processes of life affect the physical processes on the planet. Frank noted that if a human landed on Earth three billion years ago, they would die, because there would be no oxygen for them to breathe. Earth's oxygen-rich atmosphere was created through the activity of life. Specifically, the large-scale success of one kind of life—blue-green algae, the oxidic photosynthesizers. Four billion years ago, the Earth's atmosphere was mostly carbon dioxide and nitrogen, with about a million times less oxygen than the air we breathe today. The blue-green algae created the oxygen atmosphere wholesale about 2.5 billion years ago through what is known as the Great Oxidation Event. Increased oxygen in the atmosphere created the possibility of more complex life and fundamentally changed the course of the planet's history.

The Great Oxidation Event demonstrates 'co-evolution' – an important component in the way we can "think like a planet." The Earth and life are closely connected, or "coupled." (Frank emphasized that by "Earth" he means the Earth's surface, from the lithosphere to the atmosphere.) Through coupled systems, the biosphere and physical processes on Earth impact each other in incredibly complex ways. While some argue that the amount of $CO_2$ that humans put into the atmosphere cannot possibly have an effect on global climate, the Great Oxidation Event proves that life can alter the atmosphere, and by extension other systems on Earth, a great deal.

### The Heroes of the Gaia Hypothesis

Several scientists have been instrumental in bringing about the idea of coupled systems and the co-evolution of life and Earth, which had been known as the Gaia Hypothesis. The Gaia Hypothesis states that life as a whole is regulating the conditions of the planet to keep those conditions favorable to life. Frank compared the connection between life and Earth to what humans would experience if they were in a desert—they would start to sweat because evaporation cools the body and helps keep internal temperatures at 96 degrees Fahrenheit.

Likewise, life has feedbacks to physical changes that keep the planet stable and suitable to life, similar to a thermostat.

The idea of the planet as a thermostat was conceptualized by James Lovelock while he was working for NASA in 1961. When he was asked to look for single-celled life on Mars Lovelock realized he had no way of knowing what microbes would look like on other planets – they probably would not look like Earth microbes. But, he hypothesized, by studying a planet's atmosphere, scientists might be able to tell whether or not the planet had single-celled life. After all, the presence of life could be identified on Earth from great distances by the presence of oxygen in the atmosphere, which was created by the single-celled blue-green algae. While Lovelock was comparing Mars' oxygen-deprived atmosphere to Earth's, it occurred to him that Earth's life might be altering the planet's atmospheric composition to be more favorable to the dominant lifeforms. Carl Sagan, Lovelock's former colleague, later introduced Lovelock to Lynn Margulis, a biologist studying how microbes can change atmospherice content. Together, Lovelock and Margulis developed the Gaia Hypothesis.

## The Gaia Controversy

The Gaia Hypothesis, while important to our current understanding of life on Earth, was initially a controversial concept. This was in part due to how some members of the public interpreted and embraced the Gaia Hypothesis; Frank highlighted people like Oberon and Morning Glory Zell-Ravenheart, self-proclaimed Gaian priests and priestesses, who promoted ideas like the "Earth Mother." Scientists pushed back on the teleological implications behind these ideas — that the Earth had some kind of consciousness, knew how to regulate itself, and intentionally "wanted" to be comfortable for life.

Since then the Gaia Hypothesis has been more broadly absorbed into what is now called 'Earth Systems science,' which eschews the teleological components of Gaia ideas and still recognizes the biosphere as a primary player in the planet's physical history, intertwined with other planetary phenomena in 'coupled systems.' Coupled systems – the cryosphere, lithosphere, atmosphere, hydrosphere, and biosphere – cannot be separated or pulled apart. All are connected and affect each other in different and surprising ways. All together they drive planetary evolution.

## The Anthropocene

Within the context of the Gaia Hypothesis and Earth Systems science emerged the idea of the Anthropocene. The Anthropocene posits that the Earth is entering a human-dominated geological epoch, and humans are leaving enough deposits to be detectable in geological layers distinct from the Holocene. While there are on-going arguments over whether the Anthropocene has officially started and if human presence can already be detected on the planet's geological layers, there is general consensus that human activity is a driving force on the planet.

The Anthropocene suggests that the planet is going to change, with a different climate and different atmospheric circulation patterns. Entry into the Anthropocene raises new questions about the nature of human activity within Earth's coupled systems, how life impacts Earth's physical processes, and how we can build a sustainable civilization. Problems for sustaining civilization in the Anthropocene are further compounded by the increasing complexity of human networks. Right now, Frank commented, civilization's social networks are sitting on top of economic networks, that sit on top of energy distribution networks, which are connected to transportation networks. All of these networks interact with each other in complicated ways, and each individual network has its own separate vulnerabilities. As networks become more interconnected and more complex, they are more easily affected by each other's vulnerabilities. One problem that would normally affect only one network could propagate through an entire system of tightly interconnected networks.

Frank contended that a serious worry is that it would not take much to damage our civilization – not necessarily to the point of extinction, but just to the point of serious degradation. The Anthropocene is a threat to not only the planet's tightly coupled physical and biological systems, but to tightly coupled social and economic networks as well. How humans can become a sustainable driving force on Earth is a high-stakes challenge, and this is where the astrobiological perspective can be helpful.

## Astrobiology

The astrobiological perspective can both shift the conversation surrounding sustainability and ask compelling questions about life in the universe.

While people have been thinking about other planets for millennia, the field of astrobiology has only gained prominence in the last 30 or 40 years, in particular because of three scientific revolutions:

1) The discovery of exo-planets
2) The *in situ* exploration of cosmic bodies
3) The exploration of Earth's own past

### 1) The Discovery of Exo-Planets

Three thousand years ago, Greek thinkers had debated the existence of other planets around other stars. That question, what they call the plurality of worlds, has been with humanity as long as humanity has existed.

Now scientists know that every star in the sky has planets orbiting around it. Scientists also know that about one in five stars has a planet located at a distance from their star where liquid water could exist on its surface. With liquid water a planet could have rain, oceans, rivers, and lakes, and possibly life. Discovering the vast number of exo-planets in the universe completely changed how people think about the possibility of life on other planets.

### 2) Exploration In Situ

The second revolution is within solar system studies and recent developments in the *in situ* monitoring of other planets and objects within the solar system.

In 1961 scientist Jack James was tasked with designing a probe that could visit Venus. His project was highly successful and became a point of national pride and a testament to human achievement. Ever since then Americans, Russians, Europeans, and other scientists from around the world have been sending probes into the solar system to study and observe various galactic objects. Humans have sent probes to every kind of object in the solar system — asteroids, comets, dwarf planets, moons, and every planet. Some exploratory missions include only satellite observations, but others have sent devices that could land on the object's surface.

*In situ* observations of other planets have revealed much about climate change as a generic planetary feature and informed models of climate on other planets that work very well. These models have been used over decades with multiple planets and moons to study climates and climate change. Scientists discovered the greenhouse effect by observing Venus, and studies of Martian dust storms ignited the debates on nuclear winter in the 1980s. Studies on Mars also show that Mars, now dry and barren, had torrents of water on its surface 3.5 billion years ago. Martian climate models are an example of thinking like a planet — scientists know the rules of climate deeply, for all planets, and the understanding of general climate principles is applicable to any planet that has an atmosphere.

These observations are further proof that habitability — the possibility for a planet to be habitable — and sustainability, is a moving target. Sustainability is a subset of planetary habitability. We want Earth to be sustainable, and habitable, for a particular kind of life — ours — and a particular kind of civilization — ours — so we have learned from studying other plants a broad way of thinking about our own existence.

### 3) Understand Earth's Past

The third revolution is an expanded understanding of Earth's history, going back 4.5 billion years — Earth's multiple physical states over its long existence.

All three of these revolutions, Frank explained, have changed our understanding of planets, and they have allowed scientists to begin thinking about the Anthropocene in a broader context.

### What does Astrobiology Change?

Is sustainability even possible? Has civilization anywhere in the universe across the 13.7 billion years of cosmic history ever achieved sustainability? After all, if sustainability has never occurred in any civilization at any place and time, humanity is doomed. Astrobiology can help us frame and understand the options, and odds, for achieving a planet that is sustainable for human civilization.

Frank framed the concept of other-worldly intelligent life, what he calls "exo-civilizations," as a generic planetary phenomenon that sees a species becoming intelligent, learning how to harvest energy, and building an information resource processing system called a civilization. Putting aside sociological musings and focusing on physics and chemistry, scientists can begin to consider the likelihood of the existence of exo-civilizations and the additional likelihood that those exo-civilizations learned to live sustainably on their respective planets.

### Optimists Versus Pessimists

If it is the case that no other planet in the history of the universe has ever hosted a civilization, the case for astrobiological thinking falls apart. However, Frank and others have developed mathematical formulas that argue that humans are not the first and only civilization.

The history in thinking about exo-civilizations has been a battle between optimists, who believe there have been many other instances of civilization in the universe, and pessimists, who believe humanity is completely unique. Scientists conceptualize this problem through the Drake Equation, developed in 1961 by Dr. Frank Drake. The Drake Equation is a probabilistic argument that posits that the number of civilizations in our galaxy right now that can be interacted with is equal to the product of several different factors (Table 1):

- Rate of star formation
- The fraction of planets that exist around each star
- The number of planets in the right place for life to form
- The fraction of those planets where life actually does form
- The fraction of those planets where intelligence is created
- The fraction of those intelligences that go on to create technology
- The average lifetime of those species.

$$N = R^{*} \cdot f_p \cdot n_e \cdot f_\ell \cdot f_i \cdot f_c \cdot L$$

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| **N: Number of communicating civilizations in our galaxy** | **$R^*$: The rate of star formation suitable for the development of intelligent life** | **$f_p$: The fraction of those stars with planetary systems** | **$n_e$: The number of planets, per solar system, with an environment suitable for life** |
| **$f_l$: The fraction of suitable planets on which life actually appears** | **$f_i$: The fraction of life bearing planets on which intelligent life emerges** | **$f_c$: The fraction of civilizations that develop a technology that releases detectable signs on their existence into space** | **L: The length of time such civilizations release detectable signals into space** |

*Table 1: The Drake Equation and factor definitions*

## The Pessimism Line

Frank and colleague Woody Sullivan recently published a paper inspired by the Drake Equation, estimating the likelihood that humans are the first and only civilization in the universe's history. They developed what they called the "pessimism line." The previously mentioned revolutions in astrobiology created an enormous amount of data that was used as inputs for the pessimism line.

Through the pessimism line equation, Frank argued that the odds that humans are the first and only civilization are $10^{-22}$, or one in ten billion trillion. In other words, the probability for a given planet in the right place relative to its star to cultivate civilized life would have to be worse than one in ten billion trillion in order for other civilizations never to have existed at any time. As long as nature's processes can beat those odds, Frank contended, then there have been other civilizations in cosmic history. This is not to say those civilizations currently exist, because it is unknown how long those civilizations might have lasted.

Compared to famous historical pessimists, Frank and Sullivan's equation shows remarkably good odds. Evolutionary biologist Ernst Mayr argued that the pessimism line would be at $10^{-15}$, while theoretical physicist Brandon Carter said it would be $10^{-20}$, and is quoted as saying "[this value] is more than sufficient to ensure that our stage of development is unique in the visible universe." However, Frank noted, if Carter were correct, according to the Frank and Sullivan pessimism line there would still have been 100 other civilizations in history. Frank further added that because the pessimism line is so low, there would have to be a strong bias against civilization formation for it not to have happened thousands, millions, or even trillions of times.

## All Civilizations Have Driven Their Own Anthropocenes

Accepting that there have been many instances of civilization throughout cosmic history leads to questions about what happened to those civilizations. Frank's argument is that all civilizations have driven their own Anthropocenes.

The Anthropocene, Frank contended, is impossible to escape as civilizations use their planet's resources and alter the planet's physical state. The question should therefore not be, "are we driving climate change?" but rather "of course we're driving climate change! What would you expect?" Civilizations by definition harvest energy from the planet to build, organize, and move things from one place to another. The second law of thermodynamics says that energy cannot be used without creating waste. What this means on a planetary scale is that there is always pushback to any energy extracting endeavor. In fact, a recent study came out showing that two degrees of climate warming would occur even if the entire Earth were powered by wind energy.

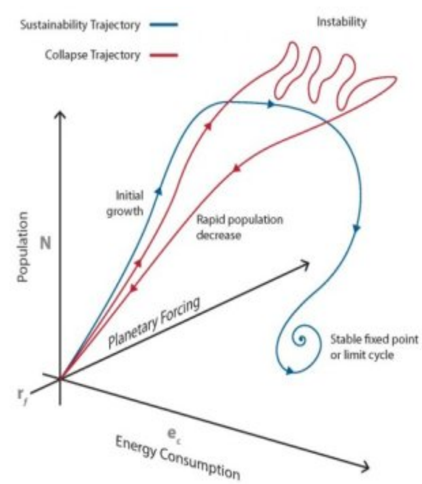


Figure 1. *Model of civilization sustainable and collapse trajectories. Frank, Adam, and Woodruff Sullivan. "Sustainability and the astrobiological perspective: framing human futures in a planetary*

These observations can guide us to the conclusion that Anthropocenes have happened before. Because scientists know generally how planets respond to waste, models can be created of the feedback between any civilization and its planet. Frank presented a model of what such a civilization could look like (Figure 1).

Figure 1 essentially shows that there are different kinds of trajectories for any kind of civilization. Some trajectories will lead to collapse, where a civilization grows, gets technology, has higher birth rates, and then pushes the planet too hard, until the planet cannot support the civilization anymore. The sustainability trajectory, on the other hand, similarly shows population numbers growing along with a general pushback on the planet, however this civilization would recognize the adverse consequences of its overexploitation, and shift over to a new energy modality. The sustainability trajectory would ultimately lead to a stable population, a stable amount of available energy, and an overall sustainable form of civilization.

By taking this broader perspective, Frank argued, we can begin to understand that the current Anthropocene is a generic event of the universe. The next questions, then, are which trajectory is humanity on? Which trajectory is average across all cosmic civilizations? Right now, human population is increasing considerably, along with energy use per capita – where does it go from here?

While there is no data on any exo-civilization, planetary physics and chemistry are well understood, and the astrobiological perspective allows scientists to theoretically model the average lifetime of a civilization like Earth's. While scientists have yet to make this estimate, we can observe that an average civilization lifetime of 200 years would not bode well for humanity, as humans would have to start making immediate changes to become more sustainable and avoid collapse. If the average civilization lifetime is two million years, however, there would be a lot of room to make mistakes and still recover.

## Conclusion

And how does this perspective give us a new way of telling the story of the human race?

Frank proposed that the story of climate change and the Anthropocene should be told as a story of humans as an energy harvesting species. Just as planets have given rise to dinosaurs and blue-green algae, planets have also fostered energy harvesting civilizations, and from that perspective, humans are not that unique. Civilizations are just one of many different experiments a planet can run on its surface, and there have likely been many civilizations throughout the universe, as the pessimism line shows. Frank argued that humans are a part of the biosphere, not above the biosphere. New York City, then, is as much a part of nature as a bird's nest. Can humans learn to cooperate with the planet and sustain their civilization, or will the Anthropocene see the Earth moving on to a different experiment?

The crux of Frank's argument is that Anthropocenes have happened before and are a natural part of the formation of civilizations. Climate change is not humanity's fault — it is simply what any civilization would naturally do. Frank cautioned that this does not mean humans are not causing climate change, but rather civilizations did not set about harvesting energy and burning coal and oil with the intention of changing the climate. The Anthropocene is not a story of human greed, human unworthiness, or humans as a plague upon the planet. It is simply a story about the natural course of events under civilizations. It is a story about a planet and its experiments.

Climate change is inevitable — any civilization will cause climate change, but whether or not we can build a sustainable civilization is an open question. A planetary view of the Anthropocene problem allows for hope and optimism in staving off a collapse of Earth's civilization. The Anthropocene, Frank contended, is not a story with villains, it's just a story about winners and losers. We want to make sure that we are on the winning side, and can join the community of cosmic civilizations that have also managed to create a sustainable world. After all, Frank concluded, if another civilization has made it, why can't we?