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Astrobiology: Reach for the Stars

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Abstract

Astrobiology is the study of life beyond Earth. It is a relatively new field—it was established just before NASA's debut in 1958—and it often receives criticism for its whimsical nature. Interest in astrobiology has escalated since the turn of the millennium, bringing questions of its worth to the forefront of modern science. Despite these criticisms, astrobiology has implications for both human welfare and scientific thought. The purpose of this paper is to follow the trajectory reinvigorated with NASA's return to Mars in 2012 and to delve into the curiosities that make up the unique, interdisciplinary field of astrobiology. The paper will progress through several stages: It will establish the background surrounding astrobiology; the value of research as a whole; motivating factors and associated nuances inspiring astrobiology's celestial focus; a discussion of the habitability of other planets; potential ethical implications of searching for life beyond Earth; and final thoughts regarding the matter.

Astrobiology:

Reach for the Stars

Introduction

Astrobiology has received criticism over the years for its celestial, seemingly whimsical focus. Mentions of astrobiology began before NASA was established in 1958. Originally called exobiology, the field was pioneered by Joshua Lederberg, a molecular biologist, and is comprised of human and robotic space programs joined with an offshoot of biology. This pairing came to be thanks to two historic advances: the first, discoveries about how life organizes itself, and the second, successes in space travel. According to Lederberg, “Exobiology is no more fantastic than the realization of space travel itself, and we have a grave responsibility to explore its implications for science and for human welfare with our best scientific insights and knowledge” (Kaufman, 2017). He wrote that statement almost a decade before Neil Armstrong stepped foot on the moon.

Astrobiology has been treated with varying levels of seriousness and enthusiasm in the years since its fruition. Excitement for finding extraterrestrial life reached an all-time high in 1976 when the *Viking* landers reached Mars. Many had predicted that there would be life on Mars, possibly even floating creatures. Despite lots of good data being gathered, the mission was a failure in regard to its hoped outcome when no evidence of such life—or any life at all, for that matter—was produced. The data from the *Viking* landers was particularly bleak; images showed a barren Martian landscape, and no signs of life were detected. The study of Mars fell into a lull of disinterest. Missions to Mars resumed in the 1990s and 2000s, but they didn’t involve life detection. Interest in astrobiological endeavors never quite disappeared, however, and returned in to a greater intensity with the landing of Curiosity in 2012, a rover sent to find out if Mars is, or used to be, suitable for life. Although the Curiosity mission didn’t explicitly involve life detection either, it revisited astrobiological questions concerning Mars that were left unsated from the 1976 mission.

This paper will discuss the value of research, regardless of its immediate applicability to the world, and how that is relatable to the field of astrobiology. It will also touch on the motivational factors causing outward exploration, particularly global warming, with solutions such as space-based solar power and solar geoengineering; musings on the habitability of both Earth and other planets, including overviews of planetary boundaries and capillary electrophoresis; studies of Enceladus and Europa, two planetary moons in Earth's solar system; and SpaceX endeavors. Finally, the paper will end on the ethical and foundational implications of altering human identity, as well as the associated implications for future research. This wide variety of topic areas is important because, while the central goal of astrobiology is to discover evidence of past or present life beyond Earth, the field has had numerous implications for present-day Earth and the future of the human population. The purpose of this paper is to follow the trajectory reinvigorated with the Curiosity mission and to delve into the curiosities that make up the unique, interdisciplinary field of astrobiology despite criticisms of whimsicality. As Lederberg put it, astrobiology has implications for both science and human welfare.

Research Value

Phage Research

Research advances are incredibly valuable in all scientific fields. An interdisciplinary field by nature, astrobiology is in a position to take advantage of advances in many different fields and synthesize them to further its own understanding of the universe and its question of life beyond Earth. This aids in clarifying the value of a field accused of impracticality.

A strong case in point would be the advances made between the *Viking* landers and the Curiosity rover (Kaufman, 2017). In the 36 years between the two astrobiology-focused missions to Mars, researchers discovered the existence of extremophiles on Earth, communities of microbes that survive in environments previously thought to be uninhabitable. Examples of such hostile environments include the total dark or bitter cold, highly acidic and salty water, highly radioactive areas, and placement miles under the ground or in the atmosphere high above ground. Researchers also discovered that all the chemicals needed for life—six elements, including carbon, hydrogen, nitrogen, oxygen, phosphorus, and sulfur, which are commonly referred to as CHNOPS—are present in space. Vessels such as meteorites and comets are depositing these crucial elements on planets, moons, and asteroids everywhere. These groundbreaking understandings, which involved more knowledge about life on Earth and therefore a more informed expectation for the possibility of life beyond Earth, are what defined the perceptive differences of outcome between the *Viking* and Curiosity missions.

In some regards, astrobiology is a field bursting with unrecognized—and unrealized—potential. Because there isn't concrete confirmation of life beyond Earth, the field may be discounted as simply a fascination or hobby. However, the field has already had an impact on science as it is known today. This is evidenced by extremophile research on Earth and pursuit of the presence of CHNOPS in outer space. While extremophile research might seemingly have a more direct effect on Earth and humanity, there is still potential for CHNOPS research to expand human limits. Take bacteriophage research as a comparative example.

Bacteriophage research, or simply phage research for short, has beginnings from over 100 years ago in the early 20^{th} century. A phage is a virus that infects bacteria. When phages were first discovered, the English physician Frederick Twort observed zones of dead bacteria on his experimental culture plates. He was unable to determine what was causing the dead bacteria with the resources available to him, so he dismissed the matter. Two years later, a microbiologist by the name of Felix d'Herelle independently made similar observations which were eventually validated. d'Herelle gave bacteriophages their name.

Keeping with its slow discovery, bacteriophage research was merited with very little significance. This mentality has changed in the last 25 years, however, with the realization that phages are the most abundant organisms on Earth (Keen, 2015). In fact, it's been discovered that phages "play profound roles in a variety of biological and environmental processes" (Keen, 2015). Phages are estimated to kill up to 40% of the ocean's bacteria each day, which has repercussions for carbon ratios, oxygen production, and possibly even global climate and weather patterns. Phages also drive bacterial evolution through horizontal gene transfer. With that, humans' understanding of phages is remarkably slim: There are fewer than 1,500 complete phage genomes documented as of 2014. Most of them haven't been tested, but it is estimated that there are tens of millions of phage species in natural environments (Keen, 2015). Perhaps most applicable to the general population, phage research has become involved with the formation of antibiotic alternative techniques called phage therapy. While still in its early stages, phage therapy has close ties with human health and has potential to be widely used in medicine and agriculture to eliminate drug-resistant and long-term bacterial infections.

Astrobiology hasn't been around as long as phage research— astrobiology has only existed for about 60 years, and it took phage research about 75 years to gain momentum—but the field has experienced a similar surge in interest in recent years due to the research advances with extremophiles, CHNOPS, and more. Similarly to phage genome recording and testing, humans have yet to test a majority of the exoplanets deemed to have potential for life, more of which are being identified at an overwhelming rate. Astrobiology is partly geared by the potential for humans to become an interplanetary species, whether or not it is necessitated by factors present on Earth or human desire. While phage research, a sect initially deemed unimportant, has transformed biology into a modern science "capable of studying the mysteries of life in unprecedented detail" (Keen, 2015), astrobiology is poised at the cusp of discovery to dive into that very endeavor: to study the mystery of life. Phages have had "an immense and unforeseen impact on [humans'] understanding of the wider biological world" (Salmond & Fineran, 2015); as such, phage research is the epitome of the importance of any research at all, whether it seems to have a particular use—or is deemed a fascination or hobby—at the time or not.

Alchemy

Alchemy, an early form of chemistry and speculative philosophy from the 16th and 17th centuries, is also comparable to astrobiology. Unlike phage research, the pseudoscience was a failure; its pursuits of the mythical Philosopher's Stone—a substance that would have the power to turn any metal into gold and produce the Elixir of Life—were misguided by an incomplete understanding of chemistry and physics. For context, alchemy operated hundreds of years before the periodic table was invented, and even Isaac Newton, the well-respected man who defined the laws of gravity, dealt heavily with the realm of alchemy and devoted a considerable amount of time to the subject (Matson, 2014). Whereas phage research was simply slow to establish momentum in the scientific community, alchemy was completely discredited.

Despite the discontinuation of alchemy, the field still affects modern science. Its legacy lives on in its experimentalism: "[alchemists] paved the way for modern chemistry and medicine through the development of new experimental techniques" (Matson, 2014). Alchemy, through subsequent advancements creditable to alchemical techniques, has benefited scientific and human welfare through its contributions to modern chemistry and medical science.

While the alchemists' diligent experimental processes were integrated into scientific thought relatively early, it took centuries for alchemy's studies to be realized in the scientific community. Recent scientific developments have revealed that alchemists—who are "often dismissed as pseudoscientific charlatans" (Matson, 2014)—were not entirely wrong about the possibility of turning any metal into gold. With the atomic age in the 20th century came the transmutation of elements (Matson, 2014). In 1980, an experiment was conducted at the Lawrence Berkeley National Laboratory in California that turned bismuth into gold; the process, allegedly, would be "'relatively straightforward to convert lead … or mercury into gold" (Matson, 2014), as well. This realization of the alchemists' dream, despite significant cost barriers and successful production of only trace amounts of gold, illustrates the reality that anything can be possible given time—even centuries of time.

Alchemy and astrobiology are comparable. Both involve the secret to life: alchemy through its Philosopher's Stone and astrobiology through its scientific knowledge and missions. Both have had an impact on experimental research: alchemy established experimental techniques leading to modern chemistry and medicine, and astrobiology has led to extremophile research, among other findings. Both can also be considered failures: alchemy as a discredited science and astrobiology as a whimsical dream.

As seen with alchemy, even the most misguided science affects the field as a whole. Alchemy was perceived to be a discredited field, but it still holds scientific value and has served as an impetus for scientific progress. While some may believe that astrobiology is misguided or unwarranted, the combined examples of phage research and alchemy—both of which contributed insight to the scientific community that took time to come to fruition—show the value of research, even if it initially seems whimsical and far-fetched. Time and dedication will be valuable factors in the evolution of astrobiology. Regardless of the potential outcome of astrobiological research, there is still much to be gained from pursuing the search for life beyond Earth.

Motivating Factors

While astrobiology carries its own intrinsic value by its aim to uncover the mysteries of life, there are concrete, motivating factors that add to the reasons one may want to invest in astrobiology. These factors involve reasons that would make Earth no longer habitable for human life.

Global Warming

One such factor is global warming. Global warming is, quite literally, the heating of the globe. Land and oceans are warmer than ever before—surface temperatures have risen 1.71 degrees Fahrenheit between 1880 and 2016—and temperatures continue to rise without a perceived upper bound (Pappas, 2017). The culprit seems to be the industrialization of human society: Beginning with the Industrial Revolution, humans have been contributing more greenhouse gases, including water vapor, carbon dioxide, methane, ozone, and nitrous oxide, to the atmosphere than ever before, effectively—albeit unintentionally—altering the chemical balance of the atmosphere. The atmospheric ratio of carbon dioxide alone, the main greenhouse gas, has nearly doubled since pre-Industrial Revolution times (Pappas, 2017).

If the Earth continues to warm due to the Greenhouse Effect—meaning that the carbon dioxide in the atmosphere absorbs infrared radiation, otherwise translated as heat, therefore causing the global mean temperature to rise—then it is in serious danger of the Runaway Greenhouse Effect. The Runaway Greenhouse Effect occurs when a planet absorbs more energy from the sun than it can radiate back into space. Venus is a prime example of the results of the Runaway Greenhouse Effect. Venus, often referred to as Earth's "sister planet," is near Earth in the solar system and maintains a similar size, density, and composition to Earth, but the two planets' atmospheres vary drastically. Venus' atmosphere is primarily composed of carbon dioxide, trapping heat and leaving the planet a steaming 860 degrees Fahrenheit or more. The planet is unhospitable.

There is controversy concerning the likelihood of the Earth reaching this stage in the foreseeable future. According to Colin Goldblatt, extremely high levels of carbon dioxide and water vapor in the atmosphere would cause Earth to broil like Venus (Billings, 2013); James Kasting believes that reaching the level of a Runaway Greenhouse Effect is outside the reach of humanity due to cooling effects of certain clouds (Billings, 2013). Despite this controversy, the effect on Earth would be devastating: The oceans would boil away and the carbon dioxide in the rocks would sublimate, further adding to the buildup of both elements in the atmosphere. Since this would ultimately leave the planet unsuitable for human life, humans would need to search elsewhere for a place to live. That's where the functionality of astrobiology and its search for habitable planets comes in.

Habitability of Earth

As of right now, the Earth is ideal for human needs. It has water, all the building blocks of life, and anything else one can imagine needing. To help describe the environmental limits of human life, one may consider planetary boundaries. Two of the planetary boundaries, climate change and biosphere integrity, are core to human life in relation to the Earth system and have the potential to individually drive the Earth system into a new state. As discussed with global warming, human actions are threatening the climate, which is one of the two planetary boundaries capable of shifting the Earth into a different state. A trajectory away from the current Holocene epoch, such as global warming, could lead to a substantially altered state that is “likely to be less hospitable to the development of human societies” (Steffen et al., 2015). It could be a threat to the habitability of Earth and carries implications for global sustainability.

However, many scientists believe that, albeit in the very distant future, the Earth will eventually succumb to the Runaway Greenhouse Effect regardless of human interference. This belief is due to the Sun’s natural life cycle; it is, slowly but surely, destined to become a Red Giant. The Sun’s habitable zone is dynamic, meaning it, as it grows into the Red Giant phase, is broadening outward beyond the Earth, and eventually leaving the Earth behind in a crispy state like Venus; the Earth will be hot enough to evaporate the oceans and extinguish both complex multicellular life and simple life (Heller, 2015). According to Heller (2015), the Earth is only marginally habitable in its current state because the “Earth is well past its habitable prime, and the biosphere is fast-approaching its denouement.” This is yet another reference to the wearing of the Earth environment. Humans, still relatively young to the planet in the grand scheme of the Earth’s history, run the risk of going extinct from self-inflicted reasons; most notably, however, the well-being of the human race is threatened by factors out of human control: the Sun’s next stage in its life cycle. While the Sun isn’t supposed to fully manifest as a Red Giant star for approximately five billion years, it will have brightened enough to enact a Runaway Greenhouse Effect within 1.75 billion years. Within half a billion years, human life will be in peril due to the warming climate. Fortunately, this timescale is significantly larger than the current history of human life on Earth, so it is feasible to consider Earthly options to lighten the effects of greenhouse effects in the interim.

Global warming, the Runaway Greenhouse Effect, and the inevitable brightening of the Sun are all factors that might cause humans to look beyond Earth for life in the hopes that humans could become an interplanetary species. If not, then the future of humanity's well-being is certain: It will cease to exist.

Solutions to Global Warming

Americans are well aware of the dangers of global warming. Studies show that 45% of Americans in 2017 "worry a great deal" about global warming, as opposed to 37% in 2016 (Saad, 2017). This is a three-decade high in the United States. To go even further, 68% of Americans believe global warming is caused by human activities, 62% believe the effects have already begun, and 42% think it will pose a serious threat in their lifetime (Saad, 2017). These numbers are reflective of a substantial concern over the state of the Earth from this human-imposed problem.

There are a couple of solar-dependent ideas for lessening the effects of global warming on Earth that relate to astrobiology. One such idea is solar geoengineering. Solar geoengineering is a proposed means of cooling the Earth via reflecting more sunlight back into space rather than allowing it to collect on Earth. To do this, reflective aerosol particles would need to be injected into the lower stratosphere. Studies show that solar geoengineering using stratospheric injection of aerosol particles would generally offset the climate effects of elevated greenhouse gas concentrations (Irvine, Kravitz, Lawrence, & Muri, 2016).

A second idea for lessening the effects of global warming is space-based solar power. On Earth, traditional solar power techniques are hampered by night, cloud cover, atmosphere, and seasonality. However, in space, the sun is always shining; about 30% of all solar radiation never makes it to the ground (Wood, 2014). Theoretically, space-based solar panels would harness this energy and transmit it down to Earth, effectively increasing the amount of clean energy available to areas around the world and reducing the use of greenhouse-gas emitting techniques.

These two solar solutions are meant to alleviate concern over global warming, one of the primary forces driving the relevance of astrobiological study. While they are connected to a motivating reason to study astrobiology, they might not seem to immediately connect with the goals of astrobiology: the study of life beyond Earth and its impact on science and human welfare. Both options, however, use the Earth as a model specimen. In order to make either option successful, scientists must study solar effects and atmospheric composition on the ground. Both options also involve interacting with space: Neither option is restricted to ground endeavors. Solar geoengineering works with the atmosphere in relation to the Sun and space-based solar panels are literally stationed in space. Studying Earth and interacting with space are two integral pieces of pursuing astrobiology; Earth conditions and space conditions are intertwined and together give cause to make technological, scientific advancements. These two options are also aimed at improving human welfare by decreasing the effects of global warming, another area of impact of astrobiology. Overall, astrobiology is present in many related fields and issues.

Habitability of Other Planets

Other planets, complete with attractive life-giving qualities, are continuously being discovered. While finding Earth-like planets is still just barely out of reach of current technical capabilities, larger "super-Earths" are easier to detect. These super-Earths orbit stars smaller than the Sun and may also be the most common type of planet. Super-Earths, as well as massive moons orbiting gas-giant planets, may offer better conditions for life than Earth itself (Heller, 2015).

Europa and Enceladus

Scientific study of Earth has revealed three main ingredients necessary for life: liquid water, a source of energy for metabolism, and the six chemical building blocks (CHNOPS). While super-Earths fall outside Earth's home solar system, there are planets with potential for life within the constraints of Mercury to Neptune. The Cassini mission, a spacecraft equipped with "remote and microwave remote sensing instruments, and fields and particles instruments […] all designed to record significant data and take a variety of close-up measurements," tasked with orbiting the Saturnian system from 2004-2017, revealed that Saturn's moon, Enceladus, holds potential for life (Dunford, Piazza, & Thompson, 2017). Jupiter's moon, Europa, has also been discovered to hold potential for life.

Jupiter's moon, Europa, and Saturn's moon, Enceladus, are both icy moons with oceans. These "ocean worlds" have raised great excitement in recent years because they have some of the ingredients needed for a habitable environment; this is the closest scientists have come to identifying places this ideal for habitation, although they may not necessarily be suitable for human life. According to Thomas Zurbuchen, the associate administrator for NASA's Science Mission Directorate, "These results demonstrate the interconnected nature of NASA's science missions that are getting us closer to answering whether we are indeed alone or not" (Northon, 2017).

Europa and Enceladus both have water, which is a huge step toward favorability for life, frozen or not. The two also have internal heat sources; Europa's internal energy seems to come from friction generated by the gravitational pull from Jupiter and the shape of Europa's orbit, while Enceladus' internal energy source is similarly generated by its orbit around Saturn. The middle of these two moons is not frozen, but the exterior is. That means that any life on the planets likely lives under the icy exteriors away from the energy of the Sun. To determine if it would be possible to have life without the Sun, scientists sent robots to the bottom of the ocean beneath the Arctic ice sheets on Earth. There, they found microbial life that used sulfur, hydrogen, and methane as chemical sources of energy instead of using energy from the Sun (Twinch, 2011). Furthermore, Enceladus features a portion dubbed the "Tiger Stripes" which are similar to fault lines on Earth. Jets of liquid water shoot out of the Tiger Stripes and promptly freeze upon contacting the cold exterior atmosphere. The Cassini space probe was able to sample the jets and registered traces of the chemical building blocks of life.

Detecting signatures of life itself was beyond the capabilities of Cassini, but the mere presence of the building blocks of life raises the potential for life on both Europa and Enceladus. According to Hunter Waite, the lead author of the Cassini study, "Although we can't detect life, we've found that there's a food source there for it. It would be like a candy store for microbes" (Northon, 2017). Again, while human life isn't necessarily feasible, microbial life very well may be, which is encouraging in the scheme of astrobiological goals to find life beyond Earth.

While these two moons don't necessarily provide options for human habitation, they are real life examples of searches for life beyond Earth and provide hope for more life beyond the Earth's solar system. The advances made in scientific understandings are helpful for considering the future of human well-being.

New Test for Life

Scientists have recently adapted a laboratory tool that may revolutionize the search for signs of life. The method is called capillary electrophoresis, and while it has been around since the 1980s, it has recently been modified to apply to the detection of extraterrestrial life on an ocean world like Enceladus or Europa. The test is made of a liquid-based technique that is over 10,000 times more sensitive than methods used by spacecraft like NASA's Mars Curiosity rover (Good, 2017). The process is relatively simple. It combines a liquid sample with a liquid reagent, followed by a chemical analysis involving the use of a laser—technically called laser-induced fluorescence detection—to observe specific molecules at different speeds. This technique is reliable even with very salty samples, such as one might receive from an ocean world. Jessica Creamer, a postdoctoral scholar at NASA's Jet Propulsion Laboratory in California, said, "'Our method improves on previous attempts by increasing the number of amino acids that can be detected in a single run … Additionally, it allows us to detect these amino acids at very low concentrations'" (Good, 2017). This innovative method is promising for the future of astrobiology. The adaptation of capillary electrophoresis shows that tangible options are being developed to push astrobiological pursuits forward, continually making the field more concrete and less whimsical and theoretical. The possibilities are closer to being within human reach.

SpaceX

Elon Musk, an affluent businessman, engineer, and inventor, is the founder of SpaceX and has set his sights on Mars with the intent to make the planet artificially hospitable for humans. Musk believes there are two fundamental paths to humans' future: one in which humans stay on Earth forever and eventually encounter some sort of extinction event, or another in which humans become a space-bearing civilization and multi-planetary species (Musk, 2017). He could have set his sights on Enceladus or Europa, but they are much farther out in the solar system, making them more difficult to reach, whereas Mercury is far too close to the Sun and Venus is too damaged by the Runaway Greenhouse Effect; the Earth's moon is too small and resource-deficient, not to mention its nearly month-long "day." That leaves Mars as the only option within the Earth's solar system.

Musk (2017) is optimistic that humans can alter Mars to make it habitable. One modification would include compressing the atmosphere, allowing humans to grow plants on

Mars. As of right now, Musk is estimating the journey from Earth to Mars to take approximately 80 days, depending upon factors such as the planetary alignment when the mission is begun. Musk hopes to eventually lower this number to 30 with the aid of technological advancements. With thoughtful vehicle design, engine development—complete with no less than 42 engines—and rocket booster, the trip would be smooth, and the likelihood of complete power failure would be minimal. Ideally, there would also be a propellant plant on Mars so that ships could make return trips to Earth; in fact, the ships wouldn't be limited to just traveling between Earth and Mars. With the installation of propellant plants on other planets or moons, people could adventure across the breadth of the solar system, increasing interplanetary reach and therefore planetary study.

SpaceX's goal is to send its first cargo mission to Mars in 2022. Along with this mission, water resources will be confirmed, hazards identified, and initial power, mining, and life support infrastructure installed (*Making Life Interplanetary*). In 2024, a second mission will go out to build a propellant depot and prepare for crew flights. The ships used for these two missions will serve as the beginning of the new city on Mars. By 2060, and admittedly ambitiously, Musk hopes to have one million humans living in a self-sustaining, thriving civilization on Mars (Drake, 2016).

This plan requires large advancements in scientific knowledge and current technological capabilities. It offers an action plan for avoiding the impending "doomsday" of the Earth, however, which is relevant to questions of life both on Earth and beyond it. Rather than discovering life, the question is adjusted to focus on preserving life in light of motivational factors.

Ethical Implications

The study of life beyond Earth is closely interwoven with the study of Earth itself. As the only known life in the universe, humans have no choice but to use Earth as the primary model for what life should look like. That being said, astrobiology is an interdisciplinary field. It ties together scientific methodologies with thought processes in the humanities—in essence, astrobiology impacts human welfare and science. In addition to looking for life beyond Earth, it lends itself to self-serving goals to be multi-planetary and inevitably raises the philosophical question of “What is life?”

Life on Earth is physically obvious; the inner spirit of life on Earth is less so. The exploratory missions of life beyond Earth have led researchers to make discoveries about Earth itself, bringing to light more and more scientific theories for how life arose in the first place. Knowing that, it is worth returning to older fields of thought as well: The philosophical nature of the composition of humanity. Plato was a dualist; he believed that life is composed of a material body and an immaterial mind. To be more precise, the mind is the most important part—one can still exist without the body, for example. For Aristotle, the mind and body are embedded in one another; they are inseparable.

Whichever way one believes humans are structured, human identity is called into question when considering the intricacies of astrobiological pursuits. With Earth as the only model for life that humans have to study, there are certain expectations that are established: Extraterrestrial life will need the same or similar building blocks as humans and extraterrestrial life will look and act similarly to humans and other Earthly life forms. Upon the finding of extraterrestrial life, or a planet habitable to current human life, humans must decide how to proceed. Does one completely leave Earth, a planet dying from human alterations with an inevitable end by the Sun, and begin anew elsewhere? Would this path allow for animal and plant life to be saved as well, or would it be left behind to die? Would humans need to make genetic adjustments to survive on another world? Would this be a violation of who humans are, and would humans even be humans when not on Earth? How much of human identity is tied to the specific Earthly circumstances?

Early philosophers such as Plato and Aristotle had only the Earth on which to base their musings; without Earthly constraints, what is a human? How does the breaking of Earth-bound constraints change the implications on human welfare and scientific advancement? These questions are valuable to keep in mind as astrobiology continues to push the boundary between the Earth and the rest of the Solar System. Only time and further exploration will truly be able to uncover the answers.

Closing Thoughts

Astrobiology is a fairly recently developed field that is often disregarded or frowned upon for its celestial focus. *Why spend time and resources on space exploration when the Earth needs humans' time and resources?*, people say. *It's like passing the Las Vegas strip and turning down a dark side road instead.*

Studying astrobiology is valuable, however. It doesn't necessarily affect the immediate Earth, that is true, but it does fuel innovative thought and Earthly discoveries. As evidenced by phage research, small discoveries can lead to huge outcomes; on top of that, the huge outcomes might not come to fruition for years and years. Phage research took 75 or so years to gain traction, and what changed its importance was the recognition that phages are the most abundant organisms on Earth. Even now, only about 1,500 phage genomes have been documented when tens of millions of phage species are estimated to exist in natural environments. With only 60 years under its belt, astrobiology is just starting to gain serious attention from the scientific community and recognition from the public. The future is open for the field. Even alchemy, a "failed" field, provides research insights into modern science and, centuries later, has been partially redeemed through the bismuth-to-gold experiment conducted at the Lawrence Berkeley National Laboratory in California. As one may say, astrobiology is a gamble in its own right, but there is much more potential along this dark side road making new discoveries than at a poker table trading recycled resources.

Astrobiology impacts the future of both human welfare and science, which, while not always seemingly rooted in Earthly matters, is directly related to the status of the Earth. It is driven by motivational factors such as global warming and the aging of the Sun, both situations jeopardizing human habitation of the planet. Human welfare is at stake, but astrobiology opens the Earth to the possibilities Space has to offer, whether it is moving colonies of humans like with SpaceX, or learning more about the nature of life itself to apply to Earth. These possibilities require scientific advances that are, similarly to phage research or alchemy, revolutionizing science as a whole. One example of this is the revolutionary test for life, capillary electrophoresis. There are options that affect the Earth, such as solar geoengineering and space-based solar panels, that involve innovations concerning global warming, Earth, human welfare, and space; they are related to astrobiology in all of these regards. Astrobiology has the power to raise philosophical questions as well, lending further to its interdisciplinary nature. Questions such as these are central to the field of astrobiology. As shown time and time again, human welfare and science go hand-in-hand with astrobiology. Humans are reaching for the stars; where will it lead?

References

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This source discusses the feasibility of the Runaway Greenhouse Effect. This is applicable because it's valuable to compare Venus and the Earth in terms of the end result of extreme global warming.

Drake, N. (2016, September 27). *Elon Musk: A Million Humans Could Live on Mars By the 2060s.* Retrieved from https://news.nationalgeographic.com/2016/09/elon-musk-spacex-exploring-mars-planets-space-science/

Many facets of astrobiology are funded privately. One such privately-owned program is SpaceX, created and supported by Elon Musk. By the 2060s, they will have formed a self-sustaining colony of humans on Mars. The goal is not to move the entire human population to Mars; rather, it hopes to develop an interplanetary human presence.

Dunford, B., Piazza, E., & Thompson, J. R. (2017). *Spacecraft: Cassini Orbiter*. Retrieved from https://saturn.jpl.nasa.gov/mission/spacecraft/cassini-orbiter/

This source details the purpose of the Cassini mission, providing valuable information about the equipment it was outfitted with to further one's understanding of the Cassini spacecraft itself.

Saad, L. (2017, March 14). *Global Warming Concern at Three-Decade High in U.S.* Retrieved from http://news.gallup.com/poll/206030/global-warming-concern-three-decade-high.aspx

Global Warming is a relevant concern in the United States. American citizens are at a three-decade high regarding level of concern about the issue.

Good, A. (2017, January 26). *A New Test for Life on Other Planets*. Retrieved from https://www.nasa.gov/feature/jpl/a-new-test-for-life-on-other-planets

Technology is constantly developing and improving. This means that there is an increasing number of methods to use to test other planets for life. One new method is called capillary electrophoresis, and it is used to analyze amino acids using liquid garnered from samples obtained on ocean world missions.

Heller, R. (2015). Better than Earth. *Scientific American, 312(1),* 32-39. doi: 10.1038/scientificamerican0115-32

Earth is believed to become less life-friendly in the distant future. The Sun will reach the Red Giant phase of its life, ultimately expanding and scorching Earth; before that point, though, the Sun's luminosity will increase by 10% every billion years, changing the habitable zone surrounding it to grow beyond Earth's placement, leaving the Earth to overheat long before the Red Giant phase. This is important to consider for the field of astrobiology when exploring options to leave the Earth for a different planetary home.

Irvine, P. J., Kravitz, B., Lawrence, M. G., & Muri, H. (2016, July 14). An overview of the Earth system science of solar geoengineering. *WIRES Climate Change, 7(6),* 815-833. doi: 10.1002/wcc.423

Geoengineering is a potential option to artificially remove the threat of Global Warming. There are pros and cons to this theoretical method, as outlined in these sources.

Kaufman, M., (2017, November 22). *A History of Astrobiology*. Retrieved from https://astrobiology.nasa.gov/about/history-of-astrobiology/

This source considers the roots of astrobiology, originally called exobiology. It traces the origins of the field back to before NASA was officially established. The main proponent of the field was Joshua Lederberg, a molecular biologist turned exobiologist. Today, the field is flourishing.

Keen, E. C. (2015). A century of phage research: Bacteriophages and the shaping of modern biology. BioEssays : News and Reviews in Molecular, Cellular and Developmental Biology, 37(1), 6–9. http://doi.org/10.1002/bies.201400152

This source outlines the history of bacteriophage research, which is comparable to the field of astrobiology through recognition of the importance of technological advancement and small discoveries that lead to life-changing outcomes.

Making Life Interplanetary. Retrieved from http://www.spacex.com/mars

SpaceX, a private program funded by Elon Musk, is aimed at increasing human capabilities in space. The ultimate goal is to form a self-sustaining colony of humans on Mars, which would effectively create an interplanetary human presence.

Matson, J. (2014, January 31). *Fact or Fiction?: Lead Can Be Turned into Gold*. Retrieved from https://www.scientificamerican.com/article/fact-or-fiction-lead-can-be-turned-into-gold/

This article discusses the historical field of alchemy and how it connects with modern scientific endeavors. It shows that alchemy, although it was a failed science, still affects the current methods and understandings of science.

Musk, E. (2017, June 1). Making Humans a Multi-Planetary Species. *New Space*, 5(2): 46-61. doi: https://doi.org/10.1089/space.2017.29009.emu

This paper is a summary of Elon Musk's presentation at the 67th International Astronautical Congress in Guadalajara, Mexico, September 26–30, 2016. In February 2017, SpaceX announced it will launch a crewed mission beyond the moon for two private customers in late 2018. This is relevant for the application of astrobiology to human welfare.

Pappas, S. (2017, August 10). *What is Global Warming?* Retrieved from https://www.livescience.com/37003-global-warming.html

This article explains the concept of Global Warming using the most recent data and an overview of global efforts to slow the continued alteration of Earth's atmospheric gases.

Salmond, George P. C., & Fineran, Peter C. (2015). A century of the phage: past, present and future. *Nature Reviews Microbiology, 13*, 777-786. http://dx.doi.org/10.1038/nrmicro3564

Phage research began as a puzzle with no foreseeably practical solution; however, when investigated, it turned out to be one of the most immense discoveries for the understanding of the larger biological world. Success stories like the study of phages provide tantalizing support for the continued exploration of life beyond Earth in the hope that it would result in similar impact. It is impossible to know how useful the research will be before it has begun.

Steffen, W., Richardson, K., Rockstrom, J., Cornell, S. E., Fetzer, I., Bennet, E. M., … Sorlin, S. (2015, February 13). Planetary boundaries: Guiding human development on a changing planet. *Science, 347(6223)*. doi: 10.1126/science.1259855

Planetary boundaries are a concept designed to define the environmental limits of human life. This is useful in determining the status of the human population and subsequent courses of action. Three of the nine proposed boundaries have potential to alter the Earth's system; one of these boundaries is climate change.

Twinch, O. (Producer & Director). (2011). *Finding Life Beyond Earth* [Motion picture].

England: Darlow Smithson Productions.

This is a NOVA documentary discussing the pursuit of life beyond Earth. It includes valuable overviews of the ocean worlds of Europa and Enceladus.

Wood, D. (2014, March 6). *Space-Based Solar Power*. Retrieved from https://energy.gov/articles/space-based-solar-power

Space-based solar power is a direct descendant of the U.S. space program. This could potentially help solve issues from Global Warming, which can be attributed to a human-driven buildup of carbon dioxide, the most common greenhouse gas, among other atmospheric gases.