Chapter 11
Extraterrestrial Life in the Microbial Age

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Abstract Humankind has long been fascinated with the potential for alien civilizations within the Solar System and beyond (e.g., Crowe and Dowd 2013; Sullivan 2013). Despite the early optimism for life beyond Earth, humankind has yet to make *first contact* with an alien race. Historical discourse on the topic of alien life can provide some useful input into questions about how the people of Earth today might respond to contact with alien life (e.g., Dick 2013). However, this discourse is primarily devoted to understanding humankind's response to intelligent life. We must recognize that the search for life's potential beyond Earth has dramatically changed since the dawn of the Space Age. We now know that advanced civilizations are not common on planets in our solar system. The search for life on nearby worlds is now limited to non-intelligent, microbial life. Any chance we have of contacting intelligent life lies in receiving transmissions from distant worlds, and contact with such cultures would be greatly limited by the vast expanse of space. This chapter discusses the need for more attention paid to the possible social, economic, and legal ramifications that the discovery of non-intelligent, alien microbial life might bring.

11.1 Changing Views of Extraterrestrial

The underlying theme of research encompassed by the many disciplines of *astrobiology* is the search for and understanding of life's *potential* in the Universe. Today, research concerning life beyond planet Earth generally falls into three categories: the search for advanced civilizations beyond our solar system, the search for planets that are habitable for life as we know it, and the search for life's

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potential in our own solar system (through robotic missions, the study of biosignatures and chemicals in meteorites, etc.) (Race 2008). A fourth category of study that could have implications similar to the discovery of alien life is the search for 'weird life' or a 'shadow biosphere' on Earth itself (e.g., Wolfe-Simon, Davies and Anbar 2009; Davies et al. 2009; Benner et al. 2010). This forth possibility refers to life forms that operate using a different biology than the life we are familiar with [for instance, life that uses molecules other than deoxyribonucleic acid (DNA) to store information]. In some ways, a shadow biosphere on our planet could be considered 'alien' as it rests outside of our current definition of Earth biology.

Public discourse on the topic of alien life is often dominated by our search for intelligent civilizations; but much of the research being undertaken today is focused on more fundamental examples of living organisms—namely single-cellular life (e.g., Randolph et al. 1997). Intelligent life, and our ability to identify and interact with intelligent life, denotes a level of complexity that we are yet unable to define, much less identify on distant worlds.

Humankind has been posing questions about life beyond our planet ever since our eyes first turned toward the heavens (e.g., Crowe and Dowd 2013; Danielson 2013; Peters 1994; Bonting 2004). Today, as with generations past, many people have an inherent belief that space is populated with a wide array of alien life forms (e.g., Chequers et al. 1996; Oliveira 2008).[1] Science, however, has yet to lend any validity to such beliefs. Alongside ever-changing technologies, our perception of life's potential in the Solar System has undergone dramatic changes over the past centuries (e.g., Crowe and Dowd 2013).

When telescopes were first applied to the field of astronomy in the early 17th century, direct scientific observation of the stars became more accessible (King 1955). The theoretical, philosophical and spiritual interpretations of the heavens made way to include scientific observation, and the contributions of astronomers dramatically altered our understanding of the Solar System. The knowledge we held of life on our own planet Earth shaped the conclusions that early astronomers drew from their observations (e.g., Crowe and Dowd 2013). A few examples include Christiaan Huygens' theory that life on Earth signified a potential for unique inhabitants on the rest of the Solar System's planets that receive light from the Sun (Danielson 2013), and the Russian astronomer Gavriil Adrianovich Tikhov theories of astrobotany on Mars based on his study of Earthshine (Briot 2013).

As the Space Age dawned, our ability to observe the Earth's celestial neighbors in great detail improved—and our hopes of contacting neighboring civilizations on planets and moons of the Solar System came to an abrupt end. The Moon was a barren wasteland of ancient impact craters. Venus was a boiling cauldron of molten rock shrouded in a dense and poisonous atmosphere. And Mars, once the purported home of fantastical canals built by intelligent hands and canyons dense with vegetation, was a barren wasteland of desiccated sand and rock.

[1] It should be noted that documentation of this belief in life beyond the Earth is mostly limited to North America and Europe (e.g., Weigel and Coe 2013).

11.2 Microbiology: A New Understanding of Life's Potential

For obvious reasons, the science of microbiology does not predate the invention of the microscope. Early microscopes sprung from the same series of discoveries that led to the telescope. It was in 1664 that Englishman Robert Hooke coined the term *cell* in his seminal book *Micrographia* (Hooke 1664). In the Netherlands, during September of the same year, Antony van Leeuwenhoek observed bacteria in a drop of lake water, and dubbed the organisms *animalicules* (Dobell 1932). However, it wasn't until the mid-1800s that scientists understood all living organisms were composed of cells and that a clear description of germ theory was introduced (Janes et al. 1986). Only by 1875 was the first classification of a bacterium made under the genus *Bacillus* (Drews 2000). Through the end of the 1800s and into the 20th century, discoveries in microbiology came in quick succession. Scientists learned how to culture and identify bacteria in the laboratory, and we began to see the integral role that the microbial biosphere played in exploiting and maintaining the habitability of Earth (e.g., Waksman 1927; Van Niel 1931; Werkman and Wood 1942).

In 1958, Joshua Lederberg, Edward Lawrie Tatum, and George Wells Beadle received the Nobel Prize for their work demonstrating the transfer of DNA from one bacteria to another. Lederberg's work would provide a foundation for the field of bacterial genetics. With his knowledge, Lederberg would also play a central role in NASA's interests in biology and microbiology.

As the Space Age dawned, Lederberg witnessed the flight of Sputnik through the night sky. At the time, he was paying a visit to the English scientist J.B.S. Haldane, who performed some of the early work in origin of life research in the 1920s (Dick and Strick 2005). Lederberg and Haldane both saw a danger in humankind's 'reckless' exploration of the Solar System (Dick and Strick 2005). With his knowledge of microbiology, Lederberg was fearful that space missions could contaminate alien biospheres with Earth bacteria, causing irreversible damage to ecosystems on other worlds. He also feared for the safety of Earth if alien contaminants were returned to our own planet (Morange 2007).

In the same year that Lederberg received the Nobel prize, US President Dwight D. Eisenhower signed the National Aeronautics and Space Act. Lederberg was quick to contact NASA's first administrator, Hugh Latimer Dryden, and was also appointed head of the National Research Council's Space Science Board's panel on extraterrestrial life. Lederberg coined the term 'exobiology,' and played an important role in guiding the early days of NASA research concerning the origin, evolution and distribution of life in the Universe.

As humankind began to expand our influence beyond Earth's atmosphere with observations and robotic missions, our dream of finding a companion among our neighboring planets was dashed; but with our knowledge of the microbial world, scientists still hoped that microbial life could be found in the soils and atmospheres of some planets. Theories of microorganisms in the clouds of Venus or the soils of Mars pervaded the early Space Age, and in many cases still hold weight today (e.g., Cockell 1999; Ivarsson and Lindgren 2010; Morowitz and Sagan 1967; Schulze-Makuch et al. 2004).

In 1975, NASA launched the first missions dedicated to studying life's potential on the surface of Mars. The Viking 1 and 2 missions each had a lander and an orbiter, and each lander carried 14 experiments to the martian surface. This included a set of experiments specifically designed to search for evidence of martian life. The results of the Viking experiments—and the controversy surrounding them—are well documented (Dick and Strick 2005). Ultimately, the scientific community came to the conclusion that no *definitive* evidence of the existence of extant life on Mars had been identified by Viking.

Following Viking, the astrobiology community went through something of an identity crisis (Dick and Strick 2005). Humankind began with the belief that the Solar System would harbor a multitude of inhabited planets filled, like Earth, with an immense diversity of life and culture. As scientific knowledge of life on Earth improved, we became increasingly aware of life's complexity and it's interconnections with the Earth system as a whole. When technology allowed us to make more in-depth observations of our neighboring celestial bodies and we revealed that complex, intelligent life in Solar System was an impossibility, we clung to the idea that simple forms of life could still persist in the harsh environments of the rocky bodies in our solar system. Now, we were faced with the prospect that Earth-like life was restricted to Earth itself.

Today, the prospects for life in our Solar System have undergone somewhat of a revival (Dick and Strick 2005; Olson and Tobin 2008). As technologies have continued to improve, our ability to identify and study life in some of the most extreme environments on Earth has increased by leaps and bounds. With this terrestrial exploration, we have found life forms that thrive in environments that were previously thought to be thoroughly uninhabitable. There was a time when scientists assumed that all energy for life was derived from the Sun. However, science has now allowed us to unravel the cellular methods by which life can survive independent of the Sun—deep in ocean sediments, or kilometers beneath the ground (Cockell et al. 2012; Gronstal et al. 2009; Satyanarayana 2005; Amalie et al. 2006; Li-Hung et al. 2006; Olson and Tobin 2008).

Regions of Earth that were once thought to be void of life actually support diverse microbial ecosystems. This incredible adaptability of life at the microscopic scale has renewed interest in the search for life in our solar system. We again imagine scenarios in which microbial life could gain a foothold in select environments on planets like Mars, particularly early in the planet's history when temperatures were warmer and water is thought to have persisted at the surface (e.g., Pollack and Kasting 1987; Squyres and Kasting 1994). Could microbial ecosystems exist deep below the surface of Mars (e.g., Ivarsson and Lindgren 2010)? Could hydrothermal vents provide the energy for life's origin and evolution beneath the icy crust of Jupiter's moon Europa (e.g., Prieto-Ballesteros et al. 2010)?

11.3 Social Implications

There has been a great deal of discourse concerning the effects of discovering intelligent alien life beyond the Earth (e.g., Dick 2013; Peters 2013). There has also been a fair amount of interest in the potential implications of discovering alien microbial life, particularly following claims in 1996 that alien microfossils had been discovered in the Mars meteorite Allan Hills 84001 (ALH 84001) (e.g., Bertka 2009; Jones 2013; McKay et al. 1996; Olson and Tobin 2008). However, considering that the search for life in our solar system is now limited to microorganisms, and current missions and scientific investigations could theoretically yield positive results in the very near future, there is still insufficient data concerning what our response could or should be (Race 2008). The SETI[2] community has led international discussion on how humankind should respond to a signal from an alien civilization, which has produced the 'SETI principles' that could act as some kind of guideline for first contact (Race 2008). A similar framework does not exist for the discovery of alien microbial life (Race and Randolph 2002). There is no guideline for how humankind should or would respond to the discovery of 'non-intelligent' life, even though such a discovery could have profound scientific, governmental, legal and societal implications (Race 2008).

There are completely different issues in terms of the legal, ethical and societal implications of finding microbial life beyond the Earth when compared to contacting intelligent life (Race 2008). For instance, the discovery of life on a planet like Mars, and the issues surrounding forward and backward contamination,[3] have already been addressed in a legal framework in the form of the Outer Space Treaty of 1967. What is not entirely clear are the social and legal implications of scientific discoveries; including issues like patent rights, commercialization, extraterrestrial property and resource rights, and environmental ethics (Race 2008; Olson and Tobin 2008).

The general public now has a working knowledge of microorganisms, yet we obviously cannot interact with bacteria and archaea on the same level as with complex organisms. Because the public in general now understands and accepts that microorganisms exist all around us (and inside of us) in nearly unfathomable numbers, it may not come as much of a surprise if we find them on other worlds in our solar system. Even so, the discovery of a native microbiology on planets such as Mars or moons like Saturn's Enceladus could still have an impact on societal and theological perceptions of the existence of life on Earth (Lowrie 2013).

The discovery of a second *origin* of life beyond Earth could directly challenge interpretations of creation stories that exist in many ancient and modern religions. In particular, if alien microbes had a distinct and independent origin from those of

[2] Search for Extraterrestrial Intelligence (SETI).

[3] For example, the contamination of Mars by organisms originating from Earth, or the contamination of Earth by organisms originating from Mars.

Earth, this "Second Genesis" of life could have profound meaning to many theological doctrines concerning the origin and meaning of life.

The history of humankind's discourse on the potential for alien life holds value in that it has provided a framework for how we can analyze first contact with a non-intelligent alien life form (Olson and Tobin 2008; Peters 1994). In fact, many major religions have broached the subject (e.g., Bertka 2013). It has been suggested by Olson and Tobin (2008) that such a discovery would only pose a problem for more fundamentalist religious traditions, whereby literal interpretations of scripture tend to be Earth-centric. Ultimately, many major religions have reconciled the possibility of non-intelligent life and have come to the conclusion that the discovery of microbial life beyond Earth would have no detrimental effect on the interpretation of current beliefs (Olson and Tobin 2008). In fact, it may present a 'mandate' for humankind's stewardship over the safety and cultivation of such life (Olson and Tobin 2008).

Contact with alien microbes would bring with it discussions of how theology's more Earth-centric view of creation and existence translate to a broader reality. However, we cannot disregard the fact that microorganisms have no discernible 'consciousness' that we can yet identify. The discovery of microorganisms on Mars would not challenge concepts that we are alone and unique as 'intelligent' life in the Universe. Microbial life forms would also not present their own native theologies or beliefs that could challenge or contradict religious views on Earth in the same way that an intelligent alien culture might. In terms of the general perception of alien microbial life, it is possible that the public will recognize the importance the discovery in terms of our understanding of life's existence in the Universe, but our Earth-centric view of the *value* of our own existence would not be challenged. The differences between extraterrestrial microorganisms and those native to Earth may be dramatic at the cellular or molecular level when viewed under the microscope, but these differences could easily be dismissed by a lay person who takes the existence of microorganisms, which are of course invisible to the naked eye, on faith alone.

The most likely sentiment that would resonate in the public is *not* concern over the religious implications of the discovery, but of the potential for contamination of our home planet. Society is most familiar with microbial life in the form of bacteria or 'germs' that cause illness. The existence of an alien microbe would likely generate a fear of alien disease, ala numerous stories in popular science fiction and fantasy. This is perhaps why issues of contamination have been a major thread through scientific exploration of the Solar System since the days of Joshua Lederberg—and why these concerns were addressed as early as 1967 with the Outer Space Treaty (Dembling and Arons 1967).

We may not be able to interact with microbial life on a 'social' level, but the presence of alien microbiology within our solar system would, in a sense, be more immediately interactive than an intelligent civilization on a distant, extra solar world. We now know that there is no intelligent life that we can identify in our solar system beyond the Earth. Our most likely identification of intelligent life will be in the form of a SETI-type signal from a distant world, with a significant gap in time between the signal's origination and when we receive it. Over the vast distances of space, actual *interaction* with an alien civilization may be extremely difficult and communication would incur significant delays in call and response times.

The discovery of a microorganism on Mars, on the other hand, would allow relatively immediate opportunities to interact with the alien life (of course, with consideration for the relevant legal and safety implications and the time it takes to develop a mission). Missions can be sent to Mars, and other locations in our solar system, to sample, retrieve and perform scientific investigations. The amount of data that could be gathered from 'first contact' with an alien microbe as opposed to an alien civilization could be, in many way, vastly greater and more complete than the data incurred by contacting an alien civilization (Race 2008).

11.4 Economic Implications

The advent of microbiology and molecular biology has also revealed that microbial ecosystems hold immense economic value. Microbes that inhabit some of Earth's most 'extreme' environments have provided chemical and molecular products that have completely changed areas of medicine and industry (e.g., Aguilar 2006; Dijkshoorna 2010; Gomes and Steimer 2004; van den Burg 2003; Kumar 2011). The unique conditions under which these microbes have evolved have allowed them to produce novel responses to environmental pressures. Microorganisms are now known to survive in a wide array of habitats previously assumed to be uninhabitable. They grow and reproduce in environments that are highly acidic, desiccated, high in radiation, low in nutrients and at extreme temperatures both hot and cold.

Microbial ecosystems on other worlds may or may not be biologically similar to life on Earth; but if they are, their adaptation to unique environmental stresses would likely produce a unique set of biomolecules that could have incredible value in areas of biotechnology and medicine. The economic value of extremophile research on Earth has been widely recognized by private and governmental institutions around the world (e.g., Aguilar 2006; Schiraldi 2002), and alien life on planets and moons that are accessible in our solar system would potentially provide a new set of laboratories in which this research could continue. In the same way that extraterrestrial civilizations could have been a unique source of trade and industry, providing humankind with new knowledge and technologies; the existence of microbial biospheres on other planets could hold a wealth of unimagined opportunities in economically relevant fields. Discovering unique proteins and enzymes produced by 'martian' cells may not be quite the same as opening trade relations with a martian civilization—but the economic and cultural implications for humankind would be similarly profound.

Some scientists have also posited theories of 'weird' life on Saturn's moon Titan, where organisms might rely on liquid methane as a solvent for cellular functions rather than the familiar liquid water of Earth (Benner, Ricardo and Carrigan

2004). Although possibly far-fetched, the discovery of life that operates under completely different conditions, such as a genetic system other than deoxyribonucleic acid (DNA), would also have profound implications for life on Earth. A 'second origin' for life may or may not provide valuable biomolecules that could function in an Earth-life system. Yet, having a second example of life would open an entirely new field of comparative biology. Much like comparative planetology, where the study of other planets like Venus can be used to understand planetary and climate processes on Earth, comparative biology could provide new insights into how biology functions—such as alternative routes for origins of life and evolutionary processes.

We currently know very little about the likelihood of life originating on Earth-like worlds in the Universe. Our ability to improve our knowledge is hindered by one simple fact—we have only one example of a habitable world thus far. Clever mathematicians have previously attempted to draw some sort of estimate on the likelihood of alien life based on this 'limited' data set—many concluding that life should be rare (e.g., Spiegel et al. 2011) and others that life has the potential to be plentiful (e.g., Lineweaver and Davis 2002; Michaud 2007).

We do not know the probability of life arising from pre-biotic environments, and we do not know how common such environments are in the Universe. We only know that life arose at least once, and can therefore not make a statistical estimate of life's prevalence beyond the Earth (Spiegel and Turner 2011). The 'optimistic' approach, as cited by Spiegel and Turner (2011), assumes that because life arose so quickly on the Earth after the conditions and climate were right, the origin of life must surely be a common process in the Universe. Rather than attempting to estimate life's prevalence in the Universe, Spiegel and Turner (2011) instead used a Bayesian statistical framework to estimate the frequency of life's origin on Earthlike worlds. Their study focuses on the elapsed time between when the conditions for life's origins arise on a planet, and when life actually arises (i.e., the time in which it took Earth to go from 'habitable' to 'inhabited').

Of course, the lack of data concerning life's abundance in the Universe (and the abundance of habitable worlds) means that there are numerous problems in such statistical estimates. Spiegel and Turner (2011, 395) readily admit this, and they sight a number of assumptions that need to be made in order to perform their calculations. However, one important conclusion of their work is this:

> Finding a single case of life arising independently of our lineage (on Earth, elsewhere in the Solar System, or on an extra solar planet) would provide much stronger evidence that abiogenesis is not extremely rare in the Universe.

We cannot begin to estimate or truly understand the abundance of life in the Universe until we identify at least one other instance of life's occurrence. If the most likely scenario for discovering alien life is to identify a microorganism on a world like Mars or Europa (or a second and independent example of life's origin on Earth)—then this discovery could help lay the foundation for a more accurate understanding of whether or not multiple origins of life have occurred in the Universe. While an alien microbe may not bring the same shock and awe as a message from an alien civilization—it's discovery would go a long way in letting us know whether or not we should be preparing for a call from somewhere deep among the stars.

11.5 Conclusion

From academia to religion and literature to film, there has been a wide range of discussion concerning our response to *first contact* with an intelligent alien culture. Academics, theologians and scientists have constructed various responses to the potential discovery of intelligent life and guidelines for how humankind should or possibly would respond. However, in light of our current efforts of exploration in the Solar System and beyond, it seems more likely that the first evidence of alien life will come in the form of a microorganism—and possibly the fossil remnants of a long-extinct alien microbe. Even if the discovery of martian or europan microorganisms would not necessarily cause any dramatic changes in societal or theological *perceptions* of life on Earth, it could cause dramatic and far-reaching waves in the technological and economical systems of humankind.

If we are to learn from historic conceptions of life beyond our planet, and provide useful criteria for how we might respond to *first contact* if and when it happens, more effort must be made to understand the potential social, economic, and legal ramifications of discovering non-intelligent life.

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