2017

Darwin's Universe: The Darwinian Foundation of the Discipline of Astrobiology

Andrea Holstein
Western University, aholstei@uwo.ca

DARWIN'S UNIVERSE

The Darwinian Foundation of the Discipline of Astrobiology.

Abstract:

This paper explores the role of Darwin's approach to the study of life in developing the core research program of astrobiology. Presently, there is little historical scholarship regarding the broad discipline of astrobiology, and, particularly, the relationship between the disciplines of biology and astrobiology. The goal of this paper is to demonstrate that Darwin's biological inquiry inspired further research into uncovering the origin and conditions for life in the universe, as well as how his research influences the modern astrobiological research program. This analysis of the impact of Darwin's research on the discipline of astrobiology was accomplished by examining how Darwin's approach to the study of life on Earth inspired other scientists to postulate a universal origin of life. Darwin's unanswered question of where life began inspired the development of the Panspermia Theory, which marks the first significant theoretical development in the emerging discipline of astrobiology, and thus demonstrates the influence of Darwin's theoretical work on modern astrobiological inquiry. Darwin's laws of biology influenced Alexander Oparin's research into the conditions for life on Earth, and his work in turn contributed to the development of the core methodology of the astrobiological research program. While scholars chiefly examine the impact of the Space Race in regard to the institutionalization of aerospace research, this paper argues that the creation of these institutions facilitated formal astrobiological experimentation inspired by the Darwinian search for the conditions for life in a universal context. This paper examines the development of the discipline of astrobiology from a historical perspective in order to analyze the role that Darwinism played—and continues to play—in shaping the modern astrobiological research program.

Keywords: Darwin; Darwinism; Astrobiology; Panspermia Theory; Exobiology

The discipline of astrobiology required the technological advancements of the late twentieth century to conduct its research, but the theoretical basis of the discipline is rooted in a much older scientific tradition. Darwinism formalized an approach to the study of life which facilitated the emergence and influenced the development of the research program of astrobiology. Charles Darwin's theory of evolution relied on extensive observational data and the merger of numerous streams of scientific inquiry. His theory provided a unified theoretical basis for investigations of the development of life. Darwin's methodology had a lasting influence on the development of the field of biology and biological inquiry. The Panspermia theory is the first evidence of an astrobiological theory which developed out of Darwin's biological inquiry. The scientific advancements of the twentieth century contributed to the formalization of the methodology for astrobiology, which in turn facilitated sophisticated investigations into the universal origin of life. The institutionalization of aerospace research during the Space Race resulted in the institutionalization of astrobiology, and provided the means for the advancement of astrobiological research. The resulting combination of the theoretical basis, methodology, and research institution contributed to the formalization of the core research program of astrobiology. Astrobiology continues to benefit from Darwin's interdisciplinary approach to the study of life, and the search for life in the universe is guided strongly by Darwinian principles.

Darwin's records of observations and consultation with his peers following his voyage aboard the *Beagle* inspired him to develop a theory that explained the transmutation of plant and animal species.[1] Darwin's observations and interdisciplinary analysis led to his conclusion that natural selection is the mechanism which causes observable changes in organisms. Darwin conceived the idea of the process of natural selection through his observations of nature, and the

[1] James T. Costa, "The Darwinian Revelation: Tracing the Origin and Evolution of an Idea," *BioScience* 59, no. 10 (Nov. 2009): 888.

input of his peers, in conjunction with his own research, led to the formalization of his theory. Darwin's research began with his observations of the geography of South America and the apparent similarities between the species of the mainland and the nearby islands.[2] He collected fossil and organic evidence which he subjected to the analyses of his peers, such as fossil-expert Richard Owens, and ornithologist John Gould, back in England.[3] Their conclusions inspired him to consider the nature of the transmutation of species. The ensuing research was heavily influenced by his understanding of animal domestication practices, and John Saunders Sebright's notion of selective breeding in agriculture prompted Darwin to consider whether there was an analogous process in nature.[4] Darwin's research into Reverend Malthus' studies of population growth led to his realization that the population growth of a species is curbed by a struggle for survival in natural environments. He proposed that the variability present in species will determine their success in the struggle and, conversely, the development of species is shaped by this struggle.[5] The challenge for Darwin, as an adherent of Herschel's ideas, was to present a theory which explained species change according to the principles of Herschelian logic. John Herschel argued that the best evidence in support of a *vera causa* in nature is to determine the underlying mechanism (i.e. what it is, how it works, etc.).[6] Darwin proposed that the process of natural selection is the mechanism which determines changes in species over time. This is significant because it provided his theory of evolution with one cause to explain numerous facts.[7] Darwin proposed that selection, as the "causal agent of change under domestication" must also occur in the natural world as a result of the "abundant variability and severe struggle, the

---

[2] Charles Darwin, "Introduction," *On the Origin of Species*, (1859; Project Gutenberg, 2013), http://www.gutenberg.org/files/1228/1228-h/1228-h.htm#link2H_INTR.
[3] Costa, "Darwinian Revelation," 888.
[4] Costa, "Darwinian Revelation," 888.
[5] Ibid., 889.
[6] Ibid., 890.
[7] This point will be explored more in-depth in the following paragraph; Ibid.

outcome of which depends in large part on that variability."[8] In order to support his conclusion, Darwin consulted the fossil record, biogeography, embryology, and other disciplines, to argue that his conclusion is "consistent with the observed facts."[9] By determining that natural selection was the underlying causal mechanism for the transmutation of species, Darwin was able to explore the "wide applicability of his theory" in order to better understand the development of species.[10]

Darwin's research had lasting implications for the scientific community, particularly the biological sciences. Darwin's theory of evolution by way of natural selection provided a unified theoretical basis, grounded in observation, for the study of life on Earth. The challenges that Darwin faced in gaining acceptance for his theory inspired him to "continue to amass data and observations for a complete and well-substantiated theory."[11] Darwin undertook numerous studies of plant and animal species in order to further his understanding of the origin, development, and divergence of species. His botanical studies enhanced his understanding of the role of divergence in the process of natural selection, and prompted him to explore the nature and patterns of variation in species.[12] Further, these studies contributed to his understanding of the origin of species. He studied plants with qualities similar to animal species, such as carnivorous and climbing plants, and he determined that these traits were evidence of fundamental physiological qualities shared by organisms. He concluded that these similar physiological qualities suggest that all forms of life share common ancestry, and that the differences in species are the result of variability and divergence.[13] Darwin's training in biogeography greatly

[8] Ibid., 890.
[9] Ibid.
[10] Ibid.
[11] Ibid.
[12] Ibid.
[13] Ibid., 891.

influenced his theory of evolution. His explanation of the transmutation of species is similar to the notion held by geologists regarding the changes to the Earth's appearance: both state that species and the terrain "change gradually, by the slow, incessant action of purely natural processes."[14] As a result of his increasing investigations, Darwin was able to propose a "process of species splitting that at once explained ever-increasing competitiveness as well as species diversification, extinction, coexistence," etc., and this information facilitated the creation of a hierarchical classification system.[15] Darwin's research and ongoing efforts to understand the implications of his theory greatly impacted the development of the discipline of biology. Darwin's peers recognized not only the explanatory power of his theory, but also how well it succeeded in unifying numerous fields of scientific inquiry.[16] Darwin's adherence to observation, the scientific process, and his "commitment to natural law" led to the development of a solid theory of the evolutionary process, and resulted in evolution becoming the "cornerstone of biology," through to the present day.[17]

The legacy of Darwin's research is demonstrated by the ongoing studies concerned with the phenomenon of life on Earth. Darwin's investigations into the origin, conditions for, and evolution of life on Earth provided the methodological basis for further investigations of the phenomenon of life. Cristina Sousa examines the lasting influence of Darwin's approach to investigations of nature in the field of biology. She argues that biological investigations are "a question-driven process, not always producing new theories."[18] This is demonstrated by Darwin's ongoing investigation of the nature of species which sought to enhance his

---

[14] Ibid.
[15] Ibid.
[16] Ibid., 893.
[17] Ibid.
[18] Cristina Sousa, "The Scientific Methods of Biology, Starting with Charles Darwin," *The American Biology Teacher* 78, no. 2 (January 2016): 109.

understanding; his ceaseless questioning of his observations enabled him to reflect upon the mechanism of species change. These continual investigations led to the development of his theory of evolution, and, by continuing to question the nature of species, he strengthened the explanatory power of this theory. The outcome of this, according to Sousa, is that Darwin is responsible for changing how scientists, particularly biologists, view the natural world.[19] In the present day, biological inquiry is still greatly influenced by Darwinian principles. Graham Bell argues that the unification of organismal biology, for example, could result from the interpretation of the evidence in Darwinian terms.[20] This specific example demonstrates that biologists in many fields—not just evolutionary biology—are working within the theoretical constraints established by Darwin. Indeed, Darwin's greatest contribution to the advancement of biological studies is his methodology. Darwin's theory of evolution by way of natural selection relied on strong evidence, rather than tangible/observable proof, which supported the probable occurrence of this process. This focus on probability—and a rigid adherence to the scientific method—enables biologists to propose laws and theories to explain the most likely cause of natural phenomena in order to continue their investigations.[21] The benefit of this methodology is that it enables biological inquiry to extend beyond the available sample pool (e.g. to consider both extant and extinct species), and reduces the impact of the limits of technology (and its ability to provide conclusive evidence) on research programs.

Darwinism inspired radically new approaches to the study of life, and the earliest astrobiological inquiries began well-before the technology had developed to investigate these ideas. The Panspermia theory is rooted in Darwinian principles, and its development in the late-

---

[19] Ibid., 110.
[20] Graham Bell, "Darwin and Biology," *Journal of Heredity* 80, no. 5 (September 1989): 421.
[21] Sousa, "Methods of Biology," 115.

nineteenth century denotes the start of modern astrobiological inquiry. Hermann Richter is credited with being the first scientific proponent of the Panspermia theory. In his review of *The Origin of Species,* he argued that Darwin's theory of evolution was incomplete as it failed to explain how life originated on Earth. Richter was an adherent to Darwin's notion of a common ancestor for all organic beings, and he proposed that this first instance of life originated in space. He supported this claim by citing the evidence of microscopic life forms which are able to survive in the Earth's atmosphere, as well as the ability of carbon-containing meteorites to host living organisms.[22] This is significant because Richter posited a common origin of life, not simply on Earth, but in the universe at large. This forms the basis of the Panspermia theory. Further, Richter argued that life spread throughout the universe by way of meteoroids and other celestial objects that pass near different atmospheres to collect microbes, which are then deposited on other planets through meteorite impacts, and then form a new biosphere.[23] Richter's theory proved popular and was developed by his peers in disciplines as varied as physics, biology, and the medical sciences, to name a few. These contributors expanded the scope of the theory, and developed its scientific basis.[24] For example, William Thomson proposed that these life-bearing meteoroids could derive from collisions of massive celestial bodies into planets that host life, the force of which would simultaneously break pieces off of the planet and eject them into space.[25] In defense of this mode of transmission of life, Helmholtz argued that the interior of a meteorite does not experience the extreme heat created during its entry into the atmosphere, thus explaining how life could survive the journey to the surface of a new planet.[26] In the early

---

[22] Rene Demets, "Darwin's Contribution to the Development of the Panspermia Theory," *Astrobiology* 12, no.10 (2012): 946-47.
[23] Ibid., 947.
[24] Ibid.
[25] Ibid., 948.
[26] Ibid.

twentieth century, Svante Arrhenius examined the viability of microbes in space and postulated how they could survive the harsh climate of space for prolonged periods of time during transit.[27] By eschewing notions of the auto-generation of life on Earth, these scientists strove to provide a universal context for the origin of life to complete Darwin's theory of evolution (i.e. by uncovering the origin of the common ancestor). The greatest challenge posed to the Panspermia theory was the fact that many of the speculations put forth by scientists could not be tested due to the limitations of the available technology.[28] Despite this, the development of the theory owes a clear debt to Darwinian principles in its goal to explain the origin of life, its transmission to new planets, and the conditions required for its viability, both in space and on its new host planet.

The Panspermia theory indicates the earliest modern attempt to adopt a theoretical approach, grounded in the scientific method, to investigate the origin of life. The scientific advancements of the twentieth century enabled biological scientists to formalize a methodology for the study of the universal origin of life. Darwin's theory provided biologists with a guide for investigating the development of life, but he concluded that "an enquiry as how life itself first emerged" was a problem for the "distant future if [it is] ever to be solved by man."[29] The advocates of the Panspermia theory developed a credible theory to address this issue. However, the limitation that both theories posed for their adherents was the inability to test their hypotheses or expand the scope of their investigations. This inspired the development of the modern methodology for astrobiological inquiry. Alexander Oparin postulated that life on Earth developed "through [the] gradual chemical evolution of carbon-based molecules in primordial soup."[30] This theory

---

[27] Ibid., 949.
[28] Ibid., 948.
[29] Charles Darwin, *The Descent of Man*, quoted in Julian Chela Flores, *The Science of Astrobiology: A Personal View on Learning to Read the Book of Life*, 2nd ed. (London: Springer, 2011), electronic edition, 7.
[30] Chela Flores, *Science of Astrobiology*, 8.

demonstrates the influence of Darwin. Sousa states that while very few laws of biology have been described (and accepted), Darwin was instrumental in defining two, the first of which states that "all known properties of living organisms follow the laws of physics and chemistry."[31] Darwin hypothesized that life originated from chemical compounds, and deemed spontaneous generation to be "not improbable."[32] Oparin, with a background in biochemistry, expanded on this point with his research. He determined that "there is no basic difference between a microbial life and condensed matter," which supports his theory that life originated from chemical compounds that are abundant in the universe. He elaborates that the complexity of microbial, and other basic life forms, are the result of the process of evolution by way of natural selection.[33] Oparin's theoretical work, though heavily influenced by Darwinism, was grounded in his empirical research. The discovery of methane in the atmospheres of the gaseous planets provided Oparin with enough evidence to postulate the chemical makeup of the Earth's early atmosphere, thus determining that it likely contained the "raw materials for the evolution of life."[34] Further, his understanding of biogeochemistry allowed him to develop models of the primitive cellular structure of early organic compounds.[35] Oparin's approach to the study of the origin of life reflects Darwin's methodology. He proceeded from accumulated evidence to postulate the most likely scenario. In this case, he proceeded from chemical evidence, which was enhanced by his understanding of organic and chemical compounds, to postulate that a younger Earth contained the necessary building blocks for life. His models demonstrate the most likely outcome of the conditions he described, in order to support his conclusion. Oparin's research established the

---

[31] Sousa, "Methods of Biology," 111.
[32] Ibid.
[33] Chela Flores, *Science of Astrobiology,* 8.
[34] Ibid., 9.
[35] Ibid.

methodological basis for further studies regarding the origin of life and he succeeded in overcoming some of the sampling limitations faced by his predecessors by incorporating non-terranean evidence into his analysis.

Current research initiatives in the field of astrobiology are possible as a result of the development of major astronomical research institutions, such as NASA, during the Space Race. The institutionalization of aerospace research marks a significant development in the formalization of the research program of astrobiology. The Cold War spurred technology research, particularly in relation to aeronautics. The Space Race "provided the impetus for increased spending for aerospace endeavors, technical and scientific educational programs, and the chartering of new Federal agencies" to oversee research and development for astronomical initiatives in the United States.[36] This national imperative led to the formation of NASA in 1958, and, within months, it had begun operations related to human space flight.[37] The establishment of NASA was important for many streams of astronomical inquiry, but this has had an incredible impact on the development of astrobiological research. Steven J. Dick calls the institutionalization of astrobiology "an interesting story of discipline building in the context of government funding."[38] The spacecraft program was developed for defense purposes during the Cold War, but the scientific community quickly recognized that "spacecraft could also be used to search for extraterrestrial life," and as instruments to study "the most fundamental problems of biology: the origin of life and its progress in independent evolutionary systems."[39] Dick argues that NASA saw the benefit in encouraging popular interest in exobiological (astrobiological)

---

[36] "NASA History: Milestones in Space Exploration and Science," *The Congressional Digest* 90, no. 7 (Sept. 2011): 196.
[37] Ibid., 197.
[38] Steven J. Dick, "Origins and Development of NASA's Exobiology Program, 1958-1976," *Acta Astronautica* 65, no. 1-2 (July-Aug. 2009): 1.
[39] Ibid., 2.

research as it could lead to budget increases to support their core initiatives.[40] The Bioscience Advisory Committee was established in 1959 to advance space medicine for the benefit of its manned flight initiatives, as well as to undertake "investigations of the effects of extraterrestrial environments on living organisms including the search for extraterrestrial life."[41] This along with other initiatives from the early period of NASA's operations enhanced both the manned space flight program, and the advancement of astrobiological research. In the 1990s, the increasing "sophistication of space missions" led to a renewed emphasis on astrobiological research.[42] NASA established its own Astrobiology Institute (NAI) in 1998, and its mission was to provide funding for researchers and ensure that "astrobiology goals are incorporated in NASA flight missions," among other aims.[43] The formation of the NAI is significant as it marks the institutionalization of astrobiology as a part of a leading space-focused research institution. The institutionalization of astrobiology occurred as an off-shoot of the greater institutionalization of aerospace research in the mid-twentieth century. As a result of this, the discipline of astrobiology gained the funding, expertise, and instruments necessary for the advancement of astrobiological investigations.

The institutionalization of astrobiology marks the union of theory, methodology, and experimentation, and, thus, the formalization of the core research program of astrobiology. The discipline of astrobiology was founded on Darwinian principles, and this intellectual legacy is present in current astrobiological research initiatives. The goal of the discipline of astrobiology is to understand the phenomenon of life in a universal context—the origin, development, evolution,

---

[40] Ibid.
[41] Ibid.
[42] Baruch S. Blumberg, "The NASA Astrobiology Institute: Early History and Organization," *Astrobiology* 3, no. 3 (2003): 463.
[43] David Morrison, "The NASA Astrobiology Program," *Astrobiology* 1, no. 1 (2001): 3.

and future of life. From Darwin, astrobiologists have inherited his method of examining "existing life and extrapolating backward" in order to uncover the fundamentals of the phenomenon of life.[44] Darwin theorized that all life on Earth demonstrates a shared beginning, or a "common ancestor." This idea inspired biological scientists to investigate the origin of life on Earth in order to better understand how life came to exist in general.[45] Darwin's first law prompted the study of life to shift from a biological focus to a biochemical one, in order to uncover the conditions for life. This resulted in investigations into the formation of the first organic compounds.[46] Further, the discovery of life forms and ecosystems on Earth that thrive in inhospitable conditions enhanced ongoing investigations to understand the conditions required for the appearance and development of life on Earth.[47] Astrobiological research initiatives developed out of this line of inquiry and current projects focus on the search for Earth-like conditions in the universe. Morrison states that "[t]errestrial life is based on chemistry of carbon moderated by liquid water" and that "[s]uch organic chemistry is common throughout the cosmos."[48] Thus, current astrobiological initiatives search for liquid water in the universe, as well as the atmospheric conditions conducive to the development of carbon-based life forms.[49] Darwin discovered the role of natural selection in the process of evolution by observing the development of a species within its environmental context. Astrobiologists examine the phenomenon of life by considering the planet Earth as a component of the greater "ecosystem" that is the Solar System.[50] This increasing understanding of the organic quality of stellar systems

---

[44] Lucas John Mix, *Life in Space: Astrobiology for Everyone* (Cambridge, MA: Harvard University Press, 2009), 9.
[45] Chela Flores, *Science of Astrobiology*, 14.
[46] Ibid., 17.
[47] Ibid., 15-6.
[48] Morrison, "NASA Astrobiology Program," 6.
[49] Marc Kaufman, "A History of Astrobiology," *Astrobiology at NASA: Life in the Universe*, accessed on May 9, 2016, URL: https://astrobiology.nasa.gov/about/history-of-astrobiology/.
[50] Chela Flores, *Science of Astrobiology*, 96.

enables astrobiologists to extrapolate their understanding of the conditions for the Earth's habitability—its position in the "habitable zone" zone of the Sun, for example—and apply this to the search for exoplanets.[51] By placing "life in the context of its planetary history," astrobiologists strive to "determine the source of the raw materials" and conditions for life in the universe.[52] Julian Chela Flores argues that the "fields of chemical evolution and Darwin's theory of evolution [are the] time-honored sub-disciplines of astrobiology."[53] Darwin's work inspired biological scientists to continue to build on his research in order to uncover the start of life on Earth. Astrobiologists expanded the scope of this project and, by adopting an approach influenced by Darwinian principles, continue the search for life in a universal context.

Darwin's approach to the investigation of species changed the way in which biological scientists studied the natural world, and led to the development of the study of life in the universe. The discipline of astrobiology developed out of the theory, methods, and principles that Darwin instilled in the discipline of biology, in conjunction with the technological advancements of the twentieth century. Darwin's extensive observational data and his interdisciplinary analyses of this allowed him to uncover the process of natural selection as the mechanism responsible for the evolution of organic beings. Darwin's rigorous study of the various components of this process not only strengthened his theory, but provided the theoretical basis for modern biological inquiry. The adherence of biologists to Darwin's methods and principles facilitated further investigations into the phenomenon of life, and provided the foundation for the modern discipline of biology. The Panspermia theory demonstrates the union of biological and astronomical research, and signals the development of modern astrobiological inquiry. The

---

[51] Mix, *Life in Space,* 121.
[52] Dick, "NASA's Exobiology Program," 5; Morrison, "Astrobiology Program," 5.
[53] Chela Flores, *Science of Astrobiology,* 209.

research and technological advancements of the twentieth century enabled biological scientists to formalize a methodology for the investigation of life in a universal context. The institutionalization of astrobiology provided the means for the investigation of the theories and principles at the core of the research program. The legacy of Darwin's work is demonstrated by the research aims of current astrobiological initiatives and the focus on uncovering evidence of life (or the conditions for it) in an Earth-like context. Darwin's inquiry was limited to ecosystems on Earth, but his theoretical work enabled his successors to apply his principles to a universal context with the goal of answering the question: how did life begin?

Bibliography

Bell, Graham. "Darwin and Biology." *Journal of Heredity* 80, no. 5 (September 1989): 417-421. Accessed on May 7, 2016. URL: [REDACTED].

Blumberg, Baruch S. "The NASA Astrobiology Institute: Early History and Organization." *Astrobiology* 3, no. 3 (2003): 463-470. Accessed on May 8. 2016. URL: [REDACTED].

Chela Flores, Julian. *The Science of Astrobiology: A Personal View on Learning to Read the Book of Life.* 2nd ed. London: Springer, 2011. Electronic edition. Accessed on May 7, 2016. URL: [REDACTED].

Costa, James T. "The Darwinian Revelation: Tracing the Origin and Evolution of an Idea." *BioScience* 59, no. 10 (Nov. 2009): 886-894. Accessed on May 6, 2016. URL: [REDACTED].

Darwin, Charles. *On the Origin of Species* (1859). Project Gutenberg, 2013. Accessed on May 6, 2016. URL: http://www.gutenberg.org/files/1228/1228-h/1228-h.htm#link2H_INTR.

Demets, Rene. "Darwin's Contribution to the Development of the Panspermia Theory." *Astrobiology* 12, no.10 (2012): 946-950. Accessed on May 7, 2016. URL: [REDACTED].

Dick, Steven J. "Origins and Development of NASA's Exobiology Program, 1958-1976." *Acta Astronautica* 65, no. 1-2 (July-Aug. 2009): 1-5. Accessed on May 8, 2016. DOI: 10.1016/j.actaastro.2009.01.058.

Kaufman, Marc. "A History of Astrobiology." *Astrobiology at NASA: Life in the Universe.* Accessed on May 9, 2016. URL: https://astrobiology.nasa.gov/about/history-of-astrobiology/.

Mix, Lucas John. *Life in Space: Astrobiology for Everyone.* Cambridge, MA: Harvard University Press, 2009.

Morrison, David. "The NASA Astrobiology Program." *Astrobiology* 1, no. 1 (2001): 3-13. URL: [REDACTED].

"NASA History: Milestones in Space Exploration and Science." *The Congressional Digest* 90, no. 7 (Sept. 2011): 196-224. Accessed on May 7, 2016. Accession number: 65456631.

Sousa, Cristina. "The Scientific Methods of Biology, Starting with Charles Darwin." *The American Biology Teacher* 78, no. 2 (January 2016): 109-117. URL: [REDACTED].