Life Beyond Earth and the Evolutionary Synthesis

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Life Beyond Earth and the Impact of Discovery

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Chapter 9
Life Beyond Earth and the Evolutionary Synthesis

Douglas A. Vakoch

Abstract For many astronomers, the progressive development of life has been seen as a natural occurrence given proper environmental conditions on a planet: even though such beings would not be identical to humans, there would be significant parallels. A striking contrast is seen in writings of nonphysical scientists, who have held more widely differing views. But within this diversity, reasons for differences become more apparent when we see how views about extraterrestrials can be related to the differential emphasis placed on modern evolutionary theory by scientists of various disciplines. One clue to understanding the differences between the biologists, paleontologists, and anthropologists who speculated on extraterrestrials is suggested by noting who wrote on the subject. Given the relatively small number of commentators on the topic, it seems more than coincidental that four of the major contributors to the evolutionary synthesis in the 1930s and 1940s are among them. Upon closer examination it is evident that the exobiological arguments of Theodosius Dobzhansky and George Gaylord Simpson and, less directly, of H. J. Muller and Ernst Mayr are all related to their earlier work in formulating synthetic evolution. By examining the variety of views held by nonphysical scientists, we can see that there were significant disagreements between them about evolution into the 1960s. By the mid-1980s, many believed that "higher" life, particularly intelligent life, probably occurs quite infrequently in the universe; nevertheless, some held out the possibility that convergence of intelligence could occur across worlds. Regardless of the final conclusions these scientists reached about the likely prevalence of extraterrestrial intelligence, the use of evolutionary arguments to support their positions became increasingly common.

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9.1 Introduction

The notion of extraterrestrial beings of bizarre yet somewhat humanoid forms existed well before science fiction movies became popular. In Christiaan Huygens's *The Celestial Worlds Discover'd*, we can see two poles of thought about life beyond Earth that are reflected in more recent works. That monograph, published posthumously in 1698, depicts possible denizens of other planets as in some ways very similar and also potentially markedly different from humankind.[1] After explaining why "Planetarians" would be upright beings with hands, feet, and eyes, he claimed that their form could still be quite alien:

> Nor does it follow from hence that they must be of the same shape with us. For there is such an infinite possible variety of Figures to be imagined, that both the Oeconomy of the whole Bodies, and every part of them, may be quite distinct and different from ours (Huygens 1968, 74).

Huygens was neither the first nor the last astronomer to speculate on extraterrestrial morphology.[2] But his position *is* representative of his profession. For many astronomers, the progressive development of life has been seen as a natural occurrence given proper environmental conditions on a planet. And even though such beings would not be identical to humans, they have argued, there would be significant parallels. A striking contrast is seen in writings of nonphysical scientists. Members of this latter group hold more widely differing views. But within this diversity, reasons for differences become more apparent when we see how views about extraterrestrials can be related to the differential emphasis placed on modern evolutionary theory by various scientists.

One clue to understanding the differences between the biologists, paleontologists, and anthropologists who speculated on extraterrestrials is suggested by noting who wrote on the subject. Given the relatively small number of commentators on the topic, it seems more than coincidental that four of the major contributors to the evolutionary synthesis in the 1930s and 1940s are among them. Upon closer examination it is evident that the exobiological arguments of Theodosius Dobzhansky and George Gaylord Simpson and, less directly, of H. J. Muller and Ernst Mayr are all related to their earlier work in formulating synthetic evolution. By examining the variety of views held by nonphysical scientists, we can see that there were significant disagreements between them about evolution into the 1960s. Within the next two decades, many but by no means all believed that "higher" life,

[1] One early reviewer of *The Celestial Worlds Discover'd* argued on the basis of analogy that stars are circled by inhabited worlds: "yet from the Analogy that is between the Sun and Stars, we may judge of the planetary Systems about them, and of the Planets themselves too, which probably are like the planetary Bodies about the Sun, (that is) that they have Plants and Animals, nay, and Rational ones too, as great admirers and Observers of the Heavens as any on Earth" (Anonymous 1699, 337).

[2] For more in-depth analysis of Christiaan Huygens's views of extraterrestrial life, see the first chapter of this volume by Crowe and Dowd (2013).

particularly intelligent life, probably occurs quite infrequently in the universe. Those arguing that extraterrestrial intelligence could plausibly exist were increasingly likely to make their case based on convergent evolution. While different scientists came to divergent conclusions about the likelihood of intelligence beyond Earth, the use of evolutionary arguments became increasingly common.

9.2 Early Critiques of Darwin's Theory of Evolution

To understand the 20th-century synthesis of evolution, it is useful to recall the main features of Charles Darwin's theory as seen in the first edition of *The Origin of Species*. His basic position can be summarized in two concepts: variation and natural selection. Darwin limited himself to minute differences between organisms that could be passed on to subsequent generations. Because each organism would be distinctly equipped for the "struggle for existence," those best suited to their environments would have the greatest chance of surviving to reproduce offspring that share some of their characteristics. Darwin (1968, 131) succinctly stated the relationship between this process of natural selection and variation: "This preservation of favourable variations and the rejection of injurious variations, I call Natural Selection."

In subsequent years, the efficacy of natural selection was questioned and rejected by many. Fleeming Jenkin (1867), for example, contended that any small beneficial variations would be diluted quickly in a population including many other organisms not similarly adapted. In later editions of *The Origin*, Darwin relied more heavily on "sports," individuals varying markedly from their forebears. This caused some critics to charge that Darwin had shifted to a position very similar to an older view that periodically new species abruptly appear.

Ironically, the mathematical analysis of heredity that was to play an important role in formulating the evolutionary synthesis began as an argument against the transmission of small variations from one generation to the next. When Francis Galton examined the "swamping effect" that Fleeming Jenkin described, he concluded that any variations from the mean type of a species would be lost in following generations. Thus, in the long run organisms would tend to have common characteristics. Deviations from the norm were, by Galton's analysis, transient. His protégé, Karl Pearson, came to the opposite conclusion. Pearson argued against the assumption that the fate of variations should be measured against a fixed ancestral type. Rather, he said that variations from an organism's ancestors could cause lasting changes in future generations.

In contrast to Pearson, others argued that evolution could only be accounted for through large-scale mutations. Supporting their views with Gregor Mendel's newly discovered paper, William Bateson, Hugo de Vries, and Wilhelm Johannsen proposed saltatory accounts of evolution. Mendel's early work focused on the inheritance of discontinuous characteristics. For example, for some of his experiments he used pea plants that had either pure yellow or pure green peas. When these were crossed, he did not obtain peas of an intermediate hue, but only of the same pure yellow of one of the parents. This emphasis on inheritance of discrete characteristics supported the views of those who explained evolution in terms of gross mutations. Moreover, many were skeptical of the existence of natural selection. For example, as late as 1915 Johannsen saw no reason to assume natural selection played a role: "Selection of differing individuals creates nothing new; a shift of the 'biological type' in the direction of selection has never been substantiated" (Johannsen 1915, 609).

9.3 The Evolutionary Synthesis

In the second and third decades of the twentieth century, there was a return to gradualistic evolution. The inadequacies of Darwin's original formulation were overcome by reconceptualizing variation and natural selection. From the combination of experimental and theoretical approaches to understanding these processes, the evolutionary synthesis was born.

A major emphasis of the evolutionary synthesis was to explain natural selection in mathematical terms. Especially through the work of R. A. Fisher, J. B. S. Haldane, and Sewall Wright, inheritance at the level of populations was explained through statistical models. Despite the highly theoretical nature of their contributions, their work was not divorced from experimentation. Fisher's work in quantifying variation and natural selection typified this synthesis of mathematics and empirical research. Using Muller's experiments, he showed how variation by micromutation could be estimated. The result was an indication of the rate at which variations entered populations. Next, he was able to specify the degree of selection by environmental factors. Either by comparing the differential rate of increase of two or more populations or by measuring changes of gene frequency within single populations, he was able to propose a statistical model of natural selection.

For all of Fisher's interest in natural populations, he was still a mathematician with little training in biology. At the other end of the mathematical/experimental continuum was H. J. Muller. By exposing genes to mutation-inducing X-rays, Muller was able to show the influence of environment on variation. But before the various stands of the evolutionary synthesis could be braided together, populations had to be understood both statistically and as they occur in nature. Theodosius Dobzhansky, George Gaylord Simpson, and Ernst Mayr were particularly adept at this.

When we consider Theodosius Dobzhansky's background, it is easy to understand why he made such an important contribution to the evolutionary synthesis. His early training with Sergei Chetverikov emphasized population genetics. In 1927 he went to the United States to work with Muller's mentor, T. H. Morgan. By combining Morgan's stress on experimentation with the Russian statistical approach, Dobzhansky did pioneering work in the genetics of free-living populations. This is evident even in his early work on variations of *Drosophila* in isolated mountain ranges (Lewontin et al. 1981). More influential, however, was his *Genetics and the Origin of Species*, first published in 1937 (Dobzhansky 1951).

Among those stimulated by this book was George Gaylord Simpson. As a paleontologist, his contacts with colleagues within his profession contributed little to his training in evolutionary theory. Paleontologists in the 1930s were more concerned with descriptive systematics than with the foundations of evolution. Consequently, Simpson (1978, 114–115) relied on the writings of people outside his discipline, including Fisher, Haldane, Wright, and Dobzhansky. After the 1930s, he also had personal contacts with Mayr and Dobzhansky (Mayr 1980a, 455). The high degree to which he assimilated populational approaches is evident in his 1944 *Tempo and Mode in Evolution*. His conclusions were in marked contrast to the Mendelians whose position was dominant a few years earlier. He acknowledged the importance of variation, but rejected macromutations:

> Single mutations with large, fully discrete, localized phenotypic effects are most easily studied; but paleontological and other evidence suggests that these are relatively unimportant at any level of evolution (Simpson 1944, 94).

His view of natural selection was diametrically opposed to that of Johannsen. According to Simpson (1944, 96), "Selection is a truly creative force and not solely negative in action. It is one of the crucial determinants of evolution."

A third major figure in the history of the evolutionary synthesis began by studying neither bones nor fruit flies, but rather birds. Unlike most other ornithologists of his day, however, Ernst Mayr worked in population genetics. Though Fisher, Haldane, and Wright had little influence on his early work, he was quickly attracted to the Russian school because of its emphasis on naturally occurring populations and taxonomy (Mayr 1980b, 421–422). Mayr's (1942, 67) central concern was speciation, which he thought could be discussed without recourse to large-scale mutations:

> Speciation is explained by the geneticist on the assumption that through the gradual accumulation of mutational steps a threshold is finally crossed which signifies the evolution of a new species.

Similarly, natural selection played a key role for Mayr (1942, 293): "Even genes with a small selective advantage will eventually spread over entire populations."

9.4 The Evolutionary Synthesis and Extraterrestrial Life

9.4.1 Simpson on the Nonprevalence of Humonoids

Now that we have seen how Darwin's notions of variation and selection were reformulated in the 1930s and 1940s by synthetic evolutionists, we are prepared to see the extent to which these ideas influenced those who speculated on the possibility of extraterrestrial life. An appropriate starting point is Simpson's article from 1964, "The Nonprevalence of Humanoids."[3] In addition to drawing on evolutionary factors

[3] For a related article see Simpson (1962). See Dick (2013) in this volume on Simpson's skepticism about exobiology being a science.

we have already seen, Simpson discussed other considerations affecting the probability of life beyond Earth. Simpson agreed with others who held that it is likely that rudimentary macromolecules will form from chemical processes, which should occur throughout the universe. But, Simpson said, this did not commit him to the conclusion that many others, particularly physical scientists, had reached: that therefore more complex forms of life will also evolve.

To go beyond chemical to biological activity, Simpson (1964, 772) said three processes were required: "mutation, recombination, and selection." (While two of these three are familiar from earlier discussions, recombination did not play as significant a role in the evolutionary synthesis.) The critical question for Simpson was whether or not these three factors interact in such a way as to make advanced forms of life a likely outcome of the origin of pre-biotic molecules. He argued that there are two ways to approach this issue: through the actual history of life on Earth and from theoretical considerations. On both counts Simpson was not optimistic that the development of extraterrestrial life would be a common occurrence.

According to Simpson (1964, 773), paleontological evidence gave no indication for the inevitability of higher forms of life: "The fossil record shows very clearly that there is no central line leading steadily, in a goal-directed way, from a protozoan to man." The reason for this can be understood by considering the mechanisms by which life arose. Variations are introduced through mutation, and individual differences are increased even more through recombination. Through interactions between the organisms and their environments, however, only a fraction of these variations will become established in the population. Given the combination of the numerous factors responsible for the evolution of any given species, Simpson (1964, 773) argued that terrestrial life is very likely to be unique:

> The existing species would surely have been different if the start had been different and if any stage of the histories of organisms and their environments had been different…. Man cannot be an exception to this rule. If the causal chain had been different, *Homo sapiens* would not exist.

9.4.2 Dobzhansky Against the Convergent Evolution of Extraterrestrial Life

Though the thrust and conclusion of Dobzhansky's argument was similar to Simpson's line of reasoning, Dobzhansky discussed explicitly two issues that Simpson dealt with only in passing: chance and convergence in evolution. Dobzhansky isolated the same three factors of mutation, sexual recombination, and natural selection as central to evolution. But only the first two, he said, operate randomly; selection works against chance. While acknowledging that selection is probabilistic, he maintained that because it relates the individual and its environment through a feedback mechanism, it is an antichance process.

Dobzhansky's speculations about extraterrestrial life were consistent with the emphasis on mutation and selection in the early days of the evolutionary synthesis.

In spite of mentioning recombination as a factor in terrestrial evolution, when he committed himself to determining the characteristics that all life should possess, he mentioned only selection and mutation:

> Despite all the uncertainties inevitable in dealing with a topic so speculative as extraterrestrial life, two inferences can be made. First, the genetic materials will be subject to mutation. Accurate self-copying is the prime function of any genetic materials, but it is hardly conceivable that no copy erors [sic] will ever be made. If such errors do occur, the second inference can be drawn: the variants that arise will set the stage for natural selection. This much must be a common denominator of terrestrial and extraterrestrial life (Dobzhansky 1972, 170).

A second issue Dobzhansky addressed was convergent vs. divergent evolution. He pointed out that in many instances on Earth, organisms of disparate ancestries can have similar characteristics. As an example he noted that fish and whales have similar forms because they both adapted to an aqueous environment. Some have held that because this sort of convergent evolution is so common on Earth, the process may be universal. Therefore, the argument goes, extraterrestrials may well resemble life on Earth. Dobzhansky argues against this belief on the grounds that in many cases similar environments have resulted not in convergent, but in divergent evolution (Dobzhansky 1972, 168–169).

Dobzhansky concluded that, given the number of discrete interactions between organism and environment in the evolutionary history of the human species, the probability of humans evolving on another Earth-like planet is virtually zero. Even assuming another planet equipped with all life forms that existed in the Eocene period, the re-evolution of humankind would involve the same mutations and the same selection on the roughly 50,000 genes that would have changed in *Homo sapiens* since then (Dobzhansky 1972, 173).

9.4.3 Muller, Mutation, and Intelligence

When H. J. Muller addressed the question of life beyond Earth, it is not surprising that he emphasized the role of mutation. What may seem more remarkable is that someone who played such an important role in the evolutionary synthesis still kept room for interplanetary convergence of intelligence. He agreed with Simpson and Dobzhansky about the importance of chance:

> Just what steps will be taken at a particular point is sometimes a matter of accident: of what mutation manages to take hold, and then what combination of mutations, until some novel structure of [sic] manner of functioning is thereby brought into being that acts as a key to open up an important new way of living (Muller 1963, 80).

Though Muller believed a wide range of morphologies was possible, he thought intelligence was the natural product of evolution (Muller 1963, 83). One possible explanation for this view of limited directedness may be the influence of one of his students, Carl Sagan (Carlson 1981, 389). Though Carl Sagan worked with him only one summer, Carl Sagan said he "always kept in touch with him" (Cooper

1980, 42–43). By the time Muller wrote the above article, the young Carl Sagan had also published about life beyond Earth.

9.4.4 Mayr and the Importance of Chance

Though Mayr claimed his analysis was very similar to Simpson's reasoning, there were significant differences. Most obvious is Mayr's lesser emphasis on mechanisms of evolution. Instead, he provided an extended summary of the history of the human species. This may simply be a reflection of the time Mayr was writing. Dobzhansky, Simpson, and Muller all wrote first about extraterrestrials in the early 1960s. Mayr's article was written two decades later. The evolutionary synthesis may have been so well accepted by then that a detailed justification of its basic tenets would have seemed superfluous. Nevertheless, throughout the piece his discussion emphasized the importance of chance. Though his primary concern was to discuss the likelihood of extraterrestrial intelligence, not merely multicelluar life, he reached the same conclusions as Simpson.

Mayr amplified Dobzhansky's argument against the convergent evolution of intelligence by addressing the multiple emergence of vision on Earth. A common argument has been that evidence for the widespread occurrences of convergent evolution can be seen in the independent evolution of eyes numerous times. Mayr said that his own studies had drawn him to conclude that eyes have developed at least 40 different times in unrelated lineages. In contrast, intelligence has evolved only once on Earth (Mayr 1985, 28).[4]

9.4.5 Divergent Views of Extraterrestrial Life: Outside and Within the Evolutionary Synthesis

Speculations in the 1950s and 1960s by those not intimately involved with the evolutionary synthesis were not as similar to one another as the views we have seen thus far. For example, in 1953 the anthropologist Loren Eiseley focused on the uniqueness of humankind. After examining mimicry among terrestrial organisms, he concluded that this could not be used to argue for extraterrestrials resembling life on Earth: "No animal is likely to be forced by the process of evolution to imitate, even superficially, a creature upon which it has never set eyes and with which it is in no form of competition" (Eiseley 1953, 84).

Even more fascinating is Eiseley's description of the opinion of cytologist Cyril D. Darlington. In Eiseley's (1953, 81) words, Darlington "dwells enthusiastically

[4] For a summary of Mayr's debate with Carl Sagan about the likelihood of extraterrestrial intelligence, see Garber (2013).

on the advantages of two legs, a brain in one's head and the position of surveying the world from the splendid height of six feet." Eiseley failed to mention where Darlington stated this, and I was not able to find any relevant passages. I was able to find a potential partial explanation for why a contributor to the evolutionary synthesis would hold a view so different from those of the other four key figures we have seen. First, note that Darlington was writing several years before the others, and thus the evolutionary synthesis may not have solidified. Second, he favorably noted Henry Fairfield Osborn's orthogenesis and Bernhard Rensch's directed evolution, which held that evolution is teleological (Darlington 1969, 22).

Another anthropologist, William Howells, concluded in 1961 that extraterrestrial intelligence probably exists. He repeatedly made comments contrary to the mainstream views of the evolutionary synthesis. Several times he suggested that evolution is a volitional process. For example, Howells (1961, 239) said "Intelligent creatures will have made a choice, early in evolution, of a nervous system which is more open to fresh impressions: a brain which can learn." He thought such "choices" would likely lead to intelligence very human in appearance.

Oceanographer and ecologist Robert Bieri's conclusions were similar to those of Howells, but the basis for his belief was more explicit. Bieri opened his article with a quote from geneticist G. W. Beadle (1959), against which he argued. In opposition to Beadle's assertion that there are an extraordinary number of evolutionary pathways open to life, Bieri (1964, 452, 457) stressed the limitations imposed by the properties of chemical elements and by the "forms of energy" available. Such constraints, Bieri wrote, are evident in the finite range of variability of terrestrial organisms. Because of these restrictions, organisms beyond Earth will conform to the same patterns imposed on life as we know it. After considering a number of characteristics that he thought would be universal, he concluded with his prediction of the form of extraterrestrial intelligence: "If we ever succeed in communicating with conceptualizing beings in outer space, they won't be spheres, pyramids, cubes, or pancakes. In all probability they will look an awful lot like us" (Bieri 1964, 457).

Bacteriologist Francis Jackson and co-author astronomer Patrick Moore seemed less decided. At one point in their 1962 book they said it would be absurd to imagine that humans are constructed on an ideal model that would be followed on other planets (Jackson and Moore 1962, 115). Yet a few pages later they included a sentence that gives the opposite sense: "It is by no means impossible that, on planets closely similar to the Earth, chemical and biological evolution might have followed a strikingly similar course, even occasionally to the production of men" (Jackson and Moore 1962, 124). There is no absolute contradiction in holding both of these views. However, it is noteworthy that Jackson and Moore were comfortable with either possibility.

As we examine works through the mid-1980s, we continue to see a variety of perspectives. Dale Russell, a paleontologist, was reluctant to generalize from evolution on Earth to extraterrestrial conditions. In only one sentence did he suggest that the existence of extraterrestrial life is by no means a foregone conclusion. Within the context of astrophysical considerations, he concluded, "It would seem that the origin of life is intrinsically a much more probable event than the origin of higher intelligence" (Russell 1981, 270).[5] Another paleontologist, C. Owen Lovejoy, was more definitive than Russell. Lovejoy thought intelligence beyond Earth could be quite common, but he distinguished this from the much rarer occurrence of cognition. He said that because cognition as exemplified in humans is the result of our specific evolutionary path, the combination of events making cognition possible is highly unlikely to occur on most planets where intelligent life is present (Lovejoy 1981, 327).

In spite of the increasing trend to view the possibility of extraterrestrials in light of synthetic evolutionary theory, there remained concerns about some of the principles of its founding fathers. Gerald Feinberg and Robert Shapiro, a physicist and a biochemist, rejected the conclusion of space scientists Roger MacGowan and Frederick Ordway "that the majority of intelligent extrasolar land animals will be of the two legged and two armed variety" (MacGowan and Ordway 1966, 240). Instead they pointed out, citing Simpson, that great divergences from terrestrial forms are possible through the joint action of mutation and natural selection. Yet they also maintained that "we will undoubtedly encounter [convergent evolution] on other worlds" (Feinberg and Shapiro 1980, 411). Paleontologist David Raup certainly understood the force of arguments against convergence toward humanoid forms elsewhere, but he countered that too little is known about the process of convergence to make any definitive claims. The evolution of other humanoids may be highly improbable, he wrote, but not necessarily impossible (Raup 1985, 36).[6]

Two other tendencies were also present among nonphysical scientists: hard-headed theorizing and more free-form speculation. In a manner somewhat reminiscent of the earlier evolutionary systematists, James Valentine approached the question by distinguishing between microevolution, involving selection within a

[5] Paleontologist Peter Ward and astronomer Donald Brownlee came to a similar conclusion in their more recent book *Rare Earth* (Ward and Brownlee 2000).

[6] More recently, while evolutionary paleobiologist Simon Conway Morris was certainly conversant with the evolutionary synthesis, he emphasized the ubiquity of convergence, contesting the view that historical contingencies make it impossible to predict the likely forms of life on other worlds: "Rerun the tape of the history of life, as S. J. Gould would have us believe, and the end result will be an utterly different biosphere. Most notably there will be nothing remotely like a human, so reinforcing the notion that any other biosphere, across the galaxy and beyond, must be as different as any other: perhaps things slithering across crepuscular mudflats, but certainly never the prospect of music, no sounds of laughter. Yet, what we know of evolution suggests the exact reverse: convergence is ubiquitous and the constraints of life make the emergence of the various biological properties very probable, if not inevitable. Arguments that the equivalent of *Homo sapiens* cannot appear on some distant planet miss the point: what is at issue is not the precise pathway by which we evolved, but the various and successive likelihoods of the evolutionary steps that culminated in our humanness" (Conway Morris 2003, 283–284). Recent supporters of Conway Morris's emphasis on convergence include anthropologists Kathryn Coe, Craig T. Palmer, and Christina Pomianek, who noted, "It is now time to take the implications of evolutionary theory a little more seriously, and convergence is the norm" (Coe, Palmer, and Pomianek 2011, 209). They also maintained that "evolutionary theory, theoretically, should apply anywhere to anything that is living" (Coe, Palmer, and Pomianek 2011, 215), in a line of reasoning similar to biologist Richard Dawkins's argument for "Universal Darwinism" (Dawkins 1983).

population, and macroevolution, dealing with evolution above the species level. He concluded that the microevolutionary details of life on another planet, e.g., their genetic materials, would probably be very different from their terrestrial counterparts. But macroevolution, he thought, should yield extraterrestrial patterns of "multicellular diversification" similar to those seen on Earth (Valentine 1981, 253).

Imagination reigned in Bonnie Dalzell's exhibit of possible alien creatures for the Smithsonian. By hypothesizing planets that vary from Earth in gravity and temperature, she created environments that would foster a wide variety of land-bound, aquatic, and aerial life (Dalzell 1974). The combination of her artistic talent and her background in paleontology seemed more heavily weighted toward the former. Anthropologist Doris Jonas and psychiatrist David Jonas, by contrast, considered not only the morphology but also the possible perceptual worlds of extraterrestrials. Though their work was not as informed by theory as that of some of the contributors to the evolutionary synthesis, their basic tenet was the same:

> One thing is for certain: we have no reason to assume that evolutionary forces on other planets will produce forms or intelligences that are the same as ours even though the basic raw materials must be similar. Whatever chance factors combine to produce any form of life, infinitely more must combine to produce an advanced form (Jonas and Jonas 1976, 9).

9.5 Conclusion

Some of the most incisive arguments for and against the possibility of extraterrestrial life have come from scientists who have only a passing interest in the question. Their views typically were more influenced by their professional work in their own disciplines than by more extended contacts with others interested in life beyond Earth. Thus, when trying to evaluate their positions, it is vital to understand the conceptual frameworks of the disciplines from which these speculations arose. One such framework that played a major role in the 20th and 21st centuries is modern evolutionary theory. By examining the extent to which this paradigm has made an impact in various fields over the past few decades, we can better understand the diversity of views about extraterrestrial life held by scientists from a variety of disciplines.

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