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Edited by Woodruff T. Sullivan, III , John Baross
Excerpt
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Part I
History

1 History of astrobiological ideas

Woodruff T. Sullivan, III and Diane Carney
University of Washington

1.1 Overview

1.1.1 Why history?

The core questions of astrobiology are not new. They have always been asked and are central to Western intellectual history. How did life begin? How has it changed? What is the relation of humans to other species? Does life exist elsewhere? If so, where might it be and what is it like? Although these questions are ancient, what *is* new are the tools at hand to search for answers, ranging from robotic spacecraft to genome sequencing, from electron microscopes to radio telescopes. These tools and other factors (see the Prologue and Chapter 2) appear to have brought astrobiology to a point where it is gelling into something qualitatively different – our first sound attack on these questions. But is this so? Or is today no different from any other time in the past few centuries?

In every era, including our own, scientists can do no more than tackle questions with the best tools available, apply the best insight they can muster, and struggle to fashion a consensus as to the nature of the world. In this manner our understanding has progressed, for example, from the "animalcules" that van Leeuwenhoek described three hundred years ago to the richness of contemporary microbiology. To understand such a thread as it meanders through history, we need to document more than the accumulation of facts. When evaluating a given episode, historians of science look carefully at evidence of not only the science itself, but also of the larger enveloping context. At each step along the way, the scientific enterprise has always been shaped by metaphysics, doctrines, and predilections as received from philosophy, religion, and society. But, you say, this is all irrelevant to *today's* science – have we not rid ourselves of such prejudices and biases? Think again! Try to get funding for a project working on the hypothesis that Earth was visited by intelligent beings 100,000 years ago, or that DNA does not carry the esssence of the genetic code, or that microbes populate the Venusian surface, or that *Homo sapiens* are the predestined outcome of the evolutionary process. Without arguing for the validity of any of these notions, we only wish to demonstrate that prejudices and biases are still very much with us. History has shown that the greatest breakthroughs often are made by those who somehow recognize, resist, and surmount the prejudices of their own time. History of science tells great stories and is intellectually fascinating, but it can also be "useful" to practicing scientists in providing some insight as to how the chalklines of today's playing field have come to be where they are.

Studying the development of astrobiological ideas has a particular allure because the associated science has often been "on the edge" of uncertain *epistemological*[1] status. Witness evolutionary biologist George Gaylord Simpson's famous remark in the 1960s that exobiology (as the field was then known) was the only science that had yet to prove that its subject matter existed! Furthermore, scientific views on these fundamental questions have often touched on religious doctrine, creating political and social pressures. Many scientists are attracted to astrobiology precisely *because* it is on the edge of our current knowledge in exciting ways; historians of science also find this fascinating as they try to understand how the practice of science has worked.

1.1.2 Synopsis

Through 2500 years of Western history astrobiological ideas have moved from the realm of natural philosophy to (Christian) theology to science; from pure metaphysics to empiricism. Ideas on extraterrestrial life have

[1] *Epistemology* is the branch of philosophy dealing with knowledge, in particular how we justify that we *know* something.

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ranged from us as the special product of all creation to the plurality of worlds, a Universe in which every star is a Sun with peopled planets. Ideas on the origin of life have shifted from pre-existence theory and spontaneous generation everywhere all the time to a series of chemical and physical events in the distant past. Our cosmological worldviews have also shifted, from geocentric to heliocentric to no special location in the Universe. Historian Steven Dick (1996; Sections 2.1 and 2.4) has stressed the intimate connection between cosmological ideas and attitudes toward extraterrestrial life. We will see that as our ideas have evolved regarding the cosmos and where we fit in it, our rating of the prospects for extraterrestrial life and its nature have also changed.

This chapter has two parts. The first (Sections 1.2– 1.9) sweeps over the history of ideas on extraterrestrial life, and the second (Sections 1.10–1.15) covers the history of ideas on spontaneous generation and the origin of life. In each part we endeavor to give the overall development of the ideas leading to today's astrobiology, but details can be afforded for only a few illustrative "episodes." For further details and entry into the literature the best accounts are the books by Dick (1982), Crowe (1986), Dick (1996), Dick and Strick (2004), Guthke (1990), Farley (1974), Fry (2000), and Strick (2000), which have been invaluable resources to us. This chapter takes the story through the first half of the twentieth century, while Chapter 2 focuses on the second half of the twentieth century. In addition, many individual chapters also cover developments of the past few decades as the basis for current views.

1.2 Peopled worlds in antiquity and the Middle Ages

1.2.1 The atomists versus Aristotle

There is a tendency to think of the ancient Greek philosophers as a mostly unified group with views veering little from Plato and Aristotle, whose ideas came to dominate Western philosophy. But in fact, over the centuries in which Greek philosophy flourished (sixth to third centuries BC) there were many schools of thought.[2]

One minority school was *atomism*, active in the fifth through third centuries BC, and represented most prominently by Leucippus, Democritus, and Epicurus. For the atomists the cosmos was infinite in extent, and completely filled with an infinite number of microscopic *atoms* (the Greek word means "indivisible"), all continually in motion and suffering collisions that produced all observed physical and chemical effects, whether the taste of sweetness or the formation of the Moon. Since collisions of these atoms had caused the formation of our Earth, atomists saw no reason why such processes should not be active elsewhere. This then implied that there were an infinite number of worlds being created (and destroyed) all the time. These worlds were of a great variety – some had moons, others not; some were forming, others were dying; some were peopled, others not. Thus a theory of the small-scale structure of matter led logically to the existence of extraterrestrial life of many kinds.

The atomist and Epicurean philosophy was passed to later Europe primarily through the long first century BC poem *De Rerum Natura* (*On the Nature of Things*) by the Roman philosopher Lucretius. He argued for the uniformity of nature and its tendency to complete all possible processes to the fullest. The historian Arthur Lovejoy (1936) has called this the *principle of plenitude* and it was to be central in many later arguments, especially when applied by Christian theologians with regard to God's will. Lucretius argued that nothing was unique:

> It is in the highest degree unlikely that this earth and sky is the only one to have been created... Nothing in the Universe is the only one of its kind, unique and solitary in its birth and growth... You are bound therefore to acknowledge that in other regions there are other earths and various tribes of men and breeds of beasts. *De Rerum Natura*, Book II, lines 1055–7, 1074–8 (Latham, 1951).

But despite the atomists, the philosophies that were to overshadow all others were those of Plato and his student Aristotle (fourth century BC). Of most relevance for the present discussion is Aristotle's *De Caelo* (*On the Heavens*), in which he laid out his familiar scheme of a finite cosmos with a spherical Earth at the center. Mundane materials were composed of the corruptible four elements – earth, air, fire, and water – while celestial realms were made of a perfect fifth element, the *quintessence*, or *æther*. Each of the four elements had its own inherent "natural motion" striving to take it to its "natural place": earth and water

[2] One of the more famous cases of a minority cosmological view was that of Aristarchus of Samos, who in the third century BC developed a heliocentric system with a rotating Earth and the planets moving around a central Sun. The theory was rejected on very rational grounds, namely the lack of any wind that would be caused by a moving Earth, and also the lack of any shifting in the stars' positions as a consequence of the Earth moving about.

downwards, air and fire upwards, and æther in eternal circles. The Earth was surrounded by heavenly spheres, each of which carried one of the seven planets (the five naked-eye planets of today plus the Sun and Moon). The outermost (but still finite) sphere carried the stars. Although Aristotle did not directly comment on the possibility of extraterrestrial life on any of the known planets, his metaphysical system allowed for the existence of only these seven planets. Nor could one have a second, similar cosmos outside of ours because of a logical contradiction: if one had *two* sets of nested spheres, a given mass in either one would be conflicted as to which of the two centers controlled its natural motion.

1.2.2 The scholastics

Beginning in the eleventh century AD, in the great universities and monasteries of the Middle Ages, there thrived *scholasticism*, a catchall term for the philosophical systems and arguments of Christian intellectuals who sought to reconcile the Bible and Aristotle, theology and philosophy, faith and reason. The possible existence of a *plurality of worlds*, as the topic came to be called, was batted back and forth as one of the central areas of doctrinal debate. In the thirteenth century, Thomas Aquinas craftily argued that yes, God's omnipotence meant that he certainly *could* have created many worlds, but that in fact he had not because there was more goodness in a unitary, perfect world (ours) than in many imperfect worlds. These sorts of things were not idle chatter – one's opinions on such matters did matter. For instance, as a result of battles between the Faculties of Arts and of Theology at the University of Paris, in 1277 Bishop Etienne Tempier issued a *Condemnation of 219 Propositions*, adherence to any of which was grounds for excommunication. Two hundred and eighteen of these heresies concerned the intelligence of angels, the mobility of God, the motions of the heavens, the nature of the soul, the relative degree of happiness in this life compared to another, whether pleasure in sexual acts impeded use of the intellect, whether Christian law impeded learning, etc. Amidst all this, Heresy Number 27 read: "That the first cause [God] cannot make more than one world," a teaching that many were espousing based on strict Aristotelian principles of a single, Earth-centered cosmos. But establishment Christianity, modifying many of Aristotle's principles, reasoned at this time that outside of *our* set of spheres, there could well be other worlds, perhaps extending indefinitely (given the immensity of God), perhaps even obeying different sets of laws.

Almost all of these commentators on the plurality of worlds did not, however, address the question of *life* on those worlds. One exception was the theologian Cardinal Nicholas of Cusa (on the Moselle River), who espoused the cause of extraterrestrial life in his marvellously titled *On Learned Ignorance* (1440), in which the word *learned* should be construed as pronounced both possible ways – the student both learns the boundaries of his ignorance and becomes wiser for having done so. This book is most famous for its prescience (to modern eyes) in stating that "the world-machine has its center everywhere and its circumference nowhere," characteristics of Cusa's boundless Universe and God. Cusa also argued that other planets would be innumerable, and would have inhabitants very different from Earth's. The nature of these inhabitants would be determined by the influence ("in-flowing") of the stars, just as for life on Earth.

1.3 Copernicanism: Earth is a planet

The Church (and its favorite natural philosophers such as Aristotle) continued to control the establishment for centuries more, but the Renaissance and the Protestant Reformation sparked ever more unorthodox thinking. In 1543, while on his deathbed, the Polish canon Nicolaus Copernicus oversaw the final proofs of his magnum opus *De Revolutionibus Orbium Cœlestium* (*On the Revolutions of the Heavenly Spheres*), a complex treatise arguing that the Sun, not the Earth, is the center of the Universe. His motivation was not that the dominant theory of Ptolemy[3] was inadequate to explain the data, but rather a philosophical predilection that the Sun, that Great Luminary and source of all heat and light, should be identified with God. His new geometric scheme could adequately reproduce the planets' sky positions as well as Ptolemy's, but its details were not, as is often erroneously stated, any simpler (Kuhn, 1957: Chapter 5). This shift from a geocentric to a heliocentric system was far more than a mathematical transformation – its philosophical and cosmological, and indeed astrobiological, implications were, and continue to be, profound. The Earth now

[3] Claudius Ptolemy, second century AD Alexandrian scholar, brought the Aristotelian scheme to its apotheosis in his *Almagest*, which became the authority for all of astronomy and cosmology for 1400 years.

was displaced from the center of the cosmos and it *moved* at a stupendous velocity (a very problematic notion at the time, but one that eventually led to physics as we know it). Furthermore, the Earth was now relegated to being only one among six planets, all orbiting the Sun. Gone was the Aristotelian dichotomy between the mundane and the celestial. Finally, Copernicus removed the stars to much greater distances,[4] and thus allowed the possibility that the Universe was vast, perhaps infinite. The stars could then be imagined as other suns, which then, by the principle of plenitude, were expected to have their own systems of circling planets (a proposition that took 452 years to verify with the discovery of the first extrasolar planet – see Chapters 2 and 21).

The implications for extraterrestrial life were enormous. Since the other planets in our system were now analogous to Earth in all respects, why should they not be inhabited, too? And likewise for the putative planets attendant to distant stars. The Earth became typical, not special, and this notion has since become enshrined as the *Copernican Principle*. It has become dogmatic for astronomy and cosmology ever since; still today, scientific models or theories that place the Earth (or the Sun, or (later) our Galaxy) in any kind of unusual situation are at best strongly suspect, often not even debated. The Copernican Principle has also been influential to this day in the realm of extraterrestrial life and indeed in all of biology, but with a more checkered history.

European culture, which had done very well over its entire history with a geocentric cosmos, was not easily swayed by one book, and it took most of two centuries before all educated persons accepted that Earth had indeed moved off-center. Giordano Bruno (1548–1600) was a flamboyant Italian Dominican monk who left his order, traveled widely, and made enemies wherever he went. His *On the Infinite Universe and Worlds* (1584) was the first major study to grab Copernicus's (and Lucretius's) ideas and run with them full tilt. Arguing that there was no absolute truth and that all things (and locales) were relative, Bruno described a Universe boundlessly filled with stars and their populated planets, suffused by an infinite God. These non-Aristotelian ideas and heretical teachings, including that Jesus Christ was not divine, caught the attention of the Inquisition in Rome and eventually led to Bruno's death by burning. We should not then be surprised that his contemporary Galileo did not seriously touch the question of extraterrestrial life. Another contemporary, Johannes Kepler, safely ensconced in Germany away from the Inquisition, did, however, argue strongly for an inhabited Moon and other bodies. In his *Somnium* (*Dream*) (1634), which details a trip to the Moon, Kepler deduces from observations the nature of the Moon's environment and inhabitants. In a similar vein the English clergyman John Wilkins in 1638 published the widely read *Discovery of a World in the Moone*. He argued for the Copernican system and for an inhabited Moon, for "as their world is our Moone so our world is their moon" (cited by Dick 1982: p. 100). The notion of extraterrestrial beings was catching on among academics, but not until much later did a popular book give much broader currency to the idea.

1.4 Plurality of worlds: Fontenelle and his *Conversations* (1686)

In the late seventeenth century Bernard le Bovier de Fontenelle wrote a slight book that had enormous influence on the reading public in Europe. *Conversations on the Plurality of Worlds* (*Entretiens sur la pluralité des mondes*) was published in Paris in 1686 and over a century ran through almost a hundred editions in many languages. By coincidence it appeared within a year of Newton's masterpiece *Principia*, but there the similarities end. In the traditional manner Newton wrote a complex treatise in Latin, aimed at his fellow natural philosophers (the term then used for scientists). Fontenelle, on the other hand, invented a new genre, writing his 100-page volume in the vernacular and with an engaging, witty style aimed at a broad audience. As he says in his Preface, "I've tried to treat philosophy in a very unphilosophical manner."[5] Under the guise of a series of moonlit conversations with a charming but unschooled marquise, Fontenelle lays out the latest in astronomical knowledge and argues strongly for the existence of inhabitants not only on the planets we know, but also on presumed planets circling every star in the sky. Because of this book's long influence, as well as its delightful arguments and style, we will discuss it here in some detail.

[4] Copernicus was forced to place the stars at a very large distance because otherwise the Earth's annual orbital motion would have caused perceptible annual shifts in the apparent positions of all stars, which in fact were not observed.

[5] All quotations are from the 1990 translation by H. A. Hargreaves (Berkeley: University of California Press).

Fontenelle (1657–1757) was a playwright and writer of some success in Parisian circles, but by far his most famous work, written when he was only 29, was *Conversations*. This served as his entrée to popularity as well as to the Academy of Sciences, where he soon became Perpetual Secretary, a post he held for over four decades. His eulogies (*éloges*) for deceased members were widely read and admired for their ability to capture the essentials of both personality and scientific contributions. Fontenelle was also a central figure in that mainstay of the French Enlightenment, the fashionable *salon* circuit, consisting of regular intellectual gatherings run by aristocratic women. The device in *Conversations* of dialogue centered on a woman is thus no surprise.

The book has chapters devoted to each of six evening lessons between a philosopher and his aristocratic hostess at a country chateau. Fontenelle immediately captures our interest with his description of a beautiful young woman with a vivacious intelligence, albeit little knowledge of the natural world. She and the philosopher engage in a lively repartee, often flirtatious, that deals with many basic philosophical and cosmological questions of the day. At the start we find a brilliant description of the nature of scientific investigation (then called philosophy):

> "All philosophy," I told her, "is based on two things only: curiosity and poor eyesight;[6] if you had better eyesight you could see perfectly well whether or not these stars are solar systems, and if you were less curious you wouldn't care about knowing . . . The trouble is, we want to know more than we can see . . . So true philosophers spend a lifetime not believing what they do see, and theorizing on what they don't see, and it's not, to my way of thinking, a very enviable situation." (p. 11)

Fontenelle is much taken by the revelations garnered through the seventeenth century's premier "mathematical instruments" (as they were known), the telescope and the microscope. The telescope had made (habitable) worlds out of planets and the microscope, especially in the recent works of the Dutchman Antony van Leeuwenhoek, had uncovered microcosms in a drop of water (Section 1.12).

> There are as many species of invisible animals as visible. We see from the elephant down to the mite; there our sight ends. But beyond the mite an infinite multitude of animals begins for which the mite is an elephant, and which can't be perceived with ordinary eyesight. We've seen with lenses many liquids filled with little animals that one would never have suspected living there . . . Even in very hard kinds of rock we've found innumerable small worms, living in imperceptible gaps and feeding themselves by gnawing on the substance of the stone . . . Even if the Moon were only a mass of rocks, I'd sooner have her gnawed by her inhabitants than not put any there at all. (pp. 44–5)

The crux of Fontenelle's reasoning rests in the Copernican picture of the Earth itself as only one among the planets circling the Sun, implying that the stars are themselves other suns. Although fully a century and a half had passed since Copernicus, his ideas were still known to only a portion of European readers. Fontenelle then employs the principles of plenitude and of the uniformity of nature to assert that the existence of all these other suns surely implies that, just as for our Sun, they have their own planetary retinues (Fig. 1.1). Likewise, these planets surely have their own inhabitants, as does our Earth. Our world exhibits a profound fecundity and diversity and it would certainly be wasteful of Nature to accomodate all these other locales without populating them. Yet in the end Fontenelle realizes that he may have extrapolated too far:

> "Listen, Madame," I answered, "since we're inclined to keep mixing foolish lovetalk with our serious conversation, the logic of mathematics is like that of love. You can't grant a lover the least favor without soon having to grant more, and still more, and in the end it's gone awfully far. Well, if you grant a mathematician the least principle, he'll draw a conclusion from it that you must grant him too, and from that conclusion another, and in spite of yourself he'll lead you so far you'll have trouble believing it." (p. 64)

These ideas were dangerous in a nation ruled by a strong king (Louis XIV) and a Church that still officially banned Copernicus's teachings – Fontenelle only escaped censorship because of good connections and the lighthearted, sometimes veiled manner in which he treated unorthodox ideas. Although he never once mentioned the role of God, he also made no explicitly antireligious arguments. To further cover his bets, in the preface he points out that it should not be concluded that the probable inhabitants of planets are

[6] The original French felicitously reads: *l'esprit curieux et les yeux mauvais* ("a curious spirit and bad eyes").

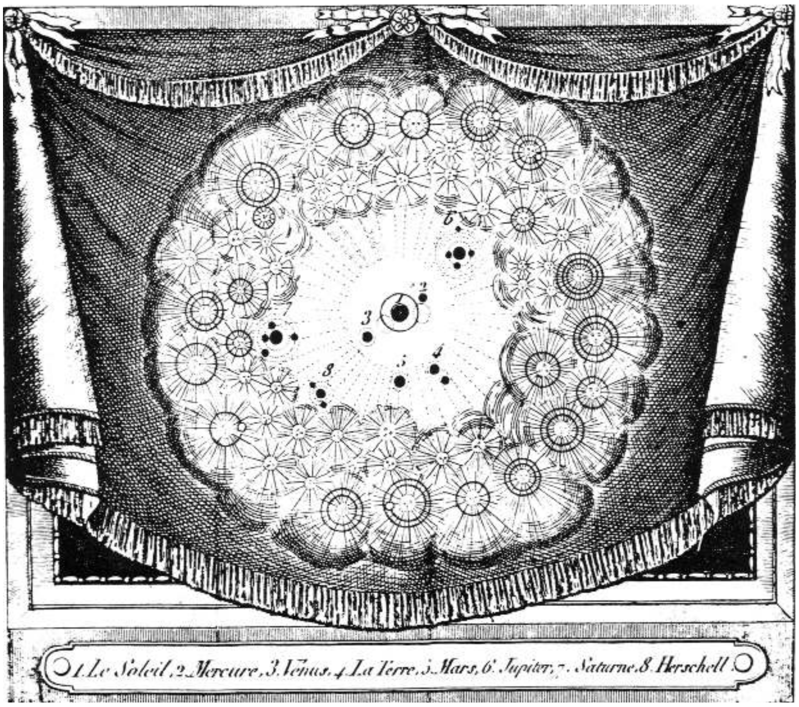

FIGURE 1.1 The frontispiece for Fontenelle's influential book *Conversations on the Plurality of Worlds* (1686), which went through over a hundred editions. The Sun is circled by numbered planets (some of which have moons circling them); but note that all of the distant stars *also* have planetary orbits girding them. This version is from an 1821 French edition, and includes the new eighth planet, called for a while (in France) Herschel, after William Herschel, who discovered what came to be called Uranus in 1781.

"sons of Adam," that is, men. Such men would then need Salvation, which would raise vexing theological questions. Rather, Fontenelle says that Nature's intrinsic diversity will guarantee that they are wholly *unlike* men. Fontenelle had no desire to risk martyrdom.

Fontenelle was an important transition figure between the so-called Scientific Revolution and the Age of Enlightenment, when rationality reigned and intellectuals were the heroes. *Conversations* influenced a whole genre of utopian novels and imaginary voyages – witness Christiaan Huygens's posthumous *Cosmotheoros* of 1698,[7] Jonathan Swift's *Gulliver's Travels* of 1726, and Voltaire's *Micromégas* of 1752.[8] Fontenelle's ideas on extraterrestrial life were the ineluctable result of this new exciting process, called *science*, that he saw as key to society's progress. By applying reason, always tempered with a healthy skepticism, to the latest observations, natural philosophers were producing a Universe in which the Earth and its inhabitants were typical, not uniquely special. Geocentrism was *passé*. This stance led to a relativism radical for its time, but one that rings modern to the ears of astrobiologists in the early twenty-first century. As he wrote:

> The same desire that makes a courtier want to have the most honorable place in a ceremony makes a philosopher want to place himself in the center of a world system, if he can. He's sure that everything was made for him, and unconsciously accepts that principle which flatters him. (p. 17)

And when the marquise asks whether, despite Earth being so small compared to Jupiter, we can be seen from the Jovian realm:

> There'll be astronomers on Jupiter who, after taking great pains to construct excellent telescopes,... will finally discover in the heavens a tiny planet that they've never seen before... [but] they wouldn't have the faintest suspicion that it could be inhabited. If anyone were to think of it, heaven knows how all Jupiter would laugh at him. It's possible we're the cause of philosophers being prosecuted there who have tried to insist that we exist. (p. 57)

7 *Cosmotheoros, or New Conjectures Concerning the Planetary Worlds, Their Inhabitants and Productions*, was very much modeled on *Conversations*, although with much more technical analysis. For example, Huygens argued that any planets circling other stars would be unobservably faint, and showed in detail how to estimate the distance to the stars (he calculated 0.4 light-years for Sirius, ~20 times too close, but his method was sound).

8 *Micromégas* is a satire aimed at the pretensions of humans. The title character is a 120,000-foot tall inhabitant of a planet of the star Sirius who tours the planets of our solar system, finding varied inhabitants wherever he goes.

The marquise muses:

> I could imagine with pleasure these telescopes aimed at us, as ours are toward them, and the mutual curiosity with which the planets consider one another and ask among themselves, "What world is that? What people live on it?" (p. 57)

On another occasion the philosopher answers a query as to what sort of beings might inhabit the Moon:[9]

> Honestly, Madame, I've no idea. If it could be that we were rational, yet weren't men, and if besides we happened to live on the Moon, could we possibly imagine that down here in this place there were bizarre creatures who called themselves the human race? Would we be able to fantasize something that has such mad passions and such wise reflections; a life so short and views so long;... such a strong desire for happiness and such a great inability to achieve it?... We look at ourselves incessantly, and we're still guessing at how we're made. (p. 32)

Fontenelle also consistently applied his skepticism to more than claims about the natural world. In a warning to his readers (also applicable to the reader of this present chapter!), he compared historic "facts" with scientific ones, arguing that neither should be considered true or false, but rather colored in many shades of epistemic gray. He reckoned that the existence of Alexander the Great had sufficient evidence that it should be considered more probable than the existence of planetary inhabitants, but that the evidence for many other accepted points of history was in fact *less* than that for extraterrestrials.

1.5 Natural theology

As modern science took shape in the seventeenth century and extended its influence, a majority of its practitioners were either Christians or *deists*, who believed in a God that created the Universe, set it running according to natural laws, and thereafter did not interfere. Many reconciled their religious beliefs and their findings from natural philosophy by learning of God (and even proving his existence) through study of his handiwork manifest in the "Book of Nature." As the mechanical Universe of Isaac Newton took hold in the eighteenth century, this approach became known as *physico-theology* or later *natural theology*, taking its place alongside *scriptural* or *revealed theology* based on the Bible. Although the great philosophers David Hume and Immanuel Kant presented cogent logical analyses against these "arguments from Design," natural theology had an important influence on mainstream science throughout Europe and America as late as the mid-nineteenth century,[10] with particular persistence and strength in Britain. The English poet Alexander Pope expressed the spirit of the age in his *Essay on Man* (1734).

> He, who thro' vast immensity can pierce,
> See worlds on worlds compose one universe,
> Observe how system into system runs,
> What other planets circle other suns,
> What vary'd Being peoples every star,
> May tell why Heav'n has made us as we are.

Numerous books tied together natural theology and the plurality of worlds. An early one was William Derham's *Astro-Theology: or a Demonstration of the Being and Attributes of God, from a Survey of the Heavens* (1715). Derham, a countryman and follower of Newton's, argued that the more magnificent and fruitful the Universe (as evidenced by extraterrestrial inhabitants), the greater was God's demonstrated glory and providence (Dick 1982: 151–4). A German study called *Hydrotheologie* (*Water Theology*) in 1734 by J. A. Fabricius pointed out that ice's lower density than water, allowing aquatic creatures to survive in cold weather, was a clear example of divine prescience (Brooke 1991: 197). A century later Thomas Chalmers, a Scottish minister, wrote an influential treatise entitled *A Series of Discourses on the Christian Revelation, Viewed in Connection with the Modern Astronomy* (1817). One argument of particular interest to today's astrobiology concerned microscopic realms, which, Chalmers said, revealed worlds and "tribes of animals" every bit as unknown and vast and fascinating as those seen in telescopes. Infinity in one direction was balanced by infinity in the other. Since God's beneficence had applied to these realms even before we were aware of them, so God cared for humans even though we might be insignificant on a cosmic scale.

[9] In the end Fontenelle concluded that the Moon, unlike the planets, was *not* inhabited, because he took it to have no atmosphere. Conversely, based on various observational evidence, Kepler and Wilkins had earlier concluded the opposite, that the Moon indeed *did* have an atmosphere and was therefore likely inhabited.

[10] Even today, those who promote the necessity, based on scientific findings, for so-called Intelligent Design are very much working in this tradition. For a remarkable example, see *The Privileged Planet* by Gonzalez and Richards (2004).

One minority view in the mid-nineteenth century came from the Cambridge don and polymath William Whewell, whose *Of the Plurality of Worlds* (1853) argued that Earth and its intelligent life were probably unique. Whewell used the latest astronomical data to point out that most stars seemed to be in binary systems, making orbits unstable and conditions on any planets highly variable. Many stars also were variable in intensity and seemed to be of lower mass than the Sun. Furthermore, physical conditions on the other planets in our own system were extreme, not at all suitable for life. Whewell's book sparked a storm of negative reviews and rejoinder books whose titles tell all: *The Universe No Desert; The Earth No Monopoly* (1855) by William Williams of Boston, for example, and *More Worlds than One: the Creed of the Philosopher and the Hope of the Christian* (1854) by David Brewster, a leading English physicist.

1.6 Two nineteenth-century revolutions

Attitudes toward extraterrestrial life were profoundly affected during the nineteenth century by developments in astronomy, geology, and biology. By century's end the standard picture was of a Solar System that formed long ago, of an Earth that had a long history that could be read through the study of rocks and fossils, of each planet having a (finite) history and future, and of many stars confirmed (through their chemical make-up) to be other suns, likely therefore to have their own life-bearing planets. On the biological side, Charles Darwin's theory of evolution by natural selection (1859) revolutionized biology and provided an entirely new context in which to think about the origin of life and about extraterrestrial life.

1.6.1 The nebular hypothesis and the start of astrophysics

The notions of a *changing world*, as well as of a *very old world*, entered the geological and astronomical worlds around the turn of the eighteenth into the nineteenth century. Before this time the world was considered largely static since the Creation about 6,000 years ago (or at least since Noah's Flood not too long thereafter). Geologists like the Scot James Hutton and later Charles Lyell (a close friend of Charles Darwin) came to startling new conclusions based on detailed fieldwork and a new principle of *Uniformitarianism* – in order to explain the present state of Earth, one should appeal to no more than the processes we *now* observe on Earth (e.g., erosion and sedimentation from rivers), not to past catastrophes such as the Flood (*Catastrophism*). But to build mountains and continents at today's estimated rates necessarily implied previously unimaginable lengths of time, counted in the millions of years and probably much longer – as Hutton famously put it: "we find no vestige of a beginning, no prospect of an end." Furthermore, fossil animals and plants were found to correlate well with sedimentary strata, implying that the past had also witnessed an ever-changing suite of species – a profound change in the *living* world, too. For the first time, the Earth and its life were perceived as not in stasis since Creation, but they had a scientific *history*. In 1837 Lyell even found these past paleontological worlds in some sense better than considering life on other planets.

> Geology . . . has demonstrated the truth of conclusions scarcely less wonderful [than the astronomer's], the existence on our own planet of many habitable surfaces, or worlds as they have been called, each distinct in time, and peopled with its peculiar races. (Crowe, 1986: 223)

On the astronomical side, a changing Cosmos was likewise coming into its own. Pierre-Simon Laplace (1749–1827), sometimes called the "Newton of France," was a mathematician and natural philosopher who analyzed the details of how planets gravitationally influence each other's orbits, in the process largely inventing the field of celestial mechanics. He had been able to mathematically demonstrate that the Solar System was extremely stable, i.e., that the perturbations on each planet's orbit from its fellows did not lead to disastrous changes with time, only oscillatory changes. But how did the planets come to be? In 1796 Laplace proposed in his masterpiece *Exposition du Système du Monde* (*Introduction to the System of the World*) (which remained authoritative for the next half-century) what became known as the *nebular hypothesis*. He was impressed with the cataloguing of thousands of *nebulae*[11] by German/English astronomer William Herschel (1738–1822), the greatest observer of his age and perhaps of all time, as well as with Herschel's

[11] *Nebula* in Latin means mist or cloud, and was applied to anything that looked diffuse in a telescope, unlike the sharpness of a star. Although obsolete, the term survives today in the names of a huge variety of objects, e.g., Orion nebula (now known to be hot gas and young stars), Crab nebula (a supernova remnant), planetary nebula (hot gas ejected by an old low-mass star (nothing to do with a planet!)), and Andromeda nebula (a galaxy).

speculation that these fuzzy patches consisted of a shining fluid out of which stars formed. Laplace sketched the idea that the Sun and planets formed from a cloud of hot gas collapsing under its own gravity. The Sun formed in the center and had a vast residual atmosphere surrounding it. The individual planets formed because the collapsing cloud eventually broke up into a series of gaseous rings, each of which gradually cooled off and coagulated into a planet. Presuming that the initial cloud slightly rotated, conservation of angular momentum would mean that all the planets (and their moons) would rotate and revolve in the same sense and in a flattened, aligned manner, i.e., all planetary orbits would lie closely in one plane (as observed). If the stars were other suns, Laplace's scheme boded well for a plurality of (inhabited) worlds.

Schaffer (1989) has shown how the nebular hypothesis lay dormant until the 1830s when it was resurrected,[12] mainly for political purposes more than astronomical ones: the notion of the formation of the Sun and planets by natural law, a type of astronomical *progress*, was used to legitimize the goals of the British reform movements, which sought to show that *social* progress was also natural and inevitable. The key book in this regard was *Views of the Architecture of the Heavens* (1837) by John Nichol, a Scottish political economist and astronomer. This book influenced the philosopher Herbert Spencer (see Section 1.7.1), as well as Charles Darwin.[13] By 1850, however, leading British scientists, for fear of their credibility, had disavowed the link between the nebular hypothesis and political matters.

A key aspect of the nebular hypothesis as it was developed during the nineteenth century (especially once thermodynamics became established in the 1840–70 period) was that the outer gaseous rings would cool off fastest (being farther from the Sun) and therefore form the first (molten) planets, which would continue to cool off and eventually solidify. Based on this model and the current measured rate of heat loss, Joseph Fourier (in 1819) and, starting in the 1850s, William Thomson (later Lord Kelvin) calculated that the Earth simply could not be as old as the geologists had deduced. The physicists' derived values ranged up to 300 Myr, but no higher. Such ages had all the authority of physics, but were nevertheless unacceptable to the geologists and of great concern to Darwin (Section 1.6.2), who required a much longer time to effect evolutionary change (Brush, 1996).

Using ideas that eventually became enshrined in the Second Law of Thermodynamics, one could also see that the Earth would continue to cool down until the inevitable high-entropy "Heat Death." As Thomson put it in 1852:

> Within a finite period of time past, the earth must have been, and within a finite period of time to come the earth must again be, unfit for the habitation of man as at present constituted. (Brush, 1996: 10)

Like geology before, physics and astronomy were furnishing the Earth with a past history (as well as a finite future). Moreover, calculations for the Sun indicated that it could be no older than 20–30 Myr – assuming it was powered by the gravitational energy that its material lost as it collapsed.[14] On these ideas one concluded that outer and/or smaller planets were today both older and cooler than inner planets – Mars was older, cooler, and nearer death than Earth, and the Moon was completely dead. In a popular book (Langley, 1884: 167–72) one finds the striking juxtaposition of three illustrations meant as analogues: the extremely wrinkled hand of an old woman, a withered apple, and mountainous terrain on the Moon! This thinking would prove important in late-nineteenth-century ideas about life on Mars (Section 1.7).

Another major trend in astronomy affecting attitudes toward the prospects for extraterrestrial life was the rise of what came to be called astrophysics. Until the mid-nineteenth century astronomy was concerned almost exclusively with measuring and trying to understand the positions and changes in positions of planets and stars – there was little else one could do with a telescope. In 1815, however, German optician Joseph Fraunhofer had first analyzed in detail hundreds of dark absorption lines in the solar spectrum, produced by passing sunlight through a slit and a prism. These lines were shown to indicate, by comparison with laboratory flame sources, the presence in the Sun of familiar elements such as sodium and magnesium.

[12] The term *nebular hypothesis* was not actually coined until 1833, by William Whewell in England.

[13] Historians debate the degree of influence that early-nineteenth-century ideas of astronomical evolution had on Darwin's thinking, but most conclude there is definitely a sibling relationship, if not a maternal one. (Brush, 1996: 62–75.)

[14] It would not be until the twentieth century that these problematic lifetimes for the Earth and Sun would be made obsolete by new discoveries: (1) an additional source of heat in the Earth's interior (from radioactive elements), and (2) nuclear reactions powering the Sun via conversion of mass into energy.