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Cosmic evolution: the context for astrobiology and its cultural implications

Steven J. Dick

Division of Space History, National Air and Space Museum, Smithsonian Institution, NASM 3559, MRC 311, Washington, DC 20013-7012
e-mail: stevedick1@comcast.net

Abstract: Astrobiology must be seen in the context of cosmic evolution, the 13.7 billion-year master narrative of the universe. The idea of an evolving universe dates back only to the 19th century, and became a guiding principle for astronomical research only in the second half of the 20th century. The modern synthesis in evolutionary biology hastened the acceptance of the idea in its cosmic setting, as did the confirmation of the Big Bang theory for the origin of the universe. NASA programmes such as Origins incorporated it as a guiding principle. Cosmic evolution encompasses physical, biological and cultural evolution, and may result in a physical, biological or postbiological universe, each with its own implications for long-term human destiny, and each imbuing the meaning of life with different values. It has the status of an increasingly accepted worldview that is beginning to have a profound effect not only in science but also in religion and philosophy.

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Introduction

During the course of 20th century a powerful new idea gradually entered human consciousness and culture: that we are part of a cosmos billions of years old and billions of light years in extent, that all parts of this cosmos are interconnected and evolving, and that the stories of our galaxy, our solar system, our planet and ourselves are part and parcel of the ultimate master narrative of the universe, a story we now term 'cosmic evolution'. Even as in some quarters of popular culture heated debate continues over Darwinian evolution 150 years after the idea was published, over the last 50 years the much more encompassing idea that Carl Sagan embodied in the phrase 'the cosmic connection' (Sagan 1973, 2000) has become more and more a part of our daily lives, and will even more in the future as our cosmic consciousness increases.

Cosmic evolution provides the proper universal context for biological evolution, revealing that the latter is only a small part of the bigger picture, in which everything is evolving, including life and culture. The more we know about science, the more we know culture and cosmos are connected, to such an extent that we can now see the cosmos is inextricably intertwined with human destiny, both in the short-term and the long-term, impinging on (and arguably essential to) questions normally reserved for religion and philosophy. It is the purpose of this article to uncover the historical evolution of this new understanding of the cosmos, describe the effects on culture so far and outline the potentially far-reaching impact on the future of humanity.

Cosmic evolution and history

The idea of cosmic evolution implies a continuous evolution of the constituent parts of the cosmos from its origins to the present. Planetary evolution, stellar evolution and the evolution of galaxies could in theory be seen as distinct subjects, in which one component evolves but not the other, and in which the parts have no mutual relationships. Indeed in the first half of the 20th century, scientists treated the evolution of planets, stars and galaxies for the most part as distinct subjects, and historians of science still tend to do so (Hale 1908; Lowell 1909). But the amazing and stunning idea that overarches these separate histories is that the entire universe is evolving, that all of its parts are connected and interact, and that this evolution applies not only to inert matter but also to life, intelligence and culture. Physical, biological and cultural evolutions are the essence of the universe. This overarching idea is what is called cosmic evolution, and the idea has itself evolved to the extent that some modern scientists even talk of a cosmic ecology, the 'life of the cosmos' and the 'natural selection' of universes (Dyson 1988; Smolin 1997).

Although the question of extraterrestrial life is very old, the concept of a full-blown cosmic evolution – the connected evolution of planets, stars, galaxies and life on Earth and beyond – is much younger. As historian Michael Crowe has shown in his study of the plurality of worlds debate, in the 19th century a combination of ideas – the French mathematician Pierre Simon Laplace's 'nebular hypothesis' for the origin of the solar system, the British naturalist Robert Chamber's application of evolution to other worlds, and

Darwinian evolution on this world – gave rise to the first tentative expressions of parts of this world view (Crowe 1986; Schaffer 1989; Zakariya 2010). The philosophy of Herbert Spencer extended it to the evolution of society, although not to extraterrestrial life or society. But some Spencerians, notably Harvard philosopher John Fiske in his *Outlines of a Cosmic Philosophy Based on the Doctrine of Evolution* (1875), did extend evolutionary principles to life on other planets (Strick 2000).

Neither astronomers nor biologists tended to embrace such a broad philosophical and empirically unsupported concept as full-blown cosmic evolution. Influenced by Darwin, 19th century astronomers and popularizers did occasionally propound the rudiments of the idea. In England, Richard A. Proctor proposed an evolutionary view in which all planets would attain life in due time (Proctor 1870). In France, Camille Flammarion argued that life began by spontaneous generation, evolved via natural selection by adaptation to its environment, and was ruled by survival of the fittest, wherever it was found in the universe (Flammarion 1872). In this scheme of cosmic evolution, anthropocentrism was banished; the Earth was not unique, and humans were in no sense the highest form of life. Thus were the general outlines of the idea of cosmic evolution spread to the populace, not only by these forerunners of Carl Sagan but also by a variety of Victorian popularizers of science (Lightman 2007).

But such a set of general ideas is a long way from a research programme. In the first half century of the post-Darwinian world, cosmic evolution did not find fertile ground among astronomers, who were hard-pressed to find evidence for it. Spectroscopy, which displayed the distinct 'fingerprints' of each of the chemical elements, did reveal to astronomers that those same elements were found in the terrestrial and celestial realms. This confirmed the widely assumed idea of 'uniformity of nature' that both nature's laws and its materials were everywhere the same. Astronomers recognized and advocated parts of cosmic evolution, as in William Herschel's ruminations on the classification of nebulae, the British astrophysicist Norman Lockyer's work on the evolution of the elements or the American astronomer George Ellery Hale's *Study of Stellar Evolution* (1908). In their published writings, however, Hale and his colleagues stuck very much to the techniques for studying the evolution of the physical universe. Even Percival Lowell's *Evolution of Worlds* (1909) spoke of the evolution of the physical universe, not a 'biological universe' full of life, his arguments for Martian canals built by an alien intelligence notwithstanding. Although Lowell was a Spencerian, had been influenced by Fiske at Harvard, and had addressed his graduating class on 'The Nebular Hypothesis' two years after Fiske's *Cosmic Philosophy*, he did not apply the idea of advanced civilizations to the universe at large (Strauss 2001).

Even in the first half of the 20th century, astronomers had to be content with the uniformity of nature argument confirmed by spectroscopy. In an article in *Science* in 1920, the American astronomer W. W. Campbell (a great opponent of Lowell's canalled Mars) enunciated exactly this general idea of widespread life via the uniformity of nature argument: 'If there is a unity of materials, unity of laws governing those materials throughout the universe, why may we not speculate somewhat confidently upon life universal?' he asked. He even spoke of 'other stellar systems . . . with degrees of intelligence and civilization from which we could learn much, and with which we could sympathize' (Campbell 1920).

That was about all the astronomers of the time could say. As Helge Kragh concluded in his history of the Big Bang cosmology, 'during the nineteenth century the static clockwork universe of Newtonian mechanics was replaced with an evolutionary worldview. It now became accepted that the world has not always been the same, but is the result of a natural evolution from some previous state probably very different from the present one. Because of the evolution of the world, the future is different from the past – the universe acquired a history'. But the 19th century went only so far: 'The Victorian conception of the universe was, in a sense, evolutionary, but the evolution was restricted to the constituents of the universe and did not, as in the world models of the twentieth century, cover the universe in its entirety' (Toulmin & Goodfield 1982; Kragh 1996).

For the most part, biologists were also reluctant cosmic evolutionists even at the beginning of the 20th century. The British naturalist Alfred Russel Wallace, co-founder with Darwin of the theory of natural selection, wrote in 1903 that 'Our position in the material universe is special and probably unique, and . . . it is such as to lend support to the view, held by many great thinkers and writers today, that the supreme end and purpose of this vast universe was the production and development of the living soul in the perishable body of man' (Wallace 1903a, b). While he believed in a modicum of physical evolution in his small solar system-centric universe, he concluded that intelligence beyond Earth was highly improbable, calculating the physical, cosmic and evolutionary improbabilities against the evolution of an equivalent moral or intellectual being to man, on any other planet, as a hundred million million to one. Clearly, for this pioneer in evolution by natural selection there was no cosmic evolution in its fullest sense, no biological universe (Dick 2008a).

Similarly, Lawrence J. Henderson, a professor of biological chemistry at Harvard, wrote ten years after Wallace 'There is . . . one scientific conclusion which I wish to put forward as a positive statement and, I trust, fruitful outcome of the present investigation. The properties of matter and the course of cosmic evolution are now seen to be intimately related to the structure of the living being and to its activities; they become, therefore, far more important in biology than has been previously suspected. For the whole evolutionary process, both cosmic and organic, is one, and the biologist may now rightly regard the universe in its very essence as biocentric' (Henderson 1913). Clearly, Henderson grasped essential elements of cosmic evolution, used its terminology, and believed his research into the fitness of the environment pointed in that direction (Fry 1996). Yet, although he had a productive career at Harvard until his death in 1942, Henderson never enunciated a full-blown concept of cosmic evolution, nor did any of his astronomical colleagues.

Henderson's idea of a biologically robust cosmic evolution in 1913 was largely stillborn, perhaps in part because just a few years later the British astronomer James Jeans' theory of the formation of planetary systems by close stellar encounters convinced the public, and most scientists, that planetary systems were extremely rare (Dick 1996). The idea remained entrenched until the mid-1940s. Without planetary systems, cosmic evolution was stymied at the level of the innumerable stars, well short of the biological universe. In the absence of evidence, cosmic evolution was left to science fiction writers like Olaf Stapledon, whose *Last and First Men* and *Star Maker* novels in the 1930s embraced it in colourful terms. But Henderson had caught the essence of a great idea – that life and the material universe were closely linked, a fundamental tenet of cosmic evolution that would lay dormant for almost a half century.

The humble and sporadic origins of the idea of cosmic evolution demonstrate that it did not have to become what is now the leading overarching principle of 20th century astronomy (Zakariya 2010). But it did, helped along by the Big Bang cosmology featuring a universe with a beginning slowly unfolding over time. The history of the Big Bang cosmology therefore parallels to some extent the history of cosmic evolution in its grandest sense, and Edwin Hubble's empirical observations of galaxies consistent with the concept of an expanding universe added a further dimension to the new world view (Kragh 1996). Almost all astronomers today view cosmic evolution as a continuous story from the Big Bang to the evolution of intelligence, accepting as proven the evolution of the physical universe, while leaving open the still unproven question of the biological universe, whose sole known exemplar remains the planet Earth. Today the central question remains how far cosmic evolution commonly proceeds. Does it end with the evolution of matter, the evolution of life, the evolution of intelligence, or the evolution of culture? But today, by contrast with 1950, cosmic evolution is the guiding conceptual scheme for a substantial research programme.

When and how did astronomers and biologists come to believe in cosmic evolution as a guiding principle for their work, and how did it become a serious research programme? In her pioneering book *Unifying Biology: The Evolutionary Synthesis and Evolutionary Biology*, historian Betty Smocovitis has emphasized that with the rise of the Modern Synthesis in biology, by mid-century evolution had become a unifying theme for biology, with Julian Huxley and others also extolling its place in cosmic evolution. By the 1940s, Smocovitis wrote, 'cosmic, galactic, stellar, planetary, chemical, organic evolution and cultural evolution emerged as a continuum in a 'unified' evolutionary cosmology' (Smocovitis 1996). But it was only in the 1950s and 1960s that the cognitive elements – planetary science, planetary systems science, origin of life studies and the Search for Extraterrestrial Intelligence (SETI) – combined to form a robust theory of cosmic evolution, as well as to provide an increasing amount of evidence for it. Only then, and increasingly thereafter, were serious claims made for disciplinary status for a field known as exobiology, astrobiology, and bioastronomy – the biological universe component of cosmic evolution. And only then did government funding become available, as the search for life became one of the prime goals of space science, and cosmic evolution became public policy.

We have already hinted at why this coalescence had not happened earlier, Spencerian philosophy, and the ideas of Flammarion, Proctor and Henderson notwithstanding. Although the idea of the physical evolution of planets and biological evolution of life on those planets in our solar system had been around for a while – and even some evidence in the form of seasonal changes and spectroscopic evidence of vegetation on Mars – not until the space programme did the technology become available, resulting in large amounts of government funding poured into planetary science so that these tentative conclusions could be further explored. Moreover, if evolution was truly to be conceived as a cosmic phenomenon, planetary systems outside our solar system were essential. Only in the 1940s, when the nebular hypothesis came back into vogue, could an abundance of planetary systems once again be postulated. During a 15-year period from 1943 to 1958, the commonly accepted frequency of planetary systems in the Galaxy went from 100 to one billion, a difference of seven orders of magnitude (Dick 1996). The turnaround involved many arguments, from the observations of a few possible planetary companions in 1943, to binary star statistics, the nebular hypothesis, and stellar rotation rates. Helping matters along was the dean of American astronomers, Henry Norris Russell, whose 1943 *Scientific American* article 'Anthropocentrism's Demise' enthusiastically embraced numerous planetary systems based on just a few observations by Kaj Strand and others (Russell 1943). By 1963 the American astronomer Peter van de Kamp announced his discovery of a planet around Barnard's star, and the planet chase was on, to be truly successful only at the end of the century (van de Kamp 1963).

Thus was one more step in cosmic evolution made plausible by mid-century, even though it was a premature and optimistic idea, since only in 1995 were the first planets found around Sun-like stars, and those were gas giants like Jupiter. But how about life? That further step awaited developments in biochemistry, in particular the Oparin–Haldane theory of chemical evolution for the origin of life. The first paper on the origins of life by the Russian biochemist Aleksandr Ivanovich Oparin was written in 1924, elaborated in the 1936 book *Origin of Life*, and reached the English world in a 1938 translation (Fry 2000). By that time the British geneticist and biochemist J. B. S. Haldane had provided a brief independent account of the origin of life similar to Oparin's chemical theory. By 1940, when the British Astronomer Royal Sir Harold Spencer Jones wrote *Life on Other Worlds*, he remarked that 'It seems reasonable to suppose that whenever in the Universe the proper conditions arise, life must inevitably come into existence' (Spencer Jones 1940).

The contingency or necessity of life would be one of the great scientific and philosophical questions of cosmic evolution, but in any case the Oparin–Haldane chemical theory of origin of life provided a basis for experimentation, beginning with the famous experiment of Stanley Miller and Harold Urey in 1953, in which amino acids – the building blocks of proteins and life – were synthesized under possible primitive Earth conditions. By the mid-1950s, another step of cosmic evolution was coming into focus – the possibility of primitive life. Again, the optimism was premature, but the point is that it set off numerous experiments around the world to verify another step in cosmic evolution. Already in 1954 Harvard biochemist George Wald proclaimed the Oparin–Haldane process a natural and inevitable event, not just on our planet, but on any planet similar to ours in size and temperature (Wald 1954). By 1956 Oparin had teamed with Russian astronomer V. Fesenkov to write *Life in the Universe*, which expressed the same view of the inevitability of life as had Wald (Oparin & Fesenkov 1961).

What remained was the possible evolution of intelligence in the universe. Although hampered by a lack of understanding of how this had happened on Earth, discussion of the evolution of intelligence in the universe was spurred on by the famous paper by the American physicists Giuseppe Cocconi and Philip Morrison in *Nature* in 1959. 'Searching for Interstellar Communications' showed how the detection of radio transmissions was feasible with radio telescope technology already in hand. In the following year astronomer Frank Drake, a recent Harvard graduate, undertook just such a project (Ozma) at the National Radio Astronomy Observatory (NRAO), ushering in a series of attempts around the world to detect such transmissions. And in 1961 Drake, supported by NRAO director Otto Struve, convened the first conference on interstellar communication at Green Bank, West Virginia. Although a small conference attended by only 11 people including Struve, representatives were present from astronomy, biology and physics, already hinting at the interdisciplinary nature of the task (Dick 1996). Thus by 1961, the elements of the full-blown cosmic evolution debate were in place.

It was at the Green Bank meeting that the now-famous Drake Equation was first formulated. The equation $N = R_* \times f_p \times n_e \times f_l \times f_i \times f_c \times L$ – purporting to estimate the number (N) of technological civilizations in the galaxy – eventually became the icon of cosmic evolution – showing in one compact equation not only the astronomical and biological aspects of cosmic evolution but also its cultural aspects. The first three terms represented the number of stars in the Galaxy that had formed planets with environments suitable for life; the second two terms narrow the number to those on which life and intelligence actually develop; and the final two represent radio communicative civilizations. 'L', representing the lifetime of a technological civilization, embodied the success or failure of cultural evolution. Unfortunately, depending on who assigned values to the parameters of the equation, it yielded numbers ranging from one (Earth) to many millions of technological civilizations in the Galaxy. Drake and most others in the field recognized then, and recognize even now almost 50 years later, that this equation is a way of organizing our ignorance. At the same time, progress has been made on at least one of its parameters; the fraction of stars with planets (f_p) is now known to be between 5 and 10% for gas giant planets around solar type stars.

The adoption of cosmic evolution was by no means solely a Western phenomenon. On the occasion of the fifth anniversary of Sputnik, Soviet radio astronomer Joseph Shklovskii wrote *Universe, Life, Mind* (1962). When elaborated and published in 1966 as *Intelligent Life in the Universe* by Carl Sagan, it became the Bible for cosmic evolutionists interested in the search for life (Shklovskii & Sagan 1966). Nor was Shklovskii's book an isolated instance of Russian interest. As early as 1964 the Russians convened their own meetings on extraterrestrial civilizations, funded their own observing programmes, and published extensively on the subject (Tovmasyan 1965).

Thus, cosmic biological evolution first had the potential to become a research programme in the early 1960s when its cognitive elements had developed enough to become experimental and observational sciences, and when the researchers in these disciplines first realized they held the key to a larger problem that could not be resolved by any one part, but only by all of them working together. At first this was a very small number of researchers, but it has expanded greatly over the last 40 years, especially under NASA patronage. The idea was effectively spread beyond the scientific community by a variety of astronomers. As early as 1958, cosmic evolution was being popularized by Harvard astronomer Harlow Shapley in *Of Stars and Men*, and Shapley used it thereafter in many of his astronomical writings emphasizing its impact on culture (Palmeri 2000, 2009). The idea was spread much more by Sagan's *Cosmos* (Sagan 1980) and astronomer Eric Chaisson's works (Chaisson 1981, 1987, 2001, 2006), and in France by Hubert Reeves *Patience dans l'azur: L'evolution cosmique* (1981), among others. By the end of the century cosmic evolution was viewed as playing out on an incomparably larger stage than conceived by A. R. Wallace a century ago.

The catalyst for the unified research programme of cosmic evolution – and for the birth of a new scientific discipline – was the Space Age. No one would claim that a field of extraterrestrial life studies, or cosmic evolution, existed in the first half of the 20th century. Even by 1955, when Otto Struve pondered the use of the word 'astrobiology' to describe the broad study of life beyond the Earth, he explicitly decided against a new discipline: 'The time is probably not yet ripe to recognize such a completely new discipline within the framework of astronomy. The basic facts of the origin of life on Earth are still vague and uncertain; and our knowledge of the physical conditions on Venus and Mars is insufficient to give us a reliable background for answering the question' of life on other worlds (Struve 1955). But the imminent birth of 'exobiology' was palpable in 1960 when Joshua Lederberg coined the term and set forth an ambitious but practical agenda based on space exploration in his article in *Science* 'Exobiology: Experimental Approaches to Life Beyond the Earth' (Lederberg 1960). Over the next 20 years numerous such proclamations of a new discipline were made. By 1979, NASA's SETI chief, John Billingham, wrote that 'over the past twenty years, there has emerged a new direction in science, that of the study of life outside the Earth, or exobiology. Stimulated by the advent of space programs, this fledgling science has now evolved to a stage of reasonable maturity and respectability' (Billingham 1981).

The extent to which NASA had served as the chief patron of cosmic biological evolution is evident in its sponsorship of many of the major conferences on extraterrestrial life, although the Academies of Science of the United States and the USSR were also prominent supporters. It was NASA that adopted exobiology as one of the prime goals of space science, and it was from NASA that funding would come, despite an early but abortive interest at the National Science Foundation (Appel 2000). Pushed by prominent biologists such as Joshua Lederberg, beginning already in the late 1950s soon after its origin, NASA poured a small but steady stream of money into exobiology and the life sciences in general. By 1976 $100 million had been spent on the Viking biology experiments designed to search for life on Mars from two spacecraft landers. Even as exobiology saw a slump in the 1980s in the aftermath of the Viking failure to detect life on Mars unambiguously, NASA kept exobiology alive with a grant programme at the level of $10 million per year, the largest exobiology laboratory in the world at its Ames Research Center, and evocative images of cosmic evolution (Fig. 1). Cosmic evolution's potential by the early 1960s to become a research programme was converted to reality by NASA funding.

This is true not only of NASA's exobiology laboratory and grants programme but also of its SETI programme. Born at Ames in the late 1960s quite separate from the exobiology programme, NASA SETI expended some $55 million prior to its termination by Congress in 1993 (Dick 1996; Garber 1999). It was the NASA SETI programme that was the flag bearer of cosmic evolution. As it attempted to determine how many planets might have evolved intelligent life, all of the parameters of cosmic evolution, as encapsulated in the Drake Equation, came into play.

With the demise of a publicly funded NASA SETI programme in 1993, the research programme of cosmic evolution did not end. The remnants of the NASA SETI programme were continued with private funding, and similar, if smaller, SETI endeavours are still carried out around the world. Within NASA, a programme of cosmic evolution research continued, with its images subtly changed. In 1995, NASA announced its Origins programme, which two years later it described in its Origins Roadmap as 'following the 15 billion year long chain of events from the birth of the universe at the Big Bang, through the formation of chemical elements, galaxies, stars, and planets, through the mixing of chemicals and energy that cradles life on Earth, to the earliest self-replicating organisms – and the profusion of life'. Any depiction of 'intelligence' is conspicuously absent from the new imagery (Fig. 2), due to Congressional action, programmatically it could no longer be supported with public funding. With this proclamation of a new Origins programme, cosmic evolution became the organizing principle for most of NASA's space science effort. In a broad sense, most of NASA's space science programme can be seen as filling in the gaps in the story of cosmic evolution.

In 1996, the 'Astrobiology' programme was added to NASA's lexicon. The NASA Astrobiology Institute, centred at NASA's Ames Research Center, funds numerous centres nationwide for research in astrobiology at the level of several tens of millions of dollars (Dick & Strick 2004). Its paradigm is also cosmic evolution, even if it also tends to avoid mention of extraterrestrial intelligence due to Congressional disapproval stemming from cancellation of the NASA SETI programme in 1993. No such restriction is evident at the SETI Institute in Mountain View California, headed by Frank Drake. The Institute has under its purview tens of millions of dollars in grants, all geared to answering various parameters of the Drake Equation, the embodiment of cosmic evolution, including the search for intelligence.

As we enter the 21st century there is no doubt about the existence of a robust cosmic evolution research programme. NASA is its primary patron, and even many scientists without government funding now see their work in the context of this research programme. Other agencies, including the European Space Agency, are also funding research essentially in line with the Origins and Astrobiology programmes, not to mention their spacecraft which help to fill in the gaps in the grand narrative of cosmic evolution. Within the last 40 years, all the elements of a new discipline gradually came into place: the cognitive elements, the funding resources, and the community and communications structures common to new disciplines. As we enter the 21st century, cosmic evolution is a thriving enterprise, providing the framework for an expansive research programme, drawing in young talent sure to perpetuate a new field of science that a half century ago was nonexistent.

Cosmic evolution and culture

Since Darwin propounded his theory of evolution by natural selection, evolution has been much more than a science. It has been a worldview that has affected culture in numerous ways, and different cultures in diverse ways (Greene 1981; Bowler 1983). As we have noted, in her history of the modern evolutionary synthesis in biology, historian Betty Smocovitis found that by the late 1950s and early 1960s, the wider culture was 'permeated with evolutionary science' and 'resonated with evolutionary themes' (Barlow 1995; Smocovitis 1996). The leaders of that evolutionary synthesis, including Julian Huxley, Theodosius Dobzhansky, Ernst Mayr and George Gaylord Simpson espoused an 'evolutionary humanism', a secular progressive vision of the world that for Huxley at least, was 'the central feature of his worldview and of his scientific endeavors' (Simpson 1949; Huxley 1964; Dobzhansky 1969). In books and articles, each of these scientists addressed the future of mankind in evolutionary terms. Huxley (grandson of Darwin's chief defender T. H. Huxley) 'offered an inquiry … into an ethical system, an ethos, grounded in evolution, now a legitimate science, with its fundamental principle of natural selection, verifiable and testable through observation and experiment'. Cosmic evolution was part of this worldview, even if Mayr and Simpson would later express serious doubts

Fig. 1 Cosmic evolution is depicted in this image from the exobiology programme at NASA Ames Research Center, 1986. Upper left: the formation of stars, the production of heavy elements and the formation of planetary systems, including our own. Left: Prebiotic molecules, RNA and DNA are formed within the first billion years on the primitive Earth. Centre: The origin and evolution of life leads to increasing complexity, culminating with intelligence, technology and astronomers. Upper right: contemplating the universe. The image was created by David DesMarais, Thomas Scattergood and Linda Jahnke at NASA, Ames in 1986 and reissued in 1997.

about the chances for success of exobiology and SETI programmes (Dick 1996).

In the 1950s and 1960s Harlow Shapley was a prime example of a cosmic evolution evangelist from the astronomical side, being among the first to popularize the cosmic evolutionary perspective with 'missionary zeal'. In Shapley's view this perspective inspired a religious attitude, needed to be incorporated into current religious traditions, and went beyond those traditions in questioning the need for the supernatural. He even spoke of a 'stellar theology', a view that had broader implication for ethics. Cosmic evolution has also been used to bolster the idea of biological evolution, though apparently with little impact to this day among sceptical Americans (Palmeri 2009). Shapley's books *Of Stars and Men: The Human Response to an Expanding Universe* (1958), *The View from a Distant Star* (1963) and *Beyond the Observatory* (1967) spread these ideas worldwide.

During the second half of the 20th century, then, the evolutionary view of the universe was not only fully in place both from the point of view of at least some astronomers and biologists, but was also spreading to the broader culture. Instead of the small and relatively static universe accepted at the turn of the 20th century, humanity was now asked to absorb the idea of an expanding (now known to be accelerating) universe 13.7 billion light years in extent, full of billions of evolving galaxies floating in an Einsteinian space-time with no centre. The Big Bang theory, though still in competition in the 1950s with Fred Hoyle's Steady State theory that denied an overarching linear cosmic evolution, would receive increasing confirmation through the detection of the cosmic microwave background in 1965, and its study at ever finer resolution through the COBE and WMAP satellites (Kragh 1996). The Hubble Space Telescope and other spacecraft brought the impact of this world view directly to the people, through spectacular imagery of objects in the evolutionary narrative, and through more global images such as the Hubble Deep Field. The biological universe full of life was conjectured, but not proven, though SETI and astrobiology programmes received much popular attention, particularly in the case of the supposed fossil life found in the Mars rock, evidence hotly contested, in part because of the high stakes for broader worldviews (Sawyer 2006).

In seeking the impact of the new universe on culture in the modern era, we need to remember that 'culture' is not monolithic and that 'impact' is a notoriously vague term. Thus, it is no surprise that the new universe and its master narrative of cosmic evolution evoked different meanings for different groups. Cosmic consciousness in the form of a biological universe was expressed in many forms in popular culture, some of them unpalatable to most scientists: belief in UFOs and extraterrestrial abduction, space-oriented religious cults, and ever more elaborate alien scenarios in science fiction. Indeed, all three of these developments may be seen as ways that popular culture attempts to work out the worldview implied by the new universe. The UFO debate and alien science fiction both had their predecessors in the late 19th century, but only in the second half of the 20th century did they come into their own as major elements of popular culture. During this time evolutionary themes became common in science fiction, notably in Arthur C. Clarke's work such as *Childhood's End*.

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Fig. 2 Cosmic evolution, as it appeared in the Roadmap for NASA's Office of Space Science Origins Theme, 1997 and 2000.

Some of the most popular films of all times featured aliens, among them *Star Wars, Close Encounters of the Third Kind, ET: The Extraterrestrial, War of the Worlds* and *Men in Black*. Obviously, and understandably, popular culture became preoccupied with whether the biological universe is hostile or friendly (Dick 1996).

Although human reactions to the new universe and cosmic evolution have not been monolithic, certain underlying themes are pervasive. In the eyes of many astronomers the increased awareness of the new universe and the possibility of a biological universe largely dashed any remaining hopes for an anthropocentric universe, with all that implies for religion and philosophy (van de Kamp 1965; Berenzden 1975). Even though the idea that the universe was made for humans survives in the form of the elegantly misnamed 'anthropic principle', in fact that principle is (to use L. J. Henderson's term from 1913 mentioned earlier), a 'biocentric' principle of the fine-tuning of universal laws that points to the possible abundance of life in the universe in many forms, rather in human form only (Barrow & Tipler 1986, Carr 2007, Dick 2008b). And if life is common throughout the universe, then our religions, philosophies and other human endeavours are too parochial and will need to be significantly altered, expanded or discarded. As physicist Paul Davies has said 'if it turns out to be the case that the universe is biofriendly . . . then . . . the scientific, theological and philosophical implications will be extremely significant' (Davies 2000).

The religious and philosophical implications of astronomical discoveries have been discussed especially since the time of the Copernican revolution, which made the Earth a planet and the planets potential Earths (Blumenthal 1987; Dick 1996). These implications were reflected by a few farsighted thinkers in the early 20th century. Much to the chagrin of the Catholic Church, the French Jesuit priest, philosopher and paleontologist Pierre Teilhard de Chardin famously made the evolution of the cosmos the central theme of his posthumous book *The Phenomenon of Man* (King 1996; Teilhard de Chardin 2002; Aczel 2007). Here, he embraced cosmic evolution, and argued for a teleological evolution in which man would end in a collective consciousness called the 'noosphere', which would ultimately lead to the Omega Point, the maximum level of consciousness, which he also identified with God. Although the idea was not accepted within the Catholic church, a few have followed in Teilhard's footsteps, including the Catholic priest Thomas Berry and physicist Brian Swimme, whose book *The Universe Story*, emphasizes the religious significance of cosmic evolution (Berry & Swimme 1994).

The new universe of the late 20th century has spawned renewed analysis of the relation of humans to the cosmos, both inside and outside established religions (Dick 2000a; Bertka 2010). Biologist Ursula Goodenough argues in *The Sacred Depths of Nature* that cosmic evolution is a shared worldview capable of evoking an abiding religious response. 'Any global tradition', she writes, 'needs to begin with a shared worldview – a culture-independent, globally accepted consensus as to how things are' (Goodenough 1998). She finds this consensus in 'our scientific account of Nature, an account that can be called The Epic of Evolution. The Big Bang, the formation of stars and planets, the origin and evolution of life on this planet, the advent of human consciousness and the resultant evolution of cultures – this is the story, the one story, that has the potential to unite us, because it happens to be true'. She calls her elaboration of the religious implications 'religious naturalism'.

Similarly, but within the Christian tradition, the British biochemist and Anglican priest Sir Arthur Peacocke has called cosmic evolution 'Genesis for the third millennium'. He believes that 'any theology – any attempt to relate God to all-that-is – will be moribund and doomed if it does not incorporate this perspective [of cosmic evolution] into its very bloodstream' (Peacocke 2000). Michael Dowd and Connie Barlow, who consider themselves, 'evangelists of cosmic evolution', have proposed 'evolutionary Christianity' – very different from Huxley's evolutionary humanism, but both featuring evolution as a central concept. Evolutionary Christianity embraces cosmic evolution, variously termed 'the Great Story' and the 'epic of evolution', much more than did Huxley's original evolutionary humanism, undoubtedly because cosmic evolution has been so much more developed over the last 50 years, complete with evocative images from the Hubble Space Telescope (Barlow 1995; Dowd 2008).

While Freeman Dyson among others have argued that the age-old mystery of God will be little changed by human attempts to read his mind, others argue that the new universe not only could, but should, lead to a new 'cosmotheology', or a new 'cosmophilosophy'. Among the elements such a cosmotheology must take into account are (1) that humanity is in no way physically central to the universe, but located on a small planet circling a star on the outskirts of the Milky Way galaxy; (2) that humanity is probably not central biologically, even if our morphology may be unique; (3) that humanity is likely somewhere near the bottom, or at best midway, in the great chain of being, a likelihood that follows from the age of the universe and the youth of our species; (4) that we must be open to radically new conceptions of God, grounded in cosmic evolution, including the idea of a 'natural' rather than a 'supernatural' God; and (5) that it must have a moral dimension, a reverence and respect for life that includes all species in the universe (Dick 2000b).

Each of these elements of cosmotheology provides vast scope for elaboration. Perhaps the most radical consequences stem from the fourth principle, which states that we must be open to new conceptions of God, stemming from our advancing knowledge of cosmic evolution and the universe in general. As the God of the ancient Near East stemmed from ideas of supernaturalism, our concept of a modern God could stem from modern ideas divorced from supernaturalism. The billions of people attached to current theologies may consider this no theology at all, for a transcendent God above and beyond nature is the very definition of their theology. The supernatural God 'meme', which we should remember is an historical idea the same as any other, has been very efficient in spreading over the last few thousand years, picking up new memes such as those accepted by Christianity and other religions. Nonetheless, the idea of a 'natural' God in the sense of a superior intelligence is appealing to some (Hoyle 1983; Harrison 1995; Gardner 2003, 2007). A natural God need not intervene in human history, nor be the cause for religious wars such as witnessed through human history. It remains an open question whether a natural God fulfils the apparent need that many have for 'the Other;' such a 'God' is different enough from tradition concepts that some may wish to call it a 'cosmophilosophy' rather than a cosmotheology. In any case some will see it as an important part of religious naturalism.

Over the next few centuries or millennia religions will likely adjust to these cosmotheological principles. The adjustment will be most wrenching for those monotheistic religions that see man in the image of God (Judaism, Christianity and Islam), a one-to-one relationship with a single Godhead. It will be less wrenching for Oriental religions that teach salvation through individual enlightenment (Buddhism and Hinduism) rather than through a Saviour, or that are this-worldly (Confucianism) rather than other-worldly. The adjustment will be not be to the physical world, as in Copernicanism, nor to the biological world, as in Darwinism, where man descended from the apes but still remained at the top of the terrestrial world. Rather the adjustment will be to the biological, or even postbiological, universe, in which intelligences are likely to be superior to us.

Even the possibility of life beyond Earth raises such theological questions, but particularly intriguing are impact scenarios in the event of the actual discovery of such life. The impact would undoubtedly very much depend on how the discovery was made and the nature of the discovery. Finding microbial life and even complex, but non-sentient life, might be of more interest to science than to philosophy or theology, as scientists probed the nature of the newfound life and determined whether it was based on the same DNA structure and biochemistry as life on Earth. The discovery of intelligent life, on the other hand, would be of immediate interest not only to science but also to such age-old philosophical problems as the nature of objective knowledge (would we perceive the universe in the same way as extraterrestrials?) and theology, typically meaning the relationship between man and God, but now recast as the relationship between all intelligent beings in the universe and God. In general, the urgency of the societal implications of extraterrestrial intelligence would depend on whether physical contact was made (considered unlikely to the extent that evidence for UFOs is weak), or if contact was made via a remote radio signal through a SETI programme. If the latter, a great deal would depend on the message received, if indeed it were decipherable.

While all of these scenarios are interesting to contemplate, most compelling, and most discussed, is the problem of how the discovery of clear evidence of a signal from extraterrestrial intelligence would affect theology on Earth, even if no messages were deciphered. This is still a complex question, because there are many terrestrial theologies and they would undoubtedly be affected in different ways. And there would be much discussion, and perhaps no consensus, even within a particular theology. We know this will be the case because the discussion has already been underway for over 500 years (Dick 1982, 1996; Crowe 1986, 1997; Randolph *et al.* 1997). As Michael J. Crowe, one of the premier historians of the extraterrestrial life debate, has emphasized, extraterrestrials have already influenced life on Earth and the history of ideas in many areas, in the sense that the possibility of their existence and the implications of their discovery have been the subject of discussion for centuries.

Real SETI programmes in the 20th century, however, made the problem more real, even if the same concerns were raised again and again (O'Meara 1999; Peters 2003). Ernan McMullin (a priest and philosopher at the University of Notre Dame) and George Coyne (the Jesuit director of the Vatican Observatory) are among those who have recently provided reflections from within the Catholic tradition. McMullin related the problem to that faced by 16th century

Europeans discovering the peoples of Mesoamerica. Fully aware of Thomas Paine's objections to Christianity in the late 18th century, McMullin noted that 'the proven reality of ETI might even more effectively encourage a broadening among the theologians and religious believers generally of the realization that the Creator of a galactic universe may well choose to relate to creatures made in the Creator's own image in ways and on grounds as diverse as those creatures themselves'. The problems of such a broadening of Christian doctrine related for McMullin to three issues: original sin, soul and body, and incarnation. He speculated that an omnipotent Creator might want 'to try more than once the fateful experiment of allowing freedom to a creature', such as the Eve/apple event in the garden of Eden. He pointed to the possibility that aliens might or might not have souls; if they did 'God also might elect to become incarnate in their nature or to interact in some other way with them', depending on their response to an Eden-like challenge. Regarding Incarnation, which he calls 'the defining doctrine of the Christian tradition', McMullin suggests that conflicting theological interpretations of that doctrine would influence anyone faced with the ETI situation. Thus, the discovery of ETI would result in a range of answers from Christian theologians with regard to whether Christ would become incarnate on another world, ranging from 'certainly yes' to 'certainly no'. McMullin's own answer is 'maybe' (McMullin 2000).

George Coyne, at that time Director of the Vatican Observatory, posed similar reservations about a definitive answer. He concluded that with the discovery of ETI 'theologians must accept a serious responsibility to rethink some fundamental realities within the context of religious belief' (Coyne 2000). Among those realities are the nature of a human being, and whether Jesus Christ could exist on more than one planet at one time. While theologians are limited in their ability to answer such questions, varying interpretations of Christian doctrines suggest that where a discovery of ETI actually made, a way would be found for Christian doctrine to absorb it, though perhaps not easily. The alternative would be extinction, and Christianity has shown its ability to adapt to scientific discovery, if very slowly at times.

The extraterrestrial life debate has also stimulated Jewish thought about the implications of ETI. Rabbi Norman Lamm, for example, noted that 'this challenge must be met forthrightly and honestly', and called those who shrink from pursuing it 'parochial and provincial'. Citing astronomers who emphasize our peripheral place in the new universe, Rabbi Lamm noted that 'Never before have so many been so enthusiastic about being so trivial'. Cautioning that extraterrestrial life is far from proven, Lamm explored 'a Jewish exotheology', and concluded that 'A God who can exercise providence over one billion earthmen can do so for ten billion times that number of creatures throughout the universe' (Lamm 1978).

The case where an extraterrestrial message is decoded is even more startling. Astronomer Jill Tarter, a pioneer in the field of SETI, believes an extraterrestrial message, unambiguously decoded, might be 'a missionary campaign without precedent in terrestrial history', leading to the replacement of our diverse collection of terrestrial religions by a 'universal religion' (Tarter 2000). Alternatively, a message that indicates long-lived extraterrestrials with no need for God or religion might undermine our religious worldview completely.

If there was any consensus, it was that terrestrial religions would adjust to extraterrestrials, an opinion echoed in late 20th century studies of religious attitudes toward the problem (Ashkenazi 1992; Dick 1996). As McMullin and others have pointed out, various extraterrestrial theological scenarios have also been worked out in detail in science fiction, including C. S. Lewis's *Perelandra* and Walter Miller's *Canticle for Leibowitz*. More recently, Maria Dorrit Russell has taken up these questions in her novels *The Sparrow* and *Children of God.* These fictional scenarios nevertheless represent deep thought about a problem that has now been with us for 500 years in hypothetical form, and that will be given greater urgency as soon as a discovery is made.

The impact of the new cosmos and its master narrative of cosmic evolution need not be couched solely in terms of theology. Mark Lupisella and John Logsdon have proposed a 'cosmocentric ethic', which they characterize as one which '(1) places the universe at the center, or establishes the universe as the priority in a value system, (2) appeals to something characteristic of the universe (physical and/or metaphysical) which might then (3) provide a justification of value, presumably intrinsic value, and (4) allow for reasonably objective measurement of value' (Lupisella & Logsdon 1997). A cosmocentric ethic would have some of the same concerns as cosmotheology, devoid of the theological implications. For example, a cosmocentric ethic would dictate how we treat extraterrestrial life forms, whether primitive or intelligent, taking into account not only our own homocentric interests but also the interests of the other life forms. The prospects of terraforming entire planets also raise the question of whether questions of terrestrial environmental ethics should be extended to the cosmic stage. In the context of spaceflight, human interaction in general, whether among ourselves or with other intelligence, would seem to demand a reorientation towards a cosmic rather than a geocentric perspective. Lupisella has recently expanded on the theme of life and the creation of cosmic value (Lupisella 2009).

Quite part from theological and philosophical implications, cosmic evolution provides humanity a cosmic context in time, allowing us to place humanity in the 13.7 billion year history of the universe. Although it is difficult to grasp that span of time, attempts have been made for several decades using the 'cosmic calendar', which conflates the history of the universe into a single year, showing humans arising in the last 1.5 hours of the last day of cosmic history, with the European Age of Discovery taking place one second ago (Sagan 1977). More substantively, a small but increasing discipline known as 'Big History' seeks to incorporate human history into cosmic history in a more systematic way (Spier 1996; Christian 2004, 2009). Big History links our understanding of human history with our understanding of other historical sciences, such as cosmology, geology and biology. It allows us to appreciate the emergent properties of culture in the same way as the emergent properties along the earlier path of cosmic evolution. And it highlights our unique collective learning ability and capacity for symbolic thought that results in our need to find meaning. In short, it reintegrates humans with the long history of the cosmos whence they sprang.

Finally, cosmic evolution integrates humans into the cosmos quite literally by teaching us that we are all 'star stuff'. Once again Harlow Shapley was an early proponent of this perspective. 'Mankind is made of star stuff', he wrote already in 1963, 'ruled by universal laws. The thread of cosmic evolution runs through this history, as through all phases of the universe – the microcosmos of atomic structures, molecular forms, and microscopic organisms, and the macrocosmos of higher organisms, planets, stars, and galaxies. Evolution is still proceeding in galaxies and man – to what end, we can only vaguely surmise' (Shapley 1963; Palmeri 2009). The colourful terminology of star stuff and 'starfolk' was picked up by Carl Sagan among others; its integration of humans into the cosmos encourages us to be 'at home in the universe' in the felicitous phrase used by several distinguished scientists in the late 20th century (Kauffman 1995; Wheeler 1996). We now know that the atoms in our bodies were forged in nuclear reactions in stellar furnaces, spewed into the universe in supernovae explosions, and incorporated into our bodies through the long process of the evolution of life over the last 3.8 billion years on Earth. We recognize that after death our bodily atoms will be dispersed once again through the universe, recycled to once again become star stuff in a cycle of events that will end only with the death of the universe itself. We are part and parcel of the universe, and at the hour of our death when we return to the universe, the old phrase from the *Book of Common Prayer* based on Genesis and often used in burial ceremonies – 'earth to earth, ashes to ashes, dust to dust' – need only be slightly altered to 'earth to earth, ashes to ashes, stardust to stardust', to be literally true. Cosmic evolution provides us with a master narrative in which our own birth, life and death are integral parts of the universe, without recourse to the supernatural. In the end, that may be the ultimate message of the new universe and cosmic evolution.

While only a small portion of humanity yet realizes the implications of the new universe and cosmic evolution, the incorporation of these ideas into educational curricula and the general reawakening to our place in the universe ensure these ideas an increasingly important role in culture. Such educational curricula have emerged from the astrobiology and SETI programmes, and are reaching an increasing number of students. The SETI Institute's 'Life in the Universe' curriculum 'Voyages Through Time' provides standards-based materials for a one-year high school integrated science course using cosmic evolution as its unifying theme. Its six modules include Cosmic Evolution, Planetary Evolution, Origin of Life, Evolution of Life, Hominid Evolution and Evolution of Technology. The Wright Center for Science Education at Tufts University is also a valuable educational resource directly centred on 'Cosmic Evolution: From Big Bang to Humankind', not surprising since the Center's director until recently was Eric Chaisson.

Following in the tradition of Shapley's *Of Stars and Men* (1958), a variety of popular books are also bringing cosmic evolution to a broader audience, including Neil DeGrasse Tyson's *Origins: Fourteen Billion Years of Cosmic Evolution* (also a Nova special on PBS); *The Universe Story : From the Primordial Flaring Forth to the Ecozoic Era – A Celebration of the Unfolding of the Cosmos* by physicist Brian Swimme and theologian Thomas Berry; *Children of the Stars: Our Origin, Evolution and Destiny* by astronomer Daniel Altschuler; and *Atoms of Science: An Exploration of Cosmic Evolution,* by astrophysicist Hubert Reeves. In short, an increasing number of people around the world are seeing for the first time their place within this naturalistic worldview. This recognition represents for humanity a return to the cosmos, a more sophisticated integration of culture and cosmos that humans possessed when cultures began, ranging from Stonehenge and the ancient civilizations such as Sumer and Egypt to native American Indians and the Australian aborigines (Krupp 1983).

Cosmic evolution and human destiny: three scenarios

In addition to the impact of the new universe on culture, cosmic evolution also provides a window on long-term human destiny. Although historians are understandably loathe to use the word 'destiny', associating it with the misguided 'Manifest Destiny' doctrine in which American colonists viewed it as their inherent right to expand westward and seize territory from the native Americans, the word can and must be dissociated from that historical event. In fact, the concept of 'destiny' has often been used in the context of theological discussion. A little over a month after the outbreak of World War II in 1939, theologian Reinhold Niebuhr began his Gifford Lectures on 'Human Destiny', published in 1941 under the title *The Nature and Destiny of Man*, in which he concluded that human destiny must lie outside of history, outside of nature, in the supernatural realm espoused by Christianity. In 1947, just after the War's end, the French biophysicist and philosopher Pierre Lecomte du Noüy published his volume *Human Destiny*, which espoused confidence in the broad scope of evolution in the universe, but ultimately found human destiny in God. And as we have seen, human destiny was explicit in Teilhard de Chardin's works, written in the first half of the 20th century.

In the realm of the natural world, in the broadest sense we have only a limited number of destinies, whether we like it or not. Cosmic evolution provides at least three vastly different scenarios of what the long-term human future may be. The ultimate product of cosmic evolution may be only planets, stars and galaxies – a 'physical universe' in which life is extremely rare. This has, in fact, been our chief worldview for the last several millennia, the plurality of world tradition notwithstanding. Almost all of the history of astronomy, from Stonehenge through much of the 20th century, encompasses the people, the concepts and the techniques that gave rise to our knowledge of the physical universe. Babylonian and Greek models of planetary motion, medieval commentaries on Aristotle and Plato, the astonishing advances of Galileo, Kepler, Newton and their comrades in the Scientific Revolution, the details of planetary, stellar and galactic evolution – all these and more address the physical universe. The physical universe is truly amazing in its own right, boasting a whole bestiary of remarkable objects.

For millennia, our perceptions of the destiny of human life on Earth were tied to the physical universe as represented by the geocentric system associated with Aristotle, with the Earth at the centre and the heavens above. This cosmological world view provided the very reference frame for daily life, religious and intellectual. Writers from Claudius Ptolemy to Dante Alighieri touted it as the true system of the world in which humans sought meaning. The heliocentric system of Copernicus changed all that, making the Earth and planet and the planets potential Earths. Societal uproar followed this daring new cosmological worldview. Since then the history of modern astronomy has been one of the increasing decentralization of humanity. In 1920, Harlow Shapley showed our solar system is at the periphery of our Milky Way Galaxy rather than its centre, and since then billions of galaxies have been discovered beyond our own.

In the physical universe scenario, all is not lost with respect to the status of humanity. In a universe in which life on Earth is unique or rarely duplicated humans may still have an important role. Indeed, in such a universe stewardship of our pale blue dot takes on special significance, for life in the universe depends on our actions over long periods of time bounded only by physical reality. In two billion years, the Sun will have increased in brightness enough to induce a runaway greenhouse effect on our home planet. Long before that we will likely have escaped to another star, offering our species and us a much longer longevity. The process will repeat, until star formation in galaxies halts in 100 trillion years (Adams & Laughlin 1999). Assuming we do not remain Earthbound, the destiny of life in the physical universe is for humans, sooner or later, to populate the universe. Many options exist for humans in a universe devoid of life, and many scenarios in science fiction address this possibility. Isaac Asimov has played out one scenario in his Foundation series, and the philosopher John Leslie has addressed some of the philosophical implications (Leslie 1996).

The second possible outcome of cosmic evolution reveals quite a different destiny. The biological universe – the universe in which cosmic evolution commonly ends in life, mind and intelligence – means that we will almost certainly interact with extraterrestrials. Ideas about a possible biological universe dates back to ancient Greece, in a history that is now well known (Dick 1982, 1996, 1998; Crowe 1986; Guthke 1990). It is the universe that astrobiology and SETI programme are attempting to prove (Dick & Strick 2004). There is again no lack of ideas about human–extraterrestrial interaction in such a universe. Science fiction is filled with possibilities, from the horrors of a war of the worlds to warm and fuzzy ETs. Arthur C. Clarke, author of *Childhood's End, Rendezvous with Rama, 2001: A Space Odyssey* and its sequels, among much other 'alien literature', is the prophet of this worldview replete with extraterrestrials. In such a universe, humanity may join what has been called a 'galactic club' whose goal is to enhance knowledge.

Taking a long-term view not often discussed, cosmic evolution may have already resulted in a third scenario. Cultural evolution in a biological universe may have already produced or replaced biologicals with artificial intelligence, constituting what I have called a 'postbiological universe' (Dick 2003). This idea requires us to take cultural evolution just as seriously as astronomical and biological evolution. It requires us to contemplate cultural evolution on cosmic 'Stapledonian' time scales, as did Olaf Stapledon in his novels *Last and First Men* (1930) and *Star Maker* (1937). While astronomers are accustomed to thinking in these terms for physical processes, they are not accustomed to thinking on cosmic time scales for biology and culture. But cultural evolution now completely dominates biological evolution on Earth. Given the age of the universe, and if intelligence is common, it may have evolved far beyond us. If intelligence is highly valued for its evolutionary advantage, extraterrestrials will long ago have sought the best way to improve their intelligence, and it is likely to be involved in artificial intelligence, yielding the postbiological universe. Nor does L need to be millions of years for such a scenario. It is possible that such a universe would exist if L exceeds a few hundred or a few thousand years, where L is defined as the lifetime of a technological civilization that has entered the electronic computer age (which on Earth approximately coincides with the usual definition of L as a radio communicative civilization.) Indeed, some predict the Earth will be postbiological in a few generations (Moravec 1988, 1999; Kurzweil 1999, 2006).

Such a postbiological universe would have sweeping implications for SETI strategies, for our worldview, and for the destiny of life on Earth if it has already happened throughout the universe. We may see our own future in the evolution of extraterrestrial civilizations, perhaps another motivation for searching. How such postbiologicals – whether terrestrial or extraterrestrial – would use their knowledge and intelligence is a valued question at present unanswerable. Whether one relishes or opposes the idea of a universe dominated by machines, the transition to such a universe presents many moral dilemmas and raises with renewed urgency the ancient philosophical question of destiny and free will.

In short, both in our relationship with extraterrestrials and with God, however, conceived, human destiny would be quite different in a universe full of biologicals or postbiologicals than if we are alone. If extraterrestrial intelligence is abundant, it will be our destiny to interact with that intelligence, whether for good or ill, for life identifies with life. It is here that the fifth Cosmotheological Principle, or the cosmocentric ethic, comes into play. The moral dimension – a reverence and respect for extraterrestrial intelligence that may be morphologically very different from terrestrial life forms – will surely challenge a species that has come to blows over superficial racial and national differences. If we are wise, humanity will realize that our species is one, a necessary realization before we have any hope of dealing with extraterrestrial beings in a morally responsible way.

Although the physical, biological and postbiological universe may be facts that the universe imposes on us, humans will still have great scope for choice and free will within these broad scenarios. The founders of the modern evolutionary synthesis emphasized this point already at the middle of the 20th century. George Gaylord Simpson for one, echoing Huxley's evolutionary humanism, wrote that 'it is another unique quality of man that he, for the first time in the history of life, has increasing power to choose his course and to influence his own future evolution. It would be rash, indeed, to attempt to predict his choice. The possibility of choice can be shown to exist. This makes rational the hope that choice may sometime lead to what is good and right for man. Responsibility for defining and for seeking that end belongs to all of us' (Simpson 1949).

Whether intelligence is rare or abundant, whether extraterrestrial life is of a lower order or a higher order than *Homo sapiens*, human destiny is intimately connected with cosmic evolution. Driven by the astronomical, biological and cultural components of cosmic evolution, the universe may have generated any of the three outcomes described here: the physical universe, the biological universe, or the postbiological universe. Which of the three the universe has produced in reality we do not yet know – this is one of the many challenges of astrobiology with its goal of analysing the future of life as well as its past and present. Ours may be a cosmos in which humanity is not central, yet where it can be at home in the universe in which it plays its role. Whatever its long-term destiny, it is surely the destiny of humanity in the near future to follow the trail of scientific evidence wherever it may lead, even if it means abandoning old scientific, philosophical and theological ideas. Humans have always known intuitively that culture and cosmos are intertwined. We are just now beginning to realize what this co-evolution may mean.

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