In press, *Ethics and the Environment*

Separated at Birth, Signs of Rapprochement: Environmental Ethics and Space Exploration

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At the same time that humans first entered space, walked on the Moon, and extended the range of human existence beyond the Earth, we began to pay attention to the habitability of our terrestrial home. The first images taken from space by the U.S. Weather Bureau's TRIOS satellite launched in 1960 showed a "pale blue dot" floating in a vast darkness (Sagan 1994). Worldwide, these images unleashed a wide range of remarks—on the Earth's fragility, insignificance, or magnificence, its stunning geographical features, and the non-existence of visible national boundaries.

While this cultural reflection was taking place, the community of professional philosophers was closeted in arcane debates. Since Dewey's death in 1952, the profession had overwhelmingly become a disciplinary domain whose research was written by and for philosophic experts. But despite the silence of philosophers (including environmental philosophers) on the subject, there is in fact a powerful link between our exploration of space, the reflections it elicits concerning the fate of our home planet, and the development of environmental ethics. This essay explores these connections, arguing that our thinking about both the future habitability of the planet ethics and the exploration of space is sharpened by bringing the two into more explicit contact.

A Lost Relation

As with our explorations of the extraterrestrial realm, the first reflections on the state of the planet were prompted by the work of scientists rather than philosophers or humanists. US Fish and Wildlife zoologist Rachel Carson's *Silent Spring* (1962) and Stanford University entomologist Paul Ehrlich's *The Population Bomb* (1968) highlighted concerns that came to nationwide expression in the first Earth Day in 1970—the year after the scientific, technological, and political triumph of the first landing on the Moon. The books shared a common rhetoric—ethical *cri de coeur* built on the supposedly objective foundation of science. For instance, Carson's claim that the effects of DDT radiated throughout the environment causing reproductive problems and death was quickly taken up as an argument for viewing nature as a web of life we needed to nurture and protect.

Professional philosophers were slow to catch up: environmental ethics did not become part of any university's curriculum until the 1970s, when it was first taught by J. Baird Callicott at the University of Wisconsin, Stevens Point in 1971. The field did not gain a real foothold within academia until the 1980s. Even now, environmental ethics remains a stepchild of philosophy: not meriting a category within the Leiter Report, and marginal within the bulk of programs and departments.

But while space exploration may have contributed to the birth of environmental consciousness—giving us a new, more global perspective on our home—and environmental ethics, environmental ethics itself has paid little attention to the philosophical dimensions of space exploration or to the relation between the sub- and superlunary spheres. Even the scientific discovery of the importance of asteroid impacts in Earth's history (c. 1981) and the imminent impact of global climate change have done little to encourage reflection on Earth within an extraterrestrial context.[i] Of course, humans have long populated the heavens with spirits, and theologians and philosophers such as St. Thomas Aquinas (d. 1274) and Giordano Bruno (d. 1600) considered the possibility of extraterrestrial rational intellects. But before the launching of Sputnik (1957), philosophic consideration of space was lodged within the science fiction literature of H.G. Wells, Jules Verne, Ray Bradbury, Arthur C. Clarke, and others.

Within philosophy a small number of scholars extended their concerns to include outer space. Eugene Hargrove's edited volume, *Beyond Spaceship Earth: Environmental Ethics and the Solar System* (1986), was the first and remains the best effort at thinking about the philosophical issues regarding humans' use of and relationship to outer space. Philosophers Robert Ginsberg (1972), William K. Hartmann (1984), Donald Scherer (1982), and Lewis Beck White (1998) also published on these topics from the early years of space exploration. But this literature is still limited, both in terms of scope and frequency of publication.[ii] Part of the problem may lie in the fact that sublunary environmental ethics had difficulty in gaining the attention of mainstream academic philosophers. But environmental ethics itself has been limited by its focus on *ethics* rather than philosophy.

The distinction is an important one. By the mid-19th century science had attained the status of being our only reliable source of knowledge. Art, metaphysics, and religion were dismissed as unverifiable expressions of subjective belief. Because of its clear practical import ethics was partially exempt from this dismissal. While some 20th century philosophers (e.g., Stevenson, 1963) and much of the public came to view ethics as consisting of mere manifestations of emotion, society was not willing to abandon all substantive ethical claims (cf. Martin Luther King, Jr.). When questions of the state of the environment came to the public's attention in the 1960s, people seeking to express their moral views used science to buttress their ethical claims—for instance, arguing for the preservation of the Pacific Yew tree because of the usefulness of Taxol as a cancer drug. Professional ethicists, sharing the prejudices of the age, were left trying to adapt their established ethical theories to these new topics. The resulting efforts at "ethical extensionism" sought to stretch ethical theories developed for humans to animals, plants, and ecosystems.

By the early 1990s the twin assumptions that our valuing of nature is solely a matter of ethics, and that our ethical claims must be grounded in science, were ready for reevaluation. The development of environmental *philosophy* (a new traditionalism, in that it looked back to the pre-19th century categories of natural philosophy and cosmology) is increasingly giving epistemological, aesthetic, religious, and metaphysical concerns about nature equal status with ethics.[iii] The wider range of environmental philosophy is better situated to describe our interests and experiences at places such as the Grand Canyon. People go to the Grand Canyon for reasons of aesthetics (its beauty), theology (the awe it inspires), or metaphysics (it gives us a new sense of one's place in the universe), not ethics. Moreover, the wider concerns of environmental philosophy are more consistent with our responses to and concerns with the extraterrestrial realm. While issues such as the possible biological contamination of other planets and space debris have clear ethical dimensions, the expansion of our understanding of the cosmos through instruments such as the Hubble Space Telescope is much more a matter of aesthetics (e.g., Hubble's stunning pictures) and metaphysics (our growing appreciation of the long view of cosmic history) than ethics. Humans tend to acknowledge ethical responsibilities to what is close at hand. The thought of environmental ethics in outer space, where few will go in our lifetimes and nothing is known to live, is quite simply unfathomable to most. But despite all this, the cosmic environment continues to awe, delight, and inspire generation after generation.

In what follows we seek to spur the rapprochement and cross-fertilization of philosophy and space policy by highlighting the philosophic dimensions of space exploration, pulling together issues and authors that have had insufficient contact with one another. We do so by offering an account of three topics: planetary exploration, planetary protection and the search for extraterrestrial life, and terraforming. The resulting synthesis seeks to change our thinking about earthbound environmental ethics as it considers the philosophical dimensions of space exploration, and introduces the possible benefits of a humanities-oriented approach to space policy.

Planetary Exploration

Lessons learned about our impact on the Earth's surface and atmosphere have relevance as we travel beyond our home planet. The unintended and often destructive effects of humankind on the Earth environment highlight the need for caution and restraint as we travel beyond our home planet. Several authors, acknowledging the probability that humans will one day be active and constant presences in space, have suggested the need to identify and preserve wilderness areas on celestial and planetary bodies.[iv] Using the United States National Parks System as an analogue, scientists Charles Cockell and Gerda Horneck suggest that an extraterrestrial park system with strict regulations and enforcement measures would go a long way to ensure that portions of Mars remain pristine for science, native biota (if any exist), and human appreciation.

Such a policy would acknowledge the competing interests and priorities of many parties: national space agencies, the international community, the community of space scientists, private enterprises who have fixed their sights on space tourism, commercial, and/or industrial enterprises in space, environmental ethicists, and the general public.

The issues involved are complex. The US National Parks were established after centuries of thinking through the relationships between human and nonhuman, nature and culture, beauty, truth, and the sublime, and humans' obligations toward the Earth. Scientists and political decision-makers will have to confront these issues, whether explicitly or implicitly, as they consider the future of the space program. But this thinking will now take place in a context where humans are aliens. Earthbound environmental philosophy occurs in a context where we are a natural part of the environment. On other planets we face a new first question: what are the ethical and philosophical dimensions of visiting or settling other planets? In short, should we go there at all?

To date, the discussion of natural places has turned on questions concerning intrinsic and instrumental values. Intrinsic values theorists claim that things have value for their own sake, in contrast to theories of instrumental value where things are good because they can be used to obtain something else of value (economic or otherwise). This debates tends tend to get caught up in attempts at extending the sphere of intrinsically valuable entities. Ethical extensionism depends on human definitions of moral considerability, which typically stem from some degree of identification with things outside us.

This anthropocentric and geocentric environmental perspective shows cracks when we try to extend it to the cosmic environment. The few national or international policies currently in place that mention the environment of outer space (e.g. NASA's planetary protection policy, UN Committee on the Peaceful Uses of Outer Space) consider the preservation of planetary bodies for science, human exploration, and possible future habitation, but there is not yet any policy that considers whether these anthropocentric priorities should supersede the preservation of possible indigenous extraterrestrial life, or the environmental or geological integrity of the extraterrestrial environment.

Anticipating the need for policy decisions regarding space exploration, Mark Lupisella and John Logsdon suggest the possibility of a *cosmocentric* ethic, "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 and Logsdon, 1997, p. 1). The authors discuss the need to establish policies for pre-detection and post-detection of life on Mars, and suggest that a cosmocentric ethic would provide a justification for a conservative approach to space exploration and science—conservative in the sense of considering possible impacts before we act.[v] A Copernican shift in consciousness, from regarding the Earth as the center of the universe to one of it being the home of participants in a cosmic story, is necessary in order to achieve the proper environmental perspective as we venture beyond our home planet.

Of course, given current and prospective space technology our range is quite limited. The current Pluto New Horizons probe, launched by NASA in January 2006, travels at 50,000 mph, the limit of chemical propulsion. At such speeds Pluto is 9 years distant, Alpha Centauri 55,000. On the other hand, there are perhaps 1000 near Earth asteroids greater than 100 meters—not counting those in the Asteroid Belt beyond Mars—with a frequency of impact of perhaps one in a hundred years that would cause a regional scale disaster.

Planetary Protection and the Search for Extraterrestrial Life

Since the beginning of the US space program NASA has taken care with the question of possible contamination, whether so-called forward contamination of space from Earth, or back contamination of Earth from hitchhiker organisms. In 1958 the International Council of Science (ICSU) established the Committee on Space Research (COSPAR), an international body charged with the coordination of worldwide space research including the prevention of interplanetary contamination. In 1964 COSPAR established a quantitative, probabilistic framework based on microbial risk, for the development of planetary protection standards. The UN Space Treaty of 1967 asserts:

> States party to the Treaty shall pursue studies of outer space, including the Moon and other celestial bodies, and conduct exploration of them so as to avoid their harmful contamination and also adverse changes in the environment of the Earth resulting from the introduction of extraterrestrial matter, and where necessary, shall adopt appropriate measures for this purpose.

By 1982—that is, *after* a large number of landings on the Moon, Mars, and Venus—COSPAR determined that the quantitative measure of risk it had been using (an assessment of the probability that life will replicate on a given planet or celestial body) was based on highly subjective speculation. In response, COSPAR adopted qualitative standards of spacecraft cleanliness based on the different life-detection priorities for planetary bodies. Different types of missions require increasing levels of cleanliness: a fly-by mission has less contamination risk than a lander or sample-return mission, and a mission to Mars or Europa would be held to higher standards than one to a planet deemed unlikely to harbor life (for example, Venus). This shift in perspective highlights the nature of speculative science: outside the controlled environment of the lab, science progresses through what is essentially refined guesswork. The science of space travel makes assumptions about acceptable levels of risk, but risk (from localized effects to planetary destruction due to human error, technical malfunction, or unanticipated factors) is ubiquitous.

How much risk is too much? Rather than being solely addressed through disciplinary science, risk evaluation involves a consideration of our values, including our notion of progress and the relationship between humans, the environment, and technology. Policy makers have long sought scientific certainty to guide legislation, but it has become increasingly obvious that policy also depends on a complex and ambiguous network of human values, political capital, and public opinion–issues that cannot be disaggregated from each other.

The Viking mission in 1976 set the gold standard for NASA's planetary protection efforts. Scientific, governmental, and public optimism about the possibility of finding Martian life increased the awareness of risk, and NASA spent impressive sums to sterilize the spacecraft. According to one columnist, "to avoid contaminating its Mars life-detection experiments, NASA did everything short of encasing its spacecraft in condoms" (Wolfson, 2002, p. 30). No mission since has achieved the same levels of compliance: not only is it cost-prohibitive to replicate Viking's planetary protection protocol, but the disappointing results of that mission's search for life suggested that cross-contamination may not be such a risk after all. However, recent information about Mars and discoveries about the nature of life on Earth have renewed the hope for, and therefore the risk of, finding life 'out there.' New evidence for massive chemical sediments at Meridiani Planum on Mars, from the Opportunity Rover have dramatically improved the case for standing surface water on early Mars. At the same time, astrobiologists have discovered that wherever liquid water exists on Earth, whether it be the highly acidic pools of Yellowstone or the Rio Tinto in Spain, or the deep within the crust, life is a real possibility.

The search for extraterrestrial life takes place on two distinct fronts, each with very different implications and policy requirements. First, the SETI (Search for Extra-Terrestrial Intelligence) community listens for signals or messages from civilizations outside the solar system. Second, within the solar system, we search for evidence of present or past life by examining physical, chemical, geological, and biological data, acquired remotely from orbit, *in situ* or through collected samples. Detection of life by any method would have dramatic consequences and require ready policy strategies for risk management, communication, education, ethical considerations, international interests, and public perception. Over a period of several years, the SETI Committee of the International Academy of Astronautics developed a Declaration of Principles to serve as guidelines following the detection of ETI. The Principles, approved by the Academy in

1989, provide operational recommendations for a course of action immediately following a discovery. These include:

- strategies for verification
- communication to scientific and political communities, the UN, and the public
- protection of data, and
- responding to the signal

The Principles are vague and not intended for long-term policy, but they provide a rational and appropriate framework from which to proceed until further decisions can be made.[vi]

Notably, there are no corresponding guidelines for addressing the detection of non-intelligent life forms, nor is there any NASA or international policy for the proper handling of ET life.[vii] Detection by SETI of radio signals light years away poses no immediate risk, but would still raise culturally portentous ethical, philosophical, theological questions. Even the discovery of microbial life would be a shock. Evidence of microbial life on another planet in our solar system would also require immediate decisions about safe handling, biological risk, experimentation procedures, scientific, legal, and societal ownership, and the proper means of communication to governmental agencies, the scientific community, and the public. These policies should be developed now, before anything is found, for the excitement incurred by such a significant discovery and the need for immediate action will likely affect our ability to formulate appropriate responses (how, for instance, would NASA break the news? How might the news be introduced to school children? How would NASA engage and respond to religious communities?) These are *humanities* policy as much as science policy questions.

With an aggressive NASA agenda for future life-detection missions, the space science and policy communities will need to develop thoughtful strategies regarding biological and/or political risk of the discovery of life. Philosophical, psychological and theological issues (the possibility, for instance, of sudden societal unrest or greatly increased cult activity), in addition to ethical considerations, will necessarily play a central role in any such thinking. The development of a comprehensive strategy for addressing this discovery[viii] will require interdisciplinary work that includes philosophers, theologians, and social scientists, as well as space scientists and policy makers.

NASA has recently given some attention to these wider concerns. Some of the research within the NASA Astrobiology Institute (NAI) has considered philosophical issues. For instance, the NAI-sponsored Center for Astrobiology at the University of Colorado includes “philosophical and societal issues in astrobiology” as one of its research themes. This research has focused on epistemological issues such as the difference between historical and experimental sciences. For example, philosopher Carol Cleland has explored the inconclusive nature of the 1976 Viking lander missions’ biology experiments, experiments which were designed absent any data about the experimental variables – namely, the composition of Martian soil. "To this day", writes Cleland, "two of the researchers involved in the Viking life-detection experiments still insist that life was found to exist on Mars" (Cleland, 2002, p. 479). Most scientists reject that claim, but the controversy demonstrates the difficulties involved in attempting to apply experimental science to the speculative realm. Such work needs to be complemented by more speculative and wide ranging reflections on how the discovery of extraterrestrial life might affect our conception of ourselves.

Terraforming

Beside Earth, the most likely place in our galaxy to support life is Mars (McKay, 1982). There are two possibilities here: either there is currently life of some sort on Mars, or the planet is abiotic but could, with modifications, support future life. Currently Mars is thought to be far too cold and dry to allow the sort of life found on Earth, but this conclusion could be wrong. Scientists' understanding of life is necessarily limited to terrestrial biology; there is no real way to know what biochemical forms life might take elsewhere in the universe. Recent discoveries of extremophiles have proven that even on Earth life is remarkably persistent and can exist in extremely harsh environments. Microorganisms have been found a foot beneath the sands of the Chilean Atacaman Desert – one of the driest places on Earth and previously thought sterile (Mahoney, 2004). Whole ecosystems thrive in hydrothermal vents 2000 meters below sea level, in complete absence of sunlight (NASA, 2001). Microbes discovered under ice in Greenland have survived at least 120,000 years (and perhaps as long as a million years) in subzero temperatures, low oxygen levels, and minimal nutrients (Britt, 2004). Halobacteria live in highly concentrated saline environments such as those that might exist, or may have existed, many locations on Mars (Landis, 2001). These and other similar recent discoveries have renewed scientists' hope that some form of life could survive the harsh Martian environment, either present or past.[ix]

Terraforming is the use of planetary engineering techniques to alter the environment of a planet in order to improve the chances of survival of an indigenous biology or to allow the habitation of most, if not all, terrestrial life forms (McKay, 1990, pp. 184-5). There is a sizeable body of literature on the science, rationale, and potential benefits of bringing life to Mars.[x] The mechanics of terraforming essentially consist of warming the Martian climate by the release of carbon dioxide or other gases into the environment. This process is the same one that warms the climate of Earth: the greenhouse effect. It is thought that we will be able to do this in the foreseeable future, using contemporary or imminent technology (Zubrin and McKay, 1997).

An argument in favor of terraforming is that such a grand experiment would yield valuable information about the complex interworkings of ecosystem processes on Earth. Robert Haynes suggests "we will never adequately understand the workings of our own biosphere until we have made a serious attempt at least to design, if not actually to generate, another one" (Haynes 1990).[xi] Indeed, the project would significantly advance our scientific knowledge of the nature of life. It is feasible to imagine that such understanding could have a dramatic effect on our ability to solve ecological problems on Earth.

Of course, the issue of terraforming is not exclusively a scientific or technological one. Indeed, a number of talented scientists have noted that terraforming must be dealt with by those qualified to address ontological and theological questions about the nature of life (e.g., Haynes 1990).[xii] Few philosophers have approached the question; the majority of literature considering the ethics of such a project has been written by scientists. Those who have written about the ethical implications of terraforming (both scientists and philosophers) have tended to appeal to the intrinsic value issues involved in introducing terrestrial life to Mars. The questions usually take the following forms: Is life better than non-life? Is there value in nature absent the presence of life? Should we preserve the natural state of the red planet, or might we have an ethical obligation to populate the universe?

The answer to the last question is often a qualified *yes*. David Grinspoon likens the issue to that of planting a garden in a vacant lot. If no life exists on Mars, then we have a duty to bring life to it: “Mars belongs to us [life] because this universe belongs to life” (Grinspoon, 2004). Of course, a vacant lot is a human creation, and thus is a questionable analogy to a planet which happens to be naturally abiotic. Christopher McKay voices a similar position: “Life has precedence over non-life,” he states; “life has value. A planet Mars with a natural global-scale biota has value *vis-à-vis* a planet with only sparse life or none at all” (McKay, 1990).

Robert Zubrin, one of the most energetic and unequivocal spokesman of the case for bringing life to Mars, claims that the act of terraforming the Red Planet will prove that “the worlds of the heavens themselves are *subject to* the human intelligent will” (Zubrin, 2002). Zubrin has called the argument that we should forgo the terraforming project if native life is found on Mars “immoral and insane,” because humans are more important than bacteria. “In securing the Red Planet on behalf of life, humans will perform an act of improving creation so dramatic that it will affirm the value of the human race, and every member of it. There could be no activity more ethical” (ibid., pp. 179-180).

The terraforming project does not receive universal approval. An advocate of the 'hands-off' approach, or what has come to be called cosmic preservationism, is Rolston, who assigns value to the "creative projects" of nature, regardless of the existence of life or consciousness. "Humans ought to preserve projects of formed integrity, wherever found,…" [we should] "banish soon and forever the bias that only habitable places are good ones, and all uninhabitable places empty wastes, piles of dull stones, dreary, desolate swirls of gases" (Rolston, 1986, pp. 170-171). Alan Marshall, another preservationist, advocates strict enforcement measures to ensure that the planet continues to exist in its natural state. For Marshall, all of nature should receive respect; rocks, for instance, exist in "a blissful state of satori only afforded to non-living entities" (Marshall, 1993).

Martyn Fogg, on the other hand, notes that efforts to protect a barren environment are often misanthropic critiques of human nature emphasizing our capacity for evil, or sentimental illusions based on out-of-date ecology. He offers as an example the ecocentrist notion of ecological harmony – "that there exists an ideal balance in nature that is perfect, unchanging, and which nurtures and sustains" (Fogg, 2000). Such a state is a cozy sentimentality, he claims. "Nature is… better regarded as a continuous state of flux dominated by chaos and disharmony" (ibid.). Fogg counters Alan Marshall's argument that rocks exist in a state of 'blissful satori' by stating, "rocks don't think, don't act and don't care. They cannot have values of their own" (ibid.).

The question, however, of whether e.g., rocks have intrinsic value is different from whether they have values of their own. Abiotic nature can also have value through the *relatedness* of nature and natural objects to human beings. This value resides in the daily presence of humans in nature, humans as part of nature—something not (yet) true of the extraterrestrial world. We may be confident that rocks do not think, or have values of their own. But humans can nonetheless value rocks for their own sake–they can be experienced as beautiful, sublime, or sacred. Metaphysical, aesthetic, and theological questions such as these must be included as we address issues of terraforming.

Conclusion: Toward a Humanities Policy of Space Exploration

Revolutions in philosophic understanding and cultural worldviews inevitably accompany revolutions in science. As we expand our exploration of the heavens, we will also reflect on the broader human implications of advances in space. Moreover, our appreciation of human impact on Earth systems will expand as we come to see the Earth within the context of the solar system—for instance, in terms of the terraforming of Mars, or Venus as of case of greenhouse conditions run amok. Most fundamentally, we need to anticipate and wrestle with the epistemological, metaphysical, and theological dimensions of space exploration, including the possibility of extraterrestrial life and the development of the space environment, as it pertains to our common understanding of the universe and of ourselves.

Such reflection should be performed by philosophers, metaphysicians, and theologians in regular conversation with the scientists who investigate space and the policy makers that direct the space program. The exploration of the universe is no experimental science, contained and controlled in a laboratory, but takes place in a vast and dynamic network of interconnected, interdependent realities. If (environmental) philosophy is to be a significant source of insight, philosophers will need to have a much broader range of effective strategies for interdisciplinary collaborations, framing their reflections with the goal of achieving policy-relevant results. If it is necessary for science and policy-makers to heed the advice of philosophers, it is equally necessary for philosophers to speak in concrete terms about real-world problems. A philosophic questioning about the relatedness of humans and the universe, in collaboration with a pragmatic, interdisciplinary approach to environmental problems, is the most responsible means of developing both the science and policy for the exploration of the final frontier.

Acknowledgment:

Special Thanks to Mark Bullock, who has been a constant collaborator on these issues, and to the Center for Space Exploration Policy Research, which provided funding for the initial Planetary Protection workshop that inspired this piece.

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i There has been a recent of philosophical work done on questions surrounding climate change: see e.g., Gardner (2004); Frodeman, (2005).

ii A bibliography on ethics and space exploration issues can be found online at: http://www.boulder.swri.edu/CSEPR/projects/biblio.php

iii See, for instance, the essays contained within Rethinking Nature, Bruce V. Foltz and Robert Frodeman, eds., (Bloomington, ID: Indiana University Press), 2004.

iv See William Hartmann (1984); Paul Uhlir and William Bishop (1986); Charles Cockell and Gerda Horneck (2004); and Dirk H.R. Spennemann (2004).

v Others who have similarly called for the articulation of a cosmocentric environmental ethic include Robert Haynes (1990), Chris McKay (1990), Don MacNiven (1995), and Martyn Fogg (2000).

vi See "The Declaration of Principles Concerning Activities Following the Detection of Extraterrestrial Intelligence," available online at http://setiathome.ssl.berkeley.edu/declaration.html.

vii For a detailed analysis of this see M. Race and R. Randolph (2002).

viii Race and Richard Randolph have suggested one such strategy (Ibid.).

ix This argument can be extended to include a discussion of how astonishingly rapid the rise of life on Earth was. There is new evidence (Ueno, Y., K. Yamada, N. Yoshida, S. Maruyama, and Y. Isozaki, 2006) for methane-producing bacteria 3.46 billion years ago. It seems that bacteria originated and inhabited the deep subsurface of the Earth, and may still today. There is substantial evidence (cited in the above paper) that the subsurface biosphere on Earth is equal to or great in size than the one we know of at the surface!

x See Martyn Fogg's extensive Planetary Engineering Bibliography, online at http://www.users.globalnet.co.uk/~mfogg/biblio.htm.

xi Haynes is speaking of the process of ecopoiesis, or the manipulation of the Martian environment to support any biota. This may or may not result in the more radical alteration called terraforming – the creation of an Earth-like environment to support terrestrial plant, animal, and human life.

xii Haynes was one of the first scientists to call on philosophers for insight into the terraforming question.