NASA/CP–2007-214567

Workshop Report on the Future of Intelligence In The Cosmos

Compiled and Edited by:

Stephanie Langhoff
Chief Scientist
NASA Ames Research Center, Moffett Field, California

Carl Pilcher
Director of the NASA Astrobiology Institute
NASA Ames Research Center, Moffett Field, California

Greg Laughlin
Assistant Professor of Astronomy and Astrophysics
University of California at Santa Cruz, California

Jill Tarter
Director of the Center for SETI Research
SETI Institute, Mountain View, California

Seth Shostak
Senior Astronomer
SETI Institute, Mountain View, California

Report of a workshop jointly sponsored
by NASA Ames Research Center,
the SETI Institute, and the
University of California at Santa Cruz
held at Ames Research Center,
Moffett Field, California
on June 30- July 1, 2007

December 2007

The NASA STI Program Office . . . in Profile

Since its founding, NASA has been dedicated to the advancement of aeronautics and space science. The NASA Scientific and Technical Information (STI) Program Office plays a key part in helping NASA maintain this important role.

The NASA STI Program Office is operated by Langley Research Center, the Lead Center for NASA's scientific and technical information. The NASA STI Program Office provides access to the NASA STI Database, the largest collection of aeronautical and space science STI in the world. The Program Office is also NASA's institutional mechanism for disseminating the results of its research and development activities. These results are published by NASA in the NASA STI Report Series, which includes the following report types:

- TECHNICAL PUBLICATION. Reports of completed research or a major significant phase of research that present the results of NASA programs and include extensive data or theoretical analysis. Includes compilations of significant scientific and technical data and information deemed to be of continuing reference value. NASA's counterpart of peer-reviewed formal professional papers but has less stringent limitations on manuscript length and extent of graphic presentations.

- TECHNICAL MEMORANDUM. Scientific and technical findings that are preliminary or of specialized interest, e.g., quick release reports, working papers, and bibliographies that contain minimal annotation. Does not contain extensive analysis.

- CONTRACTOR REPORT. Scientific and technical findings by NASA-sponsored contractors and grantees.

- CONFERENCE PUBLICATION. Collected papers from scientific and technical conferences, symposia, seminars, or other meetings sponsored or cosponsored by NASA.

- SPECIAL PUBLICATION. Scientific, technical, or historical information from NASA programs, projects, and missions, often concerned with subjects having substantial public interest.

- TECHNICAL TRANSLATION. English-language translations of foreign scientific and technical material pertinent to NASA's mission.

Specialized services that complement the STI Program Office's diverse offerings include creating custom thesauri, building customized databases, organizing and publishing research results . . . even providing videos.

For more information about the NASA STI Program Office, see the following:

- Access the NASA STI Program Home Page at *http://www.sti.nasa.gov*

- E-mail your question via the Internet to help@sti.nasa.gov

- Fax your question to the NASA Access Help Desk at (301) 621-0134

- Telephone the NASA Access Help Desk at (301) 621-0390

- Write to:
  NASA Access Help Desk
  NASA Center for AeroSpace Information
  7115 Standard Drive
  Hanover, MD 21076-1320

NASA/CP–2007-214567

Workshop Report on the Future of Intelligence In The Cosmos

Compiled and Edited by:

Stephanie Langhoff
Chief Scientist
NASA Ames Research Center, Moffett Field, California

Carl Pilcher
Director of the NASA Astrobiology Institute
NASA Ames Research Center, Moffett Field, California

Greg Laughlin
Assistant Professor of Astronomy and Astrophysics
University of California at Santa Cruz, California

Jill Tarter
Director of the Center for SETI Research
SETI Institute, Mountain View, California

Seth Shostak
Senior Astronomer
SETI Institute, Mountain View, California

Report of a workshop jointly sponsored
by NASA Ames Research Center,
the SETI Institute, and the
University of California at Santa Cruz
held at Ames Research Center,
Moffett Field, California
on June 30- July 1, 2007

National Aeronautics and
Space Administration

Ames Research Center
Moffett Field, California 94035-1000

December 2007

Available from:

NASA Center for AeroSpace Information
7115 Standard Drive
Hanover, MD 21076-1320
(301) 621-0390

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
(703) 487-4650

Table of Contents

Executive Summary

On June 30th and July 1st of 2007, NASA Ames Research Center hosted a workshop entitled "The Future of Intelligence in the Cosmos." The workshop was co-organized by NASA Ames Research Center, the SETI Institute, and the University of California at Santa Cruz. The principal goal of this two-day interdisciplinary workshop was to elucidate potential scenarios for the evolution of intelligent civilizations in our galaxy. The workshop was organized around four principal themes, namely, the Fermi Paradox, the nature of intelligence, cultural evolution, and technological evolution.

Fermi's paradox is the conundrum that states while the basic conditions for life appear to be met in our galaxy, there is no evidence whatever for the existence of extraterrestrial civilizations. We approached this paradox from the standpoint of the Drake equation, which equates the number of technological civilizations expected in the galaxy to the product of seven factors that can be roughly divided into astronomical, biological, and cultural terms. There were a number of key points that emerged from the session on the Fermi Paradox. First, current research suggests that the galaxy contains a significant number of planets that reside in the habitable zone of sun-like (G-type) stars. Kepler and other space telescopes will soon add to our knowledge of the second and third terms of the Drake equation. It was also stressed that while we have yet to communicate with another civilization, this does not equate to the absence of technological civilizations in the galaxy, because we have not yet made systematic searches of sufficient scale and ingenuity. Improving technology, however, is rapidly expanding our search capability. We also discussed how anomaly detection schemes could improve the ability to pull a signal out of the large data streams processed by SETI, and how to best search for beacons given our expectations of what an alien transmitter might be like.

Another important idea emerging from this session was that new observations provide a much better understanding of the evolution of the Universe. The picture that has emerged is one of an expanding Universe consisting of 70% dark energy, 25% cold dark matter, and 4% invisible hydrogen and helium atoms. Humankind is composed mainly of heavy elements, which constitute only about 0.01% of all matter. Furthermore, it was felt that our society today lacks an understanding of our place in the Universe, and that this lack of a shared cosmology is at odds with the development of a long-term technology capable of space exploration.

The session on the nature of intelligence started with the assertion that we need to be cautious about falling into an anthropocentric mindset when discussing intelligence. Commonalities across biological taxa show that not only are humans animals in the most fundamental sense, but that no special or unique principles or concepts should be applied to human intelligence and evolution. Thus, it is important that we cast aside anthropocentric models of nature in order to identify appropriate research questions about the future of intelligence on other planets. Intelligence was defined to be about creativity in solving novel problems. A danger of our brand of intelligence is that it can create adverse situations faster than we can solve them. This provides the potential for terminating civilization via human induced disasters, such as nuclear war or worldwide changes in climate. Issues about global warming and its impact on the survival of our technological civilization was a recurring theme in the workshop. In this session we discussed such topics as how would an intelligent species interact with the galaxy, and how would it manifest its goal of survival. The frequency of terrestrial extinction events argues that a habitat limited to one planet around one star is not a good strategy. Thus it was hypothesized that space faring at least within our own solar system is required for long-term survival.

During the session on cultural evolution, it was suggested that we use humanity's own journey as an aid to thinking about the cultural evolution of intelligent, technological beings on other worlds. We should start with our history on Earth because it is the only dataset we have and because we can't avoid thinking in this context. Unfortunately, many key questions about civilization are still hotly debated in the historical disciplines. The incompleteness and inaccuracies in both the historical and archeological record dramatically complicate the interpretation of the data. Improving our understanding of cultural evolution on this planet, however, will help us discover the range of possible evolutions of extraterrestrial intelligence.

The last term (*L*) in the Drake equation, the lifetime of a technological civilization, is one of the terms with the greatest uncertainty, as we have only a single data point. If *L* is small (less than about 10,000 years) because of a catastrophe in the evolution of human culture, then the likelihood of detecting another technologically advanced civilization is small. Barriers to at least thousands of years of technological existence (with the exception of avoidable problems such as errant asteroids) are likely to be socio-economic ones, such as man-induced disasters like nuclear war, overpopulation, or global warming.

The session on technological evolution discussed the ultimate limits to technological civilizations and to technology itself. The Kardashev scale (for classifying the technological level of a civilization) is based on the power a civilization can harness. A Type I civilization on this logarithmic scale is capable of harnessing all the power on a planet. Earth is at about 0.7 on this scale. There are also limits on technology— e.g., a technology could be feasible but unaffordable, such as cryonically preserving everyone, or physically possible but technologically intractable, such as time travel or transporters. Also discussed in this session was the concept of the Technological Singularity, which is the hypothesized creation (usually via artificial intelligence or brain-computer interfaces) of smarter-than-human entities who rapidly accelerate technological progress beyond the capability of human beings. In this context we discussed making machines with human-like intelligence, or evolving into machine-like intelligence by uploading our minds into machines. Then these, our mental descendants, will further evolve. Our artificial intelligence descendants could be made very small, yet robust, and thereby, may be capable of colonizing the galaxy.

The possibility that technological advances could induce disruptions in civilizations and lead to their collapse was discussed. Global warming and overpopulation were cited as two leading candidates for disruption. The overpopulation scenario was illustrated by a video with a map of the Earth and the changing number of people at different locations beginning at 1000 AD and projected to the year 2030. This raised the question of what human population the Earth can sustain?

The workshop included a breakout session on the second day to explore three specific questions in more detail:

(1) What research needs to be done to prepare humankind for the future and what can be done to facilitate SETI success?

(2) What are the likely options for the evolution of humans? and

(3) How do we make science more interesting to our children?

The insights that were obtained from these breakout sessions are summarized in Section VI of the report.

Future of Intelligence in the Cosmos

Stephanie Langhoff[1], Carl Pilcher[1], Greg Laughlin[2],
Jill Tarter[3], and Seth Shostak[3]

Ames Research Center

I. Introduction

On June 30th and July 1st of 2007, NASA Ames hosted a workshop entitled "The Future of Intelligence in the Cosmos." The workshop was co-organized by NASA Ames Research Center, the SETI Institute, and the University of California at Santa Cruz. The principal goal of this two-day interdisciplinary workshop was to elucidate potential scenarios for the evolution of intelligent civilizations in our galaxy.

The workshop was organized around a series of themes beginning with the Fermi Paradox, which tersely stated, is the conundrum that while the basic conditions for life appear to be met in our galaxy, there is no evidence whatever for the existence of extraterrestrial civilizations. This theme included talks about the current cosmological theories of how the universe has evolved, and the status of what is known about extra-solar planets. The status of the search for extraterrestrial intelligence was given along with a discussion of how future technologies could improve the probability for successful detection.

The second theme dealt with the nature of intelligence. The need to have the correct mindset when addressing questions about intelligence on other planets was stressed. Presentations in this session were focused on the lifetime of intelligence, and the bottlenecks that might limit the lifetime of an intelligent technological civilization. The third theme on cultural evolution continued the discussion on the expected lifetime of a technological civilization. It was emphasized that we need to further our understanding of human cultural evolution to understand the range of possibilities for extraterrestrial civilizations.

The final theme of the workshop focused on technological evolution. What are the ultimate limits to technology? The concept of the technological singularity where humans might evolve into machine-like intelligence was discussed. This session was focused on how future technologies might influence human evolution.

---

[1]NASA Ames Research Center, Moffett Field, CA
[2]University of California at Santa Cruz, CA
[3]SETI Institute, Mountain View, CA

The workshop included three breakout sessions to address the following three questions in greater detail.

(1) What research needs to be done to prepare humankind for the future and what can be done to facilitate SETI success?

(2) What are the likely options for the evolution of humans? and

(3) How do we make science more interesting to our children?

The insights that were obtained from these breakout sessions are summarized in Section VI of the report. Finally, our research priorities, future actions, and conclusions are given in Section VII.

II. The Fermi Paradox

The Fermi Paradox is the observation, attributed to Enrico Fermi, that if there are many extraterrestrial civilizations, one or more should have colonized the galaxy long ago and we should see abundant evidence of intelligent extraterrestrial life. In fact, we see no such evidence, either in the form of artifacts or signals. An estimate of the number of extant intelligent civilizations in the Milky Way Galaxy can be calculated using the Drake equation. It was very appropriate, therefore, that Frank Drake chaired the first session whose theme was the Fermi paradox. The Drake equation can be written as:

$$N = \underbrace{R^* \times f_p}_{\text{Astronomical}} \times \underbrace{n_e \times f_l \times f_i}_{\text{Biological}} \times \underbrace{f_c \times L}_{\text{Cultural}}$$

where,

N = the number of technological civilizations in the galaxy

R^* = the rate of formation of stars suitable for the development of intelligent life

f_p = the fraction of those stars with planetary systems

n_e = the number of planets in each planetary system with an environment suitable for life

f_l = the fraction of suitable planets on which life actually appears

f_i = the fraction of life-bearing planets on which intelligent life emerges

f_c = the fraction of planets with intelligent life that develop technological civilizations

L = the lifetime of a technological civilization

The terms are conventionally grouped into the categories of astronomical (R^* and f_p), biological (n_e, f_l, and f_i) and cultural (f_c and L). The workshop was focused mostly on the cultural terms, which have the greatest uncertainty. However, the first presentation in the workshop entitled "The Galactic Planetary Census" was focused on what we know about the astronomical terms of the Drake equation.

II.A The Galactic Planetary Census

Dr. Greg Laughlin gave an overview about what is currently known about planetary formation. For example, it is now known that a star and its planetary system form when an interstellar cloud of gas and dust collapses under its own weight to form a "protostar" surrounded by a spinning disk. Circumstellar disks around newly forming stars have been observed with the Hubble telescope and we have computer simulations that agree with the observations. The computer models indicate three stages of growth: early growth dominated by sticking and coagulation of small dust grains to form small planetesimals, mid-life growth dominated by gravitational attraction of the planetesimals, and late growth involving gas accretion that produces planets like Jupiter and Saturn.

M-type stars are by far the most common type of stars in the galaxy, and potentially habitable planets may form around them (fig. 1). Even though planets close to M-type stars may be rotationally locked with the central star, one could conceive of scenarios where life could evolve. Figure 2 shows a computer simulation of recently discovered planet Gliese 581 “c”, which orbits a nearby red dwarf only 20 light years away. The planet is believed to have a mass of approximately seven Earth masses and an orbital period of 12.8 days. It is slightly too close to the star for habitability, and it is depicted in figure 2 as having a very deep steamy ocean.

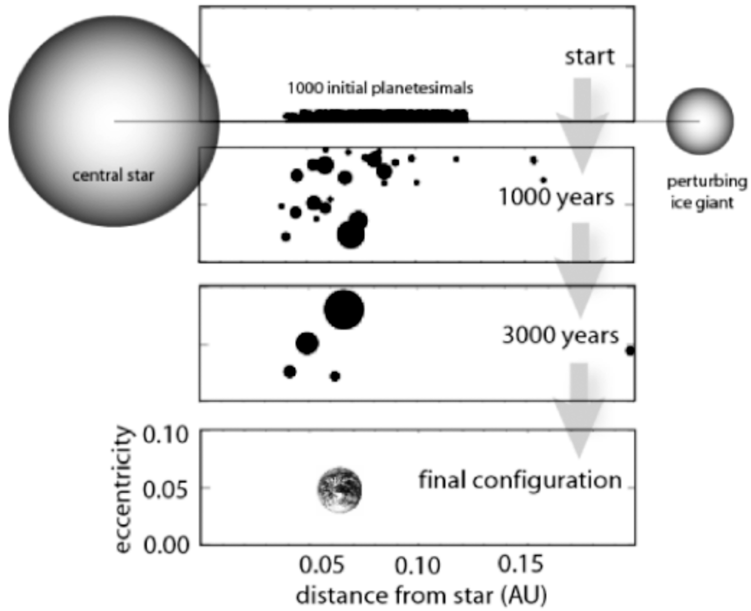

Figure 1. The results of a simulation that models the formation of a habitable Earth-like planet in a short-period orbit around a low-mass M-type star.

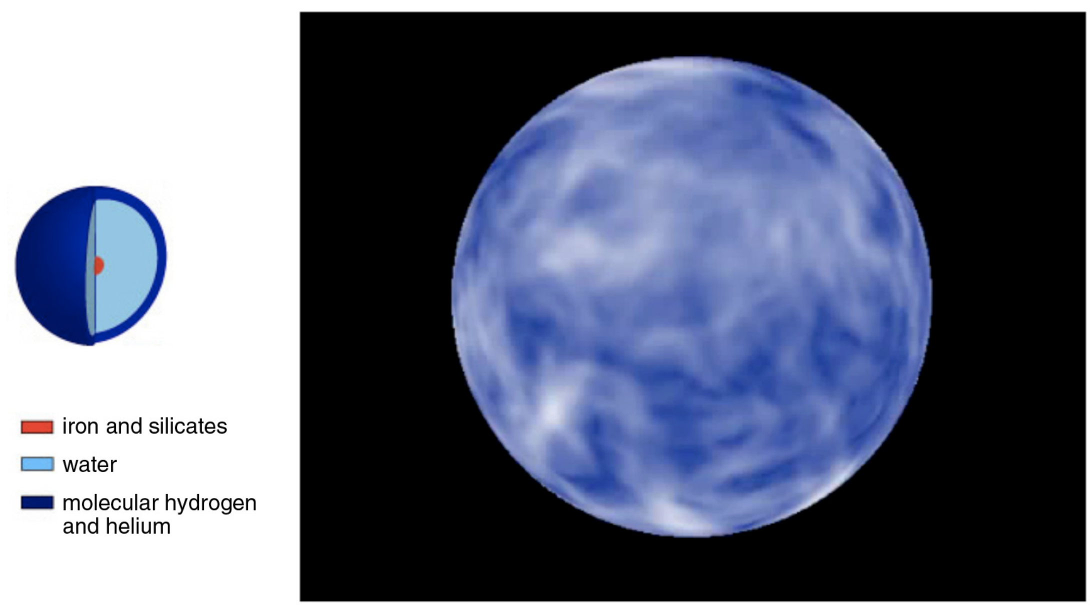

Figure 2. A computer simulation of the atmosphere of Gl 581 c.

Dr. Laughlin estimates that ~20% of G-type stars will harbor potentially habitable planets in the sense that there will be terrestrial-mass bodies orbiting within the habitable zone. Higher-level issues such as water budget, atmospheric composition, development of life, etc. are still much more uncertain (the n_e term in the Drake equation). However, with the upcoming launch of the Kepler Mission that will look for transits of Earth-size planets, we will have a much better idea of the fraction of stars that have Earth-like planets in the habitable zone. With the James Webb telescope we will be able to obtain information regarding the atmospheric composition of some low-mass, extra-solar planets. Preliminary evidence, however, indicates that the first three terms in the Drake equation do not preclude N from being quite large.

II.B The Great Silence—Or Not?

The second talk entitled "The Great Silence—Or Not?" by Jill Tarter approached the Fermi Paradox from the other side. In other words, we have yet to communicate with another intelligent civilization (The Great Silence), but does that mean that $N = 0$? Consider the logic—if there were ever another intelligent civilization in our galaxy, then it would inevitably develop the technology for interstellar travel (interstellar communication), and they would colonize (transmit to) every star in the galaxy on a time scale short compared with its age. But they are not here (there have been no signals); therefore we are the first intelligent civilization in the galaxy. Dr. Tarter's overall theme was that we couldn't make either of these statements, because we have not yet made systematic searches of sufficient scale and ingenuity. Furthermore, Arthur Clarke's third law states that any sufficiently advanced technology is indistinguishable from magic, and we may be failing in our capability to recognize this magic.

Dr. Tarter further postulated that any detectable technology has a high probability of being older than we are. The argument is that we are in the midst of a technological revolution that has taken us from a civilization that did not have the capability to transmit a signal detectable over interstellar distances, to one that now has that capability in an extremely short period of time compared with human existence on the planet, and an even smaller fraction of the planet's age. Thus if technology is long-lived (L is large), we will find an alien civilization to be technologically advanced; but if technology is short-lived (L is small), e.g., because of a disaster or bottleneck that destroys their technology, then searching for their technological signature is likely to fail.

Possible technological signatures of an alien civilization include the basic categories of deliberate signals, leakage in the EM spectrum, and artifacts such as evidence for energy consumption, transportation or colonization, conflict, graveyards, or astro-engineering projects, and the unexpected. Furthermore, astro-engineering by an advanced civilization could manifest itself in the form of cosmic miracles, Seyfert galaxies (the industrial accidents of the cosmos?), Dyson spheres, gamma-ray bursters (the acceleration event of an annihilation rocket?), rare-earth enhancement of stellar spectra (e.g., praseodymium due to dumping of fissile waste), tritium leakage from fusion plants in space, planetary system-wide impact avoidance radar, double or disappearing asteroids, spacecraft or probes in station-keeping orbits, etc. Direct observations in reflected light or radar echoes have ruled out the possibility of a large shiny "Battlestar Galactica" at the Lagrange points, but not smaller spacecraft or nanoprobes.

Phil Morrison has stated that SETI is the archeology of the future. A detected technosignature would tell us about their past and bodes well for our long-term future. The discussion next focused on the difficulty of detecting a signal against the astrophysical background and also what type signals to search for. Advanced technological civilizations may use inconceivable technologies that represent new physics for us. Signals may be unintentional or deliberate. Deliberate signals include winking stars and pulsars that glitch regularly between two pulses or are obviously artificial. Detection is complicated by the huge nine dimensional search space (3-space, 1-time, 2-polarization, 1-frequency, 1-modulation scheme, and 1-sensitivity). SETI has explored an exceedingly small fraction of this search space. The searches that have been undertaken by SETI to date were discussed, as well as what the future holds for SETI. The Allen Telescope Array, which has just recently come online, will greatly increase the search capabilities of SETI by allowing a million or more stars to be searched in the 1-10 gigahertz (GHz) spectral region during the next decade. It will also permit a survey of the inner portion of the galactic plane, exploring approximately 10 billion distant stars for signals in the cosmic waterhole between 1420-1720 MHz. Future planned telescopes such as the ATA-350 and the Omni-directional SETI System (OSS) will provide even greater capability. This is contingent on sufficient private funding and growth in computing power. Other more advanced search capabilities were briefly discussed. It is expected that over the next few decades the tools for searching will become commensurate with the size of the SETI task. Only then will a continuing great silence begin to suggest that we are the first advanced civilization in the galaxy.

II.C The Future of the Visible Universe May Depend on Us

The next two talks by Joel Primack and Nancy Abrams followed the theme of their recent book, *The View from the Center of the Universe*. Dr. Primack's thesis is that if humans are the only advanced civilization in the Local Group of Galaxies (the Milky Way, Andromeda, and a number of smaller galaxies), then the future of the visible universe might depend on us. This follows from the fact that space between groups is growing exponentially because dark energy is accelerating the expansion of the universe. When the universe is twice its present age, most distant galaxies will have disappeared over the cosmic horizon. The Local Group is gravitationally bound and will merge over the next several billion years—becoming our visible universe of the future. Now is an optimum time to view the universe, because, using the next generation of telescopes such as the James Webb telescope, we should still be able to see the formation of the first stars (about 400 million years after the big bang). With other instruments we can perhaps see back to about 400,000 years after the big bang, when the hot plasma fog clears and space first becomes transparent.

Dr. Primack discussed the Eternal Inflation theory of how the universe may have begun as a rare bubble of spacetime in the infinite cauldron of the externally inflating superuniverse. While this is somewhat conjectural, the good agreement between the observed large-scale structure of the universe and the predictions of the now-standard ΛCDM theory (that is, Dark Energy and Cold Dark Matter, or Double Dark theory) leads to a new understanding of the overall matter and energy distribution in the universe. The double-dark theory describes a universe whose composition is 70% dark energy, 25% cold dark matter, 4% invisible hydrogen and helium atoms, 0.5% visible hydrogen and helium in stars, and only 0.01% all other atoms. Thus the complex atomic matter of which humans are constituted is quite rare. This is illustrated by figure 3.

Another point made by Dr. Primack is that the time in which we currently live is very central in another way. As the Sun ages, its luminosity increases. Within less than 500 million years the Earth will no longer reside in the habitable zone, unless it is moved further from the Sun. However, a far more immediate threat to life on Earth comes from the global warming that is being driven by the exponential increases in the human population and its technological impact, leading to challenges such as the increasing tropospheric CO_2 concentration. The question was raised as to whether our global civilization can make the transition gracefully from inflationary consumption to a sustainable level? The issue that global warming could lead to a bottleneck in the advance of human civilization became a reoccurring theme in the workshop.

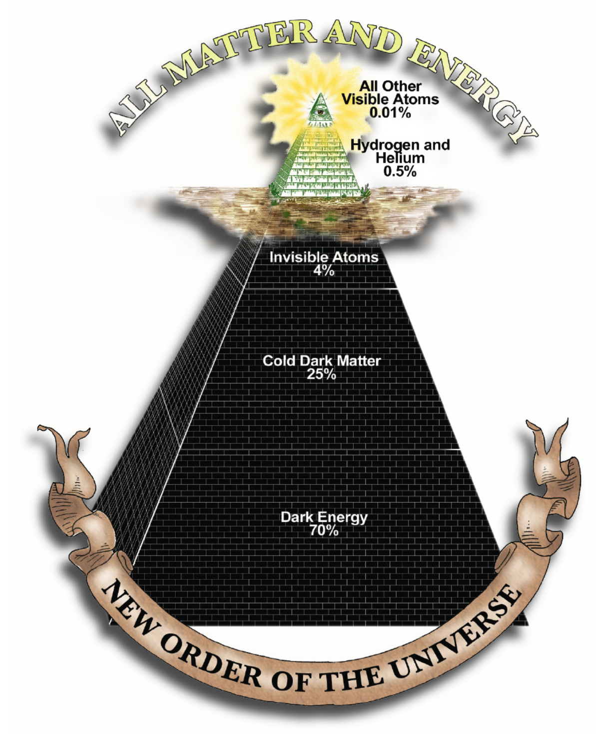

Figure 3. The Cosmic Density Pyramid. (From *The View from the Center of the Universe* by Joel R. Primack and Nancy Ellen Abrams.)

II.D Interstellar Travel Requires a Shared Cosmology

A key theme in Nancy Abrams' presentation is that space exploration and colonization, which will take place over a large time scale, require a shared cosmology in the anthropological sense, a rich and satisfying explanation of life, nature, and the cosmos that includes us. She discussed how cosmology has changed with time, from the biblical to the medieval to the Newtonian picture. Furthermore, she expressed the view that the West may now be the first major culture in human history without a shared cosmology. Most people today cannot describe the universe in a coherent way. The Newtonian picture has produced a culture that "views us as only the tiniest speck in an enormous universe." This is at odds with the likelihood that we need a shared cosmology to develop a long-term technology capable of space colonization.

A second theme in her presentation is that we live in a very special time. With recent advances in astronomical data, we now have a cogent theory (the Double Dark theory) of the origin and evolution of the universe as a whole. This produces the viewpoint that we are not insignificant specks, but rather that we are central to the principles that underlie the Double Dark universe. For example, we are made of the rarest material in the universe—stardust, heavy elements, which represent a mere hundredth of one percent of the universe. We are at the center of all possible sizes, halfway (exponentially) between the largest thing we know, the cosmic horizon, and the smallest, the Planck length. This is graphically illustrated by "The Cosmic Uroborus" shown in figure 4. We are at the center of our own visible universe. We are at the center of the galactic habitable zone, far enough from the galactic center to avoid most high-energy cosmic events, but close enough to the center to have sufficient heavy atoms for life. We live at the midpoint in time—early enough to see the cosmic horizon, but late enough to have evolved intelligent life that can see the distant galaxies, which are still visible. Finally we live at the midpoint in the existence of our solar system and the midpoint of the best period for life on Earth.

Figure 4. The Cosmic Uroboros represents the universe as a continuity of vastly different size scales. About sixty orders of magnitude separate the very smallest from the very largest size. Traveling clockwise around the serpent from head to tail, we move from the maximum scale we can see, the size of the cosmic horizon (10^{28} cm), down to that of a supercluster of galaxies, down to a single galaxy, to the distance from Earth to the Great Nebula in Orion, to the solar system, to the sun, the earth, a mountain, humans, an ant, a single-celled creature such as the E. coli bacterium, a strand of DNA, an atom, a nucleus, the scale of the weak interactions (carried by the W and Z particles), and approaching the tail the extremely small size scales on which physicists hope to find massive dark matter (DM) particles, and on even smaller scales a Grand Unified Theory (GUT). The tip of the tail represents the smallest possible scale, the Planck length. Human beings are just about at the center. (From *The View from the Center of the Universe*, by Primack and Abrams.)

Nancy Abrams concluded her presentation by returning to the theme of a need for a shared cosmology that provides not only a scientifically accurate map of reality, but the felt certainty of belonging to and having a meaningful place in the real universe. With such a vision, humans would have a moral mandate to work for the long-term good of our species, and to address immediate problems such as global warming and the inflationary growth in population and resource utilization that threaten both the health and diversity on our planet. She ended by stating that we need to act now for the future of our children.

II.E Seeking Ozymandias: Building and Searching for Beacons

The presentation by James and Gregory Benford focused on what transmitters would be like if built by alien civilizations constrained by cost. Physical law sets *universal* limitations on the Beacon-builder, independent of anthropomorphic factors. The highest power systems on earth (peak powers over 10 GW) trade peak power for average power in order to get to a much stronger signal at distance at the lowest cost. They are pulsed because plasmas form inside sources and limit pulse duration, and because heating and cooling set severe system limits and expenses. Most of these high power devices are not extremely narrow band, having bandwidths of ~1% for fundamental reasons.

Whatever the life form, evolution will likely select for economy of effort. Minimum capital cost is achieved when the cost is equally divided between antenna gain and radiated power. Such cost-optimized Beacons will have narrow beam widths, $\sim 10^{-4}$ radians. Therefore, the transmission strategy for a distant Beacon will be a rapid scan of the galactic plane, to cover the angular space.

To see Beacons we should search in the plane of the spiral disk. From Earth, 90% of the Galaxy's stars lie within 9% of the sky's area, in the plane and hub of the galaxy. We will need to be patient and wait for recurring events that may arrive in intermittent bursts. Special attention should be paid to areas along the Galactic Disk where SETI searches have seen coherent signals that are non-recurring in their limited listening time intervals.

Whatever forms might dwell further in from us toward the center, they must know the basic symmetry of the spiral. This suggests the natural corridor for communication is along the spiral's radius, a simple direction known to everyone that maximizes the number of stars within a telescope's view. Thus, a Beacon should at least broadcast outward in both directions from near the center, and we should look inward, within a narrow angle (~10 degrees) toward the constellation Sagittarius.

Thinking broadly, high-power transmitters might be built for a wide variety of motives, other than two-way communication. Some examples include *The Funeral Pyre*: A civilization near the end of its life simply announces its existence; *Ozymandias*: Here the motivation is sheer pride—the Beacon announces the existence of a higher civilization; *Leakage Radiation*: Not radio and television broadcasts radiating isotropically, but deep space radar and beaming of energy over solar system distances. This includes "industrial" spaceship launchers, beam-driven sails, and cosmic power beaming driving interstellar starships with beams of lasers. The talk presented by James Benford concluded the morning's theme of the Fermi Paradox.

III. The Nature of Intelligence

The early afternoon session chaired by Andre Bourmanis was focused on the theme of the nature of intelligence.

III.A The Nature of Intelligence: Escaping Orthogenic Concepts

The first talk, given by Lori Marino, was entitled “The Nature of Intelligence: Escaping Orthogenic Concepts.” She began her presentation with a quote from the writer and ecologist Loren Eiseley that “one does not meet oneself until one catches the reflections from an eye other than human.”

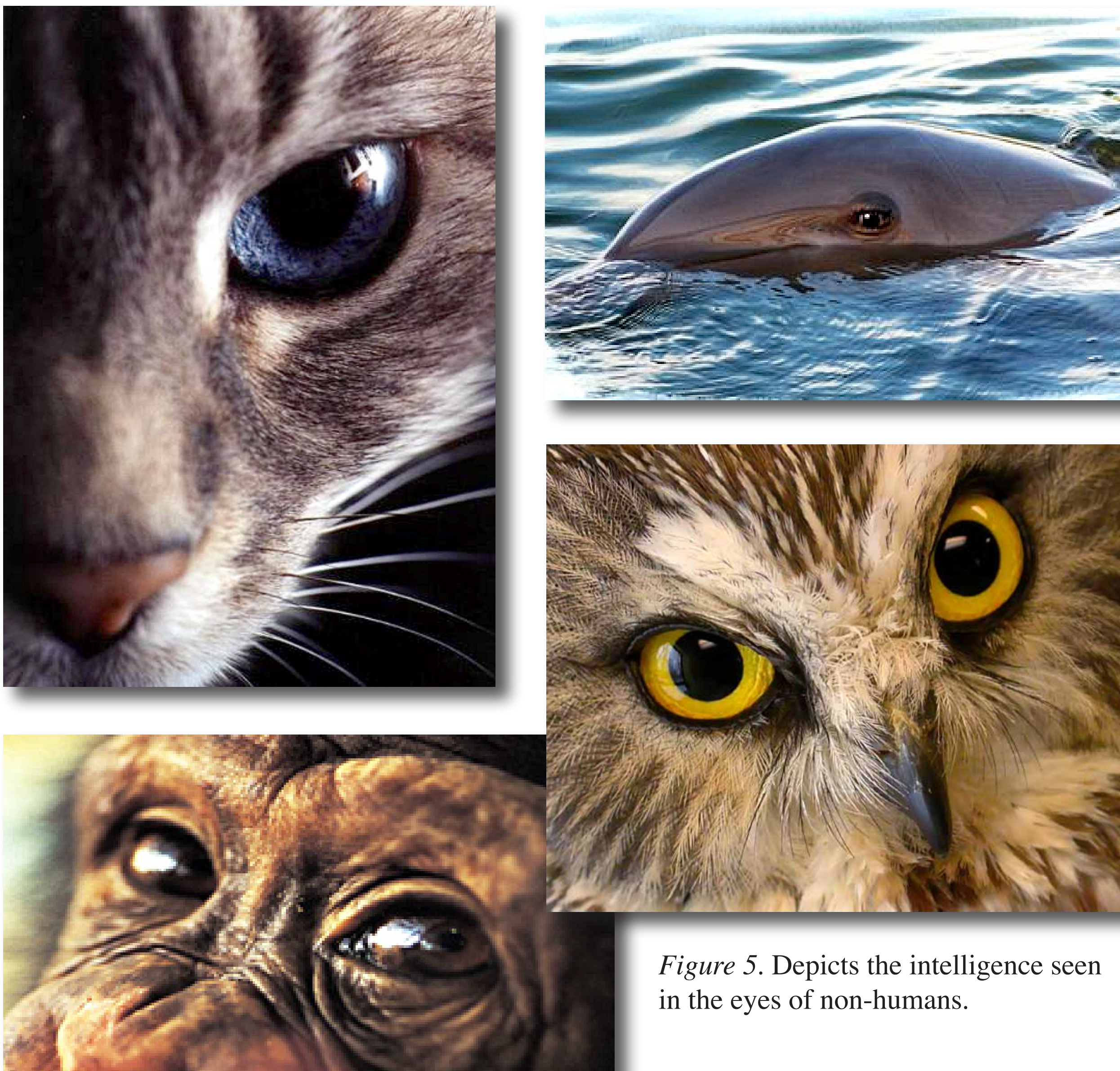

Figure 5. Depicts the intelligence seen in the eyes of non-humans.

This statement embodied the focus of Dr. Marino's talk. In other words, she strongly asserted that we need to be cautious about falling into an anthropocentric mindset when asking questions about the future of intelligence. More specifically, she argued that the Fermi paradox and similar notions are inherently anthropocentric and do not embrace the right questions. She defined anthropocentrism as regarding humans as the central element of the universe, or the interpretation of reality exclusively in terms of human values and experience. Being anthropocentric means that we "buy into" other misconceptions about nature, which focus on the idea of progression and directionality (e.g., orthogenesis, which is the evolution of organisms systematically in a definite 'goal directed' direction, and teleology, which is belief in the perception of purposeful development toward an end.) These directional notions are embodied in the ancient concept of the Great Chain of Being, or scala naturae, which not only implies progression, but also a qualitative separateness between humans and other species. The Great Chain of Being still constrains our thinking—explicitly and implicitly. The evidence is in the language we use, the way we depict nature, the way we educate students, and the way we do science. All of this conditions us to think a certain way about the universe.

In her talk, she drew on the extensive scientific literature on evolution, brains, and intelligence in a comparative context, to show how far from reality our suppositions currently are and how we need to revise our thinking in order to address astrobiological questions about the future of intelligence. The ongoing scientific findings elucidating the deep commonalities across biological taxa show that humans are animals in the most fundamental sense, and that no special or unique principles or concepts should be applied to human intelligence and evolution. Despite *scala naturae* thinking, it is clear that there has never been a linear progression from the first life on this planet to us, and that the evolution of life on this planet resembles an ever-branching tree—more like a fractal than a ladder. Human evolution itself has been anything but linear. It is, in fact, a branching pattern of speciation and extinction similar to that of all life on Earth. The fact that we are the only hominoid species at this point in time should not delude us into thinking that we are a product of a purposeful progressive process.

Dr. Marino next reviewed the milestones in the evolution of brains on Earth. She demonstrated that there is a continuity running through the evolution of all brains on this planet, including humans. While we may currently be the smartest species on the planet, this may not have always been the case. All the evidence points to the conclusion that the human brain is one variation of a shared theme that can be understood in a relational context with other species and within our evolutionary history.

In closing she argued that we still (often implicitly) adhere to the Great Chain of Being and that this concept has a profoundly misdirecting impact on our ability to address questions about the future of intelligence. It is important that we cast aside progressive and anthropocentric models of nature in order to identify appropriate research questions about the future of intelligence on other planets, and create a more veridical mindset in the next generation.

III.B The lifetime of Intelligence

The second talk in the session entitled "The Lifetime of Intelligence" was given by William Calvin. Intelligence was defined to be about creativity in solving novel problems. He noted that there is a downside to human intelligence, since we can create adverse situations faster than we can solve them. In other words, physical inventions are nimble while social reactions are ponderous. The focus of the remainder of his talk was about the potential for terminating civilization via worldwide changes in climate. He asked the question "Is global warming an intelligence test for humans?"

He talked about the dangers of an extended El Niño weather pattern. If a big El Niño were to last for two years, the rain forests would become very dry. If the Amazon and Asian rain forests burned, this would add an additional 40 ppm CO_2 to the atmosphere and we would lose a valuable sink for CO_2. He presented the evidence for rising atmospheric CO_2 concentrations. Atmospheric CO_2 has two parallel effects, global warming and ocean acidification. In the atmosphere, elevated CO_2 produces warming—and warming in turn in some areas, expands the subtropical deserts, and sets up long-lasting droughts elsewhere, which can lead to a major extinction event. The increase in the global mean temperature over the last century and a half is depicted in figure 6.

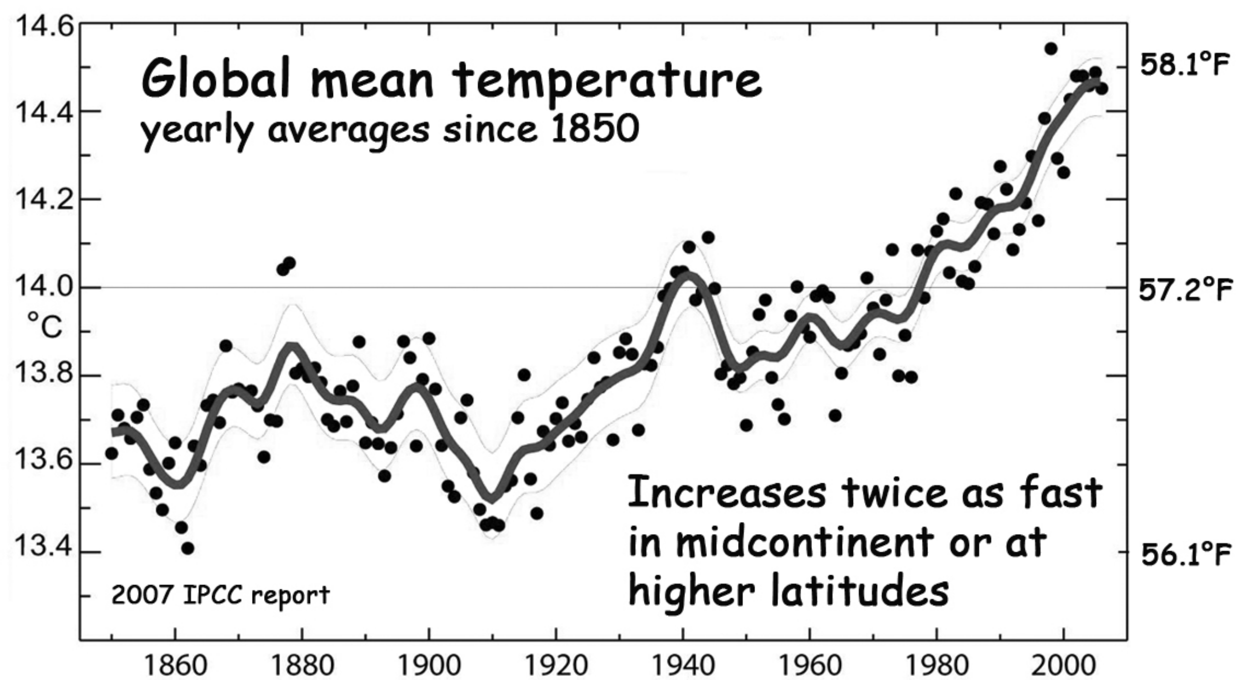

Figure 6. Global mean temperature.

More than half of the oxygen we breathe comes from photosynthesis by phytoplankton. These are grazed by zooplankton, some of which create exoskeletons that, when the little animal dies, sink to the depths, taking carbon out of circulation. Ocean acidification diminishes this “carbon pump.” Dissolving the coral reefs will add to global warming by removing an important carbon sink.

Since serious scientific warnings of global warming began about 1956, we have some history to judge why the societal response has been so sluggish. Science serves as our headlights and, if the applications of technology out drive their reach, it may prove impossible to stop in time. Without the science instrumentation satellites, we would be blind to major changes. But even with good data on how global warming and its effects have been occurring for the last 50 years, and with good coupled-circulation models for atmosphere and ocean to show us the consequences, society has mostly ignored the increasingly emphatic warnings. There are partial exceptions such as Europe and the state of California, but there are many global actors trying to modernize rapidly that cancel out the successes. Others (U.S., Australia, Canada) addicted to high-energy (and high-garbage) lifestyles have been, thanks to willful ignorance, unwilling to take even baby steps.

While denial has played a role, there is nothing here that seems peculiar to intelligent life on Earth. Explosions in population and consumption seem likely to be found in any society where intelligence is not mature enough to head off such problems. One suspects that, for every society that solves its problems in time, there should be hundreds that snuff out their own candle.

III.C Intelligence, Survival and Habitat Diversification

The next presentation in the session by Dr. Nick Woolf dealt with such issues as what is life, what is intelligence, how would an intelligent species interact with the galaxy, and how would it manifest its goal of survival. He defined life as one of a group of processes in which the free energy and material resources of an environment are used to produce modified persistence (survival). Life-like processes have exponential growth that leads to environmental limitations.

Intelligence was equated to the ability to assess options, predict their consequences, and choose a course of action based on those consequences. He raised questions such as: Why does intelligence drive space faring? Will humans become space faring, or may humans facilitate the birth of space faring extraterrestrials? What will be the reproductive strategy of these life forms? What role will local calamities play for them? How will we use this knowledge to observe them or their effects?

The paper considered the situation of how a population expands into a new habitat and reaches an ecological limit, with resultant poorer health and quality of life for the individual. It was noted that living at the ecological limit is a recipe for disaster or even extinction when the ecological limit fluctuates rapidly.

Dr. Woolf explained that reproduction is a key to survival strategies. A single organism, of necessity in a single location, is vulnerable to local extinction-producing disturbances, or to being taken over or becoming food. An intelligent life form will live with a population well below that set by its life enabling resources. Survival will be ensured by habitat diversification and transportation between habitats.

Humans use habitat diversification, but have a narrow environmental tolerance. Thus unless an environment can be "terraformed"—modified to be intrinsically long-term human friendly—we cannot populate it in the way we populate Earth. This is a severe limit that does not apply to other life forms that are able to inhabit a vacuum and that don't need materials or water except for limited processes such as repair and reproduction.

The frequency of terrestrial extinction events, and the number of index fossils, argues that a habitat limited to one planet around one star is not a good strategy. Thus space faring is required for long-term survival. The rest of the talk focused on the nature of intelligent spacefarers, and how they would prioritize their activities and protect themselves from destructive events. It was hypothesized that since intelligent spacefarers would live far below the limiting resources of their environment, aliens would be welcome. There is more to benefit by learning alien science than there is to lose by sharing resources. If your goal is modified survival for billions of years, your activities are not time critical. Intelligence is collaborative, not competitive!

IV. Cultural Evolution

IV.A Cultural Evolution: An Introduction for Visionary Scientists and Scientific Visionaries

Kathryn Denning gave the foundational talk on cultural evolution in the third session chaired by Robert Sawyer. Her talk covered selective cultural evolution on Earth, particularly the data at our disposal—its nature and limitations, the methods used to make sense of the data, and existing theories about how cultural evolution works. She then suggested ways that we might best use humanity's own journey as an aid to thinking about the cultural evolution of intelligent, technological beings on other worlds.

She noted that as we consider the future of intelligence in the cosmos, we should look carefully at cultural evolution on Earth for two reasons:

(1) It's the only dataset we have about cultural evolution, and we should make the most of it (i.e., follow the astrobiological principle of using life on Earth to explore possibilities for life elsewhere).
(2) We can't avoid it. We all unconsciously and constantly use our pre-existing ideas about cultural evolution when we try to imagine other intelligences and other worlds; it would be best to do this as rigorously as possible.

She asked the question "does the history of cultural evolution on Earth really matter?" One could argue that in thinking about extraterrestrial civilizations, we should be more concerned with machine-based intelligence. Also, one might argue that in thinking about our own future, emerging technologies like genetic engineering, nanotechnology, and artificial intelligence are putting us in a new era. All the rules are about to change, and there's no point in discussing how things used to be. While she agreed that these lines of thought should be pursued, she made very cogent arguments that the 10,000 years' worth of data about civilizations here were a good starting point to assess the future of humanity.

She noted that many key questions about civilization are still hotly debated in the historical disciplines. For example, what drives history? Why, after a hundred thousand years as hunter-gatherers, did some *Homo sapiens* change their lifestyle? How, and under what conditions, does technology become complex? How and why do civilizations emerge, develop, and decline? Do all civilizations work basically the same way, or not? Why do some societies, but not others, explore and conquer? Why are some nations wealthy and others poor? What is the relationship between societies, objects, and their environment? Can we predict what will happen next?

She talked about the anthropological approach to studying culture. First, she defined "culture" as "everything humans think and do that isn't completely wired." She noted that our culture and biology are intertwined, and that anthropologists try to document the breadth of human experience, but also to find similarities between cultures. However, the incompleteness and inaccuracies in both the historical and archeological record dramatically complicate the interpretation of the data.

Dr. Denning then talked about how anthropologists model cultural evolution as a whole. She listed many theories that had a particular focus, e.g., cultural ecology, which focuses on the interrelationship between humans and their natural environment, or conflict theory, which focuses on the conflict between cultures. She also touched on the subject of collapse and noted several instances where a long-lived society dramatically crashed and burned. Environmental changes were often a partial cause, so again the issue of climate change arose.

She concluded her talk by discussing how studies of cultural evolution might apply to the SETI search for extraterrestrial intelligence. In particular, she suggested that we reconsider the theoretical frameworks through which we explain the evolution of civilization, emphasize the range of possibilities for cultural evolution, and go back to the anthropological, historical, and archaeological data to explore relevant areas concerning the evolution of civilizations. Focusing on these will help us get the most useful information out of Earth's civilizations, and allow the available data to speak to the bigger questions of intelligence in the cosmos—in case a stranger ever does come to town. But they're also important in helping us consider the next chapters in our own journey.

IV.B Surviving the Bottleneck: The Longevity of Homo sapiens

The last presentation on the first day was by Seth Shostak entitled "Surviving the Bottleneck: The Longevity of *Homo sapiens*." His talk was focused on the last parameter in the Drake equation, namely L, the average technological lifetime of an intelligent civilation. Previous estimates for L have ranged over at least 6 orders of magnitude. Carl Sagan estimated $L =$ million years and Frank Drake estimated 10,000 years. L is 60 years for us. He noted that unless L is of the order of 10,000 or greater, the chance that anyone would survive long enough to establish communication is small. Therefore, the critical question is how long will our technologically advanced civilization survive. Dr. Shostak considered two scenarios:

A small value for L implies a catastrophe in the evolution of human culture. He cited, for example, the socio-economic arguments presented in 1972 by von Hoerner. At that time population growth was 2% per year. Population increases at this rate lead to running out of both food and energy by ~2025 AD. Waste heat was another problem leading to global warming. One could easily conceive of other disaster scenarios, such as nuclear war, asteroid impacts, etc. However, von Hoerner predictions were incorrect, primarily because the population growth rate is now <1% per annum. Interestingly, Isaac Newton also agreed with von Hoerner, predicting the apocalypse (or at least the end of the Holy Roman Empire) in 2060 AD.

He then presented some of the arguments for a larger *L* value. He noted that there are no biological barriers and there are precedents for long-lived species, noting that modern sharks evolved more or less 100 M years ago, and that there were trilobites for 300 million years. Inevitable catastrophes, such as warming of the Sun, or extinction of the Sun, have time scales of 10^8 – 10^9 years. He presented the so-called doomsday theory of J. Richard Gott, who was the first to apply the Copernican principle to the survival of humanity. The validity of these arguments is very dependent on the assumption that there is no special time in the evolution of the human race. Gott's original prediction gave 95% confidence that the human race would last for between 5100 and 7.8 million years.

He reasoned that the barriers to at least thousands of years of technological existence are (with the exception of avoidable problems such as errant asteroids) socio-economic ones, such as man-induced disasters like nuclear war or global warming. He was optimistic that we would be able to circumvent this scenario, because when you invent H-bombs, you also invent rockets. This will allow humans to travel from Earth within another 100–150 years to colonize the moon, Mars, or asteroids, and to develop artificial space habitats a la Gerald O'Neil and Tom Heppenheimer. Once dispersed, we are inoculated against total self-destruction. He cautioned, however, that there were some wild cards that could occur in the same time frame as dispersal, such as genetic engineering, SETI success, or advancements in artificial intelligence. He ended on an optimistic note that some would make it through impending bottlenecks in the next few centuries, resulting in a long run for the human race.

V. Technological Evolution

V.A The Ultimate Limits to Technology

On the morning of the second day, the workshop theme was technological evolution with Tom Pierson as session chair. Paul Davies gave the first presentation on the topic of "The Ultimate Limits to Technology." Dr. Davies introduced the Kardashev scale (after Soviet astronomer Nikolai Kardashev) for classifying how technologically advanced a civilization is. A type I civilization was defined as being capable of harnessing all the power on a planet ($\sim 10^{16}$ W); a type II, all the power from a single star ($\sim 10^{26}$ W); and a type III, all the power from a galaxy ($\sim 10^{36}$ W). For good measure he added type IV civilizations (harnessing the power of a super cluster) and type V (controlling the whole universe!). Currently humans are at about 0.7 on this logarithmic Kardashev scale.

Dr. Davies next discussed the concept of the Technological Singularity, which is the hypothesized creation, usually via artificial intelligence (AI) or brain-computer interfaces, of smarter-than-human entities who rapidly accelerate technological progress beyond the capability of human beings. Vernor Vinge later popularized the Singularity in the 1980s with lectures, essays, and science fiction. He showed a plot of Moore's law and mentioned that some futurists, such as Ray Kurzweil, consider it part of a long-term pattern of accelerating change that generalizes Moore's law to technologies predating the integrated circuit. He illustrated the countdown to the Singularity by showing the logarithmic plot of paradigm shifts for key events versus the time to the next event.

He also discussed the types of limits on technology that civilizations could encounter. For example, a technology could be possible but financially unrealistic, such as cryonically preserving everyone. Or a technology could be physically possible, but technologically intractable, such as transporters. Finally, technologies could violate the laws of physics and thus be impossible, such as faster-than-light travel, time travel, or perpetual motion machines. Thus there could be fundamental limits to how advanced a civilization could become.

Dr. Davies ended his presentation by talking about virtual reality and the possibility that there could be one real world, but many engineered worlds. In other words, the possibility that mankind may not be the deepest reality—we may be a simulation (e.g., in the matrix rather than the physics itself). He discussed the work of John Barrow and Nick Bostrom, who discuss the possibility that we are living in a simulated reality or a computer simulation. If so, might we expect to see occasional glitches and small drifts in the supposed constants and laws of Nature over time?

V.B Invent a Printing Press and Hang On

Jack McDevitt gave the second talk in this session on technological evolution entitled “Invent a Printing Press and Hang On”. The key thesis to his presentation was that there is a strong possibility that, with the rise of technology, civilization becomes increasingly vulnerable to disruption. It may be that a collapse, within a few centuries, is all but unavoidable. Technology is designed and produced by the brightest among us. But ultimately, its more dangerous applications are used by politicians and criminals. There are numerous other possible roads to collapse: greenhouse effects, overpopulation caused by failure to employ birth control devices, and/or by continued advances in life extension, nanotechology, etc.

These possibilities become more daunting in light of the fact that humans, who might act to stave them off, are so easily programmed to function in opposition to their own best interests. Note the willingness of people under Nazi control during the Holocaust to turn in their neighbors. Most of us have ideologies imposed on us when we are quite young. These ideologies sometimes overwhelm our common sense and our innate compassion. So we are fully capable of strapping on suicide belts to kill strangers, or to impose discrimination on people of a different color or a different political bent, or to demand that others live by our sexual rules. We can do all this and retain a sense of moral superiority. Thus, when TV commentators maintain that greenhouse warming is really a political ploy about which we need not worry, millions of us buy into it and cannot be dissuaded.

An important step forward would be to emphasize critical thinking in high schools. This would, of course, be difficult to implement because parents, in fact, are more interested in having their children programmed in acceptable ideologies than in actually creating kids who would value thinking for themselves. Nevertheless, it would be helpful if that type of liberal education could be implemented worldwide.

V.C 2001 is Past, but where is HAL?

The next presentation was by Marvin Minsky entitled “2001 is Past, but where is HAL?” The focus of the talk was a set of technical ideas about making machines with human-like intelligence. He predicted that we would evolve into machine-like intelligence, because we eventually will overcome death by uploading our minds into machines. Then these, our mental descendants, will further evolve in unknown ways. If we are the only such intelligent species in the universe, then this action may be necessary to keep the universe meaningful. Our artificial intelligence (AI) descendants could be made very small, yet robust, and thereby may be capable of colonizing the galaxy. He predicted that, in any case, we would need AIs to do much of the work as the lifespan of humans increases.

He noted that none of our machines have yet achieved humanlike common-sense reasoning. He described many of the types of AI methods, such as reinforcement learning, rule-based systems, neural networks, genetic programs, etc., and described the shortcomings of each. It is difficult to simulate human resourcefulness, because it is based on using multiple “ways to think.” For example, humans reason by analogy, by breaking problems into smaller parts, by reformulating the problem, and by using contradiction. In addition, humans use different representations and multiple levels of representation to solve problems. “Understanding” means having multiple ways to deal with different aspects of things. By building networks with multiple senses, a human can examine ideas from different perspectives.

Dr. Minsky next described the “critic-selector” model of the mind. Critics recognize a problem type and selectors activate a way to think. For example, if a problem seems familiar, try reasoning by analogy; if it is too complex, try replacing it by a simpler one. He described emotions as “ways to think.” He noted that Occam’s Razor (or the “law of succinctness”), which states that the explanation of any phenomenon should make as few assumptions as possible, had little application to the human brain. The brain, which contains hundreds of organs, is extremely complex. It encompasses the super-ego, which contains the self-conscious emotions and self-reflective thinking; the ego, which includes reflective and deliberate thinking; and the id, which controls learned and instinctive reactions. Clearly, designing robots with human capability to reason is well in the future. However, he ended his talk by speaking about modular robots to send to the moon, and about very early steps to incorporate AI.

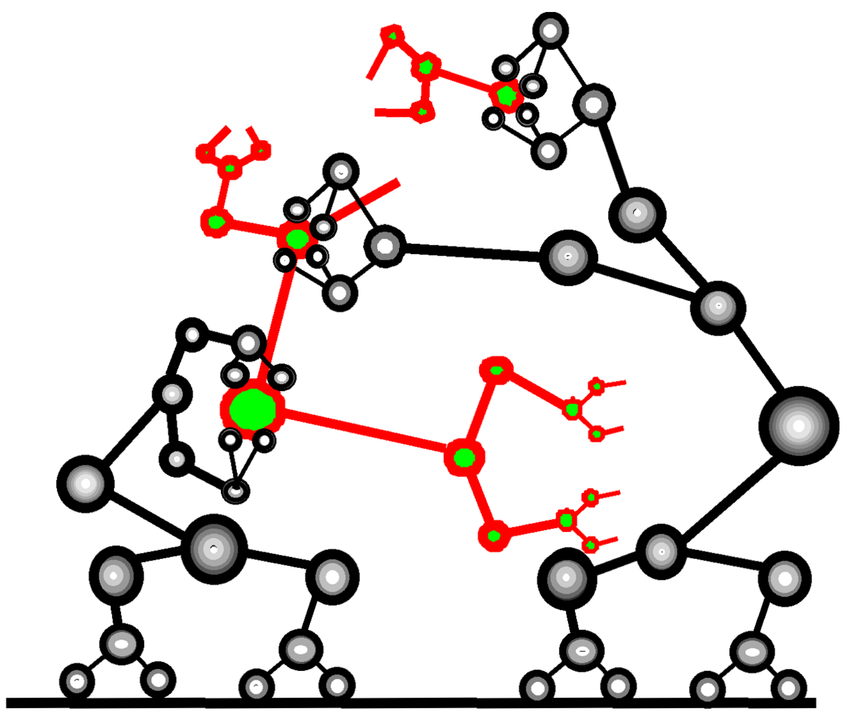

Figure 7. Two modular robots repairing each other.

V.D Astro-economics

The next talk entitled "Astro-economics" was given by Jaipal Tuttle. His key points were as follows: Human economic activity over the past several centuries has been increasingly dominated by trading activity in physical commodities, financial instruments, and increasingly in information. The scale of this activity has been growing exponentially, and the coordination of financial markets has increased exponentially as well. Timing delays of milliseconds can lead to large losses, and speed-of-light issues are becoming increasingly important. It is, therefore, not unreasonable to expect that alien civilizations may engage in trading, and indeed, it is possible that a galactic information marketplace may exist.

Using these arguments as a base, he then showed that gravitationally induced time dilation has a profound effect on interest rates, and he re-derived the standard Black-Scholes option pricing theory within a relativistic framework. In short, "Depositors" (in the abstract sense) benefit from having their money accrue interest as quickly as possible, which leads to the conclusion that "Banks" (also in the abstract sense) will be located in locally flat regions of space-time that lie in the vicinity of environments where space-time is highly curved. The galactic center, with its profusion of stellar black holes and its massive 3 x 10^6 solar mass central black hole, is an excellent example of such an environment. He suggested that information trading activity might produce a detectable SETI signal.

IV.E Beyond Reductionism: The Future of Nano-Medicine and Nano-Energy

The presentation by Jonathan Trent entitled "Beyond Reductionism: The Future of Nano-Medicine and Nano-Energy" had three contrasting sections that were meant to provide a perspective on the future of intelligence. The first perspective was to put humans into context in space-time by showing a simulation of how current theories of planetary formation generate a solar system from a dust cloud around a stellar disk. He showed the relative sizes of the Sun and the planets in our solar system, followed by a time-line for Earth and for life on Earth. He provided perspective by mapping the Earth and life time-lines onto an image of a football field. His key point was to remind us where we stand in space and time and to put our "mighty meditations" about the future of intelligence into perspective.

His presentation then shifted to focus on "tools" that are at the foundation of our technology, both of which are central to the concept of intelligence we were discussing. He began the discussion with an image of an ape/hominid with a bone in hand (an image from Kubrick's movie 2001), representing the earliest use of a tool. He then abruptly shifted to a description of nano-electronics in 2007, showing how our current sophisticated tools (computing machines) are now being built from components the size of molecules. He then discussed nano-medicine to contrast our molecular machines with the complexity of biology. Developments in nano-medicine, such as "nano-bots," were described as "new, but not true." He noted that nano-medicine's claims to drug discovery were "true, but not new." He then generalized the issue of nano-medicine and nano-devices as "new, but so what?" because such devices remain to be developed. Finally, he noted that we should expect from nanotechnology developments that should be "new, true, and important."

At this point, he shifted to the third section of his presentation—showing a video with a map of the Earth and the changing number of people at different locations beginning at 1000 AD and projected to the year 2030. The video and other graphics showing exponential population growth raise the question: What human population can the Earth sustain? This question implicitly impacts the future of intelligence because it impacts the future of civilization. He showed the population centers overlaid by the energy use in the world and quoted Nobel Laureate, Richard Smalley, who said that, the "biggest single challenge in the next few decades will be energy...." Finally, he noted a need to switch to solar energy, and suggested that we may be able to harvest the sun's energy from cellulose using a nanobiotechology approach that he was developing in his laboratory.

V.F The Role of Anomaly Detection in SETI

Ashok Srivastava's talk was entitled the "The Role of Anomaly Detection in SETI". He noted that the search for extraterrestrial intelligence is currently based on the analysis of electromagnetic signals received from large systems of radio telescopes. These signals can be thought of as streaming multidimensional time series, with each dimension corresponding to the amount of energy in a particular wavelength band. In most cases, these signals will contain white noise with no other information. We assume that white noise implies that the time series data have a flat power spectral density over the frequency range of interest. We note that due to natural phenomenon the actual signal measured may have a correlation structure that is not white but easily explained. In this case, we would consider the residual signal to be analogous to white noise, within a linear transformation. The assumption of a white noise signal is thus not a strong assumption. Information, which changes the autocorrelation structure from that of white noise, could arise through at least three potential nontrivial sources:

1. Natural phenomenon: In this case a natural phenomenon which happens to fall in the field of view of the radio telescope could change the autocorrelation structure.
2. Sensor failure: The sensing mechanism within the radio telescope could fail, which could produce a change in the autocorrelation structure and make it deviate from that of white noise.
3. Extraterrestrial transmission: In this case the observed variation in the signal is due to a deliberate change in the autocorrelation structure. In the most interesting case this transmission contains a message. It could also represent a 'burst' in the signal spectrum due to a catastrophic event at the distant civilization.

In all of these cases, the underlying task is to develop automatic schemes to detect the deviation from what is expected in the multidimensional data stream. For data streams as large as those expected in a SETI application, the anomaly detection mechanism would need to automatically build a model of what is expected based on observed data that does not contain a signal of interest. Once this nominal behavior is characterized, the algorithm can use a variety of methods to determine whether future observed signals deviate significantly from what is expected. In order to compensate for changes in the sensing technology, sensor drift, and other environmental factors, the models of nominal behavior would need to be automatically rebuilt at regular intervals.

The details of the way the underlying model is built and the measures used to determine significant deviation can be left to the particular application environment. However, as the formulators of the SETI@home project already noted, the data sets that need to be analyzed are significant in size, and thus, parallel and distributed computing techniques are needed to conduct the search.

VI. Breakout sessions

In the afternoon, the workshop participants broke into three separate groups to address three questions in more detail. The first breakout group was tasked with addressing two questions, namely, "what research needs to be done to prepare humankind for the future?" and "what can be done to facilitate SETI success?" The second group considered the question of "what are the likely options for the evolution of humans?" The third breakout group was tasked with the question of "how we can make science more exciting to our children?" The following discussion provides some of the ideas that came out of the three breakout groups.

VI.A What research needs to be done to prepare humankind for the future, whatever future that is, and what can be done to facilitate SETI success?

The research that is needed to prepare humankind for the future is tied to issues about the stewardship of Earth. The question was raised "what kind of Earth do we want?" It is not a matter of survival of Earth, per se, but the survival of the human legacy. We need to develop a cogent story of the great human journey that persuades humankind that our destiny is not predetermined, and to develop a shared cosmology and convince people that they have the power to change the future. We need to create a sense of urgency about issues such as global warming and to address the immediate threat of global warming by developing a serious research effort on emergency measures such as geo-engineering or climate control. We should institute financial incentives to reward desired behaviors and to champion conservation. The world needs to start a major research effort on alternative energy sources. In the near-term, we need to transition away from combustion and towards solar and other sustainable energy sources. We need to increase our use and acceptance of nuclear power and maintain a research effort into future energy sources such as fusion reactors.

The breakout session also discussed biodiversity or population dynamics. There is concern that the continued rapid rise in human population is neither sustainable nor good for biodiversity. How much do we want to design, control, and sustain biodiversity, and do we need to reduce the human footprint in the future? Finally, in case of a natural or human induced "crash" in human population, we should have a plan for facilitating a soft landing, e.g., disaster response, information storage, and time capsules to preserve cultural and intellectual heritage.

The question of what could be done to improve the chances of SETI success was also addressed. In general, it was felt that improving the chances of success depends on developing a comprehensive observation program. This requires systematically addressing the many dimensions of the cosmic haystack (see earlier discussion), improving data mining techniques to search the multitude of existing data sources, and developing a lunar far-side capability to mitigate against increasing interference. We should also look carefully for anomalies in other astronomical research. The subjects of the consequences and societal responses to contact were discussed. We should use existing Earth data to formulate and test hypotheses about life, intelligence, and social organization. It was suggested that we prepare to talk with aliens by trying to talk with other intelligent species here on Earth.

VI.B What are the likely options for the evolution of humans?

The second breakout session addressed the question of "what are the likely options for the evolution of humans?" A major theme of the discussion was Darwinian selection (natural) versus Lamarckian (voluntary selection). Lamarckian evolution refers to the idea that an organism can pass on characteristics that it acquired during its lifetime to its offspring. The force of natural selection lessens, because bottlenecks of location, or selection in famines, droughts etc., become less in modern times. Furthermore, as we begin to unravel the human genome and to develop the capability of selecting for individual traits, parents may choose to have certain traits placed into their offspring and these traits would remain in the population. Polls have shown that given the option, parents would opt to select for such traits as speed, strength and endurance in sports, as well as hair and eye color, height and beauty. The breakout group felt that selecting "in" as well as selecting "out" traits would become a big social issue. This has already begun, e.g., the selection against Down's syndrome. Will selection against individuals with low IQ become socially acceptable?

Human behaviors are likely to be many-gene traits, and thus harder to select for. Would society opt to eliminate criminal behaviors genetically—or would they prefer a pharmacological solution? The group discussed briefly what role the government should play if society develops the capability to make genetic alterations, as well as the potential problems with genetic selection. For example, once you start selection for genetic traits, you depart from natural selection. Some countries might select against females, producing long-term consequences. Complex traits, like criminal behaviors that are influenced not only by gene traits but social influences, are difficult to select against. Particularly relevant to the theme of this workshop was the discussion about whether society would select for intelligence. Although this would no doubt be culturally dependent, studies have shown that selection for intelligence would probably not rank very high, even if it were possible to select for.

VI.C What can we do to make these scientific questions and others more exciting to our children who will inherit the future?

The third breakout group addressed the question of "what can we do to make science more exciting to our children." There was general agreement in the group that the culture and education system in the United States was not conducive to promoting excitement about science. The group discussed a wide range of possibilities and came up with the following ideas:

(1) Support an Internet-based writing contest that asks students to submit essays describing what they would like to ask an alien civilization, should we someday make contact. Scholarships, laptop computers, or other education-appropriate prizes could be used to help motivate participation.

(2) Encourage scientists and engineers to volunteer one day a month as substitute adjunct teachers in public and private schools. Very few young students have the opportunity to interact with working scientists. Becoming a qualified substitute teacher in the public school system is a relatively simple process in most states. Working professionals can generally arrange to take a day off each month to work in their communities; those working part-time, or retirees, can certainly do this. In order to avoid a negative effect, there should be some screening process to ensure that these volunteers interact appropriately and positively with student age groups. Sharing the excitement of their work, and showing simply by their presence that real, flesh-and-blood people have meaningful careers in science, would help motivate greater student interest in science and SETI.

(3) Develop SETI-specific lesson modules for middle school students, focusing on the sixth or seventh grade, when students typically begin a serious study of science. This would be a basic, interdisciplinary, multi-week module that integrates lessons on physics, biology, astronomy, chemistry, math, and ecology. SETI is an exciting "unifying theme" to explore scientific thinking and techniques, and would help keep students interested in science at a time when their interest typically begins to wane. NASA could help by creating school curricula in crosscutting areas such as astrobiology, exercises, and lesson plans they can use in classes that contains background knowledge for the teachers as well.

(4) Create a weeklong "SETI Camp" experience at, or adjacent to, one or more NASA field centers. Modeled on the "Space Camp" approach, students would spend a week during the summer, learning about science generally and SETI, specifically through hands-on activities, experiments, and presentations by researchers actively working in the field. We should try to find corporate funding for sponsorship.

(5) Produce a series of short "YouTube"-style videos that utilize the storytelling techniques of film and television to stimulate interest in SETI among a younger audience. We should have a presence on web sites that cater to young people, such as MySpace, IPOD, and Facebook, and try to involve them in SETI and space science activities.

(6) The Al Gore documentary "An Inconvenient Truth" created a cultural impact that has helped bring the issue of global warming to the larger public. We need to find another Carl Sagan and a financial backer, who can inspire the public to learn more about science. A spokesperson who can engage a multi-cultural global audience could help develop a shared cosmology, or at least a deeper understanding of our place in the universe.

VII. Research priorities: where do we go from here?

The last session focused on ways to sustain the momentum of the workshop. This report satisfies one of the initial actions to document the workshop proceedings in a NASA Conference Proceedings. Another action was to establish a working group to develop a plan to engage the media and to expand the discussion of the future of human intelligence outside the workshop group. Inevitably this will necessitate creating a newsworthy story with many opportunities for updates. Another goal is to build support and advocacy for SETI. It was suggested that we have a celebration of the 50th anniversary of the first radio search in 2009 or 2010 to educate the public about the Allen Telescope Array as an example of the ever-increasing search capability of SETI. The possibility of a press conference, either live or in the 3-D virtual world of Second Life, in conjunction with releasing the workshop report, was discussed. A substantial number of participants agreed to participate in a press release. Another action that has been completed is the creation of a list server to promote further communication on topics related to the workshop.

Other actions suggested by the workshop were to have a follow-on meeting and to find funds for research about intelligence, being mindful of the existing work and making sure it relates to other NASA supported activities such as astrobiology. The concept of an Ames summer school for senior college students through post-docs on such themes as climate change was vetted. This could help infuse young people with the excitement of the NASA scientific mission and inspire young talent to take on research on pressing global problems such as climate change.

Two opportunities to involve students already exist at Ames: The Exploration Academy's on-going summer program, and the International Space University (ISU) that will be held at Ames in 2009. We should also explore the possibility of further workshops that are jointly sponsored by Silicon Valley businesses. Another possible venue for a follow on workshop is BEYOND: The Center for Fundamental Concepts in Science. BEYOND is a pioneering international center at Arizona State University specifically dedicated to confronting the big questions of existence. Other possible venues include the Long Now Foundation and SETI.

There was agreement that further symposia or workshops should continue to have high scientific credentials because of the sensitivity of topics related to alien life. One option would be to focus it on specific research suggestions coming out of this workshop's sub-groups, such as SETI-specific programs, planetary searches, or new searches looking at asteroids. In fact, "The Future of Intelligence in the Cosmos" workshop was one of a series of workshops sponsored by NASA Ames Research Center that focused on "out of the box" thinking.

The discussion again turned to issues of climate change and biodiversity. Many workshop participants feel that global warming is a crisis that must be dealt with immediately to avoid irreparable harm to the ecosystem. The focus on this near-term issue precluded an in-depth discussion of the longer-term future of human intelligence, such as the possibility of reaching a singularity where artificial intelligence supplants or augments human intelligence. A possibility of a future workshop focused just on machine intelligence or the Singularity was discussed.

In summary, the workshop consisted of an interdisciplinary group of world-class scientists and other practitioners meeting to discuss the future of intelligence in the cosmos. The first conclusion reached is that we need to work many short-term concerns, such as climate change, loss of biodiversity, and human population rise that divert us from a sustainable course for the future. The participant's difficulty with moving beyond a discussion of the barriers to a long-term future to a discussion of the future itself is a sobering comment on the difficulties of engaging the political and cultural leaders in an active plan for the future of intelligence on this planet. The second conclusion is that we need to understand how to work with and search for other intelligence in the universe, including other life forms on Earth. The workshop suggested a future research program, plus science-oriented activities involving students and the public. Finally, we need to get the opinion makers engaged through the release of this report in conjunction with a press release.

Agenda

Future of Intelligence in the Cosmos (A NASA-Ames/SETI/ UCSC workshop)			
		DAY ONE Saturday, June 30	
Time	**Dur. (min)**	**Description**	**Speakers & Discussion leaders**
8:00	30	Breakfast	
8:30	5	Logistics	Stephanie Langhoff
8:35	10	Welcome/objectives	Pete Worden
8:45	15	Introduction of participants	
Theme: The Fermi Paradox Session Chair: Frank Drake			
9:00	40	FOUNDATIONAL TALK: The Galactic Planetary Census	Greg Laughlin
9:40	20	Discussion	
10:00	40	FOUNDATIONAL TALK: The Great Silence - Or Not?	Jill Tarter
10:40	20	Discussion	
11:00	15	Break	
11:15	20	TALK: The future of the visible universe may depend on us	Joel Primack
11:35	20	TALK: Interstellar travel requires shared cosmology	Nancy Abrams
11:55	20	Discussion	
12:15	20	TALK: Seeking Ozymandias: Building and searching for beacons	James Benford Gregory Benford
12:35	15	Discussion	
12:50	60	Lunch	
Theme: The Nature of Intelligence Session Chair: Andre Bormanis			
13:50	40	FOUNDATIONAL TALK: The Nature of Intelligence: Escaping orthogenetic concepts	Lori Marino
14:30	20	Discussion	
14:50	20	TALK: The lifetime of intelligence	William Calvin
15:10	15	Discussion	
15:25	20	TALK: Intelligence, survival and habitat diversification	Nick Woolf
15:45	15	Discussion	
16:00	15	Break	
Theme: Cultural Evolution Session Chair: Robert J. Sawyer			
16:15	40	FOUNDATIONAL TALK: Cultural Evolution: An Introduction for Visionary Scientists and Scientific Visionaries	Kathryn Denning
16:55	20	Discussion	
17:15	15	TALK: Surviving the Bottleneck: The Longevity of Homo Sapiens	Seth Shostak
17:30	15	Discussion	
17:45		Adjourn	
19:00		**DINNER: Chef Chu's, 1067 N San Antonio Rd, Los Altos**	

Day two on reverse

Time	Dur. (min)	Description	Speakers & Discussion leaders
		DAY TWO Sunday, July 1	
Time	**Dur. (min)**	**Description**	**Speakers & Discussion leaders**
8:00	30	Breakfast	
Theme: Technological Evolution Session Chair: Tom Pierson			
8:30	30	FOUNDATIONAL TALK: Ultimate Limits to Technology	Paul Davies
9:00	15	Discussion	
9:15	15	TALK: Invent a printing press and hang on	Jack McDevitt
9:30	15	Discussion	
9:45	15	TALK: 2001 is past, What must we do to build a HAL	Marvin Minsky
10:00	15	Discussion	
10:15	15	TALK: Astro-Economics	Jaipal Tuttle
10:30	15	Discussion	
10:45	15	Break	
11:00	20	TALK: Building on reductionism: The future of nano-medicine and nano-energy	Jonathan Trent
11:20	15	Discussion	
11:35	20	TALK: Future of intelligent systems	Ashok Srivastava
11:55	15	Discussion	
12:10	50	Lunch	
Breakout Sessions			
13:00	10	Introduction to breakouts	Langhoff/Pilcher
13:10	105	Breakouts on research questions and approaches: (a) What research needs to be done to prepare humankind for the future, whatever future that is? (b) What are the likely options for the evolution of humans? (c) What can we do to make these scientific questions and others more exciting to our children who will inherit the future?	Chairs: (a) David Morrison: (b) Gregory Benford; (c) Andre Bourmanis
14:55	15	Break	
15:10	30	Reporting of breakout groups	
15:40	45	DISCUSSION: Research priorities-where do we go from here?	Pete Worden
16:25	15	Review of main points of meeting / next steps	Langhoff/Pilcher
16:40		Adjourn	

List of Participants

NAME	AFFILIATION	EMAIL
Nancy Abrams	UCSC	nancy@physics.ucsc.edu
James Benford	Microwave Sciences	jbenford@earthlink.net
Gregory Benford	UC Irvine	xbenford@aol.com
Andre Bormanis	Sky by Night Productions	abormanis@adelphia.net
William Calvin	University of Washington	wcalvin@u.washington.edu
Carol Cleland	University of Colorado	Carol.Cleland@Colorado.edu
Randall Correll	Ball Aerospace	rcorrell@ball.com
Jessy Cowan-Sharp	Planners Collaborative	jsharp@mail.arc.nasa.gov
Pauline Davies	Arizona State University	Pauline.Davies@asu.edu
Paul Davies	Arizona State University	Paul.Davies@asu.edu
Kathryn Denning	York University	kdenning@yorku.ca
Lynnclaire Dennis	ISG Global Community Foundation	ld@sync-q.com
Frank Drake	SETI Institute	drake@seti.org
Steve Jurvetson	Draper Fisher Jurvetson	steve@dfj.com
John Karcz	SETI Institute	jkarcz@arc.nasa.gov
Thomas Klisdonk	SETI Institute	tklisdonk@seti.org
Peter Klupar	NASA - Ames	Peter.D.Klupar@nasa.gov
Stephanie Langhoff	NASA - Ames	slanghoff@mail.arc.nasa.gov
Greg Laughlin	UCSC	laugh@ucoclick.org
Larry Lemke	NASA - Ames	Lawrence.G.Lemke@nasa.gov
Will Marshall	USRA-RIACS	wmarshall@mail.arc.nasa.gov
Lori Marino	Emory University	lmarino@emory.edu
Jack McDevitt	Science Fiction Writer	cryptic@gate.net
Marvin Minsky	MIT	minsky@media.mit.edu
Thomas Pierson	SETI Intitute	tpierson@seti.org
Joel Primack	UCSC	joel@physics.ucsc.edu
Robert J. Sawyer	Science Fiction Writer	sawyer@sfwriter.com
Jeff Scargle	NASA - Ames	Jeffrey.D.Scargle@nasa.gov
Rob Schingler	NASA - Ames	Robert.H.Schingler@mail.nasa.gov
Seth Shostak	SETI Institute	seth@seti.org
Ashok Srivastava	NASA - Ames	Ashok.N.Srivastava@nasa.gov
Jill Tarter	SETI Institute	jtarter@seti.org
Alvin Toffler	Toffler Associates	mashta@verizon.net
Johnathan Trent	NASA - Ames	Jonathan.D.Trent@nasa.gov
Laurie Tucker	SETI Institute	tworeallytallgirls@sbcglobal.net
Jaipal Tuttle	Oklo Corporation	jaipal.tuttle@gmail.com
Douglas Vakoch	SETI Institute	dvakoch@seti.org
Alan Weston	NASA - Ames	Alan.R.Weston@nasa.gov
Nick Woolf	Steward Observatory	nwoolf@as.arizona.edu
Al Whaley	SETI Institute	awhaley@seti.org
Pete Worden	NASA - Ames	Pete.Worden@nasa.gov

REPORT DOCUMENTATION PAGE	Form Approved OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
12/18/2007	Conference Proceedings	06/2007 – 07/2007

4. TITLE AND SUBTITLE	
Workshop Report on the Future of Intelligence In The Cosmos	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
Stephanie Langhoff[1], Carl Pilcher[1], Greg Laughlin[2], Jill Tarter[3], and Seth Shostak[3]	5e. TASK NUMBER
	5f. WORK UNIT NUMBER 292487.01.01.01

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)	8. PERFORMING ORGANIZATION REPORT NUMBER
[1]NASA Ames Research Center, Moffett Field, CA 94035-1000 [2]University of California at Santa Cruz, CA 95064 [3]SETI Institute, Mountain View, CA 94043	A-070013

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSORING/MONITOR'S ACRONYM(S)
National Aeronautics and Space Administration, Washington D.C. 20546-0001 University of California at Santa Cruz, CA SETI Institute, Mountain View, CA	NASA, SETI, UCSC
	11. SPONSORING/MONITORING REPORT NUMBER NASA/CP–2007-214567

12. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified — Unlimited Distribution: Nonstandard
Subject Category: 55, 63, 90
Availability: NASA CASI (301) 621-0390

13. SUPPLEMENTARY NOTES
Point of Contact: Stephanie Langhoff, Ames Research Center, MS 207-3, Moffett Field, CA 94035-1000
(650) 604-6213

14. ABSTRACT

The workshop was organized around a series of themes beginning with the Fermi Paradox, which tersely stated is the conundrum that while the basic conditions for life are met in our galaxy, there is no evidence whatever for the existence of extraterrestrial civilizations. This theme included talks about the current cosmological theories of how the universe has evolved, and the status of what is known about extra-solar planets. The status of the search for extra-terrestrial intelligence was given along with a discussion of how future technologies could improve the probability for a successful detection.

The second theme dealt with the nature of intelligence. The need to have the correct mindset when addressing questions about intelligence on other planets was stressed. Presentations in this session were focused on the lifetime of intelligence, and the bottlenecks that might limit the lifetime of an intelligent technological civilization. The third theme on cultural evolution continued the discussion on the expected lifetime of a technological civilization. It was emphasized that we need to further our understanding of human cultural evolution to understand the range of possibilities for extra-terrestrial civilizations.

The final theme of the workshop focused on technological evolution. What are the ultimate limits to technology? The concept of the technological singularity where humans might evolve into machine like intelligence was discussed. This session was focused on how future technologies might influence human evolution.

15. SUBJECT TERMS
Intelligence, Fermi Paradox, cultural evolution

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
					Stephanie Langhoff
Unclassified	Unclassified	Unclassified	Unclassified	40	19b. TELEPHONE *(Include area code)* (650) 604-6213

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39-18