
Exoplanets, Extremophiles, and the Search for Extraterrestrial Intelligence

Jill C. Tarter

1.0. Introduction

We discovered the very first planetary worlds in orbit around a body other than the Sun in 1991 (Wolfczan and Frail 1992). They were small bodies (0.02, 4.3, and 3.9 times as massive as the Earth) and presented a puzzle because they orbit a neutron star (the remnant core of a more massive star that had previously exploded as a supernova) and it was not clear whether these bodies survived the explosion or reformed from the stellar debris. They still present a puzzle, but today we know of over five hundred other planetary bodies in orbit around hundreds of garden variety stars in the prime of their life cycle. Many of these planets are more massive than Jupiter, and some orbit closer to their stars than Mercury around the Sun. To date we have not found another planetary system that is an exact analog of the Earth (and the other planets of our solar system) orbiting a solar-type star, but we think that is because we have not yet had the right observing instruments. Those are on the way. In the next few years, we should know whether other Earth mass planets are plentiful or scarce.

At the same time that we have been developing the capabilities to detect distant Earths, we have also been finding that life on Earth occurs in places that earlier scientists would have considered too hostile to support life. Scientists were wrong, or at least didn't give microbes the respect they deserve. We now know that extremophiles can exist (and sometimes thrive) in the most astounding places: at the bottom of the ocean around hydrothermal vents, in ice, in pure salt, in boiling acid, and irradiated by massive doses of UV and X-rays. There do appear to be places on Earth that are too dry for even these (mostly microbial) extremophiles, or perhaps our sensors aren't yet sensitive enough to find them.

Since life as we know it is so extraordinarily hardy, might it exist today (or in the past) on any of the exoplanets that are being found? A group of scientists known as astrobiologists is trying to answer that question. This

chapter will discuss what appears to be possible in the near future, as well as the questions that will likely remain unanswered until new technologies enable new explorations in the more distant future. It might even turn out that our first indication of another inhabited world will be the signals deliberately generated by its inhabitants, as sought by scientists involved in the search for extraterrestrial intelligence, or SETI.

2.0. Exoplanets

In his book *Plurality of Worlds*, Steven J. Dick (1984) has chronicled the millennia of discourse about other inhabited worlds, based upon deeply held religious or philosophical belief systems. The popularity of the idea of extraterrestrial life has waxed and waned and, at its nadir, put proponents at mortal risk. Scientists at the beginning of the twenty-first century have a marvelous opportunity to shed light on this old question of habitable worlds through observation, experimentation, and interpretation, without recourse to belief systems and without risking their lives. A good place to keep track of the latest planet discoveries is the interactive catalog of the Extrasolar Planet Encyclopedia Web site <<http://exoplanet.eu/catalog.php>>. At a glance you will be able to see how many new planets have been announced in the time between when I reviewed the copyediting of this chapter, and when you are reading it. As of November 27, 2010, there are 504 planets orbiting 422 bodies (including those puzzling pulsar planets).

Exoplanets are primarily detected by indirect techniques: astrometry, radial velocity studies, transits, and gravitational micro-lensing. The first two of these detection methods measure the reflex motion of the star due to the mutual gravitational attraction between planet and star. The transit method measures the minute diminution of brightness that occurs periodically when a favorably aligned planet passes between its star and our telescope, blocking some of the star's light. The final method (gravitational micro-lensing) measures the brightening of a distant star when another (unseen) star and its orbiting planet align perfectly and the gravitational masses of the star and planet bend the light from the distant star causing it to appear brighter. Only very recently have we actually seen images of objects we believe to be planets in orbits around stellar hosts. The Hubble Space Telescope (HST) was used with a coronagraphic mask to block out the light from the star Fomalhaut. (As an analogy, think of holding up your hand to block out the light from a distant street light while you look for something faint in the area surrounding your hand.) In 2004 observations showed a small (single-pixel) bright object located in a large disk of dust, far from the star (115 astronomical units from the star, or 115 times as far from the star as the Earth is from the Sun). This object was confirmed as a planet Fomalhaut b when an HST 2006

observation showed that it had moved slightly along a believable orbital track. A series of rapid images of the star HR 8799 using ground-based telescopes allowed observers to remove the effects of atmospheric distortion and to image three giant-planet point-sources orbiting at distances of 24, 38, and 68 AU, far from the star.

The reflex motions of a star that are induced by the planetary orbit are greater and easier to observe if the star mass is small. What we haven't found thus far is a planet like the Earth orbiting its star at just the right distance so that its surface temperature might be conducive to permitting liquid water. This just-so region around any star is called the habitable zone. For the Sun, it stretches from just outside Venus's orbit to the orbit of Mars. For more massive stars the habitable zone is farther from the star, and it is closer in for lower mass stars. We think that such terrestrial analogs exist, but we have not had the capability to detect them until now, with the launch of spacecraft capable of making precise measurements of stellar brightness to search for transits. The Kepler spacecraft is expected to detect a handful of Earth-sized planets within the next few years. If it doesn't, we will have to revise our thinking about the way stars and protoplanetary disks of gas and dust actually form planets.

Most of the planets discovered are giants, and many have been surprising, and many are in orbits that are highly inclined to the equatorial plane of the star, unlike those of our own solar. "Hot Jupiters" in short period orbits very close to their host stars, and an abundance of high eccentricity (noncircular) orbits were surprising discoveries, though we are beginning to have reasonable explanations based on interactions with viscous protoplanetary disks and a version of cosmic billiards. Initially it was assumed that the presence of hot Jupiters would doom any terrestrial planets within the habitable zone, but recent studies by Raymond et al. (2006) argue that it is possible to have wet, terrestrial planets, even though a Jupiter-mass planet has migrated through their orbital radii on its way toward the star. The near-term future, with a suite of new instruments, holds promise for the detection of other Earths, large moons of gas-giant planets, and other potentially habitable cosmic real estate. The next obvious question is "Will they be inhabited?"

3.0. Extremophiles and Weird Life

Astrobiology is the science that deals with the origin, evolution, distribution, and future of life in the universe. It has been successful in bringing together scientific specialists from many different disciplines to tackle these big-picture questions. Many of my colleagues at the SETI Institute are astrobiologists studying organisms living in extreme conditions (by human standards) in an attempt to better understand the origin of life on Earth and the potential habitable real estate for life beyond Earth.

In the past few decades we have expanded the range of conditions recognized as suitable for life. Life is no longer confined between the boiling and freezing points of water. Hyperthermophiles live at high temperatures (and sometimes also high pressures), the current record holder being archaean microbial *Strain 121* that thrives at 121 °C metabolizing iron, but it can survive up to 130 °C (Kashefi and Lovley 2003). At the other extreme, the psychrophilic bacterium *Psychromonas ingrahamii* survives and reproduces (very slowly) at -12 °C in the ice off Point Barrow, Alaska (Breezee et al. 2004). Macroscopic ice worms occupy and move through the Alaskan glaciers as well as the methane ice seeps on the floor of the Gulf of Mexico using natural antifreeze to protect their cellular structures (Fisher et al. 2000). Sunlight, once argued to be the source of energy for all life, is completely absent miles beneath the surface of the ocean, around the deep hydrothermal vents, where a rich and diverse community of organisms thrives in the dark, at enormous pressures. Small blind shrimp there have developed IR-sensing eye spots to navigate the vent environs or to travel from one vent to another using their thermal signatures (Pelli and Chamerlain 1989). Some chemical process (or processes) within the vents also produces minute quantities of visible light that are harvested by green sulfur bacteria for photosynthesis even though many hours go by between photons (Beatty et al. 2005).

Humans increasingly protect themselves from exposure to UV radiation as the protective layer of atmospheric ozone thins, since our DNA lacks sufficient repair mechanisms to survive intense radiation environments. Yet organisms inhabiting the highest freshwater lakes on Earth, in the caldera of the Lincancabur volcano overlooking the Atacama desert, have adapted to the huge UV load their altitude and evaporating environment present (Cabrol et al. 2005). Colleagues from the SETI Institute free-dive in these lakes each austral spring to catalog these organisms and study the DNA repair mechanisms they have elaborated. If life once occupied Mars, similar mechanisms might have been employed by organisms seeking to survive the dual stresses of increased radiation and desiccation due to loss of planetary atmosphere. Even more spectacular, *Deinococcus radiodurans* can withstand millions of rads of hard radiation because its DNA repair mechanisms are so effective. This skill probably evolved, not because it encountered naturally high radiation environments, but because desiccation causes the same sorts of breaks in DNA linkage; a sufficiently robust repair mechanism can endow survival independent of the damage source (Mattimore and Battista 1996). As a result, this microbe is the focus of many bioremediation programs to deal with radioactive materials, and is being sought in the Atacama to demarcate areas just too dry for life.

Neutral pH was once thought essential for life, but we now know of many organisms capable of living in either extremely acidic or highly

alkaline environments. Cyanobacteria and fish can survive at pH ~4, but the acidophile red alga *Cyanidium caldarium* and the green alga *Dunaliella acidophila* can live at pH below 1 (Rothschild and Mancinelli 2001). In the ground waters of industrial slag heaps, extremely alkaline-tolerant microbes have been found thriving at a pH of 12.8 (Roadcap et al. 2006). While salt has been used historically to preserve food from decay due to bacterial action, halophilic archean microbes have been found living within pure NaCl crystals (Rothschild et al. 1994).

Astronomers may find it extremely unpleasant to live beyond the “just right” bounds of our current terrestrial environment, but clearly life has a greater tolerance and no lack of innovative ways of making a living. Within the past few years, we have begun to accept the concept of the “deep hot biosphere,” and to acknowledge that perhaps ten times as much biomass is resident in the crust beneath our feet, as compared to the surface biomass with which we have long been familiar (Gold 1998). All these biological adaptations must inform our searches for life elsewhere in the universe.

Mindful of the adaptability of life to extreme environments, we should reconsider our own solar system (where we may have some hope of systematic in situ sampling), and we should expand our inspection to any bodies capable of providing raw materials and energy sources that might be exploited by biology of any sort. Thus, in addition to the terrestrial planets Venus, Mars, and Earth (which were all biologically connected during an earlier epoch of planet building and bombardment), we should consider the large icy satellites of Jupiter and Saturn, namely Europa, Ganymede, Callisto, and Enceladus, where liquid, briny, water oceans are thought to exist beneath their icy outer crusts. Titan might be a world hosting biology on its surface without liquid water as a solvent, although the presence of a subsurface water ice slush is now fairly certain. Perhaps results from the Venus Express mission of the European Space Agency (ESA) will shed light on whether the chemical disequilibria previously noted in the Venusean atmosphere require explanations involving Grinspoon’s revival of the Sagan and Salpeter “sinkers, floaters, hunters and scavengers” (Schulze-Makuch et al. 2004). For the foreseeable future NASA will continue a “follow the water” strategy, returning to Mars with robots and humans to look for signs of extinct life from a wetter, warmer epoch or even for subsurface extant life. The seasonal and inhomogeneous appearance of trace amounts of methane in the tenuous Martian atmosphere (Mumma et al. 2005) might be explained by the presence of methanogens in subsurface liquid aquifers, or by the more prosaic, geological transformation of olivine rock, but that too requires flowing water. Subsequent missions may venture to Europa to verify the existence of a massive water ocean and to examine the tantalizing discolorations near the surface cracks that could be the end products of organic molecule irradiation (Dalton et al., 2003), and then,

later still, return to make a sterile penetration of the ice and search for life in the water below.

The resilience and diversity of extremophiles have now also focused attention on life as we don't yet know it. Life on Earth (even extremophiles) seems completely connected; life as we know it appears to have had a single common ancestor. But what about life as we don't yet know it? Might it exist on Earth today in extreme environments, and remain undetected because of our instrumental biases toward carbon-based organisms? Might it exist on other bodies in our solar system, and in the planetary systems of other stars, perfectly suited to those local environmental conditions? What are the limits of organic life in planetary systems? It is a heady question that, if answered, may reveal just how crowded our Earth and the cosmos could be with alien biology. In 2007, the National Academy of Sciences released a report titled *The Limits of Organic Life in Planetary Systems* (Space Studies Board 2007), that is, life with an alternate biochemistry—what they called “weird life.” How would we recognize life based on different biosolvents, different nucleotides, different metabolic pathways? What instruments should we develop to aid human and robotic explorers undertaking a search for other forms of life?

It seems impossible to avoid one particular trap of being twenty-first-century humans. In seeking life, or its technological by-products, we cannot search for what we cannot conceive, and it is also impossible to guarantee that we will correctly interpret what we find. This conundrum has been shared by all past explorers. Those who were successful pushed ahead, with the tools at their disposal, or tools they invented. As my colleague Seth Shostak is fond of saying “Columbus didn't wait for a 747 to cross the Atlantic”; neither should astrobiologists.

4.0. Biosignatures

Moving out beyond the solar system, the focus will be on exoplanets, but here it will not be possible to consider in situ sample collections, at least not for a long time; remote observations will have to suffice. The first task will be the detection of, and subsequent imaging of, a terrestrial-mass planet within the stellar habitable zone. Just how exactly like the Earth does another environment have to be in order to host life? Ward and Brownlee (2000) have argued that an exact duplicate of the terrestrial environment—its history, large moon, and giant-planet shields—are required for anything bigger than microbial life. However, Darling (2001) reviews the arguments and concludes that other astronomers might exist on many worlds. In fact, the evidence is consistent with life, including intelligent life, existing on many worlds or exclusively only on Earth; there is as yet *no evidence*. We have an example of “one.” We cannot know from tracing the detailed history of that single

example what the branching ratio might be for the experiment of life; how many other ways might things have gone but didn't, at what rate, with what end result? The number "two" will be all-important in answering this question—as in the second example of an independent origin of life.

The next step will be to attempt to conduct a chemical assay of the atmosphere of any terrestrial planet imaged in orbit around nearby stars. Transiting hot Jupiters have already permitted the first analysis of chemical constituents of exoplanet atmospheres. Observations of HD 209458b reveal sodium, hydrogen, oxygen, and carbon in an extended atmosphere and/or escaping from the planet (Vidal-Madjar et al. 2004). The Terrestrial Planet Finder (TPF) (previously studied by NASA and now on indefinite hold) and the Darwin constellation under development by ESA may eventually launch during the first half of the twenty-first century, perhaps combined as an international mission. Telescopes on these spacecraft are intended to suppress the light from a central star, using either an occulting coronagraph at visible wavelengths or interferometric nulling in the IR, thereby spatially resolving and directly detecting reflected starlight from any terrestrial exoplanets orbiting within the stellar habitable zone; enormous precision is required to separate the very faint reflected light from the planet from the very much brighter star close by. Once an image has been formed, very long observations will attempt to collect sufficient light to reveal absorption lines in the exoplanet spectrum due to trace atmospheric constituents that might be clues to the presence of biology on the planetary surface.

As difficult a technical challenge as implementing these spacecraft will be, perhaps an even greater challenge will be deciding what spectral signature does or does not constitute a reliable biomarker. Using the present Earth as an example, chemical disequilibrium is one very promising sign. The coexistence of the very reactive molecular oxygen and methane gases in our own modern atmosphere is the direct result of photosynthetic cyanobacteria and plants as well as the fermenting bacteria within termites, ruminants, and rice paddies (Lovelock 1965; Lovelock and Margulis 1974). But the paleoearth would have presented a very different picture during the billions of years when life was present, but had not yet participated in the elevation of atmospheric O₂ levels; for that world, we must ask about the undeniable biosignatures of methanogens. Additionally, one must ask if there are any abiotic processes that can yield the same result. For exoplanets, the harsh realities of the remote observational circumstances are further challenges; it does not now seem feasible to observe simultaneously the visible bands of oxygen and the thermal IR signature of methane in a single instrument. The broad absorption feature of ozone (at λ 9.3 μ m) in the atmosphere of an exoplanet is currently the favored biosignature for complex life as we know it, if the host star is sun-like (Léger 1999; Kasting and Catling 2003).

When the primary is an M dwarf, other molecules such as N_2O , and CH_3Cl may be detectable along with ozone (Segura et al. 2005). While there are abiotic sources of oxygen, and therefore ozone, an ongoing biological source appears to be required for substantial atmospheric ozone concentrations on a geologically active planet. Any future announcements of atmospheric ozone detection from an exoplanet and a potential linkage to biota are likely to be accompanied by a long list of caveats, which the media will ignore. However, spectral absorption features alone are unlikely to distinguish between a future detection of alien microbes or mathematicians. To find the latter we need to search for technosignatures; we need to do SETI.

5.0. Technosignatures: The Search for Extraterrestrial Intelligence

“Are we alone?” is really a loaded question. The detection of life on another world (extant or extinct) is a real possibility within the lifetimes of the people living today. That is a thrilling possibility. Detection of irrefutable biosignatures will provide the pivotal “number two” in the record of life in the universe, but at a very deep level, humans want to know whether other intelligent creatures also view the cosmos and wonder how they came to be. Like the term *life*, there is really no acceptable definition of “intelligence.” Nevertheless, we may be able to remotely deduce its existence over interstellar distances. If we can find technosignatures—evidence of some technology that modifies its environment in ways that are detectable—then we will be permitted to infer the existence, at least at some time, of intelligent technologists. As with biosignatures, it is not possible to enumerate all the potential technosignatures of technology as we don’t yet know it, but we can define systematic search strategies for equivalents of some twenty-first-century terrestrial technologies. The science fiction author Arthur Clarke has suggested that “any sufficiently advanced technology will be indistinguishable from magic”; if they occur at all, detections of advanced technologies will probably occur as the accidental result of our detailed studies of the natural universe.

SETI is that subspecialty of astrobiology that currently conducts systematic explorations for other technology as we know it; primarily it searches for electromagnetic radiation—radio or optical signals. SETI pre-dates the current field of astrobiology, beginning life as a valid field of exploratory science in 1959 with the publication of the first paper on this subject in a refereed journal (Cocconi and Morrison 1959). This first paper advocated a search for radio signals, but the suggestion of searching for pulsed optical laser signals followed shortly thereafter in 1961 (Schwartz and Townes 1961). SETI provides another plausible avenue for discovering habitable worlds by attempting to detect the actions of technological inhabitants. More than one

hundred SETI searches can be found in the literature (Tarter 2001). (To see the search strategies that have been used, look at <https://observations.seti.org>.) The list begins with Project Ozma in 1960 the first search for radio signals from nearby sun-like stars (Drake 1960). While these searches may seem like a large effort, the sum total of all these investigations has covered only a minute fraction of the search parameter space. Imagine looking at a single glass of water scooped from the ocean, and examining it to see whether there are any fish in the ocean. That's a pretty good analogy to how much of the cosmos we've been able to search so far—one glass from an entire ocean.

Signals might be generated for the benefit of the transmitting civilization or to deliberately attract the attention of another civilization. While it may be possible for us to detect unintentional leakage radiation from another technology, deliberate signals, transmitted to be detectable, are the most likely to be found. Furthermore, any detectable signals will have originated from a technology far older than our own. If technology tends to be a long-lived phenomenon among galactic civilizations, then statistics favor the detection of signals from a technology during its old age. If technology, in general, is a short-lived phenomenon, then it will be undetectable because the chance that two short-lived technological civilizations would not only be close to one another, but also overlap in time during the thirteen billion year history of the Milky Way is vanishingly small. For this reason, Philip Morrison has called SETI the archeology of the future. The finite speed of light guarantees that any detected signal will tell us about the transmitter's past, but the detection of any signal tells us that it is possible for us to have a long technological future (Mallove 1990). This is one of the things that makes SETI important to me, and why I feel that I have the best job in the world.

Although we've been doing SETI for more than fifty years now, most of the time, most SETI searches are off the air. Historically, the searches have been conducted on telescopes constructed for other scientific observing programs, so there has been little telescope time available for SETI (the piggyback SETI@home project is a notable counterexample to this). Today the situation is changing as new instruments intended for dedicated SETI use are commissioned and beginning to look at the sky. This is an exciting time because our tools may finally be getting to be commensurate with the magnitude of our task.

Deliberate signals, intended to be detected, might be engineered in one of two ways: they could appear to be "almost astrophysical," or they could appear to be "obviously technological." The distinct benefit of the former scheme is that such signals are very likely to be captured as a young technology (such as ours) begins to deploy multiple sensors to study the universe around it. Eventually, some graduate student searching through observational databases might discover something peculiar about one of the entries, and thus discover

that the signal is actually engineered. Our rapidly improving astronomical observing capability and our curiosity about the cosmos should ensure that we eventually discover any such “almost astrophysical” signals. On the other hand, the detection of “obviously technological” signals will require construction of specific instrumentation not available from astronomical observing programs, because the characteristics of the extraterrestrial signals are precisely those that we expect nature to be unable to produce. Today we search for narrowband radio signals—a single channel on the radio dial. Natural radio emission occurs at many frequencies, but technology can compress a lot of power into a single frequency. The computerized signal detection algorithms in use can detect narrowband signals that are continuously on, or that pulse on and off, and they can be constant in frequency or change frequency during the observation due to accelerations between transmitter and receiver. Natural, background radio noise from galactic synchrotron emission rises rapidly at frequencies below 1 GHz (1 billion Hz), while the noise from atmospheric water vapor and oxygen contributes above 10 GHz; radio SETI searches have a goal of systematically exploring the naturally quiet Terrestrial Microwave Window from 1–10 GHz. Since the signals may be as narrow as 1 Hz, it means we need to search through nine billion channels on the radio dial. While nature is quiet at these frequencies, our cell phones, satellites, garage door openers, and microwave ovens generate lots of signals that cause interference. Radio telescopes are located far from population centers, and astronomers must use a great deal of computational effort to work around this interference.

At optical frequencies, signals exhibiting extreme time compression (short, broadband laser pulses) are searched for with photon counters having nanosecond rise times, a regime with no known sources of astrophysical background (Howard and Horowitz 2001). Because interstellar dust begins to absorb optical pulses over distances beyond ~1000 light years, it is desirable to extend the optical SETI search into the infrared so that more of the galaxy becomes accessible. This will happen when, and if, the requisite fast photon counters become available and affordable in the IR. Other modulation schemes employed by current terrestrial communications technologies can produce signals whose statistical properties differ from the Gaussian noise of astrophysical emitters, but they are harder to recognize than the simple artifacts now being sought. As Moore’s Law delivers more affordable computing, SETI programs are beginning to search for more complex signals (Harp et al. 2011).

At any frequency, there are two basic search strategies that can be implemented: move quickly across the sky (or a portion thereof) to cover as much of the spatial dimension of the cosmos as possible, or select individual directions deemed to have a higher a priori probability of harboring a technological civilization and make targeted observations in those directions

for longer periods of time. The former strategy minimizes the assumptions about the source of the signal, but in general, the surveys will achieve poorer sensitivity as the result of the smaller telescopes and shorter dwell times typical of this strategy. By developing a list of plausible targets, it is possible to achieve significantly better sensitivity through integration and signal processing gain for a wider range of signal types. However, if the target list is constructed under the wrong assumptions, detection probabilities are lowered rather than improved. In both cases it is desirable, but seldom affordable, to accomplish the task of signal detection and recognition in real-time, or near-real-time, so that immediate follow-up of candidate signals is enabled before they can vary with time, and opportunities for distinguishing between terrestrial and extraterrestrial technologies can be exploited.

Dan Werthimer and a group at UC Berkeley's Space Science Lab has operated a series of increasingly capable SERENDIP detectors operating at radio observatories in a commensal (or piggyback) mode to achieve maximum access to the sky for conducting random, SETI sky surveys. The SETI observers don't control the telescope pointing, but they eventually end up surveying most of the available sky from any site. Recently, SERENDIP V began taking data at Arecibo, the world's largest radio telescope, working with the multibeam ALFA receiver to search seven directions on the sky simultaneously and analyze 300 MHz of the spectrum in the vicinity of the 21 cm Hydrogen line. A few percent of the data collected by ALFA and SERENDIP V, at the precisely 1420 MHz (21 cm), is analyzed on the pioneering SETI@home global distributed computing platform (<http://setiathome.ssl.berkeley.edu/>). If you are interested, you can download a screen saver that works as a background program on your own computer to search for SETI signals in a small piece of recorded data automatically shipped to you from UC Berkeley, and you can join more than three million people who are helping the search. A commensal SETI search at Parkes Observatory in NSW, based on earlier SERENDIP technologies, is now being renovated, and may provide another opportunity for participation in SETI.

In Northern California, the SETI Institute and the University of California Berkeley Radio Astronomy Lab have partnered to build the Allen Telescope Array (ATA) at the Hat Creek Radio Observatory for the purpose of simultaneously surveying the radio sky for signals of astrophysical and technological origin (DeBoer et al. 2004). Ultimately, the array will consist of 350 antennas, each 6.1m in diameter, extending over a maximum baseline of 900 m. Currently it is operating as the ATA-42, with the first forty-two dishes spread over 300 m. The ATA provides simultaneous access to any frequency between 500 MHz and 11.2 GHz, a system temperature $\sim 50^\circ$ K, and four separately tunable intermediate frequency channels feeding a suite of signal processing backends. The backend instrumentation can produce

wide-angle radio images of the sky with ~20000 resolution pixels and 1024 spectral channels per pixel, and at the same time, study three point sources of interest within its large field of view using phased up beams at two different frequencies. This new approach to commensally sharing the sky allows SETI and traditional radio astronomical science to both utilize the telescope nearly full time. Unlike, the SERENDIP systems at Arecibo, the SETI signal detection takes place in near-real-time. The ~250,000 stars in our current catalog of “habstars” provides a few stellar targets in every array field of view at lower frequencies and enables efficient commensal observing. Another catalog of about 3500 target directions is enabling a survey of twenty square degrees surrounding the galactic center, within which are located some ten billion distant stars. Whereas the targeted searches of nearby “habcat” stars would detect transmitters as strong as the current radar signals we generate to study our ionosphere, at the distance of the galactic center this survey would detect a transmitter with a power equivalent to twenty thousand Arecibo planetary radars.

The ATA is the first attempt to manufacture a radio telescope by taking advantage of cost discounts from economies of scale, consumer off-the-shelf components (primarily from the telecommunications industry), and inexpensive commercial manufacturing technologies. Like ASKAP, now being built in Western Australia, and MeerKAT under construction in South Africa, the ATA is one of the pathfinders for the Square Kilometre Array, a project to build an international observatory with one hundred times the collecting area of the full 350-dish ATA. The ATA is very much a Moore’s Law telescope. Whereas all the data from 500 MHz to 11.2 GHz is brought to the central processing center as analog signals, only a small portion of that data is currently digitized and sent to the astronomical and SETI processors. In the future, as digitizers and processors get cheaper, the array will improve its capability by investigating more and more of the spectrum simultaneously. The ATA will continue to allow us to increase the speed with which we explore the cosmos.

Moore’s Law improvements have helped optical SETI (OSETI) programs every bit as much as they have enabled the ATA. At Harvard, Paul Horowitz and his students are using a new, dedicated, OSETI telescope for a survey of the 60 percent of the northern sky visible from the Oak Ridge Observatory in Massachusetts (Horowitz et al. 2006). The telescope is housed in a building enthusiastically constructed with student labor. The 72” primary and 36” secondary mirrors have been manufactured inexpensively by fusing glass over a spherical form and then polishing, because the system does not require image quality optics. The detection system is based on eight pairs of 64-pixel Hamamatsu fast photodiodes, and custom electronics for real-time

detection. This new telescope searches for powerful transmitters from a large collection of stars by conducting meridian transit scans of the sky in $1.6^\circ \times 0.2^\circ$ strips (with a dwell time, due to the Earth's rotation, of about one minute). The sky visible from that site can be scanned in approximately 150 clear nights. The survey sensitivity should be adequate to detect laser pulses from the analog of a current Helios-class laser being transmitted through a 10 m telescope up to a distance of 1000 light years. In Australia, at the Campbelltown Rotary Observatory at the University of Western Sydney, an OSETI program has been in operation for several years conducting a targeted search of nearby stars (Bhathal 2011).

Looking toward the future, when the ATA is fully built out, ASKAP and MeerKAT become operational, and then eventually the Square Kilometre Array comes on, we are hoping that some of the students attending the Astrobiology Science Conference will be inspired to take over from us. At the SETI Institute, we plan for success and actively try to educate the next generation of scientists. For example, we have developed a yearlong integrated science curriculum for ninth graders, called *Voyages Through Time*.

In addition to Phillip Morrison's hopeful characterization of SETI as the archeology of the future, I think that SETI is extraordinarily important because it provides an opportunity to change the perspective of every person on this planet. The successful detection of a signal, or even the serious discussion of that possibility, would have the effect of holding up a mirror to the Earth. In this mirror we, all of us, would be forced to see ourselves as Earthlings, all the same when compared to the detected extraterrestrials. SETI can help to trivialize the differences among humans that we find so divisive today. This is why, when I got to make a wish to change the world as part of my TED prize (<http://www.tedprize.org/jill-tarter/>) (Tarter et al. 2011), I said, "I wish that you would empower Earthlings everywhere to become active participants in the ultimate search for cosmic company."

SETI might succeed in my lifetime, in your lifetimes, or never. There is no satisfactory way to make an estimate. The wisest summary still remains the last sentence in the original 1959 *Nature* journal article: "The probability of success is difficult to estimate, but if we never search the chance of success is zero" (Cocconi and Morrison 1959, 846). So I invite you to stay tuned because some of us are determined to keep searching, and we could use your help.

Note

This chapter is an adaptation of J. C. Tarter, "Extremophiles and Exoplanets: Expanding the Potentially Habitable Real Estate in the Galaxy," in *ISS2009: Genes to Galaxies* (Sydney: Science Foundation for Physics, 2009).

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