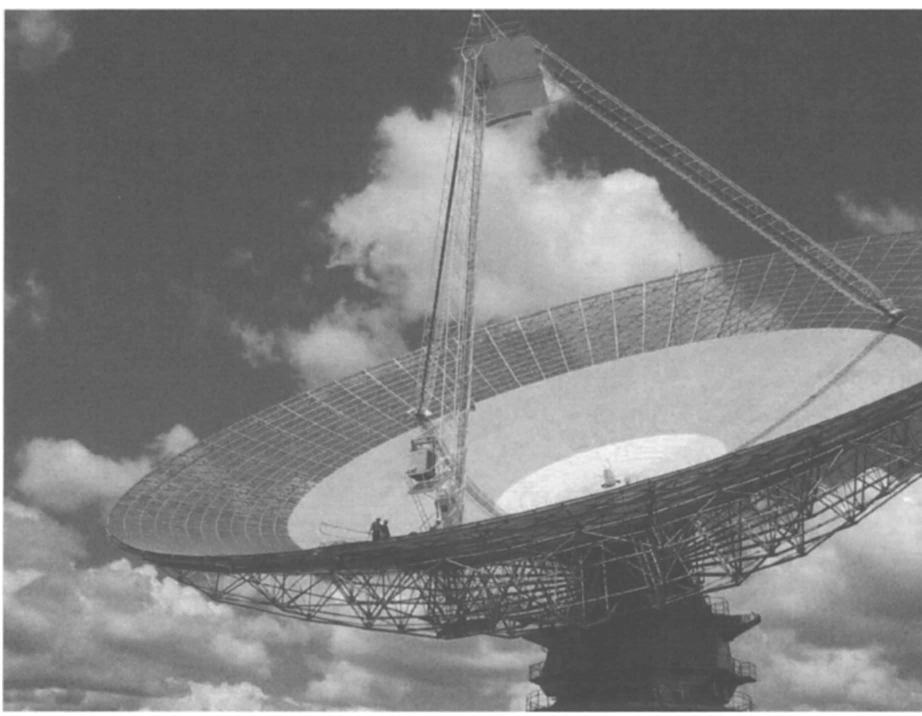
SETI



The Parkes Radio Telescope, NSW, Australia (*photo: Frank Stootman*)

https://doi.org/10.1017/S007418090019360X Published online by Cambridge University Press

Jill Tarter (*photo: Seth Shostak*)

https://doi.org/10.1017/S007418090019360X Published online by Cambridge University Press

Bioastronomy 2002: Life Among the Stars
IAU Symposium, Vol. 213, 2004
R.P.Norris and F.H.Stootman (eds.)

Life, the Universe, and SETI in a Nutshell

Jill Tarter
SETI Institute, 2035 Landings Drive, Mountain View, CA 94043, U.S.A.

Abstract. To date, no SETI observing program has succeeded in detecting any unambiguous evidence of an extraterrestrial technology. Regrettably, this paper will therefore not dazzle you with the analysis of the contents of any interstellar messages. However, as is appropriate for a plenary presentation, this paper does provide an update on the state of SETI programs worldwide. It discusses the various "flavors" of observational SETI projects currently on the air, plans for future instrumentation, recent attempts to proactively plan for success, and the prospects for future public/private partnerships to fund these efforts. The paper concludes with some tentative responses to the "What if everybody is listening, and nobody is transmitting?" query.

1. Some Pragmatic Definitions

At previous Bioastronomy meetings and related Astrobiology meetings, a significant effort has been expended in attempts to define such commonplace and familiar terms as "life" and "intelligence". The trick is to be inclusive, and yet not end up defining something like fire to be alive. As yet there are no satisfactory definitions for these terms, though everyone attending this meeting has probably had to adopt some working definitions to facilitate their on-going research. In SETI, things are no different, except that the limited scope of 21^{st} century technology permits us to adopt purely pragmatic definitions without apology. So for the record, in what follows, my definitions are:

- Life ≡ the necessary precursor to any technology that modifies its environment in ways that can be sensed over interplanetary or interstellar distances.
- Intelligence ≡ the ability to construct and operate large transmitters.
- SETI ≡ that branch of astrobiology which takes advantage of the deliberate actions of the inhabitants, in order to detect habitable worlds.

These definitions are more than a tongue-in-cheek exercise. They encompass, and specifically acknowledge, all the anthropomorphic biases with which we are burdened, while admitting that there is nothing we can do about them until such time as we discover an example of life (including perhaps, intelligent life) as we don't yet know it. Use of the word "astrobiology" in the definition of "SETI" is this author's, admittedly political, assertion that SETI legitimately lies within the continuum of research activities encompassed by the emergent field of astrobiology/bioastronomy, but the definition could stand without it.

2. What Should We Be Looking For?

What constitutes a legitimate SETI detection? What kind of technologies are we capable of detecting today, or in the near future? The answer to this second question is easy: with our primitive technology, we will only detect those technological civilizations that are far older than our own. We cannot detect less primitive technologies than our own over interstellar distances. We will only succeed in detecting another technology in the near future (with the limited technology we have at our disposal) if, on the average, technological civilizations are long-lived.

Here longevity must be measured on cosmic, rather than human, timescales. Technological civilizations cannot be temporally and spatially co-incident within our 10 billion year old galaxy, unless technologies persist for a significant fraction of the galaxy's age. This is just the degenerate form of the Drake Equation, $N \leq L$ (the number of civilizations with whom we can communicate in the Milky Way is less than or equal to the average longevity of technological civilizations measured in years)(Drake 1961). Thus statistically we can say with confidence that any technologies within the grasp of our current detection schemes will be far older than ours.

How might we detect them? An older, extraterrestrial technology could be expected to engage in one or more of the following activities, and these might manifest themselves in ways that are detectable over interstellar distances: large-scale astroengineering projects, generation/harnessing of power, interstellar/interplanetary travel, wars, information exchange. Over the past 42 years, since Project Ozma (Drake 1961), about 100 attempts have been made to search for examples of each of these activities (see historical review of SETI observing projects at http://www.seti.org/science/searches-list.html), although most of them have focused on the detection of communication signals. Such signals might be intended to attract the attention of other, emerging technologies (beacons), or signals being broadcast for some internal purposes (leakage). Leakage radiation, as well as manifestations of the other hypothetical technologies listed above, are best sought as the by-products of an aggressive observational exploration of our cosmos.

SETI researchers should, and do, encourage current and future generations of astronomers to behave like Joycelyn Bell Burnell, leaving no "bit of scruff" in their data unexplored (Bell & Hewish 1967). When it comes to a search for beacons, it is plausible to suggest that extraterrestrial engineers, intent on generating a signal that will have a high probability of being discovered, might transmit signals whose characteristics are a) *almost* astrophysical, or b) impossible to create by astrophysical emission mechanisms and thus obviously of technological origin. Signals of type a) are also best sought in the process of a vigorous astronomical observing program. Such signals will have been designed to be captured routinely by the instrumentation developed as a young technology explores its cosmic environment. Additional study would reveal behaviors inconsistent with any astrophysical explanation (e.g., a pulsar that "glitches" back and forth between two precise periods) and perhaps, eventually, the existence of some embedded information-encoding scheme. It is the beacon signals of type b) that have been, and continue to be, the objects of most SETI observing programs.

What sort of signal cannot be produced by astrophysical emission mechanisms (as far as we know)? The large number of emitters (atoms, molecules, radicals, etc.) required to generate an astrophysical signal with detectable amounts of flux, guarantees that the time-bandwidth product of the signal will greatly exceed unity (the minimum allowed by the uncertainty principle) i.e. $B\tau \gg 1$. However, because it is economically rewarding to do so, terrestrial technologies have developed a number of ways to generate signals with $B\tau \approx 1$; these are long-duration narrowband pulses (going in the limit to continuous wave, narrowband signals), and short-duration, broadband pulses. Whatever its frequency, a beacon signal must outshine its local background, or the fluctuations in that background if integration techniques can be used by the receiver to improve the signal to noise ratio. Figure 1 represents the average cosmic background radiation from the longest radio waves to the shortest gamma-rays. Historically, SETI programs have concentrated on the microwave portion of the spectrum because of the naturally low background there. The average values in Fig. 1 can be radically altered if spatial, spectral, or temporal filters are applied by the transmitter or receiver. As in the case of attempting to directly image a terrestrial planet around a nearby star (Tinney 2004), a fainter beacon signal from an optical transmitter orbiting a star could be detected if the bright starlight could be spatially filtered out. It is also possible that application of a temporal filter might permit a beacon to momentarily outshine its host star, without requiring an unacceptable energy cost for the transmitter. In addition to the local background, constructors of intentional beacons must consider the interstellar medium through which the signal will propagate.

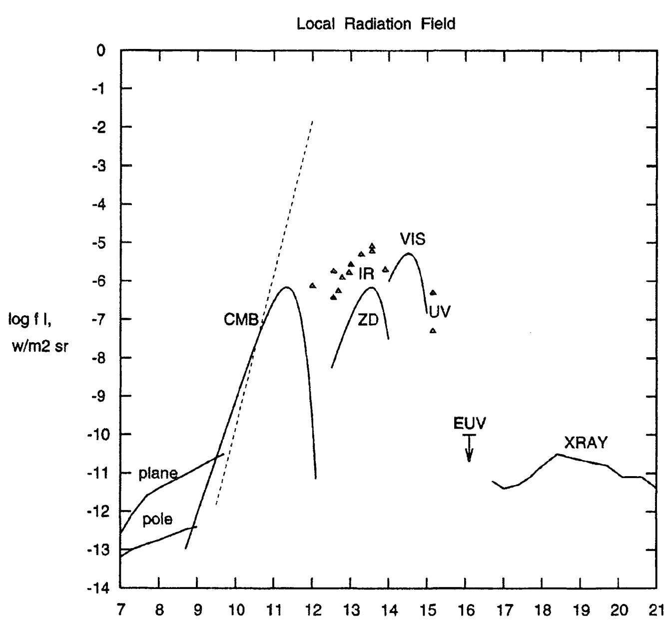


Figure 1. Average Astrophysical Background Radiation

https://doi.org/10.1017/S007418090019360X Published online by Cambridge University Press

Multipath scattering in the interstellar medium smears out the time of arrival of broadband microwave pulses, requiring additional analytic techniques to reconstruct the pulses. This increased complexity for the receiver suggests that at centimeter wavelengths, broad pulses may not be the best choice for intentional beacons, and to date microwave searches have concentrated on narrowband pulses and CW signals. At optical wavelengths, there is no problem with interstellar dispersion, but absorption by dust does limit the range of such signals to a few thousand light years. Today, SETI observing programs consist of microwave searches for narrowband signals and optical searches for broadband, micro-to-nano-second pulses as well as powerful, narrowband lasers. The optical detection techniques have not moved into the infrared (where dust would be less of a problem) because affordable, fast detectors do not yet exist.

3. Who is Searching Now, and How are They Doing It?

Once the wavelength for a search has been chosen, it is then necessary to select an appropriate observing strategy. The observer must decide whether to search the entire sky (or a large fraction thereof), spending little time at any frequency and location, or to spend larger amounts of time targeting a limited number of directions, with the ability to perform more complex pattern recognition analyses, and search for fainter signals. These so-called sky surveys or targeted searches can also utilize three different approaches for data collection. A directed search occurs when the observer has control of the telescope (often as the result of a successful observing proposal) and can specify the direction and frequency of the observation. Larger amounts of telescope time are sometimes available to researchers willing to conduct commensal or piggy-back searches, where the direction, frequency, and mode of observing are dictated by some other primary science driver. Finally, a researcher might decide to access the enormous volumes of stored data, now available from completed observational programs, and subject those data to different detection algorithms that are optimized for the discovery of technological, rather than astrophysical, signals. All of these techniques have been and continue to be used. Since the "Cosmic Haystack" being searched for the important needle-signal is nine-dimensional (3-space, time, frequency, 2-polarizations, modulation, intensity) and vast, historically many researchers have made hypotheses about "magic" frequencies, places, or times in order to limit the search to something that is achievable in a finite time, with available resources.

At present, there are a 13 search programs on various telescopes around the globe. Short descriptions and references for these searches can be found in the archive of searches previously mentioned (http://www.seti.org/science/searches-list.html). They are categorized by search strategy and frequency in the list below (Table 1), and a URL for the associated web site is included.

The line drawn through the BETA search in Table 1 indicates that it is not yet back on the air following a wind storm that lifted the dish off its mount, bending some of the panels on landing. Repairs are under way. SETI@home is listed under SERENDIP IV rather than as a separate search because it obtains its raw data by splitting off 2.5% of the digitized IF data stream from SERENDIP IV, as well as using all of the pointing information provided by the telescope

Table 1. Searches on Telescopes Today

	TARGETED SEARCHES
Type	**Microwave**
D	SETI Institute Project Phoenix (http://www.seti.org)
Type	**Optical**
D	Berkeley Optical SETI (http://sag-www.ssl.berkeley.edu/opticalseti)
C	Harvard Optical SETI (http://mc.harvard.edu/oseti/index.html)
D	Lick Optical SETI (http://seti.ucolick.org/optical)
D & C	Princeton Optical SETI (http://observatory.Princeton.EDU/oseti/)
D	Australian Optical SETI (http://www.atnf.csiro/pasa/17_2/bhathal/paper.pdf)
A	Exoplanet Archive Optical SETI (http://www.physics.sfsu.edu/ areines/seti/html)

	SKY SURVEYS
Type	**Microwave**
C	SERENDIP IV (http://seti.ssl.berkeley.edu/serendip/serendip.html) also SETI@home (http://setiathome.ssl.berkeley.edu)
D	~~BETA~~ (http://mc.harvard.edu/seti/beta.html)
D	META II (http://www.planetary.org/html /UPDATES/seti/META2/default.html)
C	Southern SERENDIP (http://seti.uws.edu.au)
D	SETI League Project Argus (http:www.setileague.org)
C	SETI Italia (http://boas5.bo.astro.it/ũniverso /webuniverso/montebugnoli/monte4.html)

Legend	D is a directed search C is acommensal search A is an archival search

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interface from that search. Although they have been included in Table 1, the Australian Optical SETI project, Southern SERENDIP, and SETI Italia have not yet published results from any on-going observational programs, and require additional maturity in their software analyses. Clearly the United States is host to the greatest number of searches, but the rest of the world is beginning to find the resources to join this enterprise. All of the searches listed have been financed from private sources. There has been no federal/national funding for SETI searches since the US Congress terminated the funds for NASA's High Resolution Microwave Survey in 1993.

4. What Should We Try Next?

It is immediately obvious from Table 1 that there have been no sky surveys at optical wavelengths. That should change by the end of 2002. A dedicated optical SETI sky survey observatory is being constructed at the Oak Ridge Observatory in Harvard, Massachusetts alongside BETA, and the commensal Harvard Optical SETI targeted search (Howard, Horowitz, & Coldwell 2000). Prof. Paul Horowitz and his students have managed to keep the cost of this observatory very low by using a roll-off roof observing building, forming the 1.8 meter primary mirror by fusing glass onto a spherical mold (imaging-quality optics are not required), restricting the mount to rotation about a single axis to accommodate drift scans, and cleverly splitting and folding the light beams to focus them onto a single signal processing board containing two linear arrays, each with 512 photomultiplier tubes (see Fig. 2). Funding for this project is being provided by The Planetary Society and the Bosack/Kruger Charitable Foundation. A sky survey from $-20° < \delta < +60°$ along strips that are $1.6° \times 0.2°$ will be possible in about 200 clear nights for observing.

The large number of entries in Table 1 is misleading; it appears that the sky is being exhaustively examined for signals of extraterrestrial intelligent origin within two frequency regimes. Yet, in truth, even after more than four decades of SETI observing programs, we have hardly begun to explore the nine-dimensional space within which signals might be detected. Part of the problem lies in the fact that SETI observations must compete for time, or share the time, on telescopes that were constructed for other purposes. Access to the sky is limited, and the observational tools are not optimal. The dedicated optical sky survey telescope being constructed by Harvard will improve the situation for laser signals, but a better SETI telescope is also required at microwave frequencies, and of course, in this era of private funding for SETI, it needs to be affordable.

As a result of workshops held by the SETI Institute in 1997-99, and published in *SETI 2020* (Ekers et al. 2002) the SETI Institute entered into a partnership with UC Berkeley Radio Astronomy Lab to design and build a dedicated facility for microwave SETI having at least 10^4 m^2 (one hectare) of collecting area. The Paul G. Allen Foundation has funded the technology development for this Allen Telescope Array (ATA) that will consist of 350 offset Gregorian dishes, each 6.1 m in diameter (see www.seti.org/science/ata.html). The partnership has been very successful in identifying ways to use commercial telcom components and manufacturing processes to minimize costs, while developing innovative feeds, receivers, and miniature coolers to achieve extremely broadband

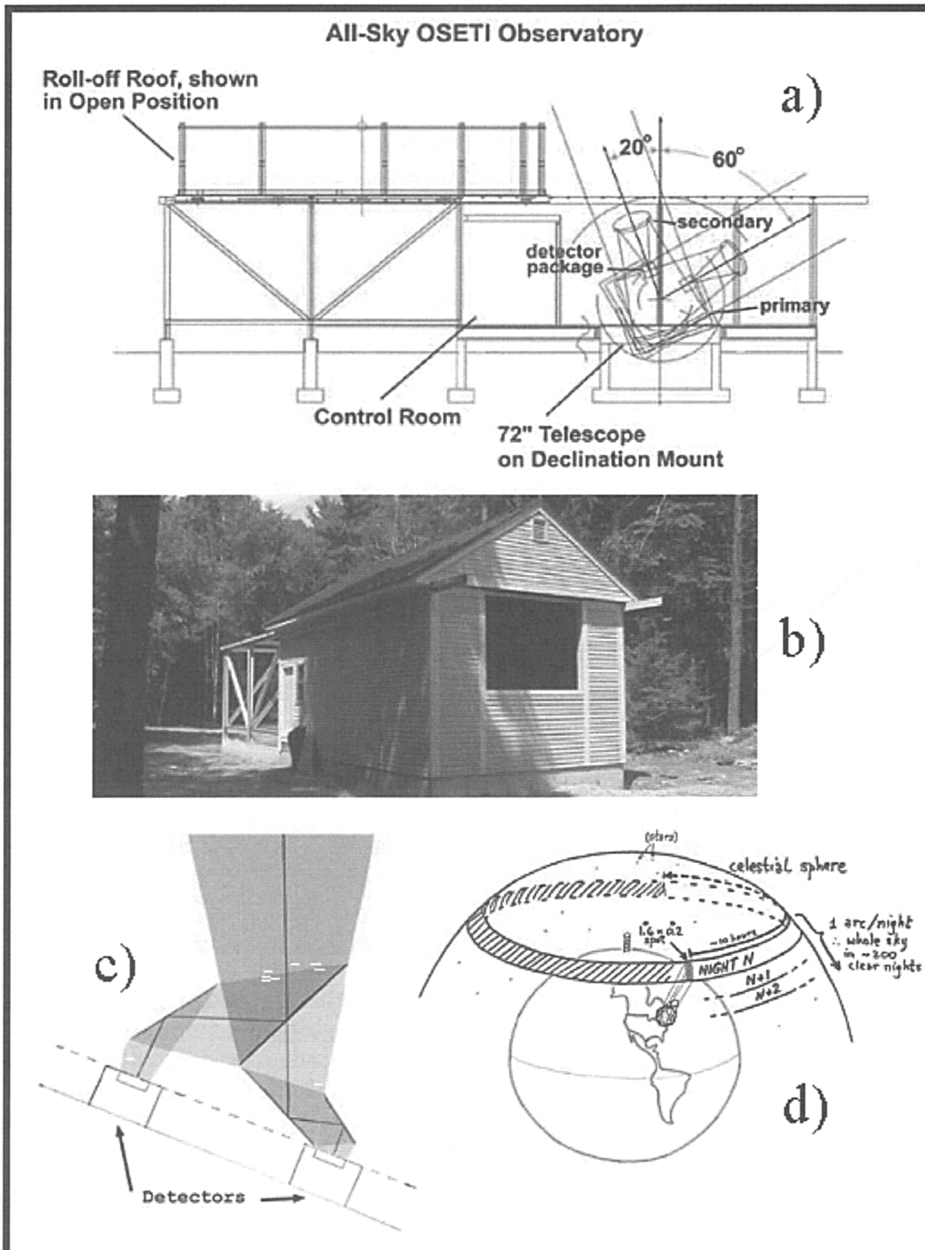

Figure 2. Harvard Dedicated Optical Sky Survey. a. Schematic of the observatory building, b. snapshot during construction, c. the optical beams, and d. the observing pattern on the sky.

instantaneous frequency coverage from 0.5–11 GHz. Assuming timely decisions

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on construction funding and land-use permits, the ATA should be completed in 2005. Figure 3 illustrates the irregular configuration for the antennas, extending over 800 m in the Hat Creek Valley north of Mount Lassen in northern California, and optimized for uniform UV coverage and low sidelobes. The large field of view that is inherent in an array of small dishes will permit SETI and traditional radio astronomy to be conducted simultaneously on the ATA. An imaging correlator will be used by radio astronomers at the same time that multiple pencil beams will be placed on individual SETI target stars within the field of view. This is a win-win arrangement that will speed up SETI targeted searching by a factor of 100 over Project Phoenix. Having 350 antennas in the array means that there are 700 degrees of freedom in the ways that signals are combined, and this will greatly enhance the ability to null out arbitrary sources of interference, such as satellites. Discriminating our own technology from possible extraterrestrial sources is the biggest challenge for SETI searches today.

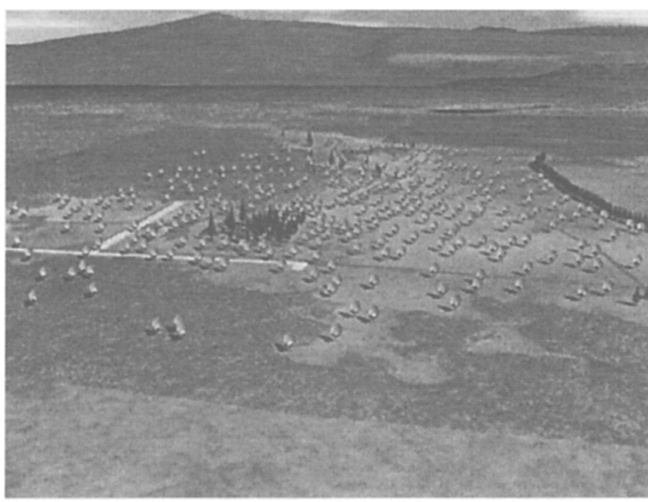

Figure 3. The Allen Telescope Array consists of 350 antennas, each 6.1 m in diameter, equivalent to a single 113 m dish.

5. What Should We Try After That?

In addition to recommending a dedicated microwave SETI observatory and optical SETI searches, *SETI 2020* also recommended a transient signal detector called the Omni-directional SETI System (OSS). The idea is to construct a "radio fly's-eye" capable of looking in all directions above the horizon at once. The OSS would be sensitive to strong, brief signals such as might arise if the Earth were being periodically illuminated by a beacon sequentially targeting a number of different planetary systems. This system uses small, low-gain elements whose field of view is $\sim 2\pi$ steradians. Spatial discrimination is done by beamforming and a large number of elements are needed to achieve even a modest amount of collecting area. The cost of such a system is dominated by computing. The

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OSS is not affordable today, but prototypes are being developed by the SETI Institute and Ohio State University (Ellingson 2002), with the expectation that Moore's Law improvements in the cost of computation will enable such a system 10 to 15 years in the future.

Arrays of separate dishes are not the only way of synthesizing larger fields of view on the sky; focal plane arrays on single dishes can also be used. The UC Berkeley SETI group is now planning to take advantage of a 7-beam focal plane array being built for the Arecibo Observatory. SERENDIP V will piggy-back on all seven beams, and use coincident detections to discriminate against interference. They will also move the SETI@home system to the southern hemisphere where it will use data collected by the 64 m antenna at the Parkes Observatory.

Optical SETI is currently being conducted on 1 m class telescopes, in the future the sensitivity of the searches can be improved if detections systems can be coupled with larger antennas. Since imaging quality is not required, it may be possible to find a way to commensally observe with some of the large optical light buckets that are being built to detect Cherenkov radiation from air showers caused by very high-energy gamma rays. If a fast trigger can be devised to pick up coincident, single-pixel events from photodiode arrays on multiple telescopes, optical SETI may find an inexpensive way to graduate to 10 m class telescopes.

Bigger is also better for microwave SETI. The international radio astronomy community is working to design and build the Square Kilometer Array (SKA), with 100 times the collecting area of the ATA operating from 300 MHz to 20 GHz Design criteria for the SKA include a large field of view and a large number of pencil beams. By sharing these beams with other astronomy projects, SETI will be able to extend its exploration ten times further out into the Milky Way Galaxy.

If aggressive and concerted efforts at interference mitigation fail to keep ahead of the growth in the number of orbital and overflying transmitters, the lunar farside may become the site of future SETI and radio astronomy observatories. In 1979, the ITU Radio Regulations defined the Shielded Zone of the Moon and mandated protection from radio frequency interference there. It remains to be seen how well this pristine electromagnetic environment can be conserved in the face of growing plans to place observatories and servicing platforms at the Earth-Moon L_2 Lagrange point and the Earth-Sun L_1 and L_2 points. With more forethought than characterized the development of the spectrum on Earth, it should be possible for both active and passive services to have access to the entire spectrum some of the time.

6. Planning for Success: Who Will Speak for Earth?

Within the International Academy of Astronautics, there has been a standing SETI Committee for over four decades. Recently that committee has established the Rio Scale for SETI, in analogy to the Torino Scale for Earth-crossing asteroids (see http://www.setileague.org/iaaseti/rioscale.htm). In the event of the announcement of a SETI detection, this group would compute a Rio Scale value that would help the public and media interpret the credibility and import of the claimed detection. Most of the SETI researchers listed in Table 1 have subscribed to a voluntary post-detection protocol previously developed by the International Academy of Astronautics and the International Institute of Space Law (see www.iaanet.org/p_papers/seti.html). This document reminds observers to carefully confirm their results before making a public announcement, and recommends that no reply to a detected signal be transmitted until an international consensus has been achieved. Just how such a consensus might be reached is the subject of a second document now under discussion by the same bodies. Lacking any global governance, it is suggested that the United Nations Committee on the Peaceful Uses of Outer Space might be the appropriate body to attempt to decide whether a reply is made, and if so, who shall make it, and what it shall say. In practice, it is extremely unlikely that this body will find time to address this issue at any foreseeable date. If a detection were made tomorrow, every individual or group with access to a transmitter would probably decide to transmit their own particular message, without consultation or coordination. In fact, that cacophony might be the most accurate descriptor of humanity and 21^{st} century Earth.

7. To Transmit, or Not to Transmit?

If everybody is listening, and nobody is transmitting, SETI will not succeed. As an altruistic gesture, should we begin deliberate transmissions from Earth? *SETI 2020* suggests that it is important to recognize our asymmetric position with respect to any other technologies in the galaxy; if they exist, they are older. Therefore, the energetically and culturally more difficult task of transmitting should be their responsibility. Emerging technologies should listen first. At the moment, our own use of the broadcast spectrum is quite wasteful, and in our youthful technological exuberance, we are leaking radiation copiously. As our transmissions become more efficient, and therefore more like pure noise, it will be reasonable to consider deliberate transmissions. But mindful of the fact that transmission must be long-term (on a cosmic timescale) if it is to have any probability of being detected, and that the difficult questions of who will speak for Earth and what will be said must be answered prior to the start of transmission, such activity still lies in our future, when, and if, we become mature enough as a species to step up to the task.

8. Concluding Remarks

In spite of the lack of any current governmental funding for SETI research, innovative projects are operating on a number of telescopes around the world, and ambitious plans are being made to expand these activities. Even though potentially multi- generational searches are better suited to private endowments than to annual federal funding cycles, it will be important to look for avenues to forge public-private partnerships to continue and improve SETI exploration. This activity is intrinsically international, and given the size of the Cosmic Haystack, success may require resources from, and agreements among, many nations.

Acknowledgments. The author wishes to acknowledge support from the SETI Institute and its many generous donors.

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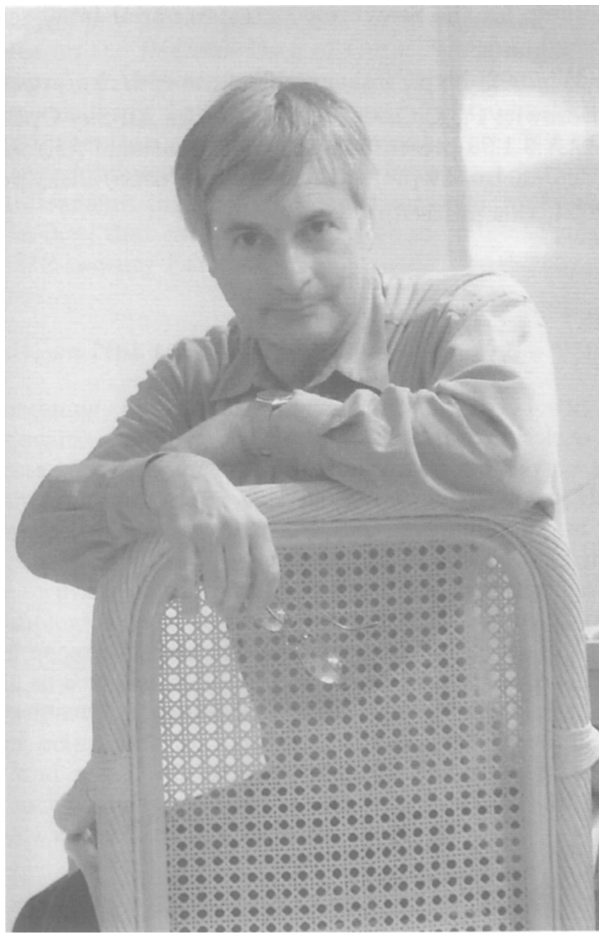

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