26 Searching for Extraterrestrial Intelligence

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26.1 Technology, Not Intelligence

SETI (*S*earch for *E*xtra*T*errestrial *I*ntelligence) can be defined as the branch of astrobiology looking for inhabited worlds by taking advantage of the deliberate technological actions of extraterrestrial organisms. This definition usually draws a chuckle during public lectures, but it underscores why this chapter is somewhat different than the preceding ones. As in other parts of astrobiology, one must consider the diversity of physical environments in the cosmos, and the limitations imposed by them. But with SETI one must also consider modifications to the environment that are not just the byproduct of life, but the result of deliberate actions by intelligent organisms intended to achieve some result.

For millennia people have speculated about the existence of other habitable worlds, and their inhabitants (Chap. 1), but the rules of the game underwent a profound change in the second half of the twentieth century. The publication of the initial scientific paper on SETI (Cocconi and Morrison, 1959) and Drake's (1961) first radio search (Project Ozma, described in Sec. 1.9) turned speculation into an observational science. No longer were priests and philosophers the sole respondents to the "Are we alone?" question; scientists and engineers could work on finding an answer empirically. Following the first flurry of observing programs in the US and the Soviet Union (Chap. 2), the acronym SETI became the accepted name for this new exploratory activity. But in fact, SETI is a misnomer because there is no known way to detect intelligence directly across interstellar distances. Even on Earth we argue about exactly what constitutes intelligence, and we have no reliable way of measuring it at a distance (either spatial or temporal). In the case of extraterrestrial intelligence, the best we can do is to search for some manifestation of another technology. Having detected it, we can infer the existence of intelligent technologists, who may or may not still be associated with the detected technology. This distinction is far more than semantic, it defines what we, with our early 21st century technology, can and cannot attempt to do.

26.2 What Technologies?

What technology might an extraterrestrial civilization utilize, and what are the observable consequences therefrom? As with so much of astrobiology, we are forced to extrapolate from what we know, even though we cannot be sure that it is appropriate for life-as-we-do-not-yet-know-it. From our own experience we deduce that a civilization might develop indirectly observable technologies for energy production, for waging war, for transportation (including perhaps interstellar travel), and for exchange of information. This is not an exhaustive list, but after decades of discussion, these remain the most commonly cited examples. With the exception of interstellar transportation (since this opens the possibility that “they” might come here), detecting these technologies requires remote sensing equipment. Over the past four decades, more than 100 searches have been madefor specific examples of each of these potential applications of technology[1]. [URL PUT AT TOP OF TABLE 26.2 NO-THAT TABLE IS ONLY RECENT SEARCHES, WHEREAS THE ARCHIVE PROVIDES INFO ON MORE THAN 100 SEARCHES SINCE 1960. URL SHOULD NOT BE ASSOCIATED WITH THAT TABLE SO I HAVE PUT IT IN AS FOOTNOTE]

Although it is very risky to speculate on the motivations of an unknown, extraterrestrial civilization, waging war, generating energy, and local transportation are all examples of technologies that are likely to be employed for the sole use of the civilizations that have invented them. In this case, there is no reason to believe that they would make any effort to enhance the probability that another civilization would ever discover them. They would be visible only through unintentional manifestations of their technology, and perhaps it then follows that the best search strategy is to explore the Universe with all possible tools, in every possible way, and conduct a robust observational program of astronomy. If and when an anomalous phenomenon appears, one that cannot be easily explained by current astrophysics, researchers should ask whether that phenomenon might be the hallmark of some form of "astro-engineering" or other technology.

In contrast, when considering interstellar travel and information exchange, one can argue that these technologies might be manipulated with us (or other emerging technologies like us) in mind. "They" might actually come here or have done so in the past, or "they" might actively generate signals for the precise purpose of attracting our attention and transferring information. With respect to the first possibility, there is no proof that "they" have visited Earth (notwithstanding spectacular but undocumented claims to the contrary). However, to be completely

[1] see archive of SETI searches maintained by the author at http://www.seti.org/searcharchive

honest, there is also no evidence proving that "they" have *not*. The physicist Enrico Fermi was sufficiently impressed with the apparent lack of visitation that he once asked his luncheon companions, "Where is everybody?" (Jones, 1985), thus originating the so-called *Fermi paradox*. If, the argument goes, there had ever been a single other intelligent, technological civilization within our Milky Way Galaxy, then they would have developed the technology for interstellar travel quickly (relative to cosmic time scales), and used it to colonize the Galaxy. For a wide range of scenarios, this colonization would have taken place in a time much shorter than the 10 Gyr lifetime of the Galaxy. But they are evidently not here. Therefore, such a civilization can never have existed at any prior time in the Milky Way.

Since seemingly simple paradoxes often lead to revealing conclusions, a great deal has been written about ways to explain away or answer the Fermi paradox. Webb (2002) summarizes 50 possible solutions, grouped under three headings: 1) They are here; 2) They exist but have not yet communicated; and 3) They do not exist. Webb himself subscribes to the third solution. His discusion of Group 2) contains many relevant arguments about the enormous energy costs of interstellar travel, as well as reasons why we might not have detected deliberate signals (though this is not strictly a part of the Fermi paradox). In discussing Group 1), he dismisses all the unsubstantiated claims of visitation as well as the idea that we-are-they (via a program of directed panspermia[2]). However, he fails to consider seriously what may be the fundamental answer, and why the Fermi paradox is no paradox after all. Humans have so poorly explored our own environment on Earth, and the surrounding solar system, that we cannot in fact say "they are not here." This is particularly true if "they" are represented by some small

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[2] *Directed panspermia* is the idea that a civilization could purposely spread the germs of its form of life to other habitable locales (Crick and Orgel, 1973)

(perhaps even nanoscale) surrogate technologies. We can only rule out the presence of large objects filled with macroscopic examples of biology (such as the crew of Starship *Enterprise*) in a few locations near Earth, but not even elsewhere in the solar system. For example, NASA's Spaceguard Survey is attempting to locate all potential Earth-crossing asteroids greater than 1 km in diameter (Morrison, 1992). Yet even this thorough search of nearby space, looking for large objects lacking cloaking devices, is incomplete and subject to surprises. Objects can sneak up from the sunward direction and not be discovered until after they pass into the evening sky, as was recently the case with the 100-m-sized asteroid 2002 MN. Small, self-replicating, robotic colonizers could certainly have gone unnoticed. Although the Spaceguard Survey is a good example of the difficulty of conducting any kind of systematic search for evidence that "they" are here, one group (coordinated by Canadian futurist Allen Tough) has not been dissuaded from taking a proactive role and has invited any nearby intelligent probe of non-Earth origin to log on to the Internet and announce itself[3].

The majority of searches for extraterrestrial intelligence in the decades since Project Ozma have instead concentrated on finding signals that are the result of exchanging information; either unintentional leakage, or deliberate beacons. The seminal Project Cyclops Report (Oliver and Billingham, 1972; Sec. 2.2.4) specified optimal requirements for transmitting information over interstellar distances. The best information carrier should:

- require minimum energy per bit of information
- have the maximum possible velocity

[3] The "invitation" can be found at http://www.ieti.org/

- be easy to generate, launch, and capture
- not be appreciably absorbed by the interstellar medium
- go where aimed

The last requirement rules out any charged particles, since they are deflected by the general interstellar magnetic field. Particles with mass also require a large amount of energy to accelerate close to the speed of light *c* (the cosmic speed limit as far as we know, 3×10^{10} cm/s). Specifically, if we denote as β the ratio of a particle's velocity *v* to *c*, the theory of special relativity indicates that a moving particle has a mass given by

$$m = \frac{m_0}{\sqrt{1-\beta^2}} \tag{26.1}$$

where m_o is the mass the particle has at rest. Unless the velocity gets close to *c*, the mass is little increased, but as β approaches 1 (relativistic velocity), the mass grows rapidly, as does the energy needed to accelerate it. For example, the mass of a single relativistic electron traveling at 0.5*c* is increased by a factor of 1.15 above its rest mass. Its kinetic energy is then 1.25×10^{-7} erg, fully 10^{10} times the kinetic energy of a single typical microwave photon.

Photons, the quanta of electromagnetic radiation, are ideal carriers of information because they are massless, travel at *c*, and have very small energies. The energy of a photon is proportional to the frequency of the wave associated with the electromagnetic radiation. Therefore radio and microwave photons, being of such low frequency, have very low energy. As with any wave phenomenon, the product of the frequency and the wavelength gives the speed of propagation: $c = \nu\lambda$. As a benchmark, a frequency of 1000 MHz = 1 GHz corresponds to a wavelength of 30 cm.

Other exotic, massless particles proposed by theoretical physicists may also travel at light speed, but we cannot now manipulate them, even if they do exist. If such exotic particles are the choice of technologies more advanced than our own, the only strategy for detecting such signals is to survive as a technological species until we learn to generate and capture them ourselves. Rose and Wright (2004) have recently suggested that if time is no concern (thus eliminating the second bullet in the list of properties for information carriers), then an extraordinary amount of information can be deliberately transferred over interstellar distances by inscribing a message into a very dense physical memory device. This missive could then travel between the sender and intended receiver at slow speeds to conserve energy. Figure 26.1 recently appeared on the cover of the Annals of Improbable Research (Ben-Bassat *et.al*, 2005). It humorously illustrates this concept; a giant African snail pulling two densely encoded data disks in a 'feed forward' transport mode can exceed the data transfer rates achievable with many broadband systems available today. The energy costs of the redundancy required to insure successful receipt of the physical SETI messengers have not been adequately addressed, nor has the required strategy for discovery by the receiver. As we have already noted, using the Spaceguard Survey as an example, small objects in our solar system can easily go undetected. So for the foreseeable future, photons remain the best bet for SETI.

26.3 The Nine-dimensional Cosmic Haystack

Having settled on a search for electromagnetic signals as the methodology for SETI, we now must decide *where* to search (3 spatial dimensions), *when* to search (1 temporal dimension), and *what* to search for (frequency, 2 possible polarizations, a modulation scheme, and a signal strength). The "cosmic haystack" to be scoured for the proverbial "needle" is thus nine-dimensional. Consider the possible scale of each of these dimensions.

A signal might be coming from any **direction** on the sky, and from a **distance** of as much as 100,000 light years (lt-yr) if it originates within our Milky Way Galaxy. The nearest neighbor galaxies are millions of light years away, so a signal coming from one of them would have to be much stronger in order to be detectable on Earth (signal strength drops off as $1/r^2$, where r is the distance to the transmitter). Section 26.5.3 discusses the issues of where to search in more detail.

The **time** at which a signal arrives could be a critical part of a search if the transmitting civilization has decided, for example, to broadcast only for one hour every year. If the signal is always present, it makes our job easier, but puts more burden on the resources of the transmitting civilization. Section 26.5.5 discusses one proposed scheme for when we should look, but very few searches have ever carried out their observations for any such special time.

Electromagnetic radiation can have two orthogonal senses of **polarization**, and both must be examined to avoid missing a signal. Right and left circular polarizations are often used in search programs because they are unmodified by propagation through the galactic magnetic field and the interstellar medium, unlike linear polarizations.

As Harwit (1981) illustrated, the **frequency** range for acquiring information over cosmic distances via photons is vast, but finite. Frequencies lower than ~100 kHz do not propagate through the interstellar medium because they are absorbed by its rarefied plasma (typical density of ~0.03 electrons per cm^3).[4] Conversely, if a photon has enough energy (high enough frequency), then when it passes near one of the ubiquitous cosmic microwave background photons left over from the birth of the Universe, it can spontaneously transform into an electron and its antiparticle, a positron. This high frequency cutoff for sending information by photons through the interstellar medium is $\sim 10^{29}$ Hz, which corresponds to a photon energy of $\sim 4 \times 10^{14}$ eV, well beyond the observed Γ-ray range. Section 26.5.4 discusses reasons for choosing specific frequencies and bands within the above huge range,

The **modulation** parameter space is difficult to constrain. *Modulation* refers to the specific techniques for encoding information onto a signal (a familiar example is amplitude modulation, or AM). In the absence of an agreed-upon scheme between sender and receiver, efficient communication is difficult. In general, the more information that is contained within a signal, the more noise-like it appears and the more difficult it is to disentangle from the natural sky background and from receiver noise. To date SETI searches have concentrated on very simple classes of signals such as narrowband continuous tones and regular pulses. As computing capability becomes more affordable, it will be possible to search for more complex signals, although Sec. 26.5.2 suggests that in the case of deliberately generated signals, this may not be necessary.

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[4] For ground-based observations, the plasma of the Earth's ionosphere sets a higher low-frequency limit of ~10 MHz.

Finally, **signal strength** is unknown. but it makes sense to search with the greatest possible sensitivity, so that a signal of a given strength can be detected at the farthest distance. The following section outlines some of the principles when considering signals and the inevitable competing noise.

26.3.1 Signal and Noise

The strength of any arriving signal depends on the power of the transmitter and its distance, as well as the fraction of the signal that is actually collected by the receiver. Consider the factors that relate the received strength to the various properties of one antenna transmitting to another at a distance *r*. P_R, the amount of signal power (watts or W) collected by a receiving antenna with an *effective area*[5] A_R , is

$$P_R = \frac{P_E A_R}{4\pi r^2}$$

(26.2)

where P_E is the *effective isotropic radiated power* of the transmitter (see below). The equation states that the received fraction of transmitted power is just the fraction of the area of a sphere of radius *r* that is covered by the receiving antenna's

[5] The *effective area* of an antenna is always less than its geometrical area, and depends on a number of efficiency factors such as the electrical properties and configuration of its materials, accuracy of its reflecting surfaces, blockage, etc.

effective area. Figure 26.2 presents a cartoon that should be helpful in understanding this simple equation. Note that the transmitter may or may not be radiating its power in all directions (*isotropically*) - at the receiving end of a signal it is not possible to know exactly how it was transmitted, nor whether it was beamed at the receiver. As an example, terrestrial television broadcast antennas concentrate all their power into a thin "fan beam" that radiates towards the horizon, since they do not currently have any potential customers high in the atmosphere.

The effective isotropic radiated power P_E is defined as P_T x G_T, where P_T is the actual transmitted power and G_T is the *antenna gain*, determined by the size and shape of the transmitting antenna. The antenna gain can be thought of as the ratio of the entire sky's solid angle[6] to that of the transmitting antenna's beam (Ω_T), $G_T = 4\pi/\Omega_T$. Unless the transmission is isotropic ($G_T = 1$), P_E is larger than P_T . Antenna theory also shows that G_T can be expressed as $4\pi\ A_T/\lambda^2$, where A_T is the effective area of the transmitting antenna, and λ is the operating wavelength. Thus the larger the antenna, the higher the gain and the more concentrated the beam; and for a given telescope, the gain is higher at shorter wavelengths (higher frequencies). In the case of the fan beam emitted by a TV transmitter, G_T is about 5. Rearranging eq. (26.2) produces the following elegant version of the free space transmission law:

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[6] *Solid angle* is a measure of the area of a patch of sky (in steradians or square degrees); the entire sky-sphere contains 4π steradians just as a circle contains 2π radians. For patches with angular sizes of less than 10° or so, the value of solid angle can be found just as one finds the area (cm^2) of a plane figure knowing its dimensions in cm.

$$\frac{P_R}{P_T} = \frac{A_R A_T}{\lambda^2 r^2} \qquad (26.3)$$

We do not know what values of P_E another technological civilization might muster for transmitting, but on Earth today our cell phones typically radiate $P_E \leq 1$ W, commercial radio stations broadcast ~10 kW, television stations generate 1 MW, and our most powerful radar transmitter, the 1 MW planetary radar attached to the large telescope in Arecibo, Puerto Rico (Fig. 26.3), transmits a P_E value of 2 x 10^{13} W to image the surfaces of distant planets and asteroids. Our SETI searches over the past four decades have not in fact been sensitive enough to detect our current level of television leakage radiation if it originated from the vicinity of nearby stars (at distances of ~5-10 lt-yr), yet some of them could have detected the equivalent of the Arecibo planetary radar transmitter from as far away as 1500 lt-yr. Table 26.1 gives the number of stars that exist within the distance that Project Phoenix (Backus *et al.*, 2002), currently the most sensitive of the microwave SETI searches (Sec. 26.6), could have detected transmitters with power analogous to those of terrestrial leakage. Some SETI programs are efficient at detecting either leakage radiation or purposeful beacons, while others are optimized for only one of the signal types. Note also that, because the Sun and its planetary retinue are all in common motion, a transmitting civilization aiming for us would need to point at the spatial location where the Earth would be when the signal arrived after many years (just like “leading” a moving duck in a shooting gallery). The transmitter would thus need to know the motion of the Sun through the Galaxy very accurately[7].

The practical question of "Can we detect a certain signal?" depends not just on its strength, but also on the sensitivity that receiving equipment and environmental factors allow, i.e., how much random *noise* competes with the signal. For a signal to be reliably claimed (*detected*), the received power P_R must exceed by a certain factor, call it *m*, the always-present "competition" from fluctuations in the average noise power $\langle P_N \rangle$[8]. The brightness of the sky, the roughness of the surface on the receiving antenna and any deviations in its shape, as well as the random motions of electrons or photons in the electronic receiving devices all contribute to the average noise power. Every search must set its detection threshold *m* high enough to reduce the statistical probability of an apparent signal actually being the result of a fluctuation in the competing noise

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[7] This problem becomes even more severe at the shorter optical wavelengths where gains of ~ 10^{12} might be used (Sec. 26.8.1).

[8] For a radio telescope $\langle P_N \rangle = k\, T_{sys}\, B/\sqrt{B\tau}$ per polarization, where B = bandwidth of the receiver in frequency (assumed to be at least as broad as the bandwidth of the signal), τ is the duration of the observation, and T_{sys} is the system temperature, which by definition is the physical temperature of a resistor that would produce the same equivalent black body noise power into bandwidth B. B, T_{sys}, and τ are all measurable quantities. For a radio telescope $\langle P_N \rangle = k\, T_{sys}\, B/\sqrt{B\tau}$ per polarization, where B = bandwidth of the receiver in frequency (assumed to be at least as broad as the bandwidth of the signal), τ is the duration of the observation, and T_{sys} is the system temperature, which by definition is the physical temperature of a resistor that would produce the same equivalent black body noise power into bandwidth B. B, T_{sys}, and τ are all measurable quantities.

power. The theory of the statistics of noise, the details of the signal detection hardware and software, and experience with sources of interfering signals in the vicinity guide the choice of the multiplier *m* (typically ~ 2–20). A detection is claimed when

$$P_R \geq m\langle P_N \rangle \quad \text{or} \quad \frac{P_E A_R}{4\pi r^2} \geq m\langle P_N \rangle \tag{26.4}$$

This last expression allows us to calculate, the range r_{max} to which a signal of a given power can be detected, given the characteristics of a particular search project.

$$r_{\max} = \sqrt{\left(\frac{A_R}{4\pi m}\right)\left(\frac{P_E}{\langle P_N \rangle}\right)} \tag{26.5}$$

26.4 How Many Technical Civilizations Might There Be?

Having investigated the size and shape of the cosmic haystack, it would be desirable to know *how many* technological civilizations (if any) produce signals that might be detectable. This would permit an estimate of how much of the haystack will need to be searched before there is a reasonable expectation that a signal will be found. It is of course impossible to know the answer in advance of success, but the *Drake Equation* (Drake, 1962) allows us to think about the problem in an organized manner. This equation tells us that *N*, the number of civilizations in the Milky Way Galaxy whose electromagnetic emissions (whether intended for communication or not) are now detectable by us, can be estimated by starting with the average rate of star formation in the Galaxy R_* and then multiplying that by various factors representing conditions that we think necessary for technological civilizations to arise. This forms an estimate for the average number of technological civilizations arising in the Galaxy each year[9], which is then multiplied by the average longevity of the emitted signals to estimate the total number N that might now be detectable. The longevity may or may not be identical to the actual longevity of the intelligent species that first invented the technology. It could, for example, be longer - on Earth, civilizations have risen and fallen many times, but some of their technologies have been adopted by subsequent civilizations. The technology could also transcend its manufacturers, and continue to generate itself. The longevity of emissions could of course also be much shorter than that of the civilization, for various economic, technical, or social reasons (see below).

The Drake Equation can be written

$$N = R_* \cdot f_\odot \cdot f_p \cdot N_e \cdot f_l \cdot f_i \cdot f_c \cdot L \quad , \qquad (26.6)$$

Where R_* is the average rate of star formation in the galaxy, $f_\odot$ is the fraction of all stars that are "Sun-like," i.e., not so massive that they fuse the hydrogen to helium in their cores in a time too short for intelligent life to evolve (probably billions of years), nor so low in mass that their dim glow offers insufficient heat to sustain life

[9] An implicit assumption in this formulation is that the rate of star formation has been constant over the last 5 Gyr. Although this assumption is not correct, the main conclusions derived from the Drake Equation are not seriously affected. [NOTE TO WOODY - ACTUALLY IT REALLY ONLY SAYS THAT R_* HAS BEEN ~CONSTANT OVER THE LAST L YEARS, AND THAT IS MORE LIKELY TO BE CORRECT SINCE L IS PROBABLY $<< 10^{10}$ YEARS.]

in their vicinity (Chap. 21). f_p is the fraction of Sun-like stars that have planets in orbit around them, while N_e is the average number of Earth-like planets in any planetary system. Here we admit our bias for Earth-like planets as the home for any life that eventually evolves into a technical civilization. f_l is the fraction of terrestrial planets on which life actually *does* start, and f_i is the fraction of all life-starts that eventually evolve intelligence. f_c is the fraction of intelligent species that develop a civilization using a technology that generates some form of detectable emission. Finally, *L* is the longevity of that emission.

If the Drake Equation's contents seem like a synopsis of all the other chapters of this book, it is no accident. Astrobiology concerns itself with a suite of interdisciplinary programs to study life on Earth, and to search for life off Earth, and in so doing, it provides the best possible estimates of the terms in the Drake Equation. Frank Drake himself favors a value for N of $\sim 10^4$.[10] Astronomers have determined that R_* is ~20 per year, with reasonable accuracy. We also take the value of $f_\odot$ to be ~ 0.1, considering all stars whose mass is within a factor of two of that of the Sun , but note that this could rise significantly if ongoing deliberations conclude that small dwarf stars might, after all, host habitable planets. Our best census of giant extrasolar planets (Chap. 21) yields a value for f_p of ~ 0.1-0.2. The Kepler spacecraft that will launch in 2008 (Chap. 21) should inform us whether N_e is < 1 or > 1, but in any case it is unlikely to be >10. All other terms in eq. (26.6), except for *L*, are < 1. Therefore, to continue discussing SETI strategies, it is sufficient to use a simple version of the Drake Equation, namely:

$$N \leq L \text{ (with } L \text{ measured in years),} \qquad (26.7)$$

[10] If you wish to calculate your own estimate for N, you can do so on the SETI Institute web site at http://www.seti.org/drake-eq-calc

without focusing on the actual magnitude of the inequality. This simple form leads to a profound conclusion: "emitting" civilizations will not be both spatially and temporally coincident (near one another in the Milky Way at the same period during its 10 Gyr lifetime) unless their emissions typically persist for a long time. For example, if N ~ 100, typical separations are ~ 10^4 lt-yr and if N ~ 10^4 (Drake's preferred value), typical separations are ~ 1000-2000 lt-yr, which would make for fewer candidate stars to search before likely success.

SETI is unlikely to succeed if *L* is short. But there are two other special conditions worth mentioning. *L* may be short because the inventors of technology turn it off for some good reason, and continue thriving in its absence. This is the case for the Chinese in the 15th century. All the great "treasure fleets" of Admiral Zheng He (Cheng-Ho), that had already navigated along the west coast of Aftrica and perhaps around the tip of South Africa, were called back to port and dismantled or left to rot on the beaches under orders from the Confucian bureaucrats who replaced the Yong-Lo Emperor , as China turned inward for the next 300 hundred years (Finney, 1985)). Or *L* may only appear to be short because we are the first such technological species in the galaxy (as asserted by the Fermi paradox), and we are still very young, with no way to know our future longevity. Gott (1993) used Bayesian statistics to estimate that there is a 95% chance that the human race will last between another 5000 and 8 million years. If we are the first technology and our technological longevity turns out to be at the long end of Gott's prediction, then perhaps SETI will eventually succeed whenever subsequent technological species emerge.

Whether or not we are the first, no technology much younger than us can be detected across interstellar distances, so any technological civilization that SETI detects will undoubtedly be older than our current selves. On the other hand, if SETI searches succeed in detecting evidence of another technology in the near future, then we can infer that the average value of *L* is large.

26.5 Search Strategies

26.5.1 The Astrophysical Background

Figure 26.4 displays the average background sky intensity over the full range of electromagnetic frequencies accessible to modern astronomy. To be detectable at a given frequency, a transmitted signal, or the portion of it that enters a particular detector, must have an intensity that can successfully compete with this natural sky background, as well as the instrumental noise in the receiver. This background radiation is due to many different classes of astrophysical sources. Stars are bright at optical frequencies, while the warm gas and dust between the stars are most readily detectable in the infrared and millimeter bands. At very low radio frequencies, electrons spiralling around galactic magnetic field lines emit synchrotron radiation, and the high-frequency, high-energy sky (X-rays, Γ-rays) is filled with the emissions from energetic explosions and hot gas in clusters of galaxies. The 2.73 K afterglow of the Big Bang (called the cosmic microwave background or CMB) fills the Universe in all directions and is most detectable in the microwave and infrared regions of the spectrum.

In practice, spatial, spectral, or temporal filters are used to exclude different types of background and make signals more detectable. For searches made from the ground, there are also unavoidable filters imposed on observations by the opacity of our atmosphere at some frequencies, and by human-caused interference at others. Figure 26.5 shows the height above sea level to which radiation at any given wavelength can penetrate. Although infrared and mm waves penetrate the interstellar dust that scatters and absorbs optical photons over large distances between the stars, water vapor in the Earth's atmosphere obscures radiation at these frequencies, requiring high-altitude observatories to look through a few narrowband windows, or orbiting telescopes operating above the atmosphere. Likewise, ultraviolet, X-ray and Γ-ray frequencies are blocked by the ozone, oxygen and nitrogen in the atmosphere (fortunately for our survival; Chap. 4) and observations at these frequencies require telescopes in space.

SETI observations have traditionally concentrated on microwave radio searches (the portion of the radio spectrum from 1 to 10 GHz) where the natural background is low and where the atmospheric transparency approaches 100% (Sec. 26.5.4). More recently, searches have also been conducted for very short pulses in the optical part of the spectrum where instrumental nanosecond time filters intentionally exclude most of the background photons from a star's light. A small optical telescope with a square meter of collecting area, observing without any spectral filters, receives an average of $\sim 10^6$ visible light photons/sec from a solar-type star at a distance of 1000 lt-yr. Therefore, the arrival of many photons (say 10-100) in only ~1 ns would represent a pulse signal of very high statistical significance. Searches for *continuous* visible light signals require even more powerful transmitters (lasers) to outshine the natural noise, and long observing times to average out fluctuations of the background starlight.

26.5.2 "Natural" or Artificial Signals?

Consider the challenge of generating some sort of a transmission that will attract the attention of an emerging technology such as ourselves. What might a deliberate beacon look like?

A case could be made that it would not be recognizable at all because any advanced technologies will only be interested in attracting the attention of other advanced technologies, and therefore their beacons would be based on science and/or technology that we currently lack. In that event, SETI will not succeed until terrestrial technology attains the necessary level of technical competence. According to Arthur C. Clarke's "third law" (Clarke, 1984): "Any sufficiently advanced technology is indistinguishable from magic."

Two classes of beacon signals that we could detect suggest themselves. The first is a signal that mimics the emission from astrophysical sources, but contains some subtle difference. The transmitting civilization would reason that when a young technology begins to explore the Universe around it, the development of certain types of astronomical detectors could be predicted by the nature of the cosmos itself. They would expect that deliberate signals, for example, resembling pulsars or quasars or Γ-ray bursters, would be registered routinely by astronomers elsewhere as they survey their environment. It might take time for these "almost natural" signals to be recognized as beacons, but the transmitting technology can have a fair degree of confidence that their efforts would eventually succeed. For instance, pulsars (rapidly rotating neutron stars) are the most precise clocks in the Universe, but physics requires that they must slow down over time. An apparent pulsar whose period did not change at all, or which oscillated between two precise values, would attract serious attention, and might finally be recognized as someone else's technology. A star whose light was 100% polarized with its sense of polarization reversing periodically would be hard to explain without technology, as would a solar-type star whose spectrum displayed an enhancement in the rare-earth elements that constitute the fissile waste products of nuclear power production (e.g., praesodymium, neodymium, zirconium). Tritium (a radioactive isotope of hydrogen containing a proton and two neutrons) has a half-life of only 12.3 years. It also has a radio frequency emission line at 1516.7 MHz (the analog of the 1420.4 MHz spin-flip transition of neutral hydrogen atoms). If discrete emissions were detected at the tritium frequency anywhere except in the vicinity of a recent supernova explosion, where it might have been created, technology would be a plausible explanation. These are only a few examples to illustrate serendipitous results that might attend our expanding exploration of the Universe in coming years.

At the other extreme, a beacon might have attributes that *cannot* be produced by astrophysics (so far as we currently understand), but can easily be generated by technology. In particular, compression in time and/or frequency could indicate a beacon. The uncertainty [NOTE TO WOODY – THE CLASSICAL UNCERTAINTY PRINCIPLE SUFFICES HERE] principle requires that the time-bandwidth product of any signal must exceed unity. i.e., that the frequency range $\Delta\nu$ of emissions from any observed phenomenon and the time scale Δt over which the phenomenon varies in intensity are related: $\Delta\nu\Delta t > 1$. Astrophysical emissions are the result of a very large ensemble of particles (atoms, molecules, ions) that are in the gas phase or in solid bodies. The kinetic and thermal energy of these particles means that they are moving with respect to one another, and even if each particle emits radiation at precisely the same frequency, the Doppler shifts of the moving particles produce a finite bandwidth $\Delta\nu$ for the ensemble emission. In almost all astrophysical cases (e.g., a sunspot or an interstellar cloud of gas), this bandwidth is very large and in general, the intensity of emission does not sensibly vary with time. Astrophysical emissions thus have time-bandwidth products that are very large. In contrast, technology can control the motions of particles (e.g., within electronic devices) and produce signals whose time-bandwidth products are much smaller and even approaching the minimum value. For example, $\Delta\nu$ values are very small for the carrier wave used in radio and television broadcasting or for the monochromatic beam of a laser.

It is also difficult for an astrophysical ensemble of particles to produce variable emissions with very short time durations Δt. Because no physical effects can propagate at speeds > *c*, the linear scale of a particle ensemble fluctuating in a coherent manner can be no bigger than $c\Delta t$, and there must be enough particles within that volume to produce a detectable emission. For example, pulsars show periodic behavior on timescales of seconds to milliseconds, but nanosecond variations have not been established.[11] A "light-nanosecond" is only 30 cm and conventional wisdom asserts that nature has no mechanism for producing detectable pulses from the particles in only a ~ 0.03 m^3 volume. In contrast, our technology can easily accomplish large compression in time. An example is the petawatt (10^{15} W) laser with a pulse duration of 440 femtosec (10^{-12} sec) recently developed at Lawrence Livermore Laboratory (Perry and Mourou, 1994).

Any transmitting civilization designing a deliberate beacon would also need to consider how signal propagation through the interstellar medium can modify the signal itself. For example, any monochromatic, continuous signal suffers from scattering off electrons in the interstellar medium and is thereby broadened in

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[11] Recent observations of giant radio pulses in the Crab nebula pulsar (Hankins *et al.*, 2003) may be challenging this statement.

frequency. At microwave frequencies, it thus makes no sense to look for signals with $\Delta\nu \leq 0.01$ Hz – in fact, most current SETI searches employ narrowband spectrometers with $\Delta\nu \sim 1$ Hz. Furthermore, as pulsar observers are well aware, any pulsed radio signal becomes dispersed in time due to interstellar electrons, with the lower frequency components of the pulse arriving later than the high frequency ones. This necessitates searching through a wide range of plausible values of dispersion to find a short pulse, which adds significantly to the detection problem. Neither of these effects is a problem at optical frequencies.

With due consideration for all these factors, microwave SETI searches in general therefore optimize their electronics to be sensitive to narrowband continuous signals and/or to long duration pulses, while broadband nanosecond pulses are sought at optical wavelengths. Although some attempts have been made to find signals mimicking astrophysics, most SETI searches have focused on signals with small time-bandwidth products.

26.5.3 Targets or Surveys?

There are two strategies to search systematically for signals in the cosmic haystack: look in all possible directions, or focus the search on directions that seem *a priori* more likely to contain a technological civilization. Since the only such civilization we know about has evolved on a planet in orbit about a G2V star, solar analogues are the usual targets for the focused strategy. This so-called targeted search strategy, however, may be unnecessarily restrictive, the result of drawing conclusions from a sample of one. For example, an advanced technology may have moved away from its stellar birth place, or the correct solar analogue may be so distant that scientists compiling a list of target stars to be investigated would not know of its existence; a sky survey covers these possibilities. So ideally, every SETI search should utilize both strategies, but in practice this is seldom possible. Large telescopes with detectors that can analyze data for a long time to achieve good sensitivity on weak signals are routinely used for targeted searches. Smaller telescopes, with larger beams on the sky, and detectors that can respond well in the short time available to look at any particular direction on the sky, are better suited to sky surveys. Although the achievable sensitivity is poorer, sky surveys look in directions that would not otherwise be selected. In general, targeted searches are superior for finding weak, nearby transmitters, and sky surveys excel at finding more powerful (and presumably rarer) distant sources. If the distribution of the output powers (P_E) of all extraterrestrial transmitters were known, it would be possible to calculate statistically whether sky surveys or targeted searches had a higher probability of success over a given time. In the absence of such knowledge, different researchers have developed a number of different figures of merit to compare the efficacy of different search strategies. These figures of merit disagree in detail, but agree that searching more stars over more bandwidth is always better.

26.5.4 Which Frequency Ranges?

Which frequency ranges are optimum for searches? In this section we will examine more closely the radio noise that competes with any signal that we are trying to detect. Figure 26.6 presents a more detailed look at the background radiation encountered by radio telescopes, and shows that a frequency band from ~1 to ~10 GHz (~30 cm to ~3 cm in wavelength) defines a low-noise “terrestrial microwave window" ideal for sensitive observations from the Earth's surface.[12] The high noise level defining the low-frequency edge of the window is due to synchrotron radiation generated by electrons spiralling around magnetic field lines that thread through the Milky Way and is stronger in the direction of the Galactic plane than towards the poles. (Part of the static that can be heard on an FM radio or television set tuned between broadcast stations comes from this galactic synchrotron emission.)

Figure 26.6 shows that the high-frequency edge of the terrestrial microwave window is caused by the noise background from absorbing atmospheric water vapor and molecular oxygen. This noise can be eliminated by going into space orbits (or the lunar farside), where only the cosmic microwave background hinders at frequencies up to ~60 GHz, at which point the shot-noise from the individual photons ($\propto h\nu/k$; labelled "quantum limit" in Fig. 26.6) becomes increasingly troublesome. Some authors have speculated that advanced technologies will select frequencies requiring space-based observing platforms as a minimum technological threshold for any civilization to detect their beacon.

Current microwave SETI programs confine themselves to the terrestrial microwave window; SETI from space is too expensive to undertake right now. Nevertheless, radio astronomers have become interested in one particular extraterrestrial locale. Because the Moon's synchronous rotation means that its far side is never visible from Earth, this is the one place in our solar system whose sky never experiences human-generated interference from the Earth. Cognizant of this

[12] The level of radio emission at low frequencies rises in Fig. 26.6 (measured in terms of noise temperature) and falls in Fig. 26.4 (measured in photon flux); the reason for this seeming paradox is that the two figures plot different measures of the radio emission. Both are useful, but for signal-to-noise considerations as in this Section, noise temperature (see footnote 8) is the quantity of interest.

growing radio frequency interference (RFI) on Earth and in Earth orbit, researchers convinced the International Telecommunications Union in 1979 to protect the shielded zone of the Moon (as defined in Fig. 26.7) from all RFI (e.g., from future spacecraft orbiting the Moon). If lunar bases are ever developed for other reasons, then SETI (and "traditional" radio astronomy) may some day be conducted from this shielded zone, investigating higher frequencies as well as those frequencies now contaminated by terrestrial RFI.[13]

Optical SETI for pulses is currently being carried out without imposing any spectral filters, eliminating the need to search through all optical frequencies. As previously mentioned, very short temporal filters are applied to eliminate stellar photons, and there do not appear to be any natural sources of background optical emission with short, nanosecond temporal variations. Instead, the challenge for optical SETI observers is that the detectors themselves produce events from corona discharge, ion feedback, and cosmic-rays, thus requiring two or three such detectors working in coincidence to reduce the number of false positive events. Extending these observations into the infrared will require high-altitude sites and/or spacecraft, as well as affordable detectors with short time constants. Observations in the infrared would avoid the problem of interstellar absorption by dust grains, which limits optical SETI to distances of ~1000 lt-yr. Within that volume, however, there are about one million Sun-like [O.K.? YES] stars.

26.5.5 Magic Frequencies, Places and Times

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[13] Ironically, one of the reasons to develop a lunar base might be to support a satellite launch and repair facility, now being contemplated by NASA, at the L_2 Lagrange point directly above the lunar farside, thereby disturbing the radio-quiet shielded zone.

Today's microwave SETI detectors require spectrometers with ≥ 10^8 spectral channels, in order to conduct systematic searches for signals buried somewhere in the terrestrial microwave window from 1 to 10 GHz (equivalent to 10^{10} channels of 1 Hz width). An alternative to covering the entire band is a search based on preferred or *magic* frequencies that can be argued as likely to be mutually adopted by transmitter and receiver. Since water is so fundamental to our form of life, some researchers have suggested that a preferred portion of the terrestrial microwave window is the "cosmic water hole" marked by the natural emission lines of H and OH, the dissociation products of water. Figure 26.6 indicates the 21 cm H hyperfine-transition emission line at 1.42 GHz [USING FREQ. IN ORDER TO BE CONSISTENT WITH FIGURE SCALE OK] and the highest of the four maser lines associated with the OH radical at 1.72 GHz. Combinations involving the 1.42 GHz H line (from the most abundant element in the Universe) and fundamental constants such as π and *e* and the fine structure constant α (~1/137) have also been promoted as potential interstellar communication channels (Blair, 1986). But by far the greatest amount of time spent on any magic radio frequency has been on the H line, as first proposed by Cocconi and Morrison (1959). At optical frequencies, the broadband nature of the sought-for optical pulses means that no particular frequencies are singled out.

There are a few distinctive *locations* and directions in the Milky Way that have attracted attention from SETI researchers: (a) the galactic center is unique; (b) 90% of the stars reside within a few degrees of the galactic plane; (c) the rotational axis of the Galaxy is well defined; and (d) there are a small number of outstanding astrophysical sources that represent oft-observed directions.

Transmissions by an extraterrestrial civilization aimed towards or away from these astrophysical sources could result in our detection of a beamed signal during the course of our routine astronomical studies. For those sources that are themselves masers (involving either OH, water, or methanol molecules), there is an added bonus. Molecular emission in these clouds can provide non-linear amplification of any signal transmitted through them at the correct frequency; a properly aligned detector on the output side of the maser would benefit from a free amplifier in space and receive a much stronger signal than was originally transmitted (Gold, 1976).

It would be extremely useful if there existed some marker in *time* that could logically be deduced by both transmitter and receiver as the moment for signal reception. Novae and supernovae are relatively rare events in the Galaxy, and might be used to synchronize the timing and aiming of deliberate transmission and reception of signals. Lemarchand (1994) has described the "SETI ellipsoid" (Fig. 26.8). In this scheme it is suggested that SETI researchers on Earth should begin observations of a given target star at the time when that star first appears on the surface of the expanding ellipsoid whose foci are a recent supernova and the Earth. Sullivan (1991) attempted to define magic periods or time durations for pulsed signals. There is little to constrain possible periodicity or duration, however, except in the case of the broad optical pulses, where $\Delta t \leq 1$ nanosecond seems consistent with technology rather than astrophysics since we have not yet discovered any natural sources of radiation that vary this rapidly. [BUT IS THIS NOT *OUR* TECHNOLOGY AND NOT A MUTUAL, PHYSICS-TYPE ARGUMENT? NO, I THINK THAT THERE CAN BE A MUTUAL UNDERSTANDING THAT ASTROPHYSICS WILL NOT OCCUPY THE

NANOSECOND AND BELOW TIME DOMAIN. IT *IS* AN ARTIFACT OF OUR TECHNOLOGY THAT EXPLORATION OF THIS REGIME HAS ONLY RECENTLY BECOME AFFORDABLE] Search programs that have used these magic, or hypothesis-constraining, observational strategies can be found in the archive of SETI searches given in footnote 1 [NOTE THAT TABLE 26.2 HAS ONLY CURRENT SEARCHES AND THE WEBSITE REFERENCED IN THE FOOTNOTE IS A COMPLETE ARCHIVE GOING BACK TO 1960 INCLUDING A BUNCH OF 'MAGIC' SCHEMES. I PUT SOME EFFORT INTO MAINTAINING THIS ARCHIVE AND WOULD LIKE TO REFERENCE IT, IN CASE SOMEBODY IS INTERESTED IN THE HISTORY]

26.6 Current Searches

Table 26.2 lists the parameters of current and recent SETI sky surveys and targeted searches, along with brief notes about the search strategies being employed, and a reference to the web site of each project. All of these projects operate with funding from philanthropic sources. Since the termination of NASA's SETI project (officially known as the High Resolution Microwave Survey) in 1993, there has been no governmental funding available for SETI observing programs in the US. With the current focus on astrobiology and a NASA mission statement that asks "Are we alone?", it is possible that this will soon change.

[JILL: PLEASE ADD HERE 200-300 WORDS OF COMMENTARY ON THE TABLE'S CONTENTS AS A WHOLE. ALSO, HOW ABOUT 500-800 WORDS SPECIFICALLY ON PROJECT PHOENIX AND SETI@HOME: COMPARE/CONTRAST THEIR PRACTICAL OPERATIONAL AND

STRATEGIC ISSUES, E.G., DEALING WITH RFI, CHOOSING CANDIDATES, ETC. DONE]

The large number of entries in Table 26.2 may give the misleading impression that a large community of scientists and amateurs are routinely and continuously conducting effective SETI explorations, in spite of the lack of federal funds for these activities. That table attempts to be inclusive so as to illuminate the various approaches to signal detection that have recently been tried, as well as the linkages among them which are used to discriminate against RFI and reduce the number of false positive events and thereby improve the efficiency of the searching. In truth, with the exception of the commensal (or piggyback) SERENDIP, SETI@home, and the Harvard OSETI program, on most days (or nights), most of the search projects are not on the air. Radio observing often takes on a 'campaign' modality whereby the primary observing resource is available for only a small percentage of the time and SETI scientists and their gear are organized to take advantage of the availability. This is true most noticeably for Project Phoenix that relied on gaining observing time on some of the largest radioastronomical instruments in the world. Phoenix started observations in 1995 renting the 64 m Parkes observatory paired with the 26 m Mopra telescope for exclusive use over a six month period. From 1996 to 1998, Phoenix used about 20% of the time on the decommissioned NRAO 140 Foot antenna at Green Bank, WV and a second 30 m telescope at Woodbury, GA that was built from an old satellite ground station by the students and faculty of Georgia Tech. Phoenix finished its targeted investigation of nearby stars between 1998 and 2004, simultaneously observing with the 305 m dish at Arecibo Observatory in PR and the 210 foot Lovell Telescope in Jodrell Bank, UK. The end result was the observation of slightly less than 1000 stars, all within 150 light years of Earth, over the frequency range from 1200 to 3000 MHz, with sufficient sensitivity to detect a transmitter as powerful as an airport acquisition radar (10^{11} W EIRP). While the Project Phoenix scientists had access to an impressive number of hours of telescope time (through outright purchase, or competitive proposals) – far more than the average astronomer – this still left the targeted searches off the air much of the time. Section 26.8.2 describes a new telescope being built as a dedicated SETI facility and simultaneous radio astronomy facility in order to alleviate this problem. When the Phoenix Project did have access to the sky it utilized a suite of near-real-time signal detection algorithms to look for patterns in time and frequency that are indicative of narrowband continuous signals that may or may not change their frequency over time (i.e. drift), as well as drifting narrowband pulsed signals. Detected signals were compared to a database of all signals seen within the previous week. Signals that matched against the database, when the telescope was looking in a different direction, were discarded as RFI, whereas unmatched signals became candidates to be immediately reobserved and compared with the results from the second observatory. Candidate signals seen at both observatories, with the appropriate difference in Doppler shift and drift characteristics at the two sites (due to the Earth's spin and motion through space relative to a distant stellar target) triggered automatic follow up observations that continued until the signal could be demonstrated to be of human origin, or was classified as a potential ETI candidate. Over the decade of Project Phoenix observations, this latter event happened very infrequently, and usually when there was some problem with making simultaneous observations with widely separated telescopes. A viable candidate ETI signal would initiate a request for an independent confirmation from another observatory and if successful, a press conference to tell the world and release discovery data to all astronomical facilities to encourage additional observations. During Project Phoenix, our false positive events never escalated to this last step.

SERENDIP and SETI@home have optimized their time on the sky by giving up on any requirement of where in the sky the observations take place. Given the unique geometry of the Arecibo telescope, it is possible for SERENDIP and SETI@home to conduct a random survey of the 30% of the sky that it is accessible to the observatory. Over several years, much of the sky gets observed multiple times, and that becomes the key to finding candidate signals. Only signals detected repeatedly whenever the same direction on the sky is accessed warrant additional attention. The SERENDIP system keeps up with the real-time signal detection required during its continuous progress across the sky by applying only a very simple algorithm that records events that excede a high threshold within its 100 MHz of instantaneous bandwidth. Information about all these events is stored up and post-processing filters can be used to recognize and discard many types of RFI. Signals that appear to reoccur from the same direction on the sky are aggregated and followed up on during specific, scheduled targeted observations. None has thus far been reacquired. SETI@home combines the complex pattern recognition algorithms from Project Phoenix with the sky survey strategy of SERENDIP. SETI@home sacrifices bandwith in order to employ the more complex signal detection algorithms from Project Phoenix. The central 2.5 MHz from the 100 MHz SERENDIP bandwidth are recorded directly to tape. These tapes are shipped to UC Berkeley where the data are sliced up into time-bandwith work units and shipped off to eager volunteers around the world, who donate a truly enormous amount of off-line compute power to process the data packets looking for signal patterns in frequency and time. The vast quantity of CPU cycles available through this innovative distributed computing project allows SETI@home to look for continuous and pulsed signals over a much wider range of drift rates, pulse widths and pulse repetition rates than Project Phoenix could, but only over a very narrow range of possible frequencies surrounding the 1420.406 MHz line of HI.

So which is better – SERENDIP, SETI@home, Project Phoenix, or some other search strategy like OSETI? That's like asking whether apples are better than oranges – both belong in a healthful diet, along with grapes and nuts. Until we succeed, it isn't possible to know what is the *best* way to search, but it does seem reasonable to suggest that this is one area where inclusion rather than exclusion may lead to a higher probability of success.

26.7 Should We Be Transmitting?

All of the discussions in this chapter have been concerned with *receiving* signals transmitted by another civilization. But since the first half of the 20th century, our own technologies have been inadvertently broadcasting radio signals that could be detected by any other civilization with technological capabilities significantly better than current terrestrial standards. Moreover, in 1974 the Arecibo Observatory celebrated the upgrade of its antenna surface by sending a 1679 bit, pictorial message (utilizing the powerful planetary radar transmitter) in the direction of the globular cluster M13 (The Staff of the NAIC, 1975).[14] On at least one occasion a for-profit group has rented the large Evpatoriya telescope in

[14] See http://www.seti-inst.edu/science/a-message.html for details.

the former Soviet Union to transmit to the stars the messages from their paying customers. These transmissions have been so short-lived that the probability of their reception by another civilization is vanishingly small. But should we regularly and deliberately broadcast signals in the direction of nearby targets, or throughout the galactic plane, or to distant galaxies, or in any of the other "magic" directions that have been previously considered for a receiving program?

As discussed in Sec. 24.4, most SETI research groups have signed a voluntary Post-Detection Protocol in which they agree that no reply to a detected signal should be sent until global consultation has approved the idea of transmission and the contents of a reply. This protocol, however, does not specifically refer to the *ab initio* transmission of deliberate broadcast signals. The SETI 2020 workshops (Ekers *et al.*, 2002) considered whether deliberate transmission should be a strategy of choice in the near future, but decided against a transmission strategy at this time.

For at least the next decade or so, our radio leakage will continue, although as we use the spectrum more efficiently, the signals will look more and more like noise. Therefore, we will continue to be detectable for the near term, and we can take time to consider whether we should initiate deliberate transmitting activities. Transmitting is a harder job than receiving, so humans, as an emerging technological species, should listen first. The job of transmission is harder not just because it is necessary to pay for the transmitted power, but because it is necessary to reach a global consensus on the ethical, political, and societal questions of who will speak for Earth and what they will say. Finally, it is necessary to "say" whatever we select for a *very* long time. The longevity of the transmitting program might be one practical definition of the value of L in the Drake Equation (26.5), and we have already seen that unless L is large, success is unlikely. We are not mature enough as a species to seriously consider plans that stretch thousands or millions of years into the future. This discussion reinforces the conclusion of Sec. 26.4; any technology that near-term SETI efforts succeed in detecting will be older than our own.

26.8 Future Searches

Even without US governmental funding for SETI, several new telescopes dedicated to searches for extraterrestrial signals at optical and radio wavelengths are under construction. A dedicated instrument for optical SETI sky surveys is being built by Harvard University. A partnership between the University of California at Berkeley and the SETI Institute is currently constructing the Allen Telescope Array to simultaneously conduct continuous targeted SETI searches and traditional radio astronomy [I WENT OUT OF MY WAY TO AVOID SPLITTING THE INFINITIVE ☺].

26.8.1 Harvard Optical SETI Telescope

The number of targeted optical SETI projects for broadband pulses is growing rapidly, as are innovative schemes for lowering the false positive rates from instrumental and natural backgrounds. No new major telescope construction for targeted searches is currently being contemplated, which means that the number of target stars that can be explored with single-beam, high angular resolution, optical telescopes will remain far short of the million or so solar-like [O.K.? YES] stars within 1000 lt-yr. Therefore, with funding from The Planetary Society and the Bosack-Kruger Charitable Foundation, the optical SETI group at Harvard University is currently constructing a 1.8 meter-diameter, dedicated all-sky survey telescope next to the existing targeted optical SETI project at the Oak Ridge Observatory in Massachusetts. The telescope is housed in a building with a roll-back roof and a removable section in the south-facing wall that accommodates drift scans with only a single axis of rotation (Fig. 26.9a). Mirrors have been manufactured inexpensively because the system does not require image quality optics. The partially assembled telescope and part of the construction team can be seen through the southern cutout in Fig. 26.9b. This new telescope will search for powerful transmitters from a large collection of stars by conducting meridian transit scans of the sky in 1.6°x 0.2° strips (with a dwell time, due to the Earth's rotation, of about one minute). The search will be optimized for detecting broadband optical nanosecond pulses by using two arrays of 512 photodiodes. The sky visible from that site (~60% of the entire sky) can be scanned in approximately 150 clear nights. When it becomes operational in 2005, an overall improvement in sensitivity of a factor of 1.6 beyond the value listed in Table 26.2 for the Harvard optical SETI project is expected, but the survey will interrogate a much larger number of stars. This instrument will be unique in the world, but its cost is sufficiently low that it could be easily copied, e.g., to permit a survey of the southern hemisphere.

26.8.2 The Allen Telescope Array for SETI and Radio Astronomy

The Allen Telescope Array (ATA) is currently under construction at the Hat Creek Radio Observatory in northern California, with initial funding provided by the Paul G. Allen Family Foundation. The ATA represents a revolution in the way large cm-wavelength antennas are built. The collecting area will be 10^4 m^2, consisting of 350 arrayed antennas, each 6.1 m in diameter. The system temperature will be about 40 K in each of two linear polarizations over an extremely wide bandwidth from 0.5 to 11 GHz that is captured with a single low noise amplifier chip and a log-periodic feed. Because of the small size of the antenna elements, the ATA will be able to image a very large field of view in any direction on the sky, and the architecture of the telescope electronics permits it to simultaneously synthesize up to 32 narrow pencil beams within that field of view, at up to four different frequencies. The cost of the ATA will be about 20% of the cost of traditional telescopes of comparable size because of the use of mass production technologies and the adaptation of inexpensive electronics developed primarily for the telecommunications industry. Figure 26.10a shows the first 21 ATA antennas assembled in the large construction tent at Hat Creek and Fig. 26.10b is an artist's rendering of the full array.

Starting with a catalog of several million target stars, in any field of view chosen for astronomical study and imaged with a radio astronomy correlator, there will be on the order of 10 candidate SETI stars visible, and this is the key to simultaneous and continuous use of the ATA for both SETI and radio astronomy. Independent pencil beams will be formed on as many of those stars as the availability of SETI signal processors permits, while other beams can also be available to study other astronomical point sources (e.g., pulsars) within the field of view being imaged. The continuous availability of the ATA and the observation of multiple target stars and/or frequencies simultaneously will combine to improve the speed of targeted SETI searches by at least two orders of magnitude. Within the next decade, it should be possible to observe ~ 1 million target stars from 1 to 10 GHz at sensitivities comparable to the best target searches to date. These target stars will be selected on the basis of their mass, spectral type, age, metallicity, information about close companion stars, and orbiting planets. As we learn more about the exact conditions within our cosmic environment that enabled the origin and evolution of life on Earth, the criteria for inclusion in a catalog of "Habstars" (Turnbull and Tarter, 2003a,b) will become more refined. Current catalogs contain only about a quarter million stars. The catalogs will grow over the lifetime of the ATA as future spacecraft missions such as SIM and GAIA[15] make fundamental measurements of more distant stars. Until then, observations will concentrate on the lower frequencies, where the observing beam of the array is larger, and current catalogs provide adequate numbers of targets. The first 42-dish array will begin

[15] See http://planetquest.jpl.nasa.gov/SIM/sim_index.html and http://astro.estec.esa.nl/GAIA/ for details of the planned missions.

operation in the fall of 2005, and the full 350 element array should be completed in 2007, if funding can be raised rapidly.

One of the goals for the ATA is to be able to observe at any frequency in the range 0.5 to 11 GHz, despite the problem of RFI. The choice of the remote Hat Creek site in northern California minimizes interference from ground-based populations, but satellite interference is inescapable. However, this array's 350 antennas, observing in 2 polarizations, yield 700 ways that signals can be combined to form the desired images or beams. The ATA will be the first array to mitigate aggressively against satellite interference in real-time by tracking them throughout observations and continuously forming nulls ("beams" with nearly zero sensitivity) on their positions.

26.8.3 The More Distant Future

In order to improve the sensitivity of both optical and microwave SETI observations it will be desirable to utilize even larger telescopes in the future. Today, 10 meter-class telescopes are the state of the art in optical astronomy, but initial design studies are underway for 30 to 100 meter telescopes utilizing very sophisticated adaptive optics. Unlike the ATA, where small array elements provide large fields of view that enable simultaneous targeted SETI observations and traditional radio astronomy research, the fields of view of these extremely large optical instruments are tiny. Even if some sort of optical camera is placed at the focus to broaden the view, it is unlikely that a SETI stellar target and an astronomical object of interest will occupy the same small field. Thus it seems that substantial improvement in the sensitivity of future optical targeted searches will require a dedicated, large optical SETI telescope, but there are no plans for such an instrument at this time. However, a random sky survey for bright pulses at optical wavelengths might be conducted at enhanced sensitivity for only small incremental cost. Several arrays of 10 meter-class, segmented optical "light buckets" (having limited imaging quality) are being planned or constructed by the scientific community interested in studying the highest energy Γ-rays (see e.g. http://veritas.sao.arizona.edu/). Each telescope has a dense cluster of photodiodes located at its focus. These photodiodes are intended to detect the light radiated from air showers generated by the interactions of energetic photons with the atmosphere. Having many widely spaced telescopes then allows calculation of an accurate direction of arrival for the triggering Γ-ray. Because many photodiodes on each antenna are expected to register during a spatially extended air shower, *single* photodiode events are discarded as noise. It may be possible for SETI teams to develop fast electronics that could "piggyback" and sense when single photodiode events occur simultaneously on multiple telescopes in the array from the same direction on the sky.

At microwave frequencies, there will be several opportunities for exploring more of the cosmic haystack in coming years: observing more of the sky all of the time in order to search for transient signals, extending the sensitivity of targeted searches by using bigger antennas, and surveying much of the galactic plane over a wide range of frequencies.

The SETI Institute recently sponsored a series of workshops to examine the most productive opportunities for searching in the decades to come. Their deliberations (Ekers *et al*., 2002) led to implementation of the first searches for nanosecond optical pulses (as previously discussed), the basic design of what has become the Allen Telescope Array, and a concept for an Omnidirectional Sky Survey (OSS) instrument to stare at all (or most) of the sky continuously at microwave frequencies, looking for short-duration signals that appear only infrequently. The OSS would make use of a huge number of very small antennas, little more than dipoles or small spiral coils (~ 30 cm in diameter). Combining the output of so many small antennas together in a manner that continuously images all the visible sky and searches for ETI signals from every different direction in the sky requires extraordinary amounts of computer capacity. Today we can afford to build the antenna elements, and are learning how to build very inexpensive digital receivers for each antenna that will provide wide frequency coverage, but we cannot yet afford to combine large numbers of these antennas together and process the received bandwidth for SETI signals. However, http://veritas.sao.arizona.edu/ if present trends in increasing computer power continue, the estimated 4 x 10^{16} ops (computer operations per second) needed to combine an array of 4096 elements (while searching over 4 GHz of bandwidth) may be affordable by 2020. And two decades later the 2 x10^{21} ops of computer power needed for an array of 10^6 elements (and a bandwidth of 1000 GHz) might be affordable. In the meantime, Project Argus, a small array of 64 elements and 1.6 GHz of bandwidth (Ellingson, 2002), is serving as a prototype to allow researchers to develop algorithms to deal with the inevitable plethora of RFI with which such an ominidirectional array must contend.

Over the past decade, an international team of radio astronomers has been developing plans to build a telescope 100 times as large as the ATA. Called the Square Kilometer Array (SKA) because of its 10^6 m^2 of collecting area, this array is intended for studying a wide variety of astronomical problems. There are a number of different concepts for building this enormous telescope at an affordable cost perhaps a decade from now, and most of them would allow the same sort of simultaneous SETI observations already described for the ATA. A factor of 100 in collecting area translates into a factor of 100 in sensitivity, so we could detect the same strength transmitter 10 times farther away. Assuming that the Square Kilometer Array gets built in an appropriate fashion, we should be able to survey a large fraction of the Milky Way Galaxy over much of the microwave spectrum within two or three decades.

It may also be possible to conduct a survey of much of the plane of the Milky Way in the nearer future. Extremely large spectrometers and SETI signal processors utilizing ~ 10^{10} channels should shortly be enabled by expected improvement in affordable computing power. If one or more of the 34 m-diameter antennas that are part of NASA's Deep Space Network of satellite tracking antennas could be provided with very wideband receivers and feeds (similar to those used on the ATA), then a survey of the galactic plane covering 2-23 GHz could be accomplished within a decade.[16]

If all of these planned searches are completed and yet no signal is found, such a null result will begin to become significant for microwave and optical technologies. There is always the chance that in coming years we will discover new technologies for other parts of the electromagnetic spectrum that may be useful in searches for signals or artifacts of astro-engineering. SETI researchers reserve the right to get smarter over time, and will aggressively pursue searches with any new technologies to the extent that funding and time permit.

26.9 What If We Succeed?

Because there is great public interest in the question of whether there are other sentient creatures in the Universe, it is important that any potential claim of discovery be accompanied by very credible evidence for the detection. A signal seen just once and/or at a level not much above the background noise is not convincing. Although there are reasonable classes of transmitters that might produce such transient signals (e.g., a high gain antenna beam steered rapidly around the sky to target a large number of stars sequentially), most SETI

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[16] Although this galactic plane survey has not yet been funded, an overview of the instrumentation required to do the job can be found at **seti**athome.ssl.berkeley.edu/~aparsons/ papers/2004-01-08_URSI_Presentation.pdf

researchers today demand that candidate signals repeat and stand up to independent confirmation attempts by others at a distant observatory. The criterion of long-term repeatability is a hallmark of SETI and immediately separates it from the claims of UFO's, etc. Independent confirmation is also the best way to guard against hoaxes. In a proactive plan for success, members of the SETI Permanent Study Group of the International Academy of Astronautics have developed the "Rio Scale," somewhat analogous to the Torino Scale that scientists use to classify the potential likelihood and degree of disaster from newly detected, near-Earth asteroids. The Rio Scale rates both the significance and the credibility of announced candidate signals and evolves over time as more cases are experienced.[17] Since there have been few opportunities to exercise or publicize this metric, it has so far been calibrated roughly only against science fiction stories that deal with the discovery of extraterrestrial intelligence.

The SETI Post-Detection Protocol (Sec. 24.4) outlines the actions that would be reasonable following the detection of a signal or discovery of other evidence of the existence of another civilization: carefully verify the suspected discovery, attempt to get an independent confirmation, tell the world, and do not reply until there is global consensus. Although SETI researchers who have adopted this protocol can be expected to abide by it, the rest of the world might not. Following a public announcement, it is possible that many people around the world with access to transmitters might decide to transmit their own messages in reply. The

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[17] The Rio Scale calculator is available at

http://www.setileague.org/iaaseti/rioscale.htm.

resulting cacophony might be the most accurate, but least informative, representation of the multi-cultural 21st century planet Earth.

How would a successful SETI program change our future? If polls taken in the US are any guide, the immediate impact might be slight. A Gallup poll conducted in 1999 found that 61% of those questioned thought there is life on other planets in the Universe and 41% thought it might be something like humans.[18] Interestingly, the poll respondents were more cynical about the possible presence of life on Mars. If so many people already believe in the existence of extraterrestrial life, even intelligent life, success in SETI will simply reaffirm their already held convictions. If education of the public and representatives of the media is actively and effectively pursued by SETI researchers, and if any future discovery team acts in accordance with the Post-Detection Protocol, makes use of the Rio Scale, and makes all discovery data fully accessible, then a detection announcement could cause little disruption to the activities of worldwide society. As Ashkenazi (1992) has shown, the world's major religions should have little difficulty incorporating this new information into their existing dogma. The social scientists, historians, religious leaders, and diplomats who joined SETI researchers to consider the various cultural aspects of a successful detection (Billingham *et.al,* 1999) concluded that short-term reaction to an announcement would unfold in accordance to the personal, religious, and political belief systems in place at the time.

In the long run, however, a successful SETI detection will change humanity's view of itself and its place in the cosmos, just as the work of Copernicus and Darwin did in the past. Philip Morrison, co-author of the initial

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[18] Gallup Poll results quoted in February 27, 2001 news release "Life on Mars?" from the Gallop Poll News Service.

journal article on SETI, has called SETI the "archeology of the future." By this he means that a signal will tell us about the transmitter's past or "archeology" because of the time that it will have taken the transmission to reach us. However, because of the large-*L* argument, it will also tell us that humans on Earth may in fact have a long-term future to look forward to. Some scientists have postulated that a signal from ETI will be a sort of *Encyclopedia Galactica* telling us many things about the Universe and offering solutions to the myriad problems faced by our own emerging technology. This is probably an overly anthropocentric speculation. However, even if the signal is only a cosmic dial-tone that proves nothing more than the fact of their existence, Morrison's conclusion about the future should provide additional incentive for humanity to solve its own problems. Knowing that another society has found a solution to long-term survival, when many current indicators would suggest otherwise, might be critical to our own future on Earth.

26.10 What If We Don't Succeed?

In this chapter, I have argued that within decades we can expect to have made microwave searches of significant portions of our Milky Way Galaxy, with sensitivities sufficient to detect analogs of 21st century Earth. In that same time, optical targeted searches and sky surveys can probably be extended to search the million or so solar-type stars within 1000 lt-yr of Earth for signals as strong as the lasers on our drawing boards today. An omnidirectional microwave search for transients will have been conducted, and probably many other surveys, as well.

What if all this turns up nothing? At every epoch in the future, humans will need to reassess whether the resources necessary to keep searching in the same ways or in new ways are justified by the importance of the question. So far, humans have not yet lost interest in answering the question "Are we alone?". For our current generation, that question has been deemed sufficiently important to justify the continuing search. Humanity today seems to concur with the conclusion of the original SETI paper: "The probability of detection is difficult to estimate, but if we never search the chance for success is zero". Future generations will have to make their own judgments.

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Table 26.1. Detectability Of Leakage Radiation From 21st Century Earth With Project Phoenix Sensitivity

P_E of transmitters	P_T x G_T	Range r (lt-yr)	# of stars within range of Project Phoenix
Cell phones: 1 W	1W x 1	$3x10^{-4}$	0
FM radio: 10-100 kW	2-20 kW x 5	0.03 – 0.1	0
TV: 300 kW	60 kW x 5	0.2	0
Airport Radars: ~ 10^8 W	35 kW x 2200	3.3	~1 (Proxima Centauri is at 4.3 lt-yr)
Ionospheric Radars: $2x10^{11}$ W	150 kW x $1x10^6$	150	~$3.5x10^5$
Arecibo Radar: $2x10^{13}$ W	1 MW x 2 x 10^7	1500	~$5x10^8$

Table 26.2. Recent & Current SETI projects (2005)

A complete archive of all past SETI searches is maintained at
http://www.seti.org/seti/seti_background/archive/Welcome.html

[JILL: PLEASE GO THROUGH TABLE AND MAKE SURE ALL IS UP-TO-DATE. ALSO, PLEASE THINK ABOUT CRITERIA FOR INCLUSION HERE – IS MY CHANGE IN TABLE TITLE FROM ‘ACTIVE’ TO ‘RECENT & CURRENT’ OK? YES HOW ABOUT INCLUDING (IN ADDITION TO THE URL’S] LITERATURE CITATIONS FOR EACH SEARCH? IF NOT HERE, THE MOST IMPORTANT LIT. CITATIONS FOR SEVERAL SURVEYS SHOULD BE WORKED INTO THE TEXT. LITERATURE CITATIONS CAN BE FOUND IN THE URL OF FOOTNOTE 1 FOR SEARCH ARCHIVE – WHEN THEY EXIST. I CHOSE TO JUST PUT URL’S HERE BECAUSE THESE PROGRAMS KEEP THEM ACTIVE.
FINALLY, IS NOT THE SETI LEAGUE ENTRY BELOW MISLEADING? IT LOOKS LIKE 121 DISHES HAVE BEEN OBSERVING FOR 8 YEARS, AND THE MENTION OF 5000 FUTURE PARTICIPANTS, NO. OF MEMBERS, ETC. SEEMS OUT OF PLACE. SOMEHOW IT SHOULD BE MENTIONED THAT THIS IS A VERY INTERMITTENT AND NONUNIFORM TYPE OF OBSERVING – VERY UNLIKE ALL OF THE OTHER SEARCHES. (IN MY OPINION WE REALLY HAVE NO IDEA WHAT THEY’VE ACCOMPLISHED BEYOND GOOD PR FOR SETI.)- I’VE TRIED TO DO THIS WITHOUT BEING TOO INSULTING. I’VE INCLUDED THEM BECAUSE MAYBE ONE OF THE STUDENTS READING THE CHAPTER IS A HAM / AMATEUR ENTHUSIAST AND MIGHT LIKE TO JOIN UP]

START DATE:	**1990**
OBSERVERS:	**Lemarchand META II**
SITE:	Institute for Argentine Radioastronomy
INSTR. SIZE (m):	30 (one of two)
SEARCH FÓREQ. (MHz):	1420.4, 1667, 3300
FREQ. RES. (Hz):	0.05 and 33
OBJECTS:	Sky survey of southern skies, 90 target stars, and OH masers
FLUX LIMITS (W/m^2):	$1x10^{-23}$ to $7x10^{-25}$
TOTAL HOURS:	Ongoing
REFERENCE:	<http://www.iar.unlp.edu.ar/ES/seti-boston.htm >
COMMENTS:	Search for signals that have been Doppler compensated to rest frame of solar system barycenter, Galactic Center or Cosmic Background Radiation. A duplicate of Harvard’s former META system

built by Argentinian engineers and financed by the Planetary Society.
Simultaneous observations with META over the declination range -10° to -30°. Major upgrades in 1996 to permit long integration times, and switching between antennas. Search through OH masers looking for amplified signals with META II and digital correlator.

START DATE: **1996**
OBSERVERS: **SETI League ARGUS**
SITE: Multiple sites world-wide (currently ~130 backyard projects)
INSTR. SIZE (m): ~ 3-10 (satellite TV dishes)
SEARCH FREQ. (MHz): 1420 - 1720
FREQ. RES. (Hz): 1
OBJECTS: Objective is to cover all the sky
FLUX LIMITS (W/m^2): ~ 1 x 10^{-21} (varies)
TOTAL HOURS: Ongoing
REFERENCE: <http://www.setileague.org>
COMMENTS: Attempt to organize radio amateurs to provide continuous sky coverage for strong, transient signals using systems that can be bought and built by individuals. SETI League currently has 1456 members running 130 sites in 23 countries. Their web site is very active, but they are financially challenged, and have not engaged in systematic observations and archiving.

START DATE: **1996**
OBSERVERS: **Werthimer et al. SERENDIP IV**
SITE: Arecibo
INSTR. SIZE (m): 305
SEARCH FREQ. (MHz): 1420 ± 50
FREQ. RES. (Hz): 0.6
OBJECTS: Random survey of 30% of sky visible from Arecibo
FLUX LIMITS (W/m^2): 5 x10^{-24}
TOTAL HOURS: Ongoing
REFERENCE: <http://seti.ssl.berkeley.edu/serendip/serendip.html>
COMMENTS: Commensal search occurring at twice sidereal rate in backwards direction while radio astronomers track targets using Gregorian system. Covers sky every 3 years; re-scans identify signals recurring at same frequency and location. The highest quality candidate signals get re-observed occasionally with directed observations.

START DATE: **1998-2004**
OBSERVERS: **SETI Institute Project Phoenix**
SITE: Arecibo Observatory and Lovell Telescope at Jodrell Bank
INSTR. SIZE (m): 305 and 76
SEARCH FREQ. (MHz): 1200 to 3000 dual pol
FREQ. RES. (Hz): 0.67
OBJECTS: 850 nearby stars
FLUX LIMITS (W/m^2): 1x10^{-26}

TOTAL HOURS:	2300 hours to date
REFERENCE:	<http://www.seti.org>
COMMENTS:	Continuation of NASA targeted search survey of nearby stars, using real-time signal processing systems and a pair of widely separated observatories to help discriminate against RFI

START DATE:	**1998-2003**
OBSERVERS:	**SETI Australia Southern SERENDIP**
SITE:	Parkes
INSTR. SIZE (m):	64
SEARCH FREQ. (MHz):	1420.405 ± 8.82
FREQ. RES. (Hz):	0.07 to 1200
OBJECTS:	Random southern sky survey
FLUX LIMITS (W/m^2):	4×10^{-24}
TOTAL HOURS:	~20% duty cycle
REFERENCE:	<http://seti.uws.edu.au>
COMMENTS:	Commensal search that used 2 of the 13 beams of Parkes focal plane array to discriminate against RFI.

START DATE:	**1998**
OBSERVERS:	**Werthimer et al. SEVENDIP**
SITE:	Leuschner Observatory
INSTR. SIZE (m):	0.8
SEARCH WAVELENGTH:	300-650 nm
FREQ. RES. (Hz):	none
OBJECTS:	7225 solar-type stars, 104 galaxies to date
FLUX LIMITS (W/m^2):	1.5×10^{-9} peak during 1 ns pulse, or 1.5×10^{-20} average per 100 second observation
TOTAL HOURS:	200 (ongoing)
REFERENCE:	<http://seti.ssl.berkeley.edu/opticalseti/>
COMMENTS:	First optical search to use two high time resolution photomultiplier tubes in coincidence to look for nanosecond pulses; since upgraded with three PMTs to improve false alarm rate.

START DATE:	**1998**
OBSERVERS:	**Horowitz et. al. Harvard Optical SETI**
SITE:	Oak Ridge Observatory
INSTR. SIZE (m):	1.5
SEARCH WAVELENGTH:	350-700 nm
FREQ. RES. (Hz):	None
OBJECTS:	13000 solar-type stars of which 4000 observed to date
FLUX LIMITS (W/m^2):	4×10^{-9} peak in < 5 ns pulse, or 4×10^{-20} average per 500 second observation
TOTAL HOURS:	Ongoing
REFERENCE:	< http://seti.harvard.edu/oseti/>

COMMENTS : Search for nanosecond laser pulses, with hybrid avalanche photodiodes in coincidence. Piggybacks on nightly searches for extrasolar planets. Now operated in coincidence with cloned detector on 0.9 m telescope at Princeton, using GPS and internet for timing.

START DATE: **1999**
OBSERVERS: **Werthimer and Anderson SETI@Home**
SITE: Arecibo
INSTR. SIZE (m): 305
SEARCH FREQ. (MHz): 1420.405 ± 1.25 MHz
FREQ. RES. (Hz): 0.6 Hz
OBJECTS: Data taken from SERENDIP IV – sky visible from Arecibo
FLUX LIMITS (W/m^2): $5x10^{-25}$
TOTAL HOURS: Ongoing
REFERENCE: <http://setiathome.ssl.berkeley.edu>
COMMENTS : Hugely successful experiment in distributed computing. Permits more sophisticated processing of a fraction of SERENDIP IV data by harnessing idle CPU cycles of 4 million personal and corporate computers.

START DATE: **2001**
OBSERVERS: **Groth et al. Princeton Optical SETI**
SITE: FitzRandolph Observatory
INSTR. SIZE (m): 0.9
SEARCH WAVELENGTH: 350-700 nm
FREQ. RES. (Hz): None
OBJECTS: solar-type stars being observed by Harvard Optical SETI project
FLUX LIMITS (W/m^2): $4x10^{-9}$ peak in < 5 ns pulse, or $4x10^{-20}$ average per 500 second observation
TOTAL HOURS: Ongoing
REFERENCE: < http://observatory.princeton.edu/oseti/>
COMMENTS : Search for nanosecond laser pulses, with hybrid avalanche photodiodes in coincidence. Operates in coincidence with Harvard Optical SETI project, using GPS and internet for timing.

Figure Captions

Fig. 26.1. This is the illustration of one way in which large amounts of data (encoded onto the disks) can be moved slowly between two destinations, and yet achieve a data transfer rate that is faster than some so-called 'broadband' wired protocols available today. The question is whether data inscribed onto a dense physical memory medium and propelled between the stars at modest speeds might be the modality of choice for deliberate interstellar communication. (Photo courtesy of Herbert Bishko, with permission from the *Annals of Improbable Research*)

Fig. 26.2. A transmitter of power P_E emits isotropically. A receiving antenna at a distance r will collect a fraction of the transmitted power. That fraction is simply the ratio of the effective area of the receiving antenna A_R to the surface of a sphere of radius r or $4\pi r^2$.

Fig. 26.3. The world's largest reflector radio telescope, at Arecibo, Puerto Rico, is 305 m is diameter and equipped with a transmitter for radar studies of solar system objects and the Earth's ionosphere. Most of its time, however, is used for (passive) radio astronomy studies. From 1998 to 2004 ~5% of its time was used for Project Phoenix run by the SETI Institute. Image courtesy of Arecibo Observatory.

Fig. 26.4. Spectrum of the natural sky background radiation from astrophysical sources. *Plane* and *pole* refer to values of radio background (primarily synchrotron emission)., when looking in the plane or towards the pole of

our Milky Way Galaxy, CMB is the 2.7 K cosmic microwave background, infrared (IR) emission comes from warm dust and gas between the stars in our galaxy, the optical (visible) emission is a combination of light from distant galaxies and stars in the Milky Way, the UV is red-shifted Lyan-α from ionized gas within distant galaxies, The X-ray and Γ-ray backgrounds arise from energetic processes in extragalactic and galactic sources as well as the intergalactic gas between galaxies. The radio portion of the spectrum extends from ~ 10^7 to ~ 10^{11} Hz.

Fig. 26.5. Atmospheric windows for electromagnetic radiation. The arrows indicate the altitude above sea level to which radiation of a given wavelength (or frequency) can penetrate the Earth's atmosphere before it is absorbed by molecules such as CO_2, O_2, O_3, and H_2O . The cartoon also illustrates the regions in which ground level, high altitude, or space-based observing platforms are appropriate. The cartoon has been adopted from an original image by DRAO.

Fig. 26.6. Observed background in units of noise temperature for radio observations from the surface of Earth; in general the most sensitive observations are possible where this background is smallest. The range 0.1 to 1000 GHz in frequency corresponds to wavelengths of 3 m to 300 µm. Atmospheric molecules responsible for the various absorption bands are indicated. The "microwave window" is the low-noise region between ~ 1 and ~ 30 GHz defined by nonthermal galactic background emission at low frequencies and by atmospheric absorption at high frequencies. "Quantum limit" refers to a fundamental minimum in receiver noise proportional to photon energy.

Fig 26.7. Shielded Zone of the Moon as defined by ITU Radio Regulations Article S22.22 – S22.2. SETI observations from the far side of the Moon would be free of the deleterious effects of radio-frequency interference (RFI) from Earth. (Drawing courtesy of Guillermo Lemarchand.)

Fig 26.8. SETI strategies in time and direction. The star symbols represent transmitting civilizations. Two transmission strategies are illustrated: 1) continuous transmission in the direction towards and opposite (indicated by short arrows) an unusual astrophysical source that is likely to be well-studied by other technological civilizations such as ours; and 2) a time synchronized transmission and reception based on the rare occurrence of a supernova (SN) or other event. In the latter case, the transmitter (two are shown with label A) begins broadcasting towards likely candidate receivers (e.g., the Sun/Earth) at the moment that it detects the existence of the supernova. Receivers on Earth begin observing particular target stars when they first fall on the boundary of an expanding "SETI-ellipsoid" whose foci are the Earth and the supernova. (Drawing courtesy of Maggie Turnbull.)

Figure 26.9. a) The Harvard Optical SETI observatory building with a removable panel in the southern wall to permit viewing declinations as low as -20°. b) The primary and secondary mirrors after mounting in their frame, and some of the students involved in the construction project. (Photos courtesy Paul Horowitz.)

Figure 26.10. a) Aerial view of the first 30 6.1 m-diameter Allen Telescope Array (ATA) antennas at the Hat Creek Observatory, including the construction tent (photo courtesy of Seth Shostak). b) Artist's rendering of the future 350-antenna

ATA in the Hat Creek Valley of northern California; planned completion is in 2007 [DATE STILL OK? YES] (artistic credit: Isaac Geary).

Fig. 26.1

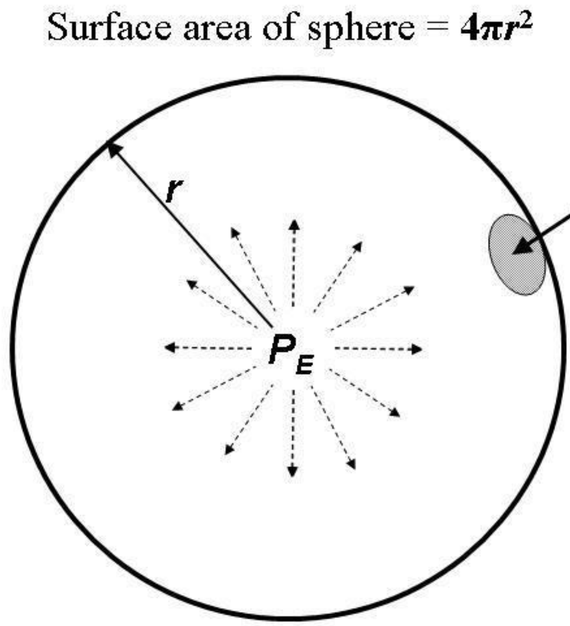

Fig. 26.2

Fig. 26.3

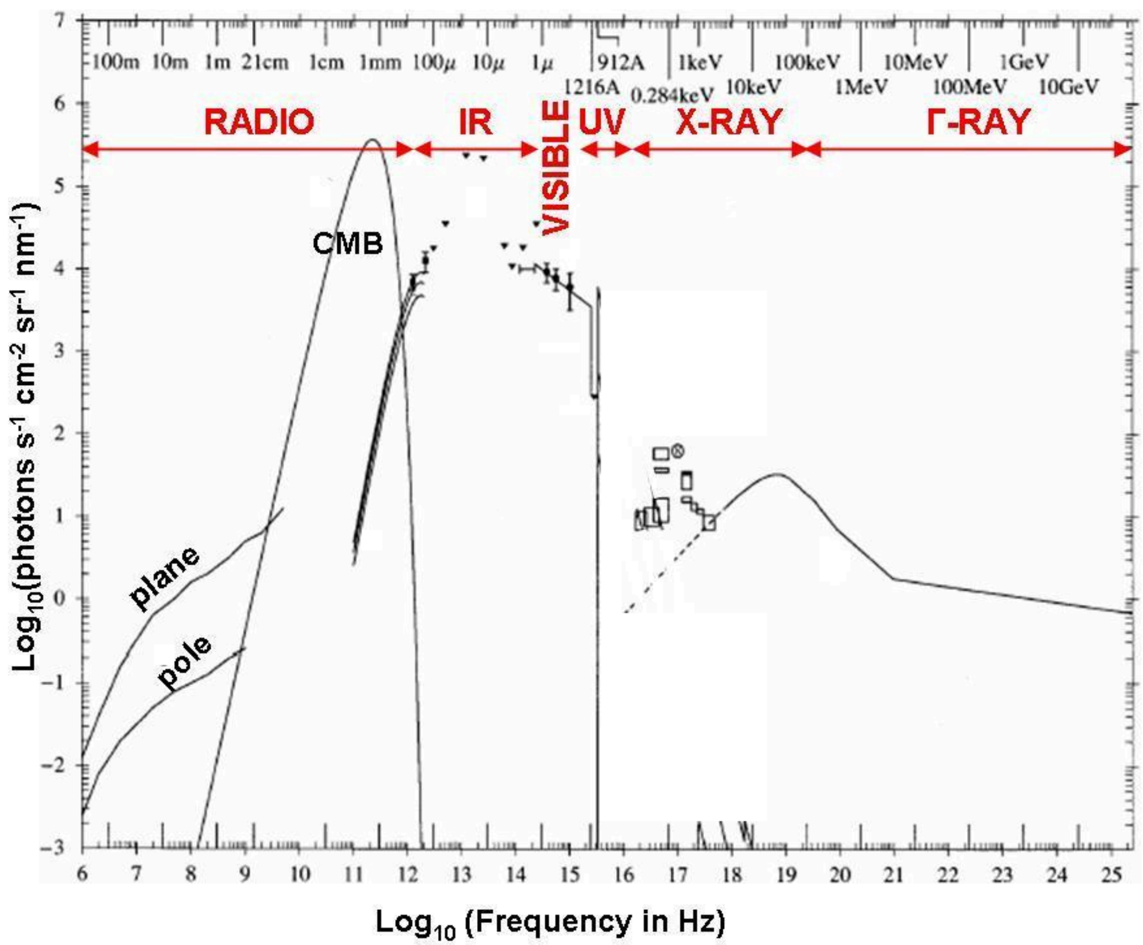
100m 10m 1m 21cm 1cm 1mm 100μ 10μ 1μ 912A 1keV 100keV 10MeV 1GeV
1216A 0.284keV 10keV 1MeV 100MeV 10GeV
RADIO
IR
VISIBLE
UV
X-RAY
Γ-RAY
CMB
plane
pole
Log10(photons s-1 cm-2 sr-1 nm-1)
Log10 (Frequency in Hz)

Fig. 26.4

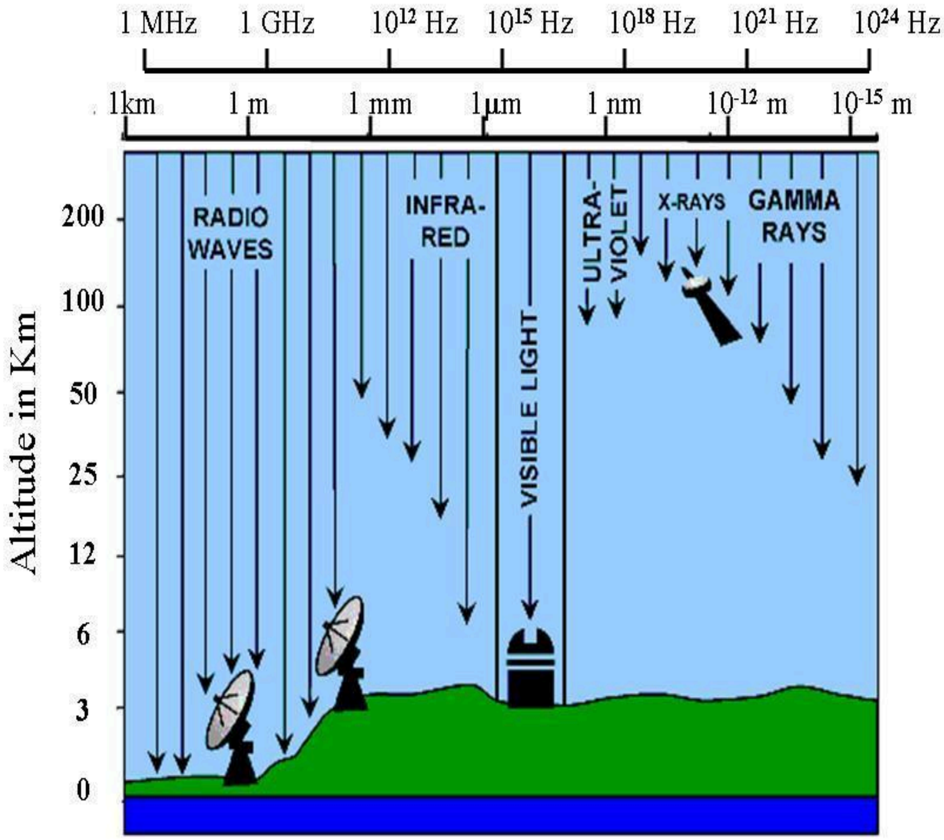
1 MHz
1 GHz
10^12 Hz
10^15 Hz
10^18 Hz
10^21 Hz
10^24 Hz
1km
1 m
1 mm
1μm
1 nm
10^-12 m
10^-15 m
Altitude in Km
200
100
50
25
12
6
3
0
RADIO WAVES
INFRA-RED
VISIBLE LIGHT
ULTRA-VIOLET
X-RAYS
GAMMA RAYS

Fig. 26.5

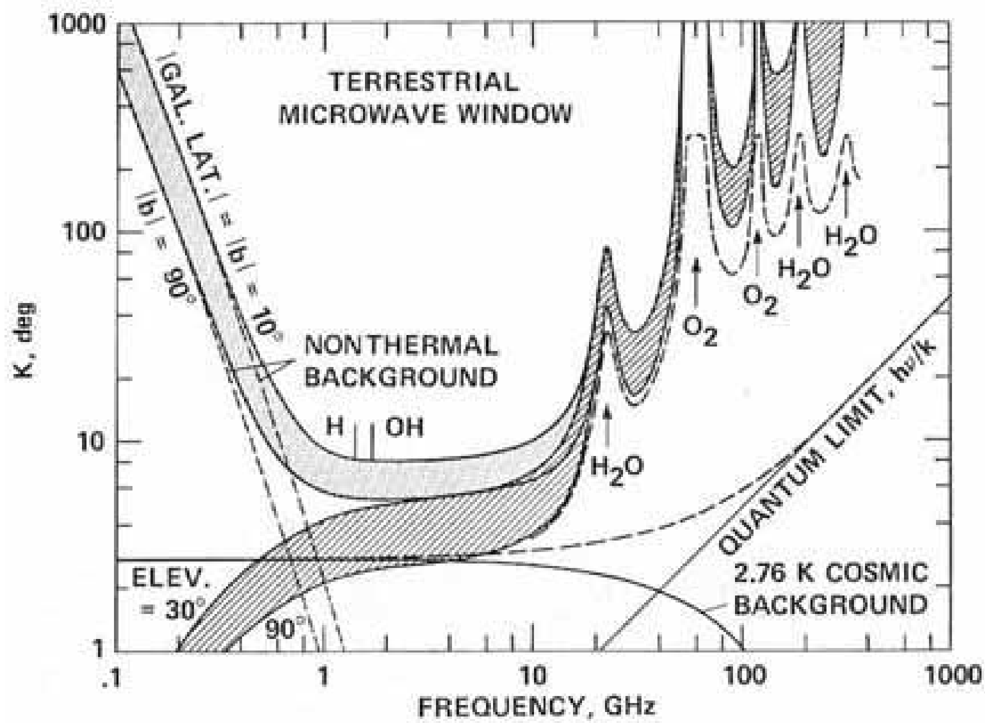
TERRESTRIAL
MICROWAVE WINDOW
|GAL. LAT.| = |b| = 10°
|b| = 90°
NONTHERMAL
BACKGROUND
H
OH
H2O
O2
O2
H2O
H2O
QUANTUM LIMIT, hν/k
2.76 K COSMIC
BACKGROUND
ELEV.
= 30°
90°
K, deg
FREQUENCY, GHz
1000
100
10
1
.1
1
10
100
1000

Fig. 26.6

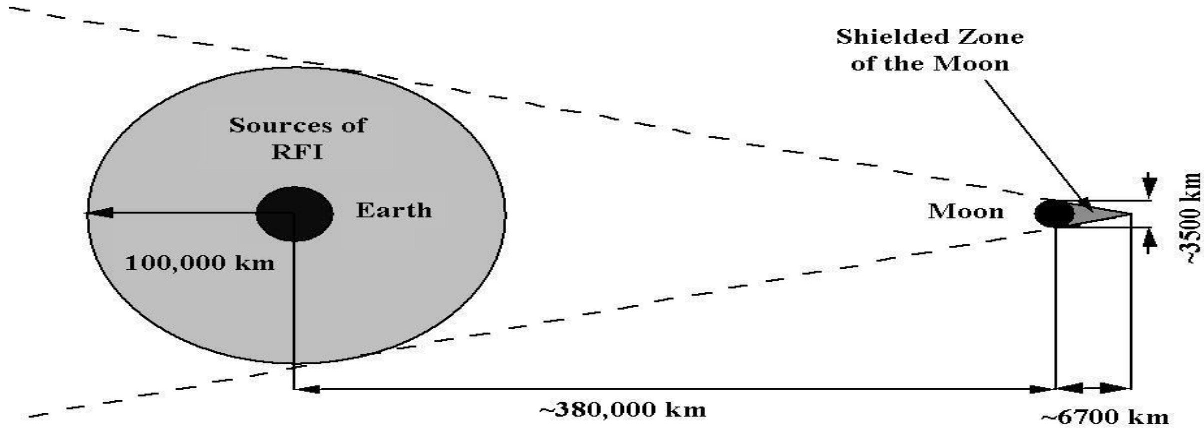
Shielded Zone of the Moon
Sources of RFI
Earth
Moon
100,000 km
~3500 km
~380,000 km
~6700 km

Fig 26.7

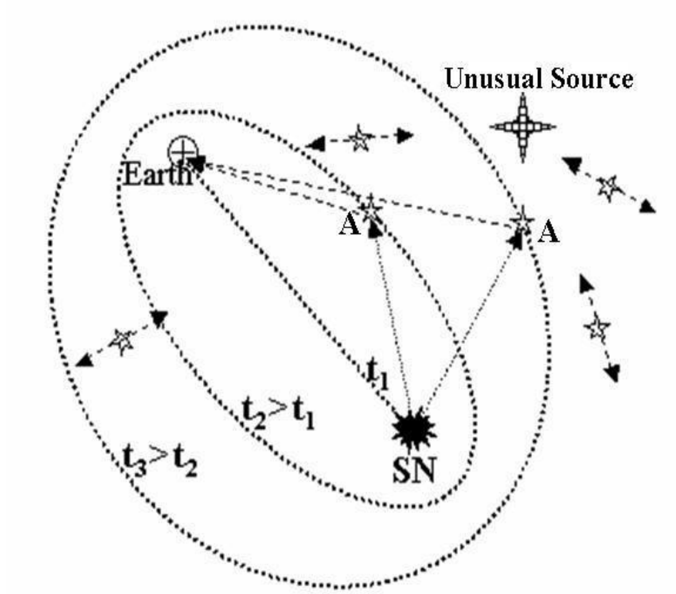

Fig. 26.8

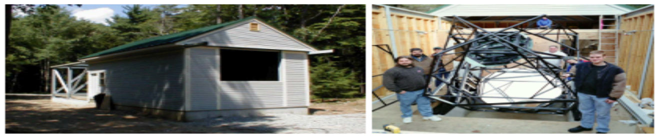

Fig. 26.9 a,b

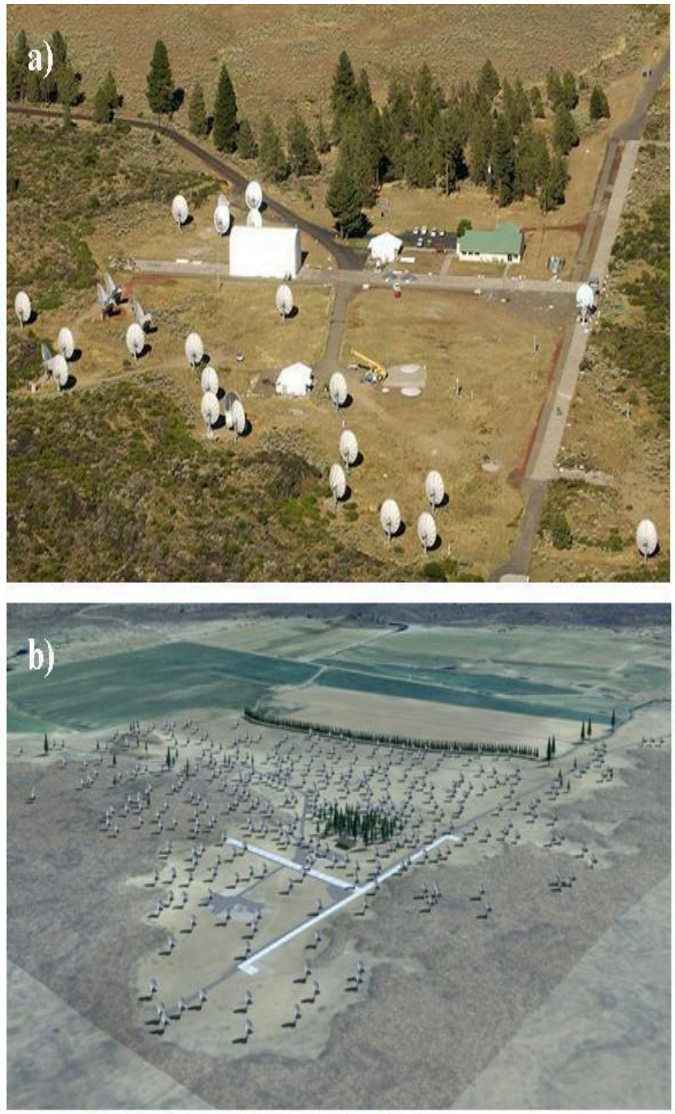

Fig. 26.10 a,b

Additional Reading

Cosmic Company: The Search for Life in the Universe

by Seth Shostak, Alex Barnett

* Hardcover: 162 pages
* Publisher: Cambridge University Press; (November 2003)
* ISBN: 0521822335

Life in the Universe Textbook

by Jeffrey Bennett, Seth Shostak, Bruce Jakosky

* Paperback: 346 pages
* Publisher: Addison-Wesley Publishing; 1st edition (July 29, 2002)
* ISBN: 0805385770

SETI 2020: A Roadmap for the Search for Extraterrestrial Intelligence

Edited by Ron Ekers, Kent Cullers, John Billingham, and Louis Scheffer

* PaperBack: 551 pages, with illustrations
* Publisher: SETI Institute
* ISBN: 0966633539

Is Anyone Out There?

by Frank Drake, Dava Sobel

* Paperback
* Publisher: Delta; Reprint edition (June 1, 1994)
* ISBN: 0385311222

The following books are suitable for younger readers, or those wanting more up-close-and-personal accounts of modern SETI observing campaigns.

Are We Alone?
Scientists Search for Life in Space

by Gloria Skurzynski

Hardcover: 96 pages ; Dimensions (in inches): 0.46 x 10.26 x 8.12

Publisher: National Geographic; (July 1, 2004)

ISBN: 079226567X

Looking for Life in the Universe

by Ellen Jackson

Winner of the 2002 National Science Teachers Association Outstanding Science Trade Book for Children Award!

* Hardcover: 64 pages
* Publisher: Houghton Mifflin Co (Juv); (September 30, 2002)
* ISBN: 0618128948

All these book are available at Amazon.com

Useful URL's

http://www.seti.org

http://www.space.com/searchforlife/

URL's for all active SETI search programs are given in Table 26.2