Science Fact

Smart SETI

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2010 marked the 50th anniversary of the first Search for ExtraTerrestrial Intelligence, SETI. With no detections in the near-zone search—we've scanned some 500 stars within a few hundred light years—it's time to rethink the problem.

While the total SETI listening time is only about a month spread over those 50 years, the silence is striking. Apparently we don't have neighbors who want to talk. Or have we missed something in our assumptions?

We decided to study the underlying conventional wisdom behind the search.

The traditional, targeted SETI strategy has much to recommend it. The background noise minimum in the "water hole" region near 1 GHz seemed plausible, as did the assumption that the altruistic radiator would beam forth steady, targeted signals of very narrow bandwidth, to make detection easy.

But we looked at SETI from the viewpoint of those who would pay the bill—and found very different conclusions than traditional SETI. Traditional SETI research takes the point of view of *receivers,* not *transmitters.* This ignores what signals should look like in general, and especially the high emitting costs, which a receiver does not pay. We assumed, like conventional SETI, that microwaves are simpler for planetary societies, since they can easily outshine their star in microwaves.

Broadcasting is expensive. Some appear to believe that beacons—that is, signals detectable beyond 1,000 light years (ly)—can be cheap. Our analysis says otherwise. With the very lowest price technology we have today, beacons that can stand out above the background noise cost $200,000 *per light year.* A more likely cost is about ten times that. So a 1,000 ly beacon will cost $200 million to $2 billion. Even hailing Alpha Centauri would cost close to a million dollars. None of the small groups who have sent brief signals to the stars have paid this price, and their messages will not be heard beyond a few light years.

Why, given such costs, should anyone bother?

All search strategies must assume something about the beacon builder. SETI has assumed a high-minded search for other life forms. But other motives are possible.

Motivations

What could drive a beacon builder? Human history suggests two major categories of long-term messages that finite, mortal beings send across vast time scales:

• *Kilroy Was Here:* These can be signatures verging on graffiti. Names chiseled into walls have survived from ancient times. More recently, we sent compact disks on interplanetary probes, often bearing people's names and short messages that can endure for millennia.

• *High Church:* These are designed for durability, to convey the culture's highest achievements. The essential message is *This was the best we did; remember it.*

A society that is stable over thousands of years may invest resources in either of these paths. The human prospect has advanced enormously in only a few centuries; the lifespan in the advanced societies has risen by 50% in each of the last two centuries. Living longer, we contemplate grander legacies. Time capsules and ever-proliferating monuments testify to our urge to leave behind tributes or works in concrete ways (sometimes literally). Marvin Minsky argues that the urge to propagate culture quite probably will be a universal aspect of intelligent, technological, mortal species.

Thinking broadly, high-power transmitters might be built for a wide variety of goals other than two-way communication driven by curiosity. For example:

• *The Funeral Pyre:* A civilization near the end of its life announces its existence.

• *Ozymandias:* Here the motivation is sheer pride. The beacon announces the existence of a high civilization, even though it may be extinct, and the beacon tended by robots. This recalls the classic Percy Bysshe Shelly lines,

And on the pedestal these words appear:
'My name is Ozymandias, King of Kings;
Look on my works, Ye Mighty, and despair!'
Nothing beside remains. Round the decay
of that colossal wreck, boundless and bare,
The lone and level sands stretch far away.

• *Help!* Quite possibly societies that plan over time scales on the order of 1,000 years will foresee physical problems and wish to discover if others have surmounted them. An example is a civilization whose star is warming (as ours is), which may wish to move their planet outward with gravitational tugs. Many others are possible.

• *Leakage Radiation:* These are unintentional, much like objects left accidentally in ancient sites and uncovered long after. They do carry messages, even if inadvertent: technological fingerprints. These can be not merely radio and television broadcasts radiating isotropically, which are fairly weak, but deep space radar and beaming of energy over solar system distances. This includes "industrial" spaceship launchers, beam-driven sails, "planetary defense" radars scanning for killer asteroids, and cosmic power beaming driving interstellar starships with beams of lasers, millimeter or microwaves.

Join Us: Religion may be commonplace in the galaxy; after all, it is here. Seeking converts is common, too, and electromagnetic preaching fits a frequent meme.

Thrifty Aliens

Our grandfather used to puff on his corncob pipe and say, "Talk is cheap, but whisky costs money." In SETI, even talk (broadcasting) is not cheap.

So is cost/benefit analysis arguably universal?

Whatever the life form, evolution selects for economy of resources. Social species evolve to an equilibrium in which each species unconsciously carries out "environmental coordination," which can follow rules like those of a market, especially among plants. Economics will matter.

A SETI broadcaster will face competing claims on resources, some from direct economic competition. Beaming will be essentially altruistic, since replies will take centuries if not millennia. SETI need not tax an advanced society's resources. The power demands are for average powers less than a GW, far less than the 17 TW we use globally. Still, setting up a beaming complex will cost a lot, judged by our mature microwave technology.

We can't assume aliens will be infinitely rich, either. Do the rich of our world spend money on interstellar broadcasts? After all, receiving is cheaper and you gain more real information. So far, attempts have been few and weak.

But even altruistic beacon builders will have to contend with other competing altruistic causes, just as humans do. Only by minimizing cost/benefit will their effort succeed. This is parsimony, meaning "less is better" a concept of frugality, economy. Philosophers use this term for Occam's Razor, but here we mean the press of economic demands in any society that contemplates long term projects like SETI.

Note that parsimony directly contradicts the Altruistic Alien Argument that the beacon builders will be vastly wealthy and make everything easy for us. An omnidirectional beacon, radiating at the entire galactic plane, for example, would have to be enormously powerful and expensive, and so not be parsimonious. (We estimate one would cost nearly the total output of Earth for a year. Good luck asking the United Nations for that.)

Parsimony has implications for SETI. For transmitting time τ, receiver detectability scales as $\tau^{1/2}$. But at constant power, transmitter cost increases as τ, so short pulses ("pings") are economically smart (cheaper) for the transmitting society. A one-second pulse sent every 10 minutes to 600 targets would be 1/600 as expensive per target, yet only ~1/25 times harder to detect. Interstellar scintillation limits the pulse time to $> 10^{-6}$ sec, which is within the range of all existing high-power microwave devices. Such pings would have small information content, attracting attention to weaker, high content messages.

Even if Earth economics generally works similarly in other technological societies, why should it apply to their transmitting beacons? Even on Earth, larger goals often override economic dictates, such as military security, aesthetics, religion, etc. But two aspects of SETI undermine this intuition:

1. SETI assumes long time scales for sender and receiver. Still, while cultural passions can set goals, economics determines how they get done. Many momentary, spectacular projects such the pyramids of Egypt lasted only a century or two, then met economic limits. The Taj Mahal so taxed its province that the second, black Taj was never built. The grand cathedrals of medieval Europe suffered cost constraints and so, to avoid swamping local economies, took several centuries of large effort. Passion is temporary; costs remain.

2. We found that the optimum cost strategy leads directly to a remarkable cost insensitivity to the details of economic scaling. *The ratio of costs for antenna area and transmitter power is about one. The two costs are usually equal and their ratio does not depend on the details of the technology and varies on Earth by only a factor of two.* Both these costs may well be related principally to labor cost; if so, labor cost cancels out. *This means fashions in underlying technology will matter little, and our experience may robustly represent that of other technological societies.*

Our quantifying approach is sobering, as it forces tradeoffs on otherwise open-ended speculations. But it also advances the subject, which many beacon ideas do not do. It's simply much clearer to pick a major organizing principle—economics—than generalize from a special design, or guess at alien ideas.

What if we suppose, for example, that aliens have very low cost labor, i.e., slaves or automata? With a finite number of automata, you can use them to do a finite number of tasks. And so you pick and choose by assigning value to the tasks, balancing the equivalent value of the labor used to prosecute those tasks. So choices are still made on the basis of available labor.

The only case where labor has no value is where labor has no limit. That might be if aliens may live forever or have limitless armies of self-replicating automata. But even such labor costs something, because to support it demands resources, materials and energy, which are not free.

Smart SETI, we feel, should take account of this basic constraint.

Counting Costs

Since the early SETI era of the 1960s, microwave emission powers have increased orders of magnitude and new technologies have altered our ways of emitting very powerful signals. The highest *peak* power systems on Earth (peak powers over 10 GW) trade peak power for average power in order to get to a much stronger signal at distance at the lowest cost.

Most of these high power devices operate in bursts of short pulses and for fundamental reasons are not extremely narrow band, having bandwidths Δ f/f, with f the frequency) of 0.01–1% of the beaming frequency. Economical beacons are also likely to be pulsed. Frank Drake, who started SETI in 1960, remarked in 1990, "The most rational ET signal would be a series of pulses that would be evidence of in-

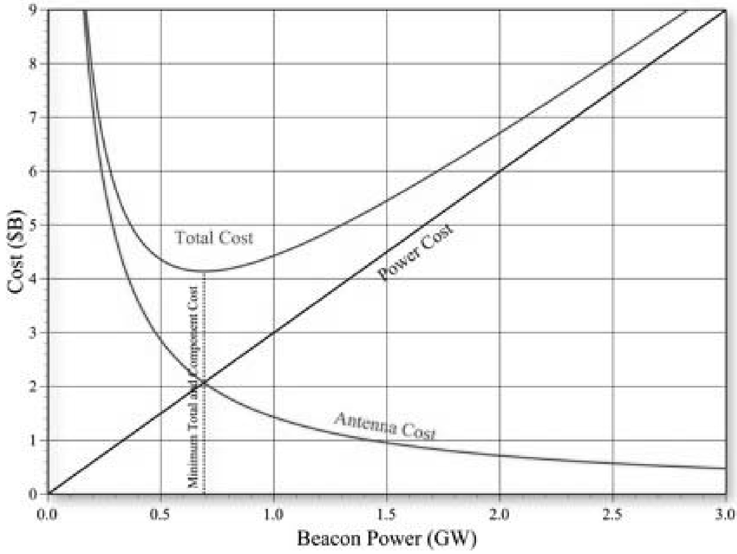

Fig. 1. Antenna, microwave power and total costs of Beacon with effective isotropic radiated power of 1017 watts. Cost is in billions of dollars, and power in gigawatts (109 watts, the power of a large nuclear reactor). It radiates at frequency 1 GHz and has costs typical of ours today. Minimum total occurs when the antenna cost and power cost are equal.

telligent design." This would be similar to the strategy of the lighthouse, pulsing and swinging the beam to get noticed.

To minimize cost, we wrote down the cost scaling of two major terms: the electrical power needed and antenna building cost, which depends on the antenna area. Quite generally, we found that minimum capital cost occurs when the cost is equally divided between antenna gain and radiated power. High power Earth systems show this general feature, no matter the application.

How could we send a broadcast? Arrays of antennas are the only means of producing the large radiating areas (~km^2) that interstellar beacons require. They also have high reliability and degrade gracefully, as loss of a few antennas does not mean failure. Arrays are widely used in radio astronomy receiving and are being planned for the new Deep Space Network refit.

A typical case SETI broadcaster, by our calculations, looks like this:

This basic approach gives us many implications:

To attract attention, beam in pulses, not steadily. It's cheaper. Steady signals are vastly more expensive.

High powers demand broadband emission. At very high voltage and currents, the electrical breakdown threshold is much higher for short pulses, so a machine of a given size can radiate much more powerfully.

Conventional SETI looks for narrowband microwaves near 1 GHz, steadily beamed. We find that on Earth, cost declines with frequency. The galactic background noise spectrum is flat between 1 GHz and 10 GHz. This is also the lowest-attenuation region of Earth's atmosphere. The most favored spectral region is near 10 GHz, since this minimizes the cost of the beacon while imposing no noise cost on the receiver.

This is quite different from some SETI thought, which privileges the "water hole" region between 1 and 2 GHz. Indeed, the metaphorical resonance between the spectral lines of H I and OH with "meeting at the water hole" may be a classic case of anthropic reasoning. The secondary reasons given as early as the 1970s Project Cyclops—that the low end of this band demands less stringent frequency stability—vanishes if the beacon is broadband, as we argue is essential for high powers.

Since that era, detection of over 100 spectral lines in the interstellar medium, many of them organic, undermines the classic argument. Further, synchrotron radiation in the 1 GHz region increases going inward toward the galactic center, where the highest density of older stars peaks. A further benefit of higher frequencies for both beacon and receiver: interstellar scintillation fades quickly with frequency, and can be ignored around and above 10 GHz. As beacon builders we will prefer that the listener not be confused by scintillation.

Our conclusion is that cost, noise, and scintillation argue for radiating above the "water hole," especially if space-based. In the atmosphere, the optimum will be below 10 GHz where atmospheric attenuation minimizes.

Cost-efficient beacons will be pulsed, narrowly directed, and broadband in the 1–10 GHz region, with a cost preference for the higher frequencies.

This means that SETI may be looking for the wrong kinds of signals.

Traditional SETI burdens itself with adjusting their receivers for narrow-band signals. This means they must account for Earth's motion, and so introduce Doppler shift corrections. But at distances >1,000 light years, Doppler adjustment to offset relative motions, as nearby SETI searches do, becomes pointless; with many stars in the field of view, none is especially addressed. Further, distortion of signals from >1,000 light years arises from interstellar scintillation. Such "twinkling" of the signal comes from both the dispersion of differing frequencies and delays in arrival time for pulses moving along slightly different pathways, due to refraction. Temporal broadening probably would limit bandwidth to >1 MHz, as we know from the broadening of pulsar signals.

So there's a gain from realizing that thrifty beacons will be broadband—we can ignore Doppler corrections and just look for quick, broad pulses.

Thrifty beacon systems would still be large and costly. They would have narrow "searchlight" beams and short "dwell times" when the beacon would be seen by an alien observer at target areas in the sky. They may revisit an area infrequently, perhaps only annually.

If this is right, what strategies should SETI change to?

Where to Look

A natural corridor to broadcast in lies along the galactic spiral's radius or along the spiral galactic arm we are in.

To see beacons as we envision them, SETI should search in the plane of the spiral disk. From Earth, 90% of the galaxy's stars lie within 9% of the sky's area, in the plane and hub of the galaxy. This suggests a limited sky survey.

We will need to be patient and wait for recurring events that may arrive in intermittent bursts. Special attention should be paid to areas along the Galactic Disk where SETI searches have seen coherent signals that don't recur in their limited listening time intervals. Since most stars lie close to the galactic plane, as viewed from Earth, occasional pulses at small angles from that plane should have priority.

Whatever forms might dwell farther in from us toward the center, they must know the basic symmetry of the spiral. This suggests the natural corridor for communication is along the spiral's radius from Galactic Center or toward it, a simple direction known to everyone. This avenue maximizes the number of stars within a telescope's view, especially by staring at the galactic hub.

A beacon near the center should at least broadcast outward in both directions, while societies at the far reaches may save half their cost by not emitting outward, since there is much less chance of advanced societies there. Radiating into the full disk takes far more time and power, so beams may only occasionally visit any sector of the radial plane. We listeners fairly far out (and fairly young) should look inward, within a narrow angle (~ 10 degrees) toward the constellation Sagittarius. **(Fig. 2)**

We are newcomers. Most stars of our type lie inward, and on average are about a billion years older than ours. Listening outward seems less efficient, since fewer life sites lie that way.

Life sites like ours will also know two rough time scales—a year and a day, from constraints on planetary habitable zones and biosphere mechanics. Observing every day over a year span might have a better chance of seeing intermittent bursts that revisit our part of the sky on a yearly time scale. To lower costs and have the best viewing range, sites near the equator seem optimal.

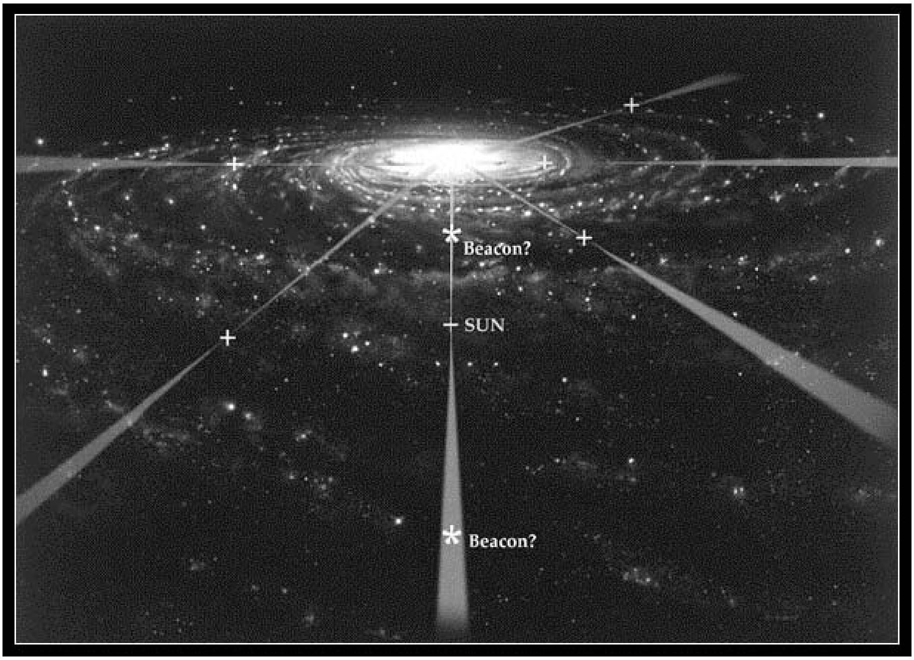

Fig. 2 We could see a cost-optimized beacon if it is part of a narrowly directed radial interstellar communication link. Art copyright Jon Lomberg 2009.

Have We Seen Beacons?

Our most important conclusion is that distant, cost-optimized beacons will appear for much less time than conventional SETI assumes. Many such signals may last for only fractions of a second.

If so, a receiver gets a short burst of pulsed microwaves, and does not see it again until a year later. Given the many possible local transient transmissions near a receiver (automobile spark plugs and other short-range machine timescales), a persistent signal for few seconds could be intuitively the best choice.

A beacon would linger a moment or two in our skies, and be back within something like a year. No search we know could have been likely to see such an event. None checked back steadily over a year. Given the shortness of pulses of such a strategy, perhaps cost-optimized beacons will be built to cover smaller, promising portions of the sky, and so revisit more often.

Earlier searches have seen pulsed intermittent signals resembling what we think beacons may be like, and may provide useful clues. We should observe the spots in the sky seen in previous work for hints of such activity but over yearlong periods. Perhaps newer search methods, directed at short transient signals, will be more likely to see the beacons we have described.

Have we already seen potential beacons? A provocative example is Sullivan's survey of 1997, which lasted about 2.5 hours, with 190 1.2-minute integrations. With many repeat observations, they saw nothing that did not seem manmade. However, they "recorded intriguing, non-repeatable, narrowband signals, apparently not of manmade origin and with some degree of concentration toward the galactic plane . . ." Similar searches also saw one-time signals, not repeated. These searches had slow times to revisit or reconfirm, often days. Overall, few searches lasted more than hour, with lagging confirmation checks.

Another striking example is the "WOW" signal seen at the Ohio SETI site. Though its signal was strong, there was no electronic ability search for a true message in this event. The check-back time was fairly long, and subsequent studies observed for short times. Further, the total time spent searching the WOW signal site, directly toward galactic center, is about 1% of a year. This fact illuminates the constraints that a Galactic Center Search Strategy imposes: a yearlong campaign will require more effort than SETI has enjoyed over the last half century.

We conclude that SETI searches may have been looking for the wrong thing. SETI has largely sought signals at the lower end of the cost-optimum frequencies. They also may have taken needless care adjusting Doppler shifts, since broadband beacons will need none. Searches have seen coherent signals that are non-recurring on their limited listening time intervals. Those searches may have seen beacons, but could not verify them because they did not steadily observe over periods of years.

Transmission strategy for a distant, cost-conscious beacon may well be a rapid scan of the galactic plane, to cover the angular space. Such pulses will be infrequent events for the receiver. Such beacons built by distant advanced, wealthy societies will have very different characteristics from what SETI researchers seek. Future searches should pay special attention to areas along the Galactic Disk where SETI searches have seen coherent signals that have not recurred on the limited listening time intervals we have used so far.

Perhaps the galaxy does have many SETI beacons, but we haven't been bright enough to see them.

References:

Our papers, with many references to these ideas, are:

http://arxiv.org/abs/0810.3966
http://arxiv.org/abs/0810.3964
http://arxiv.org/abs/1003.5938

About the Authors

James Benford is President of Microwave Sciences, which deals with High Power Microwave systems from conceptual designs to hardware. A Fellow of the Institute of Electrical and Electronic Engineering, he has written 135 scientific papers and six books on physics topics, including the textbook, High Power Microwaves, now in its 2nd edition.

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