Quantifying SETI

A state of the search report.

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It should come as no surprise to readers of *QEX* that the scientific Search for Extra-Terrestrial Intelligence (SETI, sometimes called the search for the ultimate DX) was initiated by, and is still largely conducted by, radio amateurs. The world's hams instinctively understand the nature of electromagnetic communications, as well as the nature of the "free space" (or "aether") that fills the void between the stars, and forms a transmission medium for our favored photons. If asked to identify one radio amateur whose contributions to SETI were the most significant, I would not hesitate to name the late Dr Philip Morrison, W8FIS, the father of modern SETI science.[1]

Institute Professor Emeritus of Physics and Astronomy at the Massachusetts Institute of Technology, Phil Morrison was a distinguished theoretical astrophysicist, and a pioneer in the search for extraterrestrial intelligence through radio communication. He authored scores of books, produced countless television documentaries and lectured tirelessly around the world, despite the physical limitations imposed upon him by post-polio syndrome. Phil Morrison passed away quietly at his modest home in Cambridge, Massachusetts, in April, 2005 at the age of 89; but not before inspiring a whole generation of scientists (including me) to ask the difficult questions and then attempt to answer them. It is to Phil Morrison's memory that this article is dedicated, and it is with his most important publication that it deals.

Searching for Interstellar Communications

Although speculation about the existence of life on other worlds is as old as the ancients, modern SETI science traces its origins to a single brief article published just under a half century ago in the prestigious British science journal *Nature*.[2] Co-authored by Phil Morrison, then a professor of physics at Cornell University, and his Cornell colleague Giuseppe Cocconi, "Searching for Interstellar Communications" was the first scientific paper to quantify the challenge of signaling between the stars. In just three pages, with only eight very carefully chosen equations, Morrison and Cocconi

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[1]Notes appear on page 30.

sought to summarize all that was known, or could be known, about interstellar signaling using the best available technology of their day. Its four major section headings would form the syllabus for any contemporary course in radio communications: "The Optimum Channel," "Power Demands of the Source," "Signal Location and Bandwidth," and "Nature of the Signal and Possible Sources." We will revisit those same four subjects, plus a few more, in this paper.

These two scholars were probably the first to recognize a paradigm shift, as Earth was just beginning to develop the kinds of technologies that would take a search for alien emissions out of the realm of science fiction and into the scientific mainstream. More importantly, Cocconi and Morrison went so far as to suggest that SETI was a subject worthy not just of speculation and debate, but of serious observational study. Their concluding words are as valid today as they were in 1959: "We therefore feel that a discriminating search for signals deserves a considerable effort. The probability of success is difficult to estimate, but if we never search, the chance of success is zero."

Fifty Years of Solitude

In the wake of Cocconi's and Morrison's seminal article, we have indeed invested that considerable effort in a much deserved search. The first modern SETI Experiment, Frank Drake's 1960 *Project Ozma*,[3] was, in fact, in the construction stages even as the *Nature* article went to press. That Drake's assumptions and strategies closely paralleled Morrison's and Cocconi's, even though neither group knew anything about the other's work, is an indication of what I like to call the Parenthood Principle: When a great idea is getting ready to be born, it sets out in search of a parent. Sometimes, it finds more than one.

To his credit, Drake chose for his two target stars a couple of Morrison's and Cocconi's favorite candidates. He conducted his search at the very frequency they proposed. To his consternation, Drake failed to detect our cosmic companions. Nobody said this was going to be easy.

For 47 years now, various government agencies, educational institutions, non-profit entities and, yes, even Amateur Radio clubs,[4] have conducted hundreds of searches, from dozens of countries, over literally millions of frequencies, in all conceivable directions across 4π steradians (the SI measure of angular area) of space and time. They have all been precisely as successful as Drake's *Project Ozma*: To date, not *one single* verified emission of intelligent extraterrestrial origin has ever been observed and independently confirmed. To SETI's critics, it begins to seem as though even as we do search, the chance of success is zero.

Might it, in fact, be time to reexamine Cocconi's and Morrison's assumptions? In this article, we audaciously deconstruct the most important paper in the history of SETI science to update its methodology, bringing it in line with 21st-century technology.

The Optimum Channel

Have you ever tried to work a DXpedition that didn't announce its frequencies in advance? "We'll be on the air next Wednesday," they might have advertised in *QST*, "on some ham band or other." So, you flip the band switch until you find one that is open, tune around until you hear a pileup and start calling. Sometimes, you get lucky.

Only do not expect to get lucky when that rare DX is ETI itself. First off, how do you know which bands are open? There is not likely to be a pileup lighting your way. And you do not even know for certain whether the DXpedition actually exists, much less whether it made it to that particular island in the interstellar sea.

You can improve the odds by choosing to monitor a portion of the electromagnetic spectrum where the band *might* be open. Morrison and Cocconi chose a different approach: identifying, and then excluding from the search space, those bands that were known *not* to be open to signals from beyond Earth: "Radio frequencies below ~1 Mc./s., and all frequencies higher than molecular absorption lines near 30,000 Mc./s.,…are suspect of absorption in planetary atmospheres." So, we can eliminate the very low- and very high-frequency ends of the electromagnetic spectrum. That still leaves a lot of band to scan!

Even if we guess right as to where the signal might appear on the dial, it still needs to override the background noise if we are to detect it on Earth. In their paper, Morrison and Cocconi quantified the most likely source of cosmic interference: the emission spectrum of the galactic continuum. Its known characteristics, which have not changed in the years since their article was published, allowed them to compute a frequency range with a minimum of spurious background. That broad interstellar communications band is centered around 10 GHz.

Okay, so we will search the microwave spectrum. But where, exactly? That broad noise minimum centered on 10 GHz is still more than a decade wide. That is to say, anywhere from 1 GHz to 30 GHz is fair game, if background noise is our primary consideration. Quoting from the original SETI article again, "A long spectrum search for a weak signal of unknown frequency is difficult." We need to narrow the search area. Earth's first SETIzens hoped there'd be a cosmic band plan, with a well publicized inter-species calling frequency. In "Searching for Interstellar Communications," one such frequency was proposed: "…just in the most favoured radio region there lives a unique, objective standard of frequency, which would be known to every observer in the universe: the outstanding radio emission line at 1,420 Mc./s. (λ = 21 cm.) of neutral hydrogen."

First observed from Earth in 1951, the hydrogen emission line[5] is indeed a cosmic calibrator. Hydrogen is, after all, the most abundant element in interstellar space. There's something like one hydrogen atom per cubic centimeter filling the black void between the stars. And hydrogen atoms chirp occasionally at the precisely known frequency cited above. Whereas the weak chirp of a lone cricket in an otherwise empty field might well go unnoticed, add the chirps of millions of its neighbors and the field resounds with a strong and healthy chorus. Point your antenna at the empty depths above, tune your microwave receiver to the hydrogen line, and the resulting audio is rather like unsquelching an FM handheld transceiver on an unused channel. Here, reasoned Morrison and Cocconi, is nature's crystal calibrator, marked out in hydrogen chalk for all to see.

Why would ETI choose to transmit on the hydrogen emission line? Morrison and Cocconi again: "It is reasonable to expect that sensitive receivers for this frequency will be made at an early stage of the development of radio astronomy. That would be the expectation of the operators of the assumed source, and the present state of terrestrial instruments indeed justifies the expectation. Therefore, we think it most promising to search in the neighbourhood of 1,420 Mc./s."

Note that they wrote "in the neighbourhood of" the hydrogen line. Of course, you wouldn't expect to hear ETI calling precisely on hydrogen's emission frequency. The hydrogen noise would drown out the signal. But tune around the band in that vicinity, they proposed. If hydrogen noise is present, ETI can't be far away.

That logic held so well in 1959 that, for his *Project Ozma* search, Frank Drake had already independently decided to tune his down converter-equipped Hallicrafters across a band in hydrogen's general vicinity. It seemed like a good choice then. It still does today. If you must select but a single frequency on which to conduct a search for intelligently generated signals from an alien species, then 1420 MHz is as good a guess as any.

In the years A.D. (after Drake), SETI scientists have proposed numerous other such "magic frequencies." Several still seem like fair game and in fact, spot-frequency searches still go on. But in recent decades, a technological breakthrough has occurred which may well negate this kind of reasoning: the development of real-time multi-channel spectrum analyzers[6] (MCSAs). Whereas Drake's receiver, like most ham receivers, could only tune one narrow slice of spectrum at a time, today it is possible to monitor millions of channels at once. And that breakthrough has begun to change the way the SETI game is played.

What if instead of laboriously monitoring frequencies one by one, we could concoct the ultimate panadapter, capable of viewing the entire microwave spectrum, say, 1-100 GHz, simultaneously, in real time? The analytical tool that makes MCSAs possible is the fast Fourier transform (FFT), along with the powerful and affordable microcomputers on which today it can be run. Limited only by computer power, which, as Gordon E. Moore[7] reminds us, keeps doubling every year or two, we can now apply complex digital signal processing (DSP) techniques to the challenge of monitoring ever more channels across an increasingly wide spectrum, quickly approaching that lofty goal.

Today, even modest amateur SETI stations routinely monitor tens of thousands of channels, spread across tens to hundreds of kHz of the microwave spectrum. Our professional counterparts, with their presumed greater budgets and related resources, have expanded their searches to many tens of MHz at a time, divided into millions of DSP bins. (Our ambitious goal of monitoring tens of GHz of frequency span in real time still eludes us, but achieving that objective is just a matter of time.) So, guessing right about ETI's calling frequency is becoming ever less important, and in time the significance of Cocconi's and Morrison's channel recommendation may fade into obscurity. Still, if I had to choose just one frequency on which to conduct SETI….

Power Demands of the Source

From listening for signals buried in QRM and QRN, we hams know that successful communication is achieved not just by maximizing signal amplitude, but rather by maximizing signal-to-noise ratio (SNR). To determine the signal amplitude required for interstellar communication, Cocconi and Morrison first computed the amplitude of the galactic background around the 21-cm hydrogen line. Their calculations, which have weathered the test of time, quantified the interference level across two-thirds of the sky. The authors noted, "Near the plane of the galaxy there is a background up to forty times higher." Fortunately, as viewed from Earth, there are promising target stars in all directions, so it was deemed possible to minimize QRN: "It is thus economical to examine first those nearby stars which are in directions far from the galactic plane."

"Searching for Interstellar Communications" introduced an equation for assessing the transmitter power required for overcoming the cosmic background radiation, assuming transmit and receive antennas of known and equal size. In 1959, the largest parabolic reflector on Earth was the Jodrell Bank 80-meter reflector.[8] Given two such antennas separated by 10 light years, Cocconi and Morrison computed a required transmitter power "...which would tax our present technical possibilities." They then cited a planned Naval Research Laboratory antenna of 200 meters diameter, noting that between two such dishes, "The power needed is a factor of 40 lower, which would fall within even our limited capabilities." This was true even with the very crude microwave receivers of the day, and even lacking the DSP capabilities that we now enjoy.

Just a decade later, with the completion of the 305-meter Arecibo radio telescope,[9] interstellar communication over a 10-LY path, using technology no more advanced than Earth already possessed, became entirely feasible, validating Cocconi's and Morrison's claim, "We can then hope to see a beam toward us from any suitable star within some tens of light years."

But that was then. What of now? Arecibo is still our largest radio telescope, although significantly larger capture areas are contemplated through presently planned arrays of thousands of modest antennas. But thanks to the solid-state revolution, spurred by the needs of our terrestrial telecommunications infrastructure, receiver noise temperatures have decreased from thousands to mere tens of kelvins. A combination of improved frequency stability and advanced DSP techniques has reduced our channel bandwidths—and with them, our corresponding receiver noise—from tens of kHz to mere tenths of Hz. Today, we have available microwave power amplifiers putting out megawatts of RF. Considering the very best technology extant on Earth, I compute that two Arecibos can now communicate with each other not merely over tens of LY, but rather over tens of *thousands* of LY.

Different SETI scientists come up with different solutions to the very same equations, depending upon their underlying assumptions. Frank Drake himself (onetime Director of the Arecibo Observatory, and thus as knowledgeable about its capabilities as anyone) once computed the communications range between a pair of Arecibos. He determined that they could complete a QSO from anywhere within the Milky Way galaxy,[10] a result which supposes a range on the order of 100,000 LY. My own solution suggests a more modest 30,000 LY range, under the very best of circumstances.[11] Expressed in terms of signal strength, that's about a ten dB discrepancy. Drake responded to my result by stating, "All the parameters used in the Arecibo numerical example are plausible. The point was to show that if one tried hard, one could detect an Arecibo anywhere in the Galaxy."[12] Without belaboring the precise computations, suffice it to say that Drake and I agree on the big picture: Recent advances have it made it entirely possible, using technology no more advanced than that which was possessed on Earth by the end of the 20th Century, to communicate between the stars, over very vast distances indeed.

And yet, despite these advances, and despite the best efforts of some very talented scientists and technologists, SETI success still eludes us. Might there be other factors that we have overlooked?

Signal Location and Bandwidth

In Morrison's and Cocconi's paper, great attention was paid to the expected Doppler shift—and the corresponding difference between transmitted and received frequency—of hydrogen-line signals emanating from planets orbiting their stars. While such considerations were significant in the case of magic frequencies and single-channel receivers, our previously mentioned development of multi-channel spectrum analyzers tends to make the issues moot. But there is another reason to concern ourselves with Doppler shift, and it is not the absolute frequency change, but rather the *rate* of frequency change over time, that is significant.

Consider a deliberately beamed beacon, sent Earthward from a planet orbiting a distant star. It is evident and quantifiable that there will be a change in frequency over time as that signal arrives at Earth's vicinity. That frequency change is dominated by the rotation of the originating planet, but also contains components corresponding to the planet's orbit around its star, as well as its local sun's motion relative to the galactic center. One would hope that a technologically advanced civilization wishing to make its presence known would make the task of detection as easy as possible for us mere adolescents. One of the ways they could do so is to chirp their transmitter's frequency to compensate for the relative motions of their planet and star, with respect to the Galactic Center of Rest. The mathematics of such drift compensation is relatively straightforward.

However, even with Doppler compensation at the transmit end of the path, the frequency of the signal received on Earth will still change over time, because of the Doppler components imposed by the relative motions of our own planet, and our own star. These too are easily computed, and we could in theory chirp our own receiver's local oscillator in compensation for them, resulting in a fixed frequency of reception.

On the other hand, a received signal which varies over time has certain benefits, when one attempts to validate it as being extraterrestrial in origin. Consider that Earth suffers from extreme RF pollution of its own making, from terrestrial and orbital sources of RF. Separating the cosmic wheat from the terrestrial chaff is becoming ever more challenging as we continue to despoil our electromagnetic environment. And the Doppler shift imposed on a received signal by our planet's relative motion is an excellent indicator of its interstellar origin.

Consider an interfering signal emanating from a terrestrial source. That signal was generated on a rotating and revolving planet, but also received on that same rotating and revolving planet. Hence, the relative motion between the points of transmission and reception is zero, and the received signal is stable in frequency over time. In contrast, a signal emanating from a low-Earth-orbiting (LEO) satellite, as received on Earth, exhibits significant Doppler shift, its frequency varying as an S-curve over time. Both cases, that of fixed frequency and that of rapid Doppler, can be readily excluded from further analysis as emissions of human origin.

In between these two extremes, there is the case of a signal with slow and steady Doppler shift, consistent with Earth's motion with respect to the stars. Any signal whose frequency change matches that expected by sidereal motion is a likely candidate for further analysis. Thus, modern SETI experiments attempt to measure the rate of a candidate's frequency change over time to help us in identifying it as being of extraterrestrial origin. This kind of analysis, impractical in SETI's infancy, is light work for today's signal analysis computers.

There are two ways to increase the sensitivity of our receivers when recovering a weak CW source: through decreasing the detector's bandwidth, or through averaging many samples (increasing signal integration time). Once we have solved the Doppler equations for sidereal motion, it is feasible to employ both techniques in parallel. Morrison and Cocconi proposed as much in their 1959 paper: "Of course, the smaller the bandwidth chosen, the weaker the signal which can be detected…. It looks reasonable for a first effort to choose a bandwidth Δf_d normal for 21 cm. practice, but an integration time τ longer than usual. A few settings should cover the frequency range F using an integration time of minutes or hours."

In 1959, IF filtering with LC circuits and hardware integration with RC networks ruled the day, limiting our capabilities with respect to both variables. Today's DSP techniques allow us a wider set of options and permit almost arbitrarily narrow bin widths, as limited only by signal dispersion in the interstellar medium, and equally arbitrary integration times, limited only by the visibility of the source. These flexibilities hold the potential for significantly increasing our receive station's sensitivity, at the expense of adding perhaps more degrees of freedom than we wish to tolerate in the task of SETI signal analysis.

Nature of the Signal and Possible Sources

It's reasonable to expect that any artificially generated signals detected by Earth's SETI projects most likely would have emanated from a radio transmitter on a planet's surface, or on one of a planet's moons. Planets are not particularly easy to detect from Earth. In fact, though we know of 168 extrasolar planets at the time of this writing,[13] it is only within the past decade that we have been able to detect them at all. Detecting planets' moons is even more challenging. However, planets orbit stars that are quite visible, and we have rather strong knowledge about the characteristics of those stars most likely to accommodate potentially habitable planets. So the very first SETI experiments concentrated on identifying likely candidate stars.

"The first effort," wrote Cocconi and Morrison, "should be devoted to examining the closest likely stars. Among the stars within 15 light years, seven have luminosities and lifetimes similar to those of our Sun. Four of these lie in the direction of low background…. There are about a hundred stars of the appropriate luminosity among the stars of known spectral type within some fifty light years. All main-sequence dwarfs between perhaps *G0* and *K9* with visual magnitudes less than about +6 are candidates."

Early SETI concentrated on precisely those stars identified in "Searching for Interstellar Communications." When pursuing his *Project Ozma*, Drake trained a single 85-foot dish on two of those nearby stars specifically identified by Morrison and Cocconi, though at but a single frequency, and for just a few days in April of 1960. Later studies surveyed those two candidates more extensively, along with all hundred of the mentioned promising stars within fifty light years of our Sun.

But our Milky Way galaxy contains some *four hundred billion* stars, and it is just one of perhaps a hundred billion galaxies! That makes the number of candidate star systems truly mind-boggling. The very best lists of candidate "good suns" go out only a few hundred light years, and include only perhaps a few thousand stars. Beyond that distance, the waters are relatively uncharted.

A targeted search of promising Sun-like stars makes sense if extraterrestrial radio-using civilizations are relatively commonplace. That is, if there are many such civilizations, then the average distance between them is small, and ETI's home planet may in fact be orbiting a star now in one of our catalogues. But what if radio-using civilizations are scarce? Then, it stands to reason that the distance between oases is great in the interstellar desert. Under those circumstances, a potential life site may not even appear on our maps, its interesting stars being completely unknown to us. And, should scarcity be the rule, a targeted search of known stars is unlikely to prove productive. Another search strategy is called for.

That other search strategy is the all-sky survey. It differs from the targeted searches of early SETI in that no particular direction on the sky is favored. Rather than pointing at known stars, the sky survey sweeps out broad expanses, eventually sampling the whole sky visible from a given location in hopes of stumbling across an interesting signal. It's tedious and time-consuming work; but if you do not know which star ETI calls home, the best way to stumble across his signals may be to look in all directions.

Here then is where modern SETI diverges from Cocconi's and Morrison's search modality: by introducing a complementary search strategy—the all-sky survey—to fill the gaps left by targeted searches. Since we do not know for certain whether alien plentitude or scarcity holds true, we must conduct both searches until one or the other hits pay dirt.

Targeted searches fall well into the realm of the monster radio telescopes, of which Arecibo is the prime example. If you wish to point at a particular known star, you should do so with the highest-gain, most-directional antenna at your disposal to minimize interference from other potential emit-

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The SETI League, Inc. **Link Analysis**

User specifies variables shown in **Bold**

<u>Transmitter:</u>

Frequency = **1420** MHz; λ = 21.1 cm

Transmit Power = **1.0E+06** W = 60.0 dBW = 90.0 dBm

Eff. Antenna diam. = **305** meters = 1001 ft

Illum. Efficiency = **70** %

Computed Antenna Gain = 1.4E+07 Ap = 71.6 dBi

Antenna Half Power Beamwidth = 7.1E–04 radian = 4.1E–02 degrees

Effective Isotropic Radiated Pwr = 1.4E+13 W = 161.6 dBm

<u>Path:</u>

Range = **1.3** parsecs = 4.238 LY = 4.0E+16 m

Free Space Isotropic Path Loss = 367.5 dB

Incident Isotropic Power = EIRP – path loss = –206.0 dBm

<u>Receiver:</u>

Eff. Antenna diam. = **3.7** meters = 12.1390833 ft

Illum. Efficiency = **60** %

Computed Antenna Gain = 1.8E+03 Ap = 32.6 dBi

Antenna Half Power Beamwidth = 5.9E–02 radian = 3.4E+00 degrees

Drift Scan Time (zero declination) = 1.3E+01 min = 807.9 sec

Recovered Power = P inc + G ant = –173.4 dBm

System Noise Temperature = **50** K = –7.6 dB/To

Detector Noise Bandwidth = **1** Hz = 0.00 dB/Hz

Receiver Noise Threshold = kTB = 6.9E–22 J/S = –181.6 dBm

Integration Time = **10** sec = 5.0 dB/cy

SIGNAL TO NOISE RATIO 13.2 dB

Fig 1—Arecibo from Alpha Centauri.

ters. So for years, SETI was thought to require the kinds of facilities that only governments could afford. This is why the modestly funded NASA SETI program of the late 20th Century still consumed $12.5 million a year. That Congress terminated this planned ten-year search, just one year in, is proof that SETI was requiring the kinds of facilities that *not even* governments could afford.

All-sky surveys work with a different trade-off. It is true that large antennas have high gain and are sensitive to weak signals. But if our objective is to cover all 4π steradians of the sky, that sensitivity is buried under the burden of being blind to 99.9999% of the sky at a given time. For all-sky surveys, perhaps it makes more sense to sacrifice sensitivity for sky coverage.

That is where amateur SETI comes in, and with it, a new paradigm: SETI is possible with the kinds of facilities *you and I* can afford. The radio amateur's rather modest antenna, with a sensitivity two or three orders of magnitude below that of Earth's giant dishes, has the advantage of seeing hundreds to thousands of times more sky. A reasonable number of such antennas (on the order of 100, a critical mass achieved by The SETI League perhaps five years ago[14]) can scan the whole sky once per day. A more ambitious number, say 5000 such SETI stations, can monitor the whole sky *all the time, in real time*. This is the philosophy underlying Earth's most ambitious all-sky SETI survey, The SETI League's *Project Argus*, an initiative of radio amateurs around the world, which Phil Morrison enthusiastically supported during his last decade of life. Searching for interstellar communications, Morrison realized, had come to involve search strategies that went beyond merely identifying interesting nearby sun-like stars.

How Near Do We Hear?

Computed detection ranges esti-

The SETI League, Inc. — Link Analysis

User specifies variables shown in **Bold**

Transmitter:

Frequency =	**1420** MHz;	λ =	21.1 cm		
Transmit Power =	**1.0E+06** W =	60.0	dBW =	90.0	dBm
Eff. Antenna diam. =	**305** meters =	1001 ft			
Illum. Efficiency =	**70** %				
Computed Antenna Gain =		1.4E+07	Ap =	71.6	dBi
Antenna Half Power Beamwidth =		7.1E–04	radian =	4.1E–02	degrees
Effective Isotropic Radiated Pwr =		1.4E+13	W =	161.6	dBm

Path:

Range =	**6** parsecs =	19.56	LY =	1.9E+17	m
Free Space Isotropic Path Loss =				380.8	dB
Incident Isotropic Power = EIRP – path loss =				–219.2	dBm

Receiver:

Eff. Antenna diam. =	**3.7** meters = 12.1390833 ft				
Illum. Efficiency =	**60** %				
Computed Antenna Gain =		1.8E+03	Ap =	32.6	dBi
Antenna Half Power Beamwidth =		5.9E–02	radian =	3.4E+00	degrees
Drift Scan Time (zero declination) =		1.3E+01	min =	807.9	sec
Recovered Power =		P inc	+ G ant =	–186.7	dBm
System Noise Temperature =		**50**	K =	–7.6	dB/To
Detector Noise Bandwidth =		**1**	Hz =	0.0	dB/Hz
Receiver Noise Threshold = kTB		= 6.9E–22	J/S =	–181.6	dBm
Integration Time =		**10**	sec =	5.0	dB/cy

SIGNAL TO NOISE RATIO 0.0 dB

Fig 2—Maximum Range Calculation for Amateur SETI.

mated at tens of thousands of light years between similarly equipped Arecibos may be all well and good, but how many of us are blessed with an Arecibo in our backyard? A more important question might be, "At what distance can I, with my typical backyard amateur SETI station, expect to detect an alien Arecibo beaming my way?" It is an important question because, as the late SETI pioneer Dr Bernard Oliver wrote in 1995, "If your system wouldn't detect the strongest signal the ETI might radiate, even if it came from the nearest star, then years of listening, or thousands doing it, won't improve the chance of success. To cross the Golden Gate, we need a bridge about 10,000 feet long. Ten thousand bridges...one foot long won't hack it."[15]

So let us run the numbers. My well-documented[16] backyard SETI station is typical of hundreds now operational or under construction around the world. It features a parabolic dish 3.7 meters in diameter, illuminated at 60% efficiency. My system noise temperature (including LNA noise figure, feed line losses, antenna noise temperature, and sky noise looking far from the galactic center) is on the order of 50 kelvins. My DSP software is set up for 1-Hz bin widths and 10 seconds of integration time. Assume a CW beacon from an alien Arecibo, running a 1-megawatt transmitter, beamed our way. My signal analysis spreadsheet[17] (Fig 1) shows, given the 1.3-parsec range to the very nearest star, that we can expect an impressive 12 dB SNR. That's an S-2 from Alpha Centauri, folks!

Perhaps even more interesting is the maximum range of detectability for the system described above. Let's assume that a unity (0-dB) SNR is adequate to identify the DX station. (Many of us routinely claim contacts where the signal was in fact well below the noise threshold; for EME contacts, negative SNRs are almost obligatory!) Note in Fig 2 that our maximum range for 0 dB SNR is on the order of twenty light years. Within that modest range are several dozen Sun-like stars, including Morrison's and Cocconi's most promising candidates, several of which are now known or expected to harbor planetary systems. So contrary to Barney Oliver's cautionary statement, we amateurs appear well able to cross the Golden Gate, even with our humble equipment. Whether there is anyone waiting for us at the other end of the bridge remains to be seen.

Factors Beyond Our Control

We have established that even a modest amateur SETI station can detect emissions from a civilization no more technologically advanced than our own, if it resides within 20 light years or so of Earth, and if it happens to be beaming toward us from the equivalent of our own Arecibo Observatory. But, how likely is ETI to actually direct a beacon our way, even given its existence in the right neighborhood, at the right technological level, in the right timeframe? Here I can only speculate about factors which are, in the words of the cynical Vicomte de Valmont in the De Laclos novel,[18] "completely beyond my control."

Social scientists tell us that only two possibilities motivate all human actions: altruism and self-interest, although some argue that even seemingly altruistic acts are performed with an underlying selfish motive. Can we imagine selfish or altruistic reasons why another civilization would expend considerable resources on the deliberate transmission of electromagnetic signals over interstellar distances? Much has been written about the altruistic case,[19] less about the selfish possibilities.

Successful altruistic civilizations, it has been theorized, harbor an innate desire to share their cultural wealth with those less fortunate. Such civilizations may consider it a cosmic imperative to undertake the transmission of their accumulated knowledge and experience to younger, emerging species. If this theory holds, we stand on the brink of reception of *Encyclopaedia Galactica*, a knowledge base that can transform human existence in ways we cannot begin to imagine. This justification for human SETI endeavors is only warranted if our cosmic companions are disposed to such generosity.

But what of the other possibility, that our galactic neighbors might choose to transmit in our direction, strictly out of self-interest? Of what possible benefit could such a transmission be to civilizations presumed older, wiser, and more capable than we? It's easy to concoct scenarios whereby the very act of reception of interstellar signals is somehow damaging to humanity and advantageous to the transmitting species. Competition rules the jungle, so why not the cosmos? And as Earth is, in essence, a paranoid planet, any such scenario that you can imagine will easily attract a host of followers willing to embrace it. I believe this says far more about the human condition than it does the alien. Further, such speculations have served to inhibit the acceptance and growth of SETI science on Earth as though, somehow, one can believe that turning a deaf ear to the universe can somehow protect us from harm.

There is a third possibility, little discussed in the literature, as to why we might someday find ourselves on the receiving end of an interstellar CQ. We believe that time and space are finite. Civilizations, as far as we understand the laws of nature, can be long-lived but not eternal. Imagine a technologically advanced civilization facing its own inevitable demise. Might it not wish to put its whole history and culture into an electromagnetic time capsule—a modern message in a bottle—in hopes that someone else (maybe us) might pluck it out of the cosmic pond, and simply know that they were? Might not they transmit in the hopes of achieving a degree of immortality? Might not we?

Given the above possibility, I can envision someday receiving a beamed transmission from a civilization long dead. It would seek to inform us about their art, culture, society, history, spirituality, hopes, dreams, and aspirations. Such a transmission could be an unparalleled look into a neighboring civilization's past—and humanity's future.

What Next for Amateur SETI?

The nonprofit, membership-supported SETI League, Inc[20] is a ham club formed in 1994, in the wake of Congressional cancellation of the short-lived NASA SETI program, to keep the search alive. During its first decade, the club's emphasis was on technical education. Our members wrote dozens of articles and papers, and gave scores of presentations[21] to like-minded radio amateurs at such meetings as the annual AMSAT Space Symposium; the Central States, Mid-Atlantic, West Coast, Northeastern, and Southeastern VHF Conferences; Society of Amateur Radio Astronomers meeting; International Space Development Conference; Dayton Hamvention; various ARRL Division and National Conventions; and elsewhere. Our mission in those early years was to demonstrate that credible science could be done by amateurs, with amateur equipment, and that assembling a workable SETI radio telescope was not only feasible, but affordable and rewarding.

During its second decade, the focus of The SETI League is shifting somewhat, into more of a coordination role. The microwave hardware and DSP software now are well-defined, with well over a hundred amateur SETI stations currently on the air in 67 countries on all 7 continents. Our next challenge is to achieve full sky and spectral coverage, with sufficient redundancy to ensure successful independent verification should an interesting candidate signal be detected. Given that The SETI League is an all-volunteer organization with officers who all have day jobs, families, and actual lives, such coordination taxes our limited resources. For-

More on SETI Probabilities

As Paul ably notes, Frank Drake's contributions to SETI are outstanding. In 1961, he and J. Peter Pearman organized the first SETI conference held at the National Radio Astronomy Observatory in Green Bank, West Virginia. At that small gathering, they proposed agenda representing discrete factors in the probability of interstellar communication. Almost jokingly, Drake assembled those factors into what's now known as the Drake equation or the Green Bank equation (see Paul's discussion at **www.setileague.org/editor/quantify.htm**). Although never intended to be used quantitatively, the equation relates to the number of civilizations in our galaxy from which someone would be likely to get that big CQDX.

The result is the product of seven variables, seemingly sorted left-to-right in order of increasing uncertainty:

$$N = R^* f_p n_e f_l f_i f_c L$$

where:

N=number of extraterrestrial civilizations that might expect contact from another

R^*=rate of star formation in our galaxy (stars/year)

f_p=fraction of those stars that have planets

n_e=average number of habitable planets per star that has planets (planets/star)

f_l=fraction of the above that develop life (civilizations/planet)

f_i=fraction of the above that develop intelligent life

f_c=fraction of the above that are able and willing to communicate

L=the average lifetime of such a civilization (years).

The observational uncertainty of the value of R^* is low compared with the uncertainties of the other variables: $R^* \approx 10$ is the accepted value. Drake and his colleagues estimated that about half the stars in our galaxy have planets, so they set $f_p \approx 0.5$; observation provides reasonably strong support. They set $n_e \approx 2$, although now there's plentiful evidence that typical stellar radiation levels in binary systems and those with red dwarfs would dictate a value lower by several orders of magnitude. f_l was set to unity because all our evidence points to the rise of life on Earth very shortly (in cosmic terms) after suitable conditions were met. The uncertainties of the other factors are quite high.

Note that civilization lifetime *L* could be redefined as the length of time a civilization has emitted recognizable signals, purposefully or not. As Dr Shuch demonstrates, electromagnetic signals from Earth not intended for extraterrestrial communications are unlikely to be detectable even at the nearest star; so willingness, or at least cognizance, is legitimately part of the equation. He emphasizes to *QEX* that the equation is much more useful in its originally intended role as a research tool than as an actual calculation. However, much debate continues over its numerical solution, often with misleading results because the uncertainties of some factors are so high.

Carl Sagan optimistically speculated that all factors but *L* were relatively high. His pessimism about the value of *L* had to do with our own tendency toward self-destruction. At present, observation shows that *N*=1. Think about that observation, but not for too long! Obviously, any assumptions about factors in the equation that produce values of $N \ll 1$ expose one or both of the following: 1) large uncertainties, or 2) that human beings are truly unique in the galaxy, by chance or otherwise. Without more data than we have now, the uncertainties of all the factors are uncertain! That's why the Drake equation is not yet a serious statistical tool.

We can keep trying to quantify the uncertainties, but being unique by any means can be a heavy-duty philosophical matter. At the base of modern scientific thinking regarding that is a thing called the anthropic principle. It comes in two flavors: weak and strong.

The weak anthropic principle states that we shouldn't be surprised by what we observe in our corner of the universe, since conditions must have developed in it that allowed us to be here to observe them. As Stephen Hawking wrote in *A Brief History of Time* (Bantam, 1988, ISBN: 0-553-05340-X), "It is a bit like a rich person living in a wealthy neighborhood and not seeing any poverty." In other words, if you measure that Earth is 4.5 billion years old, don't be surprised—that's how long it took for human beings to appear who were able to make the measurement.

The strong anthropic principle is much broader than the weak. It states that intelligent life as we know it couldn't exist under conditions significantly different from our own. In other words, if life as we know it didn't exist, then likely neither would our universe. That implies that a universe like ours *ought* to admit life as we know it at some point. Dr Hawking wrote, "The laws of science, as we know them at present, contain many fundamental numbers, like the size of the electric charge of the electron and the ratio of the masses of the proton and the electron....The remarkable fact is that the values of these numbers seem to have been very finely adjusted to make possible the development of life. For example if the electric charge of the electron had been only slightly different, stars either would have been unable to burn hydrogen and helium, or else they would not have exploded [to redistribute heavier elements].... One can take this either as evidence of a divine purpose... or as support for the strong anthropic principle." I told you it was heavy-duty philosophy!

The often-used estimate of $f_i \approx 0.01$ may be way too optimistic. Our solar system's orbit about the galactic center is evidently nearly circular, at such an orientation that it avoids significant radiation and ejecta from novae for hundreds of millions of years at a time. Other star systems are not so lucky. Systems like ours may be five orders of magnitude rarer than the average, indicating $f_i \approx 10^{-7}$. That might make us feel a bit lonely. On the other hand, taking only our own experience and setting $L \approx 50$ may be too pessimistic. Civilizations might be able to communicate long after they've departed the scene. That likelihood increases with the time they actually lived.

Could ours be the only planet in a galaxy of hundreds of billions of stars supporting this kind of discussion? Some feel another question should be asked: "Should we begin our search for intelligent life right here at home?" But Dr Shuch warns that funding for that research is unlikely because of its low probability of success.—*Doug Smith, KF6DX*