When Will We Find the Extraterrestrials?

There are a couple of hundred billion stars just in our own Milky Way galaxy, so the odds are good that we are not alone in the universe. On the other hand, if life abounds, why haven't we found any evidence of it—and is that about to change?

The dedication ceremonies for the Cahill Center for Astronomy and Astrophysics featured a symposium whose speakers included some of the brightest lights in astronomy—all of them former Techers. One of the day's highlights was this talk by Seth Shostak, PhD '72, a senior astronomer at the SETI Institute, where he's been since 1991. But Shostak's interest in extraterrestrials goes much farther back—as a grad student at the Owens Valley Radio Observatory with plenty of time on his hands, he, Robert O'Connell (PhD '70), and friend Jerry Rebold shot such timeless films as The Teenage Monster Blob from Outer Space, Which I Was *and* The Turkey that Ate St. Louis. *The latter can now be seen on YouTube, and is particularly noteworthy for the appearance of then-department chair Jesse Greenstein as TV newsman Walter Crankcase.*

When Shostak isn't listening for aliens, he's talking or writing about them. His weekly radio show, Are We Alone?, *is accessible at http://radio.seti.org. His latest book,* Confessions of an Alien Hunter: A Scientist's Search for Extraterrestrial Intelligence, *was published by* National Geographic *in March.*

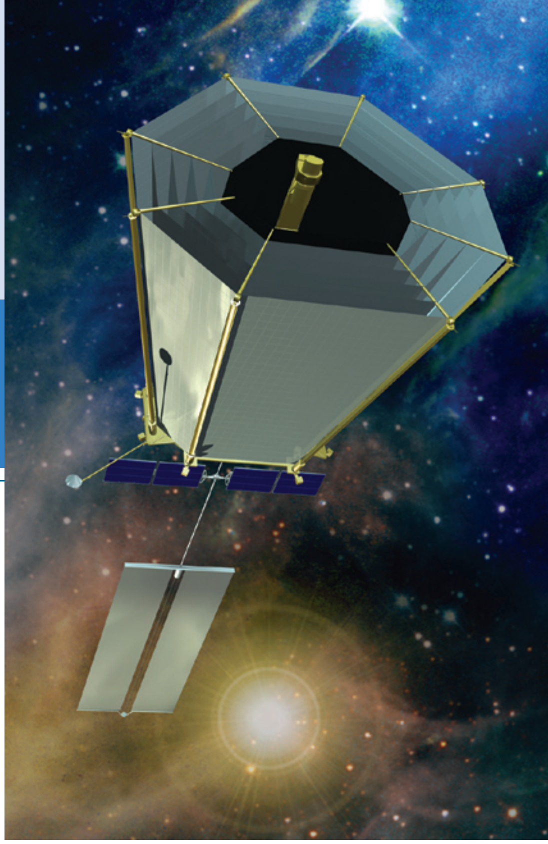
For more information on the SETI Institute, visit www.seti.org.

This article was edited by Douglas L. Smith.

http://www.youtube.com/watch?v=PyV5d-aZMbM

Above: The Hubble Ultra Deep Field is the farthest we have ever peered out into the visible universe. With the exception of one bright, four-pointed, red foreground star, everything you see in this picture is a galaxy. If we're alone in the universe, we are *really* alone. Photo credit: Steven Beckwith (PhD '78) and the Hubble Ultra Deep Field Working Group, STScI, HST, ESA, and NASA.

The Terrestrial Planet Finder mission consists of two complementary observatories: a visible-light coronagraph (right), slated to launch around 2014, and a formation-flying infrared interferometer, intended to launch before 2020.



By Seth Shostak

My day job is to look for E.T. I'm a senior astronomer for the SETI Institute, just south of San Francisco in Mountain View, only two miles from Google. SETI stands for the Search for ExtraTerrestrial Intelligence, and our mission is to scan the skies for radio signals that would prove we are not alone in the universe. (Unlike in Europe, in this country the search is entirely privately funded. Your tax dollars have not been at work in this field since Congress pulled the plug on NASA's High Resolution Microwave Survey in 1993.) Everybody who works in SETI eventually gets asked, "So, when are you going to find something?" And everybody has an answer. But I've noticed that the answer is tightly correlated with the number of years until the answerer is expected to retire. These responses probably tell you more about the people you're asking than about E.T., so I'm going to try to give you an answer that you might believe, and as a bonus I'll give you my best guess as to what E.T. might look like.

Why do we think that E.T. is out there in the first place? It's simply a matter of numbers. There are 10^{22} stars in all the galaxies visible to our telescopes today. That's a 1 followed by 22 zeroes, or 10 *sextillion* stars. Geoff Marcy's team at UC Berkeley has so far found 121 planets around nearby stars, and I recently asked him, "If you had perfect instruments, what fraction of stars would show planets?" His answer was "maybe half or three quarters," which, of course, to an astronomer is the same as "all." And since planets, like kittens, come in bunches, it's likely that the number of planets is an order of magnitude larger, or 10^{23}, which is the number of grains of sand on all the beaches of Earth. That's a lot of real estate, so if you think that Earth is the only grain of sand where anything interesting is happening, one has to admire your audacity.

That's the basic argument, but there are others. In the picture below you can see some of the oldest and best-preserved sedimentary rock on Earth. Those little lumps in the rock are thought to be the remains of bacterial colonies from three and a half billion years ago. In other words, as soon as Earth was capable of supporting life, almost as soon as the heavy bombardment of our planet by early asteroids had abated, there was life. And that suggests—although it doesn't prove, since the sample size is one—that life is not a miracle, but merely some sort of dirty chemistry that probably occurs in many places.

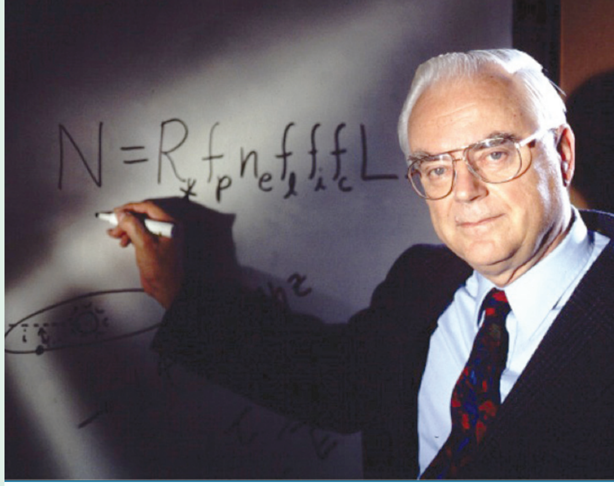
STUPID LIFE, SMART LIFE

There's a three-way horse race to find compelling evidence of life beyond Earth. I think that each of these methods has, more or less, an equivalent chance of winning. The first approach is to find it nearby—perhaps on Mars, or one of the moons of the outer solar system. A JPL mission might do that. The second approach is to build infrared telescope arrays in space, and try to find, for example, methane in the atmosphere of a planet around another star. Methane molecules are destroyed by any of several processes on a timescale of a few hundred years, so something would have to be creating fresh methane continuously for us to be likely to see it. Much of the methane in this room is produced by what is politely called "bovine flatulence," and also by porcine flatulence, so this technique would at least allow you to find pigs in space. NASA, the European Space Agency, and many universities are collaborating on such projects, which will be built in the next 20 years. In fact, on March 6 NASA's Kepler spacecraft was launched to look for Earth-like planets that could be subjected to closer scrutiny by such telescopes. (See the Random Walk item on page 6.)

Both of these approaches are attempting to find, if you will, stupid life—life that would require a microscope to see—on the not unreasonable assumption that stupid life is far more prevalent than the intelligent variety.

The third approach is to look for intelligent life. What do we mean by "intelligent?" SETI has a very simple operational definition for high IQ, namely: can you build a radio trans-

The business-card-sized lumps in this 3.5-billion-year-old, iron-rich rock from the Pilbara Hills in northwestern Australia are thought to be the remains of ancient bacterial colonies.



At age 79, Frank Drake still comes in to work every day at the SETI Institute, where he is the director of the Carl Sagan Center for the Study of Life in the Universe.

mitter? If you can, we don't care about the rest. Do you write great literature? Irrelevant. If you can build a radio transmitter, you're in.

This leads to a very contentious and complicated question. Given a million worlds with stupid life on them, what fraction of them will ever develop intelligent life? Consider that if, 65,000,000 years ago, the rock that landed in the Yucatan had whizzed by 20 hours earlier or later, there would be dinosaurs in Pasadena today. Of course, they might have learned to build radio transmitters by now, but I once asked Niles Eldridge, a paleontologist at the American Museum of Natural History, about that. (Niles, by the way, developed the theory of punctuated equilibria with Stephen Jay Gould.) He replied, "Well, Seth—the dinosaurs had 150,000,000 years to get smart *and didn't*. What would another 65,000,000 have done for them?"

However, there are mechanisms that seem to ratchet up intelligence. Getting smarter can be a weapon on either side of the predator-prey arms race, for example. But a much better driver, at least from the point of view of your next cocktail-party conversation, is called "signaling for fitness." The canonical example is the peacock. The peacocks, the males, gather in groups and display their blue tailfeathers. The peahens cruise by, and the guy with the best display gets to breed. What benefit does that peahen, with her little pea brain, garner from those big blue feathers? After all, they only attract predators. The answer is that a well-patterned tail with a dense collection of eyespots is a good indicator of a male whose genome has few harmful mutations, so his chicks will be healthy.

Evolutionary psychologist Geoffrey Miller at the University of New Mexico says that a couple of million years ago we were doing the same thing. We didn't have blue feathers, but in a predator-filled world, the mere fact that a male was still walking around was a good sign. It's like those old Clint Eastwood westerns. He rides into town, probably hasn't had a bath in three months, yet all the women turn out for him. Why? The biologists would say, "Well, look, if he made it this far, he *must* be good."

Like the peacock's tail, the human brain is tightly linked to the genome. About half of our genes have some effect on our brains, so if your brain is wired up correctly—if you can tell interesting stories, or sing, or something like that—it shows that you don't have too many bad mutations. Therefore, the best pickup strategy for a man at a party would be to take off his skull and pass his brain around. That's considered a social blunder, so instead the men talk to the women, and the competition to make good conversation ratchets up the size of men's brains.

The same holds for women. Miller says that there's a lot of evolutionary pressure on the females to be charismatic in order to hold the guy's interest so he'll help raise their future kids. He says if you doubt this, just look at the couples in a restaurant. If they're just getting to know one another, the guys are doing all the talking to charm the females. But if they've been together for a

FRANK DRAKE AND THE BIRTH OF SETI

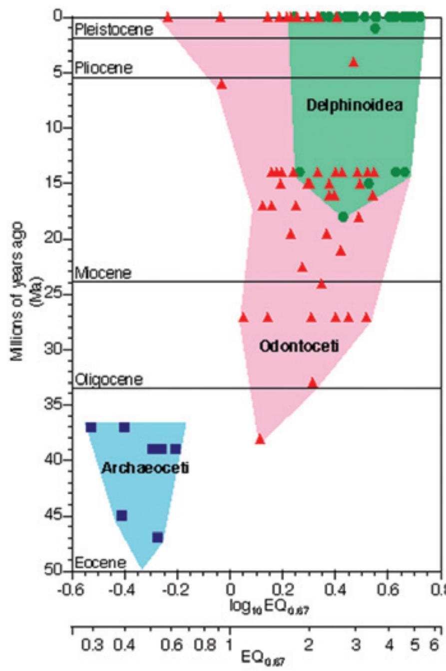
Frank Drake, then on staff at the National Radio Astronomy Observatory in Green Bank, West Virginia, did the first radio search for alien civilizations in 1960. Called Project Ozma, for the ruler of the land of Oz, it listened to two nearby, sunlike stars named Tau Ceti and Epsilon Eridani. Drake used a 26-meter dish to scan across 4,000 channels centered on the 21-centimeter emission band of cold hydrogen gas—a frequency popular with radio astronomers that he figured would be a natural choice for a species trying to make itself known. He tape-recorded the data and then printed it out on strip charts, looking for any signals superimposed on the hiss of interstellar static.

In 1961, he and J. Peter Pearman of the National Academy of Sciences organized the first SETI conference, also at Green Bank, where he proposed what is now known as the Drake equation to calculate how many civilizations (N) we might have hope of hearing from:

$$N = R_{\star} \times f_p \times n_e \times f_\ell \times f_i \times f_c \times L$$

The equation starts with a very large number, $R_{\star}$, which is the average rate of star formation in the Milky Way, and multiplies it by succession of numbers that represent the probability of critical ocurrances. Thus f_p is the fraction of stars with planets; n_e is the average number of planets in those systems that are capable of supporting life; f_ℓ is the fraction of planets that eventually develop life; f_i is the fraction of species that go on to become intelligent; f_c is the fraction of intelligent species that invent communication devices, such as radios, that we might detect from Earth; and L is the length of time that such civilizations actually broadcast into space. e&s

This plot shows the ratio of brain size to body size (abbreviated as EQ) for the common ancestors of whales and dolphins (Archeaoceti); the modern toothed whales (Odontoceti), which includes the sperm whale; and the Delphinoidea, the dolphins and porpoises. The scale is logarithmic, meaning the dolphins are way smart.



From Marino, McShea, and Uhen, *The Anatomical Record*, 281A: 1247-1255 (2004).

[Dolphins and whales] were all pretty stupid 50,000,000 years ago, but 48,000,000 years later, white-flanked dolphins were the smartest things on the planet. If you go to the local library and look up “Dolphin Literary Criticism,” it’s all from two million years ago.

while, the women are doing all the talking to keep the guys from wandering off—at least until they pay the bill.

If this hypothesis is true—which is open to debate—emergent intelligence could be a common evolutionary process that happens on lots of worlds.

Intelligence does appear to increase with time in some cases. Above right is a plot by neuroscientist Lori Marino at Emory University that shows an index computed from the ratio of brain size to body size, the so-called encephalization quotient (EQ), for a bunch of species of dolphins and toothed whales over the last 50,000,000 years. They were all pretty stupid 50,000,000 years ago, but 48,000,000 years later, white-flanked dolphins were the smartest things on the planet. If you go to the local library and look up “Dolphin Literary Criticism,” it’s all from two million years ago. Once you get to a certain level of complexity, there’s a niche market for intelligence, and it may get filled. That’s encouraging.

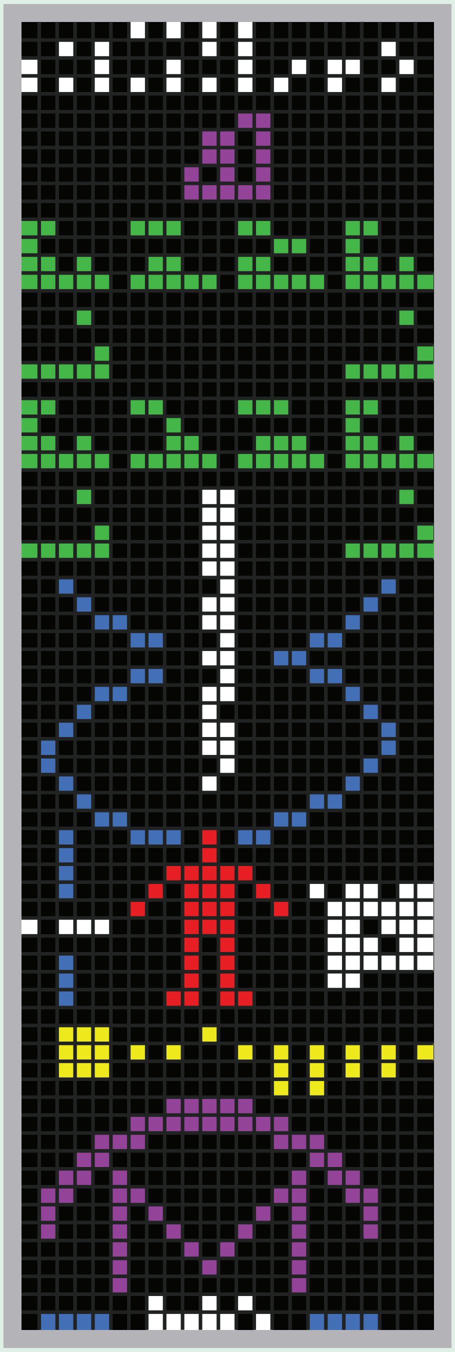
One way to find intelligent life is to look for artifacts. Advanced societies could be doing astroengineering that we might be able to see. For example, a Dyson swarm, which is a grand-scale collection of orbiting solar-power stations, habitats, and whatnot, could surround its star at a radius beyond all the habitable planets. Not much light would get out, but the inevitable waste heat out the backs of all those solar cells would betray their presence in the infrared. Richard Carrigan, a physicist at the Fermi National Accelerator Laboratory, has been looking for signs of possible Dyson swarms by perusing the Infrared Astronomy Satellite data sets. (IRAS, a joint project of the Americans, British, and Dutch, was launched in 1983, and performed the first all-sky infrared survey. Many Caltech people were instrumental in the project, and the data sets are still housed here on campus, at the Infrared Processing and Analysis Center.)

E.T., PHONE EARTH

It’s much easier to search for signals, and there are a lot of places in the electromagnetic spectrum where we could look. We can, for example, do it in the optical. Berkeley, Lick Observatory, and Princeton all have had projects that look for flashing lights in the sky, but Harvard has the most ambitious program, thanks to physicist Paul Horowitz. There’s a lot to be garnered for very little effort, as you can see by the following simple thought experiment.

A typical star like our sun emits some 10^{45} photons per second in all directions, so if you look at it with a one-square-meter mirror

This guy’s encephalization quotient is off the charts. He’s going to be very popular as a potential mate.



From Wikimedia Commons, http://en.wikipedia.org/wiki/File:Arecibo_message.svg

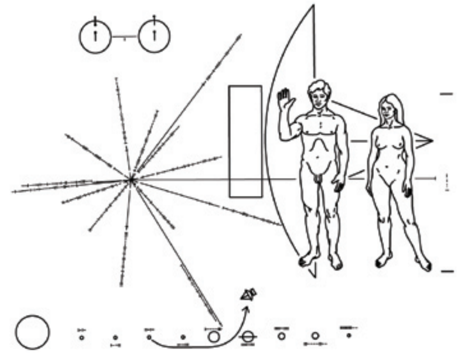
THE COSMIC WELCOME MAT

We don't deliberately broadcast into space for the benefit of the aliens, but occasionally it's done as a sort of demo project. The most famous of these efforts was the one-time transmission of an FM (frequency modulated) radio signal at 2,380 megahertz from the 305-meter-diameter antenna at the Arecibo Observatory in Puerto Rico. The broadcast, on November 16, 1974, used the dish's million-watt radar transmitter, normally employed for planetary astronomy, and the message was sent to celebrate a major upgrade to the telescope rather than representing a serious effort at communication. The signal was aimed at a globular star cluster called M13 that is 25,000 light-years away, so we won't be hearing back from them any time soon.

The message consisted of 1,679 binary digits, sent at the rate of one bit per second. The number 1,679 is the product of two prime numbers, 73 and 23, allowing the recipient to reassemble the rectangular picture they encode in only two possible ways. When correctly displayed as 73 rows by 23 columns, the diagram at left emerges, which attempts to tell any puzzle-loving species everything they need to know about us in a nutshell. (The zeroes are shown in black; the ones have been given various colors for ease of description.) Across the top are the numbers 1 through 10 (white). Next, in the same system of notation, come the atomic numbers of hydrogen, carbon, nitrogen, oxygen, and phosphorus (purple)—the constituents of DNA. The formulas for the backbone sugars and the nucleotide bases found in DNA are in green—good luck to the aliens trying to figure *them* out!—and below them is a graphic of the DNA double helix itself (blue). Within the helix is the number of base pairs in the human genome (white); below it is a self-portrait (red) of *homo sapiens*. The measuring stick to the left (blue) gives our average height (white) as a multiple of the wavelength of the radio signal. To the right of our likeness is the world's population (white), and below is a map of the solar system (yellow), with us astride an Earth set out of line from the other planets. And finally, on the opposite side of Earth is a cross section of the Arecibo radio dish, along with its dimensions (blue and white, as with the human form). The dish is shown beaming the signal into deep space from its prime focus.

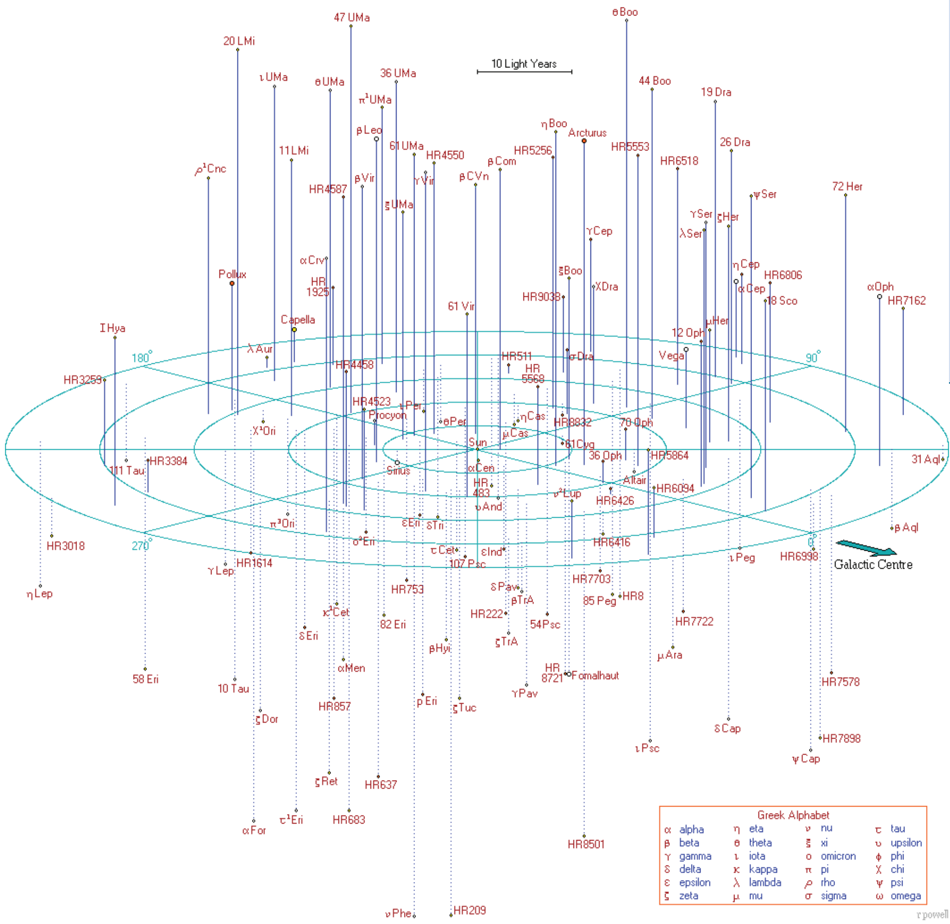
The graphic was designed by Frank Drake, then at Cornell University, with assistance from his colleague Carl Sagan, among others.

Sagan and Drake also designed the much easier to read six-by-nine-inch gold-anodized plaque (top right) that was mounted on NASA's Pioneer 10 and 11 spacecraft, now on their way out of the solar system. This plaque shows a hydrogen molecule (upper left), our sun's location in relation to 14 pulsars, our solar system, the Pioneer, and us.



Above: The plaque on the Pioneer 10 and 11 spacecraft, which were launched toward Jupiter on March 2, 1972 and April 5, 1973 respectively. Pioneer 11 went on to Saturn, making its plaque inaccurate. Below: Harvard's optical SETI telescope, which sports a 72-inch primary mirror.

From AtlasoftheUniverse.com



This 3-D map shows 133 naked-eye-visible stars, most of them very similar to the sun, within 50 light-years of Earth. If the sun-like stars have Earth-like planets, as well they might, and if said planets are inhabited by beings with television receivers, those lucky lifeforms may be enjoying *I Love Lucy*, which went on the air for the first time in 1951.

from 100 light-years away, you'll get about 100,000,000 photons per second. If you look at it for one nanosecond, one billionth of a second, that's less than one photon. Now, if you work out how many photons per second the biggest lasers we have here on Earth would put into a square meter at a range of 100 light-years—it's only been a half-century since the invention of the laser, so these are perhaps not sophisticated lasers compared to what E.T. might use—one could easily produce hundreds or even thousands of photons per square meter. In a *nanosecond*. It completely swamps the steady photon flux from the star. So to search for such transmissions, all we have to do is put a photomultiplier tube behind a modest telescope and look for nanosecond pulses.

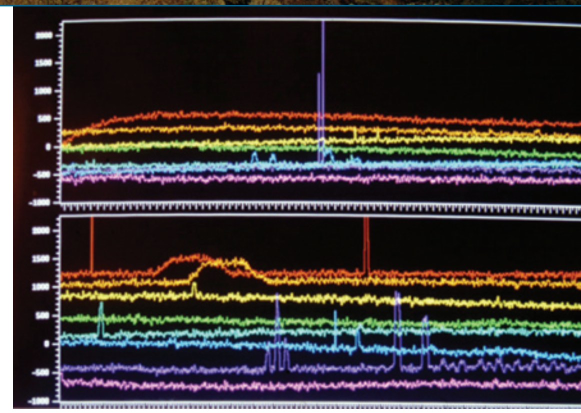
If the aliens used a one-square-meter mirror to point their laser at us from 100 light-years away, the beam would just cover our inner solar system—roughly out to Saturn. But, you ask, why would they be aiming at us? Perhaps they've detected the oxygen in our atmosphere—the spectrographic evidence has been there for two billion years—and concluded that there might be life on Earth, but not necessarily intelligent life. They could be trying a whole lot of potential bio-planets, over and over. It's not that we'd be so special, we'd just be on a very long "ping list." That's pure speculation, but it's not unreasonable, and it doesn't require us to luck out by being in the path of a randomly directed beam.

COSMIC EAVESDROPPING

We don't necessarily need to rely on E.T. reaching out to us. At the moment, we are unintentionally announcing our own presence to the universe by emitting copious amounts of television and radar waves. (The radar is more powerful, although not as interesting to listen to.) But those big red-and-white TV towers on Mount Wilson are eventually going to go away, as fiber-optic lines come into your house. Our electromagnetic signature as a society, at least in the radio, is going to go *down*, rather than up. So the question is, would highly advanced societies still be broadcasting willy-nilly into space, or do we have to count on them deliberately trying to signal other civilizations? The opinions on whether we should expect unintentional leakage or deliberate signals seem to change every 10 years, but an intelligent species might always want to have some big radars on the lookout for long-period comets, for example, which if undetected could ruin one's whole day.

Most SETI projects follow Jodie Foster's strategy in the movie *Contact*, where she used the National Radio Astronomy Observatory's Very Large Array, sprawled across the deserts of New Mexico, to look for artificial radio emissions. (The VLA has never been used for this sort of research, by the way, but it's very photogenic.) *Contact* was actually based on our work at the SETI Institute. We were consultants on the film, and I got daily calls from folks at Warner Brothers who would ask questions like, "So, Seth, Right: The Allen Telescope Array is near Hat Creek, about 300 miles north of San Francisco. The seemingly random antenna placement gives a near-Gaussian distribution to the spacings between antenna pairs and produces undistorted images of the sky.

Below, right: A tiny piece of a SETI observation at Arecibo in 1998. Each line covers about 1.25 megahertz from left to right across the screen. The sharp peaks are all local signals—from either ground-based transmitters or satellites in Earth orbit—except for the triplet on the purple line that's second from the bottom, which is from Pioneer 10's radio transmitter. The two small, flanking peaks are called sidebands, and show that the signal is amplitude modulated—in other words, the spacecraft was still sending back data.



what does it look like when you fly through a wormhole?" I'd tell them that, relativistically, the whole universe collapses into a bright point of light in front of you and one behind you. But, I added, visually that's not very interesting, so most movies animate the view one would have while flying through a pig's intestine instead. Which is what they did.

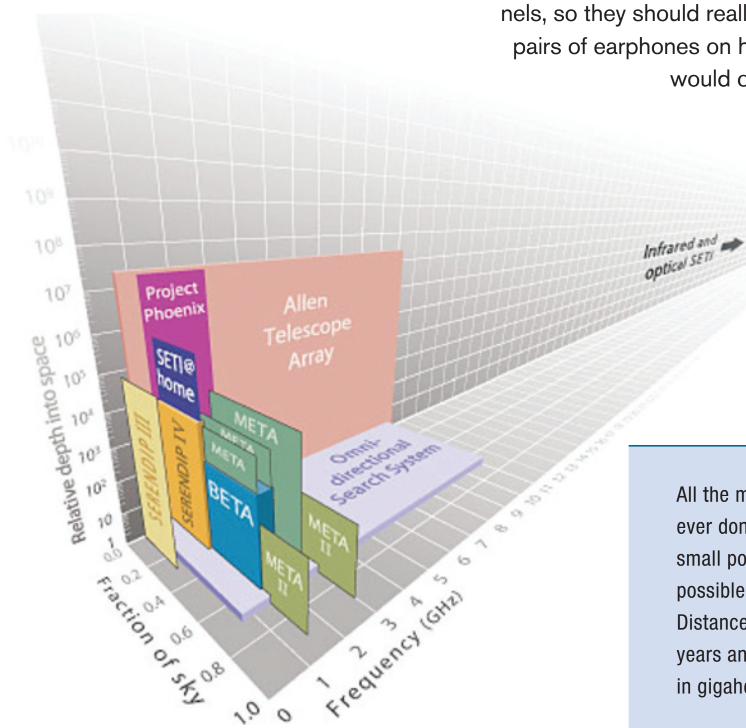
People frequently assume that, in trying to recognize E.T., we look for particular patterns in the radio noise—the value of pi, perhaps. We don't. We're not looking for a modulation, just a narrowband signal. The wider the bandwidth, the more noise collected by the receiver. So if the aliens want to be heard, they'd take all their transmitter power and put it into a one-hertz-wide channel or less—as narrow as they can make it. They can't push much information through a channel like that, of course, but at least it tells us that they're on the air. Then they could have lower-power transmitters sending more interesting signals. If we found that narrowband signal, we'd go after that spot on the sky for all we were worth, looking for the information channel.

At right is a bit of a spectrum from the National Astronomy and Ionosphere Center's Arecibo Observatory radio telescope, which is run by Cornell. (The whole spectrum covers some 20 megahertz.) You can see several narrowband peaks in there, but they're all local interference, save one—the radio transmitter aboard NASA's Pioneer 10, which at that point was about two times as far away as Pluto. We occasionally listen to a spacecraft, just to make sure that everything is still working. Otherwise, we wouldn't know whether a nonresult means that there's no signal to be seen, or whether it just means that some component in our system has silently quit on us.

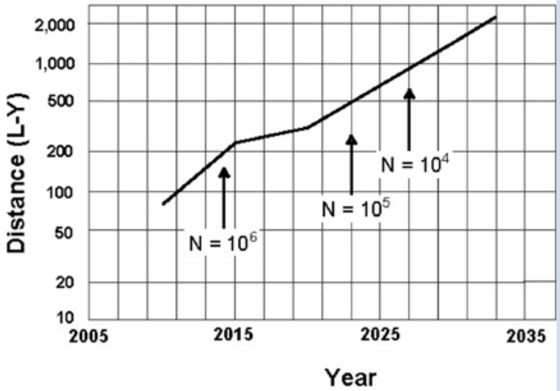
Finding E.T.'s signal was very easy for Jodie Foster—she just sat on the hood of a car for about 20 seconds with a pair of earphones. I pointed out to Warner Brothers that we were monitoring 56,000,000 channels, so they should really put 28,000,000 pairs of earphones on her. They said it would crowd the shot, so they didn't do it.

In the real world, looking for a signal takes a lot of computer processing. The incoming stream of cosmic static is Fourier transformed, almost in real time, and split into frequency channels roughly 1.4 hertz wide and separated by about a hertz. The software then examines all of these channels once per second, recording the amount of power in each. A single observation typically lasts four to five minutes, and once it ends, the computer paws through the data, looking for signals that pulse slowly, say once every few seconds. The software also looks for signals that have slowly drifted up or down the radio dial. This is extremely important. If a signal has zero frequency drift, it means that the transmitter is rotating with Earth, so the source is either bolted to our planet or is in a geosynchronous orbit. The filtering process typically nets us a dozen or so candidates per observation, which are compared to a database of known sources of interference. In general, we can tag a signal as terrestrial or not within 10 minutes or so. Some candidates have endured closer scrutiny for a few hours. In 1997, one lasted even longer than that, but eventually was traced to the NASA/ESA solar research satellite named SOHO.

So far, we've been using other peoples' telescopes, which is like doing cancer research with borrowed microscopes. Therefore, even though the first radio search was done almost 50 years ago, the total number of stars that we've looked at *carefully* over a wide range of frequencies is fewer than 1,000. In a galaxy of a couple of hundred



All the major SETI projects ever done cover a very small portion of the possible search space. Distances are in light-years and frequencies are in gigahertz.



This graph shows the radius (in light-years) of a sphere centered on Earth versus the year by which we will have listened to all the candidate star systems within that sphere. For each N, or number of civilizations "on the air" out there, the arrow marks the year by which we will have listened to enough stars to have found someone broadcasting.

billion stars, that's nothing. But the situation is about to change.

Our new instrument, the Allen Telescope Array, currently consists of 42 six-meter dishes. It's named for Microsoft cofounder Paul Allen, who gave us and UC Berkeley the money to get started. The array will eventually have 350 antennas, funding permitting. The Berkeley Radio Astronomy Laboratory is already using it, and we'll have two SETI projects under way on it by this summer. We can both use it 24/7—while the Berkeley guys are mapping galaxies, or whatever, we'll be checking the foreground stars in the same field of view for E.T.'s signals.

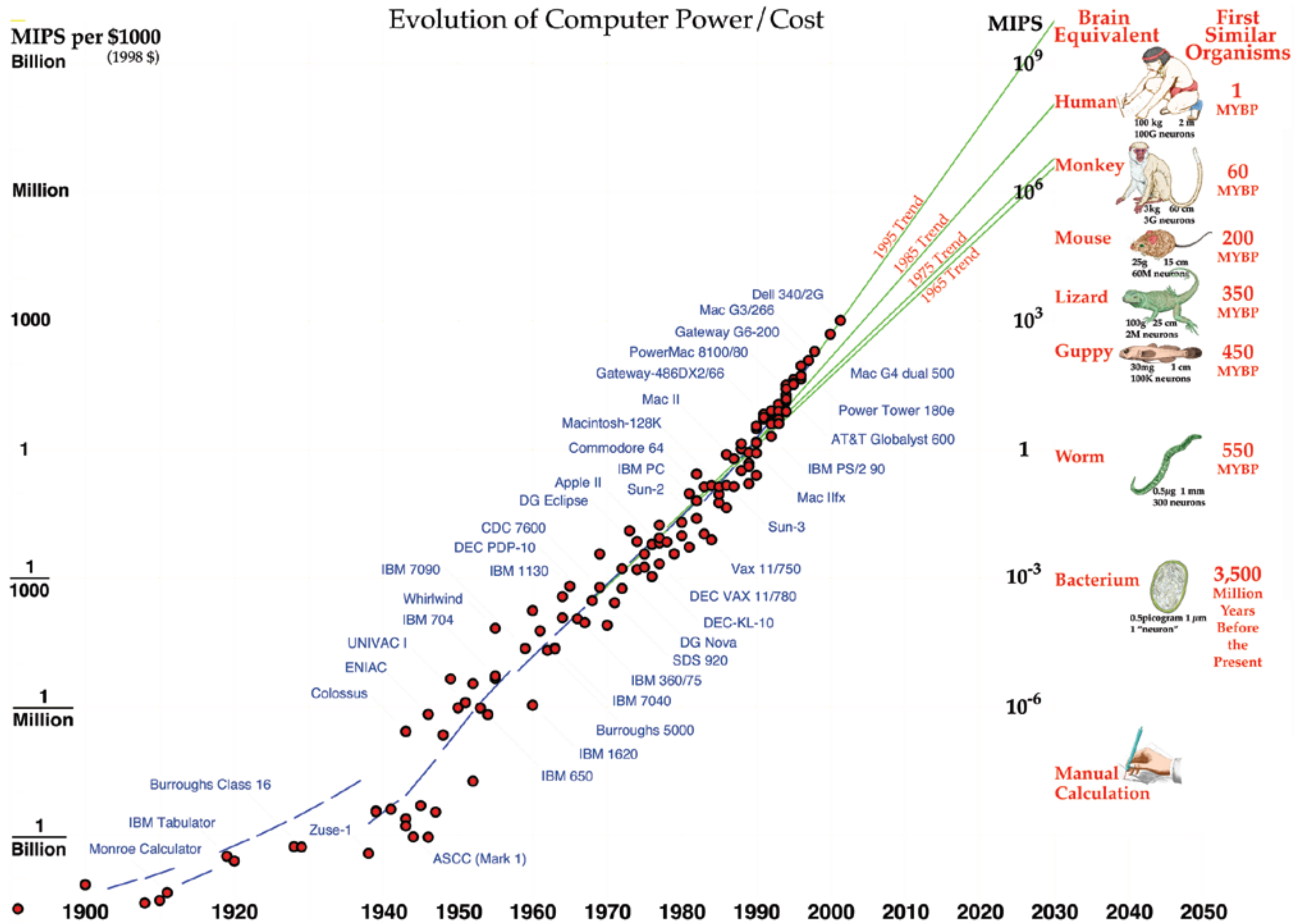
Each dish has a compact, state-of-the-art feed horn that covers the microwave spectrum from 0.5- to 10.5-gigahertz. Most radio-astronomy receivers are only good over a few hundred megahertz, and if you want to switch between different spectral regions you have to physically change out the receiver–feed horn combo. Usually this means sending someone up to the focus with a wrench, although on some big telescopes, like Arecibo, you can just push a button in the control room to rotate the receiver turret. Receiver turrets are big, heavy, and expensive, so they weren't practical for the Allen Array, and changing 350 feed horns by hand is not something I'd want to do. Inside our wide-spectrum feed horn, our receiver is also state-of-the-art—a tiny chip designed here at Caltech by Faculty Associate in Electrical Engineering Sander "Sandy" Weinreb. His chip works over our entire 10-gigahertz frequency span—a remarkable feat—and together with the feed horn makes a near-perfect low-noise device.

WHEN WILL WE FIND THEM?

I'm now ready to answer the question I posed in my title: when can we expect success? We're looking for a needle in a haystack; that's the usual metaphor. We know how big the haystack is—it's the galaxy. We don't know how many needles there are, but we can reckon how fast we're going through the hay. SETI's speed doubles, on average, every 18 months, because we use digital electronics that obey Moore's Law. This trend will continue for at least another couple of decades. If we factor in the geometry of the galaxy, we can calculate how far out into space we will have listened to all the interesting star systems by any given year, assuming we relentlessly observe them in order of distance. The Ns in the plot above are guesses by various people as to how many needles are in the haystack. Carl Sagan figured a couple of million, and if he's right we should succeed by 2015. Isaac Asimov figured 670,000, and if *he's* right, it should take until 2023. Frank Drake is more conservative, with only 10,000 civilizations broadcasting in the galaxy right now, and consequently it takes until 2027—at which point we will have looked at the nearest million star systems, three orders of magnitude better than we've done so far.

Mind you, all of these numbers could be completely wrong, but it is these guesses that motivate our efforts. The total number of people that work in SETI is fewer than any two rows of audience members in this room, but nonetheless, if that range of estimates is right, we'll find E.T. within two dozen years. I'm so sure of this that I'll bet all of you a cup of Starbucks on it. So either you'll hear news of a detection within two dozen years, or you'll get a cup of coffee in the mail. If we don't find E.T. within a generation, there is something very fundamentally wrong with our assumptions.

There's a counterargument to be made here, which was first posed in the 1950s by physicist Enrico Fermi. The Fermi Paradox runs as follows. The timescale for colonizing the galaxy, even with such primitive technologies as rockets, is not very long. It's on the order of tens of millions of years, which is short compared to the age of the galaxy. Therefore, if there is intelligence out there, the galaxy should have been colonized a long time ago. As Fermi himself is supposed to have put it, "Where is everybody?" Resolving this paradox is a cottage industry in its own right, with explanations running the gamut from "Colonizing the galaxy is



The rapid rise in the number of MIPS (Millions of Instructions Per Second, a measure of computing power) that you can buy for a constant price has rapidly outstripped the evolutionary pace of biological brains. Graph courtesy of Hans Moravec at Carnegie Mellon University's Robotics Institute.

not cost-effective, so they're smart enough not to have bothered" to "They have indeed colonized the galaxy, but we just haven't noticed," in the same way that ants probably don't notice us. I think the so-called paradox is fallacious—a very big extrapolation from a very local observation. Using similar logic, I can go into my backyard and say, "You know, there are no bears here. But they've had plenty of time to arrive. Therefore bears must not exist."

GREEN, GRAY, BORG, AND BEYOND

The SETI community doesn't know what the aliens will look like, but Hollywood does. This is not irrelevant, because our idea of what they may be like determines our search strategy. One hundred years ago we thought that the Martians had a planetwide, canal-based society, and we could find them with large telescopes in Flagstaff. Today we're talking about sending robots to Mars to drill holes to look for bacteria. What you think you're looking for affects how you look for it.

There are a few good Hollywood aliens, like the guys who gave Richard Dreyfuss a joyride in *Close Encounters of the Third Kind*. You can always tell the good ones; they look like little kids. But most Hollywood aliens are bad, *War of the Worlds* bad. The ISO standard alien—what UFOlogists call a "gray"—is just a projection of what we think we're going to become as we slowly lose our olfactory sense, our teeth, and so on. And, of course, we'll all be sitting around designing websites, so we'll have big eyes. All of these aliens are very anthropomorphic—soft, squishy guys, just like us. I think that even my colleagues figure, sort of subconsciously, that's what we're going to find. The aliens may not look like this guy, exactly, but they're *something like us*.

I believe that's wrong, and I'm going to tell you why. We're looking for intelligence, which in our case consists of a three-pound brain that draws about 25 watts of power. When you get an In-N-Out burger, one-quarter of the calories go to keep your brain warm, even though it's less than 2 percent of your body weight. Three million years ago we had a one-pound brain. One million years ago we had a two-pound brain. Today we have a three-pound brain. The difference is huge: If you have a two-pound brain, you walk upright and maybe discover fire. If you have a three-pound brain, you can get tenure at Caltech. The assumption is that we'll go on to five-pound brains, ten pounds, and so on, but I think that's unlikely. Women are already having trouble giving birth to babies with heads as big as they are, so they'll go on strike. There are also mechanical problems. If you have a ten-pound brain, you'll twist your head off the first time you turn it.

I think that E.T. will not be flesh and blood, or whatever passes for alien flesh and blood. The artificial-intelligence community predicts that we're going to invent our own successors, and the next dominant life form on the planet will be robotic. If you plot how much computing power you can buy for $1,000 as a function of time—Moore's Law again—you can see that by 2020 a desktop computer will have as much power as a hu-

The ISO standard alien—what UFOlogists call a "gray"—is just a projection of what we think we're going to become as we slowly lose our olfactory sense, our teeth, and so on.

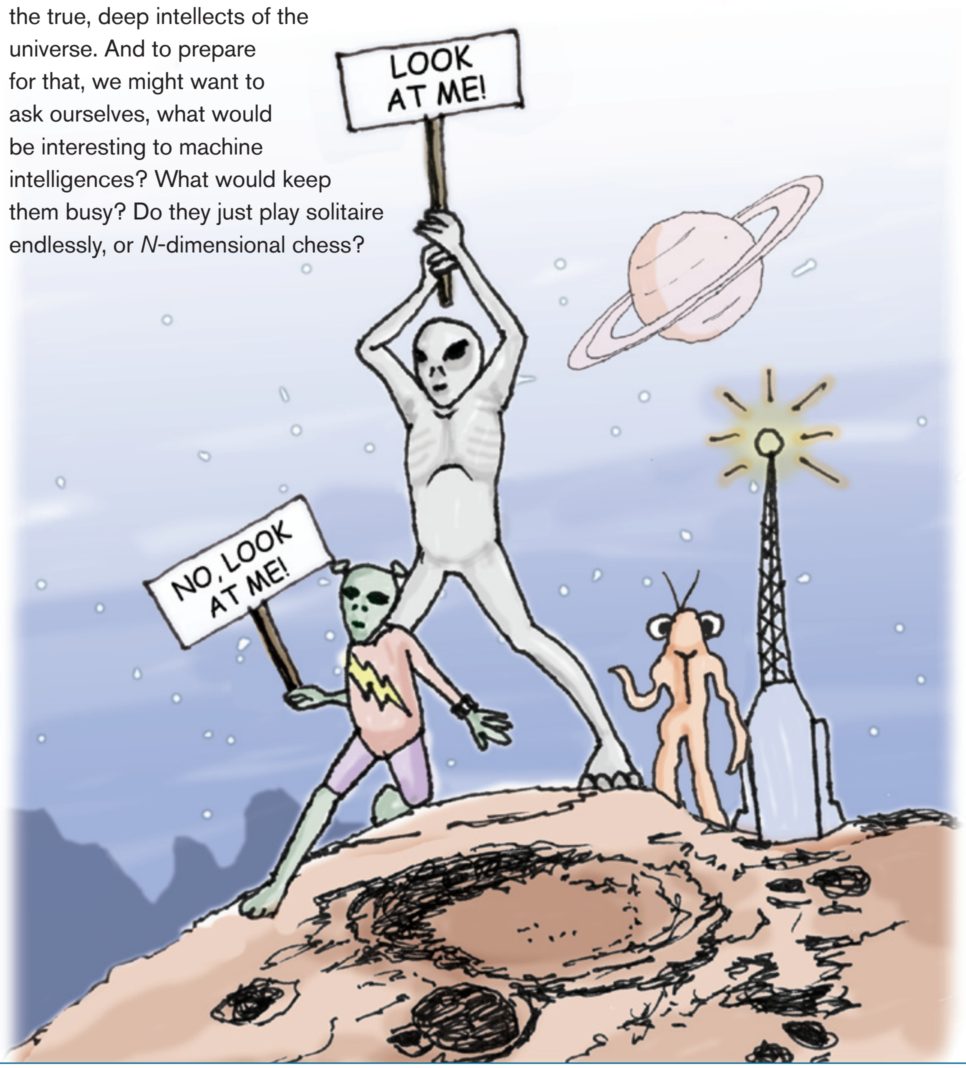
man brain. That doesn't mean it will be able to think, but *maybe it can* . . . if the software guys can keep up. At AI conventions now, they're not talking about whether machines will be able to write the Great American Novel or compose symphonies or teach high-school chemistry; they're discussing whether we'll be able to pull the plug if we need to. Of course, some folks have been trying to build AI for a very long time, but they always point out that we shouldn't confuse the lack of success with a lack of progress.

So if this happens by 2020—or 2050 or 2100, it doesn't matter—then 20 years after that your desktop computer will have as much power as the entire human species. When that happens, I for one am just going to turn the keyboard around and say to my computer, "OK, *you* type." My point is that this is a timescale argument. When Gary Kasparov lost to a chess-playing machine named Deep Blue in 1997, he said his opponent had a kind of "alien intelligence." And that was just a game-playing machine. It didn't think.

The problem is that Darwinian evolution usually proceeds pretty slowly. About 60 million years ago, a horse stood as high as your knee; now, they're the size of, well, horses. I had a home computer in 1977. It ran at one megahertz. My laptop today runs at more than a gigahertz. That's a factor of 1,000 improvement in 30 years. It just blows Darwin away. This is Lamarckian evolution—you can self-improve. Once we get artificial intelligence evolving, I think we can forget biology. Maybe we'll become the machines' pets, which may not be so bad—at least we'll get to sleep a lot. Yes, humans will try to keep up, of course. We'll put chips in our brains, but that's like putting a four-cylinder engine in a horse—after a certain point you say, let's get rid of the horse and just build a Maserati.

There are *soooo* many advantages to artificial intelligence that I think it will dominate everything. Machines can even operate in interstellar space. We're looking for signals coming from star systems that might have Earth-like planets, and maybe that's the wrong strategy. Maybe we should just look for places that have high concentrations of energy, because in the end that's presumably what the machine wants.

I think that if there's a conscious intelligence out there, it's synthetic. I think we should assume that when we find a signal, it won't be coming from a soft, squishy guy behind a microphone, but from one of the true, deep intellects of the universe. And to prepare for that, we might want to ask ourselves, what would be interesting to machine intelligences? What would keep them busy? Do they just play solitaire endlessly, or *N*-dimensional chess?



Should we be working on some really compelling PowerPoint presentations to divert their attention while we reprogram them to calculate the exact value of pi? Unless, of course, they've already done that. . . E&S