Searching for Other Civilizations

Detection of any extraterrestrial life, be it the humblest microbe, would be of profound significance scientifically and in terms of how we view our uniqueness. However, our real thrill and the main focus of science fiction is extraterrestrial civilizations. How might we detect these? Could they be very close to us, or are we resigned to exploring large distances? In this lecture we will examine various possible locations for non-human civilizations and discuss how we are currently searching for them.

Direct exploration of our Solar System

The easiest place for us to search is our own back yard. As we have discussed, in times past and in science fiction present there have been hopes that highly advanced civilizations exist on Venus, Mars, the moons of Jupiter, or elsewhere in our Solar System.

Sadly, our direct exploration has not found any evidence of even bacteria, let alone wise societies past. Yes, we still have nutcases who froth on about "the face on Mars" and the like, but these speak more to our tendency to find patterns even when they are absent than to the realization of Percival Lowell's dream. For the curious: NASA has imaged the "face" subsequent to the original Viking pictures, and it is just a hilly feature that looked like a face with low resolution and the right shadowing.

Could a civilization elsewhere in the Solar System have escaped our notice? For those who think we're being visited regularly, wait until next lecture. Otherwise, if an advanced alien species cohabits our system with us we have a couple of options. One is that they are located in some place that we haven't searched, for example deep in the Europan ocean. This would also require that for reasons of sociology or technology they have not come out to the surface and spread around where we would see them. Theoretically the same would be true of a civilization that had evolved deep in the atmosphere of Jupiter or Saturn. However, in either case this would suggest a fairly low level of technology, because otherwise you'd think they would have escaped from their confines.

The other obvious option is that there *is* a civilization elsewhere in the Solar System, but that it is (1) hiding from us, and (2) so advanced that it can do so without our detecting them. Keeping in mind Arthur C. Clarke's statement that "any sufficiently advanced technology is indistinguishable from magic", this might be possible. But would they choose to remain undetected? Admittedly this delves into the realm of alien psychology, but it sure isn't the way that human explorers have elected to operate.

Suppose then that we're the only civilization in our system. How might we find alien societies elsewhere?

Direct exploration of other systems

Our first thought is that we can simply send probes to other stellar systems. In the very long term we may well do that, but for the near future this is not practical. The fastest spacecraft we have moving out of the Solar System travels about 17 kilometers per second. At that rate, it will take about 80,000 years to reach the nearest star, and hundreds of thousands of years to reach more realistic prospects for life. We're an impatient bunch, so we need to think of faster ways. That means indirect detections, which we will now explore.

Indirect detection: what would Earth look like from a distance?

Before addressing the issue of interstellar communication itself, let's consider what might be a sign of life from a distance. One possibility is that future telescopes might be so good that we can actually see artificial structures directly. To determine how likely this is, we need the formula for how good angular resolution can be.

Suppose we have a telescope of diameter D, and we are observing light with a wavelength λ. Then the minimum angle we can resolve, measured in radians (recall: there are 2π radians in a circle), is

$$\theta_{\rm min} \approx \lambda/D\ . \qquad (1)$$

Now suppose that we are at a distance d from some source. The smallest structure that we can resolve (i.e., see individually) then has a linear size of

$$R_{\rm min} = d\theta_{\rm min} = d\lambda/D\ . \qquad (2)$$

Let's work an example. The Keck telescopes are the largest in the world, with diameters $D = 10$ meters. Light in the visible range has a wavelength of $\lambda \approx 5\times10^{-7}$ meters. Therefore $\theta_{\rm min} \approx 5 \times 10^{-8}$. Suppose we look at a very close extrasolar planet at a distance of only 10 parsecs (about 33 light years). Then the minimum size we can resolve is $R_{\rm min} = d\lambda/D \approx$ 0.1 AU. This is 2,000 times the size of the Earth. Oops!

Sadly this means we'd need to increase the size of the mirror by 2,000 times linearly (to a 20 km diameter!!) so that a planet the size of Earth didn't look like an unresolved dot. To see individual buildings of 100 meter size would require another increase by a factor of 60,000 or so, leading to a mirror the size of our Sun. That is beyond what even a science fiction author would accept.

Fortunately there is another option. By observing a source with two or more normal-sized telescopes at a large distance from each other and then combining their images in a process called interferometry, we can get the same sharpness of image that we would if we had a single telescope that spanned the entire region. This is already done on Earth with radio telescopes, but at optical wavelengths fluctuations in our atmosphere prevent it from being effective. It would work in space, though, assuming various technological advances that are probably not too far in the future.

This would be perfect except for one thing. Although interferometry gives angular resolution equivalent to a much larger telescope, the total light that is received is just the standard amount. That's a problem for resolving buildings on other planets because those buildings are so tiny compared to the planets that they reflect or emit negligible amounts of light. Even the entire light emission from the Earth is only about 1/30,000 times the light the Earth receives from the Sun, which is itself just a billionth of the Sun's total output. Since we couldn't even see the reflected starlight from an Earthlike planet 10 parsecs away, this is not an option for the near future. We need other options.

Spectroscopic detection of planets with life

One possibility is to look for spectroscopic signatures of life. For example, if there are molecules that can only persist in an atmosphere if maintained by biological processes, then observation of the spectral features of those molecules would be indirect evidence of life. Oxygen and ozone (O_3) have been proposed as such molecules, because they are reactive enough that after a relatively short time they would be incorporated into other molecules were it not for photosynthesis. Indeed, if we look at the spectra of Venus, Earth, and Mars, then all have strong carbon dioxide features but only Earth has oxygen and ozone. Earth is also the only one with water, but since water is seen in interstellar clouds this is less of a unique signature.

Another possibility has to do with the spectra of plants. Plants use chlorophyll for photosynthesis, leading to extra reflectance in the green part of the spectrum and even more in the near infrared. It has been proposed that observation of such a sharp change in the spectrum could only be caused by life. I am personally dubious about this, because I don't think we know enough about available molecules to be confident that chlorophyll is the only possibility.

Artificial emissions from Earth

What about human-produced emissions? Note that we have to specialize to electromagnetic radiation, because this is the only thing that can bridge the gap of space (recall that "in space no one can hear you scream" [Alien], so sound won't do; neutrinos or gravitational waves would technically work but their interactions are too weak to be effective communications media). Most of the electromagnetic spectrum is absorbed by our atmosphere, leaving only radio waves, visible light, and some infrared as options.

Most of our emissions thus far have been accidental. Lights at night would be a signal, but as discussed above these are simply too weak, particularly in comparison with the emissions of the host star. Radio waves are a different story. The luminosity of stars in radio waves is much lower than in visible light, so what we produce has a better chance of standing out. The first television broadcasts, and even more intensely the emissions from defense radar, are now a good 60 light years away and spreading. Civilizations much more advanced than ours might be able to pick these up. Our technology, however, would suffice to detect these emissions only out to about 1 light year, which is less than 1/4 of the distance to the nearest star from the Sun.

On the other hand, we have given a much stronger directed shout out using the largest radio telescope in the world. Located at Arecibo, Puerto Rico in a natural bowl, this dish is 300 meters in diameter. It can't be steered (too big!), and it is not a hidden underwater base for evil (as depicted in the James Bond film "Goldeneye"), but it is a tremendously sensitive receiver and can be configured as a powerful emitter.

On November 16, 1974 it was used to beam a message at the globular cluster M13, 25,000 light years away. Globulars have a few hundred thousand stars, so it was thought that this would provide the most bang for the buck; on the other hand, they are deficient in heavy elements, so planets might not be that common. In any case, the message had 1679 binary digits. Since $1679 = 73 \times 23$, the hope is that aliens would be intelligent enough to put the bits into 73 rows by 23 columns. They could then read the message, which involves counting from 1 to 10, the atomic numbers of hydrogen, carbon, nitrogen, oxygen, and phosphorus, and various other details of biochemistry, human size, and the size of the Arecibo telescope itself. Given that it will be at least 50,000 years before we could get an answer, the real point was to demonstrate the principle and the capabilities of the instrument.

This does bring up some important questions. If we decide to look for signals from other beings, then (1) how can we tell if a signal is artificial and (2) where should we look? Along these lines, let us consider the discovery of pulsars.

Pulsars and little green men

In 1967 in Cambridge, England, a graduate student in astronomy named Jocelyn Bell was finishing up her Ph.D. work. Her thesis was on quasars, which are exceptionally luminous objects usually many billions of light years away that turn out to be powered by energy released as matter spirals into supermassive black holes. These objects emit light at all wavelengths, including radio waves. To this end, Bell and four fellow graduate students of their advisor Anthony Hewish constructed a radio "telescope" that looked like you might hang your laundry. Bell was particularly responsible for the electric wiring.

After construction, Bell started taking data. This was the old days, prior to good computers, so the data were read out on paper charts that rolled along like data from a seismograph. After looking at literally miles of such charts, Bell was able to tell signals from noise. Near the end of 1967, she noticed a particular form of "scruff" in her data that reappeared every time the Earth had rotated to the same direction. Hewish suggested that she put a high-speed timer on (basically the rolls moved faster under the pens!), and it became obvious that this scruff consisted of extremely regular pulses of radio waves, once every 1.3 seconds.

They rapidly established that the emission came from the same direction in the sky, not the Earth, so this had to be of extraterrestrial origin. Nothing in astronomy was known to be that precise a clock, so there was an obvious question: could this be the signal from an advanced civilization? A couple of other similar sources were discovered in the meantime, and for fun they were temporarily named LGM 1, 2, and 3, for Little Green Men. Eventually it became clear that these were actually rotating magnetic neutron stars; a natural phenomenon, so close but no cigar. By the way, it speaks to the focus of grad students that Bell said later her first thought about the LGM possibility was annoyance; why did they have to contact her *now*, when she was working on her thesis?!

Identifying artificial signals

A challenge in determining if a signal is produced by an alien being, or in sending definitive signals ourselves, is that alien languages and cultures are probably so radically different from ours that we have nothing in common. For example, imagine sending a signal of an actor reciting "Hamlet". It's beautiful to us, but although an alien might detect some patterns and periodicities it might not be able to distinguish those from naturally occurring patterns.

It is generally felt that mathematics is the only truly universal language. Suppose, for example, that we sent a repeating series of beeps that represented prime numbers; positive integers that are divisible only by 1 and themselves, such as 2, 3, 5, 7, 11, 13, 17, and so on. No exact pattern exists for these as far as we can tell, and certainly no natural process would give them, so if we ever detected such a series we would be sure that it had to be artificial. Other mathematical sequences might work as well, but the aperiodicity of the primes make them, well, the prime candidate.

What is the best frequency?

Another question is what is the best frequency for us to search for likely alien transmissions. There are numerous considerations. Long-wavelength bands such as in radio waves are more energy efficient, and since our atmosphere is transparent to them we can search the sky with large telescopes. In addition, Sun-like stars tend not to emit much in the radio, so such signals would stand out more than signals in the optical. However, as we know from cell phones and wireless connections, the drawback of long wavelengths is that they have low frequencies and hence low bandwidth. It is therefore not possible to send a lot of information quickly in such bands. The best compromise is not clear; it could be that civilizations start out with radio waves, then communicate later with tightly focused laser beams at higher frequency. In such a case, we would be much less likely to be in the beam, so we would need to get extra lucky.

Historically, the first searches were done at the 1421 MHz frequency corresponding to a "spin flip" of a hydrogen molecule. More recently it has been suggested that a good place to look is the "water hole" around a few GHz, because this is a minimum in galactic emission and thus does not have many natural sources. The truth is we just don't know.

Status of current searches

Various attempts have been made to search the skies for artificial signals without, as yet, success. The most prominent such attempts have originated from the Search for Extraterrestrial Intelligence (SETI), which most recently ran Project Phoenix from 1995 to 2004. They used radio telescopes to search 800 stars within 240 light years of us. They also used SETI@home, software to farm out the huge amounts of analysis needed to millions of personal computers that would do the computations while otherwise lying idle. The total number of computations performed during this period exceeded 10^{21}, and currently averages more than 700 Teraflops, but still without results. A successor to this effort is being constructed: the Allen Telescope Array, which has 42 six-meter antennas and is funded by Paul Allen, a co-founder of Microsoft. We'll see what comes of this but the researchers on these projects have been very careful so we can expect that no announcement of a discovery will be anything but definitive.

What if no positive results are obtained within the next century? Would this prove that we're the only ones in our galaxy? Maybe or maybe not. It could be that other species aren't broadcasting "are you listening" signals. Maybe they only have focused beams of communication and these don't intersect the Earth. Maybe advanced civilizations are radio quiet. Maybe they destroy themselves quickly.

What do you think?