“ET Phone Home:”
Contact with Extraterrestrial Intelligence

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Abstract

For about the past century, humans have been broadcasting low-power radio messages into space. An extraterrestrial intelligence could seemingly detect our internal communications if they had a detector with the required sensitivity. Maybe this extraterrestrial civilization wouldn't even know how to interpret these broadcasts. Similarly, perhaps we can receive their messages. As it turns out, our ability to detect the existence of an extraterrestrial civilization may very well be correlated with our ability to communicate with them. Different media may make ideal modes of communication across interstellar space, but regardless of which is superior, it will still be limited by the speed of light. Sending physical objects into space that can serve as messages (e.g. Voyager and Pioneer) is even more greatly limited by Special Relativity, but probes offer other advantages. Our ability to detect and send up data is only half of the equation. Astronomers must also be able to analyze and interpret data to differentiate noise originating from space (pulsars, quasars, etc.) from an obviously artificial message. Scientists must also be able to use and understand a language based on a shared understanding of science and mathematics in order for communication to become a reality.

Contact With Extraterrestrial Intelligence

In a survey carried out by National Geographic, The SETI Institute, and the University of Connecticut, 72% of Americans would be "'excited and hopeful' to learn about a signal from E.T." (Shostak, 2012, p. 27). Not just Americans are interested in contact with extraterrestrial intelligence (ETI). All humans have a deep curiosity about the unknown, and we all want proof that we're not alone in the universe. Although the detection of ETI would itself be an achievement, we really yearn to communicate. In order for communication to become a reality, we must investigate how likely it is an ETI exists within the galaxy with which we may communicate, which means of communication are possible, and what the message itself should contain.

Why Try?

Astronomer Frank Drake, who conducted the first radio search for extraterrestrial intelligence (SETI), devised an equation to determine the prevalence of extraterrestrial intelligence in the Milky Way that know bears his name. The equation consists of a number of factors that are multiplied to give an estimate of the number of intelligent civilizations in the galaxy. It begins with the largest factor, the number of stars in the galaxy, and continues to decrease as more limits are placed into the equation. It now appears in many different forms, but they all express the same idea:

$N = S^* \text{ x } f_s \text{ x } f_p \text{ x } n_e \text{ x } f_l \text{ x } f_i \text{ x } L_i/L_{MW}$

Where S^* is the number of stars in the galaxy, f_s is the fraction of these stars suitable for life, f_p is the fraction of those stars that have planets, n_e is the number of suitable planets per system, f_l is the fraction of those planets on which life forms, f_i is the fraction of those planets on which intelligence develops, and L_i/L_{MW} is the lifetime of such a civilization divided by the lifetime of the galaxy.

The only problem with the Drake equation is that most of the values aren't known to very much accuracy. The only value that is known with much accuracy at all is the number of stars, which is 300 billion ± 30%. Still, the Drake equation can provide helpful insight as to whether or not an interest in contact and communication is really warranted.

The fraction of these stars that have characteristics deemed necessary for life—they contain heavier elements, which are necessary if planets are to form, and their luminosities aren't too high or too low—is about 10^{-2} or 10^{-3} (Goldsmith & Owen, 2002, pp. 445-446). Stars with high luminosities don't have lifetimes sufficient to allow for the evolution of complex organisms. Low luminosity stars have thin habitable zones, and the planets within these habitable zones become tidally locked.

As of April 2012, 763 exoplanets have been discovered (Schneider, *Extrasolar Planets Encyclopedia*). Although we don't really know how many of these planetary systems contain planets that might support life, the rapid discoveries of more and more exoplanets largely by the Doppler shift method suggests that it's quite common for planets to form along with their host star. Taking into account our own solar system and using Carl Sagan's assumption of mediocrity, it seems reasonable to think that for each suitable solar system there is at least one planet that contains life. Thus, a suitable estimate for this fraction could vary from 10^{-1} to 1 (Goldsmith & Owen, p. 446; Sagan & Shklovskii, 1966, pp. 357-358).

The next few factors are essentially total guesswork. f_l, the fraction of suitable planets in which life actually develops, was introduced to ensure a conservative estimate because theoretically life would form on all planets that are suitable. An estimate of ½, which was also used in *The Search for Life in the Universe,* seems okay (Goldsmith & Owen, p. 446). The fraction of these life-bearing planets that have intelligent, communicative species might be about 10^{-1}.

Homo sapiens has existed for approximately 100,000 years, but it seems likely that we will last for much longer considering the survival value of intelligence and technology. Astrophysicist J. Richard Gott proposed a very conservative estimate for our lifetime based on shaky statistical arguments resting completely on the Copernican principle of mediocrity applied to time. Gott estimates that the total lifetime of our species will be about 4 million years (1993, p. 315). Thus, a conservative estimate for L_i/L_{MW} would be $4*10^{-3}$ and a more reasonable estimate would be 10^{-1}.

Evaluating the equation with all of the suggested values, one finds that the number of civilizations in the galaxy may vary from one (ourselves) to millions of civilizations. Both extreme estimates are probably pretty far off. Drake's original estimate of 10,000 is probably more reasonable than either extreme (Garber, 1999, p. 4). The Drake equation suggests that it seems reasonable to conclude that there are at least a few other intelligent, communicative civilizations in the Milky Way. Thus, attempts at communication, especially low-cost ventures like radio, are well worth the money and energy. The payoff of receiving a message would also be huge regardless of its content. Simply knowing that there is ETI has enormous implications about the habitability of the universe and about the survival value of intelligence. If the message contains information, it might have a colossal impact on humanity. A message may share some unknown knowledge about the universe. It may also share art or music or maybe things we're not even capable of imagining.

A Brief History

For many centuries, scientists have considered the possibility of ETI. Giordano Bruno, an early 17th century philosopher, was burned at the stake for not only accepting a Copernican model of the solar system but for thinking that there were a multitude of other planets inhabited by other intelligent species. Nikola Tesla, the Austrian-American engineer and inventor, believed that he had made radio contact with ETI with one of his inventions. Guglielmo Marconi also believed that he might have received a radio signal from ETI on the planet Mars. Even Albert Einstein believed that contact with ETI might be made with light signals (Garber, pp. 3-4).

The modern, concerted effort to find ETI began with Giuseppe Cocconi and Philip Morrison. These Cornell physicists published a landmark paper in *Nature* in 1959 about "the optimum channel" that would place "a minimum burden of frequency and angular discrimination on the detector" and would not be "highly attenuated in space or the Earth's atmosphere" (Cocconi & Morrison, pp. 844-845). The radio frequencies that meet these demands must also be able to outshine their respective host star and other galactic sources. Cocconi and Morrison argue that the best frequency to begin searching is 1,420 Megahertz. This frequency meets the earlier demands; it's also the emission line of neutral hydrogen. Any civilization should, Morrison and Cocconi argue, be able to recognize the intrinsic importance of this frequency in the universe. The power required to transmit a detectable signal outlined above is within even our capabilities, so a more advanced civilization should be able to easily transmit with enough power. For sources within the plane of the Milky Way a frequency would have to be chosen near 1,420 Megahertz so the background radiation wouldn't pose a problem.

Independent from Cocconi and Morrison, Drake reached many of the same conclusions about SETI. Drake began the first real radio survey using inferior receivers in 1960 called "Project Ozma." He observed the stars Tau Ceti and Epsilon Eridani (two stars later determined by "Kepler" not to have planets). When he thought he might have finally found a signal, he discovered that it was actually secret military radar (Garber, p. 4). The technology didn't yet exist to begin a really monumental search. One year later, in 1961, Drake gathered several other scientists for a conference on SETI. This was when he first introduced his now famous equation. The conference finally brought more scientific credibility to SETI [Garber, p. 4; Sagan & Shklovskii, p. 380).

NASA scientists tried to get funding for a new SETI project, "Cyclops," which would cost $10 billion. Because of the unbelievable cost, "Cyclops," which would have consisted of 1,000 100-meter telescopes, never got funding. It wasn't until 1975 that NASA started to fund SETI. A few years later, congress cut funding. At this point, Carl Sagan talked with congressmen and convinced them to reinstate funding the following year. In the eighties, several private organizations also began making contributions to SETI. The Planetary Society funded some searches, Harvard astronomer Paul Horowitz constructed a portable "Suitcase SETI" and project "Sentinel" and the "Megachannel Extraterrestrial Assay," the University of California at Berkeley began "Serendip," and the University of Ohio began its "Big Ear" search. Finally, in 1984 the SETI Institute formed (Garber, pp. 3-5).

The Soviets also began SETI with influence from scientists Iosif Shklovskii (who coauthored *Intelligent Life in the Universe* with Sagan) and Nikolai Kardashev. Meanwhile, in the United States, in the eighties, senators and congressmen continued to argue about funding. NASA changed the name of one of the SETI programs to the "High Resolution

Microwave Survey" (HRMS). Repeatedly, senators and congressman tried and failed to cancel the program. After only a year of operations, they succeeded in killing the program once-and-for-all. It was out of the ashes of this program that The SETI Institute formed "Project Phoenix," which still continues today (Garber, p. 5).

Modes of Communication

There are many things to consider in attempting communication across the vast distances of interstellar space. Einstein's Special Theory of Relativity proved that no particle could travel faster than 300,000 kilometers per second—the speed of light. This speed barrier poses one of the greatest hindrances to sending information across space. In order to accelerate anything of mass anywhere close to the speed of light requires a massive amount of energy in addition to impressive technological ability. Because no particle can travel faster than light and because its relatively cheap and easy to produce a large number of photons, light seems to be one of the most promising media for communication.

Since electromagnetic (EM) radiation seems to be the easiest and fastest method of communication, naturally, the next question is: what part of the EM spectrum is ideal? Wavelengths greater than 300 meters (or frequencies less than 10^6 Hz) would be absorbed by interstellar gas. Wavelengths less than around 10 meters manage to pass through the ionosphere. Sagan and Shklovskii reason that most planets harboring life would have an ionosphere similar to Earth's. Planetary atmospheres block shorter wavelengths because of the effects of water vapor and other molecules. It seems likely that ETI inhabiting a planet with an atmosphere or perhaps even without an atmosphere would reach a similar conclusion. Thus, already the EM spectrum has been limited to between a wavelength of 3 centimeters and about 10 or 15 meters. The lower limit isn't necessarily a limit because satellites might be able to carry out observations of these higher frequencies (Sagan & Shklovskii, pp. 379-381).

The natural noise of the universe must also be taken into account. Much of the matter of interstellar space radiates low frequency EM radiation. The two natural sources of radiation in the universe are the Cosmic Microwave Background (CMB) left behind after the Big Bang and radiation resulting from the synchrotron process. Among all the background radiation and interference there is a gap between about 10 and 9,000 megahertz in the radio range of the EM spectrum (Goldsmith & Owen, pp. 487-490).

As previously discussed, Cocconi and Morrison's landmark paper determined that 1,420 megahertz, the emission line of neutral hydrogen, seems to be one of the most obvious frequencies for a communicative civilization to choose. Because the 21-centimeter hydrogen line itself is a considerable source of noise especially in the galactic plane, a civilization would likely choose a frequency near 1,420 megahertz but not 1,420 megahertz itself. Sagan hypothesized that ETI might multiply or divide this frequency by some fundamental constant like π or *e* in *The Search for Intelligent Life*, but more recently, in *Voyager*, he has suggested that such a demonstration of knowledge would be superfluous if the message itself was clearly artificial. Physicist Bernard Oliver instead hypothesized that ETI would transmit at some frequency between the emission lines of atomic hydrogen and hydroxyl—the so-called "water hole"—because life may require water (which consists of one hydrogen and hydroxyl) (Goldsmith and Owen, pp. 487-489). These ideas are merely hypotheses, and as technology has improved it has become possible to search many frequencies simultaneously, so they address a problem that is constantly becoming less important.

In order for interstellar communication to be a possibility, the issue of bandwidth must also be considered. A smaller bandwidth allows communication across greater distances and is easier to detect. Interstellar dispersion places a lower limit on the bandwidth of about 0.1 Hertz. Smaller frequency variations would occur naturally in the interstellar medium as a result of dispersion. An ideal bandwidth would be around 1 Hertz. Modern techniques in SETI allow multiple channels to be analyzed automatically.

Another important consideration is the power of the transmission. Obviously the signal has to be able to overpower its host star and other background radiation if there's to be any hope of the signal being detected. The directionality of radio antennas allows this feat to be easily achieved even with rather weak transmitters (Sagan & Shklovskii, pp. 382-388).

Radio transmissions may also reveal information indirectly about the planet from which they originate. Information about the planet's atmosphere and its orbit could be gleaned through a spectroscopic analysis of the signal. The Doppler effect of both the planets revolution around its star and its rotation may tell us how long the planet's day and year are (Shostak, p. 27).

Although radio seems to offer the best opportunity for communication, scientists continue to hypothesize about the use of optical frequencies. Lasers (Light Amplification by the Stimulated Emission of Radiation) and masers (an equivalent for Microwaves) produce collimated beams. Lasers are cheaper, easier to build, and more powerful than masers. Lasers are also constantly improving. Even today, lasers can outshine the sun by over a factor of 5,000 for a short period of time. Clearly, there is an emerging possibility that lasers, and maybe masers, could eventually be used for targeted beacons. The fact that lasers only produce monochromatic light make them bad choices for communication purposes since they can have no frequency modulation.

Although EM radiation offers what appears to be one of the most obvious choices for an interstellar message (IM), probes may also be used to share information with ETI. The first attempts at communication with ETI using physical objects were Pioneer 10 and 11. Both of these probes contained a plaque that indicated the solar system's location relative to several nearby pulsars and which planet the probe originated from as well as scaled pictures of a man and a woman standing in front of the probe itself (Sagan, et al., 57-59).

The Voyager spacecrafts (1 & 2) contain a gold-plated 16 2/3 RPM record containing pictures and sounds from Earth. The aluminum cover for the record is etched with instructions on how to read the record as well as the same pulsar map that was on the Pioneer plaques (Sagan, et al., pp. 36-38). Voyager 1 is now the furthest man-made object from Earth. It is about 150 Astronomical Units away from Earth and is about to leave the solar system.

Currently, probes can only be accelerated to very tiny fractions of the speed of light. They don't travel anywhere near as fast as light, but they possess advantages besides speed. Since they are physical objects, probes can theoretically last for billions of years in the vacuum of interstellar space. Long after humans are gone and all traces of humanity have been erased from the Earth, these probes will still be around. Our radio messages will also exist, but because they'll be billions of light years away. There's little chance that they'll ever be intercepted across such great distances.

Scientists have hailed radio as the most energy efficient means of communication, but new calculations by Christopher Rose and Gary Wright suggest that probes are comparably energy-efficient. Using the lightest available materials and modern advances in nanotechnology, launching matter artifacts into the cosmos may be comparable to sending high power radio messages. These calculations ignore shielding and other factors (Rose & Wright, 2004, p. 47). Still, probes offer other advantages. They last indefinitely, they could contain bacterial spores which could theoretically live in the vacuum of space for millions of years, and they could be coated with radioactive material to give the object its own radioactive clock so ETI could figure out how old the message was. Even if probes are never intercepted by ETI, they could act as time capsules for human beings. There aren't many environments on Earth that aren't subject to decay and erosion over periods of millions of years.

Radio is currently the fastest means of communication, but physical objects are the longest means of communication. The galaxy is large both with respect to time and space; thus, it is important to consider that some media are fast but short-lived while others are slow but almost eternal.

As technology progresses, there is also a possibility that new, superior means of communication will be discovered. Currently, there's a lot of speculation about the use of gravity waves or neutrinos to communicate. As of yet, these possibilities are still entirely theoretical. Neutrinos are nearly impossible to detect and therefore seem to be a terrible choice for SETI. Likewise, a single gravity wave has never been detected. Although there are probably better ways of communicating across interstellar space than have so far been considered, it seems best to stick with what we know, and hopefully, ETI will continue sending radio that even primitive civilizations are capable of detecting as their technology evolves.

Constructing an Interstellar Message

Hundreds of thousands of years ago, our ancestors used facial expressions to communicate their emotions like many primates still do today. Later, humans developed a spoken language to express abstract concepts to one another. Written language emerged even later. Written messages for the first time gave humans the ability to transmit their thoughts over vast distances of space and time. This method of communication was, and still remains, totally dependent on the fact that the receiver understands the sender's language, which is based on completely arbitrary shapes (letters or characters) and sounds. Humans continue to seek ways of speeding up communications. Only recently, humanity has learned to control and utilize the EM spectrum for messages that travel as fast as physics allow.

ETI probably won't be able to understand any human languages. Even considering that ETI may have intercepted our past radio and television broadcasts, understanding human languages would be a very complicated affair. Instead, our IMs should rely on a shared understanding of mathematics and science. In order for ETI to receive and transmit messages, it must know something about science and math, and therefore, it stands to reason that mathematics should form the underpinnings to decoding and understanding the message.

A binary numbering system is a much more natural choice than the arbitrary decenary system which emerged out of the accident of humans having ten fingers. Binary is the simplest possible numbering system since it relies on only two symbols, and many natural phenomena are binary in nature. It also arises naturally from the fact that circuits can be only on or off.

A simple message would most likely consist of a picture. There is much truth to the adage that a picture is worth a thousand words. Pictures can manage to pack more information than one might expect considering the bit length of the message. For example, the Arecibo Message, sent on November 16, 1979, consisted of 1,679 bits. As any mathematician would likely notice, 1,679 is divisible by prime numbers 73 and 23. If the message is laid out into a 73 by 23 bit rectangle, one discovers a picture packed with information. It includes information about the solar system, human beings, DNA, which elements life is composed of, and the Arecibo radio telescope itself. All of this information would be fairly easy to glean from only 1,679 bits (Sagan, et al., pp. 59-65).

IMs don't have to be restricted to pictures though. Hans Freudenthal, a Dutch mathematician, has described a language called *Lingua Cosmica* (LINCOS) based on mathematics. The dictionary for the language would begin simply in binary with basic expressions like: 1+1=10 T, 1+1=1 F, 101+11=1000 T. (In these cases, *T* would represent true and *F* false.) Building up from expressions that become more and more complex, Freudenthal creates a language capable of describing things as complicated as human emotions using only a basic, shared understanding of logic (Sagan, et al., p. 48; Freudenthal, 1966).

Since we are very capable of sending out information, we should next consider what information is worthy of representing our species. Most of our messages to ETI have consisted of a small amount of practical information. The Arecibo transmission, the Pioneer plaque, and the Voyager record contained information about the location of human beings and humanity itself. The Voyager record also contained recordings of music and black and white as well as color pictures.

Music has self-similar characteristics that emerge over time which lend themselves well to radio transmissions (Vakoch, 2003, p. 33). Music's highly-organized, complex structure makes it an obvious beacon of artificiality. Self-similarity is also a common characteristic of all life on Earth. Structures as different as trees, snails, and human blood vessels all have fractal-like structures. The emergence of self-similarity in art is therefore reflected in the structures of nature. The Golden Ratio and *e* express fundamental mathematical concepts, but they have critical importance in the natural world as well (Lam, 2004, pp. 37-38; Ollongren, 2004, pp. 38-39). Art reveals these mathematical relationships, and it simultaneously communicates information about the human consciousness that created it.

If we were to receive IMs from ETI, we would very likely be interested in their culture. In fact, information about their culture might be of more interest than their location or what elements they are primarily composed of. There is also a possibility that ETI might share their more advanced understanding of the universe with us. The benefits to all the sciences, mathematics, and even culture would be incalculably immense if humanity received a message from any ETI.

Even if our messages are never received, constructing IMs may be beneficial for us. Physical objects could act as time capsules that could one day be discovered by our ancestors. The construction of LINCOS has already benefitted the fields of logic and linguistics. Constructing an IM forces us to think about what core characteristics make us so unique.

Conclusion

Homo sapiens has always been fascinated with the heavens. We want desperately not to be alone in the universe, so we should not allow wishful thinking to cloud our judgments as it has those who believe that they've been visited by UFOs or probed by aliens. Nevertheless, everything we know about the universe urges us to seriously consider the possibility that ETI exists within our galaxy. Making low-cost attempts at radio communication will cost us almost nothing, but receiving an IM from ETI would mean everything.

References

Carlotto, M. (2007). Detecting Patterns of a Technological Intelligence in Remotely Sensed Imagery. *JBIS, 60,* 28-39.

Clar, R. (2004). The Process of Art in Interstellar Message Construction. *Leonardo, 37, no. 1,* 35. Retrieved from http://www.jstor.org/stable/1577564

Cocconi, G. and Morrison, P. (1959). Searching for Interstellar Communications. *Nature, 184,* 844-846.

Freudenthal, H. (1966). *The Language of Logic.* Amsterdam: Elsevier Publishing Company.

Garber, S. (1999). Searching for Good Science: The Cancellation of NASA's SETI Program. *Journal of The British Interplanetary Society, 52,* 3-12.

Goldsmith, D. and Owen, T. (2002). *The Search for Life in the Universe* (3rd ed.). Sausalito, CA: University Science Books.

Gott, J. R. (1993). Implications of the Copernican principle for our future prospects. *Nature, 363*, 315-319.

Kaiser, A. (2004). Sound as Intercultural Communication: A Meta-Analysis of Music with Implications for SETI. *Leonardo, 37,* 36-37. Retrieved from http://www.jstor.org/stable/15775636

Lam, L. (2004). A Science-and-Art Interstellar Message: The Self-Similar Sierpinski Gasket. *Leonardo, 37,* 37-38. Retrieved from http://www.jstor.org/stable/15775637

Loeb, A. and Zaldarriage, M. (2007). Eavesdropping on radio broadcasts from galactic civilizations with upcoming observatories for redshifted 21 cm radiation. *Journal of Cosmology and Astroparticle Physics,* 1-12. doi: 10.1088/1475-7516/2007/01/020

Ollongren, A. (2004). Large-Size Message Construction for ETI: Music in Lingua Cosmica. *Leonardo, 37,* 38-39. Retrieved from http://www.jstor.org/stable/15775638

Quill, E. (2010). Can you hear me now? Astronomers reconsider how extraterrestrials could make contact. *Science News, 177,* 22-25. Reftrieved from http://www.jstor.org/stable/20697969

Rose, C. and Wright, G. (2004). Inscribed matter as an energy-efficient means of communication with an extraterrestrial civilization. *Nature, 431,* 47-49.

Schneider, J. (2012). Interactive Extra-solar Planets Catalog. *The Extrasolar Planets Encyclopaedia.* Retrieved from http://exoplanet.eu/catalog.php

Sagan, C., Drake F. D., Druyan A., Ferris T., Lomberg J. and Sagan L. S. (1978). *Murmurs of Earth: The Voyager Interstellar Record*. New York, NY: Random House.

Sagan, C. and Page, T. (Eds.). (1972). *UFO's: A Scientific Debate.* Ithaca, NY: Cornell University Press.

Sagan, C. and Shklovskii, I. S. (1966). *Intelligent Life in the Universe.* San Francisco, CA: Holden-Day.

Shostak, S. (2012, May). What Happens When We Detect Alien Life? *Astronomy, 40(5),* 24-29.

Vakoch, D. (2004). The Art and Science of Interstellar Message Composition. *Leonardo, 37,* 32-34. Retrieved from http://www.jstor.org/stable/1577563

Ward, P. D. and Brownlee, D. (2000). *Rare Earth: Why Complex Life is Uncommon in the Universe.* New York, NY: Copernicus.