Extraterrestrial Life: Lecture #23

Search for Extraterrestrial Intelligence (SETI)

If there are other “intelligent” civilizations in the Milky Way galaxy, how might we detect them?

- what does “intelligent” mean in this context: able to construct objects or create signals that we might be able to detect…

Discuss: energetic requirements for communication, some possible search strategies…

In principle, several different ways that other civilizations might communicate with us:

Physical artifacts

Numerous locations in the Solar System (e.g. surface of the moon) where probes or artifacts could survive for billions of years… where to look?

Communication: photons (radio, light etc) or particle beams (electrons, neutrinos…) - photons are not deflected by magnetic fields and suffer little absorption… seems most efficient option.

Types of communication

Distinguish between:

Unintentional broadcast of radio (or other) signals into space, which could be detected at interstellar distances. “Leakage” may be inevitable, but level and duration is very uncertain.

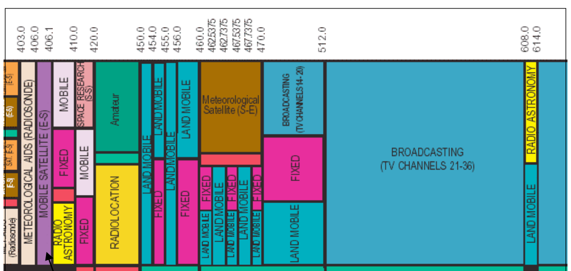
Intentional broadcast of “beacons” - signals designed to be (more) easily detectable, identifiable as artificial, and decodable.

Power and bandwidth

Critical concept for thinking about SETI searches is to distinguish between *power* and *bandwidth*.

Power is the total energy radiated per second by the transmitter - measured in Watts (Joules per second)

Bandwidth is the range of frequencies that the signal is spread out over - measured in Hz



e.g. this signal has a central frequency of 406.05 MHz and a bandwidth of 0.1 MHz

Signal detectability

Natural sources are often powerful (large number of watts radiated) but the power is spread out over a rather wide bandwidth.

e.g. natural radio sources typically have:

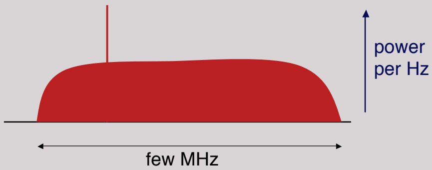
$$\frac{\Delta \upsilon}{\upsilon} \approx 10^{-4}$$

i.e. bandwidth is ~1/10,000 of the frequency (sources called *masers* have narrower signals)

Artificial signals can be very narrow-band: $\Delta\nu / \nu \sim 10^{-14}$, so given modest power they can outshine natural sources provided that we “tune” to the right frequency.

Terrestrial transmitters

Analog TV signals are spread out over several MHz, but with a narrow spike of power in the *video carrier* that is ~0.1 Hz wide:



Power is radiated approximately isotropically (in all directions) - strong TV transmitters have a total power of a few MW.

Power density in the video carrier is around 1 MW in a bandwidth of 0.1 Hz - about 10^7 W / Hz.

Sun radiates only about 10^3 W / Hz, so even leakage transmissions from the Solar System outshine the Sun and could be detectable above the natural background.

Military radars are much more powerful, but typically spread the power over a wider bandwidth.

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Signal detectability

For an isotropic source, flux received is the power divided by the area of sphere that is centered on the source:

$$F = \frac{P}{4\pi d^2}$$

For a power of 1MW, at a distance of 1 light year:

$$F = \frac{10^6 \text{ watts}}{4\pi\left(9.5\times10^{15}\text{ m}\right)^2} = 10^{-27} \text{ watts / m}^2$$

Previous SETI searches have had sensitivity ~10^{-26} watts / m^2 - insufficient to detect leakage from terrestrial analogs, especially as no star is as close as 1 light year.

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300m radio telescope at Arecibo

Change in the radio leakage with time:

- digital terrestrial broadcasts are much *less* powerful than analog TV signals
- satellite, cable and fiber optic communications produce little or no detectable emission

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Conclusions…

Unintentionally broadcast signals are in principle detectable (brighter than natural sources in some radio bands)

Could be distinguished either by their narrow bandwidth or by temporal variation (pulsed on short timescales)

Optimum search needs to cover many very narrow channels to be sensitive to narrow bandwidth signals

With current technology, surveying many stars at useful sensitivity is very difficult

"Radio loud" phase of Earth's communications is probably short lived - better technology reduces emission level

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Beacons

A deliberately broadcast signal can be much stronger, primarily because it can be *beamed* into a very small fraction of the sky - within the beam the flux is much larger than for an isotropic signal

$$F = \frac{P}{4\pi d^2 f}$$

…where f << 1 is the fraction of the sky the signal is beamed into

A satellite dish used for uplinking signals concentrates the signal into just such a narrow beam.

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How narrow can the beam be?

Waves of wavelength λ can be focused by a dish of size D into a beam with angle θ:

$$\theta = \frac{\lambda}{D}$$

…where the angle is measured in radians (1 radian = 360 / (2π) = 57.3 degrees)

A radio signal at 1 GHz has a wavelength of 30cm

The Arecibo dish (300 m across) can concentrate the signal into a beam of angle:

$$\theta = \frac{0.3 \text{ m}}{300 \text{ m}} = 10^{-3} \text{ radians } = 0.05 \text{ degrees}$$

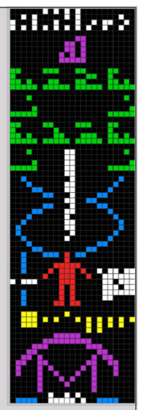
Area of the beam on the sky is about $\pi\theta^2 = 0.01$ square degrees

On the whole sky there are ~40,000 square degrees, so the Arecibo beam is beamed by a factor 4 x 10^6

Recalling the inverse square law, the beamed signal is detectable to a distance 2000 times greater than an isotropic signal of equal power.

In 1974, Arecibo was used to send a short message toward the globular cluster M13 (25,000 light years away)

Current SETI searches could detect similar signals from distance of a few 1000 light years - enough to encompass many stars



Optical SETI

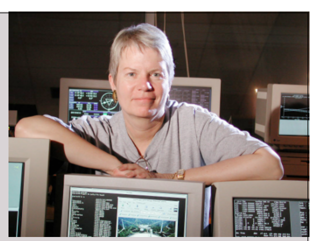
Sun is much brighter in the optical than in the radio, but lasers can be built with extremely narrow bandwidth and concentrate power in very short pulses

Detectable via coincidence - look for 2 photons arriving in a time period where that would be very unlikely due to natural sources

Relatively little work done yet…

Is SETI worth pursuing?

Congress cancelled NASA's small SETI program in the 1990s, continues with private support.



Jill Tarter: "It may take another 40 years, or 400 years, or even 4000 years for this exploratory scientific effort to find what it seeks or to conclude that there is nothing to be found. On the other hand, it could succeed tomorrow…"