I know perfectly well that at this moment the whole universe is listening to us --- and that every word we say echoes to the remotest star.

Jean Giradoux, The Madwoman of Chaillot
Search Strategies

Suppose you find a civilization.

You want to communicate.

How?
Options

Passive SETI: Listen

Active SETI: Transmit
Search Strategies

There are two issues:

A. Technical

B. Sociological
Technical Issues

Space travel is slow, expensive, and inefficient (come back Thursday to find out why).

• Photons travel at the speed of light.
• Any technologically-advanced civilization can manipulate light.
• Photons are cheap.

Let’s communicate by radio!
Photons

All electromagnetic radiation consists of photons.

Some photons are better than others.
Why Radio?

Radio has certain advantages. Radio penetrates the atmosphere.

Radio: wavelengths ~1 cm to 10 km
  frequencies ~$3 \times 10^4$ to $10^{10}$ Hz (cps)
  ($\nu = c/\lambda$)

AM radio: 1000 KHz (30,000 cm)*
FM radio: 100 MHz (300 cm)
TV: 40-300 MHz

*AM is reflected by the ionosphere
Why Radio?

Radio has certain advantages.
Radio photons are inexpensive.

Photons carry energy
\[ E = h\nu = \frac{hc}{\lambda} \]

Cost per photon decreases with increasing wavelength

At a cost of $0.20 per kW-hr,
\( 2 \times 10^{29} \) radio photons cost about $0.01
Why Radio?

Radio has certain advantages. Radio receivers/transmitters are low-tech and inexpensive.

Radio technology has been in use for over a century (since ~1890).

Tesla (1901) and Marconi (1924) thought they had detected interplanetary radio signals.

1000 ft radio telescope, Arecibo, Puerto Rico
Why Radio?

Radio has certain advantages.

Stars are faint radio sources

The Earth is the brightest MHz radio source in the solar system, 10 times brighter than the Sun.

A strong radio source from the direction of a star may be an advanced civilization.
Why Radio?

Development of radio technology seems a reasonable step in the development of a technological civilization.

**MHz radio** (FM, TV) escapes the atmosphere.

**Radar** escapes the atmosphere.
Detectability

With current technology, we can detect

• Our own military radar at 150 ly
• Directed GW power from Arecibo at 100,00 ly
Tradeoffs

- **Broadband** is expensive;
- **Narrowband** is easy to miss.
- Brightness falls off as $1/d^2$
- Signals travel at $c$; you can easily miss it.

![Diagram showing video and sound carrier frequencies with a bandwidth of 5.75 MHz.](image-url)
Where to Listen?

The water hole - 1660 MHz (18 cm)

From setileague.org
Other Frequencies

1420 mHz - H I spin flip transition

2840 mHz - twice the H I transition

2.6 GHz - because \( \frac{(2\pi e^2)^5}{(h^6 c^3)} = 2.5568 \text{GHz} \)
Listening Strategies

Targeted Searches:
• Focus on particular suitable stars

Surveys:
• Piggyback on other surveys
• Large number of stars

Bandwidth vs. Channels
• Artificial signals should have narrow bandwidth
• Broad frequency coverage requires lots of channels
How to Communicate

What will we have in common with an alien civilization?

Mathematics.
How to Communicate

Pictures are a good way to communicate.

A string of $N$ bits can be arranged into a picture if $N$ is the product of two prime numbers $X$ and $Y$.

If $N$ is a product of 2 primes, the message may be a picture.

There are two choices of picture size: $X \times Y$ or $Y \times X$
A Simple Message

Consider the message:
101011101110111011100101010001000
10100010000111011001000100010100101
01010001000100010001010101010111010001
0001110010

It consists of 115 bits

115 is the product of 2 primes: 5 and 23

What’s the picture?
A Simple Message - Decoded

5 x 23

HELLO!

23 x 5
A Real Signal

Sent in direction of globular cluster M13 in 1974
A Real Signal - Interpreted

1679 bits
23 x 73 image

Numbers 1-10
DNA Atomic Nos. (1,6,7,8,15)
Molecules in DNA

DNA # of nucleotides

Human being (+height, population)

Solar System

Areceibo telescope
Natural vs. Artificial

What distinguishes a natural signal from an artificial signal?

An **artificial** signal
- May repeat.
- May be periodic.
- May contain numerical sequences.
- Will **not** be random.

A **natural** signal
- Will not repeat.
- May be periodic.
- Will **not** contain numerical sequences.
- May be random.
PSR 1919+21

A signal that repeats every 1.337 seconds
Dubbed LGM-1
The first pulsar (rapidly rotating neutron star) detected
Listening to Pulsars

- **PSR B0329+54**: A typical, normal pulsar. Period = 0.714519 sec, i.e. ~1.40 rotations/sec.

- **PSR B0833-45**, The Vela Pulsar: center of the Vela SNR, ~10,000 years old. P = 89 msec; ~ 11/sec.

- **PSR B0531+21**, The Crab Pulsar: The youngest known pulsar (957 yrs) ; the center of the Crab Nebula. P = 33 msec; 30/sec.

- **PSR J0437-4715**: a millisecond pulsar, an old pulsar spun up by accretion of material from a binary companion star. P=5.7 msec; ~ 174/sec.

- **PSR B1937+21**: second fastest known pulsar, P = 1.5578 msec, ~ 642/sec. The surface of this star is moving at about 1/7 c.
# Ongoing SETI Searches

<table>
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<th>Hz</th>
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</table>

SETI@home - processing of SERENDIP data
Physical Messages

- Hyperfine transition of neutral hydrogen
- Silhouette of spacecraft
- Binary equivalent of decimal 8
- Position of Sun relative to 14 pulsars and the center of the galaxy
- Planets of Solar system and binary relative distances
Voyager Golden Record
Voyager Golden Record

12” gold-plated copper record

115 pictures (analog)

16/2/3 rpm audio LP
  • Greetings in 55 languages
  • Natural sounds
  • 90 minutes of music

+stylus and instructions
Tradeoffs

Physical messages make sense *in some situations*:

• They can carry a high information density
• They need not be repeated
• They do not weaken with distance

But…

• They travel slowly
• Initial cost is high.

see Rose, C. & Wright, G. 2004, Nature, 431, 47
http://www.winlab.rutgers.edu/~crose/cgi-bin/cosmicB.html
Optical SETI

Optical light has advantages:

• It can be put into a narrower beam
• It carries a higher information density

And one big disadvantage:

• Stars are very bright in the optical

Optical SETI signals are likely to be pulsed laser
Sociological Issues

Active SETI?

We’ve been transmitting since the 1920s

It’s too late to take back!

Our ambassadors:
  • Amos ‘n Andy
  • The Beverly Hillbillies
Sociological Issues

Suppose we get an answer…
What Have We Heard?

Nothing yet…

15 August 1977, Big Ear project, Ohio State
Duration: 72 seconds. Did not repeat.
Two-Way Communications

- Unlikely - the distances are large
Why Search?

• We’ve had no success in 60+ years
• The probability of success is small
• Congress has prohibited NASA from funding SETI
  (NASA was awarded “Golden Fleece Award” by Senator William Proxmire in 1976 for SETI)

• But if we don’t search, the probability of success is zero!
Want to help?

http://setiathome.berkeley.edu/
The SETI Institute http://www.seti.org/