The Cosmic Haystack

The search for ETI takes place in a multidimensional space often refered to as the *Cosmic Haystack*

The first 3 dimensions are the ordinary 3 spatial dimensions

- **1** & **2** — 2 dimensions desribe the direction in the sky.

  Since a radio telescope detects all the radiation within the beam, for an *all sky search* we must consider how many beams it takes to cover the sky.

  With a 100 m telescope operating at 21 cm the beam is about $7'$and it would take about 9 beams to cover a line 1° long. To cover the whole sky would require several million beams.

- **3** — depth

  We receive all signals along a given line of sight, however we can only detect signals above some threshold. We can increase the depth of a search by searching for weaker signals.

    To detect weaker signals we can use bigger radio telescopes, build better receivers, or increase the time of observation.

The next 2 dimensions involve the search in frequency

- **4** — bandwidth

  If the receiver bandwidth is wider than the broadcast bandwidth you get noise from parts of the spectrum where there is no signal. Hence Signal/Noise $\Downarrow$ because noise $\Uparrow$

  If the receiver bandwidth is narrower than the broadcast bandwidth you miss part of the signal. Hence Signal/Noise $\Downarrow$ because signal $\Downarrow$

  The optimum Signal/Noise is achieved when the broadcast and received bandwidths are the same.

  Unfortunately the "Interstellar Broadcast Commission" has yet to tell us the bandwidth. For "beacons" we know that it would be narrow.

- **5** — frequency

Lacking an interstellar TV Guide we must search in frequency, i.e., tune up and down the dial

First consider a search of the AM radio band which reaches from 0.55 MHz to 1.6 MHz and where the bandwidth is 5 kHz.

The number of possible stations is:

$$N = \frac{\text{Frequency(upper)} - \text{Frequency(lower)}}{\text{bandwidth}}$$

$$\text{or } N = \frac{1.6 \times 10^6\,\text{Hz} - 0.55 \times 10^6\,\text{Hz}}{5 \times 10^3\,\text{Hz}} \approx 210$$

Listening for 1 sec at each point, a single scan of the AM dial requires 210×1 sec or roughly 3 minutes.

Now consider a *SETI* search for a 1 Hz bandwidth beacon where we cover the entire low noise *SETI* window from 1 – 10 GHz. Lets suppose we "listen" at each frequency for a time t_{sample} which might be something like 30 sec. The frequency search time t_{ν_search} is

$$t_{\nu\_\text{search}} = \frac{\text{Frequency(upper)} - \text{Frequency(lower)}}{\text{bandwidth}} \times t_{\text{sample}}$$

$$t_{\nu\_\text{search}} = \frac{10 \times 10^9\,\text{Hz} - 1 \times 10^9\,\text{Hz}}{1\,\text{Hz}} \times 30\,\text{sec} \approx 3 \times 10^{11}\,\text{sec} \approx 10^4\,\text{yr}$$

Remember that for an all sky search we must search in millions of directions.

Things are not quite so bad because a typical radio telescope will allow you to observe perhaps 1000 frequencies (or channels we say) at the same time.

Still a whole sky all frequency search takes

$$t_{\text{whole\_sky}} = \frac{3 \times 10^{11}\,\text{sec/freq/direction}}{1000\text{ channels}} \times \text{few} \times 10^6 \text{ directions} \sim 10^{15}\,\text{sec or} > 10^7\,\text{yr}$$

$\Longrightarrow$ *SETI* does not fit standard radio astronomy. A systematic frequency search requires many, many frequency channels

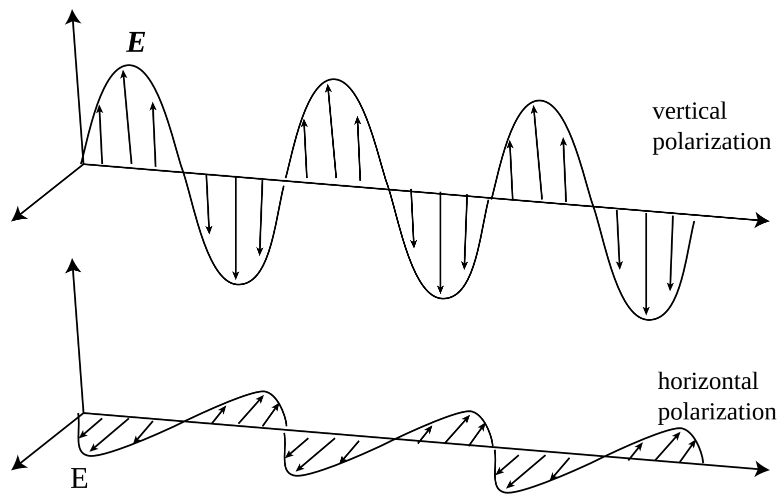
Even with 10^7 channels and cutting $t_{\text{sample}} = 3$ sec a whole sky all frequency search takes 300 years.

• **6** — Polarization

With most natural sources of radiation produce unpolarized radiation. The electric field of the different photons are oriented in different random directions.

If the electric fields are all in the same direction the radiation is call plane polarized.

The plane of the electric field in an EM wave is the plane of polarization.



There are two independent polarizations, which one could call vertical and horizontal.

In addition to "plane polarization" EM radiation can be circularly polarized—where electric field rotates as the wave propagates. Circular polarization is described as either right or left-handed.

The search in polarization presents no problem since ther are only 2 kinds. In fact, many radio telescopes observe both polarizations simultaneously.

Most astronomical sources of radiation are only partially polarized. A high degree of circular polarization is very rare. One way of flagging a SETI signal as intelligent in origin would be to broadcast circularly polarized messages.

• **7** — Modulation

Is the signal continuous, pulsed, AM, FM

Pulsed signals (like flashing lights) can be easier to detect.

• **8** — Time

The signal may not always be present

Narrowing the Search

Because the Cosmic Haystack is so big, *SETI* projects have until recently narrowed the search basically by guessing where in the Haystack to look.

- Targeted Searches

  Rather than searching the whole sky, one searches for signals from some "target." Typically targets have been nearby solar-type stars like τ Ceti.

- Magic Frequency searches

  Here one "guesses" a frequency assuming "they" are trying to make it really easy for us. I.e., they broadcast on a frequency that they know that we know. Typically these have been frequencies radiated by naturally occurring molecules. Some possibilities are:

Substance	Symbol	λ	ν
Hydrogen	H	21 cm	1.4 GHz
Hydroxyl radical	OH	18 cm	1.7 GHz
Ammonia	NH_3	1.3 cm	23 GHz
Water	H_2O	1.3 cm	23 GHz
Formaldehyde	H_2CO	6.2 cm	4.8 GHz
Carbon Monoxide	CO	2.6 mm	115 GHz
Ethanol	CH_3CH_2OH	2.9 mm	103 GHz
Positronium	e^+e^-	1.5 mm	203 GHz
Muonium	μ^+e^-	6 cm	4.7 GHz
3-Helium	$^3He^+$	3.5 cm	8.7 GHz

  The band from H to OH is often called the water hole.

  Some of these are out of the lowest noise window. They can be observed with less efficiency from the Earth or eventually from space.

  In the early 60's the only transition known in the low noise window was the 21 cm line of H. It made a lot of sense to chose this as a magic frequency then.

  It is not so obvious now what is "magic." ETI wanting to communicate with UVa students would find the ethanol line attractive. Kardashev pointed out that radio astronomers would block transmissions on frequencies of wide interest to them. He also pointed out some advantages of higher frequencies. He suggested *SETI* observations at the frequency of positronium, a hydrogen like configuration with a positron substituted for the proton. Positronium is very unstable and would not be found in large quantities in nature. Still it is well studied in the lab presumedly by them as well as us.

  Rood & Bania extended Kardashev's arguments to muonium and $^3He^+$.

  Even with a magic frequency one has to do some searching in frequency due to the Doppler shift of our motion relative to theirs.

In these terms, Drakes Project OZMA was a targeted magic frequency search.