Typical candidate SETI signal and the Procedure required to get a candidate signal.[1] [2]

We are generally looking for a “bright” (can be observed) **narrow-bandwidth** (1 Hz) signal from somewhere outside of the confines of Earth. Some good ways to do this is through the following methods:

- to point to somewhere in the sky, and see if the signal has a 24-hour period.
- To see if the signal has a Doppler shift – if it is outside the solar system, the frequency shifts will correspond to the motion of Earth around the sun and the rotation of the earth.
- Man-made sources (such as Earth-based and satellite-based) are constant; however, extraterrestrial signals are expected to be “fixed” to the stars, and so the signal entering into a radio telescope fixed to the earth would modulate over some seconds (SETI@home).

Why narrow-band? Because natural sources (pulsars, galactic noise, exploding stars, active galactic nuclei) are **broadband** sources. Of course, we are neglecting any possible SETI signal that is broadband.

Four types of signals are being searched for:

1. spikes – signals much stronger than natural noise; SETI@home examines spikes that are 22 times the background noise level.

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1 From http://www.computer.org/cise/articles/seti.htm., http://home.t-online.de/home/Bernd.Fiedler.RoschStr.Leipzig/signals.htm, and http://setiathome.ssl.berkeley.edu/about_seti/about_seti_at_home_1.html.

2 Note: these criteria are used by SETI@HOME in the determination of a signal – I am using these as a “candidate” because, to date, we have the best chance of determining a signal from them, since some of the largest amount of computing power in our recent history is devoted to analyzing the sky for SETI signals.

2. Gaussians – these are signals with a Gaussian (special kind of "humped" profile in time) profile.

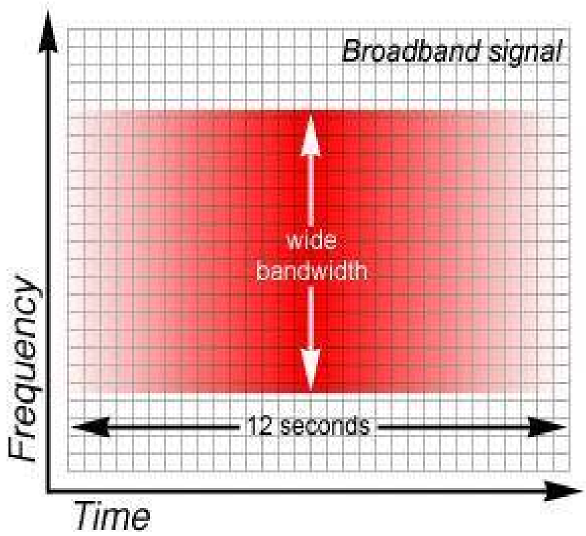
3. Triplet – pulsed signals will appear as triplets when sent as jobs to computer processors. SETI@home only locates signals that are 7.75 times the background level or above.

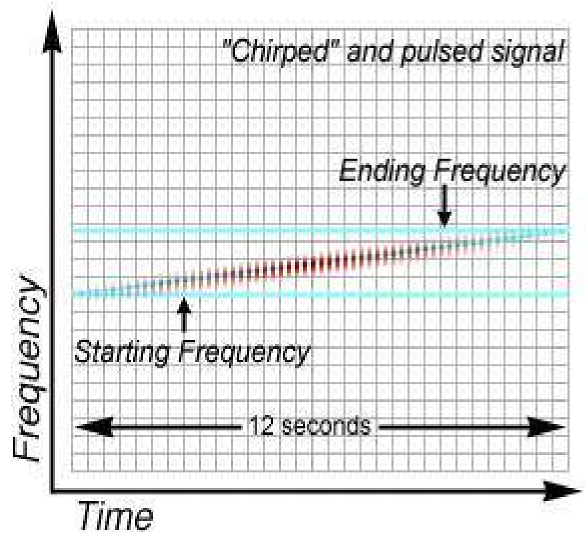
4. Pulses – signals which repeat at constant intervals, if the alien intelligence wishes to communicate this way.

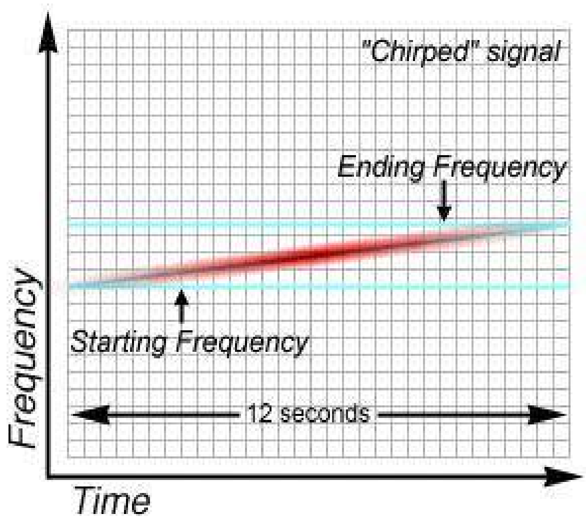
The multiple confirmation of signals from many sites around the world is not effective or particularly accurate (as was shown in the movie *Contact*) – it would most certainly be hidden in the reams of "data." We do not have the computing power to analyze the data received by various SETI detectors in the world currently operating in real time.

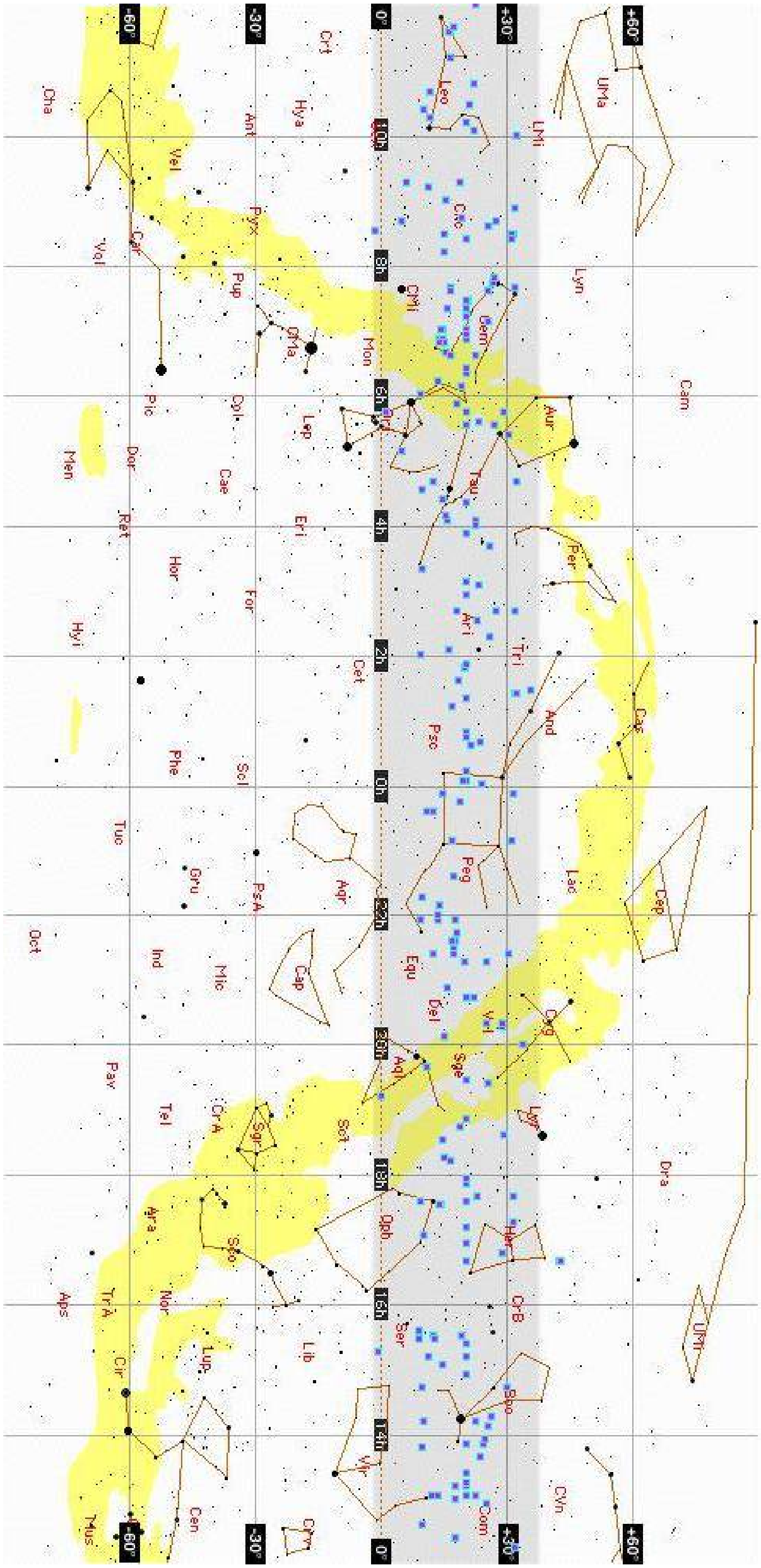
- We have no idea what it is – so of course we have to search over as wide a total frequency range as possible, in as short a bandwidth as feasible – requiring MANY MANY cycles of computing time.
- Confirmation must be done ***after the fact***.

Shown below are plots showing a broadband (natural) radio signal, a single narrowband signal, and a chirped narrowband signal – the last two are "extraterrestrial" and "artificial."









Also shown are the 150 most promising "candidates" of the SETI@home observation and computing project across the sky (collated March 2003). These candidates are shown in blue. The yellow is the Milky Way, and maps out the galactic plane.

The above results are different from what has been previously stated in the literature for the determination of a candidate signal (this information is a few years out of date, at least, so it does not behoove one to remember too closely). These previous searches were constrained by observation time and processing (computing power). There, for example, one required:

- Confirmation at later times – the data set was so small that it was expected that the only way to find a signal was to “see” it in the sky, and then confirm with other observatories.
- A much less thorough criterion for choosing signals. The huge amounts of computing time devoted to something like SETI@home is about 10 orders of magnitude greater than anything that has ever been done in SETI, and allows for much fancier more nuanced data analysis – something typically seen in experimental particle physics and biomolecular modeling, but not in astronomy.

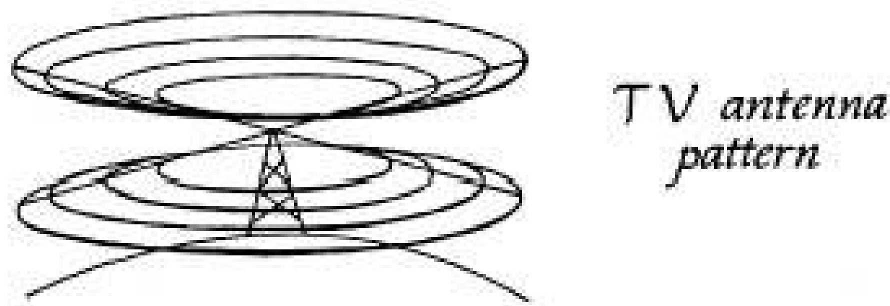
Radiation Received from Extraterrestrial Intelligences

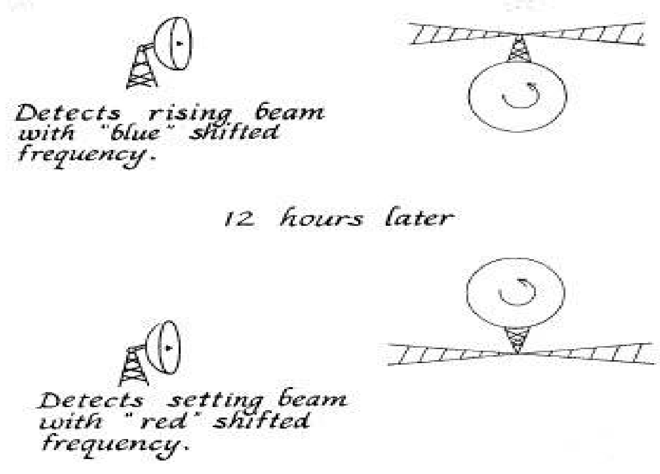
- SETI beacons
  - Very narrow bandwidth, therefore almost no information content.
  - The purpose is to send the signal as far out as possible.
  - Could (?) be directed – probably omnidirectional. It is possible that they could be directed, but might require civilizations with billions of times the energy output of our civilization (or millions of galactic civilizations).
  - Could be at a "magic frequency" – some frequency that ET knows we use, such as 21 cm hydrogen radiation.
  - Could (?) be hidden – designed to operate only when there is evidence of sufficient technological advancement.
- Overheard conversations (very unlikely to understand)
  - Almost certainly they will be **coded** and **compressed**, because this way you can get MUCH more info. Than sending out a raw signal.
  - Therefore, very unlikely that we could decipher this signal. It is even probable we could not understand this.
  - Would probably be evidence of a civilization vastly more powerful than ours – if they can beam such energy towards us.
- Leakage radiation
  - For us, this is the evidence of a radio-based civilization on Earth – an intelligence might be able to deduce some aspects of our civilization (i.e., we live on a planet, orbiting a star, etc.).
  - Might be evidence (?) of waste.

Leakage Radiation From Earth

A paper by Sullivan, Brown, and Wetherill (*Science* **199**, 377 (1978)) take the ingenious argument of an "anthropologist" measuring the leakage radio radiation – radiation that escapes Earth's atmosphere and moves out into space. They argue that with a Cyclops-type array of SETI telescopes (such as was proposed here for SETI), they could detect radio signals from Earth that are decidedly artificial up to 10 parsecs away.

- Proposed that the TV carrier signal, which has bandwidth of 0.1 Hz and carries 50-90% of the total power in the TV signal, as the most promising candidate.
    - BMEWS (Ballistic Missile Earth Warning System) – a system of extremely powerful radar systems that continuosly scan the horizon for a "first strike" nuclear ICBM attack – is more powerful, but signals are more random and very transient.
    - Only signals that generate continuously have the best chance of detection – hence the TV signals.
    - Dominated (97% of total power, as given in paper) by a few (15% of total number, as given in paper) main groups of radio stations.
- Very difficult to get information content from the signal, but there are clues in the time-variation and Doppler shift of the signals received.
- The TV signal is beamed in a sort of thin pancake shape, that has a cycle of 24 hours (12 hours, beam travels towards observer – 12 hours, beam travels away) – evidence of a day.





- The level of Doppler shift variation can give evidence of the latitude of the signal –

highest at equator, lowest at the poles.

- Rising and setting times (remember, measured in hours) gives ideas of the relative locations of groups of stations on the earth – will find that they are concentrated in
- Can work out, over period of a few years, the orbital period of the earth and also its orbital velocity – by measuring the amplitude of the Doppler shift, and estimates of the sun's mass, they can measure the distance of Earth from the sun.
- Cultural markers – from observations of the map of flux and spectrum as a function of time, they may find that radio stations are concentrated in Japan, Western Europe, and North America (US and Canada).

So what can "they" learn from us?

- Earth's orbital shape, period, orbital velocity.
- Diurnal broadcast schedules (at appropriate times in orbit, will be able to "see" Earth with night side/day side in profile and find that stations go off at night).
- Refraction of VHF signals gives evidence of ionosphere – may determine average electron number density.
- Size, rotation rate, and relative inclination of axis of rotation (from periodic changes in frequency ~ 24 hours).
- Map of stations – that they are clustered over a small part of planet.
- Size and distance to moon.
- Size of antennae – the shape of the radiation field is determined by beam shape, and radio is dominated by the largest transmitters.

Defunct SETI project – Project Cyclops

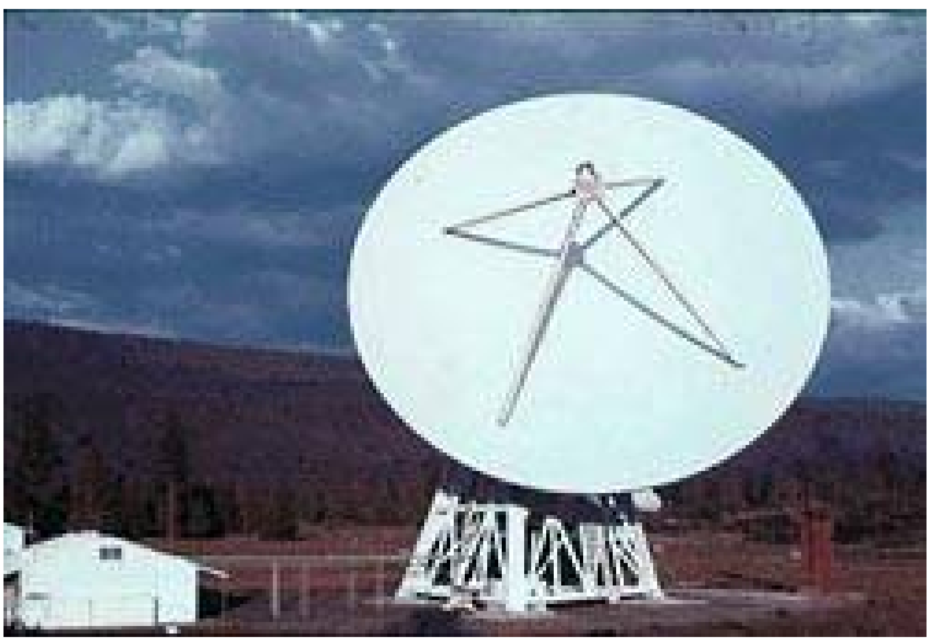
- Design study done for SETI in 1971 – the limits of radio technology of its time.
- Array of 1500, 100 meter dishes in array 8 km in diameter. Also, could search 1 million frequency channels simultaneously.
- The problem (since these dishes go for $100 million dollars each), that there is no compelling reason to spend such money on something like this.
- Hard enough to justify similar spending on something where we don't expect to see anything for years/decades of time.
    - Just look at the fusion community's "action plan"/timetable for the next 30 years – it's a trip!
    - Other examples – LIGO (the detection of gravity waves from compact sources), but the science is pretty "good" – it hasn't been discouraged such as fusion work or SETI, because perhaps it is a problem we don't know as well?
    - Null results after all this time – why should now be different?

SETI@home -- The Radio System that this Project Uses

SETI@home (the data analysis backend) uses the SERENDIP IV spectrometer at the Arecibo telescope.

The SERENDIP project is different from the others in that it is a "piggyback" system – the telescope's orientation is determined by what some scientific astronomy group wants to see, while the spectrometer analyzes a specific bandwidth of signals from that region of the sky.

SERENDIP I -- 1979, piggybacked at the Hat Creek Observatory, Northern California. Could analyze a whopping 100 channels simultaneously.



SERENDIP II – Piggybacked to the 100 meter Green Bank Observatory in West Virginia. Could analyze 65000 channels.

SERENDIP III – Used at Arecibo telescope, analyzing 4 million channels around 0.43 GHz.

SERENDIP IV – Also at Arecibo, analyzing 168 million channels around 1.42 GHz (the so-called "water hole") – which is kept quiet from radio observations due to international agreements.

The back-end data analysis is done through servers at the SETI@home headquarters. That is, they send the SERENDIP signal to you (the user), who then analyzes a chunk of it. The SETI@home servers then collect this data – but all the analysis is done by YOU.

Approximately 1 million years of CPU time were used in 4 years. At 1 GHz CPU speeds, this is approximately 3.15×10^{22} calculations in 4 years. You can figure for yourself the power used in performing these calculations.

Although the concept is somewhat similar (the use of computers to analyze the data after the collection of signal), this is about 10 orders of magnitude better than any previous signal data analysis.