The Case for Optical SETI

Cocconi and Morrison[1] first suggested the use of radio telescopes around the 21 cm hydrogen spin transition line.

Schwartz and Townes[2 3] (co-inventors of the laser) suggested the use of optical light (and optical telescopes) in order to send (and receive) signals through space, but for the longest time this was ignored.

- The light from lasers cannot continuously outshine the light from a star.
- By contrast, the radio emissions from Earth outshine the radio emissions from the sun and other planets over a wide frequency range.
- When lasers first came out, they were tricky devices to work with – by contrast, radio astronomy was a pretty mature area of science by the 1960s.
- Radios can operate in all kinds of weather (say, cloudy or rainy in some cases) that optical telescopes cannot.
- Maybe a "mafia" (the COSETI – Columbus optical SETI group at http://www.coseti.org/introcoseti.htm – has expounded this).

Which, only until the last 5 years or so, had skewed SETI searches in the radio rather than optical – that is, only in the last 5 years have people considered doing optical SETI in great detail.

However, several things have made optical SETI more attractive

- Moore's law increase in laser power – there are currently petawatt (10^{15} W) lasers operating over picoseconds (10^{-12} s), going to nanosecond (10^{-9} s), in the fusion community – that can outshine or be comparable to their parent stars for short enough times. There is no reason to suppose this exponential increase in laser power will stop in the next 2 decades.
- Very very many sources in the microwave and radio that have been seen in the sky – have dampened the enthusiasm for hydrogen-line SETI.

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

[2] R. Schwartz and C. Townes, "Interplanetary and interstellar communication by optical masers," *Nature* **190**, 205-208 (1961).

[3] C. Townes, "At what wavelengths should we search for signals from extraterrestrial intelligence?," *Proceedings of the National Academy of Science* **80**, 1147-1151 (1983).

- The whole Earth communicates over huge swathes of radio – making radio astronomy (at 1-10 GHz) less attractive over time.

Natural benefits of Optical SETI

- Laser signals can be sent out over a much smaller angular spread. Remember, the opening angle $\theta = \lambda / D$ associated with Fraunhofer diffraction.
- At radio frequencies the issues of Faraday rotation and the plasma properties of the interstellar medium cause signal dispersions (few millihertz for 1 GHz signals) – absolutely negligible for visible light.
    - This natural dispersion limits galactic data rates through the radio frequencies.
- Much better angular resolution of optical telescopes.
- Much **greater bandwidth** possible, hence much **smaller observation times** needed.

Optical frequencies are best seen as "spikes" over short (nanosecond) time periods – and the signals are best sent via "pulses" in the optical rather than a continuous signal in the radio.

- Frequency analysis techniques (looking for the "spike" in the frequency spectrum of a radio signal) is unfeasible in the optical.
    - Large frequency shifts associated with Doppler motion in the visible – a velocity of 3 m/s results in a Doppler shift of 100 Hz for a 1 GHz signal, but a 100 MHz shift for a 100 THz (terahertz) optical signal.
    - Added noise in frequency matching due to the short wavelengths of light.
- "cultural" sources of optical flashes in the nanosecond are nonexistent, even in the sky.
- Astrophysical (natural) phenomena are unknown that would emit enough power as an optical pulsed beacon.
    - Since it varies over 1 nanosecond, must be ~ 30 cm in size or smaller.
    - Must, within this time, emit enough power/area as a star does!

Problems of Noise and Attenuation in Optical SETI

- Interstellar dust scattering and absorption – factor of ~6 every 3000 light-years, and why the galaxy's interior is not observable.
- Atmospheric and extra sources
    - Photons from the parent star
    - Zodiacal light (arising from dust in orbit around the sun scattering light)
    - Airglow (light scattered by the air, such as in the daytime)
- Interstellar dust scattering and absorption – factor of ~6 every 3000 light-years, and why the galaxy's interior is not observable.
- Cosmic rays.
- Muon showers (most common induced charged particles reaching sea level).
- Cerenkov radiation (produced when a particle travels **faster** than local light speed).
- Natural radioactivity (produces electrons and photons).
- Humidity[4] – causing false discharges – as shown in the graph below, centered about the summer months (detector at Massachusetts, operated by the Harvard Optical SETI group).
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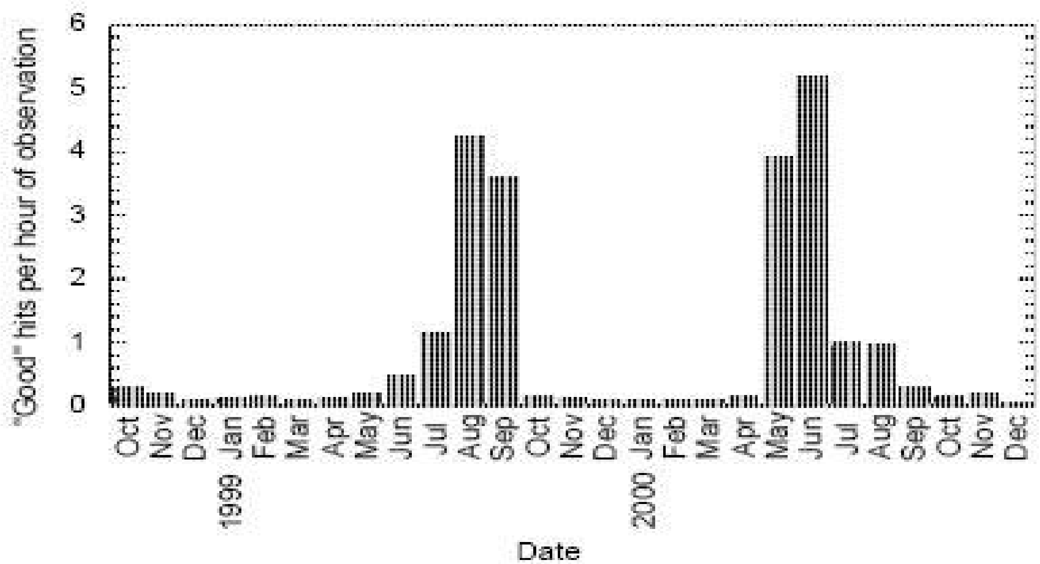

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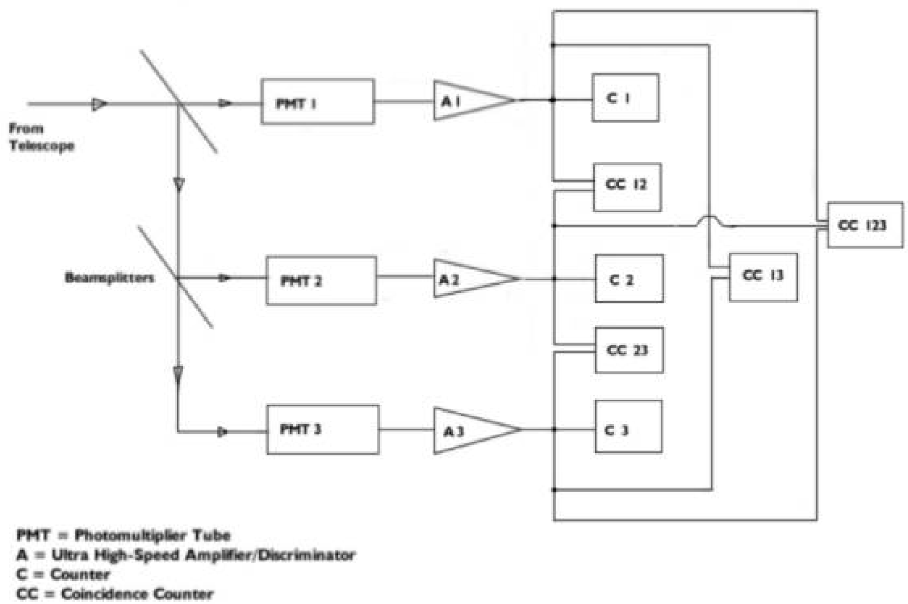
[4] This plot is taken from the preprint, "Is There 'RFI' in pulsed-optical SETI?" by A. Howard and P. Horowitz, http://seti.harvard.edu/OSETI/bkgrnds.pdf.

Optical SETI setup (applies to Harvard, COSETI, Princeton, UC Berkeley and other optical SETI experiments)

A set of photomultiplier tubes are used and attached to an optical telescope to measure the pulses coming from an optical SETI source.

- PMT's are FAST – for Optical SETI, engineered for 10^{-9} seconds. No known natural or artificial source will produce a signal comparable to that seen from a pulsed optical SETI beacon.
- Data from several PMT's in a detector are measured in coincidence –



so as to remove the error rate associated with spurious data.

Coincidence with other optical SETI observations. An example is the proposed coincidence measurements between the Princeton and Harvard Optical SETI detectors.

- Detectors are ~ 300 miles apart, hence ~ 1.6 milliseconds apart in terms of light travel time. The criterion used is ~ 4 milliseconds.
- The chance of getting a set of two separate random pulses between Princeton and Harvard is 1 event/300 years.

Harvard Optical SETI initially "piggybacked" onto the Harvard astronomy department's optical telescope. The all-sky survey, however, is all Optical SETI.

There is, as yet, no evidence from optical SETI observations of intelligent life.

Some data taken from Harvard Optical SETI[5]

TABLE 1

OBSERVATIONAL SUMMARY

Visual magnitude	Observations	Objects	"Good" hit rate	Hit Rate	Observation time
0	87	8	0.67	2.68	9.0
1	9	2	2.70	8.11	0.4
2	68	20	0.33	1.46	6.2
3	284	38	0.33	0.95	24.2
4	425	96	0.32	0.99	34.2
5	541	152	0.14	0.46	49.7
6	799	280	0.10	0.49	92.0
7	2314	647	0.11	0.50	307.5
8	3016	850	0.10	0.48	398.2
9	1476	362	0.10	0.45	240.3
10	612	185	0.11	0.45	148.0
11	102	25	0.00	0.19	26.5
12	1	1	0.00	0.00	0.3
Total:	9734	2666	0.12	0.51	1336.4

NOTE.—Here we summarize our observations to date (October 22, 1998-September 30, 2000), excluding the humid months (May 25-September 30, 1999 and May 1-September 30, 2000). Hit rates are given in hits per hour and observation time is in hours.

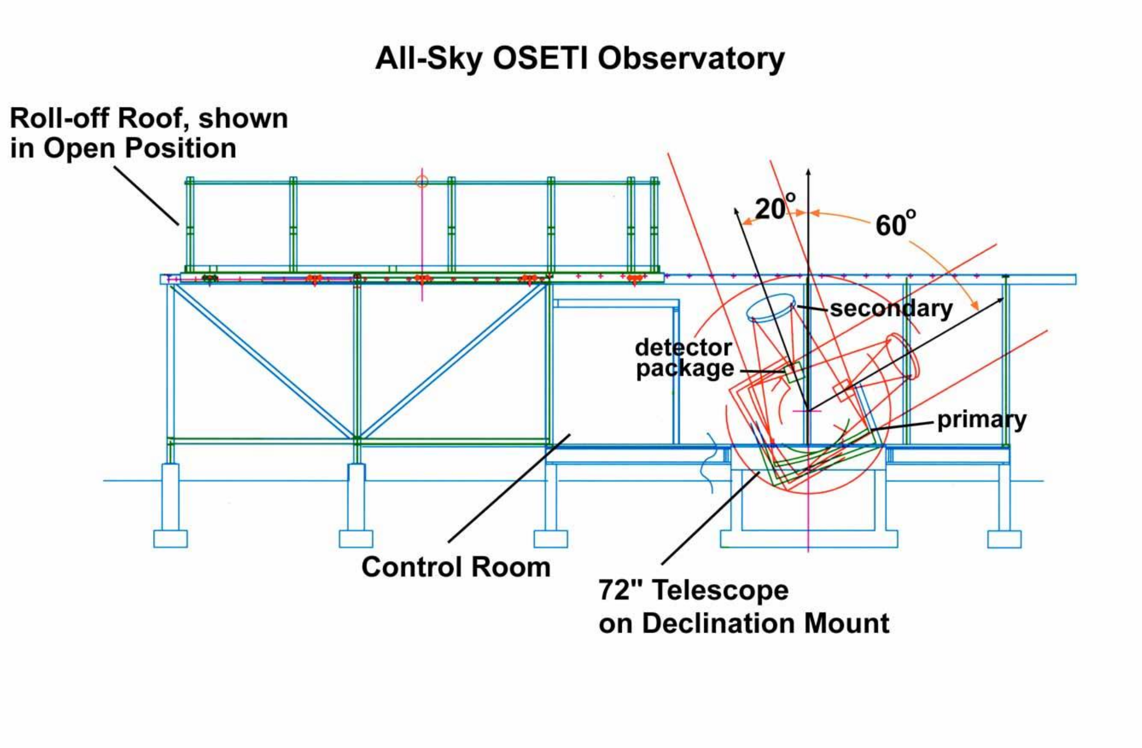
[5] Taken from http://seti.harvard.edu/OSETI/allsky.pdf.

All-Sky Search – an Example of Optical SETI (taken from http://seti.harvard.edu/OSETI/allsky/allsky.htm).

We are embarking on a new all-sky optical search, sponsored by The Planetary Society! It will use a 72" diameter glass "light bucket", with a custom camera containing 1024 ultrafast detectors. These will stare at a stripe of sky measuring 1.6 by 0.2 degrees; all stars in this "declination stripe" will pass through our detector, in review. It will take about 200 clear nights to survey the entire sky visible from our site 40 miles west of Boston.

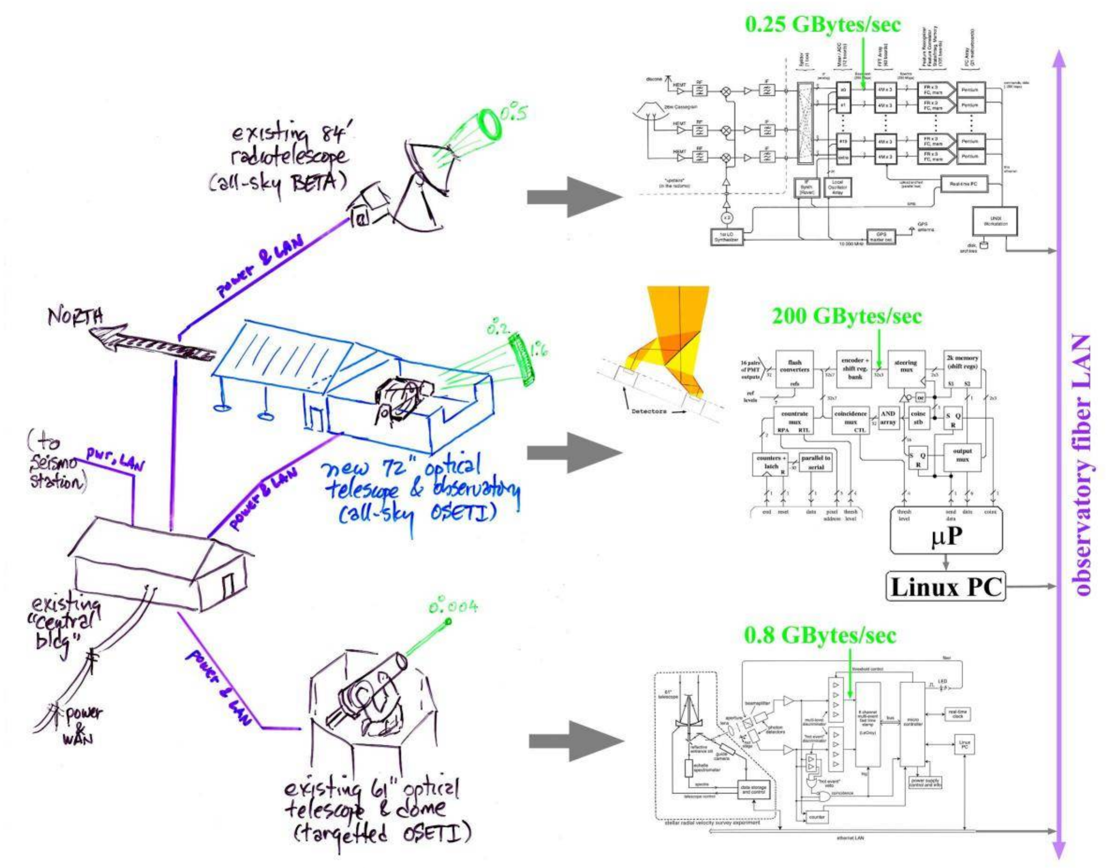
The Observatory "Dome", with Its Rolloff Roof

Here's the new dome building, with rails so the roof can roll to the north. The south wall rolls down so we can see stuff that's farther south. The design is by Nate Hazen and Jim Oliver, with lots of helpful input from Dennis diCicco and Alan MacRobert (Sky and Telescope Magazine). (click on image to get a bigger photo)



Three SETI Projects at Agassiz Station

When the all-sky search is running we'll have three (count 'em) searches at our observatory on Oak Ridge in Harvard, Massachusetts. Funding comes from The Planetary Society and the Bosack/Kruger Charitable Foundation. This figure shows the BETA microwave search (3 beams, and 250 million radio channels, with the 84-foot steerable dish); the targetted optical SETI (piggyback on the 61" optical telescope); and the new all-sky optical SETI (with its dedicated dome and telescope).



How the All-Sky Search Works

The all-sky telescope stares at a stripe of sky, 1.6 by 0.2 degrees, with an array of 1,024 ultrafast detectors. The earth's rotation carries the celestial sphere (complete with its stars!) through that stripe; so in a 10-hour night we observe about 40% of the length of that stripe. Every object within that arc is observed, with a dwell time of about a minute (the time it takes to drift through 0.2 degrees).

We move the telescope once each day, to observe the next stripe; and we complete the rest of these stripes later in the year, when the sun has moved out of the way.