Exoplanets, SETI, and Technosignatures

A short course for the KISS workshop

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(for Jason Wright)
May 20, 2019
Exoplanets are Ubiquitous

Number of planets per star: ~1 (bigger than Earth, inside 1 AU)

Fraction of Sun-like stars with Earth-size planet in Habitable Zone: 20% (*)

Kepler Space Telescope

* many caveats

Images: NASA
Exoplanets are Diverse
Some Order in the Diversity
Solar System not a Universal Template
What makes a planet ‘Earth-like’?

- Size
- Mass
- Density
- Composition
- Atmosphere

- Water
- Simple Life
- Complex Life
- Coffee, Sushi, …
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SETI

“Search for Extraterrestrial Intelligence”
Jargon

- See ad hoc committee on SETI nomenclature report (Wright, Sheikh, Almár, Denning, Dick, Tarter, 2018)
- Also:
“SETI”

Originally a radio program at NASA

Now the name of the field generally

CETI: “Communication…”
SETT: “…technology”
SETEE: “…electrical engineers”

Let’s not quibble.
“Technosignatures”

Apparently coined by Jill Tarter in 2006

Makes analogy to biosignatures explicit

Inclusive of all signs of technology: radio, laser, waste heat, whatever.

“Produces fewer antibodies” at NASA (per Michael New)

Search for technosignatures = SETI
Loaded terms

“Civilization”
“Colonization”
“Alien”
“Alien race”

If you use these, be aware that they have meanings you may not intend

Mean what you write and write what you mean.
Searches for Alien Life in Astrobiology

Biosignatures

- Exoplanets:
  - Atmospheric gases
  - Surface reflection spectra
- Solar System:
  - Microfossils
  - Molecular Biomarkers

Technosignatures (SETI)

<table>
<thead>
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<th>Communication</th>
<th>Artifact</th>
<th>“Nature-plus”</th>
<th>METI</th>
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Technosignature Axes of Merit

With so many potential technosignatures to look for, how do we compare them?

OR

Given finite resources, what do we prioritize?

Inspired by...

Can’t be avoided

Can be detected

Best Ideas

S. Sheikh, with input by D. Kipping, A. Frank, S. Walker
Dyson’s First Law of SETI Investigations

“Every search for alien civilizations should be planned to give interesting results even when no aliens are discovered.”
The birth of Radio SETI

1960 — Cocconi & Morrison suggest interstellar communication via radio waves

SEARCHING FOR INTERSTELLAR COMMUNICATIONS

By GIUSEPPE COCCONI* and PHILIP MORRISON†
Cornell University, Ithaca, New York

No theories yet exist which enable a reliable estimate of the probabilities of (1) planet formation; (2) origin of life; (3) evolution of societies possessing advanced scientific capabilities. In the absence of such theories, our environment suggests that stars of the main sequence with a lifetime of many billions of years can possess planets, that of a small set of such planets two (Earth and very probably Mars) support life, that life on one such planet includes a society recently capable of considerable scientific investigation. The lifetime of such societies is not known; but it seems unwarranted to deny that among such societies some might maintain themselves for times very long compared to the time of human history, perhaps for times comparable with geological time. It follows, then, that near some star rather like the Sun there are civilizations with scientific interests and with technical possibilities much greater than those now available to us.

To the beings of such a society, our Sun must appear as a likely site for the evolution of a new society. It is highly probable that for a long time they will have been expecting the development of science near the Sun. We look forward patiently to the Sun which would make our society has entered the equation.

The Optimum

Interstellar communication, plasma without dispersion is practical, so far as we can guess.

Since the object of this research is to find a new possible environment, the channel used with a minimum burden of frequency...
Frank Drake, Project OZMA
Not just narrowband carrier waves

- Radar
- Pulsed emission
- Spillover from point-to-point communications
- Byproducts of propulsion / high energy work
- Huge range of necessarily non-natural waveforms can be searched for “agnostically”
Communication SETI

The birth of Laser SETI

1961 — Schwartz & Townes point out lasers work well, too

INTERSTELLAR AND INTERPLANETARY COMMUNICATION
BY OPTICAL MASERS

By Dr. R. N. SCHWARTZ and Prof. C. H. TOWNES

Institute for Defense Analyses, Washington, D.C.

LONG-RANGE communication by radio-waves is already well known, and the possibility of interstellar communication by radio-waves in the microwave region has been suggested in several interesting proposals to search for signals from intelligent beings on planets associated with nearby stars. The supposition is that curiosity such as our own would motivate advanced civilizations associated with stars other than our Sun to make determined efforts to frequency-interval of about 10 kilocycles per sec. The latter case is much closer to theoretical expectations for an ideal maser in so far as coherence is concerned. There seems to be no general reason, other than the necessary dissipation of power, why solid-state optical masers cannot operate continuously high power and with a short-term monochromatic close to theoretical expectations, or hence with frequency-widths very much less than 1 megacyc
Laser advantages

- Pulsed lasers provide very high bandwidth
- Optical transmissions can have very high gains
- IR lasers have great dust penetration
- Can be concentrated in time or frequency domains
Radio/Laser SETI

**Practical**
- Search can only be done in the far future
- Search is costly
- Search has no ancillary benefits
- Search can be done now
- Search is cheap
- Search has many ancillary benefits

**Scientific**
- Short-lived
- Ambiguous
- High Extrapolation from Earth 2000 Tech
- Long-lived
- Unambiguous
- Low Extrapolation from Earth 2000 Tech
- Contrived/Specific
- Inevitable
- Non-detectable
- Detectable
- Information-Poor
- Information-Rich
Artifact SETI

Dyson (1960)

“Dyson sphere” really just any orbital material that collects or generates energy

Emission of low-entropy “waste” heat in IR is required by thermodynamics

Sensitive to almost all technological energy use in the system

Primary confounder is dust which has similar MIR properties

Search for Artificial Stellar Sources of Infrared Radiation

Abstract. If extraterrestrial intelligent beings exist and have reached a high level of technical development, one by-product of their energy metabolism is likely to be the large-scale conversion of starlight into far-infrared radiation. It is proposed that a search for sources of infrared radiation should accompany the recently initiated search for interstellar radio communications.

Cocconi and Morrison (7) have called attention to the importance and feasibility of listening for radio signals transmitted by extraterrestrial intelligent be
The discovery of infrared cirrus complicated Dyson sphere searches.
Some work

- Jugaku & Nishimura (2004): Nearby stars with IRAS
- Carrigan (2009): All-sky IRAS non-detection
- Annis (1999): Pan-galactic Dyson spheres via low optical surface brightness (Kardashev type III)
- Arnold (2005): Kepler as megastructure hunter (see also Boyajian’s Star)
Probes are slow but if they are self-replicating they have very high bits per (initial) erg. Probes might be sent for many purposes (contact, exploration) and might “pass through” or “lurk” indefinitely.
Solar System SETI

• Intelligent Martians were once legitimate scientific hypothesis

• Mariner showed no cities: now idea that technology ever existed there is taboo

• Claim that there are proveably zero probes in the Solar System now has been used to argue ETIs must not exist

• In reality, completeness is very low (Haqq-Misra & Kopparapu 2012)

• Moon has best high-resolution imaging for searches (Davies & Wagner 2013)

• Free-floating artifacts (Freitas 1980, 1983)

• ‘Oumuamua (Bialy & Loeb 2018)
Exoplanet atmospheric pollution

Very little work on this so far

Natural synergy with hunts for biosignatures

• Lin, Gonzalez Abad, & Loeb (2014)
• Lingam & Loeb (2017)
Exoplanet Pollution SETI

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Upper limits in SETI
## History of Database Mining for Technosignatures

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<th>Searching for?</th>
<th>Authors</th>
<th>Methods</th>
<th>Explicitly SETI?</th>
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<tbody>
<tr>
<td>IRAS</td>
<td>Dyson Spheres</td>
<td>Jugaku &amp; Nishimura, Carrigan</td>
<td>Least-squares fitting to expected data</td>
<td>Yes</td>
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<tr>
<td>WISE</td>
<td>Dyson Spheres</td>
<td>Griffith/Wright et al.</td>
<td>Least-squares fitting to expected data</td>
<td>Yes</td>
</tr>
<tr>
<td>Kepler</td>
<td>Dyson Spheres</td>
<td>Giles &amp; Walkowicz</td>
<td>Machine Learning (clustering)</td>
<td>No</td>
</tr>
<tr>
<td>SDSS</td>
<td>Kardashev Type III</td>
<td>Baron &amp; Poznanski</td>
<td>Unsupervised Random Forest</td>
<td>No</td>
</tr>
<tr>
<td>[n/a]</td>
<td>Shape Agnostic Artificial Radio Signals</td>
<td>Zhang et al.</td>
<td>Self-supervised Deep Learning</td>
<td>Yes</td>
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Searches for Alien Life in Astrobiology

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