THE MODERN RADIO SEARCH FOR EXTRATERRESTRIAL INTELLIGENCE

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http://seti.berkeley.edu
http://casper.berkeley.edu
SEARCHING FOR INTERSTELLAR COMMUNICATIONS

By GIUSEPPE COCCHONI* and PHILIP MORRISON†
Cornell University, Ithaca, New York
Project OZMA, 1959

Frank Drake

85ft Tatel Telescope
Project OZMA, 1959

Single 100 Hz manually tuned channel
400 kHz band around 1420.4 MHz

Frank Drake

85ft Tatel Telescope
\[ N = R^* \cdot f_p \cdot n_e \cdot f_l \cdot f_i \cdot f_c \cdot L \]

**Frank Drake**

- \( R^* \) = the average rate of star formation per year in our galaxy
- \( f_p \) = the fraction of those stars that have planets
- \( n_e \) = the average number of planets that can potentially support life per star that has planets
- \( f_l \) = the fraction of the above that actually go on to develop life at some point
- \( f_i \) = the fraction of the above that actually go on to develop intelligent life
- \( f_c \) = the fraction of civilizations that develop a technology that releases detectable signs of their existence into space
- \( L \) = the length of time such civilizations release detectable signals into space
PLANETS ARE EVERYWHERE

5.7$^{+2.2}_{-1.7}$ % of Sun-like stars have a planet with $P=200-400$ d, $R_P = 1-2R_E$

Petigura et al, 2013
Galactic Synchrotron Background
Noise Temperature (Kelvin)

Frequency (GHz)

1

10

100

1000

0.1

10

100

1000

Galactic Synchrotron Background

Terrestrial Microwave Window

Atmospheric Rotational Transitions

H₂O

O₂

O₂

H₂O
Intentional Signals...

- Low energy - Radio photons are cheap
- Easy to generate, easy to receive - Earth technology makes photons look attractive
- As fast as possible - c
- Easily distinguished from natural sources - narrowest astrophysical sources 100s of Hz wide (masers)
- Robust to the interstellar medium - Narrow band signals encounter limited broadening by the ISM, viz. Drake and Helou 1977, Cordes and Lazio, 1991 ~ 0.1 Hz at 1.4 GHz
NAIC Arecibo Observatory, Puerto Rico
Arecibo L-band Feed Array (ALFA) Receiver System:

- ~1.3 GHz band center
- 7 dual-polarization feeds
- 300 MHz Bandwidth

Adapted from a graphic courtesy J.E.G. Peek
SERENDIP V.v

Operational since Sept 2009
Approximately 6000 hours observed
Search for Extraterrestrial Radio Emissions from Nearby Developed Intelligent Populations
Sky Coverage 2009-2012
SETI@Home

• Polyphase Channelization
• Coherent Doppler Drift Search
• Narrowband Pulse Search
• Gaussian Drift Search
• Autocorrelation
• <insert your algorithm here>
AstroPulse

- Coherent Dedispersion
- Broadband Pulse Searching
The Robert C. Byrd Green Bank Telescope

Kepler Planet Candidate Survey
Kepler Field Observations

5 minute targeted observation of potentially ‘hospitable’ KOIs

‘Traditional’ HZ:
-50 C < $T_{eq}$ < 100 C

$N_{candidates} > 4$

Small, long period
P > 50d & & $R_p < 3 R_E$
Kepler Field Observations

11 hour raster scan of the entire Kepler field.

5 seconds per 10’ beam
Green Bank Ultimate Pulsar Machine (GUPPI)

8 bit sampling ➔ 2 bit quantization

Raw ‘baseband’ recording

800 MHz bandwidth, 2 polarizations

~ 1 gigabyte/second to disk
Kepler Search Analysis

Locally Performed

Synthesized high resolution spectrometer
Incoherent Doppler drift search

Synthesized coarse filterbank
Incoherent dispersed pulse search

SETI@Home

Astropulse
KOI 1199

MJD: 55696.1692
RA: 19:34:58.488
DEC: +38:56:21.48
$F_{\text{ctr}}$: 1424.9660701 MHz
Drift: 0.2788 Hz/sec
SNR: 25.2578

KOI 1372

MJD: 55696.2171
RA: 19:45:35.856
DEC: +42:23:13.92
$F_{\text{ctr}}$: 1424.7873276 MHz
Drift: 0.50555 Hz/sec
SNR: 36.5513
Fewer than $10^{-4}$ FGK stars are radio loud in orbital plane radio emission at the $\sim 5 \, L_{\text{AO}}$ level.

Number of Kardashev Type II civilizations less than $\sim 10^{-6} \, M_{\odot}^{-1}$

SETI WITH LOFAR

Analysis pipeline leveraging existing pulsar capabilities (DSPSR)

Complex baseband recording of ~8-10 phased beams over ~32 MHz bandwidth

Pilot survey of 150 nearby M-dwarfs accepted for Cycle 0 observations
NEW OBSERVING STRATEGIES
NEW OBSERVING STRATEGIES

EPIC-SETI: EXOPLANET INTERPLANETARY COMMUNICATION SEARCHES FOR EXTRATERRESTRIAL INTELLIGENCE
NEW OBSERVING STRATEGIES

EPIC-SETI: EXOPLANET INTERPLANETARY COMMUNICATION SEARCHES FOR EXTRATERRESTRIAL INTELLIGENCE

Kepler multi-planet ephemerides allow accurate prediction of conjunction times

100s of multi-planet systems provide frequent conjunction events (many per day)

24 total hours of observations w/ GBT
Aug-Sep 2013, L, S, X bands

D. Fabrycky 2012
Detectability of the Most Energetic Terrestrial Phenomena

<table>
<thead>
<tr>
<th>Frequency (GHz)</th>
<th>Detectable Range (Ly)</th>
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</thead>
<tbody>
<tr>
<td>$10^{-2}$</td>
<td>$10^2$</td>
</tr>
<tr>
<td>$10^{-1}$</td>
<td>$10^3$</td>
</tr>
<tr>
<td>$10^0$</td>
<td>$10^4$</td>
</tr>
<tr>
<td>$10^1$</td>
<td>$10^5$</td>
</tr>
</tbody>
</table>

LOFAR–core HBA
Arecibo
GBT
SKA1–low
SKA1–mid

$L \sim 10 \times AO$ Planetary Radar
$D \sim 300m$
Detectability of the Most Energetic Terrestrial Phenomena

Based on *Kepler* $\sim$5-50% of stars host an $\sim$Earth like planet.

* e.g. Dressing et al 2013, Kopparapu 2013, Petigura et al 2013

$L \sim 10 \times$ AO Planetary Radar

$D \sim 300 \text{m}$
1. at least 10-100 billion ~Earth like worlds in the Galaxy.

2. With the SKA, we will for the first time have confidence that we are sensitive to ~Earth-level ~isotropic leakage radiation from an Earth-like planet.*
SKA-low and SKA-mid are equally interesting from a SETI perspective, and each could be the preeminent facility for targeted SETI in their respective bands.

For the foreseeable future, large single dish telescopes will be best for sky surveys.

As of now, there is no provision for a SETI observing capability with SKA-low, -mid or -survey.