Finding Inhabited Worlds Among the Habitable Ones

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21st Century: The Century of Biology On Earth and Beyond
GAME CHANGERS
FROM THE 20\textsuperscript{TH} CENTURY

Exoplanets and Exomoons
Two Kinds of Deliberate Signals

Observational consequences:
- Do astronomy!

• Signals might appear
  – Almost natural
  – Engineered

• Build dedicated telescopes
The Cosmic Haystack Is Huge

Nine Dimensional
• 3 – space
• 1 – time
• 2 – polarizations
• 1 – frequency
• 1 – modulation scheme
• 1 – sensitivity
Current SETI Searches
Work on Simple Artifacts

\[ \Delta t \cdot \Delta \nu \geq 1 \] Uncertainty Principle

Technology can approach limit

Time compression: broadband optical pulses
Terrestrial Microwave Window

Feed Coverage
VOYAGER 1 SIGNAL: 106 AU AWAY
Project Phoenix: 1994 – 2004

1000 stars x 1700 MHz = 1.7 x 10^6 Star-MHz

2.2 x 10^5 Star-MHz

2.9 x 10^5 Star-MHz

4.8 x 10^5 Star-MHz

NSS: PCs + accelerators

NASA-derived

TSS: full custom
The ATA-42
6.1 m Offset Gregorian Antenna - LNSD
The Andromeda Galaxy

A familiar object for scale

2.5 degrees

Arecibo Field of View

ALFA Field of View

0.5 degrees
Field of View = 2.5 degrees at 1.4 GHz

Radio Camera with ~1250 pixels and 1024 “colors”
Field of View = 2.5 degrees

3 phased array beams at 2 frequency bands
Beam Plus Offset Null

Measured Beam Patterns, E1Offset = 0 (Galaxy 15, 1575 MHz)

Beam Gain (dB Relative to Maximum Array Gain)

Projection Nulls
0.5 – 10 GHz
Log-Periodic Feed – Frequency Independent
WBA 13 Noise Temp – Sandy Weinreb

(at 70K)

Gain [dB]/Noise [K]

Frequency [GHz]
Transmission Through Glass Dome with Polyethylene Layer

For a 1.0 mm thick fuzed quartz dome, with a polyethylene layer at various thickness with a 4.0 mm air gap between glass and layer.
Gain Curves for High Frequency ATA Feed

- 12 GHz focus
- 10 GHz focus
- 6 GHz focus
- 2 GHz focus

Frequency in GHz

Gain

0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
5C, X-pole, ABB-081, Test 15 Noise Ratio
Various Bias Settings, 2011-12-05 With SB-038-B(2), Y-pole, ABB-169, Test 15 Noise Ratio 2010-04-08

ATA Cooled Feed

Includes +0.25 dB for load emissivity

Analyzer error spec ± 0.25 dB

ATA Tsys 16.5 K

ATA Tsys 32 K

ATA Tsys 50 K

ATA Tsys 74 K

ATA Tsys 105 K

ATA Tsys 148 K

ATA Tsys 208 K

Data file

vm Vg Vd Id

Projected ATA fully cooled TDF 5C

041 Ratio: 97 52 52 66.9
042 Ratio: 97 52 52 55.0
124 Ratio: 98 55 52 55.7
125 Ratio: 98 55 55 55.7
126 Ratio: 97 55 55 55.7
127 Ratio: 98 55 55 55.7
128 Ratio: 98 55 55 55.7
129 Ratio: 98 55 55 55.7
130 Ratio: 98 55 55 55.7
131 Ratio: 98 55 55 55.7
132 Ratio: 98 55 55 55.7
133 Ratio: 98 55 55 55.7

Ratio (dB)

Frequency (GHz)
Measured Receiver + Sky Temperature

9/19/13

Temp in K

Frequency in GHz

L-band  S-band  C-band  X-band  Ku-band

Treceiver GlassBottle
SonATA (SETI on the ATA) Since 2011

- Use 3 Beamformers to target 3 systems simultaneously with 100 million channel detectors
  - All Kepler candidates
  - Exoplanets from exoplanets.org
  - $\delta > -30^\circ$

- Over the entire terrestrial MW window 1-10 GHz

4.5x10$^7$ Star-MHz
http://setiquest.info/data/obsinfo

Distant Suns-Max: Unleash Your Inner Astronaut
By First Light
Open iTunes to buy and download apps.

Description
‘Distant Suns is easy to use and understand. The graphics are amazing, and the people are stars.” Lee Brandon-Cremer, Space Shuttle Almanac

What's New in Version 3.4.2
• Astronomy Magazine NewSticker shows up-to-date space events
• Tweaked some UI bits for the iPad mini
• Fixed a problem with the Compass that caused it to use the default compass

Screenshots

Augmented Viewing...

Customer Ratings
Current Version: ★★★☆☆ 18 Ratings
All Versions: ★★★★★ 395 Ratings
IVER CHIMES / pixel
NEW TRICKS
‘Narrowband’ Signals in Image

**Sensitivity vs. Signal Bandwidth**

- SonATA
- Imaging SETI @ 100 kHz

\[
\frac{d^2 \text{Image}(n)}{df^2} \approx 2 \text{Image}(n) - \text{Image}(n-1) - \text{Image}(n+1)
\]

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Second derivative feature at 4σ
Search in Time Domain
Rather than Frequency Domain

Almost any Astronomical Source: Quasar, Pulsar, etc.
‘Fast’ Time Variable Sources

Now gathering training sets for ML
70,408 Red Dwarfs

Catalog at 1.2GHz

Catalog at 14.5GHz
SETI@home

ALFA at Arecibo
Astropulse & Other signals

Green Bank Telescope
800 MHz record
+ SETI@home
off-line processing

More SETI Today

LOFAR
Low Frequency Transients

Project Dorothy
15 Countries

SETI Italia
Harvard OSETI Sky Survey of Northern Sky

10 m^2/s/ns
Berkeley Optical SETI

100 $\gamma$/s/m$^2$/nS

HIRES at KECK Observatory
1000 KOIs
10 $\gamma$/s/hr in laser line

Leuschner Observatory
$10^{15}$ W LASER 1000 LY AWAY
2 \times 10^{13} \text{ W}

RADAR

1000 \text{ LY AWAY}

\sim 10^6 \text{ stars}

L \sim 10^5 \text{ years}
The Future

JWST and then ???

BIOSIGNATURES

Colossus

TMT

LSST

SKA

E-ELT

FAST

SETI
Longevity is key
SETI IS THE ARCHEOLOGY OF THE FUTURE
“The probability of success is difficult to estimate; but if we never search the chance of success is zero.”

Cocconi and Morrison, Nature (1959)
Amount of Sky Searched with the ATA

- Sagan (N = 1M)
- Drake (N = 10K)
- Skeptic (N = 100)

Give Up!

Year

Number of Star Systems
On a finite world, a cosmic perspective isn’t a luxury; it is a necessity.

Caleb Scharf (2014)