Ten Years of RFI –
Project Phoenix at Parkes,
Green Bank and Arecibo

Michael M. Davis, Peter R. Backus
and Jill Tarter
SETI Institute
CHARACTERISTICS OF THE SEARCH SYSTEM

• Near real-time signal processing
• Immediate follow-up two-site observation of “candidate ETI” signals

• Spectrometer (since 2002):
  – 56 MHz bandwidth, 0.7 Hz Resolution
  – 84.8 million Channels per polarization
  – Successive spectra overlapped 50%
Signal Detection

• Both Pulsed and Continuous Signals
• Frequency drift of up to $\pm$ one channel per spectrum

• Follow-up Detection:
  – Candidate ETI signals tested after one data acquisition period (~5 min)
  – If necessary, telescope moved off-source to verify
Some Parts of the Spectrum were Unusable

### PERSISTENT SPECTRUM BLOCKAGE

<table>
<thead>
<tr>
<th>Observatory</th>
<th>L-Band (1200-1750)</th>
<th>S-Band (1750-3000)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parkes 64 m</td>
<td>100 MHz</td>
<td>20 MHz</td>
</tr>
<tr>
<td>NRAO 140 Foot</td>
<td>130 MHz</td>
<td>50 MHz</td>
</tr>
<tr>
<td>Arecibo 305 m</td>
<td>170 MHz</td>
<td>424 MHz*</td>
</tr>
</tbody>
</table>

*At Arecibo, some interference at S-Band was so strong that filters were used to block 360 MHz to prevent overloading the receiver. Another 26 MHz is blocked by Digital Audio Satellite broadcasting.*
The Rest of the Spectrum was Observed at High Resolution

Time–Frequency Plot of Pioneer 10

\[ \text{Frequency} \times \text{Time} \]

\[ \text{0 dm} \]

\[ \text{right 1 Hz} \]

\[ \text{mean pwr = 0.049062} \]

\[ \leftrightarrow \text{------------ 0.7 kHz ------------} \]
Observing Procedure

• Begin Each Observing Run by ‘Priming’ the RFI Database
  – All-night scans through planned observing band while pointing at zenith
  – Identify RF and IF birdies, as well as other persistent narrow bandwidth signals

• Compare signals detected during Star observations with database, which is constantly updated with new RFI signals
The RFI Database

- Contains ALL detected signals
  - Date and Time
  - Power, Frequency, Width, Drift Rate
  - Classification Code, much more
- Formed basis of resolving almost all candidates
  - Any signal seen within the past week in another direction deemed to be RFI
  - Typically <5% of spectrum ‘blocked’ in this way, except in ‘Persistent RFI’ bands
A Tale of Two Frequency Bands

- 1400 – 1427 MHz
  - RAS Primary, ‘No Transmissions’
- 1600 – 1627 MHz
  - RAS Primary Shared, 1610.6 – 1613.8
  - Satellites (GLONASS, IRIDIUM)
  - Aeronautical Radionavigation
- Data taken at Arecibo in two observing runs in spring and fall of 2003
Presentation Format

- First four slides are from database ‘priming’ observations (RFI Scans), followed by a dozen slides of ‘signals’ from star-tracking observations. There are separate slides for each of the two bands.

- Each plot shows one characteristic on vertical axis, for each numbered signal on horizontal axis
  - Frequency (F), power (P), drift rate (D), width (W)
  - Signals are sorted differently in different plots, to bring out correlations
    - Example: F/F => Frequency Displayed, Signals sorted by Frequency
RFI Scan, 1400–1427 F/F

Arecibo RFI Scans 2003
1400 - 1427 MHz

About 160 hits, mostly noise
RFI Scan, 1600-1627 F/F

Areceibo RFI Scans, 2003
1600 - 1627 MHz

20 times as many signals as 1400-1427
RFI Scan, 1400-1427 F/P

Arecibo RFI Scans 2003
1400 - 1427 MHz

Mostly Noise Hits at first power level above threshold
RFI Scan, 1600-1627 F/P

Arecibo RFI Scans, 2003
1600 - 1627 MHz

Persistent, strong RFI
Signals, 1600-1627 F/F

Arecibo Signals 2003
1600 - 1627 MHz

1602-1610 Added to Blocked Regions based on RFI Scans

Still have nearly 6,000 signals

16-18 July 2004
RFI2004 Workshop, DRAO Penticton BC
Signals, 1400-1427 P/P
Areceibo Signals 2003
1400 - 1427 MHz

A few strong birdies saturate

Full Range Usable, half as many signals as 1600-1627
### Signals, 1600-1627 F/P

**Arecibo Signals 2003**

**1600 - 1627 MHz**

<table>
<thead>
<tr>
<th>Signal Number</th>
<th>Frequency [MHz]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1595</td>
</tr>
<tr>
<td>1000</td>
<td>1600</td>
</tr>
<tr>
<td>2000</td>
<td>1605</td>
</tr>
<tr>
<td>3000</td>
<td>1610</td>
</tr>
<tr>
<td>4000</td>
<td>1615</td>
</tr>
<tr>
<td>5000</td>
<td>1620</td>
</tr>
<tr>
<td>6000</td>
<td>1625</td>
</tr>
</tbody>
</table>

16-18 July 2004

RFI2004 Workshop, DRAO Penticton BC
Signals, 1400-1427 W/P

Wider Signals Provide more Power
Signals, 1400-1427 D/P

Arecibo Signals 2003
1400 - 1427 MHz

Non-Drifting Birdies are the most powerful signals
Signals, 1600-1627 D/P

Arecibo Signals 2003
1600 - 1627 MHz

Satellites in Low Earth Orbit Decelerate Strongly
Signals, 1600-1627 W/F

Arecibo Signals 2003
1600 - 1627 MHz

Signal Number, Sorted by Frequency

16-18 July 2004
RFI2004 Workshop, DRAO  Penticton BC
Signals, 1600-1627 P/F
Arecibo Signals 2003
1600 - 1627 MHz

Power [arb. units]

Signal Number, Sorted by Frequency
Signals, 1600-1627 F/W

Arecibo Signals 2003
1600 - 1627 MHz

Most Detected Signals have Minimum Width
Signals, 1600-1627 P/W

Arecibo Signals 2003
1600 - 1627 MHz

Signal Number, Sorted by Width

Power [arb. units]
Signals, 1600-1627 D/D

Arecibo Signals 2003
1600 - 1627 MHz

Drift Rate [Hz/sec]

Signal Number, Sorted by Drift Rate
Signals, 1600-1627 P/D

Arecibo Signals 2003
1600 - 1627 MHz

Signal Number, Sorted by Drift Rate

Power [arb. units]
Signals, 1600-1627 P/P

Arecibo Signals 2003
1600 - 1627 MHz

Power [arb. units]

Signal Number

0 1000 2000 3000 4000 5000 6000

0 100 200 300 400 500 600 700 800 900