The Robert C. Byrd
Green Bank Telescope

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The Robert C. Byrd Green Bank Telescope (GBT)

- The GBT is a facility of the National Science Foundation
- It is a 100 m Radio Telescope with
  - 7854 m² of collecting area
  - Offaxis optics
  - Real-time active surface
    - 2004 moveable reflecting panels
  - Pointing and surface precision for operation ultimately to 2.6 mm wavelength
    - Pointing accuracy of 1 arc sec
    - => Tip of feed arm positioned to <1 mm
  - Design frequency coverage:
    - ~300 MHz to 115 GHz
- In regular astronomical operation since 2003
Observational Features of the GBT

- High fidelity, widefield imaging
  - Via unblocked main aperture
  - Gregorian optics
- High sensitivity to both point-like and extended structures
  - Large, filled aperture
- Relatively high angular resolution
  - Ultimately 6" at 115 GHz
- 3 mm capability (in dev.)
  - Via active surface and precision telescope control system
- Wide frequency coverage
  - 300 MHz to 115 GHz
- Wide, instantaneous bandwidth (30-40%)
- RFI-sensitive observing
  - Quiet Zone location

National Radio Quiet Zone

The GBT is protected from radio frequency interference by the National Radio Quiet Zone, a unique, 13,000 sq-mile region in which emissions from fixed, licensed transmitters must fall below prescribed levels.
Unblocked aperture

- 100 x 110 m section of a parent parabola 208 m in diameter
- Cantilevered feed arm is at focus of the parent parabola

GBT Instrumentation

- Receivers
  - Bands covering 300 MHz to 50 GHz
    - PF1, PF2, L, S, C, X, Ku, K, Ka, Q
  - Penn Array 64 pixel, 3 mm bolometer camera (under development)
  - W-band (68-92 GHz) heterodyne receiver (under development)

- Backends
  - Spectral Line
    - GBT Spectrometer
      - up to 256,000 channels, 800 MHz, 8 bands
    - Spectral Processor
  - Continuum
    - Digital Continuum Receiver (DCR)
    - Caltech Continuum Backend (under development)
  - Pulsar
    - Spigot, BCMP, GASP, CGRS2, Spectral Processor
  - VLBI
  - Radar (Cornell/JPL Portable Fast Sampler)
GBT Receiver Mounting

Gregorian Receiver Turret

Turret from above, with feed horns shown

GBT actuators continuously adjust the surface
Telescope surface-error maps:
before: $\sigma = 370 \, \mu m$     after: $\sigma = 210 \, \mu m$

OOF, or “Out-of-Focus” Holography technique. Uses astronomical sources; provides large-scale surface figure.

Efficiency and surface accuracy

- good efficiency $\sigma = \lambda / 16$ $\eta = 0.54$
- usable efficiency $\sigma = \lambda / 4\pi$ $\eta = 0.37$

2003 October:
usable efficiency at 52 GHz $\sigma = 0.46 \, mm$
Early 2005:
good efficiency at 60 GHz $\sigma = 0.32 \, mm$
2005 October (?):
usable efficiency at 86 GHz $\sigma = 0.28 \, mm$
Target: ~0.21 mm
Science Results

- Pulsars
  - General relativity (double-pulsar binary system)
  - Quark-gluon plasma (equation of state)
- Redshift measurement of obscured galaxies
  - High redshift CO, HCN and HI detections
- Pre-biotic Astrochemistry
  - New detections of complex interstellar molecules with biological significance
    - Propenal and propanal
    - Source of very cold, shock-formed simple sugar (glycolaldehyde)
- Measuring the Universe (H$_2$O masers)
- Galactic and Extra-galactic high fidelity imaging
  - Discrete Galactic HI clouds high above the Galactic Plane
  - High velocity clouds about M31
- Bistatic radar with Arecibo and Goldstone

GBT Science Across the Spectrum
How and when did the first galaxies form?

The GBT can already see one or more CO lines at all $z > 1.3$

The “Zpectrometer” will cover 14 GHz instantaneously

IRAS F10214+47 J=1-0 HCN at $z=2.3$ (sky freq. of ~27 GHz)

Detection of High Redshift Line Emission

Peak intensity: ~400 $\mu$Jy
RMS noise level: ~60 $\mu$Jy

IRAS F10214+47 J=1-0 HCN at $z=2.3$ (sky freq. of ~27 GHz)

Also detected: HI absorber at $z=0.8$ (J. Darling 2004) First detection of a DLA HI absorber from a radio-selected survey.
Astrochemistry with the GBT


Prebiotic Astrochemistry

Disruption of Grain Mantles

Possible Delivery Mechanism
Measuring the Universe: expansion rate

Spectrum of the water maser around the massive black hole in NGC 4258

Hubble constant: distance ladder vs direct measurement

Measuring the Universe: expansion rate

AGN Water Maser Spectrum Showing Keplerian Rotation Signature
Water “Gigamaser” at $z = 0.66$

Barvainis & Antonucci

By far the most distant circum-nuclear water maser known, $L \sim 10^5$ solar

This galaxy is in the Hubble Flow.

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HI and Infrared Images
Discrete HI Clouds in the Galactic Halo


High Velocity Clouds


### How the GBT Works with other NRAO Instruments

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Description</th>
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<tbody>
<tr>
<td>EVLA</td>
<td>Provides the large scale, diffuse image component.</td>
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<tr>
<td>ALMA</td>
<td>Will provide rapid, widefield surveys to detect galaxies, diffuse emission.</td>
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<tr>
<td>VLBA</td>
<td>Adds vast collecting area to increase sensitivity of ultra-high resolution observations.</td>
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**GBT**

**Galactic Center Imaging**

GBT-only data of the Galactic Center. The two columns of gas coming out of the GC are shown by GBT data to be part of the same structure or lobe. (Law, Yusef-Zadeh, et al.)

GBT and VLA Combined Images

Free-free emission:
Orion Nebula HII region 8.4 GHz

Arecibo / GBT 70 cm radar image of the Moon

B. Campbell et al. (2004)
Summary

• The GBT is a new facility, in full scientific operation since late 2003
  ▪ Extraordinary sensitivity, image fidelity, frequency coverage
• Significant scientific results to date in
  ▪ Pulsars
  ▪ High redshift line detections
  ▪ Astrochemistry
  ▪ HI imaging of Galactic Structure
• Future science will include further studies in the above areas plus
  ▪ Cosmology
  ▪ Expanded studies of the early universe
  ▪ Millimeter-wave studies of Galactic star formation