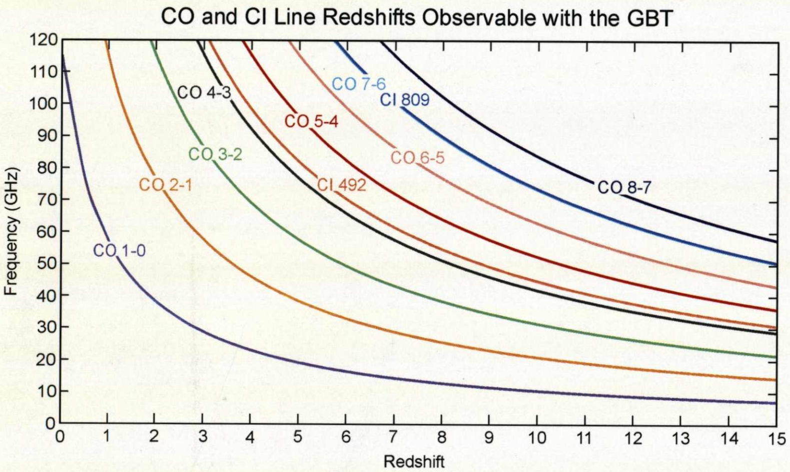
The
Robert C. Byrd

Green Bank Telescope

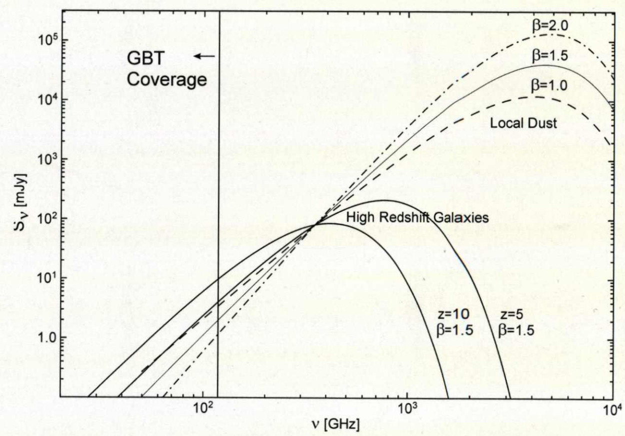
The Green Bank Telescope (GBT) is the most sophisticated large single-dish radio telescope ever built. Its advanced technical features, many unique, will give its users unprecedented access to the radio sky and allow them to tackle a wide range of astrophysical problems.

The GBT's size and unique offset geometry will let it make deep spectroscopic detections and images of unprecedented fidelity. Its active surface and laser metrology system extend its frequency coverage to millimeter wavelengths, allowing rich molecular-line and continuum observations. And the telescope's Gregorian focus can accommodate future focal-plane array receivers and detectors, including large-format bolometer cameras. With these capabilities, the GBT is well positioned to:

- make the first spectral-line observations of *unlensed* galaxies at extreme redshifts;
- make the most accurate measurements to date of the expansion and age of the Universe (through the Sunyaev-Zeldovich effect);
- detect new interstellar molecular species, including those of biological significance; and
- observe pulsar / black hole binary systems.



The redshifts of extragalactic CO and CI spectral lines in GBT observing windows. For 4 < z < 15, which is thought to cover the first epoch of stellar evolution, many of the most likely lines of CO fall into frequency ranges the GBT can observe.



By making sensitive measurements at 80-100 GHz, the GBT can discriminate between the spectral energy distributions of many types of objects. A 3-mm bolometer camera placed on the GBT would be extremely sensitive to the continuum emission from redshifted dust.

Science with the GBT

Complementing other instruments

The GBT will complement NRAO's other instruments: the VLA, VLBA and the planned ALMA telescope. Together they will give a comprehensive set of observing capabilities at radio and millimeter-wavelengths. While the interferometers will be unique in their ability to image small structures, the GBT will be adept at imaging larger fields, which set the astrophysical context – yet it will not overlook interesting compact objects. Crucially, the GBT will be able to use incoherent detectors such as bolometer cameras for continuum imaging on large scales. As well, its vast collecting area will be invaluable in VLBA projects needing extreme sensitivity.

Key features

- **a huge collecting area** – 100 m x 110 m
- **an unblocked aperture** – gives better system noise and image quality than that of a conventional antenna, and reduces spectral standing waves
- **access to the whole sky** – the telescope's mount allows it to view the whole sky above 5° elevation, giving it access to 85% of the celestial sphere
- **an active surface and laser-based metrology system** – maintains the antenna's efficiency at all elevations and under changing temperature conditions. The surface's 2004 panels can be individually adjusted by a system of 2209 actuators (small motor-driven pistons) which have a positional accuracy of 25 μm.
- **a rotatable-turret mount for receivers** – up to eight receivers can be mounted at any one time, and switching between them takes only minutes
- **wide frequency coverage** – with its active surface, laser metrology system and accurate panels, the telescope can work at wavelengths from 3 m to 3 mm (~100 MHz to ~100 GHz)
- **an advanced spectrometer** – 256K channels, ten times more resolution and bandwidth than previous instruments.

Radio frequency interference is an important consideration for any radio telescope. Both the site and the design of the GBT help to mitigate it. Green Bank Observatory is surrounded by the National Radio Quiet Zone, in which NRAO can influence the use of ground-based transmitters. Green Bank is also an isolated site, far from urban areas and shielded by surrounding mountains. These factors make it one of quietest sites in the U.S. for doing radio astronomy.

The offset reflector design of the GBT further reduces the amount of RFI entering the receivers: there are no supports to reflect RFI into the feeds, and sidelobe response is minimized. Care has been taken to reduce RFI from equipment associated with the telescope, such as motors, digital electronics and switching relays. Furthermore, NRAO is researching promising methods of interference excision that could be implemented on the GBT in the future.

National Radio Quiet Zone

(NRA[...]to by Ron Monck)

Cosmology and the early Universe

Because of its sensitivity at millimeter wavelengths, the GBT will excel at observing highly redshifted dust and spectral lines from the earliest epochs of galaxy formation. To date only a few, gravitationally lensed, galaxies at z-2-4 have been detected in their dust continuum and CO line emission: the GBT should detect many unlensed systems. The telescope will also be advantageous for studying high-redshift HI, and OH megamasers. For both line and continuum observations, the GBT will need only minutes to reach noise levels that other telescopes take hours to achieve.

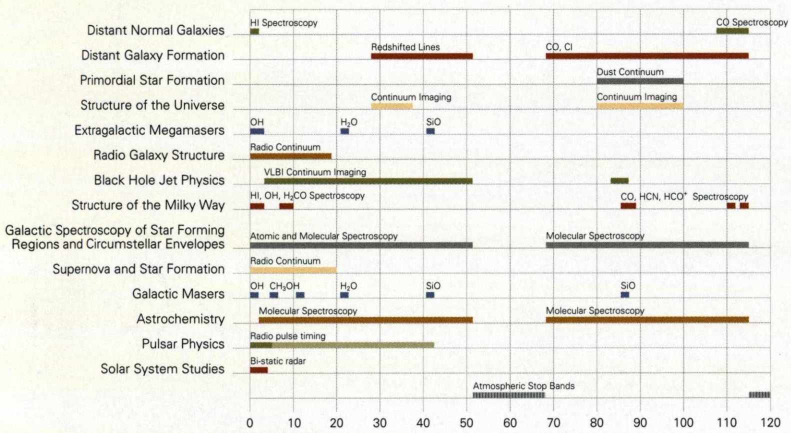
The GBT will be well suited to many kinds of cosmological studies. Its unblocked aperture will be ideal for studies of wide, weak lines, such as the hyperfine transitions of $^3He^+$. It will perform extremely well at 1-cm wavelengths (30 GHz), a preferred window for CMB studies. And it will also be a sensitive tool for determining galaxy masses and distances through the Sunyaev-Zeldovich effect.

GBT:

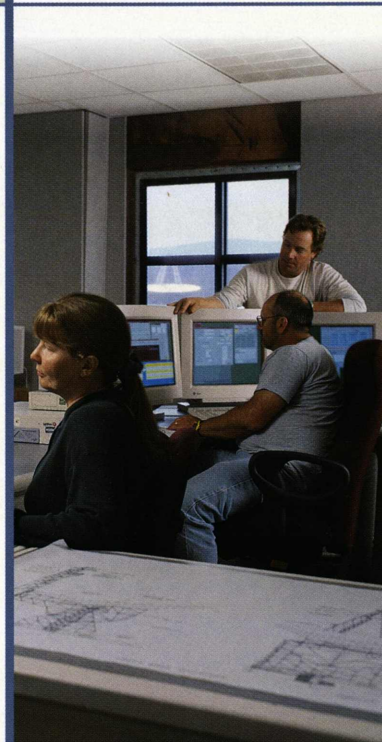
Precise

Sensitive

Versatile



Science with the Green Bank Telescope



(NRAO/AUI photo by Mike Bailey)

Green Bank Telescope Control Room

Galactic HI

The GBT will make highly accurate and absolutely calibrated measurements of Galactic HI, quickly and routinely. The antenna's low sidelobes will allow studies of faint HI in the Galactic halo, and of the energetics of the ISM. Its sensitivity to polarization will allow it to map Galactic magnetic fields, through observations of HI Zeeman splitting.

Recombination lines

With its wideband spectrometer the GBT will be able to simultaneously observe radio recombination lines and make accurate measurements of continuum emission. Along with the continuum, radio recombination lines of hydrogen, helium and carbon will be useful probes of the physical properties of ionized gas in HII regions and planetary nebulae.

Astrochemistry

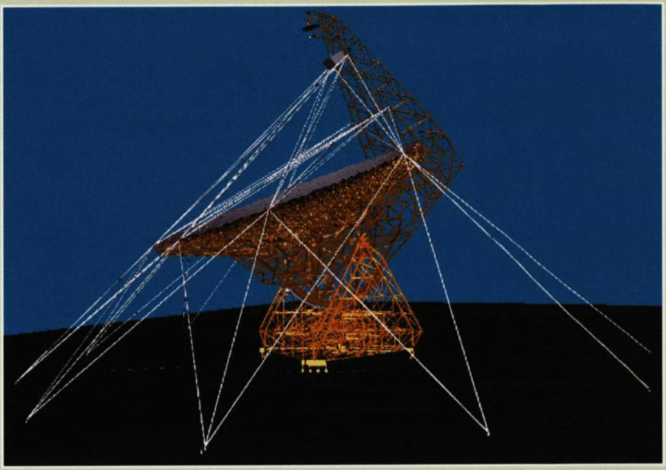
Frequency coverage, frequency agility, small beam size, and wideband spectral-line imaging: all these will make the GBT a powerful instrument for studying the chemistry of clouds around and between stars. At the low end of its frequency range the GBT will be able to gather unique data on heavy molecules, including those of biological significance. At the high end it will observe the many species in the 3-mm window. The GBT will be ideal for detecting new species.

Star formation

With its wide frequency coverage the GBT will be able to study many aspects of star formation. It will be able to map magnetic fields in star-forming regions, through Zeeman effects of several molecular species. To probe the density and temperature of pre-stellar cores, the GBT will be able to study NH_3 at 23 GHz and CS at 49 GHz. SiO, at 43 GHz, will trace jets and shocks in the outflows from young stars. And in the 3-mm band several molecules can be used to study the first, low-mass phases of star formation.

Pulsars

Pulsar hunters will benefit from many of the GBT's features: a large collecting area, sensitive receivers, ability to cover 85% of the celestial sphere, a low-interference site, and low sidelobes that help in rejecting the interference that does exist. The GBT will be able to make single-pulse observations at higher frequencies (>5 GHz) than has been practical before: this will overcome the problem of pulse broadening that occurs at lower frequencies, which can make pulses hard to detect.


(NRAO/AUI)

Laser paths on the Green Bank Telescope

The Solar System

The GBT's large collecting area will make it a prime instrument for studying Solar System objects. Used as the receiving antenna in bistatic radio experiments (with Arecibo or Goldstone as the transmitter), the GBT will be able to image planetary surfaces, near-Earth asteroids and comets. The GBT will also be excellent for spectral-line observing of comets and planetary atmospheres.

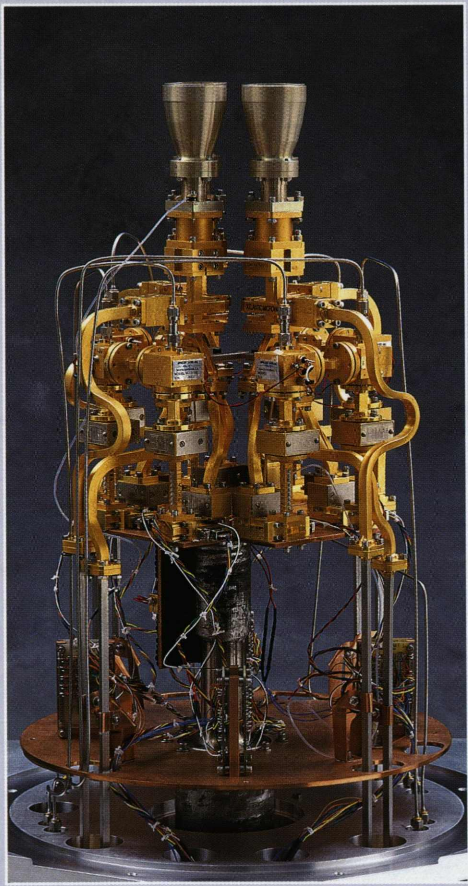
VLBI

Many interesting astrophysical problems, such probing active galactic nuclei, need both the ultra-high angular resolution of VLBI and extreme sensitivity. The GBT can improve VLBI networks in both ways. For some projects, adding the GBT to the VLBA will improve the system's imaging sensitivity by up to an order of magnitude. Together the GBT and VLA form a high-sensitivity, east-west baseline that can be added to both the VLBA and the European VLBI Network.

GBT Technology

Receivers

The GBT will initially be outfitted with five prime-focus frontends (covering 290-1230 MHz) and eight Gregorian-focus frontends (seven covering 1.15-26.5 GHz and an eighth, 40-52 GHz). Other frontends are under construction, planned or proposed. For construction status, system temperatures and the exact bands covered, see www.gb.nrao.edu/GBT/EL/rxstatus.html


(NRAO/AUI photo by Mike Bailey)

The 4-beam, 8-channel receiver for the Green Bank Telescope, operating at 40-52 GHz.

Laser metrology and active surface

The telescope's primary mirror is composed of 2004 panels, with a panel accuracy of 68 μm rms. The panels are supported by 2209 actuators, whose movements adjust the positions of individual panels. The backup structure has been designed to maintain the shape of the mirror to within 1.25 mm of the correct shape as elevation changes. The corrections will be based on the computed model of the structure. Thermal gradients and steady winds will also cause shape changes that need compensation. The adjustments required will be determined by six laser rangefinders on the feedarm, beaming onto retroreflector prisms on the primary mirror. The actuator corrections should be accurate to 100 μm. Displacements of the feedarm, determined by the rangefinders and a quadrant detector, will be corrected by moving the Gregorian subreflector.

The pointing of the telescope will be based on a coordinate system referred to the ground. Six "triplet retroreflectors" will be mounted around the edge of the primary mirror: their positions will be measured from above by the six rangefinders on the feedarm, and from below by twelve rangefinders on the ground, set in a ring of 120 m radius around the telescope. The ground rangefinders will measure the triplets' positions to determine changes in the orientation of the backup structure, relative to the azimuth and elevation encoder readings. They will also monitor the positions of other retroreflectors, mounted directly below the bearings for the elevation axle, to determine changes in orientation of the axle. Both sets of measurements will be used to correct the telescope's pointing for the effects of thermal gradients and steady winds. The accuracy aimed at for these corrections is 1 arcsecond.

GBT Operating Specifications

Diameter	100 m x 110 m
Surface Area	7853 m^2
Surface Accuracy (ms)	
- open loop surface	<360 μm
- closed loop, with metrology	<220 μm
Pointing accuracy (rms)	
- conventional	3 arcsec
- closed-loop, with metrology	1 arcsec
Slew rate in azimuth	40 deg min^{-1}
Beam size (FWHM)	720 arcsec / ν (GHz)
Flux sensitivity	1.85 K Jy^{-1} at 20 GHz

GBT Sensitivity

(in 60 seconds total integration time, with closed loop surface and laser metrology)

Spectral Line Sensitivity	Bandwidth	rms noise
1420 MHz (HI)	1 km s^{-1}	0.06K/32 mJy
22 GHz (H_2O)	1 km s^{-1}	0.03K/18 mJy
43 GHz (e.g.SiO)	1 km s^{-1}	0.03K/15 mJy
89 GHz (e.g. HCN)	1 km s^{-1}	0.04K/40 mJy
Continuum Sensitivity		
14 GHz	3 GHz	55 μJy
90 GHz	20 GHz (planned)	120 μJy

GBT Backends

Backend	**Specifications**
GBT Spectrometer	Maximum channels per IF: 262,144 Bandwidth modes for multi-inputs: 8 x 800 MHz or 32 x 50 MHz Maximum spectral resolution: 48 Hz @ 12.5 MHz bandwidth Pulsar mode: 4096 samples x 256 lags each 1.3 msec
Spectral Processor	2 x 1024 channels x 40 MHz 1, 2, 4, or 8 IF modes
Digital continuum backend	V/F converter to 28-bit counters; 16 inputs; 10 switching phases; 100 nanosec phase time-resolution
VLBI	VLBA and S2 recorders

The National Radio Astronomy Observatory is a facility of the National Science Foundation, operated under cooperative agreement by Associated Universities, Inc.

Green Bank on the web: www.gb.nrao.edu