THE GREEN BANK TELESCOPE

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ABSTRACT

The Green Bank Telescope (GBT), a new 100 m diameter radio telescope, is under commissioning and early scientific operation. The GBT has a number of novel design features including an unblocked aperture, an active surface, and a precision telescope control system that is designed to allow operation into the 3 mm wavelength range. The unblocked aperture has already paid dividends in high dynamic range images. The active surface has worked very well in its initial operation and has made a substantial improvement in gain and beam quality over a large range of elevation angles. This paper describes the features of the GBT, its status, and some of the early scientific results from the telescope.

INTRODUCTION

The Green Bank Telescope, shown in Figure 1, is an advanced single dish radio telescope designed for a wide range of astronomical projects with special emphasis on precision imaging. The telescope was formally dedicated as the Robert C. Byrd Green Bank Telescope in August 2000, and has been undergoing scientific commissioning since February 2001. The first scientific observations took place in early April 2001, and scientific observations have continued to be interspersed with commissioning activities. Novel features of the GBT include its unblocked main aperture, its active surface, and its precision telescope control system that includes a laser metrology system, feedarm ranging system, and focus tracking system. Early scientific results have included bi-static radar imaging in collaboration with Arecibo Observatory, continuum imaging of the Orion Nebula at 8 GHz with very high fidelity, the detection of several new millisecond pulsars, and the detection of the youngest-known radio pulsar in the supernova remnant 3C58. Previous general reviews of the GBT can be found in Hall et al. (1998), Lockman (1998), Vanden Bout (1998), and Jewell (2000).

Fig. 1 – The Green Bank Telescope

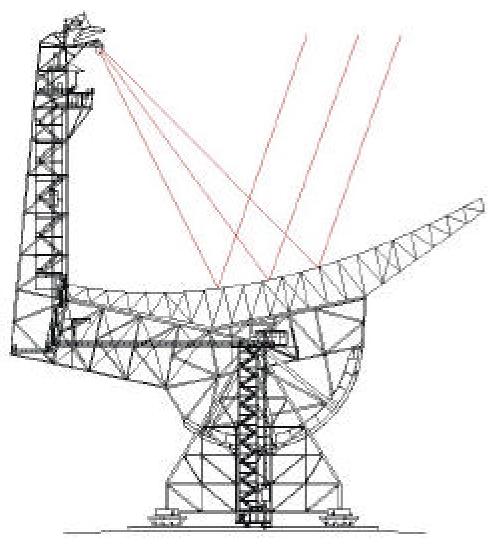

Fig. 2 – GBT offset optics

GBT STRUCTURE AND OPTICS

The GBT is a massive structure weighing approximately 7700 metric tons, and is believed to be the largest moving structure on land. It is an azimuth-elevation telescope with a wheel and track design, and can be pointed to any elevation between 5 and 90 degrees, allowing access to 85% of the celestial sphere. One of the most significant features of the telescope, particularly given its large size, is the unblocked main aperture. The GBT reflecting surface is a 100x110m section of a 208 m virtual parabola. A single, cantilevered feed support arm is attached at the edge of the surface, and at the focus of the virtual, parent parabola. With this offset design, incoming rays are not blocked before they reach the prime focus position or the secondary reflecting mirror, as shown in Figure 2.

The GBT can be used either as a prime focus system, or as secondary, Gregorian focus system. For prime focus operation, a retractable boom holding a receiver is placed in front of the Gregorian subreflector, which is concave in shape. The prime focus receiver mount can hold one receiver at a time and has a Sterling Mount with rotation and radial focus movement. The prime focus is used for the low frequency bands between 300 and 1200 MHz. The prime focus f/D is 0.29, relative to the 208 m parent parabola. The Gregorian subreflector is an 8 m mirror positioned by a Stewart Platform with 6 degrees of freedom. The Gregorian focus f/D is 1.9, referred to the 100 m effective aperture. The Gregorian receivers are mounted in a rotating turret and enclosed in a large receiver room. The turret can hold 8 different receivers that can be rotated into position under computer control within a few minutes. The Gregorian receivers include the higher frequency receivers, beginning with 1.2 GHz and will ultimately include the 100 GHz systems.

ACTIVE SURFACE

The GBT's reflecting surface is composed of 2004 panels mounted in rings that are concentric to the vertex of the 208 m parent (virtual) parabola. The rms surface accuracy of individual panels is about 75 μm, on average. The panels are mounted at their corners on computer controlled actuators such that the corners of four adjacent panels share one actuator. The actuators consist of electric motor driven, precision ball screws that can be positioned to within a tolerance of 25 μm. Each actuator assembly includes an LVDT position sensor for positive servo feedback.

The active surface can be used in at least three different modes, static correction, open-loop continuous active, and closed loop continuous active. Given the results of photogrammetry or holography measurements of surface errors, the active surface can be commanded to remove those errors at the relevant elevation angle, as a one-time static improvement to surface accuracy. This has been done once on the basis of photogrammetry measurements, and the rms surface accuracy at the rigging angle of ~45 degrees elevation is now ~450 μm. The surface can also be adjusted nearly continuously as a function of elevation angle based on a look-up table of positions. This lookup table can be generated from a finite element model (FEM) of the structure or, possibly, from a set of elevation-dependent holography maps produced by the phase-retrieval (out-of-focus) technique. As of late March 2002, the active surface is in use based on a FEM-generated look-up table. The improvement is quite dramatic in flattening the gain-elevation curve and in removing sidelobes from the beam at low elevation angles. Ultimately, the active surface will be used in closed loop mode based on position feedback from the laser rangefinders and the Precision Telescope Control System described below.

PRECISION TELESCOPE CONTROL SYSTEM

One of the most novel features of the GBT is the Precision Telescope Control System (PTCS) that should allow observations into the 100 GHz range. This system consists of several components, the most fundamental of which is a laser rangefinding system (Payne, Parker, and Bradley 1992). The transmit/receive system consists of a modulated laser, a two-axis, computer-controlled mirror system, and a phase detection system. The range-finders target retroreflecting mirrors, and can determine a position to 100 μm or less over a distance of 100 m or more. The measurement system consists of two sections: a system of twelve rangefinders on stable ground monuments that range to retro-spheres on the back of the GBT structure, and a system of 6 rangefinders mounted on the vertical feedarm that range to 2209 retroreflectors mounted above the actuators on the reflecting surface. The ground system is used to determine telescope position for pointing control. The feedarm system is used for measuring surface deformations and will ultimately be used in closed loop control of the active surface. At this writing, all twelve ground laser rangefinders are operational and undergoing tests and one of the feedarm rangefinders is mounted.

There are also several other critical components of the PTCS. A vertical feedarm ranging system measures the movement of the upper tip of the feedarm relative to a stable position below the surface of the dish. This will be used for focus-tracking refinements and, eventually, for measurement and possible removal of small oscillations in the feedarm induced by the wind or antenna drive motions. The focus-tracking system of the Gregorian subreflector is also an essential component of the PTCS, as is the active surface control. Finally, and quite importantly, this entire system must be integrated into the telescope monitor and control system. The PTCS is under active development and will be phased into normal operations over the next two years.

INSTRUMENTATION PLANS

The GBT development project included the construction of a complete suite of instrumentation for initial operation of the facility. This includes a large, autocorrelation spectrometer, a digital continuum backend, and receivers covering most of the frequency range from 300 MHz to 50 GHz. The GBT Spectrometer is a 256k-lag machine with a maximum bandwidth of 800 MHz and a minimum channel resolution in narrow-band modes of 191 Hz. The system can accept up to 16 independent IFs for processing in some modes. The receivers include prime focus receivers for 300-1200 MHz, and Gregorian receivers for L-band (1.15-1.73 GHz), S-Band (1.73-2.60 GHz), C-Band (3.95-5.85 GHz), X-Band (8.0-10.1 GHz), Ku-Band (12.0-15.4 GHz), K-Band (18-26.5 GHz), and Q-Band (40-50 GHz). All receivers are dual polarization. Ku-Band and higher frequency receivers are dual-beam, and the Q-Band receiver has 4, dual-polarization beams.

In addition to the above instruments, receivers for Ka-Band (26-40 GHz) and W-Band (68-92 GHz) are under construction. Both of these receivers are dual-beam, dual-polarization, pseudo-correlation receivers that are capable of processing wide bandwidths for sensitive continuum observations as well as providing excellent spectral line performance. Owing to its offset optics and wide field of view at the Gregorian focus, the GBT is intrinsically a highly capable imaging telescope. Consequently, a major thrust of the instrumentation development program is to construct focal plane array imagers. Two such projects are underway. The NRAO is funding a project led by the University of Pennsylvania (Devlin, Dicker, et al.) and in collaboration with NASA-Goddard, to construct a 64-pixel bolometer camera for the 3 mm (~90 GHz) wavelength range. This will be a state of the art bolometer camera using TES bolometers and SQUID readouts. This project was initiated in the spring of 2002 and should be completed in three years. In addition, the NRAO is constructing a beam-forming array for the 1.5 GHz band (Bradley, Fisher, et al.). This will be a full-sampling array of 7-19 elements using digital beam-forming techniques. This program has an initial R&D period and should lead to a production array in about five years.

COMMISSIONING STATUS

At this writing (Spring 2002), the GBT has commissioned the following instruments and capabilities: receivers through 10 GHz (largely complete) and Ku-Band (12-15 GHz) and K-Band (18-26.5 GHz) (partially commissioned). The Spectrometer is available in several modes including the 9-level, 50 MHz bandwidth mode and the 3-level, 800 MHz mode. Many more modes should be released over the coming months. Observing modes include basic spectral line modes for position, frequency, and beam switching for single point as well as imaging observations. Pulsar observing using the Berkeley-Caltech Pulsar Machine and the Spectral Processor are available. A bi-static radar processor provided by Cornell University is also available. Conventional, blind pointing accuracy of ~7" has been achieved, and offset pointing of a few arcsec is readily achievable. Beam sidelobes at low frequency have been characterized and are ~-30 dB below the main beam. Focus tracking that is easily accurate enough for observations through 26 GHz has been achieved. One of the most important achievements has been the commissioning of the active surface using the finite element lookup table, which has worked extremely well. In the coming months, we will concentrate on operational refinements and Spectrometer modes, and then move to Q-Band commissioning in the autumn of 2002. An update on commissioning results will be provided in the poster presented at the conference.

EARLY SCIENTIFIC RESULTS

As observing capabilities on the GBT have become available, scientific observations have been interspersed. This has led to a number of significant, early results including bi-static radar images of Venus (Campbell et al.), detection of millisecond pulsars in M62 (Jacoby et al.); and detection of youngest radio pulsar known in the supernova remnant 3C58 (Camilo et al.). Early imaging results are also outstanding. Shepherd, Maddalena, and McMullin have produced an image of the Orion Nebula at 8 GHz having nearly 12,000:1 dynamic range, the highest quality wide field image ever obtained with a filled aperture telescope (Fig. 3). Scientific results will also be updated at the conference.

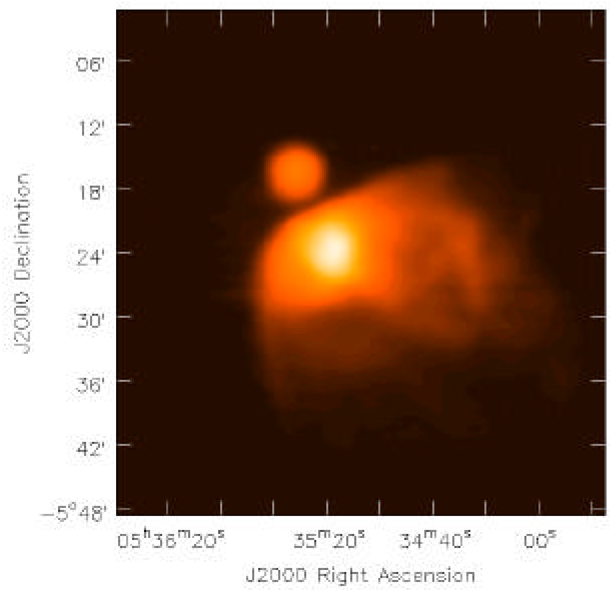

Fig. 3 – 8.4 GHz image of the Orion Nebula by Shepherd, Maddalena, and McMullin.

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