The Green Bank Telescope

- Large Collecting Area
- Unblocked Aperture
- Low sidelobes gives high dynamic range
- Resistance to Interference
- Excellent spectral Baselines
- Excellent sensitivity to low surface brightness
- Frequency coverage from 100 MHz–100 GHz
- Spectroscopy, Continuum, Pulsar, VLBI
- >85% Sky Coverage δ≥−46°
- Pointing to 1″–2″ accuracy
- Surface good for 3mm work
- Active Instrument Development Program
- Site Protected by a 13000 km² Radio Quiet Zone

Felix James “Jay” Lockman
NRAO, Green Bank
Unblocked Optics for high dynamic range
Unblocked Optics for high dynamic range
Unblocked Optics for high dynamic range
Overview: DSS Relative Efficiencies without Limits (eta/eta_mi)

GBT Dynamic Scheduling matches the project to the weather

1776 hours of observing at >18 GHz dynamically scheduled in 2010 -- this amount should rise in the coming years
A Cruise Through Some Recent GBT Science

- HI Intensity Mapping
- Discovery of new pulsars
- Redshifted HI and OH
- The most massive pulsar
- Solar System Radar
- New sources of anions
- Water in M31
- Nuclear Black Hole masses
- Shocks in Galaxy Clusters
- Galaxy Growth and Evolution
- Quiescence in Cloud Cores
- Limits on Fundamental “constants”
GBT measurements test fundamental physics with radio pulsar J1614-2230

~1 week of GBT timing observations with coherent GUPPI

Orbital inclination = 89.17(2) deg!

Companion mass = 0.500(6) solar!

Pulsar mass = 1.97(4) solar!

(Demorest et al. 2010)
The new mass determination for PSG J1614-2230 makes it the most massive pulsar known, and rules out a number of soft equations of state for nuclear matter including many “exotic” hyperon, kaon models.
A Cruise Through Some Recent GBT Science

- HI Intensity Mapping
- Discovery of new pulsars
- Redshifted HI and OH
- The most massive pulsar
- Solar System Radar
- New sources of anions
- Water in M31
- Nuclear Black Hole masses
- Shocks in Galaxy Clusters
- Growth of the Milky Way
- Quiescence in Cloud Cores
- Limits on Fundamental “constants”
When is a planet like a disco ball?

Mars

Disco Ball
When is a planet like a disco ball?
When you illuminate it with radar.
Goldstone + GBT
Bistatic Radar
When is a planet like an egg?
When is a planet like an egg?

When it has a molten core.

“Large Longitude Libration of Mercury Reveals a Molten Core”
Margot et al. 2007 Science

Goldstone + GBT
Bistatic Radar
Arecibo-Green Bank Telescope Radar View of the Moon’s South Pole (Courtesy Cornell University/Smithsonian Institution)
A Cruise Through Some Recent GBT Science

- HI Intensity Mapping
- Discovery of new pulsars
- Redshifted HI and OH
- The most massive pulsar
- Solar System Radar
- New sources of anions
- Water in M31
- Nuclear Black Hole masses
- Shocks in Galaxy Clusters
- Growth of the Milky Way
- Quiescence in Cloud Cores
- Limits on Fundamental “constants”

>12 new organic molecules detected including the first interstellar anions: \( C_6H^- \) & \( C_8H^- \)

Cordiner et al. 2011
new anion sources
A Cruise Through Some Recent GBT Science

- HI Intensity Mapping
- Discovery of new pulsars
- Redshifted HI and OH
- The most massive pulsar
- Solar System Radar
- New sources of anions
- Water in M31
- Nuclear Black Hole masses
- Shocks in Galaxy Clusters
- Growth of the Milky Way
- Quiescence in Cloud Cores
- Limits on Fundamental “constants”
GBT Discovery of H$_2$O Masers in M31

J. Darling (Univ. Colorado)

The Proper Motion of M31 is the Keystone of Local Group Dynamics

At the distance of M31 the GBT can detect
Galactic analog H$_2$O masers in 5 minutes

206 sources
5 detections
GBT Discovery of H$_2$O Masers in M31

J. Darling (Univ. Colorado)

Expect 6σ detection of proper motion in ~3 years

~30 μarcsec/year (if 100 km/s)

Proper rotation gives a geometric distance -- expect 10% uncertainty initially

~15 μarcsec/year

~70 μarcsec/year
A Cruise Through Some Recent GBT Science

- HI Intensity Mapping
- Discovery of new pulsars
- Redshifted HI and OH
- The most massive pulsar
- Solar System Radar
- New sources of anions
- Water in M31
- Nuclear Black Hole masses
- Shocks in Galaxy Clusters
- Galaxy Growth and Evolution
- Quiescence in Cloud Cores
- Limits on Fundamental "constants"
Direct Observation of a Sharp Transition to Coherence in Dense Cores

The GBT K Band Focal Plane Array is up and running

Ammonia mapping of dark clouds
Finn & Jackson

New Spectrometer on the way (with UCB)
A Cruise Through Some Recent GBT Science

- HI Intensity Mapping
- Discovery of new pulsars
- Redshifted HI and OH
- The most massive pulsar
- Solar System Radar
- New sources of anions
- Water in M31
- Nuclear Black Hole masses
- Shocks in Galaxy Clusters
- Galaxy Growth and Evolution
- Quiescence in Cloud Cores
- Limits on Fundamental “constants”
SMBH masses in Seyfert galaxies lie below the “universal” line defined by SMBH’s in elliptical galaxies

Kuo et al. 2011
Greene et al. 2010
A Cruise Through Some Recent GBT Science

- HI Intensity Mapping
- Discovery of new pulsars
- Redshifted HI and OH
- The most massive pulsar
- Solar System Radar
- New sources of anions
- Water in M31
- Nuclear Black Hole masses
- Shocks in Galaxy Clusters
- Galaxy Growth and Evolution
- Quiescence in Cloud Cores
- Limits on Fundamental “constants”
MUSTANG 3mm Bolometer Array
MACS0744+3927 \([z=0.69]\)
Korngut et al (2011)
A Cruise Through Some Recent GBT Science

- HI Intensity Mapping
- Discovery of new pulsars
- Redshifted HI and OH
- The most massive pulsar
- Solar System Radar
- New sources of anions
- Water in M31
- Nuclear Black Hole masses
- Shocks in Galaxy Clusters
- Growth of the Milky Way
- Quiescence in Cloud Cores
- Limits on Fundamental “constants”
A Cruise Through Some Recent GBT Science

- HI Intensity Mapping
- Discovery of new pulsars
- Redshifted HI and OH
- The most massive pulsar
- Solar System Radar
- New sources of anions
- Water in M31
- Nuclear Black Hole masses
- Shocks in Galaxy Clusters
- Growth of the Milky Way
- Quiescence in Cloud Cores
- Limits on Fundamental “constants”
A Cruise Through Some Recent GBT Science

- HI Intensity Mapping
- Discovery of new pulsars
- Redshifted HI and OH
- The most massive pulsar
- Solar System Radar
- New sources of anions
- Water in M31
- Nuclear Black Hole masses
- Shocks in Galaxy Clusters
- Galaxy Growth and Evolution
- Quiescence in Cloud Cores
- Limits on Fundamental “constants”
The ragged edges of HI disks

HALOGAS WSRT Survey
Heald et al. 2011, in press
15” resolution to N_{HI} limit few 10^{19}
120 hours per galaxy

Fig. 1. Overview of the HALOGAS observations of UGC 2082. The left panel shows the H I total intensity overlaid on the DSS R-band image. The H I contours originate from the 30”-tapered image, begin at N_{HI} = 1.0 \times 10^{19} \text{ cm}^{-2} and increase by powers of two. The straight line shows the orientation of the PV slice shown in Fig. 2. The right panel shows an overlay of several channels in the lowest resolution data cube, all at a level of 0.9 mJy beam^{-1} (\approx 3.75\sigma). The contours are separated by 12.4 \text{ km s}^{-1}, begin at 593 \text{ km s}^{-1} (dark blue) and range upward to 815 \text{ km s}^{-1} (dark red). Both panels show the same area of the sky. The beam size of the H I data is shown in the lower left corners of the left panel.
HVCs around other galaxies

**M31 -- GBT**


contours at 0.5, 1, 2, 10, 20 x 10^{18}

HI Masses = 10^{6-7} M_{\odot}

**M33 -- Arecibo**


lowest contour 2x10^{18}

Fig. 2. — Total column density for discrete and diffuse high-velocity H I in the M31 GBT field, after masking emission from Andromeda’s inclined, rotating disk. Contours were evaluated at 3 kpc, 72 km s^{-1} resolution and rendered at 0.5, 1, 2, 10, and 20 x 10^{18} cm^{-2}, then overlaid on H I (Thilker et al. 2004). The position angle is given by the rotating disk model.
The continuing growth of the Milky Way

GBT Image of HI in Smith’s Cloud

“The Smith Cloud: A High-Velocity Cloud Colliding with the Milky Way”
Lockman, Benjamin, Heroux, Langson. 2008 ApJL
“On the continuing formation of the Andromeda Galaxy: Detection of HI Clouds in the M31 Halo”

“On the continuing formation of the Andromeda Galaxy: Detection of HI Clouds in the M31 Halo”

“Neutral Hydrogen clouds in the M81/M82 Group”
Chynoweth et al. 2008 AJ

Westerbork + GBT

Optical + GBT + VLA
The M31–M33 stream

WSRT as single dishes
49’ Resolution


Fig. 9. Integrated H\textsubscript{I} emission from the subset of detected features apparently associated with M 31 and M 33. The grey-scale varies between log($N_{\text{HI}}$) = 17–18, for $N_{\text{HI}}$ in units of cm$^{-2}$. Contours are drawn at log($N_{\text{HI}}$) = 17, 17.5, 18, ... 20.5.
GBT spectrum of the M31–M33 stream

Free, Lockman & Shields (2011, in prep)

Scan 2757
2010-08-05
Nicole Free

V : -425.0 RADI-LSR
Int : 05 40 33.4
LST : +20 02 50.5

F0 : 1.42041 GHz
Sky : 1.42255 GHz
BW : 12.5122 MHz

Pol : I
IF : 0
Agbt10A.043.29 OnOff

Tsys: 18.16
Tcal: 1.47

01 00 00.00 +39 29 59.9

Braun0100+395

Az: 63.5 El: 33.9 HA: -4.95

This is the frontier

Tpk=3.8±0.4 mK
ΔV = 36±5 km/s
V = -262±2 km/s
N_{HI}=2.7±0.2x10^{17} cm^{-2}

6 hours on–off
σ=1.1 mk
3 km/s channels

raw data with linear baseline
no bandpass issues

Galactic HI
FLAG -- Focal Plane L-Band Array for the GBT

B. Jeff, K. Warnick et al (BYU)
J.R. Fisher, R. Norrod, A. Roshi (NRAO)

- 19 dual polarized elements. Cryogenic PAF system
- $T_{sys} \sim 20$ K; Aperture efficiency $\sim 75$ to $80\%$
- 7 beams; spacing 0.5 FWHM to 1 FWHM
- Frequency coverage – 1300 to 1800 MHz; Backend for processing signals
A few of the important spectral lines in the 3mm window

% Transmission (Elev=45°, PWV=10mm)

© 1999 by Summoning, Inc.
GBT 4mm Receiver Project

# Tunable frequency range: 68–92 GHz (Coverage to 93.2GHz is highly desirable.)
# HPBW 11” to 8”
# Tsys = 100 K
# Polarization: Dual linear with selection of circular using a 1/4 wave plate for VLB observations.
# Number of beams: Two beams each with dual polarization
# Beam separation: 4.7 arcmin
# Calibration with cold, ambient, and sky loads using optical table
Planned 3mm Focal Plane Array
a wide field mapping complement to ALMA Band 3

GBT 3mm FPA footprint on an Infrared Dark Cloud

ALMA primary beam at 3mm

Lockman -- NRAO Postdoc Symposium April 2011
The Green Bank Telescope

We are entering Green Bank’s most productive decade yet.