Discoveries with the Green Bank Telescope

The Green Bank Telescope (GBT) is used by the scientific community for an extraordinary range of research. This document gives a brief summary of some of the resulting discoveries, with an emphasis on measurements that would be difficult or impossible to make on any other telescope.

PULSARS AND COMPACT OBJECTS

Pulsars and other compact objects are unique tools for studying aspects of fundamental physics such as matter at its most dense, extreme magnetic fields, and gravity. With its wide sky coverage, excellent point source sensitivity, ability to track horizon-to-horizon, and low interference environment, the GBT is the world's premier radio pulsar observatory. Projects such as the direct detection of gravitational waves require precise timing of an array of pulsars over many years. The precision of pulsar timing arrays is dominated by the most stable pulsars and increases with the number of pulsars in the array, so there is continuing benefit from discovering more pulsars. Searches also reveal unique objects that contribute to our knowledge of stellar evolution and test general relativity, or limit theories of dense matter, such as the discovery of the two solar-mass pulsar. The GBT has discovered the majority of the millisecond pulsars found in gamma-ray sources detected by the Fermi satellite. Searches are made at frequencies below 2 GHz, where, outside of the Arecibo declination range, the GBT is the most sensitive telescope. Loss of the GBT will end searches at 350 MHz and 820 MHz, where the majority of new millisecond pulsars are being found, and will halve the sensitivity of the pulsar timing array to direct detection of gravitational waves.

Representative publications

"Limits on the Stochastic Gravitational Wave Background from the North American Nanohertz Observatory for Gravitational Waves", Demorest, P.B. et al. 2012 ApJ (in press)
"Three Millisecond Pulsars in Fermi LAT Unassociated Bright Sources", Ransom, S.M. , et al. 2012 ApJ, 727, L16
"A two-solar-mass neutron star measured using Shapiro delay", Demorest, P.B. et al. 2010, Nature, 467, 1081
"A Radio Pulsar/X-ray Binary Link", Archibald, A.M., et al. 2009, Science, 324, 1411
"Relativistic Spin Precession in the Double Pulsar", Breton, R.P. et al. 2008, Science, 321, 104
"Transient pulsed radio emission from a magnetar", Camilo, F. et al. 2006, Nature, 442,892.
"Tests of General Relativity from Timing the Double Pulsar", Kramer, M. et al. 2006, Science, 314, 97
"A Radio Pulsar Spinning at 716 Hz", Hessels et al. 2006, Science, 311, 1901
"Twenty-One Millisecond Pulsars in Terzan 5 Using the Green Bank Telescope", Ransom, S.M. et al. 2005, Science, 307, 892

DARK ENERGY

The collective Hydrogen signal from unresolved, distant galaxies has been detected using the GBT in a powerful, new technique which probes large scale structure at intermediate redshifts. This technique of "intensity mapping"' has the potential to measure the scale of the Baryon Acoustic Oscillations over the critical redshift range of z=0.5 to 1, and hence constrain the expansion rate of the Universe and the nature of Dark Energy. The telescope's size, clean optics, good sensitivity at frequencies below 1 GHZ, and low interference environment because of its location in the National Radio Quiet Zone make it the only instrument capable of continuing this research at redshifts around unity.

Representative publications

"Measurement of 21 cm brightness fluctuations at z ~ 0.8 in cross-correlation", Masui, K.W., et al. 2012, ApJL (in press arXiv:1208.0331)

"An intensity map of hydrogen 21-cm emission at redshift z~0.8", Chang, T.-C., Pen, U.-L., Bandura, K., & Peterson, J.B. 2010 Nature, 466, 463

EVOLUTION OF PHYSICAL CONSTANTS

Some fundamental physical theories predict that the constants of nature, such as the gravitational and fine structure constants, have actually evolved over cosmological time to their current values. Measurement of atomic and molecular transitions at a high redshift are used to search for change in fundamental physical constants over a signifiant fraction of the age of the Universe. The resulting limits on variation of physical constants at a look-back time of 7-9 Gyr are the most stringent to date. The important studies listed here were made at frequencies below 1 GHz, where the GBT offers high sensitivity instrumentation, a low-interference environment, and very good sky coverage that is not matched by other instruments.

Representative publications

"Constraining the variation of fundamental constants at z~1.3 using 21-cm absorbers", Rahmani, H. et al. 2012, MNRAS, 425, 556

"Constraining Fundamental Constant Evolution with HI and OH Lines", Kanekar, N. ,et al. 2012, ApJ, 746, L16

"Constraints on Changes in Fundamental Constants from a Cosmologically Distant OH Absorber or Emitter", Kanekar, N. et al. 2005, Phys Rev. Lett. 95, 1301

GALAXY FORMATION

Galaxies are thought to form in the early Universe by sequential merging of smaller gas-rich objects. The process can be studied through highly redshifted molecular emission lines. With its wide frequency coverage and high sensitivity the GBT can quickly search a large frequency band for lines, measuring the redshift, line width, and molecular mass of objects discovered at other wavelengths, e.g., through their far-IR or sub-mm emission. When outfitted with the 3mm receiver now under development, the GBT will be the only telescope that can measure the fundamental CO(1-0) line from objects at all redshifts accessible from the ground. It is the most efficient telescope anywhere for this work.

Representative publications

"Blind Detections of CO J = 1-0 in 11 H-ATLAS Galaxies at z = 2.1-3.5 with the GBT Zpectrometer", Harris, A.I. et al., 2012, ApJ, 752, 152

"Green Bank Telescope Zpectrometer CO(1-0) Observations of the Strongly Lensed Submillimeter Galaxies from the Herschel ATLAS", Frayer, D.T. et al. 2011, ApJ, 726, L22

"Intense star formation within resolved compact regions in a galaxy at z = 2.3", Swinbank, A.M. et al, 2010, Nature, 464, 733

"The Detection of a Population of Submillimeter-Bright, Strongly Lensed Galaxies", Negrello, M., et al. 2010, Science, 330, 800

"CO(1-0) in z$\gtrsim$4 Quasar Host Galaxies: No Evidence for Extended Molecular Gas Reservoirs", Reichers, D.A. ,et al. 2006, ApJ, 650, 604

EVOLUTION OF GALAXY CLUSTERS

Galaxy clusters form by hierarchical, gravitationally-driven mergers of smaller systems, a record of which is preserved in the hot cluster gas. This gas can be measured at radio and millimeter wavelengths using observations of the Sunyaev-Zel'dovich Effect (SZE). The MUSTANG 64-pixel bolometer array, operating at 3mm wavelength on the GBT, has redefined the state of the art in these studies by substantially increasing their angular resolution and sensitivity, revealing previously unsuspected pressure waves in the cluster gas and hinting at evidence for a kinematic SZE on resolved, sub-cluster scales. These observations are important diagnostics of gravity and dark energy. The GBT is preeminent worldwide for spatially resolved imaging of the Sunyaev-Zel'dovich Effect, and will remained so with the array camera upgrades that are now under way. Without the GBT these capabilities will be lost.

Representative publications

"A Multi-wavelength Study of the Sunyaev-Zel'dovich Effect in the Triple-Merger Cluster MACS J0717.5+3745 with MUSTANG and Bolocam", Mroczkowski, T., et al., 2012, ApJ (761, 47)

"MUSTANG High Angular Resolution Sunyaev-Zel'dovich Effect Imaging of Substructure in Four Galaxy Clusters", Korngut, P.M. et al. 2011, ApJ, 734, 10

"Implications of a High Angular Resolution Image of the Sunyaev-Zel'dovich Effect in RXJ1347-1145", Mason, B.S. et al., 2010, ApJ, 716, 739

BLACK HOLES & THE HUBBLE CONSTANT

Many if not all spiral galaxies have a massive black hole in their nucleus, and the growth of the black hole may be intimately related to the growth of the galaxy itself. Discovery and measurement of the properties of H_2O masers in the accretion disk around a nuclear black hole yields the mass of the black hole, and a measurement of its distance from geometry. A precise value for the Hubble constant can be derived from a sample of galaxies studied this way, giving a constraint on cosmology that is independent of traditional distance estimators. The GBT has been used to discover the masers and monitor their acceleration, and, as part of high sensitivity very long baseline array, to determine the maser location and kinematics. The masers are so weak that the GBT is required for the high angular resolution studies. Without the GBT, geometric determination of galaxy distances and of H_0 through this technique would not be possible.

Representative publications

"Milky Way Supermassive Black Hole: Dynamical Feeding from the Circumnuclear Environment", Liu, H.B. et al, 2012, ApJ, 756, 195

"The Megamaser Cosmology Project: IV. A Direct Measurement of the Hubble Constant from UGC 3789", Reid, M.J. et al. (2012 in press arXiv:1207:7292)

"The Megamaser Cosmology Project. V. The First Direct Measurement of The Angular Diameter Distance to A Galaxy Beyond 100 Mpc", Kuo, C.Y. et al. 2012 ApJ, (in press, arXiv:1207.7273)

"The Megamaser Cosmology Project. III. Accurate Masses of Seven Supermassive Black Holes in Active Galaxies with Circumnuclear Megamaser Disks", Kuo, C.Y. et al. 2011, ApJ, 727, 20

GROWTH AND EVOLUTION OF GALAXIES

Understanding gas flows within and between galaxies is key to understanding their growth and evolution. With its wide sky coverage, exceptionally clean and stable optics, state-of-the art receivers and low interference environment, the GBT routinely measures diffuse HI emission 10-100 times fainter than any interferometer and 1000-10000 times fainter than typically found in galaxy disks. It is also an extremely efficient instrument for measuring the global properties of HI in galaxies: velocity, mass and global kinematics. The multi-pixel phased array 21cm receiver now under development will give the GBT unprecedented capabilities for mapping the faintest HI emission. The GBT is pioneering breakthrough research into the properties of faint extragalactic HI clouds. No other telescope either existing or planned can reach these sensitivities and without the GBT this research will end.

Representative publications

"The Neutral Hydrogen Bridge Between M31 and M33", Lockman, F.J., Free, N.L., & Shields, J.C. 2012, AJ, 144, 52
"Mapping the Extended H I Distribution of Three Dwarf Galaxies", Hunter, D.A. et al. 2011, AJ, 142, 173
"The Origin of Neutral Hydrogen Clouds in Nearby Galaxy Groups: Exploring the Range of Galaxy Interactions", Chynoweth, K.M. et al. 2011, AJ, 142, 137
"The 200° Long Magellanic Stream System", Nidever, D.L., Majewski, S.R., Burton, W.B., & Nigra, L. 2010, ApJ, 723, 1618
"Detection of Diffuse Neutral Intragroup Medium in Hickson Compact Groups", Borthakur, S. et al. 2010, ApJ, 710, 385
"The Extragalactic Distance Database", Tully, R.B. et al. 2009, AJ, 138, 323
"The Baryon Content of Extremely Low Mass Dwarf Galaxies", Geha, M., Blanton, M.R., Masedi, M., & West, A.A. 2006, ApJ, 653, 240
"On the Continuing Formation of the Andromeda Galaxy: Detection of HI Clouds in the M31 Halo", Thilker, D.A. et al. 2004, ApJ, 601, L39

STAR FORMATION

Stars form in clusters in the densest parts of molecular clouds under conditions that are still uncertain. The GBT is a superb instrument for studying this process on a variety of angular scales in the Milky Way and other galaxies as well. Mapping clouds in multiple molecular species reveals the overall structure of the cloud, gives insight into its physical and chemical properties, and identifies locations for more detailed observation with telescopes such as the VLA and ALMA. Recombination line studies are discovering scores of new Galactic HII regions, mapping their distribution and temperature, and setting limits on the radiation field of ionizing photons in the inner Galaxy. The synergy of the GBT with other instruments is evident in the title of several of the publications referenced here. With new multi-pixel cameras, rapid mapping of wide fields in dozens of molecular lines simultaneously is now routine. The high sensitivity, instrumental stability, and new capabilities in the 70-115 GHz band make the GBT unrivaled worldwide. Without it much of this research would not be done.

Representative publications

"Herschel Observations of a Potential Core-forming Clump: Perseus B1-E", Sadavoy, S.I., et al. 2012, A&A, 540, A10
"On the Ionization of Luminous WMAP Sources in the Galaxy: Constraints from He Recombination Line Observations with the GBT", Roshi, D.A., et al. 2012, ApJ, 749, 49
"The BOLOCAM Galactic Plane Survey. VII. Characterizing the Properties of Massive Star-Forming Regions", Dunham, M.K. et al 2011, ApJ, 741, 110
"Direct Observation of a Sharp Transition to Coherence in Dense Cores", Pineda, J.E. et al. 2010, ApJ, 712, L116
"The Green Bank Telescope Galactic HII Region Discovery Survey", Bania, T.M., Anderson, L.D., Balser, D.S. & Rood, R.T. 2010, ApJ, 718, 106
"90 GHz and 150 GHz Observations of the Orion M42 Region: A Submillimeter to Radio Analysis", Dicker, S.R. et al. 2009, ApJ, 705, 226
"Testing Magnetic Star Formation Theory", Crutcher, R.M., Hakobian, N., & Troland, T.H. 2009, ApJ, 692, 844.
"Star Formation Activity of Cores Within Infrared Dark Clouds", Chambers, E.T., Jackson, J.M., Rathborne, J.M. & Simon, R. 2009, ApJS, 181, 360
"An Ammonia Spectral Atlas of Dense Cores in Perseus", Rosolowski, E.W., et al. 2008, ApJS, 175, 509
"Formaldehyde Densitometry of Starburst Galaxies", Mangum, J.G., Darling, J., Menten, K.M., & Henkel, C. 2008, ApJ, 673, 832

SOLAR SYSTEM STUDIES

The GBT is used for diverse research on objects in the Solar System including occasional tracking of interplanetary spacecraft, observation of comets, and bi-static radar using another facility as the transmitter at 0.4 GHz, 2.3 GHz and 8.6 GHz. As a component of radar experiments it has participated in Lunar geological studies, the discovery of the molten core of Mercury, determination of the shape of near-Earth objects, and measurement of the spin state of Mercury and Europa. Its excellent sensitivity and sky coverage, location on the East Coast of the US, and the stability and simplicity of a single dish make it indispensable for these studies. Without the GBT most of this research would not be possible. Cameras now under development in the 3mm band will provide unprecedented wide-field, sensitive, high angular resolution maps of molecules in coments, tracking changes on time scales of hours.

Representative publications

"Mercury's Moment of Inertia from Spin and Gravity Data", Margot, J.-L., et al. 2012, JGR, in press

"Earth-based 12.6-cm Wavelength Radar Mapping of the Moon: New Views of Impact Melt Distribution and Mare Physical Properties", Campbell, B.A. et al, 2010, Icarus, 208, 565

"Large Longitude Libration of Mercury Reveals a Molten Core", Margot, J.L., Peale, S.J., Jurgens, R.F., Slade, M.A., & Holin,I.V. 2007, Science, 316, 710.

"No evidence for thick deposits of ice at the lunar south pole", Campbell, D. B.,et al. 2006, Nature, 443, 835

"The Vertical profile of winds on Titan", Bird, M.K., et al. 2005, Nature, 438, 800

"An overview of the descent and landing of the Huygens probe on Titan", Lebreton, J.-P., et al. 2005, Nature, 438, 758

INTERSTELLAR ORGANIC CHEMISTRY

New stars and planets are formed in interstellar clouds that are rich in organic molecules. The connection between interstellar chemistry and the organic chemistry of life on Earth is of profound interest. Biologically relevant molecules are found in extended regions of molecular clouds and their emission is best studied at longer wavelengths. The low surface brightness molecular lines are generally resolved out by interferometers. The efforts of laboratory chemists combined with astronomical measurements using the GBT has already given new insights into chemical processes in space. The GBT has been in the forefront of modern interstellar chemistry studies, including detection of the first interstellar anions, as it has exceptional sensitivity and frequency coverage, and the instrumental stability needed to measure these weak lines. These studies would be severely limited, or impossible, without the GBT.

Representative publications

"Laboratory and Tentative Interstellar Detection of Trans-methyl Formate Using the Publicly Available Green Bank Telescope PRIMOS Survey", Neill, J.L., et al. 2012, ApJ, 755, 153

"Discovery of Interstellar Anions in Cepheus and Auriga", Cordiner, M.A., et al. 2011, ApJ, 730, L18

"Detection of the Carbon Chain Negative Ion C8H- in TMC-1", Brunken, S., et al. 2007, ApJ, 664, L43

"Laboratory and Astronomical Identification of the Negative Molecular Ion C6H-", McCarthy, M.C., Gottlieb, C.A., Gupta, H., & Thaddeus, P. 2006, ApJ, 652, L141

"Possible gas-phase syntheses for seven neutral molecules studied recently with the Green Bank Telescope", Quan, D. & Herbst, E. 2007, A&A, 474, 521

"Detection of Acetamide (CH3CONH2): The largest interstellar molecule with a peptide bond", Hollis, J.M., et al. 2006, ApJ, 643, L25

EXTREME ANGULAR RESOLUTION

The GBT is a very important component of the High Sensitivity Array (HSA), the group of radio telescopes that join to provide the highest angular resolution and highest sensitivity Very Long Baseline Interferometry (VLBI). Its great sensitivity, low interference environment, and location in the Eastern US provide critical capabilities for the HSA and other VLBI networks. The HSA with the GBT is measuring the proper motion of nearby galaxies through precise astrometry on masers in their star-forming regions. In 2012 the GBT began observations with the Russian RadioAstron space telescope. In 2013 it will join the Global mm VLBI Array, bringing more than twice the sensitivity of any other telescope to the Array at 3mm wavelength. This will allow the Array to resolve the structure of gas in the Milky Way's nucleus with unprecedented accuracy and derive a parallactic measurement of the distance to the nuclear black hole. In addition to the H2O maser publications discussed above, a representative sample of VLBI science with the GBT is listed here.

Representative publications

"Water Masers in the Andromeda Galaxy: the First Step Toward Proper Motion", Darling, J. 2011, ApJ, 732, L2

"The First Accurate Parallax Distance to a Black Hole", Miller-Jones, J.C.A. et al. 2009, ApJ, 706, L230

"Spatial Variations in Galactic HI Structure on AU-Scales Toward 3C 147 Observed with the Very Long Baseline Array", Lazio, T.J.W. et al., 2009, AJ, 137, 4526

"VLBI Images of 49 Radio Supernovae in Arp 220", Lonsdale, C.J. et al. 2006, ApJ, 647, 185

"The Angular Size and Proper Motion of the Afterglow of GRB 030329", Taylor, G.B., Frail, D.A., Berger, E., Kulkarni, S.R. 2004, ApJ, 665, 1304

WHO USES THE GREEN BANK TELESCOPE?

More than 900 different scientists and their students have used the GBT during the last five years. In 2012 alone the GBT received proposals from more than 600 researchers, typically organized in teams of 4 to 5. The majority of the proposals have at least one student as a co-I. The GBT user community is diverse and includes many physicists, planetary scientists and chemists, as well as astronomers and astrophysicists. The telescope is oversubscribed by a factor of more than four.