GREEN BANK OBSERVATORY 2020

OUR VISION
we are here...

TO SERVE
... To serve the scientific and educational community by offering advanced instrumentation for radio astronomy

TO DISCOVER
... To harness the power of radio astronomy to discover black holes, newborn stars, pulsars, gravitational waves, and the origins of galaxies and of life itself

TO FOSTER INNOVATION & CURIOSITY
... To pursue knowledge in a unique environment for research, learning, and teaching

TO EDUCATE
... To encourage a sense of wonder for the unkown beyond our planet

The Observatory was established in 1957 by the National Science Foundation as the National Radio Astronomy Observatory. Today, the NSF's Green Bank Observatory is an independent research facility which receives major funding from the National Science Foundation, and is operated by Associated Universities, Inc.

The country's first national observatory
Innovators leading the future of astronomy

Nestled in the rolling mountains and farmland of West Virginia, radio astronomers are seeking answers to some of humanity's most extraordinary scientific questions.

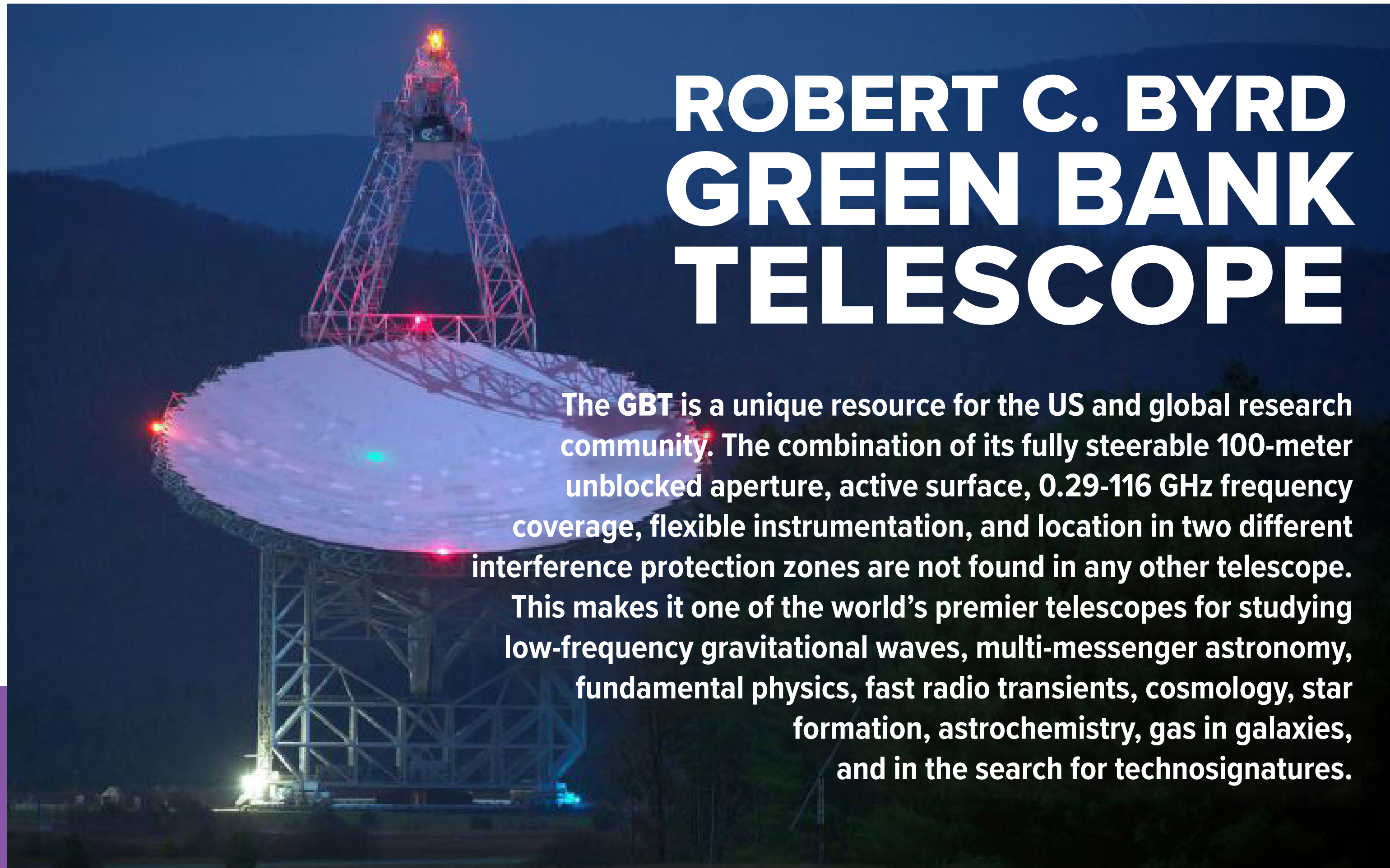
The Green Bank Observatory is the home of the 100-meter Robert C. Byrd Green Bank Telescope (GBT), the world's largest steerable single-dish radio telescope. The Observatory campus includes an acclaimed Science Center, machine shop, electronics laboratory, and seven additional radio telescopes, along with a cafeteria and housing. The Observatory's location, surrounded by the Allegheny Mountains in Deer Creek Valley, is protected by two complementary radio interference protection zones – the National Radio Quiet Zone and the West Virginia Radio Astronomy Zone – providing an excellent environment for astronomical observations.

Green Bank is an attractive location for independent research experiments, and serves as the field station for several university-based research teams.

The Observatory machine shop and electronics laboratory have built state-of-the-art components and instruments for telescopes and research facilities around the world. The 2,700-acre site has significant infrastructure which allows for the installation of any instrument which may benefit from the radio quiet location. There is ample space for new projects, a radio frequency test range, and anechoic chamber.

The Observatory's educational and public outreach programs for learners of all ages, and hands-on research experiences for students and educators, are nationally acclaimed.

Green Bank is an inclusive, creative, and tight-knit community. Our award winning staff come from the surrounding area, the country, and around the world, and they are proud to call this place home.



ROBERT C. BYRD GREEN BANK TELESCOPE

The GBT is a unique resource for the US and global research community. The combination of its fully steerable 100-meter unblocked aperture, active surface, 0.29-116 GHz frequency coverage, flexible instrumentation, and location in two different interference protection zones are not found in any other telescope. This makes it one of the world's premier telescopes for studying low-frequency gravitational waves, multi-messenger astronomy, fundamental physics, fast radio transients, cosmology, star formation, astrochemistry, gas in galaxies, and in the search for technosignatures.

100-METER DIAMETER

REACHING 85% OF THE CELESTIAL SPHERE

6,500 HOURS OBSERVING ANNUALLY

0.29-116 GHZ FREQUENCY COVERAGE

The GBT has a 100-meter diameter unblocked primary reflector with an active surface that can maintain an RMS surface accuracy of 230 µm under stable thermal conditions. This surface accuracy yields good observing efficiency at frequencies as high as 116 GHz. The unblocked aperture results in an extremely clean point spread function allowing high dynamic range observations of diffuse emission. The GBT can observe declinations as low as -47,°covering 85% of the entire celestial sphere. Green Bank experiences approximately 2,000 hours per year with atmospheric opacity suitable for observing at 70-116 GHz and near the 22 GHz water line. The GBT is scheduled dynamically to take full advantage of these conditions.

The GBT's suite of low-noise radio receivers provides nearly continuous frequency coverage from 0.29-116 GHz, and its spectrometer can process as much as 4-8 GHz of instantaneous bandwidth. The GBT has several multi-pixel receivers: the K-Band 7-pixel Focal Plane Array, the Argus 16-pixel receiver[1], and the MUSTANG2 90 GHz 223-pixel bolometer array.[2]

The Focal L-Band Array, FLAG,[3] is a cryogenically cooled phased array feed camera, a test instrument that currently holds the sensitivity record for a receiver of this type.

[1] Instrument development PI: S.Church, Stanford University

[2] Instrument development PI: M. Devlin, University of Pennsylvania

[3] The FLAG beamformer backend, PI: K. Warnick, Brigham Young University

TECHNOLOGY current & future

The GBT was built to be flexible and to be upgraded regularly to anticipate the needs of the astronomical community. In the next decade, several projects will expand the GBT's performance.

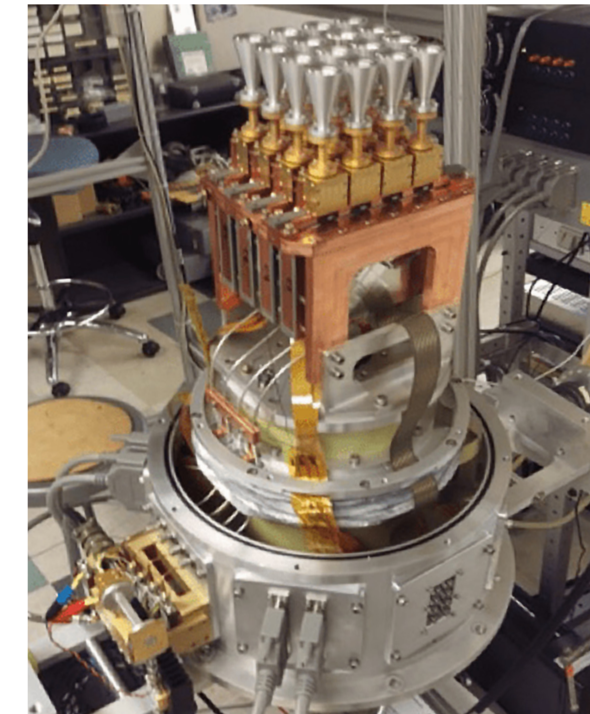
The Observatory operates state-of-the-art electronics and digital development labs specializing in the design of low-noise cryogenic receivers and FPGA-based wideband digital backend systems. The machine shop builds nearly all GBT feed horns, Dewars, RFI enclosures, and other custom components.

OPTIMIZED RECEIVERS Straightforward upgrades of existing receivers to take advantage of recent technological developments will lead to a 30-50% improvement in survey speed, even without adding additional pixels. This will impact all areas of GBT science including studies of pulsars, hydrogen in galaxies and interstellar organic chemistry.

ULTRAWIDEBAND SYSTEMS The Observatory is developing an 0.7-4 GHz Ultra Wide Band Receiver to improve its sensitivity for pulsar studies of low frequency gravitational waves and fast radio transients. It will also be used for molecular spectrosopy and measurement of radio recombination lines.

RADIO CAMERAS Argus144 is a proposed extension of the existing 16-pixel Argus receiver and would improve the traditional feed horn camera mapping speed within this 74-116 GHz band by an order of magnitude. This proposed 144 feed-horn camera with improved amplifiers would provide wide-field imaging of key molecular transitions for the study of star formation and astrochemistry. It will include a dedicated spectrometer providing a total velocity coverage of 2000 km s^{-1} with 0.015 km s^{-1} resolution at 90 GHz.

PHASED ARRAY FEED RECEIVERS A proposed 22 GHz phased array feed receiver, KPAF, will be capable of forming 225 independent, Nyquist-sampled beams which will dramatically increase the mapping capability of the GBT between 18-26 GHz. This instrument will be ideally suited to the size scales found in star-forming regions and will complement continuum studies such as Herschel's SPIRE program with kinematic information and accurate temperature measurements. It will provide ≤0.1 K RMS noise in 0.1 km s^{-1} channels, with a system temperature ≤50 K and formed beam efficiency of 0.61. FLAG2 will improve upon FLAG, the first operational cryogenically cooled PAF receiver and the most sensitive in the world. FLAG samples the focal plane of the GBT using 19 dipole elements, and its digital beamformer produces seven Nyquist-sampled beams on the sky with a bandwidth of 150 MHz. FLAG2 will have four times the survey speed and more bandwidth, providing a powerful survey instrument for pulsars, fast radio bursts, and interstellar hydrogen.



NATIONAL RADIO QUIET ZONE
13,000 square miles regulatory protection on all fixed, licensed radio transmitters

WEST VIRGINIA RADIO ASTRONOMY ZONE
10 mile radius, increased restrictions on use of all radio frequency emitters

DATA ARCHIVING & HIGH-PERFORMANCE PROCESSING TOOLS
A multi-petabyte data archive along with a new suite of data reduction software will be developed to ensure that all GBT data resulting from open-skies projects will be preserved, including pulsar surveys. Data will be easily accessible in a well-documented and commonly used format, with tools to allow easy reprocessing, and complete meta-data and processing pipelines to ensure reproducibility.

SHARING THE RADIO SPECTRUM Spectrum occupancy will continue to grow for the foreseeable future. Green Bank has been actively testing several techniques for automated RFI detection and excision. The next generation of wideband digital backends will be built incorporating these new technologies.

MORE DETAILS & WHITE PAPERS
greenbankobservatory.org/science/instruments-2020-2030

science IN THE NEXT DECADE

Over the next decade, the unique capabilities of the GBT — its sensitivity, wide frequency coverage (0.29-116 GHz), all-sky tracking and protection from interference — will be used to make major advances in fundamental physics, interstellar chemistry, star formation, the study of black holes and their environment, the structure and evolution of galaxies and galaxy groups, cosmology, our understanding of the Solar System, and the search for signs of life elsewhere in the Universe.

■ A massive star ends its life as a supernova, sometimes leaving behind a neutron star that can appear as a pulsating radio source called a pulsar. The GBT is the world's **premier pulsar telescope**; its recent detection of the most massive neutron star ever found challenges our understanding of matter in its densest form. The GBT will continue to discover more pulsars, some in environments that **test fundamental physical laws** like the equivalence principle and will also refine our understanding of gravity and general relativity.

■ The arrival time of a pulsar's radio pulses can be used to detect nanohertz-frequency gravitational waves. Through extremely accurate timing of a set of pulsars, the GBT will **directly detect gravitational waves** originating from the inspiral of binary supermassive black holes. The direct detection of individual binary systems will enable **multi-messenger observations** of dual active galactic nuclei. A direct detection of the gravitational wave background will test theories of galaxy mergers, the evolution of supermassive black holes, and how they interact with their local environment. Precision pulsar timing by the GBT is a necessary complement to ground and space-based laser interferometers for gravitational wave studies.

■ Complex organic molecules are being created in the interstellar medium through a chemistry that we simply do not understand. This is a critical gap as chemistry is an integral part of star formation, and the chemical processes that create **interstellar organic molecules** were likely the starting point of life on Earth. With its sensitivity to weak spectral lines, the GBT will lead studies of the formation and distribution of interstellar molecules and give insights into fundamental chemical processes.

■ Interstellar molecules are found within galaxies in giant gas clouds. Radio emission from these molecules can be used to understand the mechanisms that form the clouds, determine their structure, and regulate their collapse to **create new stars and new solar systems**. Within our own galaxy, the GBT will map entire molecular clouds, including their star-forming filaments and cores, and measure their internal kinematics and physical properties with high sensitivity. Using its multi-pixel cameras for radio spectroscopy, the GBT can cover an entire spiral arm yet resolve nearby star-forming cores at an angular resolution as high as 7 arcseconds.

■ In galaxies like the Milky Way, **large-scale star formation** is controlled by the distribution of gas within the galaxy, the infall of fresh gas, and the rate at which the gas is incorporated into new stars. The GBT is mapping the dense gas across nearby star-forming galaxies, and is discovering clouds of hydrogen plunging into those galaxies, bringing new material for future star formation. This research will produce unique data on the gas content of distant galaxies at high redshift, and its change as galaxies evolve through time.

■ At the center of every large galaxy lies a massive black hole that can capture nearby gas and stars. Part of the captured material is drawn into the black hole while the rest is expelled in powerful jets often accompanied by a wind. If this event is violent enough, it can strip a galaxy of all its gas. In the coming decade the GBT will provide critical capabilities for the study of **black holes and their interaction with their environment**. The GBT will discover and study gas clouds being expelled from the Milky Way nucleus. When connected with other radio telescopes around the world, the enormous sensitivity of the GBT will reveal the structure of gas accreting onto black holes in distant galaxies. The GBT provides critical sensitivity for VLBI networks that can measure a black hole mass, study the tidal disruption of a star by a black hole, and watch the creation of quasars at an angular resolution of tens of micro-arcseconds.

USING THE GBT

Calls for proposals to observe using the GBT are issued twice a year.

greenbankobservatory.org/science/gbt-observers/proposals

SHARING OUR SCIENCE

The Observatory hosts many public and private workshops and conferences each year, for special topics focusing on radio astronomy, to the Society of Amateur Radio Astronomers and other groups. Presentations from these events are often recorded, archived, and shared at our website.

greenbankobservatory.org/science/meetings-and-workshops

GREEN BANK SCIENTIFIC & TECHNICAL ACHIEVEMENTS

1950s
- Dedication of the Observatory in Green Bank
- Groundbreaking for the 140-foot telescope
- National Radio Quiet Zone established
- Dedication of the Howard E. Tatel 85-foot telescope
- Grote Reber reconstructs his telescope
- Detection of emission from Jupiter's radiation belts

1960s
- First SETI observations
- Drake Equation
- First radio astronomy at 1.4mm wavelength
- First digital autocorrelator in use
- Radio Recombination Line surveys
- Detection of Zeeman splitting of interstellar hydrogen
- Intercontinental interferometry: Green Bank to Sweden
- Discovery of the pulsar in the Crab nebula
- First organic polyatomic interstellar molecule

1970s
- First detection of radio novae
- First long carbon-chain interstellar molecule
- Radio recombination lines from the Galactic Center
- Discovery of Sgr A*, the Milky Way's central black hole
- First measurement of relativistic deflection of light with 1% errors
- Discovery of the Tully-Fisher relationship
- Extended HI rotation curves reveal dark matter

1980s
- 1400 MHz sky survey
- CBS5 survey of radio sources
- Area of the sky with the least interstellar matter
- Discovery of Extreme Scattering Events
- Galactic Plane Radio Patrol
- Surveys of He^3 emission
- First detection of HI in S0 galaxies
- First measurements of the magnetic field in molecular clouds

1990s
- GBT groundbreaking
- Green Bank Earth Station operates with Japan's VSOP satellite
- Discovery of maser emission from methanol
- Detection of long carbon chain molecule $HC_{11}N$

2000s
- GBT first light
- Discovery of high-velocity clouds around Andromeda
- Discovery of more than 20 pulsars in a globular cluster
- Detection of the first interstellar molecular anion
- Discovery of the fastest spinning pulsar
- Detection of the molten core of the planet Mercury
- Binary pulsar provides best test yet of general relativity
- GBT first observations at 3mm wavelength
- Hydrogen cloud on collision course with the Milky Way
- Many H_2O masers found around black holes in galactic nuclei

2010s
- Discovery of the most massive known neutron star
- Commissioning of 16-pixel camera for 3mm spectroscopy
- First detection of an interstellar chiral molecule
- Measurements of redshifts and molecular gas for high-z galaxies
- Intensity mapping detection of hydrogen emission at $z \sim 0.8$
- Pulsar in triple system confirms the Equivalence Principle
- Regular bi-static radar imaging of asteroids
- Galaxy clusters imaged at 9'' using Sunyev-Zeldovich effect.
- Detection of first interstellar aromatic carbon ring molecule
- Commissioning of 223-pixel bolometer camera for 3mm
- Galaxy surveys establish existence of Laniakea Supercluster
- 3mm VLBI of M87 jet at 250x80 micro-arcsecond resolution
- Best limit on a stochastic background of gravitational waves

■ In the era of **multi-messenger astrophysics** the Universe is studied through gravitational radiation as well as electromagnetic radiation. In the coming decade the GBT will be used as the most sensitive element of a long-baseline array to localize and study the remnants of the interaction of compact objects, for example, the weak radio emission associated with binary neutron star mergers. There is no instrument either current or proposed that can replace the GBT for these measurements. At 3mm wavelength **the GBT/ALMA combination** is more sensitive by a factor >20 than any other instrumental combination for the highest resolution imaging, and will remain so for the foreseeable future.

■ When the Large Synoptic Survey Telescope begins operation in 2022 it will open up a new era in **time-domain astronomy**, detecting many thousands of optically varying objects each night. The GBT will make follow-up radio observations to check for radio bursts or pulsations. The GBT will discover and monitor the enigmatic **fast radio bursts**, which probe environments in distant galaxies.

■ The GBT will continue to measure properties of objects in our solar system and around other stars. With the high instantaneous sensitivity of its wide-field radio cameras it will make rapid images of **the flow of gas from comets**. It will study thermal emission from the Oort cloud of comets around nearby stars. As the passive element of bi-static radar studies it will observe **the winds on Venus** as they modulate the planet's rotation, and the coupling of the crust and core of Mercury. The GBT will image **near-Earth asteroids** to determine their structure and precise trajectories.

■ Half of the galaxies in the Universe are in large galaxy clusters that are filled with hot ionized gas. The GBT's MUSTANG2 radio camera, with its sensitivity, high angular resolution, and wide field of view at 3mm wavelength, will measure **the structure of galaxy cluster gas** and the pressure within the cluster. These data will reveal the history of cluster formation, filamentary structures between clusters, and the evolution of massive galaxies at high redshift.

■ In the coming decade the GBT will continue its **search for technosignatures**. Radio leakage from Earth-like civilizations will be detectable through new surveys that greatly expand the volume of space and the radio frequencies that are searched.

READ MORE greenbankobservatory.org/science/science-2020-2030

the future of ENGINEERING

MECHANICAL • ELECTRICAL • COMPUTER • HARDWARE • SOFTWARE

Observatory staff possess hundreds of years of combined expertise and experience developing, building, and repairing all of the instruments and systems in Green Bank, and have built or contributed to many more projects worldwide.

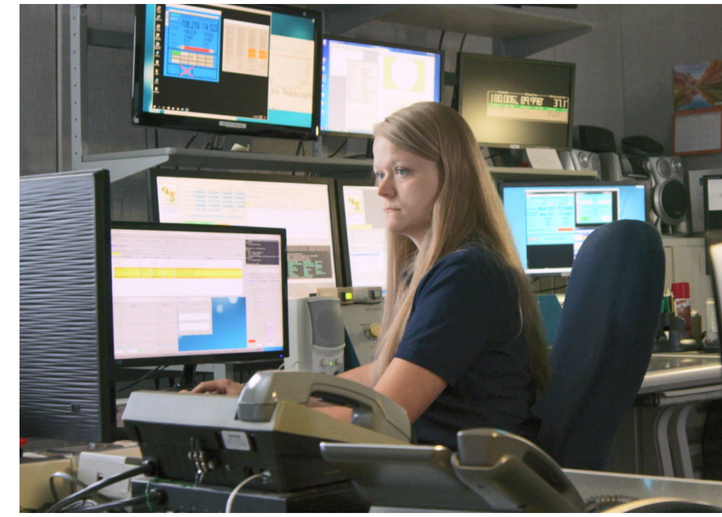
While focused towards Green Bank operations, the staff are also able to develop innovative solutions and products for other research organizations around the world.

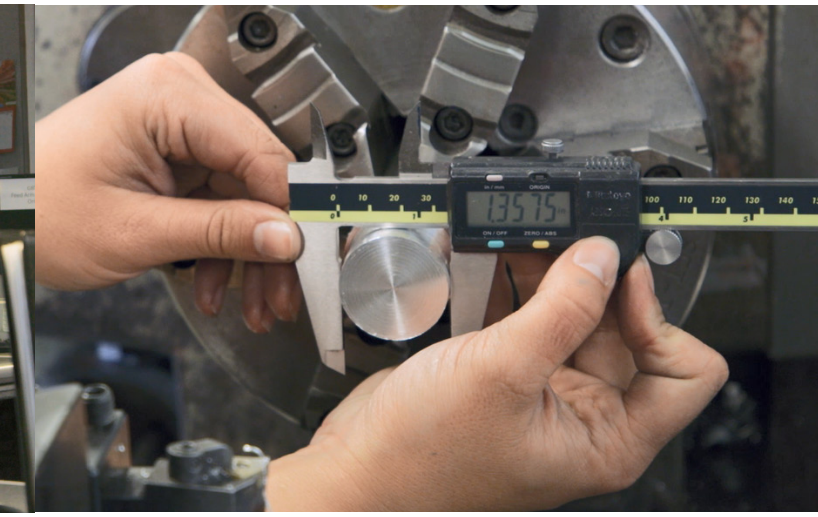
DIGITAL

Focusing on issues ranging from active surface electronics through optimized analog-to-digital conversion, active signal excision and FPGA and GPU technologies, the Green Bank Observatory's digital engineering group provides cutting-edge research and technologies into all aspects of telescope operations and signal processing. Current projects underway in the digital group include real-time RFI excision across 5-10 GHz bandwidths, modernized active surface control and metrology techniques, and high bit, high time resolution signal processing.

MICROWAVE

The Observatory's microwave engineering group maintains a laboratory equipped with state-of-the-art test and measurement equipment, including a bonding machine and probe station for building and testing Monolithic Microwave Integrated Circuit (MMIC) devices, an Anritsu Vector Star vector network analyzer capable of measuring microwave components up to 115 GHz, and an assortment of RF and fiber optic devices. The RF laboratory routinely produces working RF board and optic designs up to 115 GHz using CST Microwave and Microwave Office development software. Recent projects include a 19-element L-band cryogenic PAF receiver, a K-band focal plane array, and a dual beam 4mm receiver with calibration optics. The staff also routinely experiments with commercially available MMIC devices to improve gain stability and baseline performance of the current GBT systems.





SOFTWARE

The Observatory's software development division builds, maintains, and upgrades subsystems supporting the optimization, operation, and data reduction for all Observatory telescopes and systems, including: observation management, telescope monitor and control, telescope scheduling, data reduction, data archiving, visitor reservations, and site management and administration. The division simultaneously supports new development and ongoing operations using development methodologies that best support a given project and team, makes effective use of automation, and carefully balances custom code development with open source solution integration.

MECHANICAL

The Observatory shop completes countless challenging fabrications each year, often developed from sketches provided by engineers and scientists. Rapid repair capabilities maximize telescope efficiency and compress development schedules for producing instruments. Machinists produce parts with tolerances that are much smaller than most commercial shops. The shop utilizes a full range of fabrication techniques that include both manual and CNC machines for fabrications from the very small through the very large, along with 3D printing and welding across a wide variety of metals and techniques.

DESIGN • FABRICATION • REPAIR • MAINTENANCE • COMMERCIAL

telescopes

Green Bank's instruments have been used for a wide range of purposes including satellite tracking, spacecraft tracking, atmospheric studies, monitoring of astronomical and planetary phenomena, and educational programs.

20-METER TELESCOPE Built for the United States Naval Observatory in the 1990s, it participated in a global program of Earth Orientation very long baseline interferometry measurements in cooperation with the International Earth Rotation Service and the NASA Space Geodesy program. In recent years it has been used to search for Fast Radio Bursts, monitor the Crab Pulsar, and map OH within the Milky Way. It is used as an educational telescope as part of the University of North Carolina's Skynet program.

45-FOOT TELESCOPE This 13.7-meter diameter telescope was built in 1973 as the outlying fourth element of the Green Bank Interferometer and was critical for proving that the long baselines of the Very Large Array would be feasible. It was later converted by NASA into a tracking station for orbiting satellites. The antenna, combined with Japan's orbiting HALCA satellite, became part of what was once the largest telescope every used — an interferometer that spanned 60,000 miles. It was re-purposed for daily solar observations as part of the Frequency Agile Solar Radio telescope, through 2012.

85-FOOT TELESCOPES In 1959, the first 26-meter telescope, known as the Tatel Telescope, was built on site. Soon after, two more were added, the 85-2 and 85-3. While capable of running independently, the three telescopes were most often used together as the Green Bank Interferometer. Their active projects were completed in 2000. With modernization these telescopes can once again be available for observations.

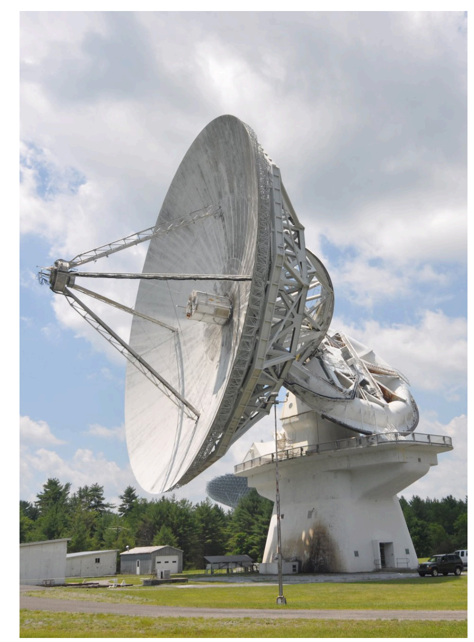
GREEN BANK OBSERVATORY TELESCOPES
AVAILABLE FOR NEW PROJECTS

DIAMETER	PERFORMANCE (Efficiency)	TRACKING SPEED (°/min)	POINTING ACCURACY (°)	SKY COVERAGE ELEVATION (°)	SKY COVERAGE AZIMUTH (°)	STATUS
45-foot (13.7m)	38% at 15 GHz	35-40	0.01-0.03	+3 to +112	-162 to +373	Operational
20-meter	50% at 10 GHz	120	0.01	+1 to +90	-270 to +270	Operational
85-foot (26m) (3 telescopes)	40% at 8.8 GHz	20*	0.01	-40 to 88**	-82 to +82**	Need modernization
140-foot (43m)	50% at 7.2 GHz	20-40	0.004	-40 to 81**	-105 to +105**	Operational
100-meter GBT	70% at 7.2 GHz 35% at 90 GHz	18-35	0.001	+5 to +90	-270 to +270	Operational from 0.29 through 116 GHz

*Original specifications

**Coverage is given in declination and hour angle (degrees).

SEE MORE greenbankobservatory.org/telescopes



140-FOOT TELESCOPE Built for radio astronomy research in the 1960s, the 43-meter diameter telescope has an equatorial mount which allows it to avoid any tracking, or "zone of avoidance," issues when tracking objects at or near the zenith. It worked as an astronomical research instrument from 1965 through 1999 when it was retired as a general user facility. Six years later, in 2005, the 43m telescope was put back into use, this time as part of a satellite tracking program instituted by the Massachusetts Institute of Technology's Lincoln Laboratory to study the ionosphere. From 2012-2019, it served as a satellite data down-link station for a space-based astronomy satellite, Spektr-R's RadioAstron instrument.

40-FOOT EDUCATION TELESCOPE
Purchased from a commercial vendor in 1961, this inexpensive aluminum instrument took only two days to set up. With a control system designed and built by Observatory staff, it became the world's first fully automated telescope, providing unmanned observing focused solely on radio calibration sources. In 1987 it was recommisioned as an educational telescope and is now used to teach radio astronomy to thousands of students and adults each year.

EDUCATION

LEARN BY DOING!
The Observatory's staff and facilities offer extraordinary STEM education through real world, hands-on experiences for learners of all ages.

reservations@gbobservatory.org
304-456-2150

STUDENTS

RADIO ASTRONOMER FOR A DAY Scientists often tackle questions that don't yet have answers. This student overnight program provides an authentic research experience with training on a working radio telescope, tours, and hands-on activities. This program is open to all school and youth groups (5th grade and above) and meets NGSS Nature of Science standards.

WEST VIRGINIA GOVERNOR'S STEM INSTITUTE Funded by the State of West Virginia, the Observatory hosts 60 8th graders for a two-week summer camp focusing on science, astronomy, and personal development.

PHYSICS INSPIRING THE NEXT GENERATION PING exposes traditionally underrepresented students to science and engineering, with a focus on physics and radio astronomy. Launched in 2014, PING engages middle school students in a two-week camp and undergraduate students in a 10-week internship that includes research and mentoring the younger students.

PULSAR SEARCH COLLABORATORY The PSC engages high school students and their teachers in the quest to discover new pulsars and transient sources by analyzing data from the GBT. Twice each academic year the Observatory holds a six-week online course to prepare high school students and teachers as researchers. Once the course is successfully completed, students gain access to new GBT data, and the research begins. Participants may apply to summer camp at the Observatory and annual capstone events. Several PSC students have discovered new pulsars and become published authors before graduating from high school!

WEST VIRGINIA SCIENCE PUBLIC OUTREACH
WVSPOT began in 2013 as a NASA partnership, training undergraduates to deliver interactive science, technology, and engineering presentations to K-12 classrooms, museums, and youth programs. To date, over 750 presentations have been given, impacting the lives of nearly 25,000 students.

SKYNET JUNIOR SCHOLARS SJS allows educators and students to gain access to telescopes around the world, including the 20m radio telescope at the Observatory. Students remotely access telescopes to collect real project data and collaborate with each other in online communities. Educators and youth leaders can form their own clubs. Learn more at skynet.unc.edu.

PROGRAM DESCRIPTIONS, DATES, & APPLICATIONS
greenbankobservatory.org/education

EDUCATORS

RESEARCH EXPERIENCE FOR TEACHERS
In conjunction with West Virginia University, this 6-week summer research program trains teachers in digital signal processing in radio astronomy. Learn how to use an inexpensive, versatile and rapidly developing technology (software defined radios) which can be implemented for astronomy applications as well as for receiving signals from satellites, like the NOAA weather satellites. Each summer, up to eight teachers spend 4 weeks at WVU, and 2-weeks at the Green Bank Observatory

CHAUTAUQUA SHORT COURSES
This 2.5 day course shares the fundamentals of radio astronomy and cutting edge scientific research with small college and community college faculty from around the nation. Each year between 25-30 participants interact with Observatory astronomers and engineers, enjoy behind the scenes tours, and use educational radio telescopes to complete projects.

CAREER DEVELOPMENT

From high school through post-doctoral studies, students have several opportunities to explore career options in STEM and other areas fundamental to the operations of the Observatory.

SUMMER EXPERIENCE FOR UNDERGRADUATES Summer positions can include astronomical research, and software, electrical, or hardware engineering, as well as working with plant maintenance and the machine shop. Students involved in basic research often attend scientific conferences and publish their results.

INTERNSHIPS These paid appointments provide staff support in a specific division, along with on-the-job training, tailored to meet specific academic requirements.

APPRENTICESHIPS Learn how to do a specialized job through on-the-job training, under the guidance of an experienced colleague. 3-6 months paid appointments are available in mechanical engineering, machining, electronics and telescope maintenance/mechanics.

POST-DOCTORAL POSITIONS Post-Docs are an integral part of the Observatory team and balance a variety of duties along with their own independent research. 2-year positions are available on a rolling basis.

CO-OPS Academic institutions are encouraged to contact the Observatory directly with proposals for student placements.

EMPLOYMENT

The Observatory is hiring for permanent and temporary seasonal positions. Current openings can be found at greenbankobservatory.org/about/careers.

A diverse staff is critical to mission success: enabling world-class science, training the next generation, and fostering a scientifically engaged society. Green Bank Observatory is committed to a diverse and inclusive work place culture that accepts and appreciates all individuals.

SCIENCE CENTER

OPEN YEAR ROUND!

The 25,000 square-foot Science Center features a 150-seat auditorium, classrooms, indoor star lab, computer lab, Galaxy Gift Shop, and Starlight Café. There is no admission fee to visit the *Catching the Wave* Exhibit Hall or take a self-guided walking tour of the Observatory's campus. Fees are charged for guided public tours and other special events. Advanced registration is required for field trips and large groups. There is ample parking for buses and RVs. The Science Center is accessible and wheelchairs can be accommodated on buses for guided public tours. **Days of operation and hours change seasonally.**

GUIDED PUBLIC TOURS

These 1-hour tours offer a fun peek into the world of radio astronomy with science demonstrations and a bus excursion into the restricted zone surrounding the telescopes. Tickets may be purchased in the Galaxy Gift Shop, and no advanced registration is required.

SPECIAL GUIDED TOURS

Developed in response to visitors expressing a desire to learn more than can be accomplished in a guided public 1-hour tour, these tours are offered less frequently. Dates and times can be found online and in our Science Center brochure.

High-Tech Tours See how technology used in radio astronomy is developed, going behind-the-scenes in labs and control rooms.

SETI Tours The search for extraterrestrial life began in Green Bank! Learn this history, visiting several locations at the Observatory.

History Tours How did the Observatory get started? What are some of the most exciting and important achievements? Learn this history by visiting several locations at the Observatory.

Some of these historic locations require the climbing of stairs.

STAR PARTIES

Explore some of the best dark skies in West Virginia with an optical telescope. Offered monthly at sunset, all ages welcome.

STAR LAB SUNDAYS

Family fun for all ages! Crawl into the planetarium balloon for a fascinating night sky tour. Reservations recommended.

FAMILY SCIENCE LABS

Select Saturdays, kids ages 4-9 enjoy hands-on science projects. Reservations recommended.

FAMILY SCIENCE DAY OPEN HOUSE

This annual afternoon of fun offers FREE guided Site Tours along with hands-on science experiments, crafts, and games for all ages.

DATES, TIMES & RESERVATIONS
greenbankobservatory.org/events

FIELD TRIPS

Tours, activities, and day and overnight field trips for organized groups of students grades K-12 are available. Overnight field trips experience hands-on scientific research projects with a working radio telescope. Field trips can be customized to complement classroom curricula and other field trips in the area.

SCOUTS

Scheduled overnight programs are offered select weekends. Using a working radio telescope, Scouts BSA can earn their Astronomy or Electronics Merit Badge, and Girl Scouts can earn a space-themed badge as well. Day activities are offered for Daisies and Brownies. Outside of these scheduled programs, Scout Troops may make reservations for tours and other hands-on science activities, with camping and other housing options available.

reservations@gbobservatory.org
304-456-2150

SPECIAL EVENTS

The Observatory hosts a variety of events year round, and many are coordinated by partners in the community.

SPACE RACE RUMPUS This annual weekend-long festival for mountain biking and road cyclists of all ages, from beginner to advanced, offer clinics and rides on trails and roads, a bike rodeo, star parties, a bonfire, live music, and camping. Lots of fun for adventurous families! Date and registration at spaceracerumpus.org

STARQUEST The largest annual optical and radio telescope star party in the nation, camp out for 4 days and 3 nights, with a full schedule of speakers, workshops, raffles, activities, and more. Date and registration at greenbankstarquest.org

explore more

A visit can complement many other adventures in the region! The Observatory is surrounded by the Monongahela National Forest. There are many scenic natural areas, historic sites, and attractions for exciting day and overnight trips.

15 MINUTES Cass Scenic Railroad State Park, GreenbrierRiver Trail

40 MINUTES Snowshoe Mountain, The Durbin Rocket, National Youth Science Camp, Seneca State Forest & Seneca Lake State Park

WITHIN 2 HOURS Seneca Rocks, Spruce Knob, SenecaCaverns, Smoke Hole Caverns, Blackwater Falls State Park, Davis, Cranberry Glades Botanical Area, Elkins, Marlinton, Lewisburg, Droop Mountain Battlefield, The Greenbrier, Monterey, Warm Springs, the Homestead Resort, Garth Newal Music Center

more information

Pocahontas County Visitors Bureau
pocahontascountywv.com

West Virginia Tourism
wvtourism.com

facilities

RESEARCH & FIELD STATIONS

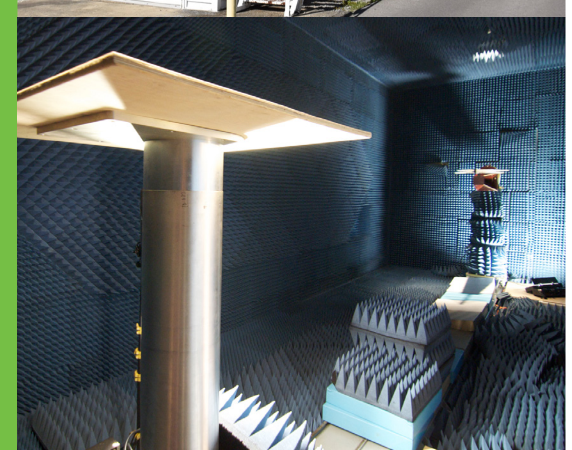
The Observatory is an attractive location for independent research experiments, and serves as the field station for several university-based research teams.

The site has significant infrastructure which allows for the installation of any instrument which may benefit from the radio quiet location, as well as a **two radio frequency test ranges** for receivers and for testing antenna beam patterns, and a large **anechoic chamber** for testing radio emissions from all types of equipment. The outdoor range tests 300-10,000 MHz, while the indoor range tests 2-115 GHz.

With **2,700 acres** of land, good network connectivity, and reliable power, numerous groups have also taken advantage of the infrastructure and radio quiet zones to deploy their own instruments on site. These include two **small telescope arrays** operating from 20-100 and 100-200 MHz, one station from a nation-wide magnetometer array, and a GPS sensor deployed as part of West Virginia's geo-spatial array.

RADIO FREQUENCY TEST RANGES

ANECHOIC CHAMBER



SMALL ANTENNA & TELESCOPE ARRAYS

2,700 ACRES

CONFERENCES

The Observatory hosts numerous public and private **meetings, workshops,** and **events** year round at **auditoriums** in the Jansky Lab and Science Center, with full presentation capabilities.

Several **classrooms** and a **computer lab** are available in the Science Center. While WIFI is not available onsite to avoid interference with radio astronomy studies, wired internet connections are available in numerous locations.

ACCOMMODATIONS

Several options for **overnight stays** are available at the Observatory, including apartments, houses, and a dormitory which is ideal for student and Scout groups. Other accomodations can be found in the surrounding area for larger groups.

The Observatory **cafeteria** can serve breakfast, lunch, and dinner. **Catering** is available across campus, including coffee breaks, receptions, and meals. Refreshments and meal options are also available directly from the Science Center **Starlight Café** , whose hours vary by season.

The Drake Lounge, located above the cafeteria, is a historic space that is often used for receptions and informal gatherings.

There is ample **parking** at several locations on site, with room for RVs, buses, and motorcoaches.

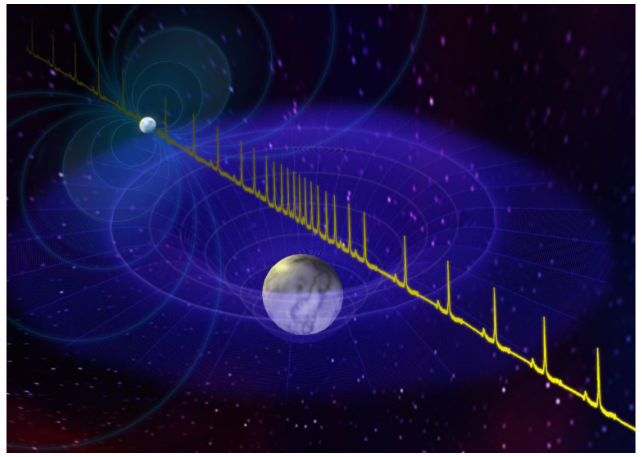
Charging stations for electronic vehicles are located next to the dormitory.

RECREATION

The Observatory features a 1.5-mile (3-mile out and back) paved, to scale, **self-guided walking tour** of the Solar System, ending at the GBT.

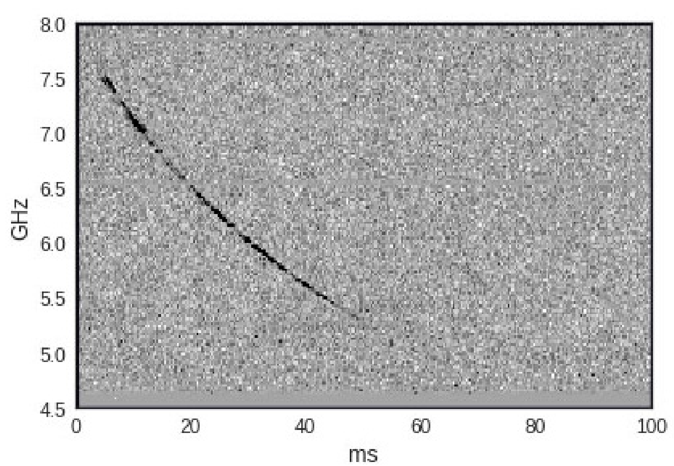
Bicycles are welcome on the grounds to explore **10-miles of trails** on paved, mowed, gravel, and single-track surfaces. Trail maps are available in the Science Center and Jansky Lab, and posted at **trail head parking** located at the rear of the Janksy Lab parking lot. **Primitive camping** is available in specific locations, and is a part of several special events each year.

science news



MOST MASSIVE NEUTRON STAR EVER DETECTED—ALMOST TOO MASSIVE TO EXIST

Astronomers using the GBT have discovered the most massive neutron star to date, a rapidly spinning pulsar approximately 4,600 light-years from Earth.
This record-breaking object is teetering on the edge of existence, approaching the theoretical maximum mass possible for a neutron star before it collapses into a black hole. *H.T. Cromartie, et al. 2019, Nature Astronomy, 439*



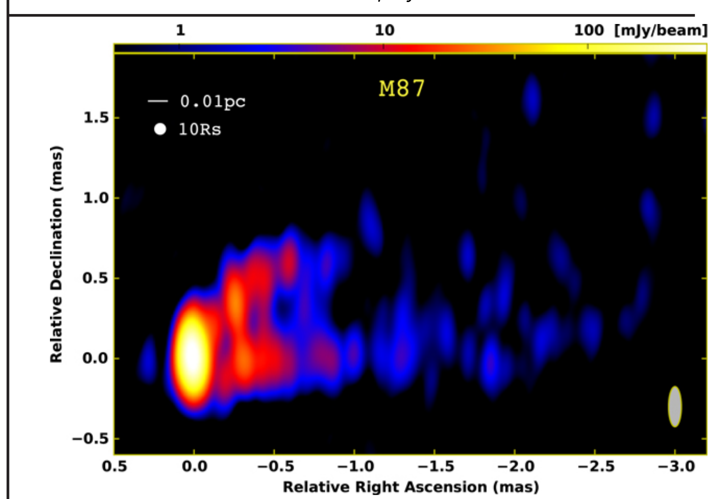
ARTIFICAL INTELLIGENCE UNCOVERS 72 NEW FAST RADIO BURST CANDIDATES IN GBT'S BREAKTHROUGH LISTEN DATA

Machine learning algorithms applied to data from the Green Bank Telescope find new pulses from the mysterious repeating source FRB 121102.
Y.G. Zhang, et al. 2018, Astrophysical Journal, 866, 149

READ MORE
greenbankobservatory.org/news

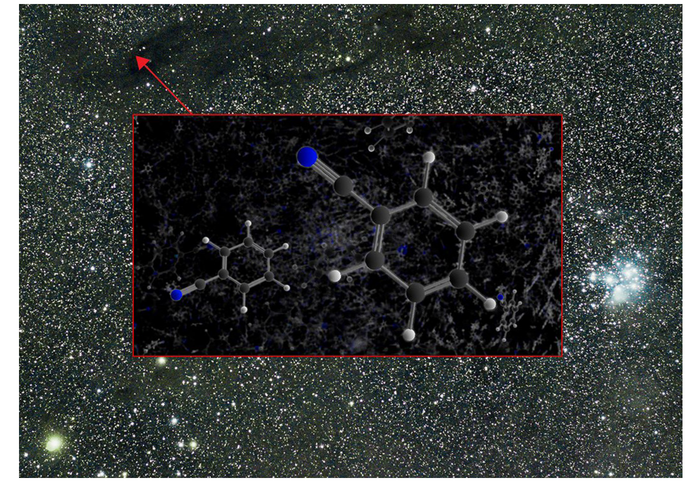
THE MOLECULAR FILAMENT IN ORION

The orange shows GBT measurements of two large interstellar gas filaments detected through their radio emission from the ammonia molecule. It is within these filaments that a new generation of stars will be formed. The filaments span more than a degree, and are superposed on an infrared map of the region.
R. Friesen, et al. 2017, Astrophysical Journal, 843, 63



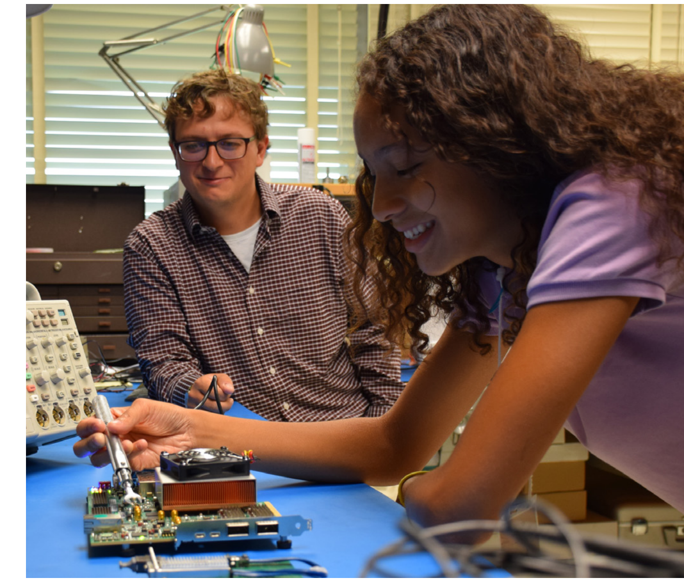
A RADIO JET FROM A BLACK HOLE

This radio image of the jet emanating from a black hole at the center of the galaxy M87 was made using the GBT with a set of smaller radio telescopes scattered across the United States. The combined array operating at 3mm wavelength had an angular resolution of 0.25 x 0.8 milli-arcseconds and a high dynamic range, showing details of the launch of the jet from the black hole.
K. Hada, et al. 2015, Astrophysical Journal, 817, 131



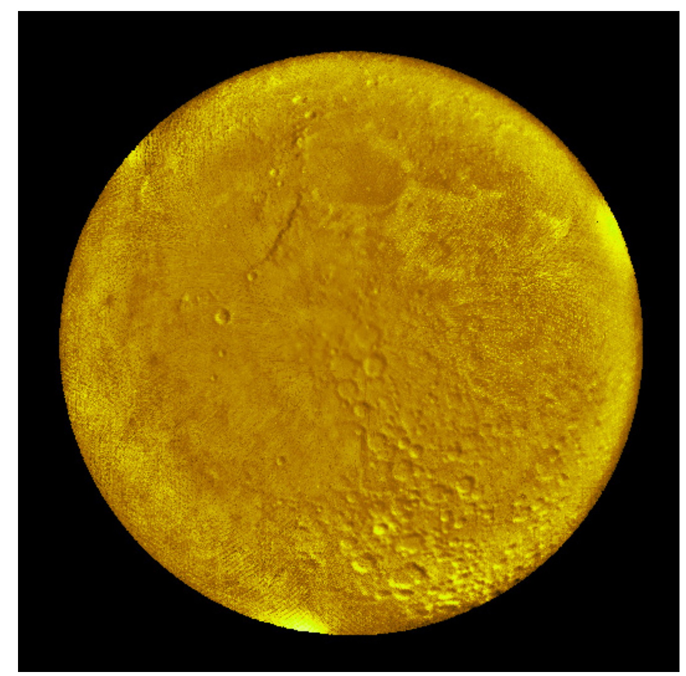
GBT DETECTION OF AN INTERSTELLAR AROMATIC RING MOLECULE

The aromatic ring molecule benzonitrile, first detected in interstellar space by the GBT, is an important link between simple carbon-based molecules and the massive polycyclic aromatic hydrocarbons that may contain as much as 10% of all Carbon in the Universe.
B. McGuire, et al. 2018, Science, 359, 202



NSF AWARDS NEW TECHNOLOGY GRANT FOR RADIO ASTRONOMY WHILE TRAINING FIRST-GENERATION COLLEGE STUDENTS

This project will enable ultra-wide bandwidth radio astronomy and innovative detection and excision of radio frequency interference, laying the foundation for the next generation of end-to-end digital signal processing systems and spectrometers. This work will be supported by an undergraduate intern and a summer research student.



A THERMAL MAP OF THE MOON

This GBT map of the Moon reveals the temperature variations across the surface. Unlike optical photographs, which show the Moon in reflected light, these 3mm MUSTANG2 bolometer measurements capture actual variations in the surface temperature that are not revealed in light or through radar. Instrumental effects cause some striping and blurring at the Moon's edge.
M. Devlin, S. Dicker, P. Hayne, B. Mason

publications

On average, a paper acknowledging the use of GBT data is published every 4.4 days.
See our extensive list of recent and past papers greenbankobservatory.org/science/publications

MISSION STATEMENT

Green Bank Observatory enables leading edge research at radio wavelengths by offering telescope, facility, and advanced instrumentation access to the astronomy community as well as to other basic and applied research communities. With radio astronomy as its foundation, the Green Bank Observatory is a world leader in advancing research, innovation, and education.

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