GREEN BANK
OBSERVATORY

Virtual Goody Bag

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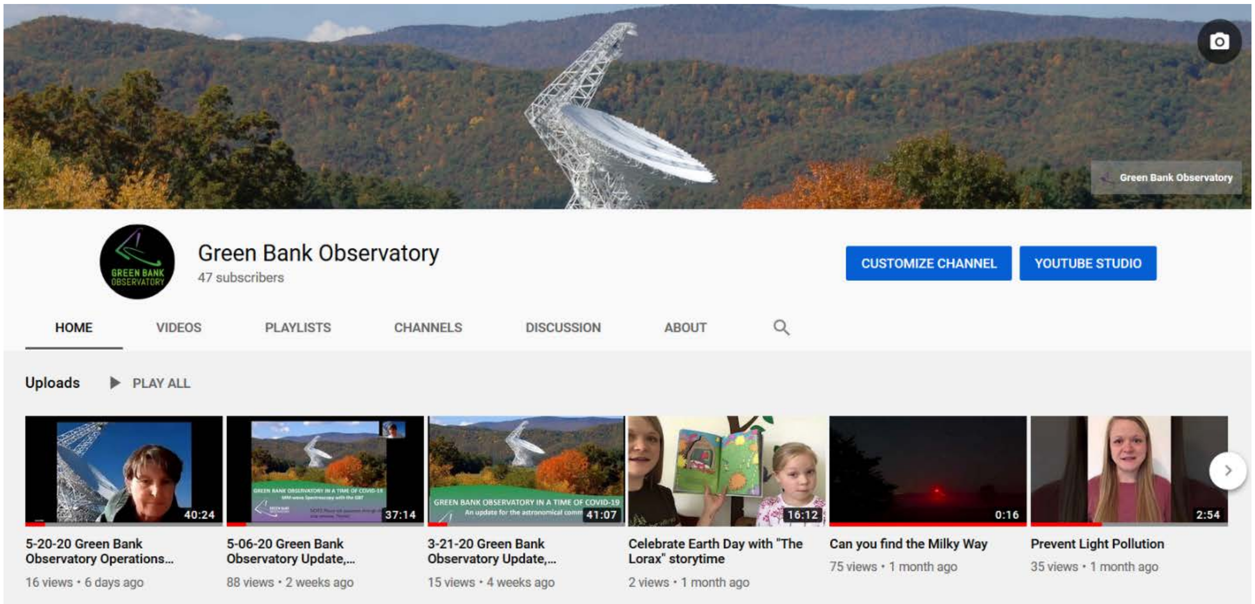
GBO Booklet

Get 10% off at the [Galaxy Gift Shop]

Discount Code **GBODIG10**

Grab a GBO mug, t-shirt, hat, sticker, and more!



For the latest news, stories, events, and more follow us

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Flickr need amazing GBT images for a presentation? Use these!

Are you on our e-news list? Sign up today! Email jmalusky@nrao.edu

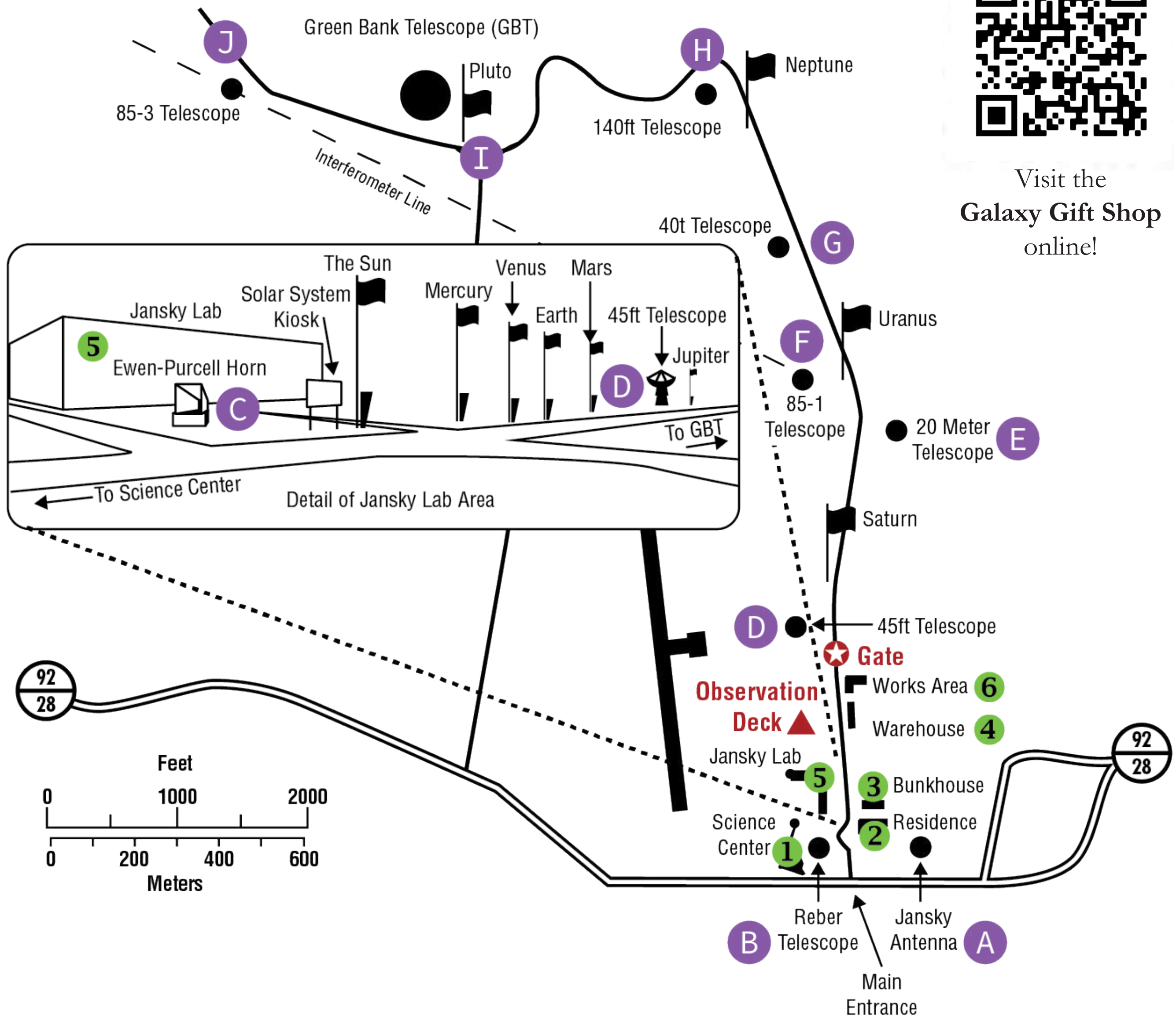
GREEN BANK OBSERVATORY

SELF-GUIDED WALKING TOUR & SITE MAP

The Self-guided walking tour may be taken anytime before dark. Visitors are welcome to walk their dogs or ride bicycles around the grounds. We request that once you pass the gate, shown in **red** with a star (✪), be certain that all electronics not vital to your health are completely turned off.

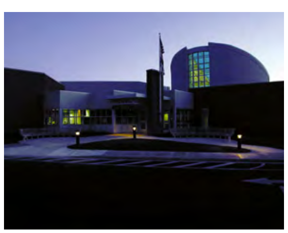
Telescopes - both active and inactive - are marked in purple letters. Points of interest are marked in green numbers. The best location to take pictures of the Green Bank Telescope is our Observation Deck, indicated by a triangle (▲), near the parking lot behind the Jansky Lab (❺).

A scale model of the solar system begins with the Sun in front of theJansky Lab (❺) and ends 1.5 miles away at Pluto, next to the Green Bank Telescope (I). This Scale model is 1 foot to 3 billion feet. The kiosk at the Sun flag provides more information.

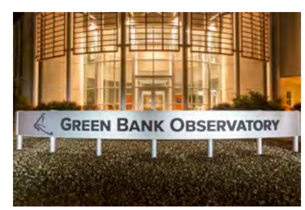


Visit the **Galaxy Gift Shop** online!

The Green Bank Science Center (❶) is open year-round and serves over 45,000 visitors a year. The 25,000 square foot facility contains the Catching the Wave Exhibit Hall, a 150-seat auditorium, classrooms, a gift shop, and a full menu at the Starlight Café.



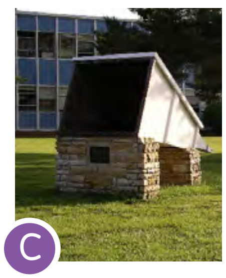
Green Bank has two short-term housing buildings. The Residence Hall (❷) is used for visiting scientists, while the Bunk House (❸) is often used for students participating in educational programs. Part of the Warehouse (❹) was our original tour center, but now hosts Observatory and community events.



Sensitive receivers and state-of-the-art data collection systems are invented and designed in the Jansky Lab (❺). The parts are fabricated and assembled in the Works Area (❻) before being transported to the telescopes for use.

The Jansky Antenna (A) is an exact replica of the antenna used by Karl Jansky in the early 1930s. With it, he found three sources of radio static: two were caused by thunderstorms, but he concluded that the third was coming from the Milky Way! After hearing of Jansky's cosmic static, radio engineer Grote Reber was determined to investigate. He built the Reber Telescope (B) himself. It was the first dish-shaped radio telescope, and its success revolutionized radio astronomy!

After the Second World War, radio astronomy took off due to newly-improved receiver technology. In 1951, Howard Ewen and Edward Purcell from Harvard University built the Ewen-Purcell Horn (C) and pointed it out of their lab window. Because of its shape, excessive rain caused it to flood their lab multiple times, and was a popular target for undergrads' snowballs. Eventually, they used it to discover the first hydrogen line emission at 1,420.4 MHz, revealing the spiral shape of the Milky Way. Today, scientists still use hydrogen line emission to investigate galaxies.



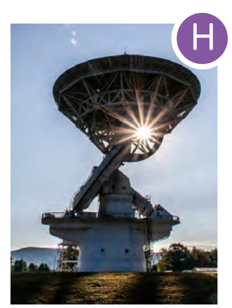
The 45-Foot Telescope (D) was designed to be mobile, and was moved around West Virginia to be the fourth telescope in the Green Bank Interferometer (GBI). In 1974, it aided the discovery of Sagittarius A*, the black hole in the center of our galaxy. It then did satellite tracking for a project with NASA and the Japanese space institute. From 2004 to 2012, it was the Green Bank Solar Radio Burst Spectrometer, which studied the Sun at radio wavelengths. Though still in working order, it awaits funding and a new project to continue its work.

Designed and built by the US Naval Observatory, the 20-Meter Telescope (E) was built to measure highly accurate time, continental drift, and the Earth's wobble, or "precession." Now it is a part of the Skynet Robotoc Telescope Network, and is used by youth groups, educators, and undergraduates. Skynet is led by the University of North Carolina at Chapel Hill.

The Tatel Telescope (F) is the oldest telescope on site and saw extensive use from from 1959 until 2000. It was first used by Frank Drake to launch the Search for Extraterrestrial Intelligence (SETI) in 1960. Although Drake found no signals from extraterrestrials, SETI investigations continue today using the techniques established by Drake. The Tatel was also one of the telescopes that was part of the Green Bank Interferometer.

The 40-Foot Telescope (G) telescope was built in 1962 to determine if the intensity of radio sources varied over time. It was also the first fully automated radio telescope. The telescope is now used by teachers and students from across the country to observe the universe and experience research first-hand. It is the only remaining onsite telescope with a mesh dish and a separate control room, all other telescopes on site are controlled from the Jansky Lab.

The 140-Foot Telescope (H) was completed in 1965 and is the largest equatorially mounted telescope in the world. It was the first telescope to detect complex molecules and neutral hydrogen absorption from another galaxy. Until Spring, 2019, it was part of the international Radioastron astronomy project that tracked a Russian orbiting satellite called Spektr-R. The satellite works with radio telescopes on Earth to exapand our knowledge of black holes, interstellar plasma, pulsars, and other radio emitting objects in the universe.



Observatory staff designed the largest fully steerable telescope in the world. Named afer the West Virginia senator who advocated for its construction, the Robert C. Byrd Green Bank Telescope (GBT) (I) is an offset-parabolic dish 100x110 meters in diameter. GBT's feed arm rises above the dish to support sensitive receivers. Its placement on the side of the dish is unique, and ensures that it is not in the way of incoming radio waves The surface can be actively monitored and adjusted in response to temperature and gravitational changes to maintain a perfect surface and provide optimal data.

The 85-3 and the Green Bank Interferometer (J). Operational until 2000, the 85-3's final job was a long-term research project to monitor 35 pulsars every day. Alongside the 85-2, the Tatel Telescope, and the 45-Foot Telescope, it was part of the Green Bank Interferometer, or GBI. The dishes operated simultaneously to simulate a larger telescope, about a mile in diameter, with much higher resolution. The GBI was the prototype for interferometer systems like the Very Large Array (VLA) in New Mexico and the Atacama Large Millimeter/submillimeter Array (ALMA) in Chile.

Green Bank Observatory is supported by the National Science Foundation and is operated by Associated Universities, Inc.

RFI Guidelines

All electronic devices give off radio frequency interference, or RFI. Just like you can't see the stars when the Sun is out, radio telescopes cannot detect distant objects when an electronic device is on nearby. Even if your cell phone were in orbit around Saturn, it would be the brightest object in the sky to the Green Bank Telescope.

For this reason, we ask you turn all electronic devices **completely off** (not just in airplane mode!) once you cross into the RFI Restriction zone (marked in **red** on the Trail Guide). If you cannot turn off your device, please leave it in your vehicle.

This policy includes:

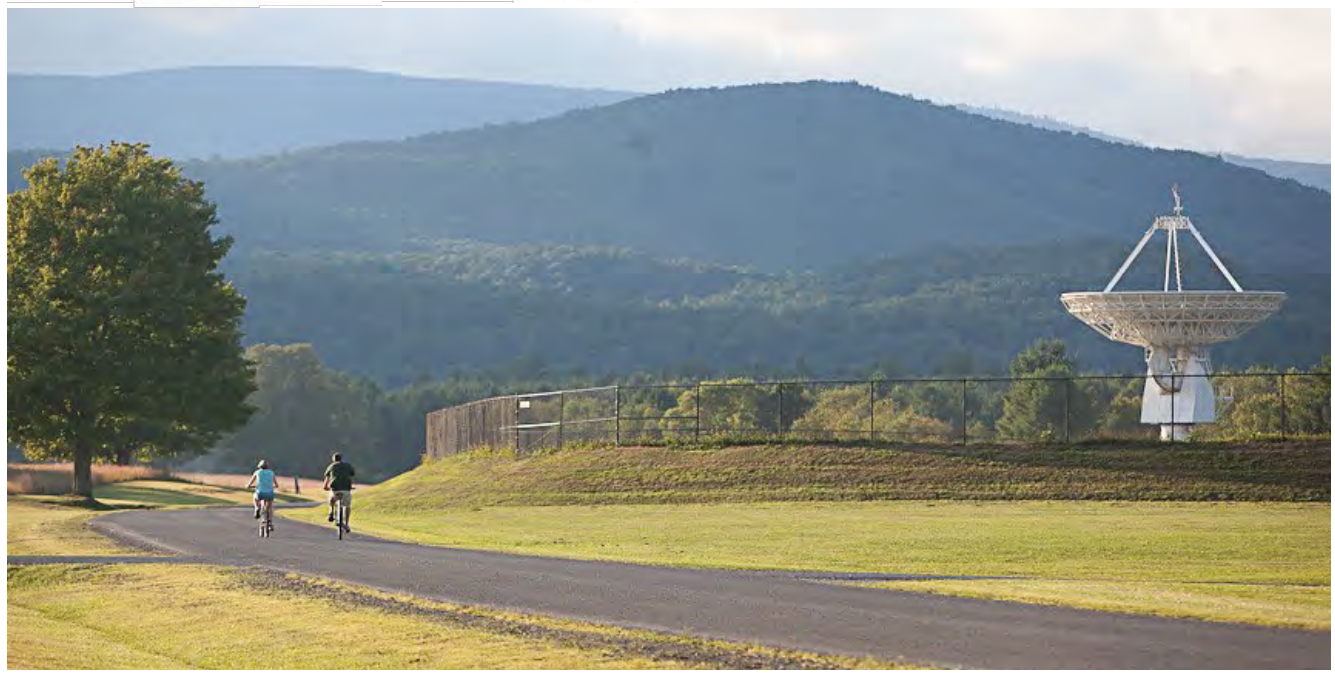
- ★ Cell phones and MP3 players
- ★ Bluetooth devices, including headphones, earbuds, and smart shoes
- ★ Smart watches and fitness trackers
- ★ Segways, motorized bikes, etc.

Medical devices, like pacemakers, hearing aids, and insulin pumps, do

(304) 456-2011

155 Observatory Road, P.O. Box 2
Green Bank, West Virginia 24944

Visit us at greenbankobservatory.org,
and follow us on these social media platforms:



This property is owned by the U.S. Government through the National Science Foundation and is therefore subject to all applicable laws related to government property. You must understand that by utilizing this site for trail use you indemnify the U.S Government and GBO/AUI from all liability, present or future claimed, and accept all risk for your activities.

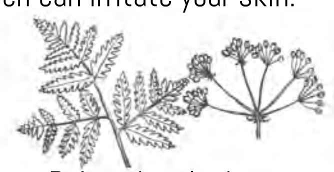
GREEN BANK OBSERVATORY AND SCIENCE CENTER

SITE TRAILS

Safety Tips

- ★ Tell someone when to expect you back.
- ★ Travel in groups, and be aware of your surroundings.
- ★ Look up when the Sun will set, and plan to be finished before dark.
- ★ Know your abilities, and respect your body's limitations.
- ★ Always keep your pets on a leash.
- ★ **Under no circumstances should you approach any wildlife.** If you do not know how to deal with native bears or snakes, please ask the front desk for a safety brochure.
- ★ Never eat any plants you find! Especially stay away from these, which can irritate your skin:

ANY mushrooms



Poison hemlock

Poison ivy

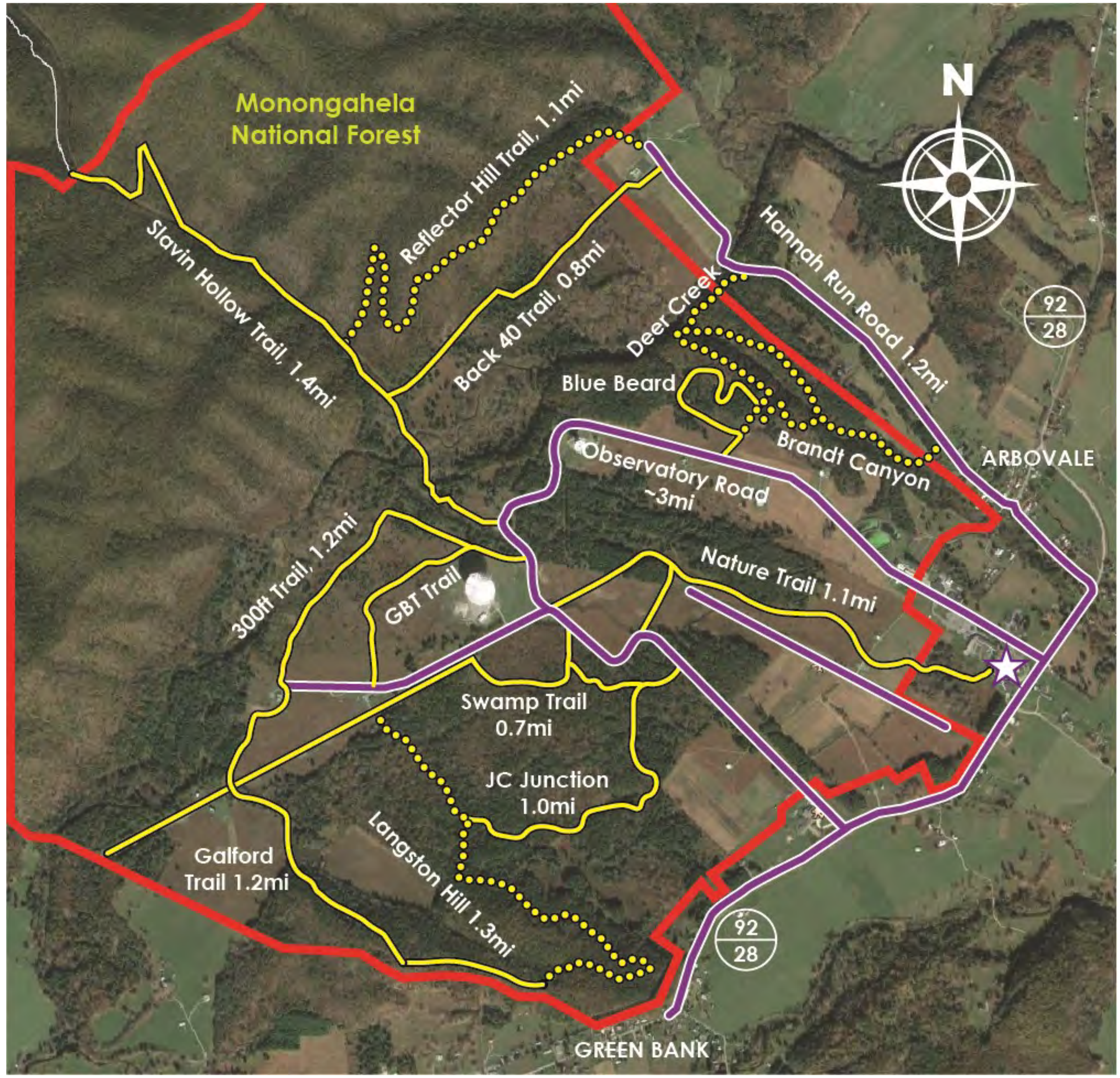
Poison oak

Poison sumac

Stinging nettle

Water hemlock

White baneberry



Yellow: Gravel or dirt track

Purple: Paved road

Red: RFI Restriction Zone boundary

Dotted lines: advanced/expert trails.

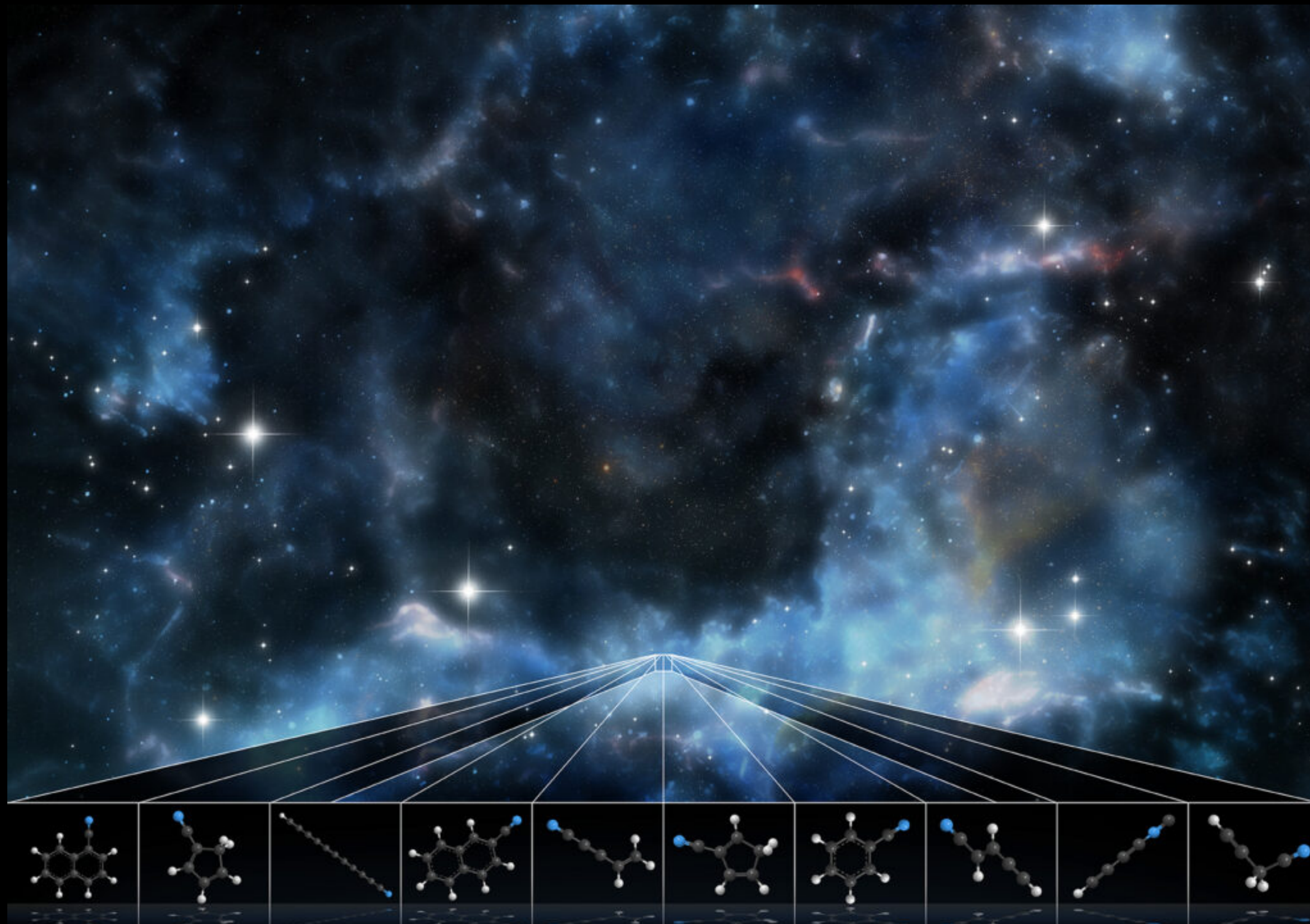
Solid lines: beginner/intermediate trails.

☆ White star: Science Center. Potable water, food, ATM, and phones available.

A colorblind-friendly version of this brochure is available.

Map courtesy of Google Earth.


2022
GREEN BANK
OBSERVATORY



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, Green Bank Observatory is a world leader in advancing research, innovation, and education.

Image above: in a series of nine papers, scientists from the GOTHAM—Green Bank Telescope Observations of TMC-1: Hunting Aromatic Molecules—project described the detection of more than a dozen polycyclic aromatic hydrocarbons in the Taurus Molecular Cloud, or TMC-1. These complex molecules, never before detected in the interstellar medium, are allowing scientists to better understand the formation of stars, planets, and other bodies in space. In this artist's conception, some of the detected molecules include, from left to right: 1-cyanonaphthalene, 1-cyano-cyclopentadiene, HC11N, 2-cyanonaphthalene, vinylcyanoacetylene, 2-cyano-cyclopentadiene, benzonitrile, trans-(E)-cyanovinylacetylene, HC4NC, and propargylcyanide, among others.
Center for Astrophysics/Harvard & Smithsonian, M. Weiss.

greenbankobservatory.org

Nestled in the mountains of West Virginia, astronomers search for answers to humanity's most extraordinary scientific questions.

Photo credit (& cover) Jay Young

The Green Bank Observatory is the home of the 100-meter Robert C. Byrd Green Bank Telescope (GBT), the world's premier 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 operations, 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 significant protection 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 nearly 2,700-acre site has significant infrastructure which allows for the installation of any instrument that 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 a welcoming, creative, and tight-knit community. Our award winning staff come from the surrounding area, across the country, and around the world, and are proud to call this place home.

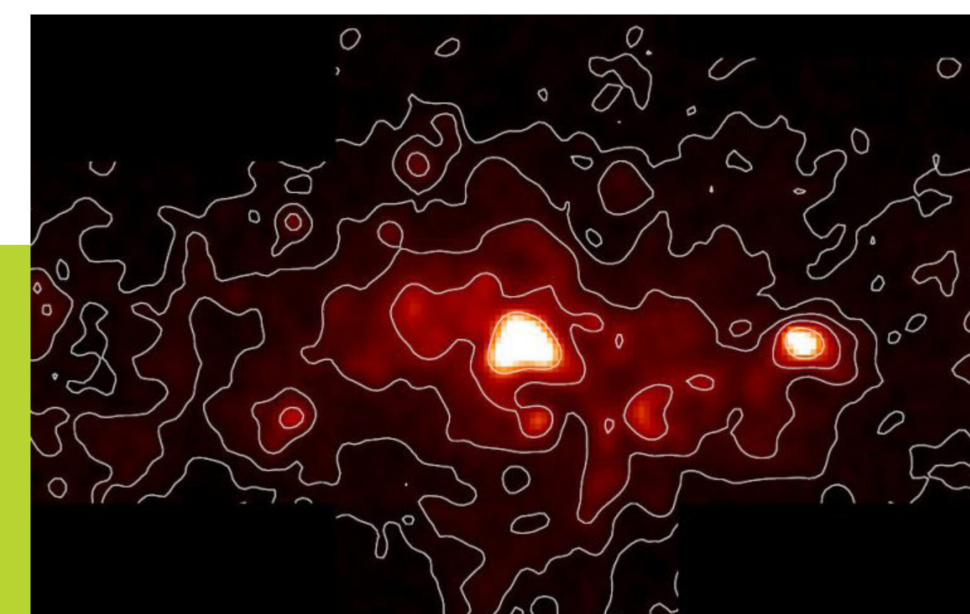


Image right: the Green Bank Telescope Diffuse Ionized Gas Survey (GDIGS) is a large ongoing survey to map radio recombination line emission from diffuse ionized gas in the Galactic plane. This GDIGS map shows ionized gas near the giant star-forming region W43.
NSF/GBO/P.Vosteen

LATEST RESEARCH

Composite image created by Kat Barger, with GBT data represented in orange, using the

MILKY WAY'S DEFENSIVE HALO BLOCKS INCOMING GAS CLOUD

How are galaxies able to keep forming stars and planets? Astronomers from Texas Christian University used the Green Bank Telescope and simulations of gas instability processes to study high-velocity clouds that are being drawn into our Milky Way galaxy by its gravitational pull. Dr. Kat Barger led a team observing Complex A, a high velocity gas cloud containing enough material to make more than 2 million Suns – if all of it could reach our Milky Way.

Credit: NASA/JPL-Caltech

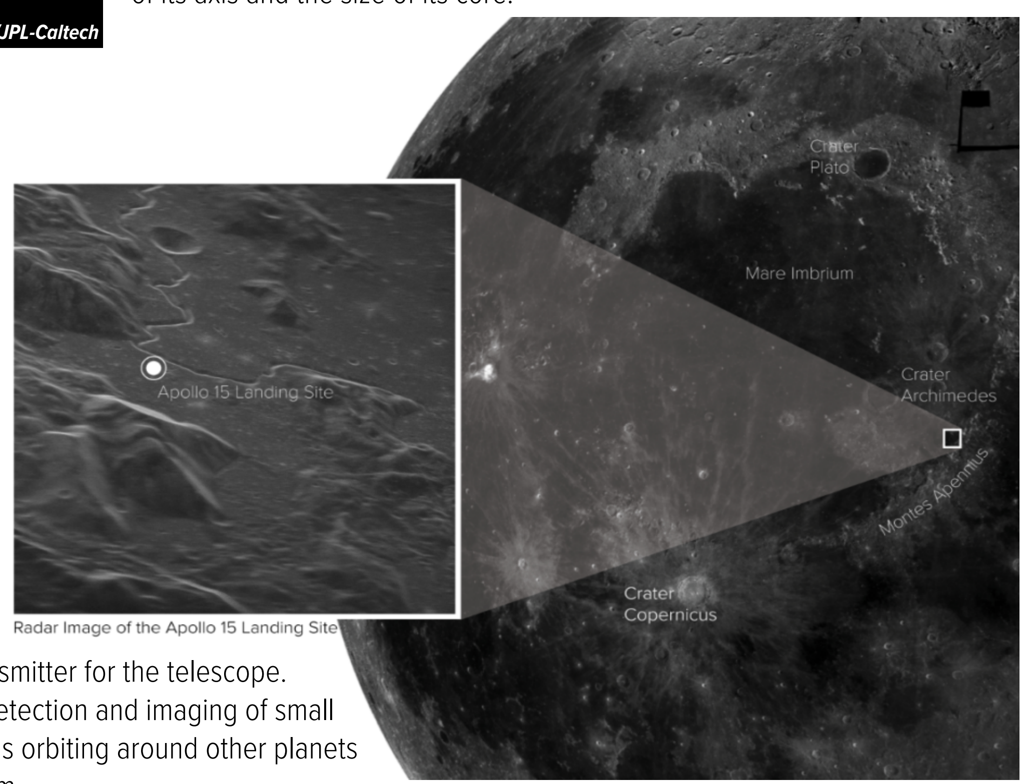
HOW LONG IS A DAY ON VENUS? SCIENTISTS CRACK MYSTERIES OF OUR CLOSEST NEIGHBOR

Venus is an enigma. It's the planet next door and yet reveals little about itself. An opaque blanket of clouds smothers a harsh landscape pelted by acid rain and baked at temperatures that can liquify lead.

New observations from the Green Bank Telescope and the Goldstone antenna are lifting the veil on some of Venus' most basic properties. By repeatedly bouncing radar off the planet's surface over the last 15 years, a UCLA-led team has pinned down the precise length of a day on Venus, the tilt of its axis and the size of its core.

SUCCESSFUL TEST PAVES WAY FOR NEW PLANETARY RADAR

The GBT was outfitted with a new transmitter developed by Raytheon Intelligence & Space, allowing it to transmit a radar signal into space. The NRAO's continent-wide Very Long Baseline Array (VLBA) received the reflected signal and produced images of the Apollo 15 moon landing site.The proof-of-concept test, culminating a two-year effort, paves the way for designing a more powerful transmitter for the telescope. More power will allow enhanced detection and imaging of small objects passing by the Earth, moons orbiting around other planets and other debris in the Solar System.



Radar Image of the Apollo 15 Landing Site

Sophia Dagnello, NRAO/GBO/Raytheon/AUI/NSF/USGS

NANOGRAV & GREEN BANK TELESCOPE POISED TO MAKE GROUNDBREAKING DISCOVERIES OF GRAVITATIONAL WAVE UNIVERSE

For the next three years, astronomers from the North American Nanohertz Observatory for Gravitational Waves (NANOGrav) will have increased access and new technologies to use on the Green Bank Telescope in their breakthrough scientific studies of gravitational waves.

This new technology and additional observation time is supported by funding from the Moore Foundation.

NANOGrav Physics Frontiers Center

GORDON AND BETTY MOORE FOUNDATION

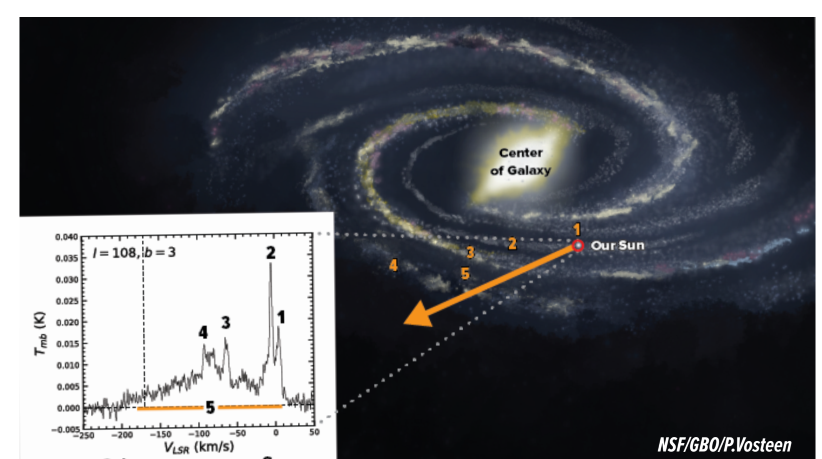
NEW INSTRUMENT WILL IMPROVE LOCALIZATION OF FAST RADIO BURSTS

West Virginia University recently announced that a $1.7 million National Science Foundation grant will be used to construct a new telescope at the Observatory. This new instrument will be used in association with the Canadian Hydrogen Intensity Mapping Experiment, or CHIME, telescope, which is located half a continent away in British Columbia. CHIME's focus is studying Fast Radio Bursts, or FRBs. The new instrument at Green Bank will work with the existing CHIME telescope to triangulate the locations of FRBs.

MORE THAN MEETS THE EYE: COMPLETE IMAGING OF CLUSTER COLLISION

This composite image of a giant cosmic collision was created by an international team of astronomers using radio, X-ray, and optical data collected with the MUSTANG-2 receiver on the GBT, the European Science Agency's (ESA) XMM-Newton Satellite, and the National Astronomical Observatory of Japan's (NAOJ) Subaru Telescope in Hawaii. The dazzling colors reveal a dramatic temperature increase resulting from the collision-induced shock – a rise from 40-million°C in the overall body of the cluster, to a whopping 400-million°C.

Image credit: PI Nobuhiro Okabe; Subaru Telescope, National Astronomical Observatory of Japan/HSC-SSP collaboration; National Science Foundation/Green Bank Observatory/Green Bank Telescope; European Space Agency/XMM-Newton/XXL survey consortium.



NSF/GBO/P.Vosteen

MASSIVE INVISIBLE GALACTIC STRUCTURE IS DISCOVERED – BY ACCIDENT

The GBT detected a massive, gaseous structure in our Milky Way, using OH as an alternative tracer of H2. The find was so unexpected, the 20-meter telscope was used to confirm it. What impact will this have on astronomy? The existence has implications for star formation theories, as well as the structure, make-up, and total mass of the interstellar medium.

SEE MORE greenbankobservatory.org/news

PUBLICATIONS See our extensive list of recent and past papers **greenbankobservatory.org/science/publications**

our SCIENCE

COMPACT OBJECTS AND FUNDAMENTAL PHYSICS

The rapid, clock-like rotation of pulsars makes them unique tools for studying fundamental physics and stellar evolution. The GBT is a premier instrument worldwide for pulsar studies because of its sensitivity, wide frequency coverage, and location in the NRQZ.

Pulsar studies will usher in the next great era of Gravitational Wave (GW) astronomy by opening the nanohertz GW spectrum, which will be dominated by the most massive objects in the Universe—supermassive binary black holes. This GW breakthrough will be achieved though monitoring the pulse arrival times from dozens of millisecond pulsars with an accuracy of tens to hundreds of nanoseconds over the course of many years using the NANOGrav Pulsar Timing Array (PTA), of which the GBT is a critical component.

STAR FORMATION AND EVOLUTION

The GBT will be used to map the starless and dense cores in the widely used dense gas tracer N_2H+ to better understand the formation and diversity of protostellar disks and binary/multiple systems. Ammonia (NH_3) lines in the Milky Way's giant molecular filaments will be mapped to determine their role in star formation. Turbulent gas within the Milky Way will be studied to further refine its role as a regulator in star formation. GBT data will also be combined with ALMA observations to systematically measure the core mass function toward a sample of the most massive, parsec-scale clusters in the Milky Way.

THE INTERSTELLAR MEDIUM

An understanding of the interstellar medium (ISM) is essential for many areas of astronomy. Stars and planetary systems form from dense regions of the ISM, and at the end of their lives, stars recycle this material by injecting heavy elements back into the ISM in supernova explosions. With its wide frequency coverage, excellent sensitivity, and location in the National Radio Quiet Zone (NRQZ), the GBT has contributed significantly to ISM studies and will continue to do so in the coming years.

The GBT has been used to survey TMC-1 at high resolution and sensitivity to accurately determine the astrochemical models for this and similar regions of the ISM. The GBT has also detected phosphorus-bearing species within the ISM, which may have been essential key to form life on Earth. The GBT also studies NH_3 in the inner regions of the Milky Way where previous observations have shown the ISM to have elevated gas temperatures to better understand heating mechanisms and their contributions to overall feedback within the ISM.

THE SEARCH FOR TECHNOSIGNATURES

The search for life beyond the solar system can be divided into two primary research areas; astrobiology (the search for complex, life-bearing signatures), and technosignatures (the search for signatures of a technological civilization).

Beginning in 1960 with Project Ozma's use of the Green Bank Tatel telescope to monitor Tau Ceti and Epsilon Eridani for technosignatures, and the formulation of the Drake Equation in 1961, the Observatory continues to play a significant role in the search for technosignatures. At the present, the majority of the Observatory's work in technosignatures is through Breakthrough Listen. Breakthrough Listen is using the GBT and other telescopes around the world to survey the 1,000,000 closest stars to Earth, the center of our galaxy, and the entire Galactic plane, as well as the 100 closest galaxies. The GBT will continue this important work, searching the most promising nearby star for technosignatures while also searching the universe for the important precursors of life.

THE SOLAR SYSTEM

The GBT is a unique asset in the field of planetary science. Working with the Arecibo and Jet Propulsion Lab's (JPL) transmitters, the GBT's large collecting area, clean beam, optimized receivers, and location on the east coast of the U.S., make it the instrument of choice for bi-static radar studies of Solar System objects and telemetry observations in support of spacecraft missions. The GBT is also ideal for the study of transitory phenomenon such as comets and asteroids. Bi-static radar techniques will continue to dominate asteroid research programs for the GBT into the future. With the upgrade of the Goldstone radar system now complete, bi-static radar imaging will continue to provide high-resolution maps of the most important and interesting asteroid bodies.

TRAINING & PROPOSAL CALLS

Training workshops are offered in the spring, summer, and fall. See our website for current workshop dates and to register https://greenbankobservatory.org/science/gbt-observers/observer-training-workshops/

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, from 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.

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

GALAXY CLUSTERS

The collapse of galaxy clusters is driven by the strongest fluctuations in the primordial matter power spectrum. As direct tracers of fluctuations in the early Universe, clusters are important signposts of the large-scale spatial distribution of dark matter, and therefore provide one of the most sensitive probes of the unknown equation of state of dark energy.

The Sunyaev-Zeldovich Effect (SZE) provides a tool for studying the hot gas in clusters that is uniquely redshift-independent due to its nature as a fractional scattering of the cosmic microwave background. With its large size and the sensitivity of a single dish to low surface-brightness emission, the GBT is uniquely positioned to study galaxy clusters through measurement of the SZE. The large format MUSTANG-2 bolometer camera on the GBT measure the SZE at 3mm with uniquely high sensitivity at an angular resolution of 10", testing predictions for the SZE signal in detail.

The GBT has observed as part of the MaDCoWS project, a comprehensive program to detect and characterize the most massive galaxy clusters in the universe at z~1 and above. The goal of the program is to understand cluster mass scaling relations, identify high mass clusters that can be sued for cosmological and strong lensing studies, and study the evolution of massive galaxies in over-dense environments.

GALAXY FORMATION AND EVOLUTION

The GBT's sensitivity to diffuse gas makes it an ideal instrument for the study of evolution of galaxies from the local (z=0) through the distant (z>6) Universe. Mapping the distribution and flow of cold gas within clusters and proto-clusters of galaxies, studying global star formation in nearby galaxies, determining the dynamics of the Galactic Bar, and mapping the HI clouds and bubbles within the Milky Way are just a few of the many ways the GBT will be contributing to our understanding of this important field.

The GBT will play a vital role in our general understanding of the evolution of galaxies through observations of redshifted CO(1-0) emission. Using the GBT, the redshifts and molecular gas masses have been measured for sets of ultra-luminous infrared lensed galaxies at high redshift that were discovered in wide-area Herschel and Planck surveys. GBT observations will continue to provide the impetus for follow-up high-resolution imaging studies of individual sources with ALMA and the VLA.

GREEN BANK SCIENTIFIC 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

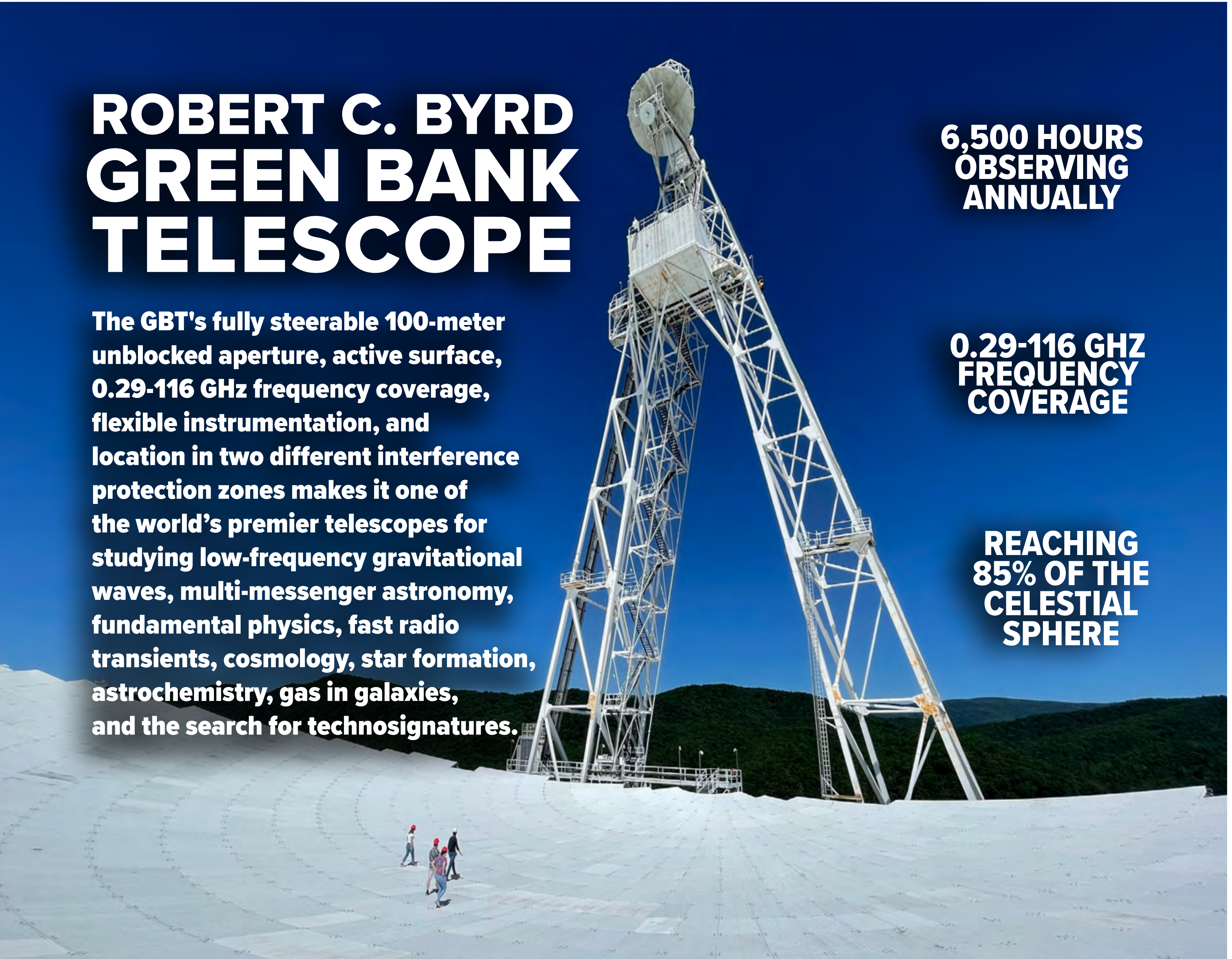
1980s
- 1400 MHz sky survey
- CBS5 Survey of radio sources
- Area of the sky found with the least interstellar matter
- Discovery of Extreme Scattering Events
- Galactic Plane Radio Patrol
- Surveys of He^3 emission
- First detection of HI in S0 galaxies
- First measurements of the magnetic field in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

1990s
- GBT groundbreaking
- Green Bank Earth Station operates with Japan's VSOP satellite
- Discovery of Maser emission from methanol

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 clouds found to be on a 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=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

2020s
- Direct detection of interstellar polycyclic aromatic hydrocarbons
- Independent determination of Hubble constant with 4% uncertainty
- Discovery of an extremely massive millisecond pulsar
- Detection of correlated red noise in a pulsar timing array
- Detection of long carbon chain molecule $HC_{11}N$



ROBERT C. BYRD GREEN BANK TELESCOPE

The GBT's fully steerable 100-meter unblocked aperture, active surface, 0.29-116 GHz frequency coverage, flexible instrumentation, and location in two different interference protection zones 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 the search for technosignatures.

6,500 HOURS OBSERVING ANNUALLY

0.29-116 GHZ FREQUENCY COVERAGE

REACHING 85% OF THE CELESTIAL SPHERE

The GBT has achieved excellent 3mm capabilities, with 35% and 18% aperture efficiency at 90 and 115 GHz, respectively. The GBT utilizes a dynamic scheduling system that optimizes each observing project's scientific goals against the predicted weather conditions. In FY2020, the last full year of operation, the GBT offered 7,172 hours of observing and test time, equivalent to an operational efficiency of 82%. This availability will continue through FY2022.

The GBT covers a frequency range of 290 MHz to 116 GHz (non-contiguous), with an instrument suite consisting of single/dual-pixel receivers from 290 MHz to 93 GHz and a seven-pixel heterodyne focal plane array at 18–26 GHz. The GBT features industry-leading signal processing systems with a high dynamic range, a state-of-the-art system for high time and frequency resolution observations, and the capability for very wide bandwidth observations for spectral line and pulsar detection experiments. Two additional cameras, ARGUS, a 16-pixel single polarization array from 90–116 GHz and MUSTANG2, a 200+ pixel bolometer array at 81–100 GHz, are operated as instruments that may require added support from their principal investigators.

Spectral and continuum observation data are processed with the VErsatile GBT Astronomical Spectrometer (VEGAS). Other instruments in use include a Digital Continuum Receiver (DCR), a Mark 6 VLBA disk recorder, and a Caltech Continuum Backend (CCB) managed by the Jet Propulsion Laboratory (JPL).

MORE DETAILS & WHITE PAPERS

greenbankobservatory.org/science/instruments-2020-2030

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.

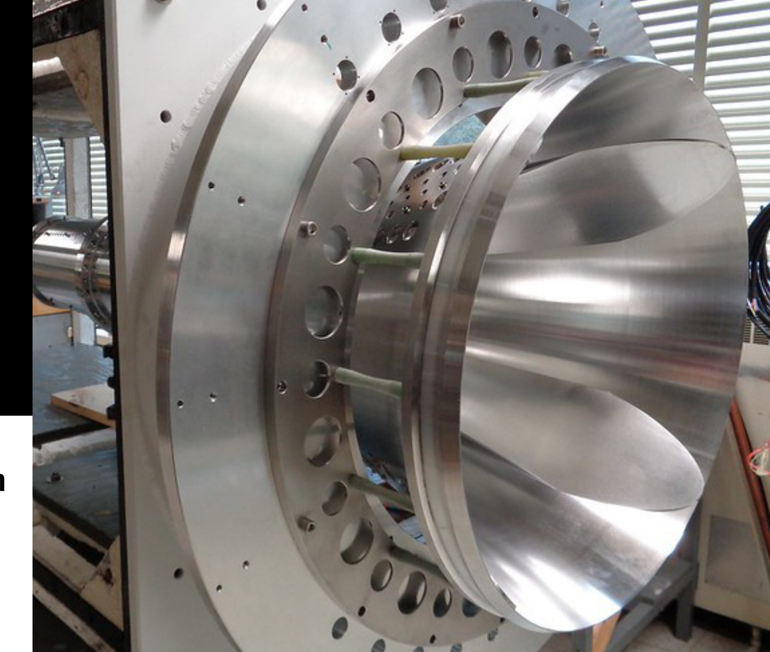
The Observatory operates state-of-the-art electronics and digital development labs specializing in the design of low-noise cryogenic receivers and FPGA-based wideband digital backend systems. The Machine Shop builds nearly all GBT feed horns, dewars, RFI enclosures, and other custom components.

ULTRAWIDEBAND SYSTEMS The Observatory is developing a 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.

IMPROVED PERFORMANCE The GBT is currently testing a new laser scanning system (LASSI) which, when complete, will increase the GBT's availability for mm-wavelength observation by 50% or more. LASSI uses a laser scanning system and the GBT's surface actuators to rapidly sample the full 2.3 acre dish and the correct for any deviations from idea in near real time, providing a surface that has an overall surface r.m.s. of accuracy better than 270 microns.

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

NEXT GENERATION VERY LARGE ARRAY (ngVLA) will include several antennae at the Green Bank Observatory. This large project is under consideration in the Astro2020 Decadal Review and will have 10x the sensitivity of the current Jansky VLA and a proposed frequency range (1.2 - 116 GHz) that complements the range of frequencies available to the GBT. The array design features a dense core of 18-meter antennae for low surface brightness imaging and extended baselines up to nearly 10,000 km for exquisite angular resolution. Site benefits include the radio quiet environment of Green Bank, geographic position compared to other planned antenna stations, and our readily available fiber, power, and infrastructure.



***TOP** the interior of the new Ultra Wideband receiver, fabricated in the Observatory Machine Shop. **MIDDLE** the UWB receiver on the Observatory test range. **BOTTOM** LASSI installed on the GBT receiver deck.*

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.

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

WEST VIRGINIA RADIO ASTRONOMY ZONE
10 mile radius, increased restrictions on all electrical emissions

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 able to be run independently, the three telescopes were most often used together as the Green Bank Interferometer. Use of the telescopes ended in 2000, and they are now preserved for their historical significance. With refurbishment, all three can be restored to full operations.

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**	Needs Refurbishment
140-foot (43m)	50% at 7.2 GHz	20-40	0.004	-40 to 81**	-105 to +105**	Operational
GBT 100-meter	70% at 7.2 GHz 35% at 90 GHz	18-35	0.001	+5 to +90	-270 to +270	Operational from 0.2 through 116 GHz

*Original specifications

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

SEE MORE
greenbankobservatory.org/telescopes

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 the 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 to prove 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. Later, it was re-purposed for daily solar observations as part of the Frequency Agile Solar Radio telescope, through 2012.

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 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.

the future of ENGINEERING

MECHANICAL • ELECTRICAL • COMPUTER • HARDWARE • SOFTWARE

Observatory staff possess decades 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.

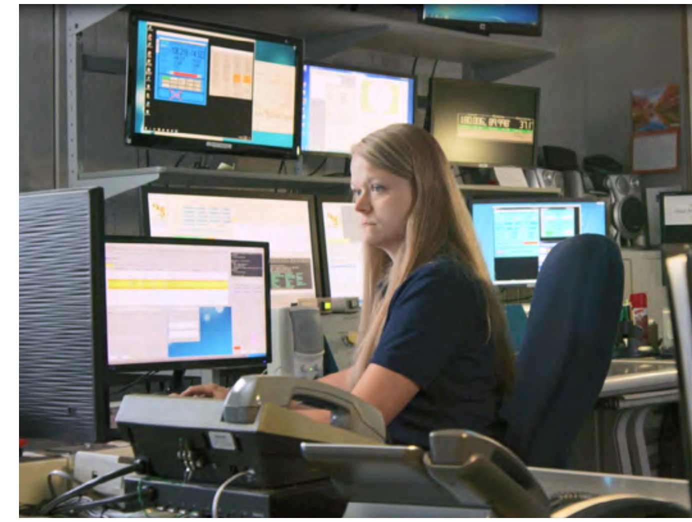
While focused towards Green Bank operations, the staff are also able to develop innovative solutions and products for other research organizations around the world.

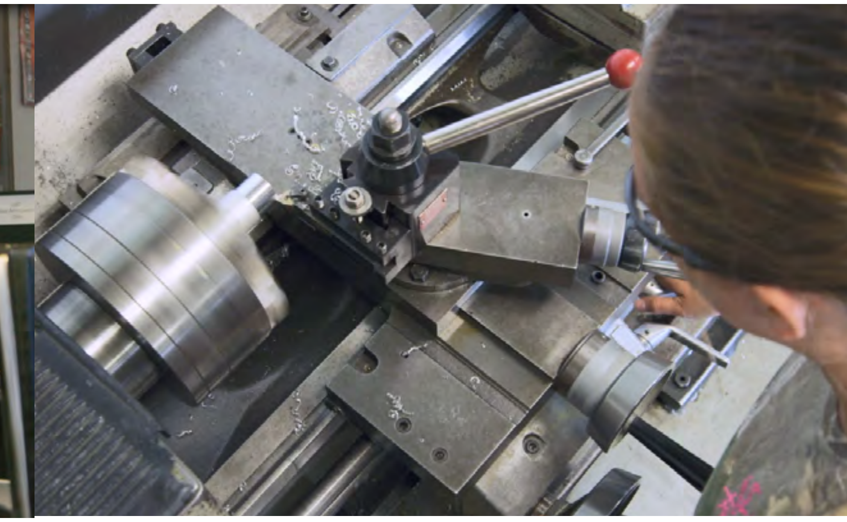
DIGITAL

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 state of the art 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 receiver designs up to 115 GHz using CST Microwave and Microwave Office development software. Recent projects include a 19-element L-band cryogenic Phased Array Feed 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. The Ultra Wide Band Receiver, X-Band Receiver, and radar projects have all been supported in-house.





SOFTWARE

The Observatory's software development division develops, 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, and 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. This 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 tighter 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 3-D printing and welding across a wide variety of metals and techniques.

DESIGN • FABRICATION • REPAIR • MAINTENANCE • COMMERCIAL

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.

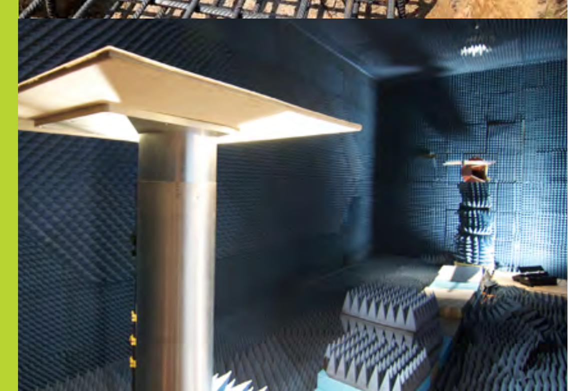
The site has significant infrastructure which allows for the installation of any instrument which may benefit from the radio quiet location, as well as a **radio frequency test range** for receivers and for testing antenna beam patterns, and a large **anechoic chamber** for testing radio emissions from all types of equipment.

With nearly **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 several arrays of telescopes and antennas operating from 20-100 and 100-200 MHz, one station from a nation-wide magnetometer array, a GPS sensor deployed as part of West Virginia's geo-spatial array, along with a CHIME prototype array and outrigger antenna.

2,700 ACRES

ANTENNAS, TELESCOPE ARRAYS & OUTRIGGERS

ANECHOIC CHAMBER



RADIO FREQUENCY TEST RANGES

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 our observations, 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 Cafe**, 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 electric vehicles are located next to the dormitory.

GALAXY GIFT SHOP

On site and online, we offer a wide range of gifts for science lovers of all ages, including unique products made in our Observation machine shop. Members, conference attendees, and educators receive a discount.
shop.greenbankobservatory.org

RECREATION

The Observatory features a 1.5-mile (3-mile out and back) paved **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 online (download and print before you visit) 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.

EDUCATION

reservations@gbobservatory.org
304-456-2150

STUDENTS

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

RADIO ASTRONOMER FOR A DAY Scientists routinely tackle questions that don't yet have answers. This student overnight program provides an authentic research experience with tours, hands-on activities, and training on a working radio telescope. 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 sixty 8th graders for a 2-week summer camp focusing on science, astronomy, and personal development.

PHYSICS INSPIRING THE NEXT GENERATION PING engages traditionally underrepresented students to science and engineering, with a focus on physics and radio astronomy. Launched in 2014, PING immerses middle school students in a 2-week residential research camp and undergraduate students in a 10-week internship that includes mentoring the younger students.

FIRST2NETWORK With funding from the NSF, the Observatory coordinates a national program to connect underserved first generation college students from diverse groups to STEM career mentorships, training opportunities, and employment.

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

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 training course. 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, that trains undergraduates to deliver interactive science, technology, and engineering presentations to K-12 classrooms, museums, and youth programs. To date, over 800 presentations have been given, impacting the lives of over 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.

WEST VIRGINIA LEAP INTO SCIENCE The Observatory provides professional development to this network of informal educators which brings engaging STEM-inspired early childhood and family science events to community settings. Educator training opportunities and other resources are available.

GBO & NRAO RESEARCH EDUCATION EXPERIENCE
Each summer nearly sixty students are paired with staff for immersive virtual and site based research and training experiences.

VIRTUAL PROGRAMS

Can't come to the Observatory? Tune in from home, and we will come to you! **Virtual Site Tours** are offered for individuals and groups of all ages throughout the year.

Approved groups of five or more students can register for a **Virtual Field Trip** to learn about the Observatory history, radio astronomy, our latest science, and more! These programs are tailored to your curriculum and time available. Learn more and sign up today:

greenbankobservatory.org/education/virtual-visits

CAREER DEVELOPMENT

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

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. Two to three year positions are available on a rolling basis.

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. Three to six months paid appointments are available in mechanical engineering, machining, electronics and telescope maintenance/ mechanics.

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

EMPLOYMENT

The Observatory is hiring permanent, temporary, and seasonal positions. Current openings can be found at **greenbankobservatory.org/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.

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.

SCIENCE CENTER

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.

Fees are charged for guided public tours and some 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. The Center may close or cancel events to support necessary safety regulations during times of need. Virtual tours and activities are available and self-guided walking tours are always welcome.

Visit greenbankobservatory.org for the latest information.

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, no advanced registration required.

SPECIAL GUIDED TOURS

Focusing on unique aspects of our site's history with limited tickets available. Reservations are highly recommended, as these sell out! Dates and times are available online and in our brochure.

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

SETI Tours The search for extraterrestrial life began in Green Bank! Learn this history, visiting several several unique locations including historic control rooms. *Some historic locations require the climbing of stairs.*

History Tours How did the Observatory get started? What are some of the most exciting and important achievements? Learn this history, visiting several locations. *Some historic locations require the climbing of stairs.*

Guided Nature Walks There is more to the site than our astronomy. Enjoy a guided walk along our nature trail and discover the valley's ecology and geology.

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 on selected 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.

SPECIAL EVENTS

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.

SPACE RACE RUMPUS* An annual weekend-long festival for mountain biking and road cyclists of all ages, from beginner to advanced. Clinics and rides on trails and roads, bike rodeo, star parties, 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**

**These events are coordinated by community partners*

DATES, TIMES & RESERVATIONS
reservations@gbobservatory.org 304-456-2150
greenbankobservatory.org/events

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, Greenbrier River Trail

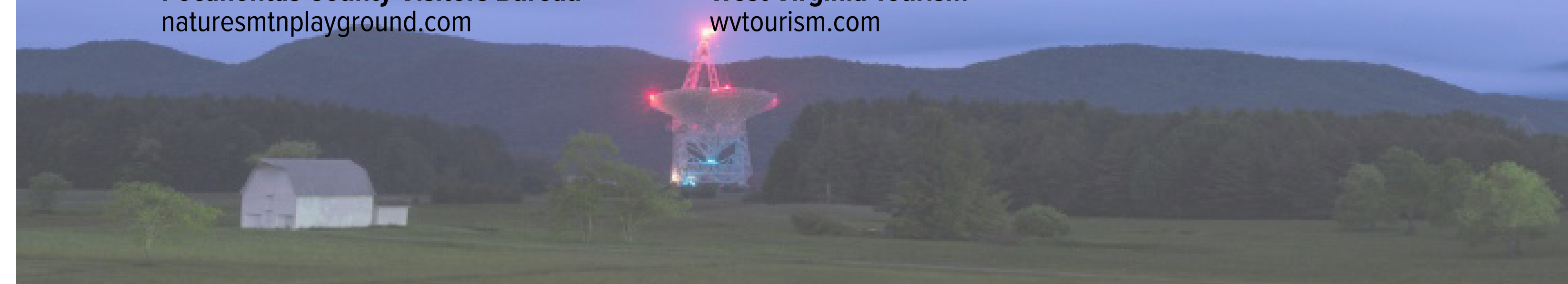
40 MINUTES Snowshoe Resort, Durbin Rocket, National Youth Science Camp, Seneca Lake State Park

WITHIN 2 HOURS Seneca Rocks, Spruce Knob, Seneca Caverns, 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 Newel Music Center

more information

Pocahontas County Visitors Bureau
naturesmtnplayground.com

West Virginia Tourism
wvtourism.com



SEE MORE

The Observatory shares news & information on several platforms including greenbankobservatory.org along with Facebook, Twitter, Instagram, YouTube, LinkedIN, & Trip Advisor
A variety of images and video for news and educational use are available on Flickr
Guidelines for visitor photography, social media policies, and press inquiries can be found at our website

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Any opinions, findings and conclusions or recommendations expressed in this material do not necessarily reflect the views of the National Science Foundation.

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