Green Bank Observatory

Program Operating Plan

FY2023

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# EXECUTIVE SUMMARY

This Green Bank Observatory (GBO) Program Operating Plan (POP) describes the planned allocation of GBO’s Fiscal Year FY2022 funding from the National Science Foundation Division of Astronomical Sciences (NSF-AST) in support of its mission to enable forefront research into the Universe at radio wavelengths. The period of performance is 1 October 2021 through 30 September 2022. GBO is managed by Associated Universities, Inc. (AUI) under AST-1928936.

The GBO POP highlights its community-driven science program, and the fundamental role these programs will play over the coming year. The POP also discusses the implementation of development programs to improve the existing GBO facilities in the near term and beyond. The GBO Long Range Plan (LRP) outlines the activities and key directions for GBO over the next five years, FY2023–2027.

The GBO enables leading edge research at radio wavelengths by offering telescope, facility, and advanced instrumentation access to the U.S. and global scientific and research community.

The Robert C. Byrd Green Bank Telescope (GBT) began regular science operations in 2001. The GBT’s 100-meter diameter collecting area, unblocked aperture, and excellent surface continues to offer the scientific community unrivaled research capabilities at 290 MHz–116 GHz.

In addition to the NSF funding provided under AST-1928936 (as amended), substantial new partnerships have been secured that complement NSF funding, and a combination of research and capability developments have strengthened GBO’s importance to the scientific community. It is vital that U.S. scientists have ready access to a large filled aperture to remain at the forefront of research, and GBO confirms its importance to the community through its significant and ongoing partnerships with the Breakthrough Listen Foundation and the North American Nanohertz Observatory for Gravitational Waves (NANOGrav). Meanwhile, GBO has maintained an availability of NSF-funded GBT Open Skies time proportionate to the funding level. The GBT is on track to be used for approximately 6,800 hours of scientific research in FY2022.

Ground-breaking new work currently underway will further enhance the capabilities of the GBT. A Laser Antenna Surface Scanning Instrument (LASSI) was implemented in FY2021 that provides the technical and algorithmic platform to increase the overall efficiency of the GBT, and in FY2022 further studies with the instrument will be underway with the goal of extending GBT usability for daytime observing above 25 GHz. With investments from AUI’s Corporate Resources and partial funding from the Gordon and Betty Moore Foundation, GBO is building an ultra-wideband receiver that will instantaneously cover 0.7 to 4 GHz. The detection of nanohertz frequency gravitational waves via pulsar timing is a key science driver for the new receiver. Two FY2020 NSF supplemental grants fund new capabilities including 1) an observing technique, Cyclic Spectroscopy (AST-1928936-009) that will add a powerful data processing technique for pulsar astronomy that can provide higher time and frequency resolution than traditional spectroscopic methods, while 2) a new data center (AST-1928936-010) will assure community access to the rich GBT archives for many years. In FY2021, Associated Universities, Inc. (AUI), was awarded grant request (MSRI-1 2114922) to initiate development of a new planetary-scale radar system for the GBT.

GBO’s broad portfolio of education and public outreach programs and activities is unmatched by any U.S. astronomical facility. GBO produces nationally acclaimed educational programs in Science, Technology, Education, and Mathematics (STEM) for learners of all ages with hands-on and virtual research experiences for science and engineering students and educators. The Green Bank Science Center enables these programs and activities with its auditorium, classrooms, and large exhibit hall. Thousands of primary, secondary, and university teachers; professors; and students participate in residential educational programs using the variety of radio telescopes available at the GBO. The five-year NSF Includes Alliance grant ((HRD-1834601), awarded in September 2018 to a collaboration led by GBO, funds important innovations in STEM student retention. A recently submitted grant, AST-2138022, would fund a workshop in early FY2022 to evaluate and define best practices in K-12 STEM research experiences across a wide variety of STEM disciplines.

The GBO has a proven track record of collaboratively constructing and commissioning cutting-edge scientific instruments and obtaining funding for important new research and development activities. Future instrumentation plans for the GBO are guided by scientific community inputs. Strong support for GBO science priorities is expected from the Astro2020 Decadal Survey on Astronomy and Astrophysics.

Due to the COVID-19 pandemic, GBO operated all of FY2021 under a series of site protocols approved by the AUI Vice-President for Radio Astronomy, the GBO Director, and the head of NRAO’s Environmental, Safety, and Security; they will remain in effect at the start of FY2022. The protocols exhibit structural consistency across the divisions yet recognize that each work group has unique operating characteristics. A common shared online directory provides access to the protocols to all employees.

Ongoing programmatic impacts of COVID have been reported in GBO’s FY2021 quarterly reporting and will be discussed throughout this FY2022 POP. While full onsite operations are expected to return by the start of FY2022, the effects of the pandemic will be felt throughout FY2022. Should a new wave of COVID-19 or variant infections affect operations, GBO will respond as necessary and document POP goal changes through the quarterly reporting process.

## Strategic Goals

The GBO Strategic Plan was updated in FY2020 and provides a long-term vision for GBO as well as strategic guidance for future initiatives that will enhance GBO’s role as an invaluable resource for astronomy in the U.S. and the world. The GBO strategic goals for FY2022 are as follows.

* **Developing an advanced Green Bank Telescope**
* **Ensuring the long-term future of the Green Bank Telescope**
* **Broadening our impact through STEM initiatives, diversity, and expanding our base**
* **Enhancing the Observatory’s environmental sustainability**
* **Being a resource to the U.S. and international scientific community**
* **Continuing to grow our partnerships and base**
* **Developing a joint radar initiative with NRAO**

Details of these activities can be found in subsequent sections.

## Introduction to the Plan

This POP describes FY2022 activities, operations, and initiatives that support the GBO Strategic Plan. This is the second POP crafted within the framework of the Cooperative Agreement established by the NSF with AUI for the operation of the GBO for FY2020–2024.

The POP serves as the primary GBO document for communicating the vision, mission, strategy, and initiatives that will serve the user community and deliver the best science results. The POP is updated annually to incorporate the latest scientific, technical, and budgetary developments. While POP milestones are limited to CSA-funded activities, GBO has multiple sources of funding incorporated into this plan, including NSF-AST Cooperative Support Agreement (CSA) funds, other awards, and partnerships. GBO targets non-CSA sources of funds to overcome operational budget shortfalls not covered by the NSF funding allocation, to maintain and support research and development efforts, and to retain key employee skills.

## Structure of the POP

Section 2 describes the key community-driven science goals, outlining a new vision for research built upon science produced since the 2010 Decadal Survey and based on numerous community workshops and discussions over the intervening decade. It addresses the topics of GBO science in the next year. Due to delays in the release of the 2020 Decadal Survey[[1]](#footnote-1), these goals will be informed by the Astro2020 report when it becomes available.

Section 3 describes GBT operations and GBO’s role in providing access to the GBT, expanding access to new users, enhancing services to users to facilitate achievement of their scientific objectives, and optimizing scientific operational efficiencies across the GBO. GBO scientists also support observer training and community outreach.

Section 4 describes other GBO assets, including additional site telescopes such as the 20-Meter telescope used for educational activities, radio quiet zones, and future instrumentation. It also describes projects and plans for use of site research assets.

Section 5 describes the GBO broader impacts to the scientific and general community including educational, outreach, and diversity programs at the GBO.

Section 6 describes the organization of the GBO, including the Director’s Office activities, Science Operations, EPO, and all of the operating divisions.

Section 7 describes the GBO and AUI workforce management plans and activities.

Section 8 discusses the Infrastructure and Maintenance plans for FY2022 to preserve and enhance the impact of the GBO in FY2022 and beyond.

Section 9 covers new initiatives for the GBO.

Section 10 discusses partnerships, new and existing.

Section 11 is the GBO budget summary for FY2022.

Five appendices provide supplementary detail: Appendix A – the FY2022 Financial Plan, Appendix B – WBS Structure, Appendix C – Major Milestones, Appendix D – references, and Appendix E – acronyms definitions.

# TRANSFORMATIONAL SCIENCE WITH THE GBT

While GBO awaits the release of the Astro2020 Decadal Survey report, it continues to focus on current priorities of the scientific community. The research program of the GBT covers a broad and dynamic spectrum that cuts across traditional disciplinary boundaries. Over the next decade, the unique capabilities of the GBT will allow for major advances across many areas of astrophysics. Here we outline the likely scientific impacts within FY2022.

## Star Formation and Evolution

Despite many recent advances, there are still major gaps in our understanding of how stars and solar systems form. It is possible that most stars form in molecular filaments, which contain dense cores, the sites of relatively isolated star formation. But how do filaments form and evolve in molecular clouds? What is the mass accretion rate and dynamical time scale of star formation in filaments? Will all density fluctuations form cores, and how do they dissipate their turbulence? With its broad frequency coverage, high sensitivity, and existing and planned suite of receivers, the GBT offers unrivaled capabilities for the study of star formation in molecular clouds.

The processes that influence star formation operate over an enormous range of linear scales, from galactic encounters across 10 to 100 kpc that can set the overall star formation rate, to the sub-parsec scale of a cluster or single star. Other important characteristic scales include the ~1 kpc thickness of spiral arms, ~100 pc diameter of large molecular clouds, ~10 pc length of molecular filaments, ~1 pc size of dense cores, and ~0.1 pc thickness of molecular filaments. Acquiring and assembling consistent information spanning five orders of magnitude in spatial scale is a daunting task, but one that must be accomplished to improve our understanding of star formation.

Over the next year, the GBT will continue to map the starless and dense cores in the widely used dense gas tracer N2H+ to better understand the formation and diversity of protostellar disks and binary/multiple systems. Ammonia (NH3) 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 GBT will also be used to better understand the distinction between complex organic molecules (COM) and complex carbon molecules (CCM). Traditionally, COMs are expected to exist in high mass hot cores, while CCM have been detected toward dark molecular clouds and low mass protostars (Suzuki et al. 1992; Sakai et al. 2008, 2009). This leads to the suggestion that in cold molecular clouds CCMs only appear at early times and become deficient as the gas reaches the steady state. Recent observations have brought this idea into question, leading to the concept of warm complex carbon molecules. The GBT’s fantastic sensitivity and resolution in the 80–100 GHz range will allow it to resolve individual sources, determining the spatial distribution, column densities, and excitation temperatures of the studied regions and providing significant insight into our understanding of COM and CCMs.

## 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.

In FY2022, the GBT will begin a large unbiased molecular absorption survey of the diffuse clouds in front of W49N, a bright Galactic HII region. The goal of this survey is to greatly increase our understanding of the molecular contents of the diffuse ISM, particularly regarding the complex molecular content. This survey will take excellent advantage of the GBT’s incredible sensitivity, detecting molecular absorption features with optical depths << 0.1, corresponding to column densities well below anything studied to date.

## 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 (see McLaughlin 2013 for a review).

The first GW detection in the nanohertz band (expected within five years for even pessimistic models of the GW amplitude; Taylor et al. 2016) will likely be of a stochastic background arising from the superposition of signals from many black holes throughout cosmic history. Details of the GW spectrum will provide important insight into the merger rate of supermassive binary black holes (and hence their host galaxies), as well as the environments in which those mergers occur and how black holes overcome the so-called “last parsec problem.” NANOGrav is already placing astrophysically important limits on all of the above (Arzoumanian et al. 2018). Detections of individual supermassive binary black hole systems will likely follow later in the decade, which will enable multi-messenger studies of these systems. In FY2022, the GBT will be critical to the continued work by the NANOGrav and International Pulsar Timing Array groups to detect the first GW detection in the NANOHertz band.

## The Search for Technosignatures

The question “Are we alone in the Universe?” is fundamental to our understanding of ourselves. 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).

Recent work (e.g. with the NASA Kepler telescope) has shown that there are potentially billions of habitable worlds within the Milky Way alone (e.g. Coughlin et al. 2016; Dressing & Charbonneau 2015). This, combined with the knowledge that many of the astrochemical building blocks of life are similarly abundant, suggests that the time is ripe for searching for technosignatures emitted from sources within and beyond the Galaxy(Gelino and Wright 2019).

Beginning in 1960 with Project Ozma’s use of the Green Bank Tatel telescope to monitor Tau Ceti and Epsilon Eridani for technosignatures (Drake 1961) and the formulation of the Drake Equation in 1961, the Observatory continues to play a significant role in the search for technosignatures through the present day (e.g., Margot et al 2018; Park et al. 2018; Enriquez et al. 2019; Sheikh, S.Z. et al. 2020 AJ, 160, 29). At present, the majority of the Observatory’s work in technosignatures is through Breakthrough Listen. Breakthrough Listen is using the GBT 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.

To date, the Breakthrough Listen team and collaborators have studied approximately 300,000 stars at distances as far as 33,000 light years, vastly farther and deeper than has ever been searched before, and placing the most stringent limits to date on the existence of powerful radio transmitters in this region of our Galaxy. Over the agreement’s next four years, this work will continue, pushing the sensitivity, distance, and types of stars to an unprecedented new level (e.g. Lebofsky, M. et al. 2019 and Price et al. 2020). In FY2022, the GBT will continue this important work, searching the most promising nearby stars for technosignatures while also searching the universe for the important precursors of life.

## 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, global studies of 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.

Understanding the role of molecular gas in stellar and galaxy evolution requires an unbiased survey across all galaxy types. Starting in FY2022, the GBT will map 150 galaxies nearby galaxies to provide the first unbiased CO imaging survey of z~0 galaxies with log[M\*/M⊙]=9-15. This data will be combined with optical spectroscopy and other molecular studies to directly test predictions of evolutionary models (e.g. Barrera-Ballesteros et al. 2018) and provide an unbiased sample to understand the true nature of galaxies at z~0.

Spiral galaxies like the Milky Way are known to have an extensive circumgalactic medium (CGM) that may contain a significant percent of the baryons of a galaxy (Werk et al. 2014). The Milky Way’s CGM includes HI high velocity clouds and the Magellanic Stream, whose properties are still not well known (Putman, et al. 2012). With its high sensitivity to faint HI emission, the GBT will be used to map the molecular gas of the Milky Way, providing ever better maps of the spiral arms and star formation regions. Looking at the cold atomic gas, the GBT will also map to incredibly high levels the gas ejection from the center of our Galaxy.

With masses in the range 106–109 M⊙, supermassive black holes (SMBHs) are the most massive compact objects in the Universe. They lurk in galaxy centers, accreting inflowing gas, and powering radio jets that regulate their further accretion as well as star formation. Many black holes are surrounded by accretion disks within which molecular gas produces bright H2O maser emission. The GBT has been the most productive instrument for detecting these masers. Using Very Long Baseline Interferometry (VLBI) techniques, the velocity structure of masers in the nuclei of active galactic nuclei (AGN) will be used to measure very accurate black hole masses or even infer direct distances (e.g. Gao et al. 2017). Without the sensitivity of the GBT, VLBI studies of these masers would not be possible, and this work will continue into FY2022 as more H2O masers are detected.

## 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. Galaxy clusters are rich laboratories for astrophysical phenomena such as shocks and cold fronts, sloshing of the gas within a cluster’s dark matter potential, sub-clustering, and X-ray cavities/radio lobes (Bally et al. 2016 and references therein).

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. In FY2022, the GBT will use the SZE to constrain the physical and thermodynamics of galaxy clusters, including directly studying the mechanism of electronic heating across shock fronts. The large format MUSTANG-2 (Multiplexed SQUID/TES Array for Ninety Gigahertz) bolometer camera on the GBT will measure the SZE at 3mm with uniquely high sensitivity at an angular resolution of 10ʺ, testing predictions for the SZE signal in detail.

In FY2022, the GBT will continue observing as part of the Massive and Distant Clusters of WISE Survey (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.

# THE ROBERT C. BYRD GREEN BANK TELESCOPE (GBT)

The GBT was designed to be able to take advantage of future improvements in instrumentation beyond what was available at the time of construction. The GBT’s 100-meter diameter collecting area, unblocked aperture, and excellent surface offer the scientific community unrivaled research capabilities at 0.29–116 GHz (1m–3.6mm wavelengths). After approximately a decade of surface accuracy and telescope pointing refinements, in 2010 the GBT active surface entered a new phase of unparalleled performance.

Since 2012, the GBT has begun significant operations in the 3mm band, opening up enhanced capabilities for spectroscopy and continuum studies over 67–116 GHz. The GBT is becoming a pivotal complement to ALMA for the U.S. scientific community. Plans to further enhance the surface control and accuracy will usher in a new area of cost-effective, world-class science.

## Current Status

The GBT operates 362 days annually. 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 availability of 82%. This availability should 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, a seven-pixel heterodyne focal plane array at 18–26 GHz, a 16-pixel single polarization array from 90–116 GHz and a 200+ pixel bolometer array at 81–100 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 (≥10 GHz) observations for spectral line and pulsar detection experiments.

### GBT Instruments - Receivers

The GBT receivers and backends available for general use are described in the following paragraphs and in Table 4.1.1. Several GBT instruments are semi-retired but can be used in exceptional circumstances and are also described.

**Prime Focus Receiver**: The GBT Prime Focus (PF) receivers are mounted in a focus rotation mount on a retractable boom. The boom is moved to the prime focus position in front of the subreflector when the PF receivers are in use, and retracted when Gregorian receivers are required. The frequency ranges generally available are 290–395 MHz and 680–920 MHz with the PF receivers divided into four frequency bands within the same receiver box. The receivers use cooled High electron mobility Field Effect Transistor (HFET) amplifiers. The feeds for the first three bands are short-backfire dipoles. The feed for the fourth band is a corrugated feed horn with an Orthomode Transducer (OMT) polarization splitter.

**Gregorian Receivers**: The receiver room at the GBT Gregorian Focus contains a rotating turret in which the Gregorian receivers are mounted. There are eight receiver box portals in the turret, all of which are kept cold and active. The Gregorian subreflector can be used for slow chopping. All Gregorian receiver calibration is done via signal injection from a noise diode, except for the W-band receiver, which employs an external calibration wheel with warm and cold loads, and the Argus array, which has an extendable hot load for calibration.

**Table 4.1.1. GBT receivers as of September 2021**

|  |  |  |  |
| --- | --- | --- | --- |
| **Receiver**  | **Frequency** | **Status** | **Gregorian/ Prime Focus** |
| Prime Focus 1  | 290–395 MHz, 680–920 MHz  | Available | Prime Focus |
| Prime Focus 1  | 385–520 MHz, 510–690 MHz  | Retired  | Prime Focus |
| Prime Focus 2  | 0.910–1.23 GHz | Retired | Prime Focus |
| L-band  | 1.15–1.73 GHz  | Available | Gregorian |
| S-band  | 1.73–2.60 GHz  | Available | Gregorian |
| C-band  | 3.8–8.0 GHz | Available for Linear Polarization only  | Gregorian |
| X-band  | 8.0–11.6 GHz | Available | Gregorian |
| Ku-band  | 12.0–15.4 GHz | Available | Gregorian |
| Ku-Wide | 13–19 GHz | Retired | Gregorian |
| K-band FPA  | 18.0–26.5 GHz, 7-pixels  | Available | Gregorian |
| Ka-band  | 26.0–39.5 GHz | Available | Gregorian |
| Q-band  | 38.2-49.8 GHz | Available | Gregorian |
| W-band  | 67–93.3 GHz | Available | Gregorian |
| ARGUS  | 80–115.3 GHz, 16 pixels, Single Pol | Available | Gregorian |
| MUSTANG2  | 75–105 GHz, 223 pixels, bolometer | Available | Gregorian |

### GBT Instruments – Backends

**VErsatile GBT Astronomical Spectrometer (VEGAS)**: VEGAS is a Field Programmable Gate Array (FPGA) and Graphical Processing Unit (GPU)-based backend comprised of eight spectrometers that can operate independently. Observers can simultaneously use any combination of spectrometers: from one to eight. VEGAS features a high dynamic range and can retain a linear response in the presence of strong radio frequency interference (RFI). VEGAS supports spectral line modes, which provide high frequency and moderate time resolution, as well as in pulsar modes, which provide moderate frequency resolution and high time resolution. VEGAS pulsar modes also offer specialized signal processing capabilities for coherent dedispersion and online phase folding

**Digital Continuum Receiver (DCR)**: The DCR is the general-purpose GBT continuum backend and is used for utility observations (pointing, focus, and beam-map calibrations, etc.) and continuum astronomical observations, including point-source on/off, and extended source mapping. This backend is the principle instrument used for measuring the GBT surface accuracy before high frequency observations.

**Mark 6**: VLBI/VLBA observing with the GBT is supported with a VLBA backend using the Mark 6 recording system.

**Caltech Continuum Backend (CCB)**: The CCB is a sensitive, wide band backend designed exclusively for use with the GBT Ka-Band receiver at 26–40 GHz. It provides carefully optimized wideband detector circuits and the capability to beam-switch the receiver rapidly to suppress instrumental gain fluctuations.

**JPL Radar Backend**: This backend is available for general use, but requires expert users to operate and reduce the data. It was developed primarily for bi-static radar observation and has more options for bandwidths and sample rates than the PFS backend.

**Portable Fast Sampler (PFS) Radar**: The PFS Radar backend is a private user backend rarely used primarily, but not exclusively, for bi-static radar observations.

**Breakthrough Listen**: The Breakthrough Listen project makes its backend available for up to 50 hours of shared-risk observations during each semester. The instrument consists of a cluster of 64 Titan X and 1080 GPU-based servers capturing 8-bit baseband voltages up to 12 GHz of instantaneous bandwidth. Data rates are typically tens of TB/hr. but a pipeline is available to generate spectra with adjustable frequency (> 3 Hz) and time (> 350 μs) resolutions, for possible science applications including fast radio transients, pulsar observations, stellar flares, SETI, etc. Before submitting a proposal, proposers must obtain permission to use the backend from the Breakthrough Listen team at the Berkeley Search for Extra Terrestrial Intelligence (SETI) Research Center.

## Time Allocation

The GBO is committed to the Open Skies policy, and will provide access to the worldwide scientific community to use the GBT through a peer-reviewed proposal process. The time available for Open Skies is proportionate to the fraction of the operational funds contributed by the NSF.

GBO’s Telescope Time Allocation (TTA) process, which is administered by NRAO, provides tools by which proposals are prepared, submitted, and peer reviewed; and by which telescope time is allocated. To minimize the burden on the scientific community and to provide a cost-effective proposal evaluation process, proposals for all GBO and NRAO Open Skies telescope time are handled through a single, unified scientific evaluation and time allocation process.

The GBO’s proposal process is semester-based with FY2022 proposal deadlines of February 1 and August 1 (5pm ET). The TTA group will prepare each Call for Proposals and all the associated documentation regarding schedules and the observing capabilities to be offered, and will support astronomers with any issues they may encounter during the submission process. All proposals will be evaluated on the basis of scientific merit by one of a number of Science Review Panels (SRP), each covering a different category of scientific inquiry. SRP members are recruited from the scientific community for a typical term of four semesters, or two years. Proposals will also be reviewed for technical feasibility by members of GBO’s scientific staff. Scientific and technical reviews are forwarded to the Time Allocation Committee (TAC) comprised of the chairs of the SRPs. The TAC will recommend the time allocations on the GBT to the GBO Director. After consideration of TAC recommendations by the Director, disposition letters will be sent to proposers and the approved science programs will be posted online.

Proposals for GBO Director's Discretionary Time (DDT) will be submitted at any time through the Proposal Submission Tool (PST), one of the tools maintained by the NRAO for the scientific users’ community. DDT proposals are intended to address targets of opportunity, high-risk/high-return exploratory time, or other science opportunities deemed sufficiently urgent to justify prompt action. DDT proposals may also be submitted for the education and public outreach, e.g., to observe an iconic source or to support an educational opportunity for students if such proposals are coordinated with GBO’s EPO activities. Overall, it is expected that approximately 5% but no more than 10% of Open Skies observing time on the GBT will be allocated in FY2022 for DDT proposals.

DDT proposals will be reviewed by the GBO Director and a small committee of GBO scientific staff members on the basis of the proposal’s scientific merit and technical feasibility in accordance with GBO’s policy regarding non-disclosure and conflict of interest. Disposition of DDT proposals will be ultimately determined by the GBO Director or their designee. If a DDT proposal is declined, a brief justification will be provided to the proposing team. If a DDT proposal is approved, then a proprietary period is assigned for the data based on scientific and programmatic considerations.

For help with proposals and various other topics, users contact GBO science support staff or send their queries through the online Observatory helpdesk, a web-based interface designed to aid with proposal submission, observation preparation, archive access, data reduction and analysis, Observatory cluster and computing access, and user accounts. The helpdesk is departmentalized based on these topics and managed by GBO and NRAO staff to ensure prompt responses and service to the individuals in our user community. The Observatory helpdesk also hosts a set of knowledge base articles reflecting common practices and guidelines.

Replacing the NRAO and GBO TTA tool suite and databases is a major joint GBO and NRAO initiative (see Section 8.4.1). To address the gender-related systematics, double anonymous proposal reviews are a design requirement for the new tools.

## Scheduling

GBT observing projects are scheduled via a Dynamic Scheduling System (DSS). Telescope schedules are built daily for the time period 24–48 hours from the time of the schedule’s release.

Science projects are loaded by the Head of Science Operations and then optimized in the DSS with input from the National Digitized Forecast Database operated by the National Oceanic and Atmospheric Observatory. The DSS automatically flags observations when the forecast falls below the minimums prescribed for the project and a substitution is made.

The Head of Science Operations and the Head of Telescope Operations jointly determine each week which day(s) to devote to maintenance, software deployment, and equipment characterization and testing. The day(s) are determined by the scope of tasks to be accomplished, the optimal weather for observations, priority of maintenance tasks, and the weather required to perform the maintenance and engineering tasks. The Head of Telescope Operations then coordinates the tasks and schedule for the maintenance periods.

A multi-year program described in Section 8.3.2 to update the DSS to reflect evolving GBT operational modes and customers began in FY2021 and will continue over the next few years.

## Interaction with Other Observatories

The GBO has arrangements with several other observatories for joint proposals involving the GBT. Joint proposals allow for a single review, avoiding double jeopardy, of a proposed project that requires data from more than one telescope. The proposal is submitted to and reviewed by the Time Allocation Committee of the primary telescope involved in the research. The secondary telescope performs a technical review of the proposal and agrees to abide by the results of the primary telescope’s Time Allocation Committee unless extenuating circumstances exist. Memorandums of Understanding (MOU) or agreements exist for joint observations between the GBT and:

* Jansky Very Large Array (proposals reviewed as part of the NRAO/GBO TAC)
* Very Long Baseline Array (proposals reviewed as part of the NRAO/GBO TAC)
* High Sensitivity Array (Proposals reviewed as part of the NRAO/GBO TAC)
* Global VLBI Array (Proposals reviewed by European VLBI Network with input from NRAO/GBO reviewer)
* Global Millimeter VLBI Array (Proposals reviewed by individual telescope)
* Fermi Gamma-ray Space Telescope
* Hubble Space Telescope
* Chandra X-ray Space Telescope
* XMM-Newton
* Swift Gamma-ray Burst Mission
* Stratospheric Observatory for Infrared Astronomy (SOFIA)

The GBO may sign future MOUs for joint proposals with other observatories, which have significant scientific overlap with the GBT.

The GBT also participates in VLBI observations as part of the High Sensitivity Array (HSA), the Global VLBI network, and the GMVA.

The GBT scheduler is responsible for scheduling the observations on the HSA working with the schedulers for the VLBA, VLA, and Effelsberg. The GBT scheduler provides input on the availability of the GBT to the schedulers of the Global VLBI and GMVA.

The GBT scheduler also works with the schedulers of the observatories requested in joint observations, especially when simultaneous observations are requested.

## Organizational Structure

GBO consists of all staff directly responsible for the operations of the Green Bank site and its facilities and instruments. The management structure is relatively flat, and all staff ultimately report to the AUI President, the AUI Vice President for Radio Astronomy, and the GBO Director.



*Figure 6.1. Green Bank Observatory Management Structure*

GBO is broken into ten separate divisions:

* Science is responsible for all scientists and astronomers on staff.
* GBT Science Operations is responsible for maximizing the scientific output of the GBT through telescope time allocation, telescope scheduling, observer support, proposal handling, and prioritization and testing of all GBT issues affecting scientific operation.
* Electronics provides all microwave, digital and analog engineers and technicians for the site. The electronics division designs, builds, and maintains all telescope instrument electronics.
* Telescope Operations is responsible for the mechanical maintenance, safety, and operation of all site telescopes. The Telescope operations division includes a telescope engineer, all telescope operators and technicians, and the seasonal painting staff.
* Mechanical oversees the GBO machine shop as well as all mechanical development and drawings on site. The Machine Shop provides all machining for the site telescopes and operations and also performs significant contract work for other observatories and organizations.
* Education and Public Outreach manages formal and informal educational programs on site, as well as the Science Center and all public tours and events. GBO’s public relations activities are included in the Outreach group.
* Software Development is responsible for custom software on site, including telescope monitor and control, data reduction, and visitor services. The software division is not responsible for any software purchased and used solely through a licensing agreement (e.g. MatLabTM, JD Edwards, etc.).
* Program Management manages projects and contracts on site, oversees resource planning for GBO’s portfolio of projects and work for others, and facilitates Observatory-wide and project performance reporting.
* Business Services coordinates the various support services and personnel needed to ensure the site runs smoothly, and includes direct management of the site visitor services (housing and food). Business also includes the budget division, which manages the planning and execution of GBO’s budget as well as invoicing, billing, reconciling, and warehouse functions.
* Plant Maintenance is responsible for all site infrastructure—buildings, water, sewage, roads, HVAC, etc.—including the maintenance, renewal, and long-term plans for the site.
* Public Relations is responsible for the outward facing and internal communications, through social media, press releases, and regular internal and external newsletters. Public relations also handle all booths at scientific meetings, the annual facilities report, and all media relations, and provides support for community projects and special events.

General Observatory services, including Human Resources, Contracts and Procurement, Computing Infrastructure, Management Information Services (MIS), and Environment, Safety, and Security (ESS) are supplied via Service Level Agreements (SLAs) with NRAO as described in Section 6.14 and are provided through NRAO’s negotiated Internal Common Cost (ICC) rate. Additional services are provided through the AUI corporate offices in Washington, D.C., and recovered via AUI’s negotiated indirect rate.

## Director’s Office

The GBO Director provides strategic leadership to the Observatory and manages the senior staff responsible for each GBO department. The Director and nine Division Heads lead and manage the Observatory’s core activities, including operations, maintenance, and science activities. Common service elements support inter-Observatory-wide functions through SLAs between GBO and NRAO. The GBO Director’s Office coordinates GBO programs, setting strategic priorities, assigning risk reduction funding, and resolving resource conflicts. The GBO Director reports to the AUI Vice President for Radio Astronomy Operations.

The Director’s office submits to the NSF on an annual basis the GBO’s recommended budget which includes recommended indirect rates for the upcoming year based on the current year’s fiscal performance and recommended rates for standard contracts for outside users of GBT and other telescope time, as well as use of the GBO facility to host third party stand-alone scientific instruments. The largest single user of contracted GBT observing time is the Breakthrough Listen Initiative.

### Advisory Council

The Green Bank Observatory Advisory Council was established in October 2016 upon the separation of Green Bank from the NRAO. The primary responsibility of the Green Bank Advisory Council is strategic planning for GBO, focusing on long-term instrument development plans, site development, and establishing/maintaining partnerships. Specifically, the Council is responsible for providing advice regarding:

* Long term operational planning for the Observatory (2, 5, 10-year plans)
* Identification of, and assistance in, seeking funding opportunities for the site and instruments
* Long term budget planning for the facility (2, 5, 10-year plans)

The Advisory Council is not responsible for overseeing the operational functions of GBO.

### AUI/GBO Visiting Committee

AUI charges an independent Observatory Visiting Committee, comprised of leading scientists with expertise in facility management, to assess GBO’s science productivity, community service, EPO, management operations, and the general health of GBO. The Visiting Committee will conduct a site visit and hold a plenary meeting every two years, meeting via teleconference in intervening years. The committee submits a written report annually, and the Chair will meet with the AUI Board during the plenary year. The reports, along with responses of the GBO Director, are forwarded to a Green Bank Advisory Council (described in Section 6.2.1), the NSF, as well as the AUI Board of Trustees.

### NRAO/GBO User’s Committee

NRAO and GBO have a joint Users Committee which provides advice on scientific, technical, operational, and development issues relating to the NSF-funded Open Skies community’s current and future use of Green Bank Telescope. The committee also makes recommendations to maximize the GBT’s NSF-funded Open Skies scientific productivity and improve its effectiveness for their user communities.

## Science Operations

The GBT Science Operations division is responsible for maximizing the scientific output of the GBT. The division’s duties include, but are not limited to: all aspects of GBT proposal handling, telescope scheduling, observer training and support, instrument and software testing and commissioning, and scientific prioritization of maintenance, repair, and improvements. The division is also responsible for recommending long-term strategies to the Director’s Office to ensure the GBT remains scientifically productive well into the future. The majority of the Green Bank scientific staff have significant time matrixed to this division.

GBO scientific staff serve as the interface between the scientific user community and the Observatory, providing access to GBO facilities, observer support, and an interface to the GBO’s long-term planning process. Working under the GBT Science Operations division, GBO scientists ensure the scientific outputs of all site telescopes are maximized, and they support GBO’s EPO division by providing lectures, mentorships, and workshops for students, the public, and the scientific community.

A highly matrix-managed division, the staff scientists provide much of the support for the GBT Science Operations division, scientific leadership and input into the GBO Director, and scientific guidance and testing for the Program Management group and other site divisions. GBO scientists enable the publication of GBT scientific results. All staff members in this division report to the GBO Director.

Specifically, the scientific staff provide:

* Community information and engagement: Through deep involvement with the scientific research community, scientific staff are a two-way conduit of information on the state and plans of all site instruments;
* Proposal support: Technical reviews for submitted proposals, helpdesk support for any proposal questions, and preliminary (post-SRP, pre-TAC) grading of the proposals;
* Observer support: On-call support for GBT observations, helpdesk support for any observing questions, act as ‘friends’ to GBT proposals, providing pre-observation support, training, and data reduction help for GBT;
* Documentation: Maintain all instrument documentation, aid in the proposal calls, maintain the Observer’s and Proposer’s guides, expand and maintain the GBT Memo series, and monitor publications for GBT results for wider dissemination;
* Track and measure telescope performance: Gain curves, performance monitoring, pointing, surface and tracking models;
* System health and maintenance feedback: Run routine health checks to identify hardware; failures; confirm fixes; characterize and monitor the effects of RFI on astronomical data;
* Training and mentoring: Mentor summer research students, students visiting as part of varied education programs, post-docs; organize and run two to three observer training workshops annually; organize and run one single dish training school annually; organize one to three community workshops focusing on GBT science; ongoing recruitment, training, and support of two to three postdocs, participate in all other onsite training workshops and schools as mentors and lecturers; and
* Software/Hardware testing and validation: Provide and carryout scientific test plans for all new and modified software and hardware for all site telescopes.

## Electronics

The Electronics division incorporates a multidisciplinary staff of engineering and technical specialists to maintain all electronic and cryogenic systems of the Observatory. Responsibilities also include support of the Interference Protection Group (IPG). The division continually works to improve reliability of GBO electronic systems, ensuring data quality, and modifying existing equipment as necessary for new applications. The division assists with public outreach activities, and engages in technology transfer when possible. The division frequently interacts with the at-large astronomical community in an effort to gauge satisfaction of the data acquired with GBO instruments and understand their future scientific requirements. The division historically collaborates with college and university groups in addition to other observatories in pursuit of advanced technology providing the scientific community with the next generation of radio astronomy instrumentation.

Two groups comprise the division: a microwave group that maintains the suite of receiver systems, and a digital group that maintains the active surface, telescope control systems, and digital signal processing equipment. Commensurate with receiver system maintenance are development projects motivated by improved performance and reduced equipment physical size and carbon footprint. The digital group shepherds the active surface component repair and replacement efforts and pursues advance digital signal processing techniques. Active projects include the Ultra-Wideband Feed, Active Surface replacement, active RFI elimination techniques, X-band receiver, and modernization of all site antenna control system components.

### Facilities and Capabilities

For testing current and new instruments, the microwave 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 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 included 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.

The digital group has experience with Field Programmable Gate Array (FPGA) design concepts and produces many specialized digital processing systems. This group also experiments with digital servo control systems and metrology techniques for measurement and control of large radio telescopes. Recent signal processing equipment for pulsars and spectral line observations were developed utilizing tools created by the Collaboration for Astronomy Signal Processing and Electronics Research (CASPER) project. This employs FPGA-based hardware and firmware developed at University California-Berkeley with XilinxTM FPGAs and MatlabTM and SimulinkTM development environments. This advanced technology affords the opportunity to develop algorithms that actively detect and excise RFI. Interference Protection Group (IPG).

The Electronics division supports the IPG by providing technical expertise for inspecting transmitters in the Radio Quiet Zone, performs testing and qualification of electronic equipment located on site, and provides mitigation for interference-producing equipment. One technician performs all site inspections and investigates sources of RFI reported by the scientific staff. A full-time engineer maintains and performs all tests in the anechoic chamber.

The GBO RFI protection policy differentiates two zones, one for the radio astronomical instruments (Zone 1), and one for the laboratory, housing, works areas, and the Science Center and other visitor facilities (Zone 2).

In Zone 1, the ground zero of the scientific instruments, the general philosophy for interference mitigation is a preventative, proactive approach. Interference potential is assessed through testing within GBO’s anechoic chamber, and equipment is shielded and filtered as necessary before installation. All installed equipment is required to comply with the limits stated in International Telecommunication Union-Radio (ITU-R) RA.769, assessed with respect to the prime focus point of the GBT at its highest elevation. To avoid strong broadband emissions from spark plugs, motorized traffic is limited to diesel vehicles. Tourists and other site visitors are required to leave their electronic devices behind when they go on GBO site tours by bus or on foot.

In Zone 2, the laboratory, housing, and visitor areas, GBO differentiates between intentional radiators and unintentional radiators. An intentional radiator is any electronic device that intentionally transmits radio waves. All intentional radiators except for a select list of coordinated devices that are absolutely necessary for safety (e.g., the 43 MHz site radios) are strictly prohibited.

### New Instrument Initiatives and Collaborations

The Electronics division assists in writing grant proposals in these research areas ensuring currency with the latest technologies, and it collaborates to improve scientific capabilities and GBT observing efficiency. Included in the proposals are opportunities for both undergraduate and graduate students to participate in design and construction. These proposals also have an EPO component, which contributes to the division’s history of developing cost-effective circuitry and instrumentation for students to explore radio astronomy.

## Software

### Development

The GBO Software Development Division (SDD) develops, maintains, and upgrades subsystems supporting the operation of the GBT and other GBO telescopes and systems. Major subsystems include: observation management, telescope monitor and control, telescope scheduling, data reduction, and data archiving. Other supported applications include the Green Bank Reservation System and a small suite of tools to support NRQZ administration.

### Software Infrastructure

**CLEO Update**: CLEO, the Command Library for Operators and Engineers, is the primary software used by staff to operate and diagnose issues with GBO telescopes using the standard monitor and control system software. SDD has assumed responsibility for this application from the Science Division and is in the process of porting it from Tcl/Tk to Python and updating the associated documentation. Because the existing CLEO system is stable, the project to port CLEO to Python is not a top tier priority for the SDD team. Therefore, it is currently being staffed as a second-tier effort, and SDD expects this process to conclude in FY2024 at the anticipated level of effort.

**Dynamic Scheduling System (DSS)**: One of the main tools for managing GBT Science Operations activities and a cornerstone of efficient GBT operation is the Dynamic Scheduling System (DSS). Commissioned in 2009 for the 2009C trimester, the DSS replaced an entirely manual scheduling system with an algorithmic-based scheduler which takes input from the proposal process, available GBT receivers, and predicted weather conditions to effectively and efficiently schedule observing projects on the GBT, maximizing the weather sensitive high frequency observations. The DSS has performed admirably, however in the intervening years new capabilities, enabled by the anticipated expansion of high frequency availability due to LASSI, scheduling constraints of fixed (windowed) observations, plus contracted GBT observations, require an update to the definitions and algorithms employed by the DSS. The planning and requirements gathering activities phase of this internally funded project was intended to launch in FY2021, however much of that work has been delayed, and the launch is now planned for FY2022.

### User Facing Tools

**Proposal Submission Tool**: Observing proposals for the scientific use of AUI-managed telescopes employ a common tool and are evaluated on the basis of scientific merit and technical feasibility using a joint, panel-based review system run by NRAO. The scientific assessment and ranking of proposals is undertaken by a number of Science Review Panels (SRP) which each consider a specific science area, and are then collated by a Telescope Allocation Committee (TAC) made up of the SRP chairs. Proposals are submitted using the NRAO’s Observatory Proposal Submission Tool (PST), which also supports the work done by the SRPs. The Observatory-specific Proposal Handling Tool (PHT) and Dynamic Scheduling System (DSS) support the assignment of scheduling priorities by the TAC and the scheduling and preparation of the observations for accepted proposals.

Using NRAO and GBO resources, a substantial effort is underway to develop a new suite of Telescope Time Allocation (TTA) software tools, with an initial focus on the proposal process (PST/PHT) and any interfaces to software downstream (e.g., DSS). The new software tools will benefit proposals for the GBT, as well as the VLA, VLBA, and Global Millimeter VLBI Array (GMVA). To the extent possible, the new tools will provide a unified user experience across all the AUI facilities. Ideally, the experience of a user submitting a proposal also should be as similar as practical to ALMA proposal submissions using the ALMA Observing Tool suite.

**Archive Access Tool**: A common AUI observatory data archive consists of metadata and raw data for the VLA, VLBA, and GBT. An Archive Access Tool (AAT) provides an interface to search and retrieve data from the archive. For the GBT, data products consist of individual Flexible Image Transport System (FITS) files or a single SDFITS file, stored in the Next Generation Archive System (NGAS).

A modernized AAT is presently under development by NRAO that will contain data from all AUI facilities, including ALMA, VLA, VLBA, and GBT. Included in this project is effort to improve support for the GBT data products. A goal to have the initial set of existing GBT data searchable and retrievable via the NRAO AAT is expected to be met by the end of FY2021.

In FY2022, a next stage of enhancements to GBT archival data is planned to take advantage of GBO’s new data center. The infrastructure will be installed and developed to ingest GBT data into the new GBO data center. After the data is ingested, the NRAO Archive Access Tool will be updated to accommodate the new location of GBT archival data. Included in this project is planning for proper data management of new data.

The online NRAO archive tool provides astronomers with the means to access their GBT data obtained during observations, training, and workshop sessions. GBT data will continue to be ingested into this tool for the foreseeable future. If changes are made to the archive tool to meet NRAO requirements that render it unusable for the GBT archive, GBO may develop a new tool for the GBT, as resources permit.

The GBO Archive Project will also establish the additional search parameters that would be desired by the pulsar and transient community, changing the descriptive files used by the AAT to locate data and include the additional data files. Implementation of this work is a multi-year project that will build off of the availability of GBT data in the NRAO AAT launched in late FY2021.

**Telescope Time Allocation Tools (TTAT)**: The TTAT initiative is being led by NRAO under an SLA. A new set of tools will support the solicitation, preparation, review, and allocation of time to proposals. The software development of these tools began in FY2021 and extends throughout a multi-year project. NRAO’s SRDP program will support the development of the logical design and prototype through the refinement of requirements and testing of prototype implementations. GBO SDD is working on a collaborative NRAO/GBO team to implement the overall architecture as well as the implementation of GBO-specific requirements. Milestones for this project are covered as part of NRAO’s Program Operating Plan.

## Telescope Operations and Maintenance

GBO currently operates three active telescopes: the GBT, the 40-Foot telescope, and the 20-Meter telescope. Other site telescopes do not currently have observing programs, and the Telescope Operations division provides only caretaker maintenance for them. Engineering for replacements is provided by the Chief Telescope Engineer and servo system engineers matrixed from the Electronics division.

### Telescope Maintenance

The Telescope Operations Division performs preventive and corrective maintenance tasks on all the site telescopes and their systems. Preventive maintenance, testing, and calibration tasks were developed jointly by the Telescope Mechanics, the Telescope Electrician, and the Chief Telescope Engineer, and are performed in accordance with a master preventative maintenance schedule. Engineers and technicians from the Electronics division guide and perform maintenance and repair tasks for the servo motors of the telescope, with assistance from Telescope Operations. Preventive maintenance tasks include routine lubrication, scheduled equipment change outs, painting, and inspections. The Chief Telescope Engineer reviews findings from preventive maintenance tasks, oversees the collection of oil and grease samples and analysis, and performs vibration analysis of motors.

All operating telescopes undergo routine maintenance for all front- and back-end systems, including cold-head and compressor maintenance for the cryogenic receivers, repair of failed parts in the front ends, servo and Local Oscillator systems, and the maintenance and repair of fiber optic connections. Antenna mechanics also analyzed lubricants for metal and other foreign particles on all GBO antennas, to be alerted to potential failure of moving parts, especially azimuth truck bearings and elevation gears and bearings. Routine telescope structural maintenance continues all telescopes.

### Telescope Operations

A rotating work group of operators control the operations of the GBT and the 20-Meter from a single operator work station. They can manage the current observing programs for these telescopes productively. Additional programs, or major changes to the current program, will likely require additional resources or restructuring of workflow. Each operator has an 11-week rotation, with 8 weeks on operations duty and 3 weeks office duty, during which time they provide relief and maintenance support, training, documentation, and procedure development.

## Mechanical

The Mechanical division consists of two parts: Green Bank Mechanical Engineering, and the Green Bank Machine Shop.

### Green Bank Mechanical Engineering

Mechanical Engineering is responsible for the mechanical design of all new equipment on the Green Bank site and improving the life and function of existing equipment. The Division’s mechanical engineer is involved with failure analysis, process improvement, and implementation.

### Green Bank Machine Shop

The Green Bank Machine Shop’s (the “Shop”) rapid repair capabilities maximize observation time and compress development schedules for Observatory instruments. Without the Shop, the cost of machining many of Green Bank’s specialty parts would increase and there would be significant challenges in finding outside companies who could prioritize our work at the level necessary to keep the site telescopes operational. It would also be difficult to find an affordable organization with the expertise necessary to build the precision and unique parts required by GBO. The onsite Shop is able to participate in an iterative design/build/analysis development routine that is much more cost effective than a series of formal outsourced fabrications to a commercial facility.

When mechanical work for GBO and other AUI observatories allows, the Shop reaches out into the local industry for short-term shop and fabrication work.

The Shop has capabilities for machining both very large and very small parts and assemblies, from amplifier bodies and feed horns to large actuators and other equipment for the site instruments and facilities. In addition to several manual milling machines, the shop also has two conversational mills, similar to CNC mills, which can quickly be used to program a tool path in a complex pattern, especially useful for O-ring and seal grooves.

The fabrication area has a plate roller, a shear, a metal brake, and an ironworker often used for fabricating RFI boxes. Welding shop staff are skilled at TIG, MIG, and stick welding, and regularly weld aluminum, stainless steel, and steel. For complex shapes, the Shop has a CNC plasma cutting table that can cut out shapes in stainless steel, aluminum, or steel.

### New Instrument Initiatives and Collaborations

When working with new initiatives, the Mechanical division plays an integral part by designing and fabricating packaging and mounting, as well as designing mechanically active elements. Environmental, RFI, rigidity, and precision are all factors that demand attention when transitioning an instrument from the lab to the telescope. The design and fabrication of active elements such as the LASSI laser scanner allow for greater flexibility and performance of instruments when installed on the GBT. Experience with these elements combined with knowledge of materials and fabrication allow the Mechanical division to provide stable and reliable platforms for new instrumentation.

When an instrument’s component has high precision requirements and challenging geometry such as the Ultra-Wideband Receiver, the Mechanical division uses its knowledge and experience to find a way to fabricate these parts. The ultra-wideband receiver’s size and complex geometry will require special handling typical of the Shop to achieve the precision required. The Shop’s initial efforts to fabricate a proof of concept of an ngVLA feed have also proven successful and will likely require further effort.

When operations or a new instrument call for new techniques such as subreflector nodding via the actuators, the Mechanical division is called upon to investigate the equipment capabilities and repercussions such as wear or reliability. When there is a need to improve mechanical performance, such as the receiver turret, the Mechanical division is called upon to design and fabricate the components. Potential large projects such as a GBT radar will require this type of extensive design and fabrication and will include load bearing, cooling, and active mechanical elements.

As the Mechanical division is a service group to other divisions and projects, its milestones are captured in the project plans and reports of other GBO divisions.

### Environment

SDD simultaneously supports new development and ongoing operations. To accomplish this with minimal staff, SDD identifies 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.

For routine updates to existing systems, the division uses workflow management methodologies that encompass standard Software Development Life Cycle best practices. For unfamiliar problem domains or projects involving new technology, SDD favors an agile approach (e.g., Scrum). Both approaches work effectively with GBO’s program management and NSF’s Major Facilities Guide processes.

SDD uses git repositories for software revision control and utilizes open source tools to automate system builds and unit/integration testing. This results in rapid detection and resolution of problems. Most of the code base for the GBT is written in C++ and Python and the division makes extensive use of open source libraries and development tools. When open source tools are not available or prove difficult to tailor to system requirements, the division writes custom applications or frameworks to support GBT science. As a recent example, SDD developed the Matrix framework, a dataflow application framework designed to support high performance computing applications.

### SDD Operational Support

As its highest priority, SDD provides ongoing operational support for existing systems to ensure essential systems remain functional. This includes responding to urgent requests to restore operational status and resolving critical (“show-stopper”) issues as quickly as possible. Repairs, enhancements, and new functionality to existing operational systems that are not identified as critical (i.e., are not show-stoppers to current operational use) are assigned for development based on a GBO-wide prioritization and planning processes. Additionally, SDD refactors existing systems to stay up to date with evolving scientific requirements and software standards.

Critical and high priority updates to GBT monitor and control (M&C) systems are thoroughly tested and deployed in patches. As opportunities arise for a full deployment of large infrastructure items and new features, these deployments are scheduled on an as-needed basis. Prior to FY2021, M&C releases were bundled into one, annual deployment. By planning for as-needed deployments, releases are better aligned with major project milestones and features can become available on a timelier basis.

In FY2021, the software team developed a General Telescope Monitoring System incorporating off-the-shelf technologies Prometheus and Grafana. The monitoring system provides information about the status and health of internal systems ranging from spectrometer GPU temperatures to items such as GBT servo monitors and maser SiteTime managers and samplers. This tool assists with operational monitoring and troubleshooting, and is designed to be easily expandable. In FY2022, the system will be enhanced with prioritized feature requests from GBO staff with a release of enhanced features in Q3 FY2022. Knowledge transfer and documentation will be an emphasis for the SDD team in FY2022 and FY2023 as key current experts approach planned retirements. This effort will focus on video-taped team presentations as well as the development of documentation for critical areas of software expertise.

### Current and Planned New Development

In addition to its operational support responsibilities, SDD undertakes new development and project work based on defined grant-funded milestones and GBO directed priorities. As noted in the previous section, it is vital that GBO staffs new projects with a combination of expert, mid-career, and early-career developers for knowledge transfer, so essential subsystems can be maintained and extended as current experts near retirement. This approach will require minimal overstaffing of each of the projects so there is a pool of staff that will remain robust in the face of normal staffing turnover.

### New Instrument Initiatives and Collaborations

The core monitor and control system utilize an object-oriented design which permits developers to extend the system in a straight-forward way to accommodate new GBT instruments. In addition, the core system interacts with other sub-systems comprising the observing and data reduction interfaces in a way that results in high cohesion and low coupling. Consequently, the Software division staff can support a wide spectrum of collaborator goals and capabilities. For instruments not intended for wide community use, collaborators may simply interface with a database that provides minimal GBT status information to support their observing. This approach is ideal for path finding or rapid prototyping instrument projects.

At the other end of the spectrum, SDD maintains a checklist of about a dozen subsystems that can be updated to fully integrate instruments into the GBT system. This approach is desirable for instruments expected to be used by the general radio astronomy community. Full integration results in better monitor and control by GBO staff, instrument access via the standard observing interfaces, and inclusion in the data analysis and reduction applications.

## Plant Maintenance

Responsibility for the infrastructure of the site buildings, facilities, and site housing rests within this division. Plant Maintenance, working with Business, is also responsible for carrying out Green Bank’s commitment to sustainability, an NSF priority for its facilities. As such, the group works to find avenues of operation that reduce waste and cost to the facility.

### Facilities Maintenance

GBO site buildings and grounds will continue to undergo routine annual inspection and maintenance. This includes annual road repair and winter plowing; roof repairs; heating and cooling systems maintenance; pest and weed control; servicing of sewer systems, water supply, backup generator power, HVAC systems, electrical lines, and related systems.

**Road repair, maintenance, and plowing (as needed)**: The Observatory owns and maintains all roads within its boundary, and is therefore responsible for repairing all damage and keeping the roads clear for proper use and, most importantly, for the passage of emergency vehicles when necessary. The maintenance group is responsible for plowing the roads of snow in the winter. Proper maintenance of the roads has kept them in outstanding shape over the course of the last 60 years with minimal outlay of funds for replacement. These activities are required to ensure GBO and the GBT remain in a current state of repair.

**Vehicle Support**: GBO maintains a passenger vehicle fleet of approximately 46 vehicles ranging in age from new to 50 years old, and a roster of approximately 39 pieces of heavy equipment. These vehicles are mostly diesel engine powered, a necessity due to the more radio-quiet nature of diesel engines (no spark plugs) versus gasoline engines for astronomical observation purposes. The passenger-style vehicles range from four passenger cars to multi-passenger utility vehicles to heavy duty pickups and are utilized for various excursions to the telescopes, hauling equipment to the telescopes or various locations on site, and transportation of materials and supplies off-site to various businesses and GBO rental properties for maintenance needs. The heavy equipment inventory includes loaders, bulldozers, tractors, mowers, generators, and aerial lift platforms, all utilized for the maintenance and operation of the site and facilities. These vehicles are mostly NSF-owned and, therefore, are maintained with NSF license plates and reported through the FAST vehicle system. Additional vehicles are leased through GSA and reported through that system. It is anticipated that the current fleet of NSF-owned vehicles will be transferred to the managing organization as recipient-owned within the FY2022–2026 time frame.

All vehicles and equipment meeting the necessary requirements are maintained within GBO’s inventory control system as government-owned property, and a strict maintenance schedule is utilized to ensure proper and safe operation.

**Water Treatment Facility**: GBO maintains its own water treatment facility for drinking water, as no municipal water service exists. This system, built almost 60 years ago, consists of two drilled wells, one elevated water tower and a distribution network to buildings and fire hydrants. Although this system for both potable water and fire suppression is solely for GBO, it is regulated by the State of West Virginia as a standalone public water treatment facility. Daily measurements and sampling of GBO’s public drinking water system by employees certified in managing a public water treatment system are required. Maintenance includes required system drainage and structural and mechanical inspections of the water tank.

**Observatory Electrical System**: As described in Section 8.7.1, the GBO electrical distribution infrastructure is in the midst of a multi-year significant upgrade for reliability and safety. The 4160V distribution lines, transformers and switch gears are in process of being replaced with priority work on the most critical sections. Specifically, the Jansky Laboratory and the 40-Foot Telescope power feed cables will be replaced due to age and concern of reliability.

**Fire Monitoring and Suppression**: Fire monitoring and fire suppression systems are critical for asset protection and safety for GBO employees and visitors. Maintenance will be continued in order to maintain or restore current systems to modern standards.

## Observatory Assets

The following are key site assets at GBO that support its science and broader impacts activities.

### Green Bank Science Center

The Erma Byrd Science Center is a multi-purpose building that draws 45,000 visitors each year[[2]](#footnote-2). A 4,000 square foot exhibit hall includes interactive displays. In addition to the exhibit hall, gift shop, and café, the Science Center hosts a 120-person auditorium, three separate classrooms, a computer lab, a large open basement space for project work, and the offices of the science center staff.

### Housing and Food Services

The isolated location of GBO and a highly limited choice of housing and dining facilities in the county requires GBO-provided facilities in order to support the science mission and visitor services. The GBO maintains accommodation in the form of houses, apartments, a dormitory, hotel-style rooms, cafeteria, and a smaller café available during Science Center hours for staff, visitors, and the public. During typical summer months (June through September), GBO housing frequently is 100% utilized by students and educational programs. GBO is able to operate these facilities so that they are revenue-neutral and self-sustaining. In FY2021, the residence hall dormitory, and café, were all closed for the year and the cafeteria ran only very limited service. The effects of COVID-19 on FY2022 are unclear, but it is expected that recovery to full operations and revenue will take at least 12–18 months.

### Other Buildings

GBO maintains the Jansky Laboratory, which houses offices, the electronics laboratory, the telescope operations rooms, anechoic chamber, plus all buildings associated with the site instruments, two storage (warehouse) facilities, the plant maintenance works area, a paint shop, and other miscellaneous buildings.

### Vehicles

Green Bank maintains a fleet of NSF-owned and General Services Administration (GSA)-leased vehicles. The fleet consists of transportation, maintenance, and support vehicles, plus specialized site maintenance heavy equipment. With no facilities to lease or rent vehicles within a reasonable distance, it is more economical to maintain a GBO fleet.

### Green Bank Machine Shop

The Green Bank Machine Shop (the “Shop”) is a technical and financial asset to AUI and GBO, performing iterative, challenging, and non-standard fabrications that are often not available from commercial shops. Research and development fabrications typically are iteratively developed in close collaboration with engineers and scientists. The Shop’s rapid repair capabilities maximize telescope observation time and compress development schedules for GBO instruments.

### Other Active Telescopes

The research and science capabilities of GBO extend well beyond the GBT. The GBO is a highly self-contained site that consists of three active radio telescopes; technical, engineering, and administrative buildings; short and long-term residences; and the necessary infrastructure to support all of the scientific activities and staff on the site. This section describes GBO’s other telescopes and research instruments. In addition to the GBT, two other telescopes are in active operation at the GBO.

**20-Meter Telescope**: GBO’s 20-Meter telescope, used by the Education and Public Outreach (EPO) division, is an integral element of Skynet, a distributed network of robotic telescopes operated by the University of North Carolina-Chapel Hill for educational purposes, and is contractually available for scientific research, controlled via the Skynet web interface. This opens access to authentic radio astronomy observing activities and labs to middle/high school and undergraduate students anywhere. The 4-H Organization has recently accepted Skynet Junior Scholars as a national curriculum project. Additionally, several colleges are using the 20-Meter to conduct observations as part of their Astro 101 courses.

**40-Foot Telescope**: The 40-Foot telescope is operated by the EPO division exclusively for on-site education and outreach. This telescope features basic operating controls and recording instruments and is one of the few telescopes ideal for students in high school through college undergraduates. Remote operation of the 40-Foot telescope is not currently possible nor planned.

### Inactive Telescopes

The 140-Foot Telescope was refitted for operation as a downlink earth station for the Lebedev Physical Institute’s (LPI) RadioAstron VLBI science satellite. At this time, no contracts are in place and this telescope is idled; although, it remains a scientifically important GBO asset, as the LPI contract demonstrated.

The 45-Foot telescope, last used for solar observing and not funded for operations, is mothballed.

Three 85-Foot telescopes, formerly part of a Green Bank Interferometer, are mothballed and maintained only at a level to prevent any risk to safety or structural integrity.

Possible scientific applications for these inactive telescopes are being explored. While these assets are currently inactive, possible future uses may be found if necessary refurbishment is externally funded by a research initiative.

### Other Site Instruments

GBO’s excellent site infrastructure, combined with its location inside two radio quiet zones, makes it an attractive location for other research instruments. Each of the following instruments is located on site, with operating terms and service offerings covered by contract or Memorandum of Understanding (MOU) or site hosting agreement between GBO and the instrument PI as primarily a cost recovery and GBO science mission support activity. The GBO currently hosts three instruments.

**Low Frequency All-Sky Monitor Project (LoFASM)**: LoFASM is a University of Texas Rio Grande Valley project that will consist of four arrays of phased dipoles separated by several thousand kilometers. One of its first arrays was installed at the Green Bank site in FY2013, and the instrument is now fully operational. Green Bank provides space for the array antennas and data collection computer, power, and network connectivity. No support or maintenance work is performed on the instrument by GBO staff.

**West Virginia Geospatial Information Network**: A Continuous Operating Reference Station (CORS) Global Positioning System (GPS) sensor for the West Virginia Geospatial Information Network is installed at GBO. This project is staffed and operated through the State of West Virginia. GBO provides space for the sensor and computer, power, and network connectivity. No support or maintenance work is performed on the instrument by GBO staff. In addition to the State’s use of the station, GBO has used the CORS for precise location of the 140-Foot telescope and other GBO instruments.

**Canadian Hydrogen Intensity Mapping Experiment (CHIME) Prototype Array**: In FY2020, GBO contracted with West Virginia University (WVU) to support the installation of 12, 6m class, parabolic antennas on Observatory grounds. These antennas, which consist of a pole mounted mesh reflector and a prime focus feed, were installed near the GBO Interferometry Control Building (ICB) where a small rack of electronic equipment is located in an RFI enclosure. The electronics are connected to the GBO LAN concentrator at the ICB via a fiber cable and the electronic equipment is fed a maser-referenced timing signal from the GBO timing center. Site hosting for this prototype array will be provided through FY2022.

**CHIME Outrigger Antenna**: CHIME is comprised of 20-m by 100-m semi-cylindrical paraboloid reflectors. The prime CHIME site located on the grounds of the Dominion Radio Astrophysical Observatory (DRAO) near Penticton, British Columbia, is composed of four reflectors.

Based on the CHIME Prototype proof of concept conducted in FY2020 at GBO by West Virginia University (WVU), the CHIME project desires to build a more extensive adjunct to the main telescope.

In FY2021, construction of a Chime ‘Outrigger’ reflector at GBO began, through contract between WVU and the Gordon and Betty Moore Foundation. The outrigger will be similar in design to the reflectors located in Penticton. Initial construction is for a single 100m x 20m semi-cylindrical paraboloid reflector, which may be expanded to two reflectors if needed. Accompanying the cylindrical reflectors in the FY2023–24 timeframe is an array of 64 six-meter class fixed-position parabolic prime focus antennas of the same basic design as those used for the 12-antenna prototype arrays described above.

An environmental review was completed in FY2021 in accordance with NSF requirements. Foundation construction is completing in FY2021 with antenna construction in FY2022 consisting of installation or supervision of cylindrical antenna foundations, supervision of parabolic antenna mounting masts, cable conduit installation, and primary power provisioning and installation to the CHIME Correlator Building, During construction, GBO will provide oversight activities for the construction and connections to GBO’s power distribution system, RFI testing and mitigation consulting, connections to the GBO fiber network, and provisioning space in the 85-1 Control Building for power and fiber connections.

Post construction, GBO expects to host the CHIME installation for multiple years, potentially through at least FY2026.

## Structure Maintenance

### Painting

All telescopes require painting to minimize corrosion and are painted white to minimize thermal distortions that would affect telescope pointing and focus. For the GBT, the annual goal has been to paint 10% of the structure annually during the summer months. In FY2021, the triannual telescope inspection process indicated concern regarding the age of the base paint and the fact that painting, due in part to the COVID-19 pandemic, was behind the 10-year goal. As a result, a paint consultant was hired to look at the GBT painting process, and his recommendations have been received and will be implemented beginning in FY2022.

First, due to the 20-year age of the telescope, and following the recommendations of the outside paint consultant, in FY2022, GBO will be pursuing a change in the overall painting strategy, with the aim to completely strip and repaint the telescope structure and dish over the course of only one to three years. In FY2022, GBO will be seeking cost estimate for this activity and, once costed, begin seeking funding for this change in painting cadence.

Second, the outside consultant recommended a change in both the paint and painting technique for the telescope. Unless funding for the proposed chance in painting cadence is received, in FY2022, a new strategy for hiring and training painters will be developed, using the new paint and painting techniques.

The other idled telescopes are not scheduled for any painting in FY2022.

### Track Repair

The GBT track is 14 years old and showing signs of wear. The GBT track system was replaced in 2007 to address premature wear and still requires periodic maintenance. The primary component requiring replacement are the wear plates, and beginning in FY2014, an annual program was initiated to replace GBT track pieces showing significant wear. In FY2018, ultrasonic peening was added to the manufacturing of the steel track pieces, with the aim of extending their lifetime. This process continued to be added to new track pieces through FY2021. In FY2021, the annual track inspection process showed the effectiveness of the peening, and this practice will continue into the future. In FY2020, work was also undertaken to inspect the grout layer of the track, and replace sections of the grout as needed.

For FY2022, the goal is to purchase an additional 12 new track plates, conduct inspection of the plates and grout, and replace the most worn 8–12 track plates as well as up to another 7–10 grout pockets. However, a request has been made of the NSF to provide funding to allow for acceleration of the track replacement. If this funding is received, these goals will be superseded.

Finally, it should be noted that due to COVID-19 impacts to the supply chain, the grout work and track replacement scheduled for FY2021 may be delayed and not completed until Q1 FY2022.

### Structural Inspection

The design service life of 20 years for the GBT was based on fatigue cycles of critical components. The number of cycles each year since 2002 are equivalent to only 30% of the cycles predicted; hence, the service life of the GBT will far exceed the original design life. The GBT is inspected annually during the summer maintenance period by the Chief Telescope Engineer. Additionally, to monitor and document GBT condition, an inspection of the critical structural members of the GBT is performed by an outside engineering firm every three years, with a full structural inspection completed over two inspection cycles (six years). Findings are corrected following each inspection. The last full inspection occurred in FY2021, and the report from that inspection will be released in FY2022.

In FY2022, a request will be made for a funding increase to GBO to allow for the structural inspections to be moved to bi-annual (from triannual), due to the age of the telescope.

### Structural Repairs

While the final report for the FY2021 structural inspections is not yet released, initial reports note that the inspectors found significant degradation in a few of the tubular U-connections in the upper feed arm (the saddle clamps). During FY2021, a structural paint expert and the inspectors were consulted, and work was done to stabilize the connectors. In FY2022, GBO will pursue a plan, and seek associated funding, to repair or replace all 22 U-connections on the telescope.

### Coolant Pipes

The coolant pipes on the GBT are now 20 years old and have begun to show wear, through mild leaks in the piping. In FY2022, GBO will replace the coolant pipes for the lower have of the GBT (below the elevation axis), and develop a timeline and cost for replacement of the upper coolant pipes.

### Prime Focus System

In FY2022, the Prime Focus Boom balls screws will be inspected and repaired, and a new cover for the ball screws will be designed, purchased, and installed. Additionally, the mount plate for the sterling mount will be removed and the mount holes repaired.

### Cable Lines Inspection and Replacement

Regular inspection and, when required, replacement of the accessible cables and cable connectors on the GBT is part of the annual maintenance procedures. In FY2022, several extraordinary activities will begin, including the documentation of the cables and cable ties and inspection (and when needed replacement) of the cables for the GBT subreflector, Prime Focus boom, and GBT actuators.

### Surface Molds

The original molds for the GBT’s primary and secondary surface are currently improperly stored and consequently unusable in their current condition. In FY2022 the molds will be cleaned, inventoried, and moved to a secure storage system. Additionally, in FY2022, the surface setting tool will be inspected.

### Data Center

As described in Section 2, the GBT continues to play a leading role in exiting new science areas including multi-messenger astrophysics. As the ability to collect large amounts of data grows, the existing computing support infrastructure (space, power, HVAC) in the Jansky Laboratory equipment and server rooms is at capacity. The NSF Windows on the Universe program provided an opportunity to expand data storage and processing capabilities commensurate with the planned new instruments, and in particular the housing of the GBT archive. With a supplemental award to the GBO CSA, construction of a new facility began in FY2021 adjacent to the Jansky Laboratory with its own power, emergency power, servers, data storage systems, HVAC, and networking to house the GBT archive and support growth of GBO computing systems. In FY2022, the GBO data center building will be completed and made ready for operational use.

### GBT Active Surface (Not yet funded)

The GBT active surface has been operational since shortly after GBT commissioning and is a major contributor to the planned expansion of high frequency performance of the GBT over its lifetime. The Active Surface system is an integral part of the Green Bank Telescope (GBT) primary optics used for high frequency observing. The hardware components for the Active Surface were originally procured starting in early 1992 and component test and evaluation began shortly thereafter. In FY2021, many components of the Active Surface system are, or are approaching, obsolescence. This plan will define how to replace the current, obsolete control system with a modern, reliable, and maintainable one as soon as funds are available.

From 2014 to 2018, GBO collaborated with West Virginia University (WVU) to engage three different student groups (11 total students over three separate academic years) to work on an Active Surface Control System upgrade capstone project. The students, supervised by a GBO staff digital engineer and by Dr. Parviz Famouri at WVU, designed a modernized hardware platform to upgrade the current GBT Active Surface system. The upgraded system will improve accuracy, and the modernized hardware and communications protocols will render GBO systems less susceptible to hardware obsolescence.

The original control system consists of a Versa Module Europa (VME) bus-based architecture, along with VME hardware interface boards that communicate with the control modules. Two VME single board computers interact with 70 pairs of control modules to adjust the surface. The communications protocol is proprietary and the architecture obsolete, so a new design is required. The WVU groups implemented a redesigned control module based on an embedded microcontroller that can control 16 actuators, a typical GBT actuator grouping. Each module must command the movement of its actuators and read back each actuator’s position to close the control loop.

The group demonstrated successful control of a single actuator to higher precision than the existing GBT system (<10 microns vs the current spec of ~25 microns). They also expanded the initial single-actuator design into one that can, in theory, control 16 actuators.

During FY2020, the designs were refined and an initial costed plan developed. The building and testing of the 16-module design along with packaging into an RFI-tight enclosure meeting Zone #1 emission specifications will be the next phase of the project. Approximately 320 modules (including spares) will be built for this project.

Expected improvements from the planned upgrade design have been evaluated. Based on approximately 4,000 separate Argus observations taken between 2018 and 2020, the current actuator performance was quantified. An effective average surface error due to the current actuators is 58 microns corresponding to an efficiency factor of 0.953, in comparison to 1.0 if the actuators were perfect. Assuming the new proposed system reaches an error of 20 microns in commanding, then a 4.3% gain in efficiency would be achieved (efficiency factor of 0.9943), normalizing the observational results to 90 GHz. This would correspond to a 9% improvement in the observing time needed to reach the same point-source noise level. At 115 GHz, the improvement in observing time would be about 15%, assuming a 20-micron control capability in comparison to the current system.

In FY2021, the project went through a successful Conceptual Design Review. Following that review, the project plans and designs are being refined and detailed. Funding for the project has been requested of the NSF.

## Receivers

The majority of work in this section is falls into routine maintenance. Only the exceptional activities to occur in FY2022 are listed here.

### Receiver Room

In FY2022, the weather/RFI seal for the turret rotator will be inspected for damage and, if damaged, a plan for repair/replacement will be made. Additionally, the RFI seal on the receiver room door will be replaced.

### Receiver Room Network

The fiber network in the receiver room will be fully documented in FY2022, including all switches, fibers, etc. Once complete, a plan for removal of the 10 Gbs hardware will be developed.

### X-Band Receiver Replacement:

In FY2020, the Electronics division undertook an internal project to replace the existing X-Band receiver which was becoming increasingly unreliable with a new design that replicates all of the existing X-Band receiver capabilities with a more reliable system and a wider (8–12 GHz) bandwidth, allowing for observations of spectral lines previously outside of the existing receiver’s frequency range. In FY2022, this receiver will enter the integration, test and commissioning phase, and will become the primary x-band receiver in FY2023. The successful completion of this project will also allow for the retirement of the last CTI 22 refrigerator.

## Documentation

As is true with most operational facilities, there are significant holes in the documentation for the GBT. Solving all documentation issues is a broad, multi-year initiative. In FY2022, GBO will focus on ongoing development and high priority tasks to begin improving this situation. The following documentation areas will be addressed:

* Documentation of the new SCU system
* Documentation of the network hardware/fiber in the Receiver room
* Video documentation of a number of routine and complicated maintenance tasks
* Documentation of the FITS files for the Argus and W-band receivers
* Collecting all existing documentation on the Argus receiver from the collaboration team
* Review, consolidate, and complete documentation of the subreflector actuator replacement techniques.

In addition, a new system for indexing documentation will be investigated.

## Site Infrastructure

The majority of work in this section falls into routine maintenance. Only the exceptional activities to occur in FY2022 are listed here.

### GBO Electrical System

The GBO electrical distribution infrastructure is in the midst of a multi-year significant upgrade for reliability and safety. The 4160V distribution lines, transformers and switch gears are in process of being replaced with priority work on the most critical sections. Specifically, the Jansky Laboratory and the 40-Foot Telescope power feed cables will be replaced due to age and concern of reliability.

Additionally, all of the material required to complete the Cafeteria / Residence Hall electrical upgrade has been purchased. The work will be scheduled Q1 FY2022.

The transformer that serves the Works Area and Machine Shop is original to the building was built and is housed in the Plumber / HVAC mechanics room. The works area is fully populated so the affected staff cannot be moved out of the area. The Transformer that serves Cryogenics Lab, Warehouse, and Old Tour Center is also aged and due for replacement. GBO plans to install one large transformer outside and serve both buildings. A replacement plan and budget will be developed in FY2022. A load study of the generator for the Jansky Lab Generator will be undertaken. The generator typically runs at 96% of its’ capacity during power failures during the summer months. The load study will develop a plan to shed noncritical load in the event of a commercial power failure, and will provide information to engineer a generator that will feed the entire building without a potential overload situation.

### Fuel Tank Replacement

The fuel tank for the heating system for the Cryogenics and GBO warehouse requires replacement. The tank has been ordered but delivery is delayed due to COVID. The old tank will have to be removed from the ground and the soil will need to be tested prior to backfilling the hole. The removal and testing is scheduled for September 2021. An independent soil scientist with LTT Soil LLC will visit GBO to complete the fuel plume analysis and process the samples. The tank and contaminated soil will be removed from the ground. The soil analysis will determine if additional soil will need to be removed and treated for fuel contamination. Once the cleanup is complete the replacement tank will be installed. We anticipate this work completing in Q1 FY2022.

### Water Tank Improvements

A list of immediate issues has been identified and Environmental, Safety, and Security staff have reviewed the list and set a schedule for the list of items to be addressed. One of the items is replacement of the vent on top of the tower. This will be a major undertaking with a completion date not later than the end of FY2022 pending budgetary approval.

## Education and Public Outreach

The Education and Public Outreach (EPO) division serves the strategic GBO goal of broadening public appreciation of and participation in STEM. EPO develops cutting edge programs for youth that build STEM identity and self-efficacy, professional development workshops that prepare teachers to teach Next Generation Science Standards, and an engaging program for the public. EPO highlights the discoveries, technologies, and careers pioneered and exemplified by the Observatory via news releases, multimedia, and the Science Center. Many EPO projects require multi-division coordination. For instance, news articles and press releases are written in consultation with the science staff. EPO staff designs new web pages, but relies on science and engineering staff to develop content for those pages. Many of the youth-centered programs are enhanced through mentorship, as GBO technical staff advise young scientists while they conduct observational projects with GBO telescopes.

FY2022 should show the return of the varied operation programs and events, although it is expected that return to former operational levels will take time. Detailed descriptions of the EPO activities in FY2022 can be found in the Broader Impacts section.

## News and Public Information

GBO’s Public Relations Specialist provides expertise in developing a strategic communications plan and content to fulfill the communications goals of the Science Division and the Education and Public Outreach department and produce evidence-based engagement with target audiences.

The communications plan identifies target audiences, including the specialist and professional scientific community along with amateur astronomers, students, families, and other tourists, and explains the mode of communications best for each audience and frequency, based on and responsive to data from analytics.

The modes of communications include the Green Bank Observatory website, email communications, social media, and streaming platforms. The website content is updated on a weekly basis, as press releases are distributed, and other notable GBO media mentions are shared. Resources for the scientific and educational community, along with press kits, photos, videos, and other marketing materials, are also updated on a weekly basis on the website and other sharing platforms, significantly improving community access and engagement.

The process for producing, scheduling, and posting timely and responsive content for social media platforms has been professionalized by the Public Relations Specialist, who has the expertise and experience to maximize the use of these resources, even from the NRQZ. This includes the use of a social media content management system, which allows for the advanced scheduling and deployment of content across multiple platform at once, along with analytics, ensuring that content type (photo, graphic, video, meme, link, etc.), date, and time are strategically chosen for maximum target audience engagement. In FY2021, this resulted in scientific training workshops filling to capacity well in advance of their deadlines, and the need to create waitlists.

An annual calendar identifies dates for AAS and other conferences, GBO and partner workshops, proposal calls, EPO programs, and other special events, organizing the design, production, distribution, and evaluation process for marketing and promotional materials. A strategic communications campaign is created for each project, for example, for the AAS conferences extensive planning for content creation and use of the conference hashtag resulted in a significant increase in website traffic to access resources for the astronomical community.

GBO takes advantage of an extensive network for distribution of press releases. GBO will continue to distribute news via the NSF, American Astronomical Society (AAS), the American Association for the Advancement of Science (AAAS), and commercial newswire services. GBO will also continue to target at least one special session each at AAS and AAAS meetings to provide information and news regarding GBO. GBO will sponsor a booth (in person or virtual) at each AAS meeting as well as at other major astronomy events (e.g. URSI General Assembly) to provide information to the scientific public about our facility.

GBO produces a scientific newsletter several times a year, including two special editions released at the January and June AAS conference, and two mini newsletters in advance of the August GBT Proposal Call and fall workshops. This newsletter links extensively to GBO scientific resources, driving traffic to the website, and provides updates on the GBT and the site as well as information about new staff, proposal calls, new instruments, and recent scientific discoveries. The GBO Public Relations Specialist also produces a comprehensive Facilities Booklet, outlining the history, achievements, and resources available on site for scientific research projects and educational programs. This booklet is a full-color, 16-page publication available in print for distribution at conferences or workshops, and as a PDF for download from the website, or email. It is a useful document for marketing new business partnerships, advocacy, and education.

GBO receives multiple requests each month from news and media representatives, documentary producers, photographers, writers, and vloggers. These requests are vetted by the Public Relations Specialist, who coordinates their shoots if approved, including crew security screenings, matching crews with staff for stories, escorting them on the grounds for shoots, or sharing photo and video resources with them for projects. All noteworthy media mentions of GBO are documented in an annual log, along with requests for interviews, photos, and videos.

## Program Management

Program management is the application of internationally recognized knowledge, skills, tools, and techniques to a portfolio of Observatory strategic planning activities, business initiatives, and projects to meet AUI and GBO’s objectives. Green Bank’s Program Management Department (PMD) defines and implements the processes used to achieve successful programmatic outcomes. The PMD staff adhere to project management and systems engineering best practices as defined by the Project Management Institute (PMI), International Council on Systems Engineering (INCOSE), and Scrum Alliance and hold professional credentials from those organizations.

PMD supports each of the GBO departments in the implementation and continuous improvement of Program Management operations, Proposal Development, Project Management (PM), and Systems Engineering (SE) practices, which includes the process, tools, and techniques described by GBO PMD Standard Operating Procedures (SOP). PMD staff are responsible for PM/SE implementation and often function as the project manager and/or systems engineer in internal and external WFO projects. Furthermore, PMD supports required reporting, Observatory-wide risk management, interface between budget and Contracts and Procurement, and other related activities as requested.

### Program Management Office Operations

PMD ensures that standardized practices are applied consistently across GBO to improve outcomes, manage and control costs, schedules, scope, and risks while adhering to a code of ethics for professional conduct. Common standards provide transparency and uniformity in programmatic and project-specific oversight, communications, and reporting. PMD staff use documented Standard Operating Procedures (SOPs) and templates for projects with PMD engagement. A growing library of completed projects with their SOPs and other documentation has helped to establish best practices for guidance with future efforts. SOPs are living documents and they will mature through continuous improvement processes. PMD will continue to revise the SOPs and templates to incorporate new processes and industry-standard best practices.

The PMD team facilitates business process improvement initiatives to gain efficiencies in service and technical processes using program management frameworks such as Agile and Lean. As GBO continues to evolve its stand-alone processes, it must continuously improve its ability to deliver high-quality services as quickly and economically as possible. GBO’s proposal development and contracting life cycle is one such inter-departmental and inter-Observatory process that has benefited already from continuous improvement initiatives. For example, GBO’s process for securing and processing small 20-Meter telescope time sales has been streamlined significantly.

PMD provides project management and systems engineering oversight of GBO research and development initiatives and projects involving the development or production of products and services to external organizations. This includes management coordination for broader impact and educational initiatives. Typically, grant-funded projects cover an appropriate allocation of program management staff assigned to ensure their proper delivery.

Working with the Director and GBO management team, PMD also develops GBO-wide documentation and deliverables, including program operating plans, long range plans, quarterly and annual performance reports, as well as program and grant documentation.

### Proposal Development

PMD supports all GBO departments in proposal development, including construction/production projects, research and development projects, and others in which PMD involvement is requested. PMD support includes leadership, coordination, and assistance in achieving SOP compliance. Deliverables from the proposal phase include a statement of work, budget, risk register, and export control documents. This effort gains internal alignment and project approval prior to project initiation. PMD also ensures that inter-observatory policies are adhered to for collaborations involving NRAO.

## Business

Responsibility for the business needs of the site, care of the occupants of the buildings, facilities, and site housing rests within this division. Business Services, working with Plant Maintenance, is responsible for carrying out Green Bank’s commitment to sustainability, an NSF priority for its facilities. As such, the group works to find avenues of operation that reduce waste and cost to the facility. For instance, the cafeteria and café operations will continue to evaluate the use of paper and plastic products and convert, where possible, to recycled and verified re-used products in their respective areas. Recycling programs have been instituted and through the next several years the business team will continue to evaluate the capability of the recycling efforts to expand mitigation of the waste stream. Business is also responsible for the site budget and accounting.

### Administration

The Business Services division provides staffing and resources for all necessary business processes for the operations of the facility. These include, but are not limited to, invoice processing, cash receipts, billing services, credit card processing, employee relocation, clerical support, vehicle fleet management, inventory control, reservation and on-site activity management, educational program support, food services for employees, visitors, and workshops, mail services, and shipping and receiving. The number of personnel in the Business Services group is dictated, in part, by audit requirements to ensure the proper handling of processes and the checks and balances required.

Business Services manages policy development and compliance for GBO as a wholly owned federal facility including Federal Real Property reporting, energy management reporting, FAST vehicle reporting, Government-owned property control and fleet management, and compliance with the Cost Principles for Federal Grants 2 CFR Part 200.

As part of the overall site land management philosophy, GBO works with several external entities and government organizations on different projects and programs. Under the auspices of the West Virginia Division of Natural Resources (WVDNR), GBO holds a controlled deer hunt in the fall. The purpose of this hunt is to control the deer population within a sustainable level as recommended by the food availability of the site. This population control allows diversity of species in the wildlife population on site, both in fauna and flora. GBO has entered a sustainability phase of control and anticipates that the hunt will not be held in FY2022, based on a WVDNR determination of need.

Working with the National Forest Service, GBO has become a trailhead for the Allegheny Trail, a subsection of the Appalachian Trail system. Approximately 10,000 acres of National Forest lies to the west of the site and GBO property fronts that section of forest. Access to the trail system is part of an ongoing effort for the county to become a hiking and mountain bike center for the state of West Virginia. As such, the participation of GBO in this program has increased tourism in the area and to the site, allowing GBO to increase participation in its public education programs. As part of this project, the Forest Service has provided signage to GBO, which allows it to emphasize its programs and educate the public about the quiet zones and the needs of GBO to maintain a low radio frequency noise environment.

###  Visitor Services

The Green Bank site hosts 23 houses, 5 townhouses, 4 apartments, a dormitory that sleeps up to 60 students, 16 hotel-style rooms, a cafeteria that can serve up to 100 people in one sitting, a smaller café, 3 classrooms, and 2 auditoriums. Currently all housing is in use by the site-resident staff and long-term visitors, but when available can be used for short-term visits. Business Services manages the reservations, staffing, and operations of all visitor services. The housing and other facilities make the Green Bank site an excellent location for small scientific workshops and serve to house visitors to take part in research, development, and educational activities. Usage of these facilities is high and availability of space limits the ability to schedule multiple events simultaneously. Having student and teacher visitors on site concurrent with scientific and engineering workshops creates a valuable environment for introducing future scientists and engineers to various disciplines and leaders in the field.

### Budget

The Budget division plans, forecasts, and reports the program expenditures of GBO within the scope of the cooperative agreement and other funding contracts, per all applicable regulations. GBO’s Budget Manager works with all Observatory divisions to understand their respective operations in depth and to deliver analyses tailored to the divisional needs. In addition, GBO has a service level agreement with NRAO for budgetary oversight, review, and analysis (see Section 6.14).

## Inter-Observatory Services

In its role as manager of multiple observatories, AUI continuously evaluates individual activities to identify areas where shared services result in improved operational efficiencies while maintaining the unique attributes of each observatory. Often these services require specialized skills that are uneconomical to replicate at multiple locations.

As part of the separation of GBO from NRAO at the start of FY2017, AUI established a series of Service Level Agreements (SLA) between the two organizations. The SLAs are reviewed periodically, updated, and extended by mutual agreement. Renewals are subject to funds being available in the GBO budget, and resource availability through NRAO and GBO.

The SLA documents areas in which shared services provide either clear advantages to both the NRAO and GBO or areas in which shared services have significant cost savings or other advantages for Green Bank. Several independent statements of work, each with its own point of contact, are specified within a common framework. The SLA is established with the understanding that in all cases, for identified work packages, the receiving observatory will be provided with a level, quality, and responsiveness of service that is consistent with and undifferentiated from those of the providing observatory.

It should be noted that, as sister organizations within AUI, the NRAO and GBO will, when feasible, continue to share resources and services beyond what is described by the SLA through the use of direct cost reimbursement. Shared services will be handled in accordance with the AUI Policy on Inter-observatory Activity.

The following NRAO divisions and programmatic activities are staffed, from a skills and force perspective, to share services with GBO. Requisite incremental funding in support of the SLA effort is provided by GBO either directly or through the Internal Common Cost pool, as noted.

* Proposal Submission and Time Allocation: GBO and NRAO will continue to share proposal submission tools as well as the proposal review and Time Allocation Committee (TAC) process.
* Conferences, Workshops, Colloquia, and Lectures: GBO and NRAO will continue to coordinate and share workshops, colloquia, etc. as feasible.
* Library Services: GBO will be given access to the NRAO library for all book and journal access.
* Student Programs and Training: NRAO and GBO will continue to share a single REU program and to collaborate on the undergraduate student training workshops.
* Metrics: The NRAO metrics group will continue to provide observing and proposal metrics for the Observatory as requested.
* Data Archive: NRAO will provide offsite backup and archive access to GBT data.
* Communication Infrastructure: NRAO will ensure GBO has the same level of cyber security, systems access protocols, telephones, network, etc. as all other AUI Observatories.
* Scientific Communications: The NRAO Communications Office will work with the observatory Public Relations Specialist to support GBO’s displays for scientific meetings as well as special sessions and splinter sessions at major astronomical meetings.
* Human Resources: NRAO will provide all Human Resources functions for GBO not provided through AUI’s corporate offices.
* Contracts and Procurement: The NRAO Contracts and Procurement office will provide contract management, contract tracking services, procurement, and all legal fees and insurance for GBO.
* Import/Export: NRAO import/export office will remain available for GBO’s use.
* Safety: NRAO will provide a safety officer for the GBO site and oversight for that officer.
* Budget: NRAO Budget will provide budget oversight, review, and analysis for Green Bank.

## Radio Quiet Zones

The extraordinarily sensitive equipment used for radio astronomy makes our telescopes extremely susceptible to electronic interference. The Green Bank site is unique in the United States, as the only radio observatory located within two radio quiet zones, the National Radio Quiet Zone and the West Virginia Radio Astronomy Zone, providing unique protection from many forms of human-made radio frequency interference.

### NRQZ and WVRAZ Administration

The Interference Protection Group (IPG), comprising staff from the Electronics, Science, and Business divisions, manages the observatory interference identification and mitigation efforts. GBO has the most robust protection from human-generated radio frequency interference of any U.S. observatory, given its location in the NRQZ and the West Virginia Radio Astronomy Zone (WVRAZ).

Working with colleagues from the NSA’s Sugar Grove Station, Green Bank continues to administer all FCC applications within the NRQZ. Such administration is done through formal agreement with NRAO, which is legally tasked to administer the NRQZ. NRQZ management and administration is carried out by the GBO Director (operating as an adjunct NRAO Assistant Director solely for this purpose) and will continue to do so until such a time as the federal regulations can be changed to make GBO the legal administrator of the NRQZ. In managing the WVRAZ, Green Bank continues looking for potentially harmful interference and working with the community to find solutions for their needs which do not impinge upon GBT observers.

Business Services is responsible for the administration of the federally mandated NRQZ through review and comment on all FCC and NTIA application for fixed-based transmitters within the designated 13,000 square mile area surrounding GBO facility and the NSA Sugar Grove Research Facility while also managing the analyses required by the WVRAZ, WV Code 37A. These measures maintain a “radio quiet” protection for the GBO facility and the excellent noise floor for radio astronomy at the site. In a typical year, the GBO’s NRQZ administration office will process approximately 3,000 applications and GBO Electronics division engineers conduct approximately 100 site compliance inspections.

The GBO anticipates developing a software-based system for pre-application reviews so that applicants can work to design transmitter facilities prior to official submittal. The intent is to lessen the review efforts on the NRQZ administrative staff and allow a streamlining of the application process for the applicant. The initial phase of software development is complete and operational, and provides a more centralized database of applications for processing. Areas for improvement will be identified throughout FY2022 and plans for an updated release will take place in FY2023.

### National Radio Quiet Zone

The National Radio Quiet Zone (NRQZ) encloses a land area of approximately 13,000 square miles near the state border between Virginia and West Virginia. Coordination is required for all new or modified, permanent, fixed, licensed transmitters inside the NRQZ to minimize possible harmful interference to GBO in Green Bank, and the radio receiving facilities for the United States Navy in Sugar Grove, WV.

### West Virginia Radio Astronomy Zone

The West Virginia Radio Astronomy Zone (WVRAZ) defines a 10-mile radius within which it is illegal to operate or cause to be operated any electrical equipment which interferes with radio astronomy.

### National Radio Dynamic Zone

NRAO is leading an NRDZ project that launched in summer 2021. The NRDZ project is divided into three parts: Concept Definition, Advanced Spectrum Monitoring Hardware (ASMH) and Broader Impacts. In FY2022, NRAO will create a statement of work defining GBO’s involvement in the project.

### RFI Monitoring Station

As RFI increasingly presents at higher frequencies, the IPG approach to mitigating the interference is by developing a system to monitor, record and report RFI data to the GBO staff and GBT observers. Working with the NRDZ project (NRAO), a new system will be developed and deployed in Green Bank over the next several years.

# WORKFORCE MANAGEMENT

As noted below in the GBO Five Year Proposal Workforce Management Plan, during the course of the proposal, HR is predicting an overall 20% reduction in the number of staff due to retirement eligibility. After two years into the proposal, the predicted retirements are on pace to reach the 20% reduction. GBO continues to focus on succession planning and staff transition opportunities to address the unique skills that are difficult to find.

GBO Five Year Proposal Workforce Management Plan FY2020–2024: NRAO will provide all HR functions for Green Bank Observatory, including an onsite full-time HR manager, and training equivalent to that given to all other AUI observatories. NRAO support will include administrative oversight of compensation, benefits, performance management, recruiting and retention, training and development, and employee relations. This administrative oversight includes access to the developed systems and yet to be developed systems that support all of the HR functions such as Saba, JobVite (online applicant portal), the compensation management tool, and central HR website information.

An expansion of programming through external funding or grants could grow the workforce, however the estimated upcoming retirement projections could total up to 20 staff over the next five years. Much recruiting will be focused on backfilling and training staff to maintain current programming. Unless a major funding opportunity is introduced, it is likely the staffing numbers will stay consistent.

With the possible retirement of 20% of the workforce, knowledge transfer and recruiting efforts will be necessary for key roles particularly in the area of Electronics Engineering, Software Engineering, and Telescope Operations.

A continued aggressive hiring strategy to fill critical roles will involve leaning on a multitude of strategies including telecommuting agreements, remote workers, apprenticeships, short-term assignments that are assigned to project work, co-ops, and the recruitment of early career candidates with a focus on training. GBO will work with various state agencies, technical trade schools, and universities to identify candidates and strategies for these efforts.

## Training and Development

Developing the next generation of leaders within GBO is paramount to its future success. The generational switch in the next five to ten years could leave the organization with a leadership void as today’s leaders exit the workplace, and so the next generation of leaders is needed to step into these roles.

**Observatory Leadership Cohort (OLC) III**: The success of the previous two OLC programs have been amazing. The Observatories are proud of the 24 graduates who have successfully completed the year-long program. GBO has contributed with 7 of the 24 graduates. As a result of the pandemic, the FY2021 Cohort participated virtually. In FY2022, HR are hopeful that the Cohort will be able to visit each of the sites and meet the cohort participants face to face. The members of the Cohort receive a myriad of trainings and participate in activities to hone their leadership capabilities. At the end of the program, participants present proposals that can be implemented Observatory-wide.

**Mentoring Program**: In FY2021, HR spent significant time working with the Observatory Leadership Cohort, MIT Lincoln Labs, and researched the design and development of a pilot mentoring program as a first step to evaluate the resources needed to create an Observatory-wide mentoring program in the future. In FY2022, the HR team will establish the first round of mentor and mentees across the Observatories.

The forced virtual working environment during 2020–2021 enabled the Human Resources team and Observatory Leadership Cohort to visualize how the mentorship program can be expanded across the sites. This new way of working will help to match potential mentorship partnerships with more resources.

By Q4 FY2022, 10–15 partnerships will be established and a pilot training program will be implemented to help both mentors and mentees benefit from the program.

## Compensation

As part of the NRAO service level agreement with GBO, the NRAO Compensation Manager will work closely with the AUI Sr. Benefits Analyst to provide support and alignment of the Observatory’s Total Rewards philosophy.

**Total Rewards Review**: In Q2 FY2022, Benefits and Compensation will review the results of the Total Rewards Survey to identify potential areas of improvement. The Total Rewards Survey was launched in July 2021 and included questions spanning all aspects of AUI’s current pay and benefits program. An analysis of survey results will provide an understanding of the Total Rewards program effectiveness and a better understanding of employees’ preferences. These insights will be used to support current offerings, propose new offerings, and make long-term total reward program design decisions to help attract and retain talent across the Observatories.

## Benefits

HR works closely with AUI Benefits to develop benefits programs to attract, recruit, retain, and reward employees. Benefits and HR are constantly reviewing and benchmarking available programs for competitiveness and employee engagement. Additionally, HR assists with benefits enrollment processes to ensure benefits plans are administered accurately and efficiently.

## Recruitment/Employment

The Recruitment/Employment function of the HR department is the first point of contact prospective employees experience with the Observatory. The strategies and tactics deployed in the recruitment and hiring of qualified candidates are key in contributing not only the GBO commitment to diversity and inclusion but to achieving the overall mission of GBO.

**Implement Client Relationship Management (CRM) Platforms**: The development of a candidate pipeline has been established as a priority for the recruitment team. Using software options such as a Client Relationship Management (CRM) platform will allow the recruitment team to organize candidate information, build candidate pipelines, and communicate effectively to prospective applicants. By improving the branding and communication to prospective candidates, the recruitment team can increase the number of qualified candidates and improve the time it takes to fill open positions. A CRM allows more targeted recruitment of specific skill sets and increases the diversity of candidate pools. The recruitment team researched and evaluated CRM options and selected Jobvite CRM and Onboarding modules that will be implemented in Q2, FY2022. This platform will dramatically help GBO to identify possible candidates for the current recruitment challenge.

# BROADER IMPACTS

Beyond its impact to the astronomical sciences, GBO contributes in a unique and expansive manner to society. Education and Public Outreach (EPO) programs leverage the technical village that is Green Bank Observatory (staff and facilities) to create unique STEM learning experiences that combine the science, engineering, and coding work that is done here with real-world educational experiences for K-16 students and educators and professional scientists. Learning by doing is the philosophy behind all GBO STEM programs. Additionally, GBO will continue to use internships, co-ops, and a fair and balanced approach for all staffing decisions to maximize the opportunities for diversity within the staff.

AUI and GBO’s strategic goals emphasize broadening participation in STEM by cultivating future generations of scientists and engineers, to maximize the scientific knowledge of current scientists and engineers, and to engage the public in dynamic programming that will instill a greater appreciation for the value of radio astronomy, scientific discovery, and STEM in general.

AUI is committed to a strong EPO effort that aligns with NSF’s interests in promoting STEM literacy and education at its research facilities.

## Observer Training

The GBO scientific staff provides the scientific community with the support necessary to execute successful scientific programs, providing education and outreach services to astronomers who use the GBT, including face-to-face visitor support/data reduction visits, helpdesk support, knowledge base articles, science forums, online documentation, as well as training workshops and events, including biannual Observer Training Workshops and an annual Single Dish School. The scientific staff will maintain online training and educational material, including data reduction tutorials for the GBO.

The Single Dish School (SDS) is organized annually by GBO. These workshops are primarily comprised of lectures on single dish observing theory and techniques at a level appropriate for graduate students in astrophysics. They are designed for those who do not have any prior experience in radio astronomy. The SDSs also include hands-on tutorials demonstrating observation preparation and/or data reduction for the GBT. The SDS is held annually, alternating between a late spring and early fall date, to accommodate varied college schedules. In FY2022, the school will be held in the spring.

New Observer Workshops are conducted three times a year and offer an opportunity for new and prospective users of the GBT to travel to GBO for a series of hands-on training in the GBT systems, how to observe with the GBT, data reduction tools and techniques, and how to create proposals to submit to the GBT call for proposals.

In FY2021, a new series of Proposer’s Workshops were run through a virtual platform, to provide the community with the opportunity to learn about GBO’s proposal submission tools, processes, and to aid in the accurate planning of proposals. The Workshops were well attended, with approximately 35 attendees at each of the two workshops. In FY2022, GBO will continue these workshops, offering one workshop in advance of each proposal deadline. Each workshop will be recorded and the recordings offered for community viewing.

##  Astronomy Community Outreach

Each year, GBO hosts workshops that bring members of the astronomical community together to share ideas and plot future directions for the field. The EPO division works closely with the Science division and the local organizing committees to plan, execute, and report on the workshops. Resources from these activities are live streamed, recorded, archived, and shared to increase capacity, participation, and outreach.

In FY2022, a series of workshops will be held, both face-to-face and virtually, to plan the instrumentation needs of the community in the upcoming decade. These workshops will be planned around the science themes of the 2020 Decadal Survey, with the first workshop to be held in early 2022.

In addition to the workshops, schools, and other educational activities held at or sponsored by GBO and described below, GBO is also an active participant at most major astronomical meetings. GBO is an exhibitor and has regular press conferences and sessions at the semi-annual AAS meetings. GBO is also an exhibitor at the biannual URSI General Assembly and the triannual IAU General Assembly.

## Formal Educational Programs

All GBO education programs are strongly integrated with the science and engineering mission of the GBO. That students and teachers can interact with STEM professionals within the environment of a federally funded research and development center amplifies the impact of all of the GBO’s programming. Residential programs are important in the educational portfolio. Recognizing that not all interested students and teachers will be able to visit the GBO site, virtual and outreach activities are conducted as well.

### WVSPOT

GBO operates the West Virginia Science Public Outreach Team (WVSPOT) program which is supported through a partnership between GBO, West Virginia Space Grant Consortium, and several sponsors, and in-kind contributions from universities and colleges in the state. WVSPOT recruits and trains undergraduate college ambassadors to bring interactive presentations and hands-on activities about current West Virginia science, technology, and engineering research to West Virginia K-12 classrooms, museums, and youth programs. The program, which has seen steady growth since its inception, was limited to virtual visits in FY2021. Nonetheless, the SPOT program expanded to include Ambassadors from several new colleges in the state. GBO will continue to manage the WVSPOT program in FY2022 with a goal of expanding the program to include ambassadors from three new colleges. It is GBO’s plan to operate a hybrid program in FY2022, offering both in-person visits to schools and virtual visits. In FY2022, GBO also plans to seek funding from the NSF AISL program’s January 2022 proposal call to scale SPOT, expanding to other (nearby) states.

### WV GSI

West Virginia’s Governor’s Stem Institute (GSI) is a two-week residential program funded by the state of West Virginia for 60 STEM interested students preparing to enter the ninth grade. GSI builds academic research skills and cultivates interest in STEM careers among young students. Assessment is a strong and integral component of this program in which the immediate impacts are measured of the experience on students’ research skills, their attitudes toward inquiry, and their confidence in their abilities to conduct research in STEM.

In addition to improving STEM self-efficacy and identity in West Virginia youth, and cultivating interest in STEM careers among young students, WV GSI builds leadership skills in WV undergraduate STEM students. Between 10 and 12 undergraduate students who attend state colleges and universities are employed to mentor GSI participants, and provide enrichment programming related to their own studies. WV GSI operates on a three-year application/funding cycle. In FY2020, the program was suspended due to COVID-19, and in FY2021, GBO held WVGSI virtually. The state is expected to issue a request for proposals in FY2022, and GBO will pursue funding to continue this program.

### PING

EPO’s success with the GSI program led it to develop Physics Inspiring the Next Generation (PING), a national program for underrepresented youth. A central component of PING is a two-week summer camp. Like GSI, in PING Camp the central theme is radio astronomy research with exposure to topics in science, technology, engineering, and mathematics. Students are on location at GBO and immersed in the research activities of this national research center. While in residence, students work in small teams led by a teacher and supported by a student mentor and a Green Bank staff scientist (astronomer, physicist, engineer, etc.) to conduct research by observing the universe with the 40-Foot diameter radio telescope and the 20-Meter telescope. Supporting material in chemistry, physics, mathematics, and engineering are provided. At the conclusion of PING Camp, the student groups present their findings to each other, GBO scientists, and guests in an academic colloquium that reinforces the need for ongoing research and exploration. Supplemental educational activities, including field research in ecology, bench experiences building electronic circuits, and data analysis using computer-based image processing software, complement the primary research theme. Outdoor activities and fun hands-on seminars round out the experience. PING undergraduate mentors are chosen from among the applicants for the general Research Experience for Undergraduates (REU) program. Role models are sought for the students while making a conscious effort to increase the diversity of the Green Bank REU student cadre in the process.

The goals of the PING program are to build STEM identity and self-efficacy in under-served youth and undergraduates through authentic astronomy research, to create a pathway to further STEM opportunities, and to support undergraduates in research and mentoring to younger students. GBO selects up to 20 rising ninth graders for the program. GBO also supports two to four undergraduate mentors, who participate in eight to ten weeks of research and two weeks as mentors to PING high school students.

GBO will continue this program and FY2022, with a plan to improve recruitment and increase the application rate of under-represented students. Beginning in Q4 of FY2021 through Q1 of FY2022, GBO will work with NRAO’s Office of Diversity and Inclusion to establish relationships with members of their networks. As GBO has three primary target locations from which to recruit (DC Metro area, Charlottesville and Richmond, VA), the GBO will join the Virginia Association of Teachers and exhibit at their conferences, connected with the Richmond Museum of Science.

### NSF INCLUDES Alliance: First2 Network

The NSF INCLUDES Alliance: Expanding the First2 STEM Success Network aims to improve the persistence of first-generation college STEM majors through their first two years of college. The success of the Alliance rests on three critical approaches. First, it improves student preparation for and transitioning to college. Second, it endeavors to replace ingrained institutional practices that stifle the development of STEM self-sufficiency. Undergraduate students are at the center of all activities—co-creators of solutions. Embedded in this idea is the FIRST Ambassadors program that guides undergraduate students to explore the disconnect between home life and STEM education, while reaching out to hometown students, their collegiate institutions, and state legislators. Third, the Alliance will advance our knowledge of barriers to success and solutions that increase the success of first-generation students in STEM. The First2 Network is a planned five-year program that will run through August 2023.

GBO is the lead PI institution for the Alliance, which currently includes higher education institutions in West Virginia, the WV Department of Education, several STEM initiatives and organizations, and the WV Higher Education Policy Commission, which manages the WV Established Program to Stimulate Competitive Research (EPSCoR) office.

Milestones for this work are captured and tracked as part of the NSF INCLUDES grant.

### **Pulsar Search Collaboratory**

GBO collaborates with WVU on the NSF-funded Pulsar Search Collaboratory (PSC). The PSC trains teachers and students in the techniques of pulsar searching and identifying their signatures in GBT data. They participate in online training workshops and an annual week-long summer camp at GBO. When a potential detection is identified, the students join PSC astronomers to re-observe the object to confirm or reject the candidate.

The PSC annually engages ~150 high school students, 20 undergraduates, 20 high school teachers, 6 graduate students, and 5–10 faculty. The PSC develops STEM self-efficacy and identity in youth and teachers, fosters belonging of all stakeholders in a STEM community, and models STEM pathways. In FY2022, the GBO will engage new teachers and students in two online workshops, and collaborate with partner institutions to completely redesign the online collaboration portal.  In FY2021, GBO partnered with WVU and community colleges to submit a proposal to the NSF Improving Undergraduate STEM Education (IUSE) program. This would fund preliminary work to build PSC research experiences into courses or extra-curricular activities at community colleges. GBO awaits word on this proposal. Additionally in FY2022, the PSC will submit one or more funding requests to build on the current PSC. In the event outside funds are not awarded, GBO will use CSA funds to limit activities to two online workshops for PSC students and teachers in October and February; support teams of advanced PSC students to conduct 20-meter research on scintillation, giant pulsars, and magnetars; pilot test the building and using of HI horn antennas; and may host a virtual capstone seminar in May.

### Skynet Junior Scholars

Skynet Junior Scholars (SJS) is a national program developed collaboratively by GBO, University of Chicago's Yerkes Observatory, University of North Carolina, the Astronomical Society of the Pacific, and 4-H. SJS engages middle school youth in out-of-school time programs in using research-grade robotic telescopes and data analysis tools to explore the Universe. Youth learn about the universe and prepare for STEM careers by conducting authentic astronomy research, completing astronomy-related hands-on modeling activities, and interacting with astronomers and other professionals who are part of the Skynet Robotic Telescope Network.

The innovative project provides a diverse community of youth (including sight- and hearing-challenged youth and those from underrepresented groups) with opportunities to use high-quality, remotely located, Internet-controlled telescopes to explore the heavens by surveying galaxies, tracking asteroids, monitoring variable stars, while learning about the nature and methods of science. The 20-Meter telescope is the only radio telescope in the network, and affords an introduction to radio astronomy. In FY2022, the GBO will offer two online mini workshops to teachers and informal educators including 4-H leaders to prepare them to facilitate SJS activities with youth.

## Supporting a STEM Workforce

As students’ progress along their STEM career path, GBO provides mentored research experiences through summer and academic year internships, pre- and post-doctoral mentoring, and professional workshops.

### Summer Research Student Program

The Summer Research Student Program brings an average of ten undergraduate and graduate students to work and live at GBO. Diversity is maximized through an extensive focus on demographics during the student selection process. The 10-12 weeks that these students contribute includes interaction with most divisions across the site including Hospitality, EPO, Science, Engineering, Program Management, Business Services, and the larger Green Bank community. Funding for this program is through the combination of GBO program income and an NSF-REU grant.

### Co-ops, Internships, and Other Programs

The Observatory supports various training, cooperative, and mentoring programs. Each year, as many as 36 undergraduate students and recent high school graduates participate in a summer maintenance program where they experience hands-on application of trade skills in the maintenance of GBO facilities and grounds. GBO has consistently hired recent graduates of the local high school ProStart Culinary program to serve in our Hospitality division. The summer work experience exposes early career students to basic workplace conduct, safety, and business practices.

Cooperative students will be invited by the Electronics, Software, and Mechanical Engineering divisions to work on projects that are more extended than those undertaken during the shorter REU program period. Often the Co-op student will continue a project that has been started or supported by previous Co-ops or summer research students.

GBO staff will serve as mentors to the local high school in programs both at the high school and GBO facilities in STEM-related topics such as mathematics, software engineering, and electronics. GBO staff have led the teaching of the middle and high school computer classes and robotics programs.

### Post-doctoral Research Positions

GBO typically employs two to three postdoctoral research fellows, a level expected to continue through the next five years. All post-docs are given approximately 50% of their time to formulate and carry out scientific research either independently or in collaboration with other scientists within the wide framework of GBO interests. The remaining 50% of their time is dedicated to supporting the GBO, primarily through observer support and aiding in the testing or commissioning of instruments. In accordance with GBO’s postdoctoral mentoring plan, all post-docs are given a mentor who meets with them on a regular basis to ensure their career plans and scientific research are moving forward at a reasonable pace. Post-docs are also given an annual travel budget that can be used for any research related travel at their discretion.

### Student Workshops and Observer Training

In partnership with NRAO, GBO hosts an annual five-day Undergraduate Radio Astronomy Workshop at the beginning of the summer to introduce all GBO and NRAO summer students to radio astronomy and to train the students on basic radio astronomy techniques, observation strategies, and data reduction. Sessions are designed and presented by NRAO and GBO scientific staff. This integral part of the summer student program will continue.

GBO’s annual Single Dish Summer School and the triannual GBT Remote Observer Workshop are covered in Section 5.1.

### Teacher Professional Development

The GBO leads several teacher professional development programs, and these are expected to continue in FY2022.

#### **Leap into Science**

Combining literature and hands-on STEM activities, Leap into Science prepares librarians, informal educators, and elementary school teachers to offer STEM programming to young children and families using pre-prepared kits of materials. GBO is a West Virginia lead organization for this national program.

#### **STEP UP**

STEP Up is a program of the American Institute of Physics designed to attract more women into the Physical Sciences. GBO EPO staff are leaders in this program and offer teacher professional development at state science teacher conferences, and as stand-alone events. The EPO Educational Assistant is a STEP UP Ambassador and has been trained in delivering the presentations. In FY2022, GBO will fund preparation and delivery of two workshops to teachers. One staff member will attend each workshop which will be held at the WV Science Teachers Association Meeting with the other in spring or summer.

### Chautauqua Short Courses

Chautauqua Short Courses are hosted annually at the Observatory and bring together Observatory scientists and engineers to meet intensively over several days with undergraduate college science teachers. These workshops provide an opportunity for invited scholars to communicate new knowledge, concepts, and techniques directly to college teachers in ways that are immediately beneficial to their teaching. The program was suspended in FY2020 and FY2021 due to travel restrictions imposed by COVID-19. The Green Bank program is expected to continue in FY2022.

## Externally Run Programs Supported by GBO

GBO hosts and supports numerous external groups that provide educational programs and workshops, including:

**The Undergraduate ALFALFA Team**: A consortium of 23 undergraduate-focused institutions that collaborate on a multi-faceted program to promote undergraduate research within the ALFALFA (Arecibo Legacy Fast ALFA, where ALFA refers to the Arecibo L-band Feed Array detector). The ALFALFA team has successfully involved 126 undergraduates and 21 faculty mentors (~50% women) to offer undergraduates and faculty at its diverse set of institutions access to cutting-edge collaborative research projects within a major legacy survey. The program runs an annual team workshop at GBO which will continue in FY2022. With the demise of the Arecibo telescope, the ALFALFA group are continuing to work through archived Arecibo data. Green Bank staff are working with the ALFALFA group to explore moving more of their observations to the GBT.

**ERIRA**: Every summer since 1992, Professor Dan Reichart of the University of North Carolina (UNC) and a small group of radio astronomy educators from across the country have taken 15 mostly undergraduate students but also a few high school students and occasionally a member of the general public on an intense, one-week workshop at GBO called Educational Research in Radio Astronomy (ERIRA). This program was cancelled for FY2020 and FY2021 due to the COVID-19 pandemic and related issues.

## Public Outreach and Visitor Programs

The COVID-19 pandemic had a dramatic effect on FY2021 public outreach and visitor programs, with most of the face-to-face programs suspended for the year. However, a record number of virtual programs were offered attracting a geographically diverse audience. As GBO begins to return to normal operations in FY2022, it plans to continue to offer these popular virtual events. Specifically, GBO will offer monthly virtual tours of the observatory, continue to offer classroom visits on demand. For example, in FY2020, GBO supported Green Bank Elementary/Middle School’s live contact with an astronaut at the International Space Station, and GBO organized a multi-day, multi-month celebration of the GBT 20th anniversary.

GBO hosts a 25,000 square foot visitor facility—the Erma Byrd Green Bank Science Center. The Green Bank Science Center is open year-round and serves as the starting point for guided tours of GBO. The Science Center includes the *Catching the Wave* Exhibit Hall, an interactive room filled with exhibits explaining radio astronomy, a 150-seat auditorium, classrooms, a gift shop, and the Starlight Café. GBO’s public outreach program includes Observatory tours for casual visitors, development of interactive exhibits for the public, outreach to teachers, students and the public, and special programs for K-16 students, scouts and families.

Normally the tour program draws roughly 45,000 visitors each year[[3]](#footnote-3), a remarkable number for such a remote location. Visitors experience interactive displays in the 5,000 square foot exhibit hall, hear presentations about radio astronomy, and take tours around GBO. Four types of tours are currently given. The daily telescope tours give a look into the world of radio astronomy, and include science demonstrations and a bus excursion into the electronics-restricted zone around the telescopes. Suspended in FY2021, the Science Center will reinstate the monthly high-tech tours through the engineering labs and telescope control rooms, and biweekly SETI tours that celebrate Green Bank’s historic and current role in the search for extraterrestrial intelligence. The SETI tour includes admittance into the Tatel telescope and the 140-Foot telescope’s control room and a question and answer period with a GBO astronomer. Self-guided walking tours are also available.

One additional change that occurred in FY2021 as the GBO Science Center re-opened after a 14-month shutdown due to the pandemic, was the addition of a charge to enter into the Science Center exhibit hall. This change will be explored, and is likely to continue into the future.

### Radio Astronomer for a Day

GBO also hosts school field trips throughout the year, which engage students in hands-on astronomy, engineering, and coding activities.

GBO’s signature field trip program engages up to 2,000 students each year[[4]](#footnote-4) in observational projects using the 40-Foot telescope. The 40-Foot is maintained as an analog instrument so that students can easily learn to operate the telescope and understand its workings. After collecting data with the telescope overnight, a data reduction and interpretation discussion ensues that is focused more on the research process than physics/astronomy content. Students are guided to form explanations and debate the strength of each one, based on their data.

Students and teachers visit Green Bank, typically in small groups of a few dozen students with their teachers, for sessions lasting two to three days. Students are housed in the GBO bunkhouse and take meals in the cafeteria. They receive in-depth tours of the electronics labs, training in use of the 40-Foot telescope, and interactions with GBO staff. Trips can be arranged to coincide with current classroom curricula or other visits in the Green Bank area.

Restart of this program will begin in Q1 of FY2022, although the start will be slow due to the requirement for all participants to be fully vaccinated against the COVID-19 virus.

### Special Events

Special events are held on site, including quarterly family science labs for young children and their families, annual open house events, and multi-day Star Parties. These events cultivate an interest in scientific discovery among members of the community and the public with a focus on family members and children.

## Community Outreach

A healthy workforce requires a healthy community in which to live and work. With this in mind, GBO strives to be an active member of the local community, providing expertise and aid in many areas. A listing of programs in which GBO is currently involved is given below. It is expected all these commitments will continue in FY2022.

* Pocahontas County Science Fair
* Pocahontas County Math Field Day
* Pocahontas County High School Computer Science class
* Pocahontas County High School Robotics and Mathematics class
* Pocahontas County High School After School Robotics Team

Secondary School Career days

* Hour of Code Events
* STEM scholarships

GBO staff also volunteer outside of their work duties to aid the community in many ways, from coaching local sports teams to helping with the public library system, providing announcements for sporting events, volunteering for the local humane society, and sitting on boards for varied community organizations. As these duties lie outside of work hours and are performed within the employees’ own time, such activities are not tracked but are an important component of GBO’s impact in the local community.

* Pocahontas County Chamber of Commerce
* Local Fire Departments and Emergency Services
* Mentoring county elementary and middle school robotics teams
* Pocahontas County Convention and Visitors Bureau
* Northern Pocahontas Community Wellness
* Allegheny Mountain Public Radio
* Northern Pocahontas Community Wellness
* West Virginia Space Grant

GBO also offers facilities free of charge for appropriate uses by community groups or organizations. As a result, GBO typically hosts many school and community activities, including annual Emergency Medical Technician (EMT) training classes. These activities will resume as safety protocol from the COVID-19 pandemic allows.

## Diversity and Inclusion Programs

GBO places diversity and inclusion at the top of its priorities in developing all new programs and events, and “Broadening Participation in STEM” is the major focus of several of the programs. Specifically, WVSPOT and the WV Governor’s STEM Institute (GSI) target West Virginia youth, who, as largely rural students, have fewer opportunities to experience authentic STEM than students elsewhere (Avery 2013). PING is a national program that recruits underserved minority students and girls, and the First2 Network is an NSF INCLUDES Alliance aimed at improving the success of first-generation students, initially in West Virginia, then expanding to other EPSCoR states. Two other national programs: Pulsar Search Collaboratory (PSC), and Skynet Junior Scholars, are leveraged to scaffold additional opportunities for these students who exhibit an affinity for astronomy.

To maintain the broad portfolio of educational programs and STEM initiatives, GBO has leveraged a funding model that combines NSF cooperative agreement and external grants and awards to assist in paying for the student and participant support costs.

# LOOKING AHEAD: NEW INSTRUMENTS and Capabilities

GBO has a suite of ground-breaking new development projects underway to enhance the GBT in support of its science goals for the next decade. Each of these projects is supported by the various site divisions, and milestones for these projects are given in the milestone table (Appendix C).

## Cyclic spectroscopy (CS)

Cyclic spectroscopy (CS) is a powerful data processing technique for pulsar astronomy that can provide higher time and frequency resolution that traditional spectroscopic methods. To our knowledge, there is no facility-supported real-time CS backend system at any radio observatory in the world. As part of GBO’s project titled “Windows on the Universe – Multi-messenger Astrophysics: Improving Gravitational Wave Sensitivity through Real-Time Cyclic Spectroscopy” (NSF award AST-1928936, amendment #009), GBO will build the first such real-time system and commission it as an expert-user instrument. The primary science motivation is to advance multi-messenger astrophysics by improving sensitivity to nanohertz-frequency gravitational waves, which are likely to be detected in the next few years through high-precision timing of radio pulsars. The benefit of CS lies in the potential to measure and mitigate interstellar medium-induced noise in high precision pulsar timing and increase the number of pulsars that are suitable for use in gravitational wave detection. The GBT is one of the world’s premier telescopes for pulsar astronomy, and is a crucial component of the North American Nanohertz Observatory for Gravitational Waves Physics Frontiers Center (NANOGrav).

Over FY2021–2023, GBO staff will develop a prototype of the first such real-time system as a test instrument. During FY2022, the GBO PMD department will assist the PI in the planning phases for this project, including supporting the initial procurement for a sub-set of the full hardware, which will be used for early development and testing efforts. During FY2022, SDD will provide inputs into the science and stakeholder requirements and the selection of initial hardware. SDD will also design the software architecture and commence early implementation efforts.

## Laser Antenna Surface Scanning Instrument (LASSI)

In FY2018, GBO received NSF-Mid-Scale Innovations Program in Astronomical Sciences (MSIP) funding to implement a laser metrology system for measuring the surface of the GBT precisely and quickly. All 2,008 panels of the primary surface of the GBT can be adjusted in real time to maintain its parabolic shape. At present, the surface is measured using “out-of-focus” holography, which takes approximately 30 minutes but remains valid for many hours at night. During the day, however, thermal gradients in the antenna backup structure can vary on timescales approaching one hour, requiring calibration measurements at least this often. This is extremely inefficient, and as a result, observations at 3mm are rarely made during the day. Recent advances in commercial technology have made it possible to use a laser scanner mounted on the GBT that produces a hundred million angle and range measurements of the surface every few minutes. Any given measurement has a range uncertainty ~2mm, but the data can be averaged to reduce the errors to tens of microns on the relevant angular scales. Measured surface distortions are then corrected using the active surface.

LASSI was mounted on the GBT in September 2020, and commissioned in FY2021. The initial phase of LASSI development, funded by the MSIP award, concluded successfully in early summer of FY2021 and provides an initial baseline system. Continued operational enhancements are planned and will include the integration of LASSI into DSS scheduling. These continued refinements will enable measurement of the GBT surface to take place in near real time to allow operation at the highest frequencies night or day, significantly increasing the available telescope time for observing for all projects that operate above 25 GHz. This project takes advantage of the GBT active surface and large collecting area, which makes it the largest telescope in the world operating at mm wavelengths.

## Ultra-Wideband Receiver (UWBR)

In 2018, the Gordon and Betty Moore Foundation (GBMF) partially funded a project at GBO to build an Ultra-Wideband Receiver that will instantaneously cover ~0.7–4 GHz. The primary science driver is the detection of nanohertz-frequency gravitational waves via pulsar timing. Radio pulses from pulsars are dispersed by their passage through ionized gas in the interstellar medium. Measurement of pulses at widely spaced frequencies is necessary to characterize and remove dispersive effects. This currently requires use of two separate GBT receivers, often on different days. The new receiver will allow these measurements to be made simultaneously with a single instrument, improving the signal-to-noise for pulsar observations, and improving observing efficiency for high-precision pulsar timing programs. The receiver will also enable wideband spectroscopic studies of fast radio bursts and other transients, as well as regions rich in molecular lines at these frequencies.

Milestones associated with the receiver assembly and lab testing are covered by the Moore Foundation funding. GBO is funding work associated with the instrument commissioning, which is planned for Q4 FY2022.

Due to project delays, which included delays to feedhorn fabrication due to the quarantine restrictions in response to COVID-19, a project extension was granted through FY2022. It is anticipated that the construction and testing phase of the project will conclude by Q3 FY2022, and astronomical commissioning will commence in summer 2022. GBO anticipates that the UWBR will be an important new instrument for pulsar observing to be available during FY2023.

## Wide-band Digital Technology and Interference Excision

The next generation of very fast ADCs and powerful FPGAs are opening new possibilities for direct sampling of ultra-wide bandwidths directly at radio frequencies, and also provide the resources needed to realize real-time RFI excision. This is important for building systems that are robust against the effects of RFI. However, a complete Ultra-Wide Bandwidth (UWB) digital signal processing (SP) system that takes advantage of these advances is not yet available, and significant research and development is needed to realize this potential. In FY2019, GBO received an NSF Advanced Technologies Instrumentation (ATI) award for research and development into new RFI and DSP technologies that includes:

1. Exploration into new DSP technologies for radio astronomy applications.
2. Creation of standard, quantitative, and well-tested procedures for validating real-time RFI excision techniques and ensuring that they preserve scientific data quality.
3. Evaluation of new algorithms for identifying and removing RFI in real-time.

This research and development effort is expected to complete in FY2023. At the conclusion of this research, GBO may seek funding to proceed to a more detailed design and implementation phase for revolutionary upgrades to the GBT that will expand its available bandwidth (BW) and enhance performance across all areas of radio astronomy science. Milestones for this project are tracked as part of the ATI grant.

## Potential Future GBT Instrumentation

### Overview

The GBT was built to be flexible and continuously upgraded to meet the needs of the astronomical community (e.g. opening the 3mm band over the past decade). A whitepaper submitted to the Astro2020 Decadal Survey (“Advanced Capabilities for the Green Bank Telescope,” Lynch et al), presents several projects that would expand the GBT’s performance in four key areas of survey speed, point source sensitivity, radio frequency interference (RFI) protection, and accessibility and preservation of legacy data. These long-term goals include:

* Expanding the instantaneous field of view (FoV) of the GBT with advanced radio cameras.
* Increasing the instantaneous bandwidth of the GBT by developing ultra-wideband analog and digital instruments.
* Preserving scientific data quality while sharing the radio spectrum with a growing number of private, commercial, and civil users through better identification and excision of RFI.
* Ensuring long-lasting public access to GBT data through a multi-petabyte data archive and high-performance processing tools.
* Providing increased funding for peer-reviewed use of the GBT for the U.S. astronomy community.

This section describes several future instrumentation plans for the advanced GBT. Funding for this work falls outside of GBO CSA funds, but these instruments are mentioned to provide a view into potential future capabilities for the GBT. Development of these instruments will only proceed as associated funding is obtained. In most cases, proposals have already been developed for the instruments described, and, if funded, construction and commissioning of these instruments will last beyond FY2026. White papers for many of these instruments were submitted to the Astro2020 Decadal Survey and the results from the committee reviews will inform GBO’s priorities. In FY2022, once the Decadal Survey results are out, GBO will be holding a number of virtual and face-to-face meetings with the community to define the future instrumentation path for the GBT. The examples below are two of the possibilities being pursued.

#### **Joint Radar Initiative**

AUI, NRAO, GBO, and Raytheon Technologies Inc. are collaborating to develop high-frequency radar transmission and reception capabilities with the NRAO/GBO instruments. This program includes activities to develop scientific and technical projects of common interest, an active exchange program of students, postdoctoral fellows, scientific and engineering staff between our available sites, joint scientific workshops and to form joint research groups on specific scientific or technical goals of common interest, and exploration of commercialization and Federal-commercial ventures arising from the collaboration. In FY2021, a low-power, low frequency transmitter was placed on the GBT and a series of detection experiments using the Very Long Baseline Array as a multistatic receiver were successfully undertaken. The next step is a detailed design study and plan for the development of a high-power radar system. Funding for this system is being pursued.

#### **Argus-144: 144-pixel, 80-116 GHz Camera**

Argus-144 is a proposed 144-element radio camera for spectroscopic studies in the 3mm band (74–116 GHz) to operate as an Open Skies instrument on the GBT. Argus-144 would provide a ten-fold increase in mapping speed compared to the current 16-element Argus pilot version of the instrument. Combining the 6’ x 6’ field of view of Argus-144 with the 6.5” x to 10” beam of the 100m GBT will provide high spatial dynamic range maps of interstellar molecules that are critical in understanding the physical processes and astrochemistry associated with star formation, from the scale of entire galactic disks to the sub-parsec scale of interstellar filaments and dense molecular cores. The GBT with Argus-144 will be unequaled worldwide for wide-area 3mm spectroscopic mapping, and will be a critical complement to ALMA, which has high angular resolution but a small field of view.

#  SECURING THE FUTURE

## Partnership Development

GBO’s establishment of substantial partners is a requirement to complement NSF operational funding. GBO currently has two major long-term partners that intend to continue in their current capacity. It is essential that these partners are provided the services they expect and that their voices are heard in the prioritization of GBO developments.

### Existing Partnerships

GBO offers partner organizations the opportunity to access guaranteed observing time on the GBT, or other services, in exchange for operations funding. For the GBT, hourly operations costs are determined annually according to AUI protocols and consider the purpose of the observing (scientific research use being heavily discounted) and the user type (federal, foreign, academic, educational, and commercial).

AUI and senior GBO management have secured multiple partners who will contribute to Green Bank operations. GBO and AUI establish formal agreements with these partners, primarily research organizations interested in special observing programs. The Green Bank Program Managers will serve as the primary point-of-contact for these agreements, and will ensure adequate performance and compliance with their terms.

The current major GBO partners and their roles are described in the following sections.

**Breakthrough Listen**: Currently, Breakthrough Listen pays for ~20% of the available GBT observing time. Breakthrough Listen is the largest scientific research program ever to seek evidence of civilizations beyond Earth. The scope of the search is unprecedented: a survey of the 1,000,000 closest stars throughout the entire plane of the Milky Way, including those toward and in the Galactic Center. Breakthrough Listen will survey beyond the Milky Way by listening for messages from the 100 closest galaxies and will ultimately cover more than ten times as much of the sky than any previous SETI program. Breakthrough Listen will also cover at least five times more of the radio spectrum, and do it 100x faster. The program’s sensitivity is sufficient to hear common aircraft radar transmitting toward Earth from any of the 1,000 nearest stars.

The current Breakthrough Listen contract carries through CY2025.

**North American Nanohertz Observatory for Gravitational Waves (NANOGrav)**: The NANOGrav consortium includes scientists from across the United States and Canada who are interested in studying the Universe using gravitational waves. NANOGrav uses the Galaxy itself to detect gravitational waves via a network of millisecond pulsars and a Pulsar Timing Array. NANOGrav scientists make use of some of the world's best telescopes and most advanced technology in physics, computer science, signal processing, and electrical engineering. The consortium’s short-term goal is the detection of gravitational waves at nanoHertz frequencies within the next decade. The NANOGrav team selects and prioritizes the targets and time for all NANOGrav observations at the GBT.

NANOGrav has two separate contracts with GBO. The first, funded through the Gordon and Betty Moore Foundation, is a three-year contract which lasts until July 31, 2024. The second, funded as part of NANOGrav’s NSF Physics Frontier Center, continues through July 31, 2026.

**Other Partnerships***:* In addition to major partnerships, GBO has and will continue a successful program to bring in smaller customers for telescope time, Observatory site hosting of instruments, and Work for Others. Currently GBO has multi-year contracts with MIT Lincoln Laboratory for GBT bistatic radar observations, New York University/Abu Dhabi for student GBT observing, and UCLA for student GBT observing. Historically GBO also has one or more reoccurring shorter contracts for GBT observations for NASA and JPL projects.

### Plan to Grow Partnerships

In seeking additional partners, AUI prioritizes highly leveraged situations that provide the most return for least reduction in Open Skies time. This could be accomplished through agreements for elevated level of priority or enhanced level of service. The business confidential nature of some early partnership discussions prevents elaboration at this time. Retaining 60% of time for Open Skies is desired, proportional to the level of NSF funding.

AUI and GBO also will continue to actively explore funding options for expanding the use of the GBO campus, including housing and food service facilities, while also looking for opportunities to increase revenue from the facilities and to grow additional long-term telescope contracts.

Increased partnership may be achieved through the following mechanisms:

* Identifying a new long-term partner for funding operations in exchange for telescope access, site hosting, or GBO staff expertise.
* Increasing the degree of partnership of an existing partner.
* Identifying one or more development projects desired and funded by a new or existing partner.

AUI emphasizes its commitment to developing new users and stakeholders for the GBO, and it has the proven leadership organization to establish potentially transformative strategic alliances and new uses for the site. There is no more important responsibility for AUI leadership and the GBO Director than securing new strategic partnerships for GBO. GBO provides an attractive array of assets suitable for collaboration with other federal government agencies, commercial organizations, space object tracking initiatives, telescope time sales, as well as potential external uses for its research and educational campus facility.

## New Research and Development Initiatives

AUI and GBO encourage the pursuit of Research and Development (R&D) projects, substantial undertakings that result in considerable new capability or modernization. A pipeline of new capabilities is necessary to ensure the ongoing scientific competitiveness of the Observatory as well as retention and continued development of its staff. The funding for much of the Observatory R&D activities is outside the annual NSF cooperative agreement-funded operating budget, so these projects are not included in this proposal’s budget, but are described in Section 9 to show planned directions for GBO. Continuous proactive efforts to acquire external funding for these efforts will be made throughout FY2022, with particular attention paid to development proposal solicitations and to development resources that may be available through GBO partners. When seeking funding, AUI will also seek external stakeholders such as potential development partners and users.

AUI encourages the disclosure and supports the pursuit of Intellectual Property (IP) protection for inventions and ideas. AUI continually seeks external parties interested in partnering or licensing technology developed as a matter of course of the running the GBO.

## Other AUI Observatory Synergies

### Overview

AUI leads other facilities and projects that offer synergies with GBO, namely the NRAO suite of instruments—the VLA, VLBA, and ALMA. The GBT’s filled aperture has comparable collecting area and sensitivity to ALMA and the VLA, but with the image brought to a single focal plane. This provides the GBT with extraordinary sensitivity to extended, low surface-brightness objects as well as high sensitivity to point-source radiators such as pulsars. The single focal plane is ideal for rapid, wide-field imaging systems—cameras. Because the GBT has access to 85% of the celestial sphere, it serves as the wide-field imaging complement to both ALMA and the VLA. The single focal plane also provides an accessible development platform and allows much of the advanced instrumentation to be provided by university-based laboratory groups. The GBT’s high sensitivity imaging and point-source capabilities enable a large and varied program of key science projects. In addition, the GBT often joins the VLBA for interferometry observations to provide a critical threshold of sensitivity for a number of important projects, including, for example, the megamaser cosmology experiment.

To maximize the ability of the community to take advantage of the telescopes within the AUI observatories, the VLA, VLBA, and GBT use a single proposal submission tool and the same proposal deadlines, which allows proposers to select one, two, or all three telescopes for their proposal. The international nature of ALMA prevents joining the ALMA proposal submission tool or proposal deadline with that of the other AUI Observatories, but joint GBT+ALMA proposals may still be permitted, with the ALMA TAC results typically given precedence over the GBT TAC, to prevent instances of double jeopardy to the proposers.

### ngVLA Synergies

As the plans for the ngVLA develop, GBO remains in close communications with NRAO colleagues concerning areas where the GBO or the GBT in particular strengthen the science capabilities or facilitate construction of the planned instrument. There are three general areas of discussion. These will become more formalized in FY2022 as ngVLA plans mature and stabilize.

**GBT+ngVLA**: A significant number of the ngVLA science cases are enhanced by the existence of a large (diameter ≥45-m) single dish telescope with frequency coverage at least equal to that of the ngVLA. In FY2021 an ngVLA memo was written, exploring the role of the GBT within the ngVLA. The outcomes of this memo will be taken into consideration by NRAO and GBO management in FY2022 for both facilities’ long-term plans.

**ngVLA Green Bank Site**: Current plans for the ngVLA include placement of a long-baseline site at GBO.

**ngVLA Antenna Testing**: As technical progress for the ngVLA continues, GBO will be a partner site for testing ngVLA technologies, utilizing GBO’s capabilities in manufacturing and testing of individual components. Activities include installations of the various ngVLA antenna designs in an RFI-monitored environment, custom machining in the GBO shops, and utilizing the GBO indoor and outdoor test ranges.

**The Green Bank Arra**y: A second possible role for GBO within the ngVLA would be the placement of ~10 ngVLA antenna in Green Bank, creating an instrument known as the Green Bank Array (GBA). The GBA could be operated together as either an interferometer, or as a (distributed-aperture) single dish, i.e. phased array. It is intended to improve the VLBI capabilities of the ngVLA itself, and to operate as a standalone facility, which dramatically transforms the capabilities of the GBT into those of a world-class interferometer at a relatively modest cost.

## Work for Others

Work for Others (WFO) is the term used to describe contract work performed by GBO staff for external (potentially partner) organizations. Some examples of WFO activities include providing organizations with data in a form that is not currently supported by operations (e.g., supplying baseband voltage data rather than raw data products), or supporting through development of new software or hardware specific missions such as real-time downlink of data. Because staff subject matter expertise is being used, revenues from WFO can exceed the mean cost rates for operations of the GBO, and thus yield a budgetary advantage with less-than-commensurate loss of observing time.

WFO serves three purposes. First, it can be used as a tool to mediate fluctuations in workforce requirements without excessive changes in staffing. Second, it can be used to maintain and develop skills and broaden the capabilities of the GBO staff. Third, well-bid contracts generate revenue that can be used to fund operations, EPO, infrastructure improvements, and R&D activities.

WFO projects that require fractions of Full-Time Equivalents (FTE) of effort are carefully managed by the appropriate division heads and program managers, as these efforts typically need to be accomplished by existing staff.

Table 9.2.4. Recent Telescope Time Sales and WFO activities*.*

|  |
| --- |
| **Telescope Time Sales** |
| Organization | Purpose |
| West Virginia University | 20-meter student observing & FRB monitoring |
| JPL/NASA | Mars Insight EDL monitoring |
| NYU Abu Dhabi | GBT time |
| MIT/Lincoln Labs | GBT time  |
| SARA | 20-meter telescope time  |
| West Virginia University | 20-meter student observing  |
| Union College | 20-meter student observing  |
| Pennsylvania State University | 20-meter student observing |
| FAST, China | GBT Time |
| Berry University | 20-meter student observing |
| Haverford College | 20-meter student observing |
| Lycoming College | 20-meter student observing |
| American University | 20-meter student observing |
|  |
| **Work for Others** |
| Organization | Purpose |
| MIT | HERA site hosting and maintenance |
| West Virginia University | Site hosting Chime Prototype Antenna |
| McGill University (CHIME) | Site hosting CHIME Outrigger Antenna |
| University of Virginia | CTP antenna research site hosting |

GBO leadership continually explores opportunities to work with external organizations to develop technology and capabilities. Examples of past and existing WFO activities span major, mutually beneficial partnerships such as Breakthrough Listen, significant telescope time sales to University groups (e.g., MIT/Lincoln Labs), and international consulting agreements (e.g., FAST in China). When potential opportunities are identified, standard GBO PMD processes are followed to assess and document the scope and impact. AUI Contracts and Procurement processes are also followed to ensure that NSF is notified and/or approves as appropriate.

Proceeds from WFO and sale of telescope time are critical to establishing a balanced budget.

#  BUDGET

The budget for Green Bank Observatory operations for FY2022 totals $15,687,234 inclusive of indirect costs of which $9,120,000 will be supported by NSF.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Funding** | **CSA-G** | **WFO** | **GBO ICC** | **TOTAL** |
| NSF Allocations |  9,120,000  |  |  |  9,120,000  |
| Carry-Over |  1,075,631  |  |  |  1,075,631  |
| Telescope Time Sales |  3,448,163  |  |  |  3,448,163  |
| Other Program Income |  1,197,700  |  |  |  1,197,700  |
| NRDZ Subaward |  | 269,062  |  |  |  |  |  |  269,062 |
| WFO |  |  576,678  |  |  576,678  |
| **Grand Total, Funding** |  15,110,556  |  576,678  |  | 15,687,234  |
|  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |
| **EXPENSES** | **CSA-G** | **WFO** | **GBO ICC** | **TOTAL** |
|   | **FTE** | **Expenses** | **FTE** | **Expenses** | **FTE** | **Expenses** | **FTE** | **Expenses** |
| **1000-Telescope Operations** | **59.07** | **7,293,440**  |  |  | **0** | **0**  | **59.07** | **7,293,440**  |
| **1100-Maintenance** | **10.77** | **1,674,730**  |  |  |  |  | **10.77** | **1,674,730**  |
| 1110-Corrective | 2.05 | 941,270  |  |  |  |  | 2.05 | 941,270  |
| 1120-Preventive | 8.72 | 733,461  |  |  |  |  | 8.72 | 733,461  |
| **1200-Operations** | **36.9** | **3,947,554**  |  |  |  |  | **36.9** | **3,947,554**  |
| 1210-Scheduling | 0.33 | 53,041  |  |  |  |  | 0.33 | 53,041  |
| 1220-Operating | 16.85 | 1,570,477  |  |  |  |  | 16.85 | 1,570,477  |
| 1230-Support & Testing | 19.72 | 2,324,037  |  |  |  |  | 19.72 | 2,324,037  |
| **1300-Spectrum Management** | **2.95** | **295,985**  |  |  | **0** | **0**  | **2.95** | **295,985**  |
| 1310-Interference Suppression | 1.85 | 215,027  |  |  | 0 | 0  | 1.85 | 215,027  |
| 1320-NRQZ Management | 1.05 | 74,244  |  |  | 0 | 0  | 1.05 | 74,244  |
| 1330-Anechoic Chambers | 0.05 | 6,713  |  |  | 0 | 0  | 0.05 | 6,713  |
| **1400-Infrastructure Modifications &** | **0** | **2,769**  |  |  |  |  | **0** | **2,769**  |
| 1420-Modifications | 0 | 2,769  |  |  |  |  | 0 | 2,769  |
| **1500-Management** | **8.45** | **1,372,402**  |  |  |  |  | **8.45** | **1,372,402**  |
| 1510-Telescope Operations Mgmt | 1.88 | 291,117  |  |  |  |  | 1.88 | 291,117  |
| 1520-Science Support Mgmt | 2.38 | 486,400  |  |  |  |  | 2.38 | 486,400  |
| 1530-Mechanical Engineering Mgmt | 0.88 | 156,375  |  |  |  |  | 0.88 | 156,375  |
| 1540-Electronics Mgmt | 1.34 | 163,977  |  |  |  |  | 1.34 | 163,977  |
| 1550-Software Mgmt | 0.4 | 67,983  |  |  |  |  | 0.4 | 67,983  |
| 1560-Program Mgmt | 1.57 | 206,550  |  |  |  |  | 1.57 | 206,550  |
|  | **CSA-G** | **WFO** | **GBO ICC** | **TOTAL** |
|   | **FTE** | **Expenses** | **FTE** | **Expenses** | **FTE** | **Expenses** | **FTE** | **Expenses** |
| **2000-Development Programs** | **2.42** | **544,396**  | **0** | **400,000**  |  |  | **2.42** | **944,396** |
| **2200-Technology Development** |  |  | **0** | **400,000**  |  |  | **0** | **400,000**  |
| **2300-R&D Support** | **1.38** | **323,842**  |  |  |  |  | **1.38** | **323,842**  |
| 2330-R D Infrastructure | 1.38 | 323,842  |  |  |  |  | 1.38 | 323,842  |
| **2600-NRDZ Development** | **1.04** | **220,554**  |  |  |  |  | **1.04** | **220,554**  |
| **3000-Science Operations** | **4.21** | **955,676**  |  |  | **0** | **0**  | **4.21** | **955,676**  |
| **3100-General Science Support & TAC** | **0.47** | **74,996**  |  |  |  |  | **0.47** | **74,996**  |
| 3130-Proposal Review & Time Allocation | 0.47 | 74,996  |  |  |  |  | 0.47 | 74,996  |
| **3200-Reference** | **0** | **10,000**  |  |  |  |  | **0** | **10,000**  |
| 3210-Library | 0 | 10,000  |  |  |  |  | 0 | 10,000  |
| **3300-Broader Impacts** | **0.07** | **97,839**  |  |  |  |  | **0.07** | **97,839**  |
| 3310-Student Programs | 0.07 | 80,943  |  |  |  |  | 0.07 | 80,943  |
| 3340-Diversity & Inclusion | 0 | 16,896  |  |  |  |  | 0 | 16,896  |
| **3400-Scientific Staff** | **0** | **84,500**  |  |  |  |  | **0** | **84,500**  |
| 3410-Staff Research | 0 | 84,500  |  |  |  |  | 0 | 84,500  |
| **3600-Scientific User Services** | **3.02** | **623,004**  |  |  |  |  | **3.02** | **623,004**  |
| 3610-Community Support | 0.32 | 106,511  |  |  |  |  | 0.32 | 106,511  |
| 3620-Science Data Processing | 2.7 | 516,493  |  |  |  |  | 2.7 | 516,493  |
| **3700-Science Software** | **0.65** | **65,337**  |  |  |  |  | **0.65** | **65,337**  |
| 3710-Post Processing Software | 0.65 | 65,337  |  |  |  |  | 0.65 | 65,337  |
| **4000-Administrative Services** | **13.82** | **4,771,337**  |  | **140,660**  | **22** | **(79,980)** | **35.56** | **4,832,017**  |
| **4100-Business Services** | **0** | **0**  |  |  | **5.8** | **568,471**  | **5.83** | **568,471**  |
| 4110-Business Office | 0 | 0  |  |  | 4 | 347,876  | 4 | 347,876  |
| 4120-CIS |  |  |  |  | 1.8 | 220,594  | 1.83 | 220,594  |
| **4200-Facilities** | **1.67** | **309,271**  |  |  | **13** | **1,518,595**  | **15.08** | **1,827,866**  |
| 4210-Building/Plant Maintenance |  |  |  |  | 13 | 974,077  | 12.61 | 974,077  |
| 4220-Communication |  |  |  |  | 0 | 54,905  | 0 | 54,905  |
| 4230-Utilities | 0 | 121,328  |  |  | 0 | 373,810  | 0 | 495,138  |
| 4260-Vehicles |  |  |  |  | 0.8 | 115,803  | 0.8 | 115,803  |
| 4270-Central Instrument Shop | 1.67 | 187,943  |  |  |  |  | 1.67 | 187,943  |
| **4300-Auxiliaries** | **12.15** | **1,008,323**  |  |  |  |  | **12.15** | **1,008,323**  |
| 4310-Visitor Centers | 1.15 | 65,988  |  |  |  |  | 1.15 | 65,988  |
| 4320-Housing | 1.43 | 142,012  |  |  |  |  | 1.43 | 142,012  |
| 4330-Food Handling | 7.22 | 514,122  |  |  |  |  | 7.22 | 514,122  |
| 4340-Gift Shops | 1.3 | 207,303  |  |  |  |  | 1.3 | 207,303  |
| 4350-Management | 1.05 | 78,897  |  |  |  |  | 1.05 | 78,897  |
|  | **CSA-G** | **WFO** | **GBO ICC** | **TOTAL** |
|   | **FTE** | **Expenses** | **FTE** | **Expenses** | **FTE** | **Expenses** | **FTE** | **Expenses** |
| **4500-Management** | **0** | **3,616**  |  |  | **2.5** | **438,704**  | **2.5** | **442,320**  |
| 4510-AD Mgmt | 0 | 0  |  |  | 2.5 | 438,704  | 2.5 | 438,704  |
| 4520-Community Relations | 0 | 3,616  |  |  |  |  | 0 | 3,616  |
| **4800-NRAO Overhead** | **0** | **3,450,126**  |  | **140,660**  | **0** | **(2,605,749)** | **0** | **985,037**  |
| **5000-Director's Office** | **0** | **961,272**  |  | **35,521**  |  |  | **0** | **996,793**  |
| **5800-AUI Fee and IDC** | **0** | **961,272**  |  | **35,521**  |  |  | **0** | **996,793**  |
| **6000-Education & Public Outreach** | **6.95** | **584,435**  |  |  | **1** | **79,980**  | **7.95** | **664,415**  |
| **6100-News and Media Releases** | **0.5** | **46,767**  |  |  |  |  | **0.5** | **46,767**  |
| 6110-Press Publications | 0.5 | 46,767  |  |  |  |  | 0.5 | 46,767  |
| **6200-STEAM Education** | **2.95** | **315,386**  |  |  |  |  | **2.95** | **315,386**  |
| 6210-Formal Education | 0.75 | 89,570  |  |  |  |  | 0.75 | 89,570  |
| 6220-Informal Education | 2.2 | 225,816  |  |  |  |  | 2.2 | 225,816  |
| **6300-Digital Learning & Multimedia** |  |  |  |  | **1** | **79,980**  | **1** | **79,980**  |
| 6350-Web/Apps Development |  |  |  |  | 1 | 79,980  | 1 | 79,980  |
| **6400-Visitor Center Operations** | **3.05** | **188,677**  |  |  |  |  | **3.05** | **188,677**  |
| 6410-Guided Tours Operations | 2.55 | 104,691  |  |  |  |  | 2.55 | 104,691  |
| 6420-Exhibits Maintenance | 0 | 5,353  |  |  |  |  | 0 | 5,353  |
| 6430-Community Engagement | 0.5 | 78,634  |  |  |  |  | 0.5 | 78,634  |
| **6500-EPO Management** | **0.45** | **33,604**  |  |  |  |  | **0.45** | **33,604**  |
| 6510-Administration | 0.45 | 33,604  |  |  |  |  | 0.45 | 33,604  |
| **Grand Total** | **86.47** | **15,110,557**  | **0** | **576,181**  | **23** | **(0)** | **109.21** | **15,686,738**  |

# APPENDIX A: FINANCIAL PLAN

The financial charts have been produced with an organizational view of the Observatory using a Work Breakdown Structure. The WBS definitions were created in conjunction with the operating units of the Observatory assuring that the definitions correspond with actual work units. WBS effort captured includes FTEs, direct salary and benefits budgets, travel budgets, and materials, equipment and supplies.

Benefits Assumptions: The costs for the following employee benefits are treated as a pool: employer retirement contributions, FICA, employer paid medical and dental plan contributions, wellness initiatives, worker’s compensation, unemployment, life insurance, tuition, and paid time off (PTO). PTO includes vacation, sick leave, AUI holidays, and other miscellaneous compensated leave. Lastly, the benefits pool includes designated amounts to retire outstanding unfunded vacation and retiree health obligations acquired under AUI’s pay as you go benefits program which ended with FY2019. This pool is liquidated across AUI to all salary and wage expenditures, excluding AUI’s Chilean local staff members. The benefits rate is a budget allocation and recovery mechanism and applies whether or not the incumbent is eligible for/receives all the noted benefits. The projected FY2022 benefits rate is 58.62%, a modest decrease from FY2021.

GBO Internal Common Cost (ICC): There are several departments which provide programmatic support and services to all the telescopes and/or site. These units are: Site Director, Business Office, Plant Maintenance, and Sitewide Computing and Infrastructure. Their activities make up the bulk of the GBO ICC activities. The NRAO and GBO ICC rates are federally negotiated rates compliant with 2 CFR Part 200. For FY2022 the rate used was 25.52%. GBO pays NRAO for Negotiated Services utilizing their Admin Rate One of 6.10% and Facility One rate of 3.55%.

AUI IDC and Fee: The AUI IDC rate is a federally negotiated rate compliant with 2 CFR Part 200. This recovery pays AUI corporate costs, including Fiscal Operations, associated with the management of the GBO. AUI IDC has been budgeted at 6.57%

The GBO budget includes AUI fee of $90,000.

**Funding Sources**

NSF Allocations: Annual Congressional appropriate budgets provided by NSF.

WFO: GBO participates in WFO projects. These projects are shown to demonstrate their contribution to indirect cost recovery.

Telescope Time Sales: The GBO makes time available for sale. Anticipated program income revenues from telescope time sales are recorded as program income.

Carry-Over: Funds which have been allocated by NSF in prior years but have not been spent. GBO has budgeted a carry-over of $1,075,631 for FY2022. The bulk of this is funds awarded for multi-year projects.

Other Program Income: GBO provides services to visitors including housing, food service, tours, and a gift shop.

# APPENDIX B: WBS STRUCTURE

Observatory Work Breakdown Structure (WBS) Dictionary (Part 1 of 5)



Observatory Work Breakdown Structure (WBS) Dictionary (Part 2 of 5)



Observatory Work Breakdown Structure (WBS) Dictionary (Part 3 of 5)



Observatory Work Breakdown Structure (WBS) Dictionary (Part 4 of 5)



Observatory Work Breakdown Structure (WBS) Dictionary (Part 5 of 5)



# APPENDIX C: MAJOR MILESTONES

| **FY2022 Major Milestones** | **FY2022** |
| --- | --- |
| **Category** | **Milestone** | **Q1** | **Q2** | **Q3** | **Q4** |
| Broader Impact | Camps: Complete FY2022 PING camp  |   |   |   | EPO.1 |
| Broader Impact | Camps: WVGSI Governors School |   |   |   | EPO.2 |
| Broader Impact | Camps: Pulsar Search Collaboratory |   |   |   | EPO.3 |
| Broader Impact | Summer Student Program (REU, PING, Interns) |   |   |   | EPO.4 |
| Broader Impact | Outreach: Pocahontas County Math Field Day | EPO.5 |   |   |   |
| Broader Impact | Teachers: professional development programs | EPO.6 | EPO.6 | EPO.6 |   |
| Broader Impact | Outreach: Family Science Labs | EPO.7 | EPO.7 | EPO.7 | EPO.7 |
| Broader Impact | Outreach: Radio Astronomer for a Day | EPO.8 | EPO.8 | EPO.8 | EPO.8 |
| Broader Impact | Outreach: High Tech Tours | EPO.9 | EPO.9 | EPO.9 | EPO.9 |
| Broader Impact | Outreach: Monthly Star Parties (10) | EPO.10 | EPO.10 | EPO.10 | EPO.10 |
| Broader Impact | Outreach: Pocahontas County Schools Science Fair |   | EPO.11 |   |   |
| Broader Impact | Outreach: Hour of Code for county 9th graders |   |   | EPO.12 |   |
| Broader Impact | Outreach: Replace Science Center Exhibits (FY2021 carry forward) |   | EPO.13 |   |   |
| Broader Impact | Outreach: Open House  | EPO.14 |   |   |   |
| Broader Impact | Proposal for Expanded WVSPOT | EPO.15 |   |   |   |
| Broader Impact | WV Governor's STEM Institute |   |   |   | EPO.16 |
| Broader Impact | PING Student/Mentor Recruitment Plan | EPO.17 |   |   |   |
| Broader Impact | PING Student Selections |   |   | EPO.18 |   |
| Broader Impact | PING Evaluation |   |   |   | EPO.19 |
| Broader Impact | PSC Proposal Submission  |   |   |   | EPO.20 |
| Broader Impact | SkyNet Junior Scholars Mini Workshops | EPO.21 | EPO.21 |   |   |
| Broader Impact | REU/Summer Students Selected |   | EPO.22 |   |   |
| Broader Impact | Summer Student Program (REU, PING, Interns) Bootcamp |   |   | Sc.10 |   |
| Broader Impact | Summer Student Program (REU, PING, Interns) Completed |   |   |   | Sc.11 |
| Broader Impact | Chautauqua Short Courses Conducted |   |   | EPO.23 |   |
| Broader Impact | Training: Single Dish Workshop |   | Sc.13 |   |   |
| Broader Impact | Training: Observer Training Workshops | Sc.14 | Sc.14 |   | Sc.14 |
| Broader Impact | Training: Proposer's Workshops |   | Sc.15 |   | Sc.15 |
| Broader Impact | Astronomy Community Workshops |   | Sc.16 | Sc.16 | Sc.16 |
| Broader Impact | Establish FY2022 Observatory Leadership Cohort |   |   |   | HR.1  |
| Broader Impact | Development: Establish Mentoring Program |   |   | HR.2 |   |
| Infrastructure Improvements | AAT: Design Review of Phase 2 Plan |  |  So.1 |   |   |
| Infrastructure Improvements | AAT: Archive infrastructure in Data Center |   |   |   | So.2 |
| Infrastructure Improvements | ARGUS Calibration Vane Upgrade (FY2021 carry forward) |   | E.3 |   |   |
| Infrastructure Improvements | DSS 2.0 Initial Science & Operations Requirements (FY2021 carry forward) |   |   |   | Sc.12 |
| Infrastructure Improvements | X Band Receiver Hardware assembly  |   | E.4 |   |   |
| Infrastructure Improvements | X Band Receiver Integration Testing |   |   | E.5 |   |
| Infrastructure Improvements | X Band Receiver Software Integration Testing |   |   | So.7 |   |
| Infrastructure Improvements | X Band Receiver Lab Testing |   |   |   | E.6 |
| Infrastructure Improvements | X Band Receiver Commissioning |   |   |   | Sc.19 |
| Infrastructure Improvements | TTAT Development Support | So.3 | So.3 | So.3 | So.3 |
| Infrastructure Improvements | Data Center Commissioned |   | P.13 |   |   |
| Operations | Budget: GBO Indirect Rates |   |   | B.1 |   |
| Operations | Budget: Annual Operating Budget |   |   | B.2 |   |
| Operations | Compensation: Total Rewards Review |   |   | HR.3 |   |
| Operations | Client Relationship Management implemented |   | HR.4 |   |   |
| Operations | Conference: AAS Materials & Support Winter |   | PR.1 |   |   |
| Operations | Conference: AAS Materials & Support Summer |   |   | PR.2 |   |
| Operations | GBT: Painting Resource and Schedule Plan | T.1 |   |   |   |
| Operations | GBT: Painters Hired |   | T.2 |   |   |
| Operations | GBT: Painting Completed  |   |   |   | T.3 |
| Operations | GBT: Complete FY2021 track work (FY2021 carry forward) | T.4 |   |   |   |
| Operations | GBT: GBT Structural inspections report |   | T.5 |   |   |
| Operations | GBT: GBT Procure Track Plates for FY2022 installation | T.6 |   |   |   |
| Operations | GBT: GBT Track Materials Procurement for FY2022 installation |   | T.7 |   |   |
| Operations | GBT: GBT FY2022 Track work completed |   |   |   | T.8 |
| Operations | Inspect concrete for grout pocket replacements |   |   | T.9 |   |
| Operations | Grout pocket repairs  |   |   |   | T.10 |
| Operations | Funding request for U-connection repair/replacement | T.11 |   |   |   |
| Operations | Contract in place for coolant pipe replacement | T.12 |   |   |   |
| Operations | Coolant pipe replacement (lower half) complete |   |   |   | T.13 |
| Operations | Prime Focus maintenance, screws, Sterling mount, cables |   |   |   | T.14 |
| Operations | Develop a plan for GBT primary and secondary surface molds | T.15 |   |   |   |
| Operations | Complete cleaning and inventorying of GBT surface molds |   |   | T.16 |   |
| Operations | GBT Semester 22A TAC Materials | Sc.1 |   |   |   |
| Operations | GBT: Semester 22A Review complete | Sc.2  |   |   |   |
| Operations | GBT: Release 22B proposal call |   | Sc.3 |   |   |
| Operations | GBT: Semester 22B TAC Materials |   |   | Sc.4 |   |
| Operations | GBT: 22B Proposal review complete |   |   | Sc.5 |   |
| Operations | GBT: Release Semester 23A proposal call |   |   |   | Sc.6 |
| Operations | Track performance measurements | Sc.7  |   |   |   |
| Operations | Track model updated |   | Sc.8  |   |   |
| Operations | Argus and W-band manager documentation |   |   |   | Sc.9 |
| Operations | Order Digital LVDTs for FY2022 replacements | E.7 |   |   |   |
| Operations | GBT motor maintenance preparation |   | E.8 |   |   |
| Operations | GBT actuator maintenance |   |   | E.9 | E.9 |
| Operations | Historic: Calibration horn rehabilitation |   | P.12 |   |   |
| Operations | Newsletter: 2022 Facilities Booklet | PR.3 |   |   |   |
| Operations | Reports: Facilities NSF reports | B.3 |   |   |   |
| Operations | Reports: Vehicle (FAST) NSF reports |   |   |   | P.10 |
| Operations | Reports: Energy NSF reports |   |   |   | P.11 |
| Operations | Reports: Master site plan | B.4 |   |   |   |
| Operations | Reports: Inventory NSF Reports |   |   | B.5 |   |
| Operations | Reviews: GBO Advisory Council Meetings | A.1 |   | A.1 |   |
| Operations | Reviews: AUI/GBO Visiting Committee meeting |   | A.2 |   |   |
| Operations | Reviews: NRAO/GBO User’s Committee meeting |   |   | A.3 |   |
| Operations | Review SLAs with NRAO |   | A.4 |   |   |
| Operations | Safety: Annual fire systems inspection | P.1 |   |   |   |
| Operations | Oil Tank Replacement | P.2 |   |   |   |
| Operations | Works area transformer replacement |   |   |   | P.3 |
| Operations | Jansky Lab generator load study |   |   |   | P.4 |
| Operations | Residence Hall Electrical Upgrade |   |   | P.5 |   |
| Operations | New power feeder upgrade |   |   | P.6 |   |
| Operations | ICB Transformer and Service Replacement |   |   |   | P.7 |
| Operations | New power feeds to GBT warehouse |   |   |   | P.8 |
| Operations | New power feeds 300' control |   |   |   | P.9 |
| Operations | Enhancements to telescope monitoring system |   |   | So. 4 |   |
| Research & Development  | Active Surface Upgrade Design (FY2021 carry forward) | E.1 |   |   |   |
| Research & Development  | Active Surface Revised Budget (FY2021 carry forward) |   | E.2 |   |   |
| Research & Development  | Cyclic Spectroscopy: graduate student identified (FY2021 carry forward) |   | Sc.17 |   |   |
| Research & Development  | Cyclic Spectroscopy: Advisory group established (FY2021 carry forward) |   | Sc.18 |   |   |
| Research & Development  | Cyclic Spectroscopy: Initial Hardware Procurement (FY2021 carry forward) |   |   | Sc.20 |   |
| Research & Development  | Cyclic Spectroscopy: Software Architecture (FY2021 carry forward) |   | So.5 |   |   |
| Research & Development  | Cyclic Spectroscopy: Software Development |   |   |   | So.6 |
| Research & Development  | Cyclic Spectroscopy: resource plan (FY2021 carry forward) |   | PM.1 |   |   |
| Research & Development  | Cyclic Spectroscopy: Stakeholder and Science Requirements | Sc.22 |   |   |   |
| Research & Development  | UWBR: commissioning  |   |   |   | Sc.21 |
| Research & Development  | Support UWBR: commissioning  |   |   |   | So.8 |
| Research & Development  | UWBR: Closeout Report |   |   |   | PM.2 |

| **Milestones:** | **Deliverables:** |
| --- | --- |
| A.1. GBO Advisory Council meeting | A.1. Advisory Council meeting minutes |
| A.2. AUI/GBO Visiting Committee meeting | A.2. Visiting Committee Presentations |
| A.3. NRAO/GBO User’s Committee meeting | A.3. User’s Committee Presentations |
| A.4. Review and negotiate SLAs with NRAO | A.4. FY2022 SLAs established |
| B.1. Indirect Rate submission | B.1. Indirect Rate proposal to NSF |
| B.2. FY2022 Operating Budget | B.2. Operating FY2022 Budget proposal to NSF |
| B.3. Facilities Reports | B.3. Facilities Reports developed to NSF |
| B.4 Master Site Plan | B.4. Master Site Plan submitted to NSF |
| B.5. Inventory reports | B.5. Inventory report filed with NSF |
| E.1. Detailed Active Surface hardware design | E.1. Detailed Active Surface Hardware Design Document |
| E.2. Detailed Active Surface Budget | E.2. Detailed Active Surface Upgrade Budget Developed |
| E.3. Argus vane modifications completed | E.3. Argus vane upgrade complete |
| E.4. X Band Receiver Hardware Assembly | E.4. X band receiver hardware assembled and documented |
| E.5. Initial X band hardware and software integration testing | E.5. X band initial integration tests completed and documented |
| E.6. X band receiver testing in the lab | E.6. X band receiver testing completed in the lab |
| E.7. Order Digital LVDTs for FY2022 replacements | E.7. LVDT ordered |
| E.8. GBT motor maintenance preparation | E.8. Motor ordered |
| E.9. GBT actuator maintenance | E.9. Replace 40 actuators |
| EPO.1. Complete PING camp  | EPO.1. Conduct PING attendee evaluations |
| EPO.2. Complete WVGSI school | EPO.2. Conduct WVGSI attendee/mentor evaluations |
| EPO.3. Complete PSC camp  | EPO.3. Conduct PSC attendee evaluations |
| EPO.4. Summer programs  | EPO.4. Conduct attendee/mentor evaluations |
| EPO.5. Pocahontas County Math Field Day | EPO.5. Pocahontas County Maty Field Day conducted |
| EPO.6. Conduct teacher professional programs | EPO.6. Teacher materials provided |
| EPO.7. Conduct family science labs | EPO.7. Family science attendee count |
| EPO.8. Conduct ongoing astronomer for a day program | EPO.8. Radio Astronomer for a Day attendee count |
| EPO.9. Conduct monthly GBO High Tech tours | EPO.9. High Tech tour attendee count |
| EPO.10. Conduct GBO Star Parties | EPO.10. Star Party attendee count |
| EPO.11. Host and lead county schools science fair | EPO.11. Science Fair attendee count |
| EPO.12. Participate in Hour of Code program | EPO.12. Hour of Code attendee feedback |
| EPO.13. Exhibit replacement plan (FY2020 carry forward) | EPO.13. Annual Open House Attendee Count |
| EPO.14. Annual Open House Event | EPO.14. Exhibit replacement plan and budget |
| EPO.15. Proposal for expanded WVSPOT program | EPO.15. WVSPOT expansion proposal submitted |
| EPO.16. WV Governor's STEM Institute | EPO.16. WV GSI Camp conducted |
| EPO.17. PING Recruitment Plan | EPO.17. Complete plan for PING student/mentor recruitment |
| EPO.18. PING Student Selections | EPO.18. PING Student selections completed |
| EPO.19. PING evaluation | EPO.19. PING Evaluation Feedback completed |
| EPO.20. New PSC funding proposal | EPO.20. Proposal submitted for new PSC funding |
| EPO.21. Skynet Junior Scholars mini workshops | EPO.21. Conduct online Skynet mini workshops |
| EPO.22. Select summer students | EPO.22. Summer students selected and notified |
| EPO.23. Chautauqua Short Courses completed | EPO.23. Chautauqua Short Courses workshop completed |
| HR.1. Establish FY2022 Observatory Leadership Cohort | HR.1. Two GBO staff in OLC program  |
| HR.2. Establish Mentoring Program | HR.2. Mentoring program established with 5 GBO mentors |
| HR.3. Total Rewards compensation evaluation | HR.3. Total rewards compensation review completed |
| HR.4. Client Relationship Management System implementation | HR.4. CRM platform implemented for recruitment  |
| P.1. Fire system inspections | P.1. Fire inspection reports filed |
| P.2. Oil tank replacement | P.2. Oil tank replaced |
| P.3. Works area transformer replacement | P.3. Works area transformer replaced |
| P.4. Jansky Lab generator load study | P.4. Plan created to shed non-critical loads  |
| P.5. Residence Hall Electrical Upgrade | P.5. Residence Hall electrical systems upgraded |
| P.6. New power feeder upgrade | P.6. New Power Feeder from EH #2 to EH #4 |
| P.7. ICB Transformer and Service Replacement | P.7. ICB Transformer and Service Replaced |
| P.8. New power feeds to GBT warehouse | P.8. New Power Feeds from EH #5 to GBT Warehouse  |
| P.9. New power feeds 300' control | P.9. New Power Feeds from EH #8 to EH #9 - 300’ Control Building |
| P.10. Vehicle report (FAST) | P.10. Vehicle reports submitted |
| P.11. Energy reports | P.11. Energy report filed with NSF |
| P.12. Calibration horn rehabilitation plan | P.12. Plan submitted to NSF |
| P.13. Data Center Building commissioned and ready for use | P.13. Data Center power, switching, networking completed |
| PM.1. Cyclic Spectroscopy resource plan | PM.1. Cyclic Spectroscopy Resource Plan approved |
| PM.2. UWBR Closeout Report | PM.2. UWBR Closeout submitted |
| PR.1. Materials and support for AAS Winter Meeting | PR.1. AAS Winter booth materials and exhibit installation |
| PR.2. Materials and support for AAS Summer Meeting  | PR.2. AAS Summer booth materials and exhibit installation |
| PR.3. Update design/content of 2022 Facilities booklet | PR.3. Produce and distribute 2022 Facilities Booklet |
| Sc.1. Semester 22A TAC Materials | Sc.1. Semester 22A TAC Booklet |
| Sc.2. Semester 22A Review complete | Sc.2. Semester 22A Disposition letters, Web pages |
| Sc.3. Release 22B proposal call | Sc.3. Observer community notification |
| Sc.4. Semester 22B TAC Materials | Sc.4. Semester 22B TAC Booklet |
| Sc.5. 22B Proposal review complete | Sc.5. Semester 22B Disposition letters, Web pages |
| Sc.6. Release Semester 23A proposal call | Sc.6. Observer community notification |
| Sc.7. Track performance measurements | Sc.7. Measure the track smoothness after the summer track work |
| Sc.8. Track model updated | Sc.8. Update the track lambda values of the pointing model. |
| Sc.9. Argus and W-band documentation | Sc.9. Document receiver and FITS files produced by Argus and W-band |
| Sc.10. Conduct undergraduate training ‘Bootcamp’ | Sc.10. Staff training presentations |
| Sc.11. Summer student program conclusion | Sc.11. Student presentations |
| Sc.12. DSS 2.0 Initial Science & Operations Requirements | Sc.12. Stakeholder Requirements document |
| Sc.13. Single dish workshop | Sc.13. Student presentations |
| Sc.14. Observer training workshop | Sc.14. Remote Observer Qualifications |
| Sc.15. Proposer's Workshop | Sc.15. Proposer's Workshop Conducted |
| Sc.16. Astronomy community workshops | Sc.16. Astronomy workshops/meetings conducted |
| Sc.17. Cyclic Spectroscopy graduate student identified | Sc.17. Cyclic Spectroscopy Graduate student offer letter |
| Sc.18. Cyclic Spectroscopy Advisory group established | Sc.18. Cyclic Spectroscopy introductory meeting completed |
| Sc.19. X Band astronomical commissioning | Sc.19. X Band commissioning completed and documented |
| Sc.20. Cyclic Spectroscopy: Initial hardware procurement (FY21 carry forward) | Sc.20. Procure the computers and processing systems |
| Sc.21. Ultra-wideband astronomical commissioning | Sc.21. Ultra-wideband commissioning completed and documented |
| Sc.22. Cyclic Spectroscopy: Stakeholder and Science Requirements | Sc. 22. Requirements document for Cyclic Spectroscopy |
| So.1. AAT: Design Review of Phase 2 plan | So.1. Conceptual Design Review of plan for enhancements to AAT |
| So.2. AAT: Archive Infrastructure Development | So.2. Preliminary archive infrastructure implemented in Data Center |
| So.3. TTAT Development Support | So.3. Ongoing GBO software collaboration on NRAO-led TTAT  |
| So.4. General telescope monitoring system enhancements | So.4. Operational monitoring tool enhancements released  |
| So.5. Cyclic Spectroscopy Software Architecture | So.5. Cyclic Spectroscopy Software Architecture document  |
| So.6. Cyclic Spectroscopy Preliminary Software prototype | So.6. Cyclic Spectroscopy Software prototype developed |
| So.7. X Band receiver software M&C integration | So.7. X Band software integration testing completed |
| So.8. Support UWBR commissioning | So.8. Support Ultra-wideband commissioning  |
| T.1. Establish plan for increasing number of summer painters & painting schedule | T.1. 2022 summer hire and painting goals plan |
| T.2. Hire summer painters, acquire paint and tools, inspect equipment | T.2. 15-20 painters hired, inventory on hand, person lifts inspected and ready for service |
| T.3. Complete summer 2022 painting goal | T.3. Nominal 10% structure painted |
| T.4. Track inspection, replacement, and repair (FY2021 carry forward) | T.4. Include in summary report. |
| T.5. Receive structural inspection report | T.5. Inspection report |
| T.6. Procure additional track wear plates for FY2022 installation | T.6. Track wear plates received. |
| T.7. Procure materials and consumables for FY2022 GBT maintenance | T.7. Materials received. |
| T.8. Track inspection, replacement, and repair | T.8.  Submit track inspection summary report. |
| T.9. Inspect concrete for grout pocket replacements | T.9. Plan and contract for group pocket repairs in place |
| T.10. Grout pocket repairs | T.10. Grout pocket repairs completed |
| T.11. Plan for U-Connection repair/replacement | T.11. Proposal submitted for U-Connection repair |
| T.12. Contract for coolant pipe replacement | T.12. Coolant pipe replacement contracted |
| T.13. Coolant pipe replacement (lower half) | T.13. Coolant pipe replacement completed |
| T.14. Prime Focus maintenance, screws, Sterling mount, cables | T.14. Prime Focus maintenance, screws, Sterling mount, cables |
| T.15. Develop a plan for GBT primary and secondary surface molds | T.15. Plan developed for GBT surface molds |
| T.16. GBT surface molds are cleaned and inventoried | T.16. Inventory and storage of GBT surface molds completed |
| Divisions: A=Admin; B=Business; E=Electronics; EPO=Education & Public Outreach; HR=Human Resources; P=Plant Maintenance; PM=Program Management; PR=Public Relations; Sc=Science; So=Software; T=Telescope Operations |

# APPENDIX D: REFERENCES

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# APPENDIX E: ACRONYMS

| **Acronym** | **Definition** |
| --- | --- |
| AAAS | American Association for the Advancement of Science |
| AAS | American Astronomical Society |
| AAT | Archive Access Tool |
| AGN | Active Galactic Nuclei |
| ALFALFA | Arecibo Legacy Fast Arecibo L-band Feed Array detector |
| ALMA | Atacama Large Millimeter/submillimeter Array |
| ARGUS | 16-pixel W-band focal plane array for mm spectroscopy |
| ASTRID | Astronomer's Integrated Desktop |
| ATI | Advanced Technologies and Instrumentation |
| AUI | Associated Universities, Incorporated |
| BYU | Brigham Young University |
| CA | Cooperative Agreement |
| CASA | Common Astronomy Software Applications |
| CASPER | Collaboration for Astronomy Signal Processing and Electronics Research |
| CCB | Caltech Continuum Backend |
| CGM | Circumgalactic Medium |
| CHIME | Canadian Hydrogen Intensity Mapping Experiment |
| CLEO | Command Library for Operators and Engineers |
| CO | Carbon Monoxide |
| Co-PI | Co-Principal Investigator |
| CORS | Continuous Operating Reference Station |
| CMU | Carnegie Mellon University |
| CST | Computer Simulation Technology |
| CY | Calendar Year |
| DARPA | Defense Advanced Research Projects Agency |
| DCR | Digital Continuum Receiver |
| DDC | Digital Down-Converter |
| DDT | Director’s Discretionary Time |
| DiFX | Distributed FX Correlator |
| DEGAS | Dense Extragalactic GBT+Argus Survey |
| DSPIRA | Digital Signal Processing in Radio Astronomy |
| DSS | Dynamic System Scheduler |
| ERIRA | Educational Research in Radio Astronomy |
| EPO | Education and Public Outreach |
| EPSCoR | Experimental Program to Stimulate Competitive Research |
| ESS | Earth/Space Sciences Passport |
| FAST | Five hundred meter Aperture Spherical Telescope, China |
| FCC | Federal Communications Commission |
| FIRST2 | NSF INCLUDES: First Two Years of College Student Success Network |
| FITS | Flexible Image Transport System |
| FLAG | Focal L-band Array for the Green Bank Telescope |
| FPGA | Field-Programmable Gate Array |
| FRB | Fast Radio Burst |
| FRM | Focus Rotation Mount |
| FTE | Full-Time Equivalent |
| FY | Fiscal Year |
| GBO | Green Bank Observatory |
| GBMF | Gordon and Betty Moore Foundation |
| GBSE | Green Bank Session Editor |
| GBT | Green Bank Telescope |
| GBTIDL | Green Bank Telescope Interactive Data Language |
| GHz | Gigahertz |
| GLOBE | Global Learning and Observation to Benefit the Environment  |
| GMVA | Global VLBI Millimeter Array |
| GO | General Observing |
| GPS | Global Positioning System |
| GPU | Graphical Processing Unit |
| GRB | Gamma Ray Burst |
| GSA | General Services Administration |
| GSI | Governor’s STEM Institute |
| GW | Gravitational Wave |
| HCN | Hydrogen Cyanide |
| HERA | Hydrogen Epoch of Reionization Array |
| HFET | Heterojunction Field-Effect Transistor |
| H1 | Hydrogen |
| HSA | High Sensitivity Array |
| HVAC | Heating, Ventilation, and Air Conditioning |
| IAU | International Astronomical Union |
| ICC | Internal Common Cost |
| IDC | Indirect Cost |
| IEE | Institute of Electrical and Electronics Engineers |
| INCLUDES | Inclusion across the Nation of Communities of Learners of Underrepresented Discoverers in Engineering and Science |
| IPG | Interference Protection Group  |
| IRAC | Interdepartment Radio Advisory Committee |
| ISM | Interstellar Medium |
| ITU-R | International Telecommunication Union-Radio |
| IVS | International VLBI Service for Geometry and Astrometry |
| JIVE | Joint Institute for VLBI in Europe |
| JPL | Jet Propulsion Laboratory |
| KFPA | K-band Focal Plane Array |
| KPI | Key Performance Indicators |
| LASSI | Laser Antenna Surface Scanning Instrument |
| LIGO | Laser Interferometer Gravitational-Wave Observatory |
| LMT | Large Millimeter Telescope |
| LoFASM | Low Frequency All-Sky Monitor Project |
| LPI | Lebedev Physical Institute |
| MaDCoWS | Massive and Distant Clusters of WISE Survey |
| MIS | Management Information Services |
| MMIC | Monolithic Microwave Integrated Circuit |
| MOU | Memorandum of Understanding |
| MPIfR | Max Planck Institute for Radio Astronomy |
| MSIP | Mid-Scale Innovations Program in Astronomical Sciences |
| MUSTANG | Multiplexed SQUID/TES Array for Ninety Gigahertz |
| NAC | National Astronomy Consortium |
| NANOGrav | North American NanoHertz Observatory for Gravitational Waves |
| NASA | National Aeronautics and Space Administration |
| NEA | Near-Earth Asteroids |
| NGAS | Next Generation Archive Systems |
| NGSS | Next Generation Science Standards  |
| ngVLA | Next Generation Very Large Array |
| ngVLBA | Next Generation Very Long Baseline Array |
| NM | New Mexico |
| NRAO | National Radio Astronomy Observatory |
| NRQZ | National Radio Quiet Zone |
| NSF | National Science Foundation |
| NSF-AST | National Science Foundation - Division of Astronomical Sciences |
| NWNH | New Worlds, New Horizons |
| NxGen | Next Generation Science Standards  |
| OMT | OrthoMode Transducer |
| OV | Owens Valley, California |
| PAF | Phased Array Feed |
| PF1 | Prime Focus 1 receiver |
| PF2 | Prime Focus 2 receiver |
| PFS | Portable Fast Sampler |
| PI | Principal Investigator |
| PING | Physics Inspiring the Next Generation |
| PMD | Program Management Department |
| PMI | Project Management Institute |
| POP | Program Operating Plan |
| PROMPT | Panchromatic Robotic Optical Monitoring and Polarimetry Telescopes  |
| PSC | Pulsar Search Collaboratory |
| PST | Proposal Submission Tool |
| PTA | Pulsar Timing Array |
| R&D | Research and Development |
| RDBE | ROACH Digital Backend |
| RET | Research Experience for Teachers |
| REU | Research Experience for Undergraduates |
| RFI | Radio-Frequency Interference |
| ROACH | Reconfigurable Open Architecture Computing Hardware |
| RSRO | Resident Shared Risk Observing |
| SARA | Society of Amateur Radio Astronomers |
| SBC | Single Board Computer |
| SDD | Software Development Division |
| SDS | Single Dish School |
| SE | Systems Engineering |
| SETI | Search for Extraterrestrial Intelligence |
| SFR | Supplemental Funding Request |
| SHAO | Shanghai Astronomical Observatory |
| SHPO | State Historic Preservation Office (WV) |
| SJS | Skynet Junior Scholars |
| SLA | Service Level Agreement |
| SMBH | Supermassive Black Holes |
| SPOT | Space Public Outreach Team |
| SQUID | Superconducting Quantum Interference Device |
| SRO | Shared Risk Observing |
| SRP | Science Review Panel |
| SSA | Space Situational Awareness |
| STEM | Science, Technology, Engineering, and Mathematics |
| SZE | Sunyaev-Zeldovich Effect |
| TAC | Time Allocation Committee |
| TES | Transition Edge Sensor |
| TTA | Telescope Time Allocation |
| URSI | Union Radio-Scientifique Internationale |
| UV | Ultraviolet |
| UWBR | Ultra-Wideband Receiver  |
| VEGAS | VErsatile GBT Astronomical Spectrometer |
| VISTA | Volunteers in Service to America  |
| VLA | Very Large Array |
| VLBA | Very Long Baseline Array |
| VLBI | Very Long Baseline Interferometry |
| VME | Versa Module Europa |
| WFBT | Wide Field Burst Telescope |
| WFO | Work for Others |
| WIM | Warm Ionized Medium |
| WV | West Virginia |
| WV GSI | West Virginia Governor’s STEM Institute |
| WVRAZ | West Virginia Radio Astronomy Zone |
| WVSPOT | West Virginia Science Public Outreach Team |
| WVSTA | West Virginia Science Teachers Association |
| WVU | West Virginia University |

1. https://www.nationalacademies.org/our-work/decadal-survey-on-astronomy-and-astrophysics-2020-astro2020 [↑](#footnote-ref-1)
2. Due to restricted operations in FY2021 due to the COVID-19 pandemic, FY 2021 visitor numbers will be significantly lower and not indicative of visitor interest. [↑](#footnote-ref-2)
3. Due to restricted operations in FY2021 due to the COVID-19 pandemic, FY 2021 visitor numbers will be significantly lower and not indicative of visitor interest. [↑](#footnote-ref-3)
4. [↑](#footnote-ref-4)