Astro2020 APC White Paper
State of the Profession Consideration

Green Bank Observatory - Broader Impact

Brief Description: During the next decade, Green Bank Observatory will continue to create unique STEM learning experiences that combine the technical work done onsite with real-world educational experiences for students, educators, and professional scientists. Learning by doing is the philosophy behind all Observatory STEM programs.

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> *Every U.S.-educated scientist and engineer begins his or her science, technology, engineering, and mathematics (STEM) education in the K–12 grades. There, talents may be built or discovered, interest in STEM cultivated, and knowledge acquired that allows students to succeed in pursuing STEM degrees in postsecondary education. For those who do not pursue STEM, the mathematics and science knowledge needed to function as consumers and citizens emerges largely from K–12 education.*
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> *- National Science Indicators 2018, National Science Board*

1.0 Science and Society: The Key Issue

An understanding of, and appreciation for, science is key both to the development of scientists and engineers within the astronomical fields and to ensuring an understanding and appreciation of scientific endeavor within society. With this in mind, it is vital the astronomical community reach out both to students at all levels of their careers (pre-kindergarten through post-graduate) and the teachers and professors who are educating each successive generation. Without such efforts, the astronomical community will suffer from a lack of sufficient highly qualified scientists and engineers to work within the profession, and a lack of public support for continued pursuit of astronomical research.

2.0 Green Bank Observatory, an Introduction

Beyond its impact to the astronomical sciences, Green Bank Observatory contributes in a unique and expansive manner to society. During the next decade, Green Bank Observatory's Education and Public Outreach programs will continue to leverage its staff and facilities - the technical village that is the Observatory to create unique Science, Technology, Engineering, and Mathematics (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 Observatory STEM programs. Additionally, the Observatory 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.

Green Bank Observatory's strategic goals emphasize broadening participation in STEM by cultivating future generations of scientists and engineers; maximizing the scientific knowledge of current scientists and engineers; and engaging the public in dynamic programming that will instill a greater appreciation for the value of radio astronomy, scientific discovery, and STEM in general.

2.0 Diversity and Inclusion Programs

The Observatory 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, the West Virginia (WV) Science Public Outreach Team and the WV Governor's STEM Institute target West Virginia youth, who, as predominantly rural students, have fewer opportunities to experience authentic STEM than students elsewhere (Avery 2013). Physics Inspiring the Next Generation (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 states that have EPSCoR ("Established Program to Stimulate Competitive Research")

status. Two other national programs: Pulsar Search Collaboratory (PSC), and Skynet Junior Scholars, are leveraged to provide additional opportunities for those students who exhibit an affinity for astronomy.

To maintain its large portfolio of educational programs and STEM initiatives, the Observatory combines NSF cooperative agreement funds with external grants and awards as well as other program to assist in paying for the students and participant support costs. The five-year NSF INCLUDES Alliance grant is an important, recent addition to our efforts.

3.0 Formal Education Programs

All Observatory education programs are strongly integrated with the science and engineering mission of the Observatory. The impact of all of the Observatory's programming is amplified because students and teachers can interact with STEM professionals within the environment of a federally funded research and development center. Residential programs are important in the educational portfolio. However, recognizing that not all interested students and teachers will be able to visit the Observatory site, outreach activities are conducted as well.

3.1 WVSPOT

Supported through a joint partnership between the Observatory and West Virginia Space Grant Consortium, the West Virginia Space Outreach Team (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. WVSPOT has seen steady growth since its inception. In 2017/2018 (its 5th year), SPOT ambassadors reached over 50 schools in West Virginia, and impacted 5,000 K-12 students. Visit http://wvspot.org to learn more. Over the next ten-year period SPOT is expected to continue to grow, reaching approximately 75,000 students (cumulative) by 2030.

3.2 WV Governor's Stem Institute (GSI)

Two programs preparing youth for future STEM careers are the WV Governor's Stem Institute (GSI) and PING. The Observatory will continue to operate a two-week residential program for rising ninth graders from across West Virginia, funded by the state of West Virginia. GSI builds academic research skills and cultivates interest in STEM careers among young students. Assessment is a strong and integral component of this program: immediate impacts are measured 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, and should continue at its current level well into the Observatory's future. Information on the GSI is available at https://govschools.wv.gov/GSI/Pages/default.aspx

3.3 Physics Inspiring the Next Generation (PING)

The Observatory's success with the Governor's School 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 the Observatory 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 radio telescope. Supporting material in chemistry, physics, mathematics, and engineering are provided. At the conclusion of PING Camp, the student groups present their findings in an academic colloquium attended by Green Bank scientists and guests, an activity that reinforces the need for ongoing research and exploration.

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. The Observatory selects 20 rising ninth graders for the program and hires two to four undergraduate mentors. Over the next five years, the PING program is expected to grow to about 40 students and 6-8 mentors by 2025. Information on the PING program is available at https://greenbankobservatory.org/education/research/

3.4 NSF INCLUDES Alliance: First2 Network

The NSF INCLUDES Alliance: Expanding the First2 STEM Success Network (First2 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 and are 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. Finally, the Alliance will advance our knowledge of barriers to success and solutions that increase the success of first generation students in STEM. Information on the First2 Network can be found at https://first2network.org/

The Observatory 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 includes the WV EPSCoR office. The First2 Network is a planned five-year program that will run through 2023. By that point the program will have been absorbed into the West Virginia Department of Education, and will be run completely through that institution.

3.5 Pulsar Search Collaboratory

The Observatory collaborates with West Virginia University on the NSF-funded Pulsar Search Collaboratory (PSC - Williamson et al. 2019). Through this national program, high school

students analyze GBT data in the search for pulsars. To date, PSC students have discovered seven pulsars and a rotating radio transient. The PSC trains teachers and students in the techniques of radio astronomy, pulsar searching, and identifying their signatures in GBT data. They participate in online training workshops, a several day Capstone event at West Virginia University and several other hub universities throughout the United States, and an annual week-long summer camp at the Observatory. 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 10 faculty. Online collaboration and annual face to-face convening of all community members develops STEM self-efficacy and identity in youth and teachers, fosters belonging of all stakeholders in a STEM community, and models STEM pathways. Information on the pulsar search collaboratory can be found online at http://pulsarsearchcollaboratory.com. Over the next ten years, the PSC will continue to grow across the country, gradually expanding the number of schools, students, and faculty participating in the program.

3.6 Skynet Junior Scholars

Skynet Junior Scholars (SJS) is a national program developed collaboratively by Green Bank Observatory, University of Chicago's Yerkes Observatory, University of North Carolina, the Astronomical Society of the Pacific, and 4-H (Heatherly, et al. 2014; Hoette, et al. 2014; Langston, et al. 2013). 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, and monitoring variable stars, while learning about the nature and methods of science. The 20-Meter telescope is the only telescope in the network operating at radio wavelengths. In 2018, the SJS curriculum was accepted by the 4-H organization as a national curriculum. Over the next several years, the Observatory will be working with partners to ensure expansion of SJS through 4-H. Information on SJS is available through https://skynetjuniorscholars.org/

4. Supporting a STEM Workforce

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

4.1 Summer Research Student Program

The Summer Research Student Program brings an average of ten undergraduate and graduate students to work and live at the Observatory. An extensive focus on demographics during the selection process best maximizes this opportunity to expand diversity within the staff.

The three months that these students are in residence gives them interaction with most divisions across the site including Hospitality, EPO, Science, Electronics, Program Management, Business Services, and the larger Green Bank community. Funding for this program is through the combination of Observatory program income and an NSF-REU grant. This program will continue at its current level through the next decade, with the exception of doubling the number of PING mentors by 2025, as discussed above.

4.2 Co-ops, Internships, and Other Programs

The Observatory supports various training, cooperative, and mentoring programs. Each year, 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 Observatory facilities and grounds. In addition, the Observatory 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 are invited by the Electronics and Mechanical Engineering divisions to work on projects 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.

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

The Observatory is currently working with West Virginia state initiatives such as Coalfield Development Corporation to grow the program to place 2-4 apprentices in the Observatory's trade operations annually across the next decade. Apprentices will work alongside senior staff to acquire basic skills but also the more specific skills needed to support radio telescope maintenance, machining, and facility maintenance. Senior staff will serve as mentors and trainers.

Finally, the observatory regularly hosts students from high schools, colleges, and universities around the nation to aid in their research training and programs. This can vary from the students using one of the site telescopes for a class research project to individual students running their own scientific research for anywhere from a few weeks to a few years on site.

4.3 Postdoctoral Research Positions

The Observatory typically employs two to three postdoctoral research fellows, a level expected to continue through the next five years. Approximately 50% of each postdoc's time is dedicated to carrying out scientific research either independently or in collaboration with other scientists within the wide framework of Observatory interests. The remaining 50% of their time is dedicated to supporting the Observatory, primarily through observer support and aiding in the testing or commissioning of instruments. All postdocs have a mentor who meets with them on a regular basis to ensure their career plans are moving forward at a reasonable pace, and an annual travel budget for any research related travel at their discretion. The Observatory is planning to continue this program, employing 2-4 post-docs annually across the next decade.

4.4 Student Workshops and Training

The Observatory holds a number of training workshops for undergraduate and graduate students annually.

The NANOGrav consortium holds an annual workshop to teach undergraduate participants about radio astronomy and pulsars, and to train the students on basic radio astronomy techniques, observation strategies, and data reduction.

During the summer, Green Bank holds a weeklong series of lectures and workshops to introduce students to radio astronomy as part of the annual Undergraduate Radio Astronomy Workshop. The curriculum includes basic radio astronomy techniques, observation strategies, and data reduction.

The Single Dish School (SDS) is organized annually by the Observatory. 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 telescope operation or data reduction. 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 2019, the School will grow to include a partnership with the Arecibo Observatory.

New Observer Workshops are conducted two to three times a year and offer an opportunity for new and prospective users of the GBT to travel to the Observatory 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.

Both the school and the training workshops will continue at their current rate, training 40-60 students annually for the next decade.

4.5 Faculty and Community Workshops

Each year, the Observatory hosts workshops that bring segments of the astronomical community together to share ideas and plot future directions for the field. A list of recent and upcoming workshops can be found at https://greenbankobservatory.org/science/meetings-and-workshops/

4.6 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 Green Bank program is expected to continue through the next ten years.

4.7 Externally Run Programs Supported by the Observatory

The Observatory 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 the Observatory expected to continue through the next five years.
- 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 the Observatory called Educational Research in Radio Astronomy, or ERIRA.
- Digital Signal Processing in Radio Astronomy (DSPIRA) Research Experience for Teachers: The Observatory plays a support role in the WVU led program that engages up to nine teachers each summer in digital signal processing. Teachers spend four weeks on the WVU campus and two weeks at the Observatory, working alongside engineering staff on software defined radio applications. Teachers also develop classroom activities and pilot test these with PING students.
- Ad-hoc on site college courses: Every year colleges and universities across the U.S. and Canada take advantage of the Observatory's facilities and staff for their own college astronomer and radio astronomy courses. Depending on the institution and funding, these courses vary from an onsite weekend visit to use the site's telescopes and staff for training to 2-3 week courses held on site using the facilities and staff to aid in teaching the course material.

5.0 Public Outreach and Visitor Programs

The Observatory hosts a 25,000 square foot visitor facility, which is open year-round. It serves as the starting point for guided tours of the Observatory and includes a 5,000 square foot Exhibit Hall, filled with exhibits explaining radio astronomy, a 150-seat auditorium, etc. The Science Center draws roughly 45,000 visitors each year, a remarkable number for such a remote location. Visitors experience interactive displays in the exhibit hall, hear presentations about radio astronomy, and take tours around the Observatory. Further information is available at https://greenbankobservatory.org/visit/. The Observatory aims to grow the number of on-site visitors by 25% within the next ten years.

5.1 Radio Astronomer for a Day

The Observatory also hosts school field trips throughout the year, which engage students in hands-on astronomy, engineering, and coding activities. The Observatory's signature field trip program engages up to 2,000 students each year in 1-3 day observational projects using the 40-Foot telescope. The 40-Foot is maintained as an analog instrument so that students can easily learn to operate it 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

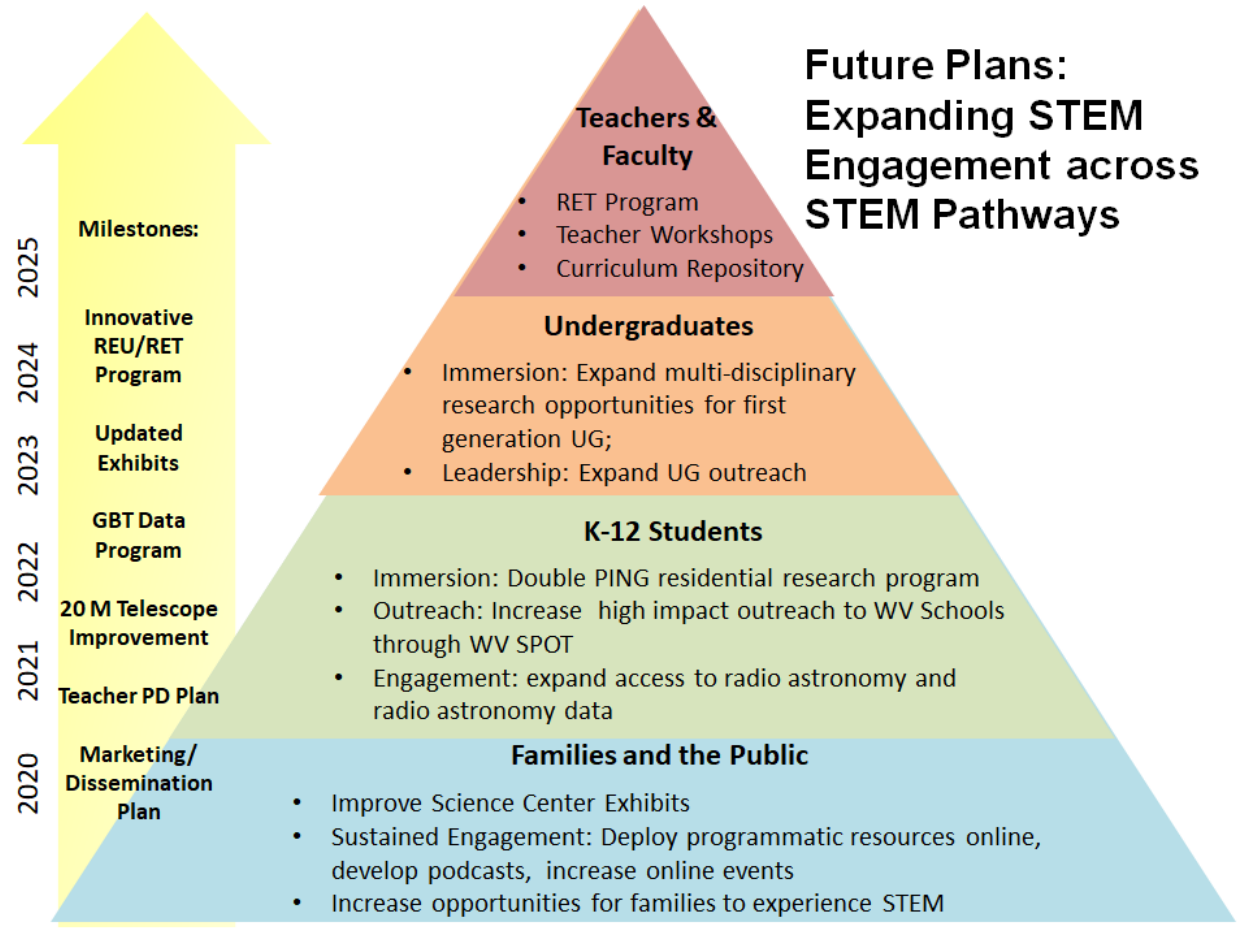

Figure 1. Depiction of the next five years of growth for the Green Bank Observatory's Education and Public Outreach division.

debate the strength of each one, based on their data and previous classroom activities undertaken in advance of their visit. The Observatory will continue to gradually grow these programs, with the aim of sending more than 12,500 students through the program in the 2020 decade.

5.2 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.

6.0 Community Outreach

A healthy workforce requires a healthy community in which to live and work. With this in mind, the Observatory strives to be an active member of the local community, providing expertise and aid in many areas. A listing of programs in which the Observatory is currently involved is given at https://greenbankobservatory.org/about/community-development/.

7.0 Future Plans and Funding

Over the next ten years, the Green Bank Observatory will continue to grow its existing programs, reaching out to an increasing number of students and educators annually (Figure 1).

However, continuation of this program requires continued funding of the Observatory as a whole. Prior to 2012, the National Science Foundation provided roughly 85% of the funding required to run the existing educational programs at the Observatory through the Observatory's Cooperative Agreement (general operations) grant. As of 2019 that figure is closer to 50%, with the difference made up through external contracts and grants. A specific commitment from the National Science Foundation for these programs at the $1M level would ensure that at least the current programs would not decline, while additional funding would allow the program to grow as planned.

8.0 Partnerships

Green Bank Observatory's program of broader impacts is accomplished with collaboration of many organizations. Below is a listing of the principal partners and collaborators, along with the primary programs that are supported through that collaboration.

- 4-H (Skynet Junior Scholars)
- Arecibo Observatory
- Astronomical Society of the Pacific (Skynet Junior Scholars)
- Breakthrough Listen (Financial partner)
- Central Appalachian Astronomy Club (Green Bank StarQuest)
- Fairmont State University (First2Network)
- High Rocks Educational Corporation (First2Network)
- NANOGrav (Financial Partner, workshops)
- National Radio Astronomy Observatory (REU program)
- Northern Pocahontas Community Wellness (Space Race Rumpus)
- State of West Virginia (GSI, AIM apprenticeships)
- The Undergraduate ALFALFA Team (ALFALFA - Colgate U, Cornell U., George Mason U., Hartwick C., Lafayette C., Lynchburg C., Macalester C., MSU Denver, St. Lawrence U., San Francisco State U., Siena C., Skidmore C., Union C. U. Puerto Rico, U. San Francisco, U. Wisconsin Madison, U. Wisconsin Platteville, U. Wisconsin - Stevens Point, Utica C., Valparaiso U., Washington & Jefferson C., West Virginia U., West Texas A&M)
- United Therapeutics (Workshops, student support)
- University of Chicago's Yerkes Observatory (Skynet Junior Scholars)
- University of North Carolina (Skynet Junior Scholars, ERIRA)
- West Virginia EpSCor Office (First2Network)
- West Virginia Higher Education Policy Commission (First2Network)
- West Virginia Space Grant Consortium (WVSPOT)
- West Virginia University (WVSPOT, PSC, DSPIRA)

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