THE OBSERVER

NEWS FROM THE GREEN BANK OBSERVATORY
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DIRECTOR'S NEWS

This month marks both the 60th anniversary of the dedication of the National Radio Astronomy Observatory here in Green Bank, and the one-year anniversary of the creation of the Green Bank Observatory.

On October 17, 1957, the National Radio Astronomy Observatory came into existence. Over the past 60 years, the scientific discoveries and milestones achieved at the site have been momentous. The list of accomplishments is far too large to fit within one article, but they include: the first search for extraterrestrial intelligence; creation of the Drake equation; discovery of flat galactic rotation curves; first pulsar discovered in a supernova remnant; first organic polyatomic molecule detected in interstellar space; black hole detected at the center of the Milky Way; determination of the Tully-Fisher relationship; detection of the first interstellar anion; measurement of the most massive neutron star known; first high angular resolution image of the Sunyaev-Zel'Dovich Effect; discovery of only known millisecond pulsar in a stellar triple system; discovery of pebble-sized proto-planets in Orion, and the first detection of a chiral molecule in space.

Looking back just at the past year, our first as the Green Bank Observatory, the list of accomplishments is equally impressive. In the past year the first results from the Breakthrough Listen project were published; FLAG, the world's most sensitive phased array feed receiver was commissioned; first data was released from the ammonia survey of the Gould Belt; two new molecules were detected in the ISM (HC5O and C7H); the first full season for observing with ARGUS and MUSTANG-2 was completed; and the recent Terzan 5 results directly measured the gravitational potential

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Upcoming Proposal Deadline

The submission deadline for Semester 2018B proposals is Thursday, February 1, 2018.

of a globular cluster for the first time. Looking to the other work done at and to support the Green Bank Observatory, the accomplishments of the past year include: hosting more than 2,000 visitors to view the solar eclipse, painting 84,000 square feet of the GBT, hosting 900 visitors at our annual open house (and launching 150 rockets in two hours that same day), releasing our new visitor reservations system, and hosting more than 30 film and news organizations.

The historical impact this facility has had on the scientific community is profound, and it is an impact that continues to grow. In the coming year we expect to see the first scientific results from our three new instruments, ARGUS, MUSTANG-2 and FLAG, and VEGAS, our GPU/FPGA backend, should begin pulsar observations. The legacy of our Observatory is great, but as the past year has proven, the potential for our scientific future is also fantastic.

Dr. Karen O'Neil,
Director, Green Bank Observatory

NEWS

STRIKING NEW RADAR VIEW OF THE LUNAR SURFACE

Researchers from the Smithsonian's National Air and Space Museum used radio telescopes at the Arecibo Observatory and Green Bank Observatory to map the Moon with radar. The radar signals, transmitted from the Arecibo telescope and received at the Robert C. Byrd Green Bank Telescope, probed many meters below the surface of the Moon, just like ground-piercing radar on Earth. They revealed Lunar structures that can't be seen in optical images because they're hidden from view under the layer of dust and rubble that covers the Moon's surface. The scientists are searching for unseen structures of Lunar geology such as lava flow complexes and buried craters.

This radar view of the Moon's southeastern highlands shows the densely cratered surface formed as the result of more than 4 billion years of meteorite impacts. The radar can distinguish the age of some craters. Younger impact craters have enhanced radar

In this image, north is up and the bright crater at the upper right is Theophilus. The dark ring in the image is due to the pattern formed by the transmitting and receiving antennas. (AUI, GBO)

return showing bright floors and surrounding areas due to rocky material that has not yet been worn away by very small meteorites.

NEW RESULTS ON REPEATING FRB

The Green Bank Telescope (GBT) has been used to detect 15 brief but powerful radio pulses emanating from FRB 121102. These fast radio bursts (FRBs) are brief, bright pulses of radio emission from distant but unknown sources. Single FRBs have been detected from many directions on the sky, but this object is the only one known to repeat. More than 150 individual bursts have been detected from FRB 121102, which has been localized to a dwarf galaxy about 3 billion light years from Earth.

The discovery was made as part of the Breakthrough Listen project, an initiative to find signs of intelligent life in the Universe. Breakthrough Listen uses the Green Bank Telescope, and other instruments, to observe nearby stars and galaxies for signatures of extraterrestrial technology. When scientists found evidence that FRB 121102 occasionally produced repeated radio bursts, the project team at the University of California, Berkeley, added it to their list of targets.

In the early hours of Saturday, August 26, 2017, the Green Bank Telescope was pointed at FRB 121102 using a receiver tuned to frequencies of 4 - 8 GHz, much higher than any previous fast radio burst had

been detected. Using a special instrument to break the data into billions of extremely fine frequency channels, the Breakthrough team accumulated 400 terabytes of data over a five-hour period. Analysis by Breakthrough Listen postdoctoral researcher Vishal Gaijar revealed the 15 new pulses.

Possible explanations for the repeating bursts range from outbursts from rotating neutron stars with extremely strong magnetic fields, to speculation that they are directed energy sources used by extraterrestrial civilizations to power spacecraft.

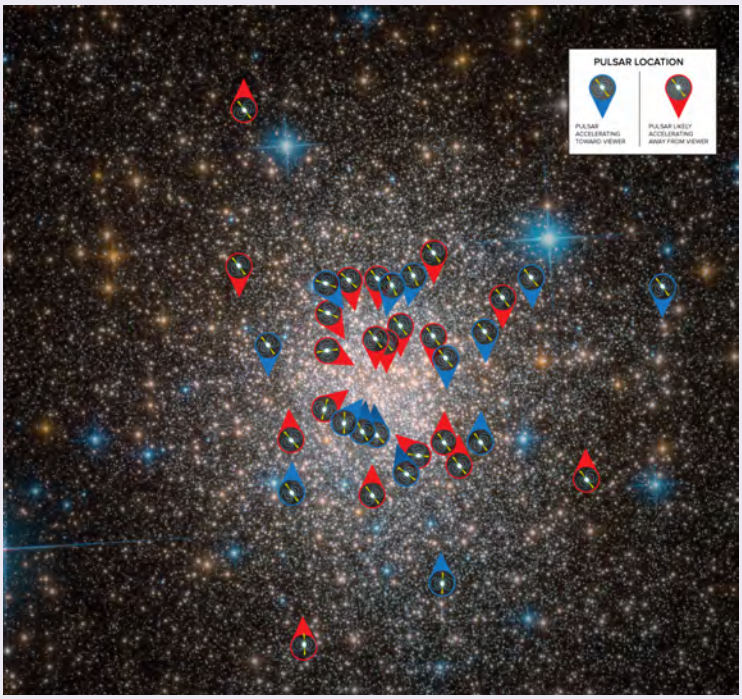
PULSAR JACKPOT REVEALS GLOBULAR CLUSTER'S INNER STRUCTURE

The Milky Way is chock-full of star clusters. Some contain just a few tens-to-hundreds of young stars. Others, known as globular clusters, are among the oldest objects in the Universe and contain up to a million ancient stars.

Some globular clusters are thought to be fragments of our galaxy, chiseled off when the Milky Way was in its infancy. Others may have started life as standalone dwarf galaxies before being captured by the Milky Way during its formative years.

Regardless of their origins, many globular clusters reside either in or behind the dusty regions of our galaxy. For ground- and space-based optical telescopes, however, this poses a challenge. Though it is possible to observe the cluster as a whole, the dust hinders astronomers' efforts to study the motions of individual stars. If astronomers could track the motions of individual stars, they could see how "lumpy" the globular cluster is or if it contains something really dense, like a giant black hole at its center.

Fortunately, radio waves – like those emitted by pulsars – are unhindered by galactic dust. So rather than tracing the motions of the stars, astronomers should be able to map the motions of pulsars instead. But, of course, things are never that simple. Though globular clusters are brimming with stars, they contain far fewer pulsars.



Graphic showing locations of millisecond pulsars inside the globular cluster Terzan 5 in an optical image taken by the Hubble space telescope. Pulsars represented in blue are accelerating toward observers on Earth; those in red are accelerating away. These relative accelerations were derived by measuring minute changes in the speed of rotation of the pulsars.Credit: B. Saxton (NRAO/AUI/NSF); GBO/AUI/NSF; NASA/ESA Hubble, F. Ferraro

"That's what makes Terzan 5 such an important target of study; it has an unprecedented abundance of pulsars – a total of 37 detected so far, though only 36 were used in our study," said Brian Prager, a Ph.D. candidate at the University of Virginia in Charlottesville and lead author on a paper appearing in the Astrophysical Journal. "The more pulsars you can observe, the more complete your dataset and the more details you can discern about the interior of the cluster."

The Terzan 5 cluster is about 19,000 light-years from Earth, just outside the central bulge of our galaxy.

For their research, the astronomers used the National Science Foundation's (NSF) Green Bank Telescope (GBT) in West Virginia. The GBT is an amazingly efficient instrument for pulsar detection and observation. It has exquisitely sensitive electronics, some specifically optimized for this task, and a 100-meter dish, the largest of any fully steerable radio

telescope.

Pulsars are neutron stars – the fantastically dense remains of supernovas – that emit beams of radio waves from their magnetic poles. As a pulsar rotates, its beams of radio light sweep across space in a cosmic version of a lighthouse. If the beams shine in the direction of Earth, astronomers can detect the exquisitely steady pulses from the star.

As the pulsars in Terzan 5 move in relation to Earth – drawn in different directions by the varying density of the cluster -- the Doppler effect comes into play. This effect adds a tiny delay to the timing if the pulsar is moving away from Earth. It also shaves off the tiniest fraction of a millisecond if the pulsar is moving toward us.

In the case of Terzan 5, astronomers are particularly interested in a class of pulsars known as millisecond pulsars. These pulsars rotate hundreds of times each second with a regularity that rivals the precision of atomic clocks on Earth.

Pulsars achieve these remarkable speeds by siphoning off matter from a nearby companion star. The infalling matter hits the edge of the neutron star at an angle, increasing the pulsar's rate of spin in much the same way that a basketball balanced on the tip of a finger can be spun up by striking its side.

Millisecond pulsars are a particular boon to astronomers because they make it possible to detect almost infinitesimally small changes in the timing of the radio pulses.

"Pulsars are amazingly precise cosmic clocks," said Scott Ransom, an astronomer with the National Radio Astronomy Observatory (NRAO) in Charlottesville, Virginia, and coauthor on the paper. "With the GBT, our team was able to essentially measure how each of these clocks is falling through space toward regions of higher mass. Once we have that information, we can translate it into a very precise map of the density of the cluster, showing us where the bulk of the 'stuff' in the cluster resides."

Previously, astronomers thought that Terzan 5 might be either a warped dwarf galaxy gobbled up by the Milky Way or a fragment of the galactic bulge. If the cluster were a captured dwarf galaxy, it might also harbor a central supermassive black hole, which is one of the hallmarks of all large galaxies and can be found in many dwarf galaxies as well.

The new GBT data, however, show no obvious signs that a single, central black hole is lurking in Terzan 5. "However, we can't yet say for sure if a smaller, intermediate mass black hole resides there. The new observations also provide better evidence that Terzan 5 is a true globular cluster born in the Milky Way rather than the remains of a dwarf galaxy," said Ransom.

Future observations using more sophisticated acceleration models may better constrain the origin of Terzan 5.

GREEN BANK MACHINE SHOP EXPANDS PRODUCTION CAPABILITIES

The Machine Shop in Green Bank recently took delivery on a new Haas VF-5/40 machining center.

The new machine has a slightly larger worktable and 5-axis capability (e.g., it moves in more directions during machining) making it a very capable, state of the art machine. The machine will be used to make high-precision receiver and telescope components.

OPEN SOURCE RADIO TELESCOPES

Over the past few years, advances in the development of software defined radio (SDR) have encouraged tinkerers to construct low-cost radio telescopes suitable for detecting emission from galactic neutral hydrogen. One of the first such systems was developed by REU students at Haystack Observatory in 2013. (See https://www.cfa.harvard.edu/~npatel/hornAntennaAASposterPDF2.pdf).

Observatory staff became intrigued after an NRAO conference to discuss potential radio astronomy citizen science projects. This initial interest has expanded on several fronts over the past year.

First, retired NRAO scientist, Glen Langston, who

has created several working prototypes in his home workshop, mentored EPO staff in constructing and documenting a feed horn telescope specific to the 21 cm hydrogen line using only readily available materials bought from home improvement chains, the local general store, and MiniCircuits, and then using the telescope to map hydrogen in the Galaxy.

This in-house expertise and documentation in turn formed the foundation for a unique NSF funded engineering internship experience for 12 rising college freshmen last July, who spent 2 weeks in residence at the Observatory to improve the initial design and further document their work. The internship produced two successful telescopes.

Meanwhile, the GBO partnered with West Virginia University to host an NSF funded a Research Experience for Teachers (RET) cohort of nine high school teachers. The focus of the RET experience was digital signal processing, and with the assistance of WVU engineering faculty, each teacher built their own 21 cm horn antenna, including the low noise amplifier!

Software to acquire and display the data was developed separately by each group using GNU Radio blocks as a starting point.

Finally, in a separate project, GBO high school intern Ellie White worked with Observatory staff to construct an instrument using SDR to measure low frequency ionospheric disturbances.

In an effort to spur community participation in SDR-Radio Astronomy applications, we created Open Source Radio Telescopes (http://opensourceradiotelescopes.org/), where this initial documentation has been shared. There is a list-serve as well. For more information visit the website or contact Dr. Richard Prestage.

EPO HAPPENINGS

WV SCIENCE PUBLIC OUTREACH TEAM WORKSHOP TRAINS NEXT GENERATION OF AMBASSADORS

The West Virginia Science Public Outreach Team (WV SPOT), is an ambassador program that trains undergraduates from WV colleges and universities to go into K-12 schools and present engaging and interactive "shows" on science and engineering that is occurring in West Virginia.

Recently, 46 undergraduate students from across the State participated in a two-day workshop to prepare for their role as SPOT science ambassadors to K-12 students in the mountain state. With support of veteran SPOT ambassadors and Observatory staff, new recruits participated in training sessions enabling them to lead hands-on activities, learn effective public speaking techniques, and master the content of their chosen SPOT show during the weekend workshop.

Because they are successful college students – not that much older than the kids they present to – who go to school in West Virginia, SPOT ambassadors make a huge impression on the K-12 students they visit. Students can see themselves as future successful college students and they also learn that they don't have to leave WV if they want to be a scientist or an engineer! Our shows feature the science going on at the Observatory, as well as NASA missions and additional shows that feature other kinds of science and engineering beyond space-themed presentations..

Our current ambassadors come from 7 different colleges across the state, and they travel far and wide to deliver interactive shows. Last year alone, ambassadors were able to present at schools in 24 different counties, reaching 3,525 students! Since WV SPOT's inception in 2013, the program has reached 14,258 students.

Thanks to funding provided by grants from researchers at West Virginia University and Marshall University, and the West Virginia Space Grant consortium, student ambassadors receive modest payment for their outreach.

At the end of the weekend, 74% of the ambassadors felt more prepared to talk to students and teachers and 70% indicated they had learned more about science! It is no secret to us that this observatory is a place of inspiration, wonder, and science. The magic that surrounds the Green Bank Observatory, along with its ability to eliminate distractions helped the

ambassadors find their voice in STEM.

ECLIPSE VIEWING EVENT

The day the long anticipated Great American Eclipse arrived, so did over two thousand students, science buffs, and families, all streaming into the Green Bank Observatory with traffic lines backing up on both North- and Southbound lanes of Rt. 28/92.

Many people made this event a stunning success. The Science Center staff did their usual superb job of making visitors welcome and setting up fun activities, The Cafe' and Cafeteria staff kept everybody fed, the Works group had the tents in place and the grounds looking great, and the rest of the staff volunteers handled everything from parking directions, items sales, activity staffing, to roving eclipse and site experts answering visitor questions.

Some statistics:

- Estimated crowd size – 2,100 (one of the largest in the history of the Green Bank facility)
- Eclipse glasses distributed – 1,961
- Pizzas prepared – 126
- Lunches served – 720

Hopefully this wonderful community experience will be replicated in 2024. Save those glasses!

MEET THE STAFF

HEATHERLY RECOGNIZED WITH THOMAS K. BRENNAN AWARD

The Astronomical Society of the Pacific announced its 2017 National Award recipients. Our own Sue Ann Heatherly received the prestigious Thomas J. Brennan Award, which is given to an individual demonstrating excellence in the teaching of astronomy at the high school level in North America.

When you think about the breadth of her reach to students all across the nation, the innovative educational programs she has developed and her pioneering of the education programs for both the NRAO and GBO, it is no wonder that the ASP took notice.

Sue Ann began her career in STEM education 31 years ago as a science teacher, but after attending a summer residential teacher enrichment program as a participant, she knew Green Bank was where she could make the greatest contribution to the field. Since joining the Observatory in 1989, Sue Ann has

pioneered immersive, hands-on field trip opportunities such as the Radio Astronomer for a Day program that has served over 30,000 students. It is because of Sue Ann's efforts and vision that we now have the Green Bank Science Center, its buses and bunkhouse as well as our public tour programs that have served over 600,000 since opening the doors 14 years ago. Sue Ann developed the residential, summer programs for West Virginia's Governor's School, Physics Inspiring the Next Generation, the nationally-recognized Pulsar Search Collaboratory, and the FirstTwo statewide collaboration supporting first-generation rural STEM students during their first two years at the college level, not to mention one-week to two-month teacher enhancement workshops. In addition to her own programs, she has built partnerships to host several successful on-site programs such as Star Quest Star Party, the Society for Amateur Radio Astronomer's Conference and Chautauqua short courses for college teachers.

You've put together so many successful programs over the years. Do you have a favorite?

I love anytime I have teachers here for a couple of weeks--they are my people! But, my favorite work we do is with our rising 9th graders. They are just at a remarkable age. These students are smart, fierce in their quest for knowledge, independent, and I haven't been disappointed by them in all my years.

What is the biggest program delivery or development challenge you face?

It's always very challenging to keep programs funded. You create this amazing program and then after your three years are up, you are faced with finding ways to keep these programs sustained over time.

From the standpoint of an educator professional in the field, what has made the biggest impact in STEM in the last 5 years?

Perhaps the most negative impact on STEM education has been the hard focus on standardized testing. It hasn't been used in the right way for personalized improvement. It also inhibits the creativity of science teachers, who are among the most creative teachers I know. They are experimenters and tinkerers by nature and the more you can engage students in that and less checking off things that are going to be tested, the better.

On the positive side, I am really excited about the acknowledgement of STEM as vitally important at the local, state levels. Here in West Virginia, our last governor created a STEM council and brought together people to figure out how to improve STEM in the state. It gives us the opportunity to fit into statewide and national imperatives.

No interview would be complete without this very important question: What is your favorite lunch in the cafeteria?

Hamburger Bean Casserole. I love it!

"There is no doubt that Sue Ann Heatherly has left an indelible mark on students and teachers she has mentored through her 31 years of dedication to impact the approach teachers have toward understanding astronomy." Just as there is no doubt SA has left an indelible mark on this observatory and all those who work with her. Read more on the ASP's website. [https://www.astrosociety.org/society-news/the-astronomical-society-of-the-pacific-announces-its-2017-award-recipients-for-astronomy-research-and-education/]

HISTORY : SPECIAL COMMEMORATIVE SECTION

As we celebrate the 60th Anniversary of the dedication of the National Radio Astronomy Observatory and radio astronomy in Green Bank, we invite you to enjoy our brand new, interactive timeline on our website at greenbankobservatory.org/timeline-green-bank-observatory.

We also commemorate other notable milestones:

- 1st Anniversary of Green Bank Observatory
- 30th Anniversary of Education Programs in Green Bank
- 80th Anniversary of the pioneering Grote Reber Telescope

Enjoy this list of Green Bank Milestones and the following articles commemorating these landmark achievements.

60 YEARS OF RADIO ASTRONOMY IN GREEN BANK

1957	Dedication of the National Radio Astronomy Observatory
1958	Dedication of the Tatel Telescope (85-1)
1958	National Radio Quiet Zone established
1959	Discovery of Jupiter's radiation belts
1959	First Green Bank summer students arrive
1960	First Search for Extraterrestrial Intelligence--Project Ozma
1961	Drake equation written and presented to the Symposium for Extraterrestrial Intelligence
1961	Development of bolometers and mm-wave receivers/telescopes.
1962	First 300' Telescope observations
1964	First Green Bank Interferometer observations
1965	140' observations begin
1965	First high signal to noise detection of radio recombination lines
1967	First U.S. VLBI observation: Green Bank to Maryland
1967-1973	Discovery of flat galactic rotation curves, implying dark matter
1968	First detection of Zeeman splitting of hydrogen
1968	First intercontinental interferometry: Green Bank to Sweden
1968	First pulsar discovered in a supernova remnant (Crab Nebula)
1969	First organic polyatomic molecule detected in interstellar space
1970	First detection of radio novae
1971	First long-chain molecule detected (HC3N)
1974	Detection the black hole at the center of the Milky Way (Sgr A*)
1975	First radio confirmation of Einstein's relativistic bending of light
1977	Determination of the Tully-Fisher relationship
1979	GBI retires and is run by the naval observatory for earth orientation and timing
1985-1986	300' Telescope 1400 MHz sky survey
1987	First residential teacher workshop/ 40' Telescope becomes dedicated educational instrument
1988	300' Telescopes collapse
1989	CBS 5 GHz survey of radio sources
1989	Senator Robert C. Byrd sponsors an appropriation for the Green Bank Telescope (GBT)
1991	GBT groundbreaking
1995	140' 30th anniversary conference and celebration
1995	20-meter Telescope built by the Naval Observatory and begins measurement of Earth's orientation and rotation
1997	Operation of Green Bank OVLBI Earth station with VSOP
2000	Green Bank Telescope dedication and first light
2001	Most detailed radar image produced of Venus's surface geography
2003	Green Bank Science Center dedicated
2004	Detection of a population of high-velocity hi clouds around Andromeda
2005	High-resolution radar mapping of the Moon
2005	Discovery of >20 millisecond pulsars in a globular cluster Terzan 5
2006	Detection of the first interstellar anion
2006	Discovery of the fastest millisecond pulsar, with a spin of 716 times/second
2006	First light for 3mm GBT Observations (Mustang)
2006	Best tests of general relativity from a double-pulsar system
2007	Detection of the molten core of the planet Mercury
2007	GBT track replaced

2007	PAPER begins fabrication for Galford Meadow Array
2008	First detection of pre-biotic molecules in space
2008	First discovery of a pulsar by a high school student
2009	Fabrication of PAPER antennas for deployment in South Africa
2009	GBT achieves planned surface performance at 3mm
2009	Discovery of the first radio pulsar/x-ray binary "missing link"
2009 - Today	Launch of most successful low-frequency pulsar survey, the GBNCC Pulsar Survey
2010	Measurement of the most massive neutron star known
2010	First redshift determinations for the Herschel sub-mm galaxies
2010	Development of GUPPI Pulsar Backend
2010	Intensity mapping developed to study hydrogen at z~0.8
2010	50th anniversary of SETI conference
2010	GBT receiver turret capability extended
2010	First high angular resolution image of the Sunyaev-Zel'Dovich Effect
2011 - Today	Ongoing discovery of millisecond pulsars in Fermi unassociated sources
2012	Detection of the second >2 msun neutron star
2013	Limits on the stochastic gravitational wave background
2014	Mustang 1.5 deployed, with rotator
2014	Discovery of only known millisecond pulsar in a stellar triple system
2014	Mapping by GBT results in the identification of Laniakea Supercluster
2014	Discovery of excess dust emission at 3mm in the Orion Integral Shaped Filament.
2015	GBT determines Gravitational Constant uniform across the universe
2016	GBT discovers pebble-sized proto-planets in Orion
2016	Detection of Massive Gas "Smith Cloud" on collision with Milky Way
2016	First detection of a chiral (handed) molecule in space
2016	NANOGrav limits on the nHz gravitational wave background start to constrain binary supermassive black hole environments
2016	Green Bank Observatory established
2016	Mustang 223 feedhorn bolometer
2016	First multi-pixel camera for GBT 3mm spectroscopy (Argus)
2017	Commissioning of the most sensitive phased array feed in the world (FLAG)
2017	Phased Array Feed commissioned on GBT
2017	GBT beamformer 3mm results
2017	GBT reveals "ageless" silicon that may indicate a well-mixed galaxy

GBO AT ONE YEAR

Op Ed by WVU President, Gordon Gee

For six decades now, Green Bank Observatory has been helping to fill in the vast blank spaces on our map of the universe through radio astronomy.

From detecting the first signal of an organic molecule in space to searching for low frequency gravitational waves from pulsars, Green Bank has been an integral part of radio astronomy and astrophysics research and discovery throughout its existence.

And for 60 years, West Virginians have celebrated this extraordinary facility. During the state's centennial in 1963, the silhouette of the original 300-foot Green Bank radio telescope graced a special commemorative license plate. During the statehood quarter design competition in 2003, numerous entries featured the Green Bank Telescope.

Photos of the facility hang in classrooms and libraries across the state. An effort is underway to add Green Bank to UNESCO's Astronomy and World Heritage Initiative.

The facility brings the world to West Virginia and we are proud to showcase our cutting-edge scientific equipment as well as our natural beauty. At the height of the Cold War in 1961, Russian scientists came to Green Bank for a symposium. High school students from every state visit Green Bank every summer as part of the National Youth Science Camp.

Researchers from institutions around the world rely on the radio telescopes at Green Bank for their work. Thousands of visitors each year enjoy the state-of-the-art Science Center.

And yes, Green Bank has been and remains a leading center for the search for extraterrestrial intelligence. The search began at Green Bank with Frank Drake and Project Ozma in 1960. We are proud of this fact, too, perhaps most of all because of what the search itself represents.

I think James Gunn, the author of the 1972 science fiction novel "The Listeners" about radio astronomy and the search for other life in the universe, said it well: "It may be that there is no one out there or if there is someone out there he will never speak to us or we to him, but our listening is an act of faith akin to living itself. If we should stop listening, we would begin dying and we would soon be gone, the world and its people, our technical civilization and even the farmers and peasants, because life is faith, life is commitment. Death is giving up."

I have been honored to serve as president of West Virginia University, the state's flagship, land-grant, research university, on two occasions almost 30 years apart. Based on that experience, I have found West Virginians to be determined, patient, resilient people.

Perhaps that is why Green Bank resonates so much with us. The monumental task of studying the universe in order to unlock its secrets requires determination, patience, and resilience. Even in the face of technical challenges, mixed signals, and financial setbacks, Green Bank perseveres.

Residents of West Virginia — a state born from the strife of the Civil War, beset by natural disasters, buffeted by economic downturns — can relate to that. That is why Green Bank is a great symbol for West Virginia.

As we celebrate this history, the future of Green Bank hangs in the balance. The National Science Foundation is in the midst of decreasing its funding for the facility. As someone immensely proud of Green Bank and its 60 years of scientific research, education, and outreach, I believe we must preserve and expand this essential place and continue its fundamental work.

Who knows what discoveries the next 60 years may hold? Let us keep listening. We must not give up.

30 YEARS OF 40-FT EDUCATION PROGRAMS

In the midst of celebrating the 60th anniversary of the Observatory at Green Bank, it's easy to overlook another anniversary. July, 2017 marks the 30th anniversary of educational programs at the Green Bank Observatory. In July 1987, the Green Bank facility opened its doors to 27 teachers in an experimental two-week summer institute, designed to introduce educators to a national research center. The following remembrance is from our Education Officer.

The Forty Foot Telescope has been at the heart of the experiences we've offered teachers and students at Green Bank. Built in 1962 to make repeated observations of a small list of radio sources, it is an unabashedly old-fashioned telescope:

- Data is recorded on a chart recorder;
- There is no feed horn, no cryogenics, no computer;
- There is no tracking ability. The Forty Foot is a transit telescope.

And yet, it is one of the most useful and productive instruments in radio astronomy! It is certainly true that the 40 Foot Telescope serves more users annually than all of the NRAO plus GBO telescopes combined! Here are a few notable observing stories from my

years with the 40 Foot Telescope.

1. You found us! During that first summer, teacher teams used the 40 Foot to makes maps of the sky around Cygnus A and Virgo A, and to measure the telescope's efficiency and beam shape. Our team decided to mimic the operation of the 300 Foot, nodding the 40 Foot north and south to collect more data in a shorter time-frame. As we nodded the telescope from north horizon to south, we noticed a huge bump in the chart recording trace. Excited to discover a huge radio source, we raced our chart recording back to the astronomers. They smirked a little bit and asked us to go back down to the telescope and see if it was still there. It was. And it was at midnight, at 3 AM, in fact every time we looked! That big bump occurred right as the telescope passed through the zenith. We had indeed detected a radio source, the Earth! We were picking up radiation from the ground! In that context did teachers learn about "spillover".

2. We are not alone! Teachers mapping the Sagittarius A region in 1989 were startled to see the chart pen start jerking up and down ... were they seeing rapidly fluctuating interference? They quickly switched on an audio speaker to hear a NutraSweet commercial originating, apparently, at the Galactic Center.

3. Sagittarius A! One summer, in the mid 1990s, both south limit switches failed and the telescope plowed into the ground. Rather than registering horror at this state of affairs, teachers and staff rejoiced alike because, at least for a short time, the 40 Foot could finally see the Galactic Center. (The 40 Foot's southern limit is normally a frustrating ½ degree north of true center of our galaxy, Sagittarius A.) Luckily the hearty 40 foot sustained no permanent damage.

4. We are not alone – Part II. In January 1997, Glenville State College students discovered a signal of short duration (1.5 minutes) at the celestial location of RA 20:32 and Dec. 39.5 degrees. The source persisted through several days of observing, occurring at the same sky location each day.

Although Green Bank astronomers dismissed the signal as interference at first, its sidereal reoccurrence and the tenacity of the students soon had staff intrigued. Other observatories were asked about the phenomenon, and couldn't identify it. Two weeks later the Glenville students returned to the Observatory, but this time to use the 140 Foot Telescope.

The signal was there!

Unfortunately, spectral analysis revealed a "spread spectrum" and the signal was eventually determined to come from a military satellite, which had a 2X sidereal orbit.

5. What's that funny wire? For almost as long as the 40 Foot has been an educational telescope, Dan Reichart of UNC has been organizing his own educational camp. They rig up some pretty fancy recording equipment to the 40 foot to digitize the signals. A few years back they noticed a weird little wire poking out of the drive controller rack. As the teams cycled through the telescope they played with this little wire, pulling on it, trying to tuck it back in. Eventually, under closer inspection, they realized it was a mouse tail!

Those first summer institutes were good ones. The Observatory has continued the program and now, after 30 years, over 1300 K-12 teachers, 500 college faculty, and hundreds of K-16 students have graduated from what has affectionately been called: "Radio Astronomy Boot Camp".

Some of those teachers have started their own programs for students, and some of those students are now astronomers or young science teachers bringing their students to Green Bank.

Thanks to Rich Bradley for working hard in 1987 to make the 40 foot functional for the first groups of teachers, and the telescope mechanics for keeping it that way, Carl Heiles for inspiring us to observe neutral hydrogen, a true staple of our educational programs for teachers and youth, Bill Radcliffe (do you remember the time you single handedly took the front end off the telescope???), Nathan Sharp, and Dave Woody for coming to the rescue when the 40 Foot needed a technical swift kick, Skip Crilly for updating the telescope and getting rid of pesky RFI, and all of the astronomers who have enlightened teachers and students over the years.

Special gratitude goes out to Carl Chestnut, who was my Forty Foot partner in crime for many years and who is missed daily.

80 YEARS OF THE REBER TELESCOPE

The following is a little story about one of the early pioneers of radio astronomy, Grote Reber.

Grote Reber built the first radio telescope in his backyard in Wheaton, Illinois, a suburb of Chicago, where he lived with his mother. Grote was fascinated when he learned of Jansky's discovery in 1933 of radio radiation from the Milky Way. Unable to find a job following up on Jansky's discovery, he decided to study the "cosmic static" on his own, while at the same time working for a radio manufacturing company in Chicago.

He studied telescopes and optics and determined that a telescope based on a parabolic reflector would be the best for measuring radio waves from the Milky Way, if they existed. He was very meticulous and planned the project in great detail. In about 1937 he built a large reflecting parabolic dish with a receiver at the focal point of the parabola. He built the largest dish antenna that was possible with materials from the local builders supply store, about 31 feet in diameter.

It was assumed that the radiation would be due to thermal processes, thus the power would increase with shorter wavelength, so Grote designed a receiver for the shortest wavelength possible with the technology of the time, about 9 cm (3.3GHz). He took advantage of his contacts with electronics manufacturers to get the most advanced amplifier tubes.

He worked his day job, and at night surveyed the sky. He detected nothing at the 9 cm wavelength, so he redesigned his receiver for a longer wavelength, 33 cm.

Again nothing was detected from the Galaxy. Grote has written, "In a measure, it was disappointing. However, since I am a rather stubborn Dutchman, this had the effect of whetting my appetite for more."

Reber redesigned his receiver for a longer wavelength of 187 cm (160 MHz), and improved the sensitivity by several factors of 10. Now he found it was very sensitive to man-made radio interference, especially from automobile spark plugs, but this quieted down after about 10 pm. He finally detected the Milky Way and proceeded to survey the radiation over much of the sky over several months. He then developed an even more sensitive receiver for 62 cm (480 MHz) with which he could also detect the Milky Way.

He found that the strength of the radiation from the Milky Way increased with longer wavelengths, contrary to what was expected for thermal radiation. It was not until the 1950s that the theory of synchrotron radiation was developed that explained the type of emission that came from the Milky Way.

Reber published his results both in Engineering journals and in Astronomy journals, and the science of radio astronomy was recognized as an important field of research. After World War II, some of the physicists and engineers that had worked on developing radar for wartime uses took up the study of radio astronomy. This led to the establishment of the National Radio Astronomy Observatory in Green Bank in 1957, along with similar efforts in several other countries.

In 1959, Reber was invited to be a visiting scientist at Green Bank. He spent about a year there where he

supervised the re-assembly of his telescope on the Observatory grounds as an exhibition. He also had a replica of Jansky's antenna constructed on the site, having found that the Bell Telephone Laboratories still had the original drawings.

In 1972 the Reber Telescope was put on the National Register of Historic Places and in 1995 he donated his equipment to Green Bank. You can see his 1930s -40s vintage receivers and recording equipment in the Science Center today.

Reber is an inspiration to astronomers for his dogged persistence in carrying out his research, and also for the meticulous planning that characterized everything he did. He once advised a student, "Pick a field about which very little is known and specialize in it. But don't accept current theories as absolute fact. If everyone else is looking down, look up or in a different direction. You may be surprised at what you will find."

References:

G.Reber: "Early Radio Astronomy at Wheaton, Illinois," Proc. IRE, Vol 46, Jan 1958.

G.Reber: "A Play Entitled The Beginning of Radio Astronomy", J.Roy.Astron.Soc.Canada, vol82, No.3, 1988.

J. Kraus, "Grote Reber, founder of Radio Astronomy", J.Roy. Astron.Soc.Canada vol 82, No.3, 1988.

EVENTS

Guest Speaker Series

Oct. 17th

Current staff members and retirees will present **Celebrating 60 Years of Radio Astronomy in Green Bank**

Oct. 25th

Dr. Fran Bagenal, University of Colorado Laboratory for Atmospheric and Space Physics, will present **Exploration of the Outer Solar System: New Horizons at Pluto and Juno at Jupiter**

Oct. 27th

2017 Jansky Lectureship Awardee Dr. Bernie Fanaroff will present **Observing the Universe from Africa: Linking radio astronomy and development**

Nov. 2nd

Sarah Scoles, author of ***Making Contact: Jill Tarter and the Search for Extraterrestrial Intelligence***, will present **A History of False Alien Positives** followed by a book-signing event

Transformative Science Workshop Updates

October 16 – 20

Big Questions, Large Programs, and New Instruments: With new instruments and excellent performance, the 100m Green Bank Telescope is only just reaching its full potential. On this 60th anniversary of the ground breaking for the Green Bank Observatory, we are holding a workshop looking toward the next 10, 20, and even 60 years of the Green Bank Observatory, and invite the community to attend and aid us in planning the future. For more information, please visit: [greenbankobservatory.org/transformative-science/]

CAREER OPPORTUNITIES

FACILITIES ENGINEER (4266)

Green Bank Observatory is looking for a Facilities Engineer. This person will be responsible for the coordination and oversight of all new construction and special projects that affect the site or facility and overall maintenance and upgrade of this scientific research facility containing laboratories, offices, shops, residences, vehicles, roads, water and wastewater facilities, power distribution systems and radio telescopes. This position will also head the Plant Maintenance Division and coordinate the work of all crafts/trades involved.

Read the full description and apply online at:

[http://jobs.jobvite.com/nrao/job/oKFG5fwU]

SOFTWARE ENGINEER I-IV (OPEN RANK)

We are also seeking an entry level or early career software engineer to join the Green Bank Observatory (GBO) Software Development Division (SDD). The division's primary focus is maintaining and upgrading the subsystems supporting the operation of the Robert C. Byrd Green Bank Telescope. The major subsystems include: telescope monitor and control, telescope scheduling, data reduction, and data archiving. The team also develops new software to meet challenges posed by new observing paradigms and state of the art instrumentation. Job classification and compensation will be commensurate with education and experience.

ESSENTIAL DUTIES AND RESPONSIBILITIES

Using prescribed methods, researches, conducts or coordinates detailed phases of software engineering work as assigned. Performs work that involves conventional software engineering practices. The successful candidate will collaborate with members of the Software, Electronics and Science Divisions to contribute to full life cycle development of web and systems applications supporting GBO operations. Opportunities also exist to develop software in other radio astronomy-related domains including embedded systems, FPGA systems, software defined radio, and machine learning.

Full description and application can be found online:

[http://jobs.jobvite.com/nrao/job/oG3a6fwJ]

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