

United States Department of the Interior
National Park Service

National Register of Historic Places Continuation Sheet

Name of Property _____

County and State _____

Section number _____ Page _____

Name of multiple property listing (if applicable) _____

SUPPLEMENTARY LISTING RECORD

NRIS Reference Number: 07000525

Date Listed: 9/23/08

Property Name: National Astronomy and Ionosphere Center

County: Arecibo

State: PR

This property is listed in the National Register of Historic Places in accordance with the attached nomination documentation subject to the following exceptions, exclusions, or amendments, notwithstanding the National Park Service certification included in the nomination documentation.

Patricia Andrus
Signature of the Keeper

9/23/2008
Date of Action

Amended Items in Nomination:

Section 5: Ownership of Property

Ownership is hereby changed to PRIVATE.

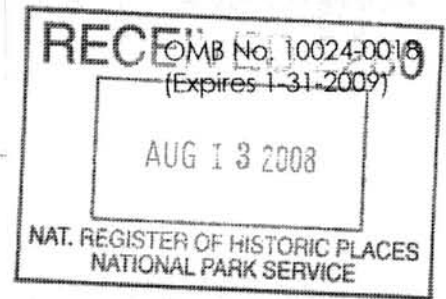
The buildings, structures, and land associated with the Arecibo Observatory, National Astronomy and ionosphere Center, are owned by Cornell University.

The Puerto Rico State Historic Preservation Office was notified of this amendment.

DISTRIBUTION: National Register property file; Nominating Authority (without nomination attachment)

United States Department of the Interior
National Park Service

National Register of Historic Places
Registration Form



1. Name of Property

historic name National Astronomy and Ionosphere Center

other names/site number Arecibo Observatory

2. Location


street & number Esperanza Ward, San Rafael Sector, Road 625 not for publication

city or town Arecibo vicinity

state Puerto Rico code PR county Arecibo code 013 zip code 00613

3. State/Federal Agency Certification

As the designated authority under the National Historic Preservation Act, as amended, I hereby certify that this nomination request for determination of eligibility meets the documentation standards for registering properties in the National Register of Historic Places and meets the procedural and professional requirements set forth in 36 CFR Part 60. In my opinion, the property meets does not meet the National Register Criteria. I recommend that this property be considered significant nationally statewide locally. (See continuation sheet for additional comments.)


Aida Belen Rivera Ruiz
Signature of certifying official/Title

11 August 2008
Date

Puerto Rico State Historic Preservation Office
State or Federal agency or Tribal government

In my opinion, the property meets does not meet the National Register criteria.
(See continuation sheet for additional comments.)

Signature of certifying official/Title

Date

State or Federal agency and bureau

=====
4. National Park Service Certification
=====

I, hereby certify that this property is:

- entered in the National Register
 See continuation sheet.
- determined eligible for the National Register
 See continuation sheet.
- determined not eligible for the National Register
- removed from the National Register
- other (explain):

Patrick Andrus 9/23/2008
Signature of the Keeper Date of Action

=====
5. Classification
=====

Ownership of Property

- private
- public-local
- public-State
- public-Federal

Category of Property

- building(s)
- district
- site
- structure
- object

Number of Resources within Property

Contributing

8
0
1
0
9

Noncontributing

5 buildings
0 sites
0 structures
0 objects
5 Total

Name of related multiple property listing

N/A

Number of contributing resources previously

listed in the National Register N/A

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6. Function or Use

=====

Historic Functions

Education: Research Facilities

Current Functions

Education: Research Facilities

=====

7. Description

=====

Architectural Classification N/A

Materials

foundation concrete

walls concrete

roof concrete

other aluminum, steel

Narrative Description

See continuation sheets.

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8. Statement of Significance
=====

Applicable National Register Criteria

- A** Property is associated with events that have made a significant contribution to the broad patterns of our history.
- B** Property is associated with the lives of persons significant in our past.
- C** Property embodies the distinctive characteristics of a type, period, or method of construction or represents the work of a master, or possesses high artistic values, or represents a significant and distinguishable entity whose components lack individual distinction.
- D** Property has yielded, or is likely to yield, information important in prehistory or history.

Criteria Considerations

Property is:

- A** owned by a religious institution or used for religious purposes.
- B** removed from its original location.
- C** a birthplace or a grave.
- D** a cemetery.
- E** a reconstructed building, object, or structure.
- F** a commemorative property.
- G** less than 50 years of age or achieved significance within the past 50 years.

Areas of Significance Science, Engineering, Education

Period of Significance 1963 - 2008

Significant Dates 1963/1965/1973/1974/1982/1989/1992/1993/2002/2003/2006/2007/2008

Significant Person N/A

Cultural Affiliation N/A

Architect/Builder William E. Gordon, T.C. Kavanaugh

Narrative Statement of Significance

See continuation sheets.

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9. Major Bibliographical References

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Bibliography

See continuation sheets.

Previous documentation on file (NPS):

- preliminary determination of individual listing (36 CFR 67) has been requested.
- previously listed in the National Register
- previously determined eligible by the National Register
- designated a National Historic Landmark
- recorded by Historic American Buildings Survey # _____
- recorded by Historic American Engineering Record # _____

Primary Location of Additional Data:

- State Historic Preservation Office
- Other State agency
- Federal agency
- Local government
- University
- Other

Name of repository: Cornell University, and National Astronomy and Ionosphere Center

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10. Geographical Data

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Acreage of Property 118 acres

UTM References Twelve (12) UTM points are used to identify the site. See continuation sheets and USGS Map.

<u>Zone 19</u>	<u>Point</u>	<u>Easting</u>	<u>Northing</u>
	A	737212	2030318
	A-C 1	737208	2030091
	A-C 2	737234	2030044
	A-C 3	737203	2029756
	A-C 4	737151	2029753
	A-C 5	737152	2029550
	A-C 6	737197	2029554
	B	737716	2030319
	B-D 1	737741	2029979
	B-D 2	737777	2029956
	C	737198	2029480
	D	737761	2029469

Verbal Boundary Description

See continuation sheets

Boundary Justification

See continuation sheets.

National Astronomy and Ionosphere Center
Arecibo, Puerto Rico

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11. Form Prepared By
=====

name/title Juan Llanes Santos / PRSHPO

organization PRSHPO

date March 20, 2007

street & number PO Box 9066581

telephone (787) 721-3737

city or town San Juan

state Puerto Rico

zip code 00906-6581

=====
Property Owner
=====

name: National Astronomy and Ionosphere Center, Cornell University

street & number 504 Space Sciences Building

telephone (607) 255-3735

city or town Ithaca state New York

zip code 14853-6801

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National Astronomy and Ionosphere Center
Arecibo, Puerto Rico

Narrative Description

Figure 1. Arecibo Radio Telescope



The National Astronomy and Ionosphere Center (Arecibo Observatory), located in the Esperanza Ward in the western hills of the town of Arecibo, Puerto Rico, is the site of the world's largest and most powerful radar and radio astronomy telescope. The Arecibo Observatory is part of the National Astronomy Ionosphere Center (NAIC), a national research center operated by Cornell University (Cornell), under a cooperative agreement with the National Science Foundation (NSF). The NSF is an independent federal agency whose aim is to promote scientific and engineering progress in the United States.

The telescope was designed under contract with the U.S. Air Force Cambridge Research Laboratories, and was completed in 1963 at a total cost of about \$9 million with funds from the Advanced Research Projects Agency of the Department of Defense.

The Arecibo telescope was originally designed primarily for detailed study of the ionosphere, following studies in 1958 by Professor William E. Gordon, then professor of electrical engineering at Cornell University. But the installation functions also both actively as a radar telescope and passively as a radio telescope.¹ The capabilities of the instrument derive from its unique design, which includes a large reflector, movable line feeds that correct for spherical aberration, and high-performance transmitters, receivers, and computers for taking data and analyzing them.

¹ A radio telescope receives the natural radiation emitted by the sun, planets, and other more distant celestial radio sources. A radar telescope is used both to transmit a powerful radio signal out into space and then to receive the small amount of radio energy that is returned to it from objects in space. Stan Gibilisco, *Astronomy Demystified*. New York: McGraw Hill, 2006. Pp. 447 – 474.

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National Astronomy and Ionosphere Center
Arecibo, Puerto Rico

Fig. 2 Map of Puerto Rico (Arecibo in black)



The observatory occupies an area of 118 acres in the Esperanza ward in the town of Arecibo (**Fig. 2**). The **Arecibo Radio Telescope** facility is located within one of the most important karst areas in the island. Puerto Rican karst is spectacular: a wilderness with a diversity of landforms, rugged topography, unusual landscapes and contrasting

vistas.

Puerto Rico is basically an urban island with an average population density of over 425 people per square kilometer. The island has experienced high rates of deforestation. In the 1940's, it reached a low forest cover of about 6 percent; in 1990, forest cover was about thirty-two percent.² The karst belt is similar to the rest of the island in terms of the history of forest cover but with two exceptions. First, people have almost completely abandoned any occupation or use of the rugged karst belt. The density of paved state roads in the karst belt is negligible compared with the road density of the rest of the island. Second, as early as 1977 to 1978, forest and shrub cover in the karst belt was 49 percent higher than the average value for the island as a whole.

Significant portions of the karst belt have eighty-six percent forest cover or more. For these reasons, this part of Puerto Rico is inaccessible and constitutes wilderness. Its forest has been recovering from past human uses for over five decades and forms a canopy over a large area that has very little human influence. Because of the low human impact on these forest lands, the Puerto Rican karst belt harbors some of the least disturbed karst forests in the Caribbean.³

² United States Department of Agriculture. Puerto Rican Karst—A Vital Resource. Forest Service. Gen. Tech. Report WO-65. August 2001. P. 8.

³ Ibid.

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Arecibo, Puerto Rico

Fig. 3 Partial view of cone hills around Arecibo Observatory in the Northern Karst area.



The Northern karst forests are the largest track of continuous forest cover in the island. The dominating topographical resources in this area are the Cone karst (conical hills). The hills are grouped linearly with intervening sinks. These formations are attributed to solution along joints in the limestone, or to the notion that the cones are residuals after the collapse of caverns of underground rivers. The best developed cone karst in Puerto Rico occurs near the **Arecibo Observatory**, where many of the cones are sharp, pointed, nearly circular or oval, 200 to 300 meters in diameter at the base, and rise 50 to 75 meters from the bottom of adjacent depressions (**Fig. 3**).⁴

The site chosen for the **Arecibo Radio Telescope** was one of those natural sinkholes formed by the collapse of huge limestone caves and protected by the surrounding hills. The natural depression helped to minimize the excavation for the huge dish. Located about 10km south of the town of Arecibo, the site is away from populous areas and air lanes, which help to reduce radio interferences.

The facility consists of thirteen buildings used for a variety of purposes: research labs, living quarters, machine shops, recreational facilities, warehouses, a visitor center, a learning center, a library, among others. The buildings which are part of the district are significantly important, not because they comprise or embody a method or architectural or engineering construction, but because the Arecibo Radio Telescope would not be able to operate without the support of many functions performed within these buildings. Many of the experiments and investigations involved many years of research. Housing, administrative and office buildings are essential for the completion of projects.

⁴ Ibid. P. 24.

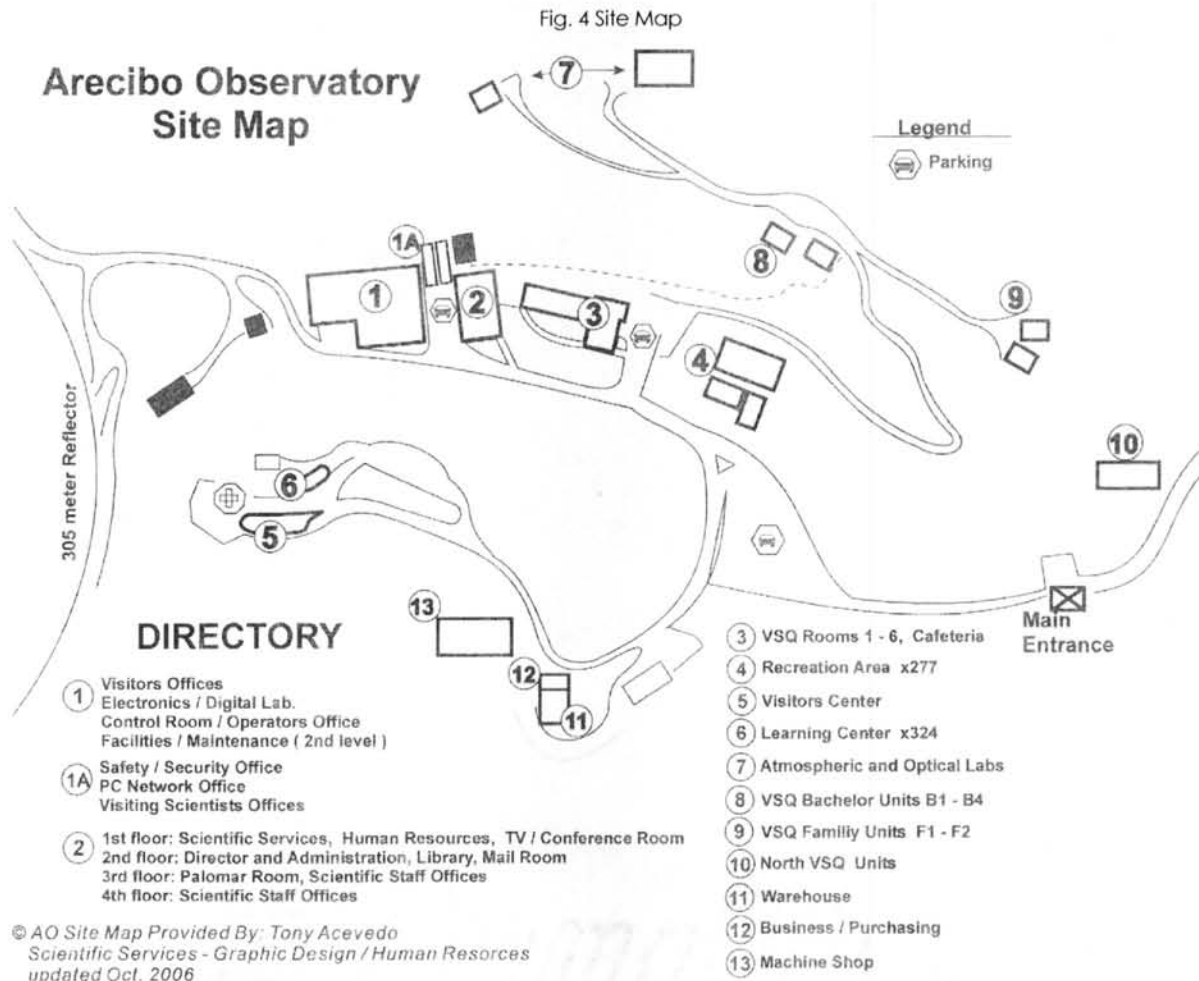
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Arecibo, Puerto Rico

The district is self sufficient providing various services: administrative and management offices, support and technical facilities for the telescope, housing and recreational services, and educational and exhibition buildings (Fig. 4). The district's layout is organized according to the topography. The main road follows topography contours, and buildings are aligned to it.



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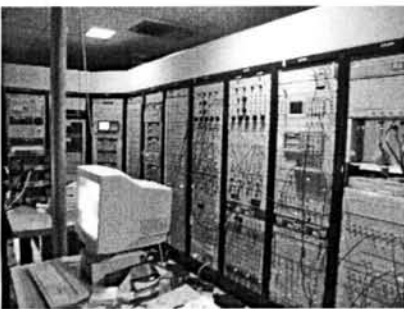
Fig. 5 Building # 1



This structure was built in 1963. It is partially a one-story concrete building which houses the Electronics Department and the Telescope Control and Receiver Rooms. It also contains the offices for the operation technicians and the Facilities Utilities Department. This building includes visitor's offices, electronic facilities, digital laboratories, control room, operator's office facilities and a two story-maintenance facility.



This is the main research building. The precise pointing of the radio telescope is controlled from here. The transmitter room generates signals that are transmitted either to the atmosphere or to objects in the solar system (moons, asteroids, planets). The data acquired by the sensitive electronic equipment on the platform travels along cables and fiber optics to the control room for signal processing and analysis by the scientific staff.



A variety of signal equipment is kept within this building. Many were designed and built by the Arecibo Radio Telescope staff. Other equipment belongs to different universities that also sponsor scientific investigations. For example, the computer assigned to S.E.T.I. (Search for Extra Terrestrial Intelligence) program is located within this building.

To coordinate properly the time stamped arriving signals of the Arecibo Radio Telescope, a series of atomic clocks are kept in Building # 1.

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National Astronomy and Ionosphere Center
Arecibo, Puerto Rico

Fig. 6 Building # 2



Building # 2 it's a four-story concrete structure built in 1963. The first floor provides scientific services, human resources, a television and a conference room. The second floor harbors the director's office and administration offices, the library and the mail room. The third floor provides office space for the scientists' staff and the Palomar room. The fourth floor is dedicated to scientists' staff offices.

Fig. 7 Building # 3



It's a one-story concrete structure that houses six quarters for visiting scientists and the cafeteria.

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National Astronomy and Ionosphere Center
Arecibo, Puerto Rico

Fig. 8 Building # 4



Building # 4 is a one-story concrete structure and recreational area. It includes a basketball and volleyball court, swimming pool and room facilities for special activities.

Fig. 9 Building # 5



More than 100,000 visitors each year are expected at the *Fundación Angel Ramos* Visitor and Educational Facility (Building # 5). Designed by Puerto Rican Architect Luis Badillo and named for the publisher and philanthropist Angel Ramos, it was built in 1997. The facility provides guests with a wide-angle view of the 305-meter diameter radio telescope. The viewing platform is located 60 meters above the main reflector's rim. The building also houses a 100-seat multipurpose theater, meeting rooms, and an extensive exhibit explaining, in English and Spanish, the work done at Arecibo in radio astronomy, radar astronomy and atmospheric science. The main rooms of the building house an exhibit titled "More than Meets the Eye—Exploring the Invisible Universe", which reflects the idea that we can study the unseen sky with telescopes that extend our direct sensory experience.

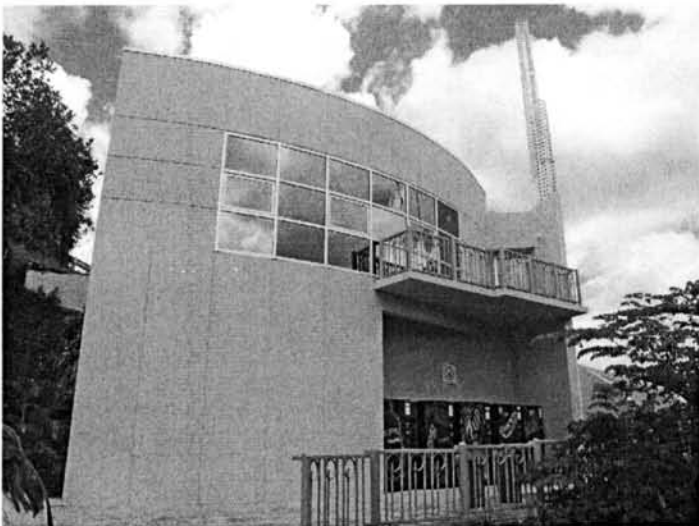
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Arecibo, Puerto Rico

Fig. 10 Building # 6



The Learning Center (Building # 6) was constructed in 2001. It is a one-story concrete facility that houses a conference room used for educational workshops, technical and professional meetings.

Fig. 11 Building # 7



The observatory includes two optical facilities, on a hill near the 305-meter dish, that house instruments for atmospheric related research. The airglow lab (figure on the right) was built in 1985 and houses photometers, interferometers and spectrometers used to study terrestrial airglow emissions. The LIDAR (left), built in 1997, has several lasers that allow scientists to do remote sensing of the upper atmosphere.

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Fig. 12 Building # 8



Building # 8 consists of two duplex housing units. Each one is a one-story wooden cabin set over concrete piles, with a pitch wood and zinc roof. These wooden housing units are reserved for single visiting scientists. Each cabin consists of a living room, kitchenette, bathroom and bedroom.

Fig. 13 Building # 9



Building # 9 consists of two housing units. Each one is a one-story wooden cabin, sit over concrete piles, with a pitch wood and zinc roof. These wooden housing units are used by visiting scientists and their families. Each unit consists of a living room, kitchenette, bedroom and bathroom.

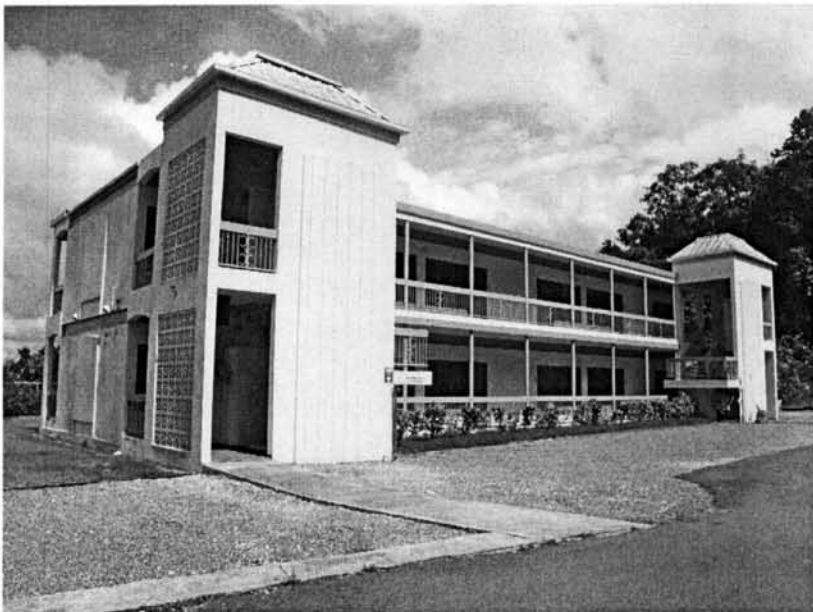
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Fig. 14 Building # 10



This building was constructed in 2002. It is a two-story, concrete guest house that includes twelve rooms for visiting scientists, teachers, conference speakers and other guests.

Fig. 15 Building # 11/12



warehouse. The building has a section designated as Building # 12 that serves as an office facility.

It is an aluminum sliding and steel structure, built in 1967. It is used as a general storage facility. It offers support, maintenance and equipment storage for cables, hardware and parts for the telescope. Parts for the telescope are mainly custom-made, so it is very important to maintain an on-site

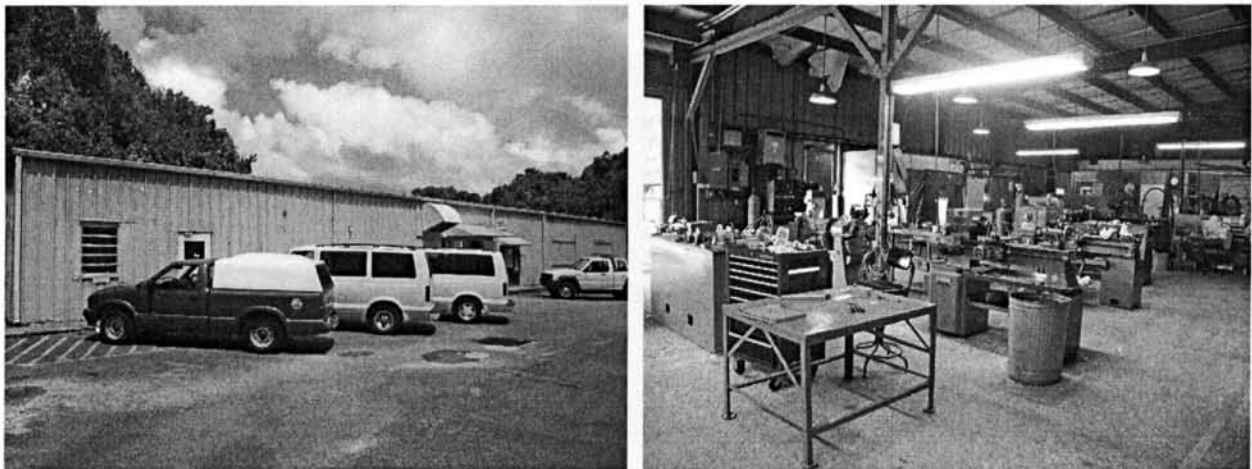
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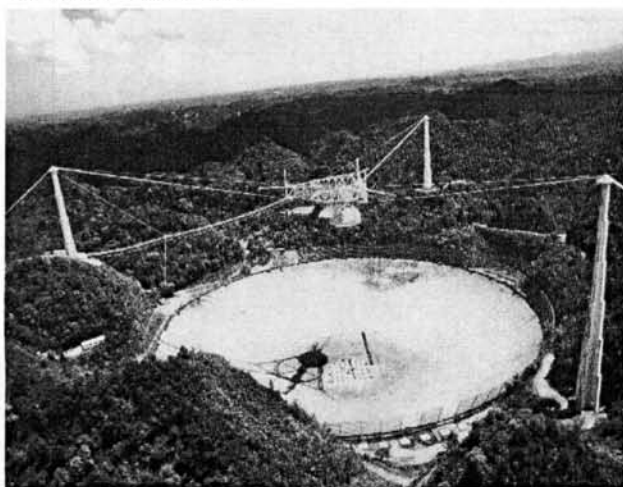
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Fig. 16 Building # 13



Building # 13 it is an aluminum siding and steel structure warehouse, built in 1967. This building houses the machine shop and office quarters for the maintenance crew.

Fig. 17 Main reflector dish.



But the main attraction to the more than one hundred thousand people that visit the site every year is the huge main reflector dish (**Fig. 17**). The reflector has a diameter of 1,000 feet, a depth of 167 feet, and covers an area of about 18 acres. The present reflector surface is made out of almost 40,000 aluminum panels, supported by a network of steel cables strung across a natural limestone sinkhole. Above the dish, at an altitude of 450 feet, is the Gregorian Dome reflector system. The triangular platform and movable feed arm, from where the Gregorian is suspended, weighs 700 tons. At the same time, the platform hangs from 18 cables strung from three reinforced concrete towers. The towers are held in place by additional cables attached to huge anchor blocks.

The lower edge of the triangular frame of the upper platform carries a circular track on which the

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telescope's azimuth arm turns. The arm is a bow-shaped structure 304 feet long, from which the feed system (the receive/send signal structure and the Gregorian enclosure) are suspended, and along which they can move to observe sources as far as 20 degrees from the zenith. By placing the feed system at a particular location, the electronic equipment receives and sends signals to the deepest parts of the known universe.

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National Astronomy and Ionosphere Center
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Narrative Statement of Significance

Fig. 18 Arecibo Radio Telescope



The **National Astronomy and Ionosphere Center** (Arecibo Observatory) has nationwide significance under Criterion A, because of its contribution to the history of the sciences of ionosphere studies and the development of radio and radar astronomy in the United States (**Fig. 18**). The property is also eligible under Criterion C, because it represents a significant work of engineering.

The **Arecibo Observatory** is the site of the world's largest single-dish radio astronomy telescope, capable of examining phenomena that occurs as

close as three kilometers (about two miles) above us, on the Earth's atmosphere, and of probing objects ten billion light-years away, at the very edge of the discernible universe. Thousands of students conducting their graduate research and thousands of scientists, some of whom have produced Nobel Prize winning research, have used the **Arecibo Radio Telescope** for their investigations. In 2001, the Arecibo Telescope was declared an **Electrical Engineering Milestone** by the Institute of Electrical and Electronic Engineers (IEEE) and a **Historic Mechanical Engineering Landmark** by the American Society of Mechanical Engineers (ASME) in recognition of its significance. The contribution of the Arecibo Radio Telescope to the human knowledge of space is, literally, beyond this world. All of this achievements evidence its exceptional importance, thus the property qualifies under Criterion G. After almost fifty years of operations, the **Arecibo Radio Telescope** has become a popular icon, it is recognized as an engineering landmark, and scientist from all over the world compete to use the facility. The **Arecibo Telescope** remains unmatched in its sensitivity and versatility for radio studies of the atmosphere, the solar system, and the universe.

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National Astronomy and Ionosphere Center
Arecibo, Puerto Rico

Historic Background

The Development of Radio Astronomy

Radio astronomy is the study of distant objects in the universe by collecting and analyzing the radio waves emitted by those objects. Just as optical astronomers make images using the light emitted by celestial objects such as stars and galaxies, radio astronomers can make images using the radio waves emitted by such objects, as well as by gas, dust and very energetic particles in the space between the stars. Radio astronomy has been a major factor in revolutionizing our concepts of the universe and how it works. Radio observations have provided a whole new outlook on objects we already knew, such as galaxies, while revealing exciting objects such as pulsars and quasars that had been completely unexpected. From revealing the remnant of the Big Bang to showing the afterglows of the superenergetic Gamma Ray Bursters, radio observers have provided science with insights unobtainable with other types of telescopes. Of the ten astronomers who have won the Nobel Prize in Physics, six of them used *radio* telescopes for the work that won them the Nobel. Radio telescopes today are among the most powerful tools available for astronomers studying nearly every type of object known in the universe.⁵

Fig. 19 Karl Jansky



The science of radio astronomy began with Karl Jansky as a result of an accident (**Fig. 19**). Karl Guthe Jansky was born in Norman Oklahoma October 22, 1905 (d.Feb.14, 1950), graduated with a degree in physics from the University of Wisconsin, and joined the staff of the Bell Telephone Laboratories in Holmdel, NJ, in 1928. In 1930, Bell Labs was in the process of investigating the origin of the static that was plaguing ship-to-shore and trans-Atlantic radio transmissions. Jansky was assigned the job of investigating the sources of static. He built an antenna, designed to receive radio waves at a frequency of 20.5 MHz (wavelength about 14.5 meters). It was mounted on a turntable that

⁵ National Radio Astronomy Observatory (NARO). *Radio Astronomy. Contributing to American Competitiveness*. October 2006.

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allowed it to rotate in any direction, earning it the name "Jansky's merry-go-round". By rotating the antenna, one could find what the direction was to any radio signal.

After recording signals from all directions for several months, Jansky identified three types of static: nearby thunderstorms, distant thunderstorms, and a faint steady hiss of unknown origin. Jansky spent over a year investigating the third type of static. Human-made noise was ruled out when Jansky noticed that the source of the faint noise seemed to change with the time of day. It was found to have a rotational period of 23 hours and 56 minutes, exactly the same as the sidereal rotation period of the earth. Jansky concluded that the radio noise was of extraterrestrial origin. It rose and fell once a day, leading Jansky to think at first that he was seeing radiation from the Sun.

But after a few months of following the signal, the brightest point moved away from the position of the Sun. The signal repeated not every 24 hours, but every 23 hours and 56 minutes. This is characteristic of the fixed stars, and other objects far from our solar system. He eventually figured out that the radiation was coming from the Milky Way and was strongest in the direction of the center of our galaxy, in the constellation of Sagittarius. The discovery was widely publicized.

Jansky had discovered what Bell Labs needed to know—and much more. He suggested building a 31-meter (100-foot), disc-shaped antenna to conduct further investigations into cosmic radio waves. With the US in the midst of the Great Depression, however, this project was dismissed as an unnecessary expense. Nonetheless, although slowly, other people started to appreciate Jansky's work. Among these was Grote Reber.

Grote Reber was a radio engineer and avid amateur "jam" radio operator in Wheaton, Illinois. In the 1930s he read about Karl Jansky's 1932 discovery of natural radio emissions coming from outer space. As an amateur operator, Reber had won awards and communicated with other amateurs around the world, and later wrote that he had concluded "there were no more worlds to conquer" in radio.⁶

⁶ G. L. Verschuur. *The Invisible Universe Revealed. The Story of Radio Astronomy*. New York: Springer-Verlag, 1987.

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Fig. 20 Grote Reber's telescope in his back yard in Wheaton, Illinois, about 1938.⁷



Learning of Jansky's discovery gave Reber a whole new challenge that he attacked with vigor. Analyzing the problem as an engineer, Reber concluded that what he needed was a parabolic-dish antenna, something quite uncommon in the 1930s. In 1937, using his own funds, he constructed a 31.4-foot-diameter dish antenna in his back yard. The strange contraption attracted curious attention from his neighbors and became something of a minor tourist attraction (**Fig. 20**). Reber succeeded in detecting "cosmic static" in 1939.

In 1941, Reber produced the first radio map of the sky, based on a series of systematic observations. His radio-astronomy work continued over the next several years. Though not a professional scientist, his research results were published in a number of prestigious technical journals, including *Nature*, the *Astrophysical Journal*, the *Proceedings of the Institute of Radio Engineers* and the *Journal of Geophysical Research*.⁸

⁵ Reber's original dish antenna now is on display at the National Radio Astronomy Observatory's site in Green Bank, West Virginia, where Reber worked in the late 1950s. All of his scientific papers and records as well as his personal and scientific correspondence are held by the NRAO.

⁸ Reber also received a number of honors normally reserved for scientists professionally trained in astronomy, including the American Astronomical Society's Henry Norris Russell Lectureship and the Astronomical Society of the Pacific's Bruce Medal in 1962, the National Radio Astronomy Observatory's Jansky Lectureship in 1975, and the Royal Astronomical Society's Jackson-Gwilt Medal in 1983.

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The technology developed during World War II quickly led to enormous progress in radio astronomy. Sensitivity of radio detector systems was increased with better electronics and bigger telescopes. A higher angular resolution (meaning sharper vision) was achieved through novel techniques developed by radio astronomers. They also developed new ways to improve their ability to map the details of radio sources they observed. With their greatly increased capabilities, scientists discovered new sources of radio emission. For example, in 1963 Maarten Schmidt of the California Institute of Technology discovered quasars as a result of his research on radio galaxies. Subsequent radio observations of quasars led to the discovery of pulsars by Jocelyn Bell and Tony Hewish in 1967. Pulsars are spinning neutron stars that sling lighthouse-like beams of radio waves or light around as they spin.⁹

One of the most astonishing accomplishments done by radio astronomy was the discovery of the residual remnants of the Big Bang. When the intellectual history of the 20th century is written, a few achievements will tower over all. Albert Einstein's theory of general relativity will be one; the laws of quantum mechanics will be another. The so-called Big Bang Theory of the origin of the universe will be a third.

In the 1950s, there were two theories to the origin of the universe. The first was called the Steady State Theory. It had been put forward by Hermann Bondi, Thomas Gold and Fred Hoyle and held that the universe was homogeneous in space and time and had remained like that forever, essentially, that the universe existed in "a steady state". In the 1950's Steady State Theorists took a heavy blow when radio galaxies were discovered showing that, consistent with Big Bang Cosmology, galaxies evolved and were very active billions of years ago.

The rival, more controversial theory sought to incorporate the expansion of the universe into its framework. Edwin Hubble had shown in 1929 that galaxies are moving away from one another at remarkable speeds, implying that the space between galaxies is constantly expanding. A few physicists led by George Gamow had taken this notion and argued that the separation between galaxies must have been smaller in the past. If one stretched the idea to the limit, it meant that the universe had been infinitely dense at one point sufficiently

⁹ William Brysong. *A Short History of Nearly Everything*. New York: Broadway Books, 2003.

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back in time. Using the laws of physics, Gamow and his colleagues were able to show that the point—which was also infinitely hot—corresponded to the moment of creation. Everything in the universe had emerged from this incredibly dense and hot state in a cataclysmic and singular event that astronomers call “the Big Bang.” The Big Bang Model is a broadly accepted theory for the origin and evolution of our universe. It postulates that 12 to 14 billion years ago, the portion of the universe we can see today was only a few millimeters across. It has since expanded from this hot dense state into the vast and much cooler cosmos we currently inhabit.

The Big Bang model was a natural outcome of Einstein's General Relativity as applied to a homogeneous universe. However, in 1917, the idea that the universe was expanding was thought to be absurd. So Einstein invented the cosmological constant as a term in his General Relativity theory that allowed for a static universe. In 1929, Edwin Hubble announced that his observations of galaxies outside our own Milky Way showed that they were systematically moving away from us with a speed that was proportional to their distance from us. The more distant the galaxy, the faster it was receding from us. The universe was expanding after all, just as General Relativity originally predicted.

Hubble's expanding universe was one of the most profound observations of the 20th century. This expansion implies the universe was smaller, denser and hotter in the distant past. When the visible universe was half its present size, the density of matter was eight times higher and the cosmic microwave background was twice as hot. When the visible universe was one hundredth of its present size, the cosmic microwave background was a hundred times hotter (273 degrees above absolute zero or 32 degrees Fahrenheit, the temperature at which water freezes to form ice on the Earth's surface). In addition to this cosmic microwave background radiation, the early universe was filled with hot hydrogen gas with a density of about 1000 atoms per cubic centimeter. When the visible universe was only one hundred millionth its present size, its temperature was 273 million degrees above absolute zero and the density of matter was comparable to the density of air at the Earth's surface. At these high temperatures, the hydrogen was completely ionized into free protons and electrons.

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Since the universe was so very hot through most of its early history, there were no atoms in the early universe, only free electrons and nuclei (nuclei are made of neutrons and protons). The cosmic microwave background (CMB) photons easily scatter off of electrons. Thus, photons wandered through the early universe, just as optical light wanders through a dense fog. The accurate finding of the CMB was considered to be an important test of the Big Bang theory.

Fig. 21. Dr. Robert Wilson (left) and Dr. Arno Penzias.



In 1965, the conflict between the two theories (the Big Bang and the Steady State Theory) was resolved by Dr. Arno Penzias and Dr. Robert Wilson, from the Bell Laboratory (**Fig. 21**). They had been using an ultra-sensitive microwave receiving system to study radio emissions from the Milky Way when they found an unexpected background of radio noise with no obvious explanation. It came from all directions and, after repeated checks, it appeared to emanate from outside the galaxy. Penzias

and Wilson consulted with Princeton physicist Robert H. Dicke, who had theorized that if the universe was created according to the Big Bang theory, a cosmic microwave background (CMB) radiation at 3-degree Kelvin would exist throughout the universe. Dicke visited Bell Labs and confirmed that the mysterious radio signal Penzias and Wilson detected was, indeed, the cosmic radiation that had survived from the very early days of the universe. It was proof of the Big Bang. Arno Penzias and Robert Wilson's discovery of the CMB gained them a Nobel Prize in 1978.¹⁰

The contribution of radio astronomy to other applications has been more than the basic technology transfer from one discipline to another. In addition to the greater understanding of the physical processes in the universe gleaned from radio astronomy that has been a catalyst for basic and applied research in other fields, the technical requirements driven by the construction of radio astronomy instruments has both driven new technological

¹⁰ Edward Harrison. *Cosmology: The Science of the Universe*, 2nd ed. Cambridge: Cambridge University Press, 1999. See also, Michael Lemonic, *Echo of the Big Bang*. Princeton, NJ: Princeton University Press, 2003.

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advances and pushed existing technologies. Radio astronomy has contributed significantly to the development of sensitive microwave antennas and receiving systems, data analysis and visualization methods, computer processing technology, time and frequency standards, navigation and geodesy. Technical innovations developed or enhanced for radio astronomy are found in communication antennas, transistor design, cryogenic coolers, medical and scientific imaging, atomic clocks and GPS navigation, precision spacecraft navigation, location of cell phone, 911 calls, laser rangefinders, and quasi-optical applications.¹¹

Beyond the contributions of radio astronomy to the advancement of technology, the understanding of the universe stills its main concern. In this search, the telescope is the essential tool. Radio telescopes vary widely, but they all have two basic components: a large radio antenna (or arrays of antennas) and a sensitive radiometer or radio receiver. The sensitivity of a radio telescope, the ability to measure weak sources of radio emission, depends on the area and efficiency of the antenna and the sensitivity and bandwidth of the radio receiver used to amplify and detect the signals. Because cosmic radio sources are extremely weak, radio telescopes are usually very large and only the most sensitive radio receivers are used. Moreover, weak cosmic signals can be easily masked by terrestrial radio noises, and great effort is taken to protect radio telescopes from human-generated interference.

The ability of a radio telescope to distinguish fine detail in the sky depends on the wavelength of observations and the size of the telescope. Because radio telescopes operate at much longer wavelengths than do optical telescopes, radio telescopes must be much larger than optical telescope to record the same level of detail. At radio wavelengths, the distortions introduced by the atmosphere are less important than at optical wavelengths, and so the theoretical resolution of a radio telescope can be achieved even for the largest dimensions. Radio signals from a single source can be measured over large distances without distortion, and it is possible to build radio telescopes of essentially unlimited

¹¹ National Radio Astronomy Observatory (NARO). *Radio Astronomy. Contributing to American Competitiveness*. October 2006

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dimensions. This has led radio astronomers to solve engineering problems related to the construction of very large telescopes and arrays of smaller telescopes.

Some of these radio telescopes and antennas have already reached high levels of recognition, like the Horn Antenna and the Reber Radio Telescope.¹² The first one is associated with the research conducted by Dr. Arno Penzias and Dr. Robert Wilson in the 1960s (**Fig 22**). The second one was the homemade antenna built by Grote Reber in the 1930s, which today sits as a historic relic (painted in red, blue and white) at the site of the Green Bank Telescope in West Virginia (**Fig. 23**).

Fig. 22 The horn antenna used by Penzias and Wilson, 1965.

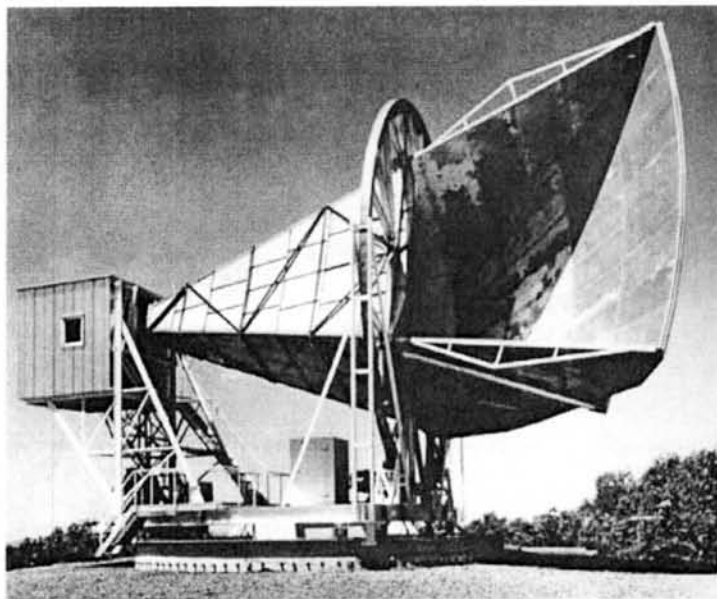
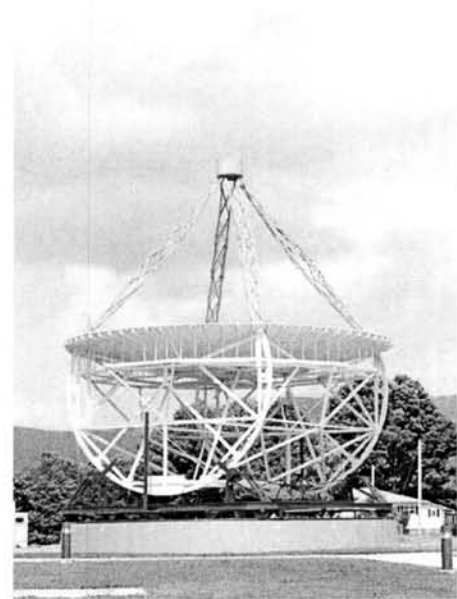


Fig. 23 Reber's antenna at West Virginia.



¹² Harry A. Butowsky. *Astronomy and Astrophysical National Historic Landmark Theme Study*. National Park Service. May 1989. Pp 227 and pp. 303.

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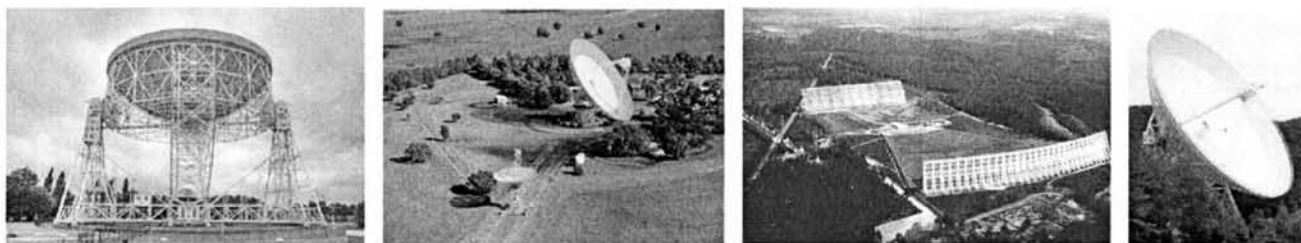
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But the modern radio telescopes have long surpassed these pioneers in complexity, sensitivity and size. After the initial pioneering work of Karl Jansky and Grote Reber, radio astronomy evolved like any science, with instruments and activity in many countries. In particular the English built the first of the large, fully steerable antennas at Jodrell Bank, which was completed in time to detect and decode Sputnik's signal. That Soviet demonstration of technical capacity helped to spur US investment in radio facilities. The **Arecibo Telescope** opened in 1963, and so is part of this second wave of large, single-aperture radio telescopes. It was built contemporaneously with the Parkes 210-foot in Australia, and the French Nacay telescope. These were shortly followed by the 300-foot at Effelsberg in Germany (**Fig. 24**)

Fig. 24 From left to right, the Lovell telescope at Jodrell Bank, the Parkes Observatory, the Nacay telescope and the radio telescope at Effelsberg.



The radio telescope at Jodrell Bank in England (the Lovell Telescope) was constructed in the mid 1950s. At 250-foot in diameter, it was the largest steerable dish radio telescope in the world; it is now the third largest.¹³ The Parkes Telescope, located at New South Wales, in Australia, was completed in 1961. The primary observing instrument is a 64-meter movable dish, and it has operated almost continuously to the present day. The Parkes Observatory was one of several radio antennas used to receive images of the Apollo 11 moon landing in July 1969.¹⁴ The French Decimetric Radio Telescope was built on a 150-hectare site acquired in 1953 at Nancay, 200 km due south of Paris, France. The completed instrument was dedicated by the President of the French Republic, Charles de Gaulle, in 1965. Last, the Effelsberg 100-meter radio telescope, inaugurated in 1972, it was, for nearly thirty years, the

¹³ Jodrell Bank Centre for Astrophysics. The University of Manchester. <<http://jb.man.ac.uk/>> May 2008.

¹⁴ Australia Telescope National Facility, Parkes Observatory. <<http://parkes.atnf.csiro.au/>> 2007.

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world's largest fully steerable telescope, until the opening of the Green Bank Telescope in West Virginia.¹⁵

Fig. 25 The VLA site in New Mexico.

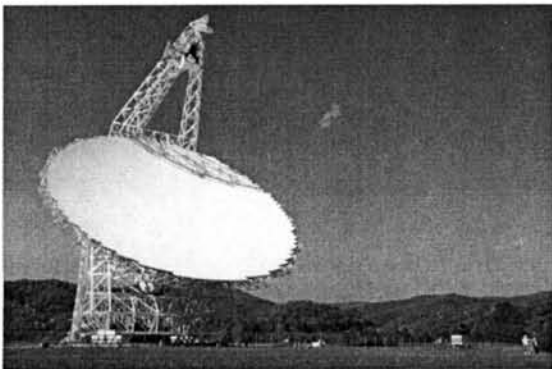
Among the best examples of modern radio telescopes in the United States today are the



Very Large Array (VLA) and the Green Bank Telescope. The Very Large Array is a collection of 27 radio antennas located at the National Radio Astronomy Observatory (NRAO) site in Socorro, New Mexico (**Fig. 25**). Each antenna in the array measures 25 meters (82) feet in diameter and weighs about 230 tons. The Y-shaped array can be arranged into 4 different configurations, depending on the distance between the antennas. The VLA is an interferometer, which means that the data from each antenna can be combined electronically so that the array effectively functions as one giant antenna.

Dedicated in 1980, the VLA is used by astronomers from around the world to study everything from black holes to planetary nebulae.¹⁶

Fig. 26. The GBT in West Virginia.



The Robert C. Byrd Green Bank Telescope (GBT) is the world largest fully steerable radio telescope (**Fig. 26**). It is located in Green Bank, West Virginia. The GBT achieved "first light" in August 2000. The GBT stands 485 feet-tall. Its dish measures 100 (330 feet) meters. Unlike conventional radio telescopes, which have a series of supports in the middle of the surface, the GBT's aperture is unblocked so incoming radiation meets the

¹⁵ Max Planck Institute for Radio Astronomy, Bonn. Radio Telescope Effelsberg. <<http://mpifr-bonn.mpg.de/English/radiotelescope/index.html>>

¹⁶ National Radio Astronomy Observatory. Very Large Array. <<http://vla.nrao.edu/>>17 October 2007.

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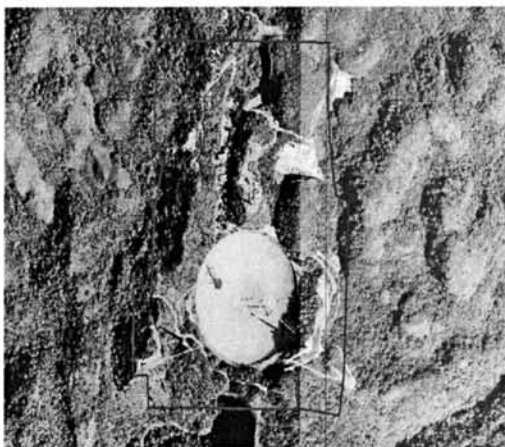
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surface directly. This design increases the useful area of the telescope and eliminates reflection and diffraction that ordinarily complicate a telescope's pattern of response. The GBT weighs 16 million pounds and can be pointed with an accuracy of one arcsecond, or the equivalent to the width of a single human hair seen six feet away. Composed of 2,004 metal panels, the telescope's surface covers almost two acres. In 2000, the GBT made detail radar images of the cloud-shrouded surface of Venus and of a tiny asteroid that passed near the Earth. These were the first scientific contributions of the GBT. But the GBT was not working alone at that time. Its first contributions were done in combination with the world's most powerful radar, the **Arecibo Radio Telescope** in Puerto Rico.¹⁷

The Arecibo Radio Telescope

Fig. 27 View of the 118-acre lot.



The **National Astronomy and Ionosphere Center**, the world's largest and most powerful telescope for radar and radio astronomy is set amid the limestone hills of the northwestern town of Arecibo, Puerto Rico (**Fig. 27**).¹⁸ The construction of the Observatory began by August 1960. Three years later, the **Arecibo Ionospheric Observatory** (AIO) was fully operational. The observatory sits on a 48-hectare (118 acres) site outside the town of Arecibo. The site selected was a natural depression (to minimize excavation for the projected dish), located away from populous areas and air lanes, in order to reduce radio interference.

¹⁷ National Radio Astronomy Observatory. Robert C. Byrd Green Bank Telescope. <<http://gb.nrao.edu/gbt/>>27 March 2008.

¹⁸ Radio astronomy deals with the observation of radio frequency signals emitted by objects in space. Radar astronomy is an active effort of bouncing radar signals off objects, so the signals can be analyzed to study the object's composition. Radio astronomy and radar astronomy are essential parts of the Arecibo Observatory's mission.

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The telescope was designed under contract with the U.S. Air Force Cambridge Research Laboratories and was completed in 1963, at a total cost of \$9.3 million from the Advanced Research Projects Agency of the Department of Defense. In 1974, an upgrade to the system cost an additional \$9 million. The most recent upgrade was completed in 1997, with the addition of the Gregorian Dome reflector system, a new radar transmitter and ground screen that cost \$25 million. If the entire facility were to be built today, it would cost over \$100 million.

Fig. 28 William E. Gordon



William E. Gordon, a professor of electrical engineering at Cornell University during the 1950s, conceived the Arecibo radar (**Fig. 28**). During the Second World War, Gordon was stationed at the Aleutian Island in the Pacific. Gordon was one of the meteorologists working in the Radar Section in the Aleutians. One recurrent problem in the Radar Section was the many false alerts that occurred when military radar facilities received signals that looked like Japanese ships. It was later realized that these signals were a refraction of

radar waves from islands far beyond the horizon. This phenomenon, related to the characteristics of the atmosphere, promulgated the creation of a strong meteorology body in the United States Air Force. Among those young scientists interested in the study of the scattering of radio waves was William E. Gordon.

At the end of WWII, Gordon accepted a position at the University of Texas, where the engineering research lab was deeply involved in studying radio refraction in the troposphere.¹⁹ By 1947, Gordon transferred to Cornell to pursue his doctorate degree. At Cornell, Gordon's interest in radio propagation was extended to include radio astronomy. His Ph.D. thesis was developed in the subject that finally took him to think out the Arecibo Radio Telescope: the explanation of the characteristics of radio scattering in the troposphere. Gordon wanted to study the properties of the Earth's upper atmosphere, the ionosphere, and thought that he could use a radar system to measure the density and temperature in this difficult region. Gordon's calculations estimated that an antenna of approximately 305 meters in diameter was necessary to overcome the crucial obstacle of using radio waves for space exploration: the

¹⁹ William E. Gordon. Copy of manuscript titled "Self-interview". December 14, 1979. pp. 1-5.

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weakness of cosmic signals. In order to collect these weak signals, an enormous sensitive radar was needed.

By the spring of 1958, Gordon was involved in selling his idea for the construction of a huge antenna to study the highest levels of the Earth's atmosphere. He was able to involve both Cornell's Electrical Engineering Department and the Civil Engineering Department in his "crusade." Eventually, the Physics Department was also brought into the project. By the end of 1958, the theoretical postulates of the future radar were developed. The Physics Department contributed with very strong suggestions and theories about how such huge and sensitive radar could be successfully used to study space well beyond the ionosphere.²⁰

Even with the brilliant supporters at Cornell, Gordon realized the need to incorporate an outside company with the actual capabilities of constructing the huge antenna. The selection proceeded by open competition. Three companies were initially selected; each received \$25,000 and the same amount of time to present their designs. Once the designs were turned in, a group of experts from Cornell, other research facilities and the U.S. Air Force selected the structural design from Thomas Kavanaugh (from the New York firm Praeger, Kavanaugh and Waterbury) as the winner.²¹

At the very same time, Gordon and his associates at Cornell were looking for a project sponsor. It was clear that looking for possible sponsors required the assistance of a government agency. The only agency that was likely to have funds, in the quantity that was needed, was the Department of Defense (DoD). The DoD had what was called the Advanced Research Projects Agency (ARPA). This agency was geared to support advanced ideas with the potential for defense applications. The ARPA was a relatively new agency not tied down by a lot of regulations and red tape. They were fairly free to move in directions that were new and different and, perhaps, even a bit far out. They were the appropriate agency to sponsor the construction of a 1000-foot diameter dish, something considered impossible, by a lot of outsiders, in the late 1950s. Through hard and continuous sale of the project, Gordon was able

²⁰ Ibid. pp. 20 -30.

²¹ T.C. Kavanaugh and D.H. Tung. Construction Division. American Society of Civil Engineers. 91. (No. C01), 69 (1965).

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to get the financial and technical support from ARPA.²² Professor Gordon was appointed to head the Cornell twenty-five men team responsible for the technical aspects of the construction of the huge facility.

In addition to the technical details and financial sponsorship, the other task in Gordon's mind was selecting a location for the future observatory. The fact that the antenna ought to be supported by the ground was already established in Gordon's estimates. An effort was put in finding the perfect site. There were particular requirements: it had to be near the equator, since there the radar (capable of studying the ionosphere) could also be used to study nearby planets. Furthermore, a site with moderate temperature changes and low winds was desirable for the stability of the instrument — to minimize the expansion and contraction of the structure and to reduce swaying of the suspended feed. The geological formation of the future site was also a very important factor. Gordon contacted Dr. Donald J. Belcher, a professor of Civil Engineering at Cornell and an expert in mapping and aerial photography. Dr. Belcher was asked to locate an appropriate "hole in the ground." After considering such places as Hawaii, Mexico, Texas, Cuba, and some smaller islands in the Caribbean, Puerto Rico was selected.²³

Fig.29 View of the site selected by Belcher and Gordon in June 1960.



Dr. Belcher studied the karst topography of northern Puerto Rico and identified three possible sites, one in the Municipality of Florida, one in San Sebastian and the third in Arecibo. The latter was chosen after an on-site inspection conducted by Gordon and Belcher.²⁴ (Fig. 29)

The physical considerations were combined with political ones. Puerto Rico, besides having the optimum geological site, had the advantage of being a politically safe and stable United States territory. When informed, the local

²² Op. Cit. pp. 24 –25.

²³ *El Mundo*. April 14, 1962. pp. 5

²⁴ Daniel R. Altschuler. Unpublished paper titled "The National Astronomy and Ionosphere Center's (NAIC) Arecibo Observatory in Puerto Rico, 2000. Dr. Altschuler, presently part of the Staff, was Director of the Observatory from 1994 until 1998.

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government embraced the project with enthusiasm. Cornell's selection of Puerto Rico as the site for this monumental construction fitted perfectly with the local government's plans. At the time, the social and economic policies of Operation Bootstrap were taking off. The government representatives were involved in breaking the island's dependency on the agricultural production by rapidly re-orienting the economy toward the light and heavy industry. The projection of Puerto Rico as a safe heaven for American and international investment and the creation of the showcase image of an Island immersed in the new high-speed technology were essential to *Manos a la Obra* (Operation Bootstrap). The local government made great efforts to facilitate the construction: the donation of public land for the site; the use of public resources for the building of roads to the hardly accessible area in the mountain range; special escorts for equipment arriving from the United States to speed-up the delivery process to the construction site; laws to prohibit the installation nearby of any electronic facilities that could interfere with the radar's operation, and other helpful steps.

By 1960, the three main considerations for the construction of the **Arecibo Observatory** came together: the formation of the "braintrust" with the technical know-how, the source of financial support, and the selection of an appropriate site. By the summer of 1960, the construction permits were acquired, as well as the land and some of the surrounding buildings. The Air Force Cambridge Research Laboratory divided the project into two parts: the antenna and the support facilities. Cornell's personnel were responsible for the construction of the antenna and the Air Force Corps of Engineers was in charge of the support facilities. The support facilities included access roads to the site, a power plant, a water reservoir, buildings for the antenna's operation and other activities such as a machine shop area, housing, a cafeteria, a library, among others.²⁵ Gordon and his Cornell associates, in conjunction with Kavanaugh and his engineers, handled the radar and technical side of the project. The work was divided among twelve subcontractors.²⁶

²⁵ Neftalí Rivera Castillo. First draft of paper titled "*Spring of 1958: The Conception of the Arecibo Observatory*". University of Western Sydney. Topics in the History of Astronomy. April 2001. pp. 6.

²⁶ William E. Gordon. *Self-interview*...pp. 54.

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Fig. 30 Blasting the site, March 7, 1961.



The construction of the entire site was an engineering challenge. Even the natural sinkhole had to be properly adjusted. Despite the general shape of the sinkhole, nature had to be improved upon by excavating about 270,000 cubic yards of soil. The contractors also had to place 200,000 cubic yards of compacted fill to shape the excavation. **(Fig. 30)**

Fig. 31 One of the anchors being built, Jan 19 1962.



Another complex and interesting aspect of the construction had to do with the erection of the towers. Cables from three towers hang the feed support structure. Each of the three concrete towers, two of them 265 feet high and the third 365 feet high, was poured in a slip form that was raised at a rate of about 9 inches/hour so that new concrete was exposed about five hours after it was poured. A 265-foot tower took about 375 hours to pour, approximately 16 days of continuous pouring. A total of 9,100 cubic yards of concrete were used, the equivalent of 1,000 standard cement trucks. A concrete production plant was installed on site. The towers are labeled T4, T8, and T12 following the numbers on the face of a watch, T12 being the one due north ²⁷ **(Fig. 31)**.

²⁷ To build in a slip form means that the form is built, the concrete is poured, and before the concrete is finally set, the form is slipped upward. This is supposed to amount to a single pour of great amount of concrete for every single tower.

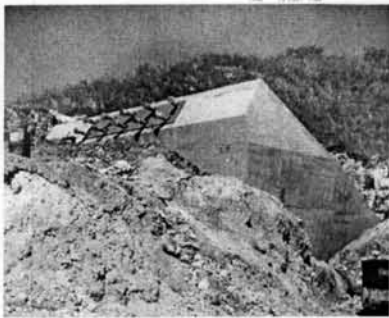
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Fig. 32. Anchor block.



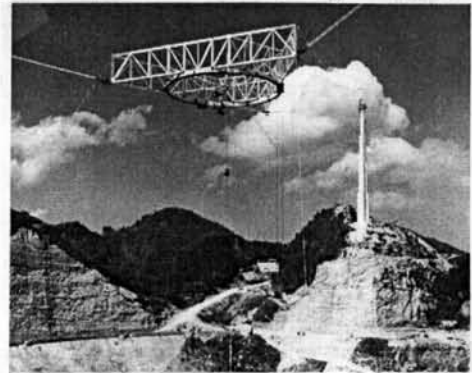
The towers are held in place by additional cables attached to immense concrete anchor blocks (**Fig. 32**). Another big feature of the construction was the building of the triangular support structure (the feed platform), suspended 150 meters above the ground. The feed platform had a total weight of 550 tons.²⁸ It was suspended from four three-inch diameter cables (that run from each platform corner to the top of the corresponding tower) and five three-and-a-quarter inch diameter cables (that run from the top of the towers to the concrete anchors). The structure was built in the bottom of the bowl. The platform

began to be lifted at the end of October 1962, proceeding at about 50 feet per hour. This was the most critical operation of the entire project.²⁹ After the lift, the three-inch diameter main cables, which had been hanging from the three corners of the platform, were attached to the top of the towers. Next, the ring girder, holding the azimuth track and the feed arm, was raised to the platform. By August 1963, the line feed was lifted. (**Figs. 33-35**).

Fig. 33 Building the triangular platform in the ground, June 15, 1962.



Fig. 34 Raising the triangular platform, February 21, 1963.



²⁸ The weight was later increased to about 900 tons after the Gregorian upgrade in the 1990s.

²⁹ Daniel R. Altschuler. *The National Astronomy...*pp.10.

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Fig. 35 August 14, 1963, the 430-MHz line feed is lifted.

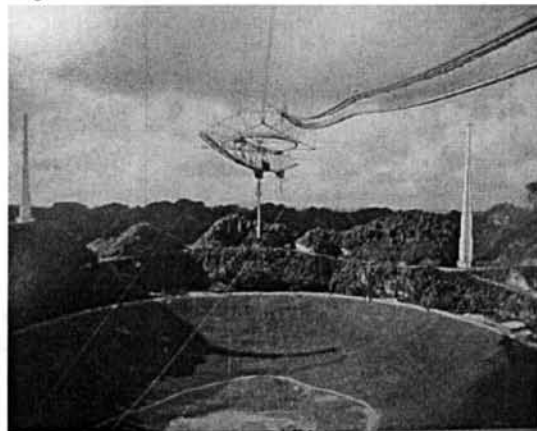


Once the triangular platform was in place, the reflector subcontractor (Farnsworth) proceeded with the construction. When finished, by 1963, the reflector surface was made of a half-inch-square wire mesh, suspended above the ground from cables that maintained its spherical surface (**Fig 36**). The mesh wire was not woven. All the wires in one direction were laid on top of others running in the opposite direction. They were welded together at every joint to form a stiff hardware "cloth." To this day, the reflector (which spherical, not parabolic) is still that part of the site that catches the attention of every visitor. The dish has a diameter of 305 meters (1,000 feet), a depth of 51 meters (167 feet) and covers an area of about 8 hectares (18 acres), or the equivalent of 26 football fields. (**Fig. 37**).

Fig. 36 Network of cables to hold the mesh layout, February 14, 1963.



Fig. 37 Partial view of the 1963 wire mesh reflector.



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Fig. 38 From left, Governor Muñoz Marín, W.E. Gordon and Major General Ostrander on Nov 1, 1963.



The facility was completed by August of 1963. The official inauguration was held on November 1st, in front of a large audience. The Governor of Puerto Rico, Luis Muñoz Marín, was present at the historical occasion (**Fig. 38**). Muñoz Marín, highly impressed by the Observatory, commented that the site should be considered a **"new wonder of the world."**³⁰ The Governor was not far from the truth.

With the most updated technology of its time, the **Arecibo Observatory** was ready to

become our biggest "ear" to listen to what Carl Sagan used to call the "harmony of the Cosmos."³¹

Upgrading the Arecibo Observatory

On October 1, 1969, the National Science Foundation took over the facility from the Department of Defense and the Observatory became a national research center. In 1971, the observatory was renamed the National Astronomy and Ionosphere Center (NAIC). By 1969, Cornell and the National Science Foundation considered the idea of upgrading the reflector. The contract was awarded to LTV ElectroSystems, Inc., which subsequently became E-System, Inc., of Dallas, Texas.

³⁰ El Mundo. November 2, 1963. p. 1.

³¹ Carl Edward Sagan (1934 – 1996). American astronomer and astrobiologist and a highly successful popularizer of astronomy, astrophysics and other natural sciences. He is world-famous for writing and presenting the award-winning 1980 TV series *Cosmos: A Personal Voyage*, which has been seen by more than 600 million people, making it the most widely watched PBS program in history. During his lifetime, Sagan published more than 600 scientific papers and popular articles and was author of more than 20 books.

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To minimize cost, the E-System design centered on retaining as much as possible of the existing reflector. Only the old mesh surface was removed, to be replaced by 38,778 individually installed aluminum plates. The panels, each about 40 inches by 80 inches, are supported on the telescope's original cables system, which was reinforced with 29 new primary suspension cables running north-south, underneath the reflector surface. The three miles of new steel cables, each an inch in diameter, keep the reflector from changing its shape as temperatures fluctuate and winds blow. IBEC Corporation of Puerto Rico carried out the installation of the cables and panels under subcontract to E-System.

Fig. 39. Aluminum network that holds the "dish".



The thousands of panels were assembled in a special factory, built for this purpose on the Observatory grounds. The factory allowed for close contact between manufacturing and installation personnel and eliminated the need to transport the fragile panels over the tortuous roads between the town of Arecibo and the Observatory. It processed some 300 tons of aluminum to cover the 18-acre dish with a new surface, consisting of carefully formed, perforated sheets of aluminum, stapled to aluminum frames. This new frame consists of 277

miles of aluminum (**Fig. 39**).

Fig 40. Panel number 38,788 is placed on the reflector on November 1973.



The first new panel was installed in February 1973, the 38,778th in November of the same year (**Fig. 40**). At the maximum rate of panel production, an area of the new reflector surface equal to the collecting area of a 85-foot telescope was being manufactured each day. This means that in as little as three months' time the factory produced as much new reflector surface as had existed in the combined collecting areas of all other telescopes in the world.

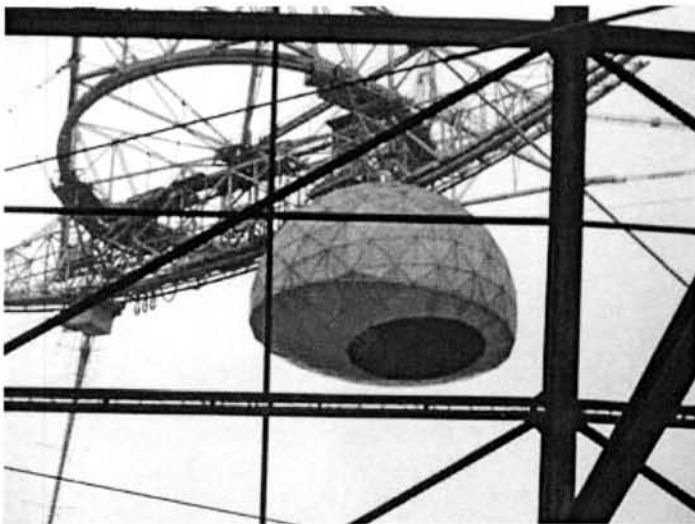
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Fig. 41. The Gregorian as view from under the "dish".



The latest upgrade was done in 1997. The main change was the addition of the Gregorian dome.³² Suspended 137 meters (450 feet) above the dish, the Gregorian dome contains a new high-tech system that enormously increases the range and the sensitivity of the radar. It uses two reflecting surfaces or mirrors, one 22 meters in diameter, the other 8 meters. Besides the reflectors, the dome contains the radar transmitter and microwave receivers. The larger mirror collects the radio waves bounced off Arecibo's main spherical dish reflector, and relays them to the smaller reflector. The second mirror converges the

beam to a focal point where it enters a collecting device called a "feed horn," which passes the signal to the receivers. The dome is six stories high and weights 68 metric tons (75 tons) (Fig. 41).

The scale of the reflecting surface or radio mirror astounds those who see the **Arecibo Radio Telescope** for the first time. It is the size of this reflector that makes the **Arecibo Observatory** so useful to scientists. A larger size means a larger collecting area, which allows weaker radio signals to be detected. It is the largest curved focusing antenna on the planet, giving it unrivaled sensitivity, and allowing those who use it to study weaker radio-emitting objects and to make more accurate measurements of particularly interesting sources.

³² The reflector is named in honor of James Gregory, a seventeenth century British mathematician and inventor of the first practical reflecting telescope.

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The most significant contributions of the Arecibo Radio Telescope ³³

The numerous and significant contributions of the **Arecibo Radio Telescope** to the science of astronomy in the United States (and the entire world) give this property its exceptional character and its national level of significance. Among these, in approximately chronological order, are:

- ❖ Mercury's rotation rate was determined by Arecibo to be fifty-nine days in 1965, rather than the previously estimated 88 days. This was one of the first accomplishments of the Observatory. Mercury is both small and close to the Sun, which makes optical observation from Earth difficult: these were the only kind possible before the Arecibo radar obtained this result.
- ❖ The first pulsar in a binary star system was discovered at Arecibo in 1974. This in turn led to the physical demonstration of the reality of gravitational waves, which are a major prediction of Albert Einstein's theory of general relativity. By 1999 the orbital decay of PSR B1913+16 in this binary system, obtained from twenty-five years of timing measurements, agreed with the predictions of General Relativity to better than 1%. This demonstration is perhaps the single most important physics result in Arecibo, truly a landmark result in the history of science: it earned astronomers Russell Hulse and Joseph Taylor the 1993 Nobel Prize in Physics. Further, this demonstration provides mankind with a whole new approach for exploring the Universe, by directly detecting gravitational waves from cosmic sources. Several hundreds of millions of dollars have since been spent on LIGO (Laser Interferometer Gravitational-wave Observatory) and LISA, its projected space-based counterpart, to exploit this non-photonic channel for exploring the cosmos.

³³ The information in this section is ascribable to the following personnel: Dr. William E. Gordon, Professor Emeritus, Cornell University, Founding Father and first Site Director of the Arecibo Observatory; Dr. Robert B. Kerr, Arecibo Observatory Site Director; Dr. Brian Murray Lewis, Arecibo Observatory Astronomy Department Director; Dr. José L. Alonso, former *Angel Ramos Foundation Visitor Center* Director; Dr. Paulo Freire, Arecibo Observatory Research Associate, Astronomy and Dr. Michael C. Nolan, Arecibo Observatory, Research Associate, Astronomy.

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- ❖ The mapping of the Moon, Venus, Mars and Mercury. The **Arecibo Telescope** is used to study distant targets, like the moon and inner planets, by analyzing radar echoes from them. Measurements of the absolute delay of the radar echo and the Doppler shift in frequency have given much more accurate information about the orbits of these bodies. Studies of the radar echoes from Mercury, Venus, Mars and the moon have provided valuable information about the characteristics and average smoothness of their upper surfaces layers.

- ❖ The first millisecond pulsar was discovered at Arecibo in 1982. This spins 640 times a second about its axis, 20 times faster than any other observed up to that date: it is still the second fastest yet discovered. Its surface has a rotation velocity of more than 10% the velocity of light. The regular timing of millisecond pulsars provides us with the prospect of pulsar-based time scales that rival the best atomic time-keeping available from the world's entire collection of atomic clocks over intervals of months to years. The regular timing of millisecond pulsars also provides us with our only current means for detecting the gravitational-wave energy density (akin to the 3 degree Kelvin microwave black body spectrum) at nano-Hertz frequencies- a task at which Arecibo continues to excel.

- ❖ The first OH Megamaser (in Arp 220) was discovered by Arecibo in 1982. This megamaser has since been found to be generated by gas surrounding the nuclei of two colliding galaxies. It has also led to the realization that OH megamasers can be detected at very large redshifts, so they are being used to explore the distant Universe. However, the easy detection of molecules in Arp 220 led to widespread searches in other galaxies for molecules, via the megamaser phenomenon. Many of these have been shown to be generated by a disk of molecular gas in orbit about a central black hole, which in turn led directly to the conclusion that supermassive black holes lie at the center of many galaxies. Further detection of water masers from NGC 4258, while following up the megamaser phenomenon, led to the first direct trigonometric distance determination to an external galaxy. This leapfrogs over a hierarchy of chained inferences and methods to provide a reliable estimate of one of the most difficult parameters in astronomy.

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- ❖ The **Arecibo Observatory** made the first discovery of the "black widow" pulsar. This is a pulsar in orbit about a second star that the pulsar is slowly destroying. The mass evaporating from the companion star is detected as a wind that at certain phases of the binary orbit affects the timing of the neutron star's radio pulses. In due course the pulsar will have no companion, as it will have completed evaporated.
 - ❖ Arecibo made the first delineation of the "cosmic web", where galaxies were shown to be preferentially distributed on the surface of shells or in filaments, rather than randomly distributed through space. This work earned Riccardo Giovanelli and Martha Haynes the 1989 Henry Draper Prize from the National Academy of Science. It uses the ready detection of neutral hydrogen in individual nearby galaxies to determine their recession velocities, and hence notional distances, thereby mapping the distribution of galaxies in the local volume.
 - ❖ The **Arecibo Radio Telescope** was responsible for the detection of the first extra-solar planets in 1992. Timing observations of the pulsar B1257+12 resulted in the detection of three planets. These, sixteen years later, are still the most-comparable-to-Earth planets yet detected outside our Solar System. They are also the only planets discovered about a pulsar. Their very existence points to new phenomena in the accumulation of mass into planets about a neutron star, after it has experienced a supernova outburst, during the dying stages of a star's life.
 - ❖ In 1993, Arecibo demonstrated the overwhelming predominance of "dark matter" in the external galaxy DDO 154. Arecibo was used to map its neutral hydrogen distribution. DDO 154 has a modest optical luminosity, while its hydrogen distribution extends in radius to at least eight times its optical extent, and traces a flat rotation curve. Only "dark matter" can account for this rotation curve while gravitational theory as we know it is held to be applicable.
 - ❖ The Arecibo Hydrogen Millennium Survey in 2003 overturned the existing Ostriker and McKee equilibrium paradigm of the Inter Stellar Medium (ISM) that had reigned since 1977. The Millennium Survey found that a large fraction of interstellar gas is thermally unstable, thus implying a much more dynamic model for the ISM: that in turn affects how

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we think about star formation and the recycling of elements over time. The same survey also implied very strongly that interstellar clouds are much more likely to be parts of sheets or filaments than puffy blobs like those on Earth.

- ❖ Since 2002, Arecibo has been used to demonstrate the existence of sub-nanosecond structure in the giant pulses from the Crab Nebula pulsar. This is record territory. It is equivalent to measuring a less than six inch diameter emission region at a distance of 6,000 light years. The emission has structure somewhat analogous to studying radio burst emission from the Sun: these emissions peak have by far the most intense brightness temperature yet measured by astronomers.
- ❖ In 2006, Arecibo was used to measure the magnetic field strength in the first extra galactic object, the ultra luminous infra red galaxy Arp 220. This success has already been extended to other galaxies.
- ❖ In 2007, Arecibo discovered neutron stars with 50-100 % larger masses than the up to then universal neutron-star mass circa the 1.4 solar mass Chandrasekhar limit. The new massive pulsars are all located in globular clusters, which suggest that they have increased their mass after their formation. However, the existence of such massive stars provides important constraints on the equation of state of neutron star matter. Neutron stars allow us to explore the equilibrium properties of matter at densities grater than those found in the nuclei of elements: the more massive the neutron star, the more significant the constraints imposed on the theory. Mankind's other approach to gleaning information about such physics, is via the head-on collision of heavy nuclei in particle accelerators, such as the Large Hadron Collider, that take decades to implement. Data gleaned from understanding pulsars is complementary, as it comes from the study of system in equilibrium, and comes much more cheaply.
- ❖ The **Arecibo Radio Telescope** discovered four apparently "Dead" OH/IR stars. OH/IR stars exhibit strong 1612 MHz masers, with gain paths measured in light-days, while the travel time of mass to the massing zone is typically measured in hundreds of years. However, four of these systems have masers that completely disappeared in less than 20 years.

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while one has been resurrected again. This is the first instance of the defining characteristic of a cosmic body being changed non-explosively on a human time-scale.

- ❖ Arecibo was used to show that ice exists within craters at the polar regions of Mercury. This is in locales that are unable to receive direct sunlight, and suggests that the planet has been stable in its orientation with respect to the Sun from very soon after its formation. There may be practical applications for NASA, if ice can be found in accessible locales beyond the Earth, as it can be much cheaper to man a space station when essential supplies, like water, do not have to be lifted off the Earth.
- ❖ The surface of Venus was mapped through its dense cloud cover using a high resolution radar imaging system at Arecibo. This led in due course to NASA mounting its Magellan space mission to Venus, to map the surface again from an orbiting space craft.
- ❖ Arecibo radar observations made the first direct detections of the Yarkovsky (2003) and YORP (2007) effects of solar radiation on the motion and rotation of asteroids respectively. These effects are tiny over human timescales, but dominate the forces that deliver meteorites to the Earth over thousands and millions of years. The Yarkovsky effect is believed to be responsible for sending the "dinosaur killer" asteroids towards the Earth 65 million years ago. One strategy for deflecting the motion of Near Earth Asteroids away from a potential collision course with the Earth is thus to apply reflecting paint judiciously to their surfaces. The Arecibo radar provides by far the most accurate orbital parameters for these objects, and has been used to assess the probability of future collisions with the Earth.
- ❖ The first near-Earth triple asteroids system was discovered at Arecibo in 2008. This result is particularly exciting because Arecibo also obtains the shapes and sizes of the satellite asteroids, which is not yet possible for optically-detected multiple systems in the main asteroid belt and beyond. That information, together with the characteristics of the orbits, allows the masses and a good estimated of the densities of components to be determined. This is extremely cost-effective as it saves the need to send out space missions to obtain this data. About half of the asteroids with known companions were discovered using the Arecibo radar.

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- ❖ The Observatory has made many contributions to the understanding of the chemistry and dynamics of the Earth's upper atmosphere and ionosphere. Before the Observatory was built, the means of obtaining information about the ionosphere from the Earth was to reflect short-wave radio signals from it, a method that reaches out only 200 miles above the surface. The radar used at Arecibo bounces signals off the electrons and ions in the ionosphere, allowing its properties to be measured to altitudes of 4,000 miles or higher. Many observatories around the world now use the techniques developed at Arecibo.
- ❖ The **Arecibo Observatory** has been an essential player in the Search for Extra Terrestrial Intelligence (SETI). It has been used to examine thousands of star systems in the 1,000 MHz to 3,000 MHz frequency range. It hosted the SETI-at-home receiver, which operated whenever the telescope was live, and provided data for processing by more than five million PCs world-wide in the World's first globally distributed computer system. This computing operation has since been emulated for processing data from LIGO, which is seeking gravitational wave signals, by searchers for ever larger prime numbers, and for exploring the folding properties of proteins, among others. Major SETI projects are operated by the SETI Institute in California at Berkeley. Arecibo's radar was also used in 1974 to send a coded message towards the globular star cluster M13, another first.
- ❖ The **Arecibo Radar Telescope** has been the main tool for the creation of detail maps of the distribution of galaxies in the universe. In the search for new radio sources, many galaxies have been found to emit substantial radio energy as a result of the spiraling deceleration of their very fast electrons. Through the **Arecibo Observatory**, the positions of these galaxies have been determined with such accuracy that it is often possible to identify them with an object seen through large optical telescopes; in other cases, the radio sources captured by the Observatory are so distant that even the largest optical telescopes have been unable to detect them. Only the "Big Ear" in Arecibo has detected them.

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Fig. 42. Visitors Center, Angel Ramos Foundation.



Another major contribution of the Observatory has been the opening of the highly complex science of astronomy to the amateur public. In the 1990s, the Observatory established the *Fundación Angel Ramos Visitor and Educational Facility* (Fig. 42). Since its inauguration, the facility has received more than 100,000 visitors each year—from school children to senior citizens, from local scholars to tourists—who come to see the operation of the largest radar observatory of the world and learn about the wonders of the Universe, as discovered and studied at the Observatory. The facility provides a terrace from where

the visitors have a wide view of the radio telescope. The center also houses a 100-seat theater, meeting rooms and an excellent high-tech exhibit explaining, in English and Spanish, the work done at Arecibo. In the theater, a 15-minute presentation, "A Day in the Life of the Arecibo Observatory," tells the story of the people who make Arecibo possible. The theater is also a venue for workshops and training in the sciences for educators. It is the locale for colloquia engaging the local academic community, as well as for international scientific meetings.

The transformation of the Observatory into a popular icon shows in the developed taste of Hollywood's producers to use the property for their filmmaking. The Observatory was the site for the dramatic scenes of James Bond's *Goldeneye* movie (1995). The movie *Contact* (1997), based on Cornell's astronomer Carl Sagan's science fiction novel of the same name, was also filmed on the premises.

Most definitely, the extremely significant contributions of the **Arecibo Observatory** to the understanding of the complexity of the Universe, as well as the popularization of the astronomical sciences among the masses, go beyond the national boundaries.

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At this time about 125 persons are employed by the Observatory, providing everything from food to software support. A scientific staff of about 16 individuals divides their time between scientific research and assistance to visiting scientists. Hundreds of scientists from all over the world travel to Arecibo each year to conduct research using the Observatory's unique capabilities and state-of-the-art instrumentation for data collection and analysis. Use of the Observatory is available on an equal opportunity, competitive basis to all scientists throughout the world. Observing time is granted on the basis of the most promising research, as determined by peer review of the proposals, conducted by external referees.

In 2001, the **Arecibo Telescope** was declared an **Electrical Engineering and Computing Milestone** by the Institute of Electrical and Electronic Engineers (IEEE) and a **Historic Mechanical Engineering Landmark** by the American Society of Mechanical Engineers (ASME) in recognition of its significance.³⁴ Both institutions recognized that *"the Arecibo Observatory's design and implementation led to advances in the electrical engineering areas of antenna design, signal processing, and electronic instrumentation, and in the mechanical engineering areas of antenna suspension and drive system. The drive system positions all active parts of the antenna with millimeter precision, regardless of temperature changes, enabling the telescope to maintain an accurate focus. The **Arecibo Observatory's** operation led to advances in the scientific fields of radio astronomy, planetary studies, and space and atmosphere sciences."*³⁵

According to ASME, a landmark status indicates that the artifact, site or collection represents a significant step forward in the evolution of mechanical engineering and is **the best known example of its kind**. Nearly 250 landmarks had been designated by ASME throughout the world, since the program was started in 1971. Besides the 1920s Mount Wilson Observatory, the **Arecibo Telescope** has been the only other astronomy site, and **the only radio telescope in the world**, to receive such designation by ASME.³⁶ Either one of these awards alone is a great recognition, but the two together are another "first" for Arecibo.

³⁴ Institute of Electrical and Electronic Engineers.

http://www.ieee.org/web/aboutus/history_center/arecibo.html 2008.

³⁵ Electrical Engineering Milestone and Mechanical Engineering Landmark Award Ceremony Brochure, November 3, 2001.

³⁶ American Society of Mechanical Engineers.

http://www.asme.org/Communities/History/Landmarks/216_Arecibo_Radiotelescope.cfm 2008.

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Although the site does not meet the fifty-year span requirement for the National Register of Historic Places, the exceptionality of the property is undeniable. In May 1989, National Park Service, in the *Astronomy and Astrophysics National Historic Landmark Theme Study*, included the **Arecibo Radio Telescope** on the list of sites of less than 50 years that "should be re examined for national significance in the future."³⁷

That future is now. The contributions done by the **Arecibo Observatory** to the advancement of astronomy and radio astronomy in the United States, its engineering landmark status, the high-standing recognition of the facility in the international scientific community, the world-wide significance of the discoveries done by the Observatory and its uniqueness among other radio telescopes through-out the world, make the **Arecibo Radio Telescope** a property worthy of a national level significance in the National Register of Historic Places.

³⁷ Harry A. Butowsky. "Astronomy and Astrophysics National Historic Landmark Theme Study". National Park Service, Department of the Interior. May 1989, p. 345.

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Arecibo Radio Telescope Observatory Facility / Cornell University Personnel

Dr. William E. Gordon, Professor Emeritus, Cornell University

Dr. Robert B. Kerr, Arecibo Observatory Site Director

Dr. Brian Murray Lewis, Arecibo Observatory Astronomy Department Director

Dr. José L. Alonso, Arecibo Observatory, former Angel Ramos Foundation Visitor Center

Director

Dr. Paulo Freire, Arecibo Observatory Research Associate, Astronomy

Dr. Michael C. Nolan, Arecibo Observatory, Research Associate, Astronomy

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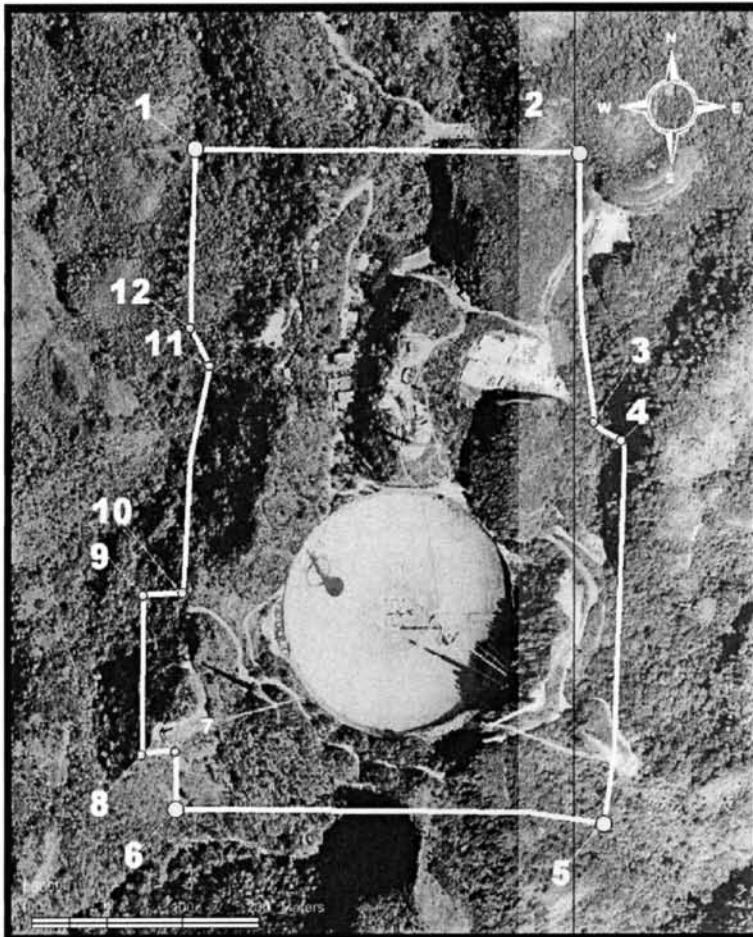
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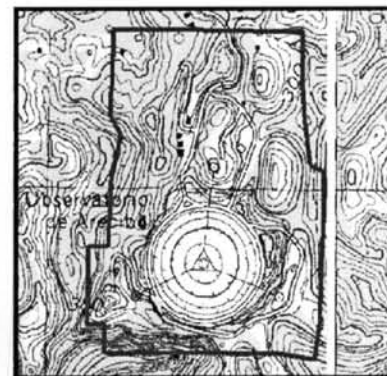
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Geographical Data

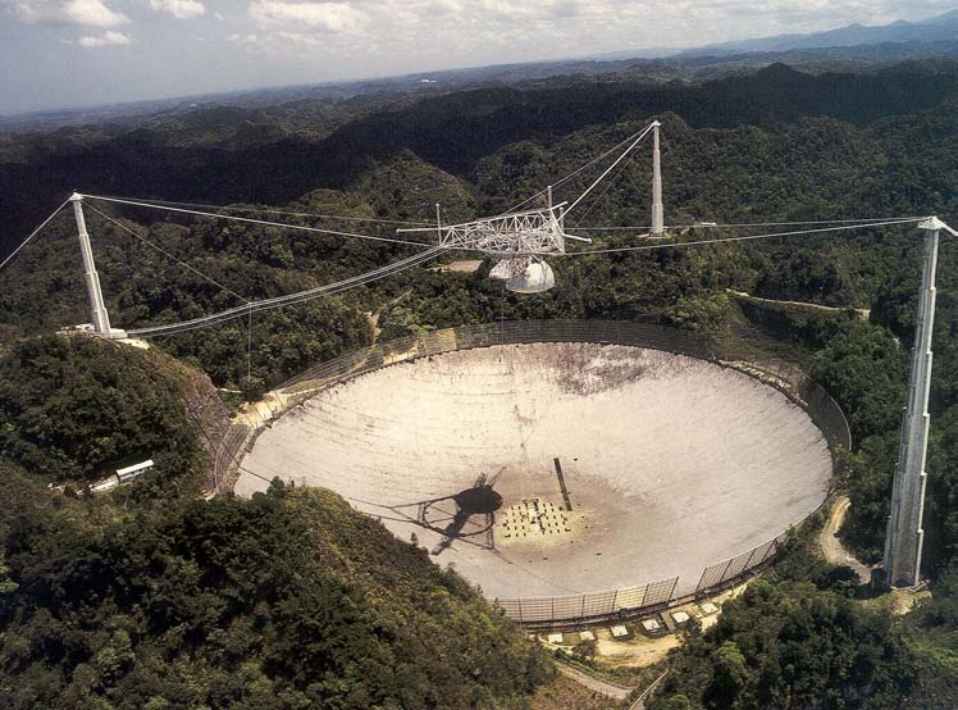


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8	2030319.53	737716.56
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Source: Aerial Photograph (1957);
USGS. (Revised 1982). Topographic Maps of the Utuado and Baynevy Quadrangle, PR























OBSERVATORIO DE ARECIBO

CENTRO DE VISITANTES
FUNDACION ANGEL RAMOS





BUILDING NO. 2







TELEPHONE

WARNING

