III. International

Don't Be Dinosaurs— For Planetary Defense, Build the Advanced Arecibo Observatory Now!

by Janet G. West

> If you dream, have big dreams. And have talented supporters to help you.
>
> —William E. Gordon,
> father of the Arecibo Observatory

Sept. 9—On Dec. 1, 2020, a catastrophe occurred for Puerto Rico, and for the world. On one of three towers of the Arecibo Radio Telescope, one cable supporting the Gregorian dome suspended over the telescope's receiver dish unraveled and snapped out of its socket; then another, and then another. The great instrument came crashing down upon the 305-meter-wide (1,000-foot) dish of the radio telescope, damaging it irreparably. Damage extended to numerous surrounding structures, but thanks to the caution of security engineers, no one was injured. (Drone footage of the collapse can be seen here.)

The yawning gash in the dish represented damage greater than that sustained by just glass, metal and cement—it was a wound profoundly felt across Puerto Rico, and especially to planetary scientists, astronomers, and other researchers throughout the world.

Now plans are being made by scientists and others to rebuild this unique and world-famous radio telescope, but on an even more advanced technological plane. With this territory's worn-out infrastructure being struck down by storm after storm, no project could better reverse the neglect and indifference repeatedly shown to the island. Will the political will and funding be found?

FIGURE 1

Wikimedia Commons/Mario Roberto Durán Ortiz

The Arecibo Observatory

The Arecibo Observatory (AO), located in Barrio Esperanza, Arecibo, Puerto Rico, and also known as the National Astronomy and Ionosphere Center (NAIC), is owned by the U.S. National Science Foundation (NSF), which, according to its website, "is an independent Federal agency created by Congress in 1950 to promote the progress of science; to advance the national health, prosperity, and welfare; to secure the national defense...." Its current budget is $8.8

billion, and that is increasing significantly under the just-passed "Chips and Science Act."

Prior to its collapse, the AO was home to the most powerful radar system and the most sensitive *radio* telescope in the world. Its construction was completed in 1963, and over its 57-year lifespan, even on its final day of operation, the telescope continued to produce new, groundbreaking science, adding to its long history of extraordinary achievements, including a Nobel Prize in Physics for the first evidence of the existence of gravitational waves. It was the world's largest single-aperture telescope for 53 years, surpassed only by the Five-Hundred-Meter Aperture Spherical Telescope (FAST) built in China in July 2016.

The main instrument was the Arecibo radio telescope (now referred to as the Legacy Arecibo Telescope, or LAT) (**Figure 1**), a spherical (not parabolic) reflector dish nearly 51 meters deep, constructed in a karst sinkhole; its surface comprised 38,778 perforated aluminum panels. These were supported by a network of steel cables, with a cable-mounted steerable receiver and several radar transmitters suspended 150 meters above the dish. The cables supporting the transmitters were secured to three towers by zinc spelter socket joints (often used to secure cables on suspension bridges), and the although the three towers were of different heights—two measuring 81m, and the third 111m—their tops were all at the same elevation above sea level.

There are two possible reasons for the choice of a spherical over a parabolic reflector. A spherical reflector is easier to construct. And William E. Gordon, the originator of the idea for the radio telescope and its designer, wanted the largest area possible for the given site, to enable the telescope to detect even very faint radio signals from deep space. The reflector dish was built into the sinkhole and could not be steered, so the steerable elements were the feed antenna (the rod suspended downward from the dome structure) and the Gregorian dome—shown on its curved guide beam in photos of the legacy telescope—which could be moved to focus on a particular portion of the sky.

The "Gregorian" dome (**Figure 2**) is named for the 17th-Century Scottish astronomer James Gregory, and has three reflectors inside its structure—primary, secondary, and tertiary—which are angled in such a way as to focus incoming radio waves. When the telescope is "looking" at a particular area of the sky, incoming radio waves first strike the large, immovable reflecting dish at various angles, then bounce into the Gregorian dome structure (receiver), and then are further focused by the dome's reflectors and eventually directed into a feed. From there, they are "translated" by computer into images.

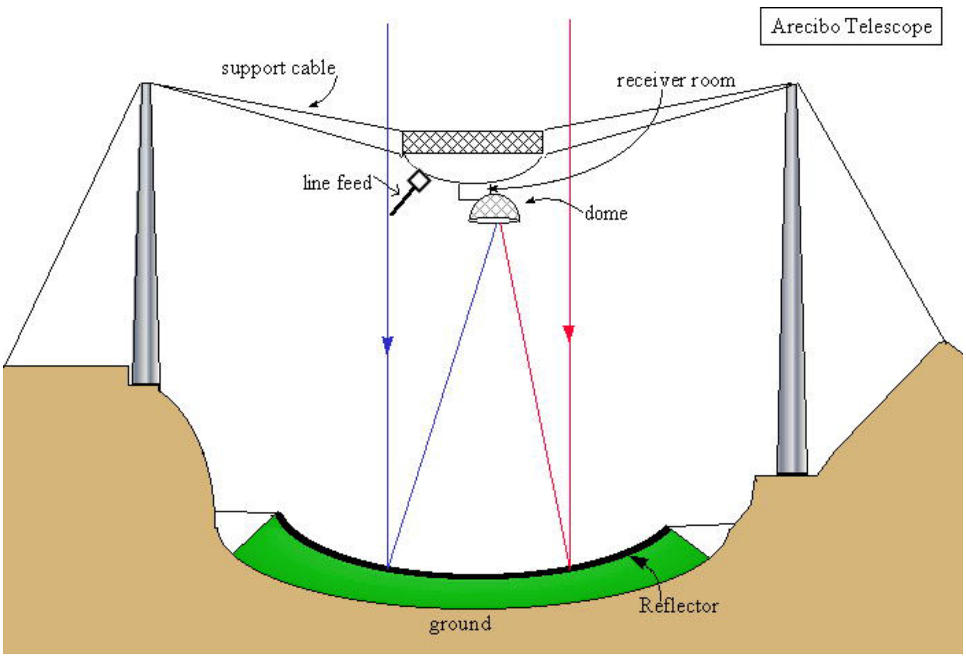
FIGURE 2

CC/David Broad

The NAIC website described the configuration in great detail:

> Suspended 450 feet above the reflector is the 900-ton platform. Similar in design to a bridge, it hangs in midair on eighteen cables, which are strung from three reinforced concrete towers.... Each tower is back-guyed to ground anchors with seven 3.25-inch diameter steel bridge cables. Another system of three pairs of cables runs from each corner of the platform to large concrete blocks under the reflector. They are attached to giant jacks which allow adjustment of the height of each corner with millimeter precision.
>
> Just below the triangular frame of the upper platform is a circular track on which the azimuth arm turns. The azimuth arm is a bow-shaped structure 328 feet long. The curved part of the arm is another track, on which a carriage house on one side and the Gregorian dome (installed in 1996) on the other side can be positioned any-

FIGURE 3
Operation of the Gregorian Dome Receiver



ALFALFA

The 1 MW planetary radar transmitter, located in a special room inside the dome, directs radar waves to objects in our solar system. Analyzing the echoes provides information about surface properties and object dynamics.

The giant size of the reflector is what makes the Arecibo Observatory so special to scientists. It is the largest curved focusing antenna on the planet, which means it is the world's most sensitive radio telescope. Other radio telescopes may require several hours observing a given radio source to collect enough energy for analysis, whereas at Arecibo this may require just a few minutes of observation.

where up to twenty degrees from the vertical. Inside the Gregorian dome two sub-reflectors (secondary and tertiary) focus radiation to a point in space where a set of horn antennae can be positioned to gather it. Hanging below the carriage house are various linear antennas, each tuned to a narrow band of frequencies. The antennas point downward and are designed especially for the Arecibo spherical reflector. By aiming a feed antenna at a certain point on the reflector, radio emissions originating from a very small area of the sky will be focused on the feed antenna (**Figure 3**).

Attached to the antennas are very sensitive and highly complex radio receivers. These devices operate immersed in a bath of liquid helium, to maintain a very low receiver temperature. At such cold temperatures the electron noise in the receivers is very small, and only the incoming radio signals, which are very weak, are amplified. The Arecibo system operates at frequencies from 50 megahertz (6 m wavelength) up to 10,000 megahertz (3 cm wavelength). A total of 26 electric motors control the platform. These motors drive the azimuth [arm] and the Gregorian dome and carriage house to any position with millimeter precision….

Unique and Crucial Research at AO

The main areas of research at the Arecibo Observatory had been radar astronomy and radio astronomy. Use of the telescope had been part of the Search for Extraterrestrial Intelligence (SETI) program, and was also part of NASA's Near-Earth object detection.

Its other facilities include a 12-meter radio telescope intended for very-long-baseline interferometry (VLBI) with the main telescope, and a LIDAR facility. The LIDAR research has continued since the main telescope's collapse.

VLBI is a type of astronomical interferometry in which several large radio telescopes around the world are linked up and coordinated to increase the "size" of the telescope. The European Space Agency explains:

> There are physical limitations to the size of a telescope, while the wavelength of interest in many cases cannot be chosen arbitrarily. To get around this limitation, radio astronomers use the technique known as interferometry to match and surpass the highest resolutions obtained in other regions of electromagnetic spectrum (for example, visible light). This involves linking antennas

together to act like as a single large radio telescope. The angular resolution of the resulting image is as good as [would be] obtained from a single antenna with a diameter equal to the largest separation (or "baseline") between the individual antennas.

The Very Long Baseline Interferometry (VLBI) technique—the ultimate case of interferometry—was originally developed in the 1960s by astronomers who were seeking ways to push the angular resolution of radio telescopes to the limits for studies of distant celestial objects. Its record high angular resolution exceeds by far the "sharpness" of any other available to date measurement technology.

In addition, by using telescopes at various locations, radio astronomers effectively increase the collecting area of the receiving antenna, thus increasing the sensitivity. Combined, these two properties make the VLBI technique the sharpest and the most sensitive tool for receiving radio signals from space, whether of natural or man-made origin.

LIDAR, also in use at the Arecibo facility, is an acronym for "Light Detection and Ranging," and is a method for determining ranges (variable distances, such as to different points on an irregular celestial body) by targeting an object or a surface with a laser and measuring the time for the reflected light to return to the receiver. Since laser light has much shorter wavelengths than radio waves, LIDAR has better accuracy and precision, and digital 3-D representations can be created from its images, for example, of areas on the Earth's surface; and by varying the laser wavelength, of the ocean bottom in the intertidal and near-coastal zones.

Wikipedia notes:

> LIDAR for meteorological applications … represents one of the first applications of laser technology. LIDAR technology has since expanded vastly in capability and LIDAR systems are used to perform a range of measurements that include profiling clouds, measuring winds, studying aerosols, and quantifying various atmospheric components. Atmospheric components can in turn provide useful information including surface pressure (by measuring the absorption of oxygen or nitrogen), greenhouse gas emissions (carbon dioxide and methane), photosynthesis (carbon dioxide), fires (carbon monoxide), and humidity (water vapor). Atmospheric LIDARs can be either ground-based, airborne or satellite, depending on the type of measurement.

Atmospheric LIDAR remote sensing works in two ways: by measuring backscatter from the atmosphere and by measuring scattered reflection off the ground (when the LIDAR is airborne) or other hard surface.

Backscatter from the atmosphere directly gives a measure of clouds and aerosols. Other derived measurements from backscatter, such as of winds or cirrus ice crystals, require careful selecting of the wavelength and/or polarization detected.

In physics, backscatter is the reflection of waves, particles, or signals back to the direction from which they came. Backscatter has important applications in astronomy, photography, and medical ultrasonography. The opposite effect is forward scatter, e.g., when a translucent material like a cloud diffuses sunlight, giving soft light.

A dramatic, but common example of the scattering of light can be seen at dawn or dusk in the sky opposite the sun. When the sun is near the horizon during those times, the sunlight appears reddish, because the light rays have to travel through the thickest part of the atmosphere, scattering all but the longest wavelengths, which are reddish. Under the conditions of a clear sky, during a sunset, as the sun sinks lower and eventually below the horizon, Earth's shadow itself is projected onto the atmosphere, which is seen as a blue band close to the opposite (eastern) horizon (**Figures 4** and **5**).

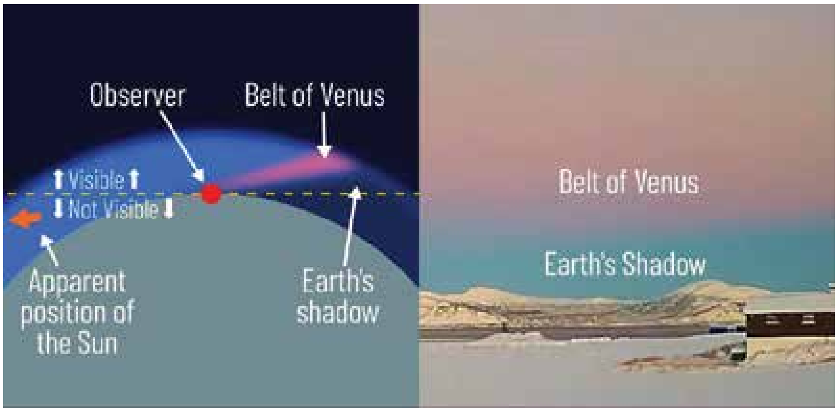
Radar Astronomy

"Radar" stands for Radio Detection and Ranging.

The Basics of Radar Astronomy, a PDF report published by the Goldstone Apple Valley Radio Telescope Project, describes it as follows:

> Planetary radar operates by sending and receiving a narrow beam of electromagnetic energy either in the microwave or radio range into space from an antenna. The object reflects the radio waves back to Earth where they are detected by the same antenna that sent the signal. The time between sending the signal and receiving the signal can be measured with great precision. Because the speed of the electromagnetic energy is

FIGURE 4



FlatEarth.ws

Earth's shadow is the shadow Earth casts into its own atmosphere, toward the horizon opposite from the Sun. Above Earth's shadow is the Belt of Venus, a pink band which is created by the back-scattering of sunlight through the atmosphere.

FIGURE 5

FlatEarth.ws

known [it is the speed of light —author] the distance to an object can be determined….

The velocity or speed of the object is measured by applying the Doppler principle. If the object is approaching the radar antenna, the frequency of the returned signal is greater than the frequency of the transmitted signal. If the object is receding from the radar antenna, the returned frequency is less; …

Radar astronomy actively transmits radio waves that bounce off of objects and sends the signal back to the receiver [*radio* astronomy is passive, and receives radio waves from celestial bodies —author]. Radar astronomy allows us to precisely measure the position and motion of the planets, asteroids and comets; other instruments can detect the mass, size, composition, and orbit trajectory in particular of asteroids and comets. In 1946 radar beams from the earth were reflected back from the moon and scientists were able to reveal through radar technology that the moon had sand-like structures. This observation was made before any landings on the moon were made.

Arecibo was the largest and most accurate telescope able to detect asteroids or comets that might eventually crash into Earth. Radar astronomy is critical and irreplaceable, not only for planetary defense, but for planetary science in general.

Radio Astronomy

The NAIC site again explains:

Radio Astronomy is the study of radio waves produced by a multitude of fascinating astronomical objects such as the Sun, planets, stars, pulsars, star-forming regions (i.e., birthplace of stars), gas clouds, galaxies, supernova remnants, and more. The radio signals from these objects give astronomers a plethora of physical information across vast distances and scales in our Universe, from a three-dimensional view of the energetic solar wind from our Sun, to the composition of exoplanetary atmospheres around other stars, to the motion of distant galaxies. To detect even the weakest radio signals requires a dish with a large surface area, and the enormity of the 305-meter Arecibo radio telescope allows astronomers to detect these faint radio waves from far-off regions of the Universe. The Radio Astronomy Group at Arecibo consists of scientists who are not only users of the telescope but who also use their expertise to help other astronomers to plan and carry out their observations.

Some of AO's notable accomplishments over its nearly 60-year history include:

- 1967—Arecibo discovered that the rotation rate of Mercury is 59 days, not the previously estimated 88 days.
- 1974—Arecibo discovered the first-ever binary pulsar. The 1993 Nobel Prize in physics was awarded to Russell A. Hulse and Joseph H. Taylor for this discovery. It tested Einstein's General Relativity theory

FIGURE 6

IAU/L. Calçada

Arecibo discovered the first-ever exoplanet in 1992. Here, an artist's impression of an exoplanet as seen from its moon.

and gave first evidence of the existence of gravitational waves.

- 1992—Arecibo discovered the first-ever exoplanet: In subsequent observations, an entire planetary system was found around the pulsar PSR 1257+12. (**Figure 6**)
- 2008—Arecibo detected for the first time methenamine and hydrogen cyanide molecules—two organic molecules that are key ingredients in forming amino acids—in a galaxy 250 million light-years away.
- 2017—Arecibo discovered two pulsars that seem to vanish and reappear intermittently, upending the widely held view that all pulsars are the orderly ticking clocks of the universe.

The Sad State of Planetary Defense

All 8 billion-plus human beings on the planet, plus all of the billions of other living creatures, are essentially sitting ducks as our planet spins through space—in its orbit around the Sun, at nearly 30 kilometers per second (67,000 miles per hour), while our entire Solar System whips around the center of our Milky Way galaxy at some 220 kilometers per second (490,000 miles per hour).

NASA's Planetary Defense Coordination Office (PDCO) and Center for Near Earth Object Studies (CNEOS) monitor over 26,000 asteroids that pass by Earth, and of those, over 2,000 are potentially dangerous Near Earth Asteroids (NEA). NASA has extensive asteroid and Near Earth Object monitoring programs that do view the entire sky around Earth: for example, the Asteroid Terrestrial-impact Last Alert System (ATLAS), a state-of-the-art detection system operated by the University of Hawaii (UH) Institute for Astronomy (IfA).

The crucial capacity at Arecibo Observatory—which is now missing—could provide the mass, rotation, composition, and direction more accurately than any other observatory, and make a finer resolution of the image, such that a binary asteroid system—two asteroids in close rotation around each other—could be visible as two separate bodies.

Although NASA, through its Jet Propulsion Laboratory (JPL), currently has a mission to study how the impact of a spacecraft on an asteroid might affect its trajectory, more advanced technology and thinking is required.

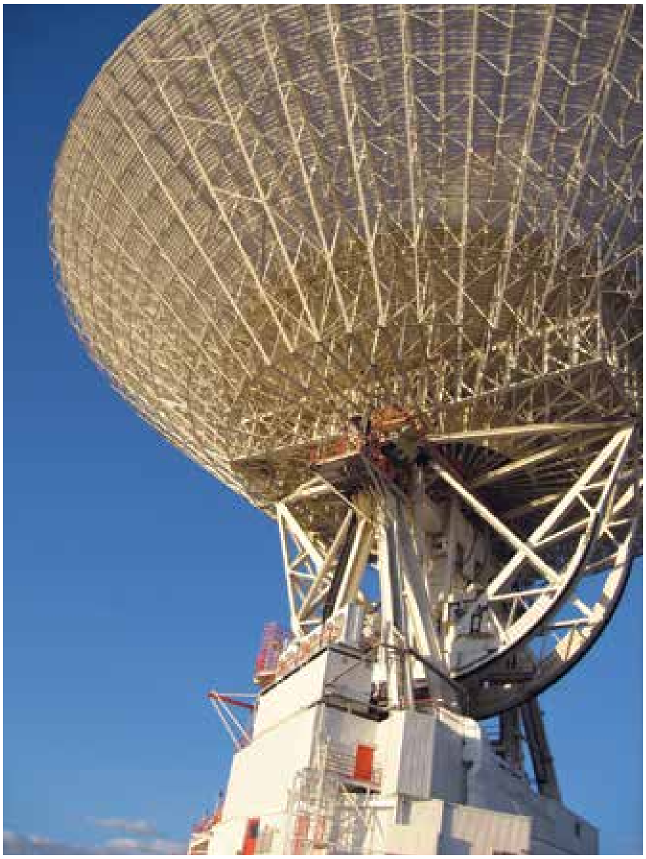
To detect the threat of an asteroid or comet collision with Earth, radar capability such as that represented at AO is essential; it was the most powerful radar system in the world. The Goldstone Deep Space Communications Complex headquartered in Barstow, California is the next best observatory, but it will miss asteroids and comets that AO would have detected (**Figure 7**).

The NASA/JPL mission is called the Double Asteroid Redirection Test (DART), which launched on Nov. 24, 2021 and is currently scheduled to impact an asteroid around Sept. 26, 2022 at 7:14 p.m., U.S. EDT. The mission website notes:

> DART's target is the binary asteroid system consisting of Didymos (Greek for "twin"), about a half-mile across, and its smaller companion Dimorphos, about 530 feet across. DART will use an autonomous targeting system to aim itself at Dimorphos. Didymos is the ideal candidate for humankind's first planetary defense experiment, although it is not on a path to collide with Earth and therefore poses no actual threat to the planet.

This is the first time such an attempt has been made. Didymos was discovered in 1996 by Kitt Peak Observatory in Arizona, and was later distinguished as a binary system using radar astronomy at the Arecibo Observatory in 2003 (underscoring the importance of

FIGURE 7



cc/Kevin Stanchfield

The Goldstone Radio Telescope of 70-meter diameter in the Mojave Desert, California.

the radar imaging which determined its binary nature, an important factor if this were a threat to Earth).

However, it's a relatively crude approach to simply use something to hit an asteroid, and (hopefully) use that momentum to put it off course. This is known as kinetic deflection.

Other options for deflecting an incoming asteroid or comet are a "gravity tractor" and a "tether system." According to NASA, a gravity tractor spacecraft would fly alongside the asteroid for a long period of time (years to decades) and slowly pull it out of its path to Earth. NASA admits that this most likely wouldn't work on the largest asteroids of over 500 meters in diameter, which might be the greatest threat to Earth; that this technique has never been tried; and that it would be decades in the building, launching and deployment of such a device.

Science Times reported on Arecibo and the tether system on June 19, 2020:

> [R]esearchers from the Arecibo Observatory at the University of Central Florida used computer simulations to estimate the dynamics of such a tether system for an array of different primary conditions [using asteroid Bennu as their test subject]. This led to their conclusion that it would be achievable for use as a planetary defense system….
>
> The approach suggested by [the team] uses the tether to attach the dangerous Potentially Hazardous Asteroid (PHA) to another smaller asteroid, causing it to change the center of mass of the two. By doing so, it would hopefully bring the PHA to a safer orbit.
>
> Experts have previously noted that a considerable risk correlated with "high-impact" mitigation techniques is fragmentation.… Smaller pieces of the PHA falling to Earth is something which could in itself, cause extensive damage.

Other proposals include the rapid development of nuclear fusion rockets that would not only decrease the time of transit to destinations such as the Moon or Mars, but would be much more powerful than chemical-powered rockets. Fusion-powered rockets could be deployed to push an asteroid off a trajectory towards Earth.

The Next Generation AO Telescope

Consider this proposal for a next generation telescope at Arecibo:

> In order to accomplish the overarching scientific goals stated above, we present a concept for the Next Generation Arecibo Telescope (NGAT)—an innovative combination of a compact, phased array of dishes on a steerable plate-like structure. Compared to the LAT, the NGAT will provide 500 times wider field of view, 2.3 times larger declination coverage [northward and southward from the celestial equator —author], 3 times more frequency coverage, nearly double the sensitivity in receiving radio astronomy signals, and more than four times greater transmitting power required for both Planetary and Atmospheric investigations….
>
> The new telescope will coexist with an extended High Frequency (HF) facility, and a diverse set of radio and optical instrumentation

> that continue to operate at AO and at the Remote Optical Facility (ROF). The largely new proposed concept for a radio science instrument requires extensive engineering studies that will be the next step to ensure the new facility achieves the driving scientific requirements for the aforementioned science objectives.

So begins an ambitious white paper written by 75 scientists, researchers, astronomers and others to promote the construction of a new telescope. The paper is titled, "The Future of the Arecibo Observatory: The Next Generation Arecibo Telescope." This paper is available in the public domain, and readers are encouraged to study it.

> We propose that NGAT be located at the Arecibo Observatory, preferably at the location of the LAT to take advantage of the existing infrastructure and the extension of the RFI active cancellation system, an active project in development at the AO location.

The paper explains a host of other advantages for a new-generation telescope at the Arecibo site. There are these scientific advances:

- The proximity to equatorial latitudes is ideal for observing Solar System objects.
- The location uniquely enables radar intelligence, surveillance and reconnaissance (ISR) studies both parallel and perpendicular to the Earth's magnetic field lines.
- The geographic and geomagnetic location provides unique latitude coverage which is not offered by other facilities in the world.
- It is a strategic location from which to study the effects of the South Atlantic Magnetic Anomaly (SAMA) in the Caribbean upper atmosphere as well as on the trans-ionospheric radio signals.

Then there are economic and educational objectives to the project:

- To serve the population of Puerto Rico by inspiring and educating new generations while contributing to the socioeconomics of the island.
- To take advantage of the existing infrastructure, which is on Federal property, and has the local government's support, significantly offsetting costs.
- To leverage the strategic location in the Caribbean Sea, trafficked by the largest vessels, for which accurate geo-positioning is critical, and the ISR inputs for space weather forecast models are crucial.

The Arecibo Observatory is located in a Radio Frequency Interference (RFI) Coordination Zone; that minimizes the effects of RFI, protecting the radio bands needed for science operations. The scientists' paper asserts that the next-generation telescope, the NGAT, will offer enhanced capabilities in planetary science, including radar surveillance and spectroscopic studies of comets, and support of spacecraft.

The advanced AO will perform studies of the solar wind and space weather, including:

- Tracking coronal mass ejections (CMEs)
- Faraday Rotation and the internal magnetic field of CMEs
- Solar radiofrequency studies
- Solar impacts on the AIMI system
- In-situ investigations of the plasma tails of comets.

It will conduct intensive studies of pulsars and wide searches for new ones. It will likewise perform very long baseline interferometry (VLBI) studies on general relativity, stellar physics, and "extragalactic continuum polarization." It will use high radio frequencies to probe stellar evolution, pulsars, and transients. The so-called Standard Model of particle physics will be tested, as it is by the James Webb Space Telescope.

There are more space and atmospheric studies the advanced AO will be designed to perform, particularly on interactions between Earth's atmosphere and its boundary with space. These are known as atmosphere-ionosphere-magnetosphere interactions (AIMI). The AO will have a "remote optical facility" (ROF) elsewhere in Puerto Rico, on Culebra Island, probing the atmosphere with high-Doppler-resolution measurements of vertical motion in the thermosphere. And in the other direction—down—the new AO will conduct subsurface studies of the planet with 40-60 MHz radar observations.

Most Essential Reason for a New Observatory—Youth

A number of the scientists, researchers and students either involved with, or supportive of the AO and the necessity for a new, more advanced astronomical system at the site, have emphasized that one of its greatest priorities is cultural. To build a cutting-edge, technologically advanced telescope would be much like the effect that the building of great cathedrals had on the common person during the period from the 12th to the 16th centuries. Skilled masons constructed their "Apollo projects" of the day, and not only were they themselves inspired by the beauty of the building they were constructing, but many of these projects spanned generations, inspiring generations of builders, and the poor and illiterate who participated in an uplifting experience during Mass inside those cathedrals.

Or, think of the impact of dam, flood control, hydropower and other construction under the Tennessee Valley Authority in the 1930s and '40s, which trained thousands from undereducated populations in the area as skilled industrial workers, and brought libraries and other educational, cultural and health facilities to transform the entire region.

Many of the people in the Arecibo region of Puerto Rico participated in the building of the Observatory and all of its facilities; young elementary and high school students took field trips there—some, several times while growing up.

In an online video about the AO, some of the comments reveal the profound impact that visiting the facility had on their lives. One person reported,

> I visited the facility as a child during a school trip and it awoke an incredible desire to get into science and space investigation that stayed with me to this day. One can say it changed me from a dumb kid with no interest in anything life had to offer, into a science-loving kid with an unending thirst for knowledge. It seriously changed my life in the best way possible (**Figure 8**).

Another commented,

> I can't remember the exact first time I had visited it, but I have been there a few times in my life.... One of my uncles also delivered material for the building of the Arecibo Radar dish. It is a great loss not just for Puerto Rico, but for science and research as well.

A documentary about the Arecibo Observatory directed by Andrew Hernandez Sepulveda, *The Biggest Dream*, is a wonderful, moving and informative film that deserves a broad audience. In it, students from the STAR Academy at the AO emphasize the importance of the legacy of the Observatory. One young man was passionate about the role of the younger generation in disseminating the numerous discoveries of the AO out to the broader population, to inspire others to seek answers to scientific questions. A young woman called radio astronomy "curiosity materialized," saying she felt there is so much to explore in the field that "the science will not die with us."

FIGURE 8

Kansas Tourism

A young visitor considers a Moon rock at the Kansas Cosmosphere & Space Center, Hutchinson, Kansas.

When America committed itself to sending a man to the Moon and returning him safely, it inspired thousands of students to specialize in areas of math, physics, engineering and astronomy; it also served to mobilize our economy in its richest form—to apply new materials and new technologies back into the productive economy, such that it is estimated that the Apollo mission returned $14 to the economy for every one dollar invested. And, it promoted something that terrifies the oligarchy of the world: *unbridled optimism!*

With the proper orientation in terms of rebuilding a more advanced astronomical platform at Arecibo, and applying American System economics as developed by economist Lyndon H. LaRouche, the *price* of the rebuilding could be in the hundreds of millions of dollars, but the *net cost* would be zero, because of the economic, scientific and cultural benefits to society as a whole.

Looking up to the stars with a sense of wonder is uniquely human. Let us keep looking up, and advance our observatories and sciences, such that future generations need not fear any threat coming in from far beyond our Solar System. Instead, millions of youth will become astronomers, shining light from Earth as a beacon of hope out into the far reaches of the Universe.