THE LEGACY OF ARECIBO OBSERVATORY IN PLANETARY SCIENCE AND BEYOND. P. A. Taylor[1] and E. G. Rivera-Valentín[1], [1]Lunar and Planetary Institute, USRA, Houston, TX (ptaylor@usra.edu)

Introduction: For 57 years, from its inauguration in 1963 until 2020, Puerto Rico's Arecibo Observatory and its William E. Gordon telescope were at the forefront of planetary science, radio astronomy, and space and atmospheric sciences. Originally conceived to study Earth's ionosphere, the telescope design was modified and upgraded to allow for planetary radar of our solar system and radio astronomy of our own galaxy and beyond. While it is impossible to describe the complete legacy of Arecibo, we review a sample of the important contributions Arecibo Observatory has made to planetary science over the last six decades.

Telescope: At 305 meters in diameter, the William E. Gordon telescope at Arecibo Observatory provided incredible sensitivity and antenna gain over some 10 GHz of the electromagnetic spectrum. Two main radar systems were available: the P-band (430 MHz; 70 cm) system, which was used for the duration of the telescope's existence, and the S-band (2380 MHz; 12.6 cm) system that was in use since the mid-1970s. With up to 1 MW of continuous output power, an antenna gain of 20 million, and 20 acres of collecting area, the Arecibo S-band planetary radar was the most powerful, most sensitive, and most active planetary radar system in the world. Capable of studying solid bodies from Mercury out to the rings of Saturn and Titan, the Arecibo planetary radar systems have been invaluable to planetary science, planetary defense, and space exploration.

Planetary Radar Science: Arecibo planetary radar observations of solar system bodies commenced from the outset in 1963 with the first major results being the determination of Mercury's rotation period [1] and confirmation of the rotation period of Venus [2]. Mapping of the lunar surface [e.g., 3, 4], imaging of the surface of Venus through its dense atmosphere [e.g., 5, 6], and constraining the value of the astronomical unit [7] soon followed. These radar studies continued for decades [e.g., 8-16] and further led to the identification of water ice at Mercury's poles [e.g., 17, 18] and constraints on water ice within lunar craters [19] (also in concert with the Lunar Reconnaissance Orbiter [20]), the search for active volcanism and tectonism on Venus [e.g., 14, 15], evaluation of spacecraft landing sites on Mars [e.g., 21, 22], monitoring of the Galilean satellites [e.g., 23, 24], the study of the rings of Saturn [e.g., 25, 26], and the suggestion of liquid hydrocarbons on the surface of Titan [27].

433 Eros was the first asteroid observed with the Arecibo P-band radar system in 1975 [28], followed by 1580 Betulia with the S-band system in 1976 [29]; 1 Ceres was the first main-belt asteroid detected in 1977 [30], and 2P/Encke was the first comet nucleus detected with radar in 1980 [31]. While radar detections of small bodies were initially sparse due to the limited number known, especially among near-Earth asteroids, and the large sizes and close approaches required for radar detection, observing rates quickly improved with the advent of modern optical asteroid discovery surveys. As interest in planetary defense grew, tracking and characterization accelerated to more than 850 near-Earth asteroids (125 in 2019 alone), more than 100 main-belt asteroids, and 15 comets (including comae and nuclei) detected [https://echo.jpl.nasa.gov]. Arecibo radar observations of near-Earth asteroids confirmed the existence of binary [32, 33] and triple [34, 35] asteroid systems, verified the effects of non-gravitational accelerations on small bodies [36, 37], and have helped guide and prepare spacecraft missions to small bodies [38-42].

Beyond the study of radar scattering from planetary and small-body surfaces, Arecibo radar was also used to document the population of geocentric space debris [43], constrain the electron content of the interplanetary medium [44], measure the perihelion advance of Mercury in confirmation of General Relativity [45, 46], and locate and assess the status of spacecraft (i.e., SOHO [47] and ISEE-3 [48]).

Beyond Radar: Not all planetary science at Arecibo was limited to radar. The sensitivity of Arecibo allowed for detailed characterization of the outflows and jets of active comets through OH spectral emission [49], the detection of the first exoplanets via precise pulsar timing [50], and further verification of General Relativity and inference of gravitational waves via binary-pulsar timing [51, 52], which received the Nobel Prize for physics in 1993.

Beyond Science: The Arecibo Observatory is a monument to science and engineering in Puerto Rico and a source of inspiration on the island and beyond. The Angel Ramos Science and Visitor Center (ARSVC) at the observatory typically hosted over 80,000 visitors per year from around the world to see the structure declared a milestone and landmark in electrical and mechanical engineering[1]. The ARSVC offered engagement events for the local community, including public observing nights where the public engaged with observatory scientists, local university staff, as well as student clubs. Additionally, the observatory staff operated the Arecibo Observatory Space Academy, an out-of-school research and supplemental education activity for high school students in Puerto Rico. Started in 2014, the program served over 300 students, many of whom are now pursuing careers in the space and planetary sciences. The successful undergraduate internship program at Arecibo further served over 300 college students since 1972, and nearly 400 doctoral theses have been published based on research using Arecibo. Many of these past interns and graduate students are active (or retired!) professional researchers and faculty members in the astronomy and planetary science communities. As an observatory with several decades of history, Arecibo has had a profound impact on the Puerto Rican and international communities. Many Boricua scientists, even those outside of astronomy and planetary science, began their paths in the fields of science, technology, engineering, and mathematics with inspiration taken from the Arecibo Observatory.

Conclusions: Arecibo Observatory has left an indelible mark on planetary science, radio astronomy, and space and atmospheric sciences over its near six decades of operation and its legacy is impossible to fully encapsulate. Arecibo's contributions to the field of planetary science are wide ranging from revealing the properties of planets, both inside and outside our solar system, tracking and characterizing asteroids in the defense of our own planet, and supporting spacecraft exploration. While the William E. Gordon telescope at Arecibo Observatory, at least in the form that we have known it, is gone, its legacy will live on forever.

[1] Arecibo Observatory became an Electrical Engineering Milestone of the Institute of Electrical and Electronics Engineers and a Mechanical Engineering Landmark of the American Society of Mechanical Engineers in 2001.

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