**Report on the Arecibo Observatory, Arecibo Puerto Rico**
**required by the Explanatory Statement accompanying**
**H.R. 133, Consolidated Appropriations Act, 2021**

The collapse of the 305-meter radio telescope's suspended platform, which housed many key instruments at the Arecibo Observatory (AO) in Arecibo, Puerto Rico, represents a significant loss for the U.S. scientific community and the people of Puerto Rico. During its 57 years in operation, the telescope was an integral part of U.S. capabilities to advance scientific research in radio astronomy, planetary research, and the geosciences, and served as an iconic site for the residents of Puerto Rico and the scientific community. In the Consolidated Appropriations Act, 2021, NSF was *"directed to report to the Committees within 60 days of enactment of this Act on the causes and extent of the damage, the plan to remove debris in a safe and environmentally sound way, the preservation of the associated AO facilities and surrounding areas, and the process for determining whether to establish comparable technology at the site, along with any associated cost estimates."* With this report, NSF provides the requested information to the Committees, much of which is still preliminary given the ongoing investigations of the collapse and the nascent exploration of future opportunities for AO and the communities it has served for decades.

## Collapse of the 305-m telescope – Cause and Extent of the Damage.

On August 10, 2020, at roughly 3:00 AM ET, an auxiliary cable[1] from tower 4 supporting the suspended platform above the 305-m reflector pulled loose from its socket, damaging about 250 of the approximately 40,000 aluminum reflector panels that make up the dish of the telescope. This cable failure[2] also caused external damage to the Gregorian dome that houses an array of scientific instruments. In order to ensure the safety of the telescope, the workforce, and any visitors, the Gregorian dome was moved to a position that enhanced the stability of the suspended platform and normal science operations ceased. Users of the 305-m telescope were notified of a hiatus in observations that would last at least two weeks, the Visitors Center was closed for safety, and staff access to the reflector dish and surrounding areas was curtailed except for activities needed to complete critical tasks.

NSF immediately engaged with its managing organization, the University of Central Florida (UCF), to understand the cause(s) of the failure of the auxiliary cable socket. While detailed modeling of the event was begun by expert engineering firms, initiation of a full physical analysis was put on hold until it was deemed safe to retrieve parts of the failed cable and socket. In early October, when engineering analyses indicated that it was safe to do so, the failed socket was

[1] The "auxiliary" cables were installed in the 1990s when the weight of the platform was increased and were not part of the original telescope construction.

[2] The cable that pulled loose was not the cable for which a replacement had been planned as part of the Hurricane repair appropriation. When Arecibo was constructed in the 1960s, one of the main cables on Tower 8 was constructed to be several feet too short and was connected to the tower by a splice. After Hurricane Maria, engineering analyses identified this cable as a possible risk. The Hurricane repair appropriation included funds to replace that cable to improve the structural integrity of the 305-m telescope platform support system.

removed and sent to NASA Kennedy Space Center for analysis. Since the platform collapse, engineers have been able to obtain additional physical evidence (such as samples of various cables) previously unavailable to them. Forensic analysis is still ongoing with respect to the cause of the auxiliary cable socket failure. Engineers designed a stabilization plan, including friction clamps to prevent other cable failures where slippages were observed (e.g., backstay at tower 12; see Figure 1), and cables were ordered and set to be installed in December 2020. The implementation of these stabilization efforts was set to begin on November 9, 2020.

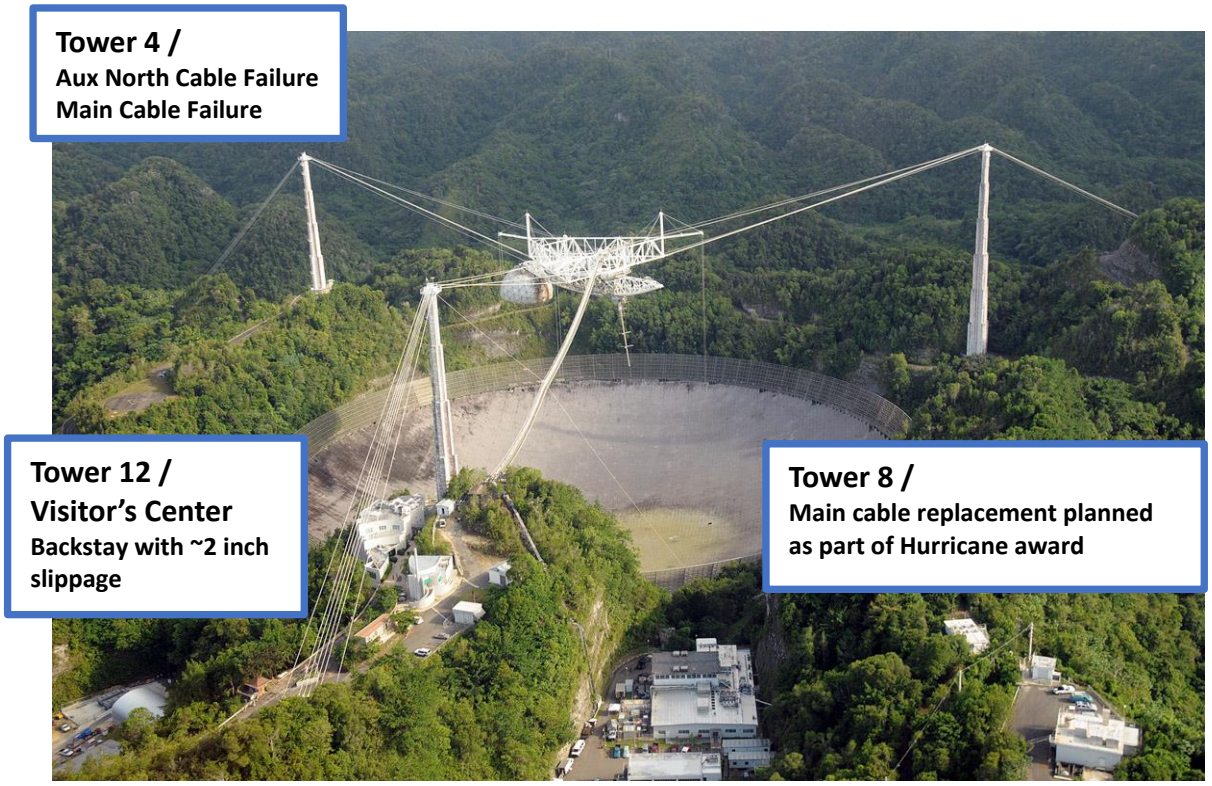


Figure 1: The Arecibo 305m telescope before the collapse. Tower numbers shown for reference.

On November 6, 2020 at approximately 8:15 PM ET, a main cable, also on tower 4, broke. Based on the detailed structural modeling developed to help understand the first cable failure, this cable broke under conditions that should have been well within its support capabilities, indicating that it, along with the remaining main cables, may have been weaker than expected.[3] After the telescope suffered this second cable break, NSF was informed by the engineer of record[4] that a subsequent cable failure would likely be catastrophic. In addition, it was clear from engineering analyses that an uncontrolled collapse could endanger not just the telescope, but also a portion of the surrounding infrastructure including the Visitors Center, a key component of the Observatory's

[3] The "main" cables are original equipment on the telescope, dating from the 1960s.

[4] See https://www.nsf.gov/news/special_reports/arecibo/index.jsp for a list of three engineering reports provided to NSF following the failure of the second cable. Thornton Tomasetti was the engineer of record, WSP provided project management and historical perspective, and Wiss, Janney, Elstner Associates, Inc. was responsible for forensics and determining the safety zones. All three of these engineering firms were under contract to UCF.

outreach efforts. At that point, NSF determined that the wisest course of action was to begin planning for a controlled decommissioning of the telescope, with the goal of saving as many of the observatory's assets as possible. Concurrently, potential remediation efforts that might be executed safely were still being explored. NSF, along with the contracted engineering firms and the United States Army Corps of Engineers, continued to review the safety analysis for several proposed actions – including backstay de-jacking to slightly tilt the towers and reduce load on the cables, installation of friction clamps where socket slippage was observed, high-resolution photographs of the cables, and helicopter retrieval of the socket that had held the failed main cable.

However, the uncontrolled collapse of the suspended platform around 7:00 AM ET on December 1, 2020 superseded all ongoing efforts to stabilize the structure and planning efforts for a controlled decommissioning of the telescope. Since the first cable break in August 2020, NSF's first priority was maintaining safety at the site. After the collapse, with safety still the top priority, NSF prioritized conducting a complete damage assessment as quickly as possible, and taking action to understand, contain, and mitigate any environmental damage caused by the collapse of the structure.

Later in the day on December 1, 2020, engineers from Thornton Tomasetti, a firm that had been contracted by UCF to do analysis of the structure before the collapse and became the Engineer of Record for planning potential telescope repairs, and CSA Group, an environmental consulting firm, arrived at AO. They immediately began assessing the site, with an emphasis on examining potential environmental impacts and evaluating the structural integrity of the towers to determine the safety zones around the site moving forward. The preliminary assessment was that all critical damage had occurred within the previously defined "keep out" zone, indicating that the engineers had correctly outlined the restricted zone after the main cable failure on November 6, 2020, which contributed to the lack of injuries when the platform collapsed.

Initial findings indicate that the platform and Gregorian dome are a complete loss for scientific purposes. A large number of reflector panels were damaged when the platform crashed through them to the ground, breaking many of the reflector support cables that held up the main dish of the telescope. The top 18 meters of the platform support towers 12 and 4, and approximately 37 meters of the taller support tower 8, broke off, and further assessments of the structural integrity of the towers continue.

Damage beyond the main 305-m dish and support structures was limited. Buildings 1 and 2, which house Arecibo Operations and Administration respectively, sustained minimal damage from concrete debris from tower 12. The Learning Center suffered significant damage to its roof; however, it is believed that this damage is reparable. The Cable Car shed suffered some damage but was not a complete loss. A trailer used by the Educational and Public Outreach staff was demolished. The Visitors Center was largely unaffected; however, it did sustain some minor damage to its roof from falling concrete. No other facilities were impacted.

Forensic evaluation to understand the causes of the collapse is ongoing. Evaluation of the initial auxiliary socket and cable, which failed on August 10, 2020, is being led by UCF's contractor Wiss, Janney, Elstner Associates, Inc. with help from experts at NASA Kennedy Space Center. The remaining forensic evaluation is being led by UCF's contractor, Thornton Tomasetti. NSF

currently expects to have initial findings from both engineering firms by the end of FY 2021, with final reports by December 2021.

In addition to the efforts described above to quickly address the urgent needs of cleanup and the causes of the failure, NSF has requested that the National Academies of Sciences, Engineering, and Medicine (NASEM) conduct an expedited independent study into the causes of the cable failures. Development of that study is under way. The Academies' findings will also improve NSF's planning and stewardship of current and future facilities. Discussions about the timing, scope and other details are ongoing.

**Debris Removal and Site Restoration**

Ensuring safety has continued to be NSF's top priority. This includes not only the safety of personnel on the site, but also the safety of the environment in the area and the need to address concerns about historic and cultural preservation.

The engineering firm Thornton Tomasetti has been leading efforts to plan and oversee the urgent cleanup at the site, in addition to pursuing the forensic investigations necessary to understand the causes of the collapse. The engineers have carefully mapped the distribution of the debris for the purposes of both forensic analysis and debris removal. All scientific infrastructure that can be utilized is being saved. D.H. Griffin, a company specializing in disaster cleanup, is onsite working to clear debris and provide safe access to areas where there are potential environmental impacts, as well as developing a longer-range comprehensive work plan to support a cost estimate for the needed cleanup activities. This cost estimate will be further refined in the coming months, but preliminary analysis indicates cleanup costs will be in the range of $30 – $50 million spread over fiscal years 2021 and 2022.

Figure 2: An overhead image illustrating the portions of the reflector and support structure damaged by the collapse. This photo was taken after the cleanup process was well underway so much of the debris

had been removed, exposing the ground underneath and allowing access to the collapsed platform at the upper left of the dish.

### *Environmental Mitigation*

In addition to the work being performed by subcontractors under the direction of UCF's contractor, Thornton Tomasetti, specialists from Jacobs Engineering have been brought in to provide oversight of environmental work on NSF's behalf. Representatives from both Thornton Tomasetti and Jacobs Engineering have been assisting UCF and NSF in identifying environmental compliance requirements, including those related to pollution prevention, sampling and analysis, and biological resources. Cleanup work has included soil sampling and excavation to remove soil impacted by hydraulic oil released during the collapse, as well as the development and implementation of plans for the sampling and analysis of soil, groundwater, and surface water and a Stormwater Pollution Prevention Plan to prevent sediment and pollutants from migrating offsite. Biologists are conducting wildlife and vegetation surveys to inform protection measures relating to species of concern.

Since the collapse and continuing to the present, NSF and Jacobs Engineering (with the support of Thornton Tomasetti, its subcontractors, and UCF) have reached out to federal agencies, including the Environmental Protection Agency, the Council on Environmental Quality, and the U.S. Fish and Wildlife Service, to provide updates on the activities occurring onsite and to seek guidance. To date, no concerns regarding our response to the collapse have been raised by these federal agencies. NSF and AO staff have also provided notifications to the Puerto Rico Department of Environment and Natural Resources.

### *Historic and Cultural Preservation*

NSF has also been in contact with the Puerto Rico State Historic Preservation Office (PR SHPO) and the Federal Advisory Council on Historic Preservation (ACHP) since the day of the collapse to consult on the protection and preservation of historically important elements of the structures and site. NSF arranged for representatives of the PR SHPO to participate in a site visit one week following the collapse, after which they communicated that they were not concerned about impacts of cleanup activities on historic properties at the site. They did, however, state that they did not want the collapse to result in a de-listing of the historic district from the National Register of Historic Places. NSF assured the PR SHPO that NSF has no plan or intention of seeking a de-listing of the historic district. NSF intends to continue to provide updates to both the PR SHPO and the ACHP as appropriate.

At NSF's direction, UCF has established the Salvage Survey Committee, which is tasked with screening the debris to identify scientific equipment that could be reused and objects of potential scientific, cultural, or historic value that need to be preserved for potential display at the site or other museums. This committee includes members of the AO staff, scientific community, Smithsonian Institution, and the NSF historian. If the committee determines that such items are present, those items will be removed and placed in a separate location for protection and further

use. Neither the ACHP nor the PR SHPO raised any concerns with our proposed plan, and we continue to provide both agencies with updates regarding our progress.

**Continued Science at Arecibo Observatory**

NSF's process for determining whether to establish comparable technology at the site incorporates the understanding that there was not a single technology, but instead many technologies and more than a dozen distinct capabilities comprising AO. These capabilities served diverse scientific communities, ranging from various radio astronomy interests and planetary studies to geoscience research. Some of these technologies are still available, while restoration of others or establishment of comparable technology would require differing levels of effort and funding. NSF's process in each case will be to examine the technology, the cost, schedule, and feasibility to restore or establish comparable technology, and the scientific merit and broader impacts of the science that the technology would enable.

As NSF stated in its initial comments after the catastrophic failure of the cables supporting the platform, AO is not closing and continues to support scientific research. Current scientific activities have been focused on restoring immediate scientific productivity, including prioritizing those technologies that are already operational and those funded for restoration using normal operations and maintenance funds. Repairs to some facilities (such as the 12-m telescope and LIDAR facility) were originally budgeted in the FY18 supplemental (PL 115-123) after Hurricane Maria; those repairs are also proceeding with the appropriated funding. Ongoing scientific and related activities include use of the LIDAR facility to study the composition and motion of the ionosphere along with maintenance of the roof of the facility and modernization of the laser equipment. In addition, scientific staff continue to work on analysis of data in the historical archives, operations of the remote Culebra optical facility, and restoration and use of the 12-meter radio telescope. If all, or even part of, the 305-m reflector dish is repaired, technologies such as the High Frequency ionospheric heaters operating at frequencies of 5 and 8 MHz may be restored. For these technologies, NSF is considering what infrastructure is still in place, and the cost and schedule for recovering these capabilities under various short-term repair options.

Table 1: Overview of Arecibo Observatory Technologies and Status

| **Discipline** | **Technology** | **Status** |
|---|---|---|
| Space & Atmospheric | High Frequency Ionospheric Heaters<br>• 5 MHz<br>• 8 MHz | Much infrastructure still exists; cost and schedule to restore is being evaluated |
| | Incoherent Scatter Radar | Possible to restore if 305-m reflector is repaired; cost and schedule to restore is being evaluated |
| | LIDAR | Currently operational; repairs now prioritized using Hurricane Maria supplemental appropriation |
| | Passive Optics | Currently operational |
| | Remote Optical Facility | Currently operational (Culebra) |

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| Astronomy | 12-meter Receivers<br>• S band (2 – 4 GHz)<br>• X band (8 – 10 GHz) | Currently operational; repairs now prioritized under Hurricane Maria supplemental appropriation; receivers are un-cooled; cost and schedule to upgrade to cooled receivers being evaluated |
| | 305-m Receivers<br>• 327 MHz<br>• 430 MHz<br>• ALFA (1.225 – 1.525 GHz)<br>• L-wide (1.12 – 1.730 GHz)<br>• S-wide (1.8 – 3.1 GHz)<br>• S-narrow (2.24 – 2.43 GHz)<br>• S-high (3 – 4 GHz)<br>• C (4 – 8 GHz)<br>• X (8 – 10 GHz)<br>• ALPACA (1.3 – 1.72 GHz)<br>• Ultrawideband receiver (0.7 – 4.0 GHz) | Currently none of these receivers are operational or easily restored; low frequency (327 MHz and 430 MHz) may possibly be restored if reflector is repaired; cost and schedule to restore those are being evaluated; options for comparable technology at higher frequency will be considered following NSF processes<br><br>These receivers were funded to be built and added to the 305-m before the collapse; consideration of how to utilize them will be considered following NSF processes |
| Planetary | 305-m S band radar (2.38 GHz) | Currently not operational |

NSF's process for establishing any significant new scientific facility relies on priorities established by the scientific community and rigorous peer review of the intellectual merit and broader impacts of the proposed activity. A significant source of community input is obtained through the "Decadal Surveys" conducted by the NASEM. Since AO technology serves multiple communities, the Astronomy and Astrophysics, Solar and Space Physics, and the Planetary Science & Astrobiology decadal surveys have the potential to identify scientific priorities that could be addressed by comparable technology at AO. In the near term (probably April 2021), NSF is planning to sponsor a community workshop to bring together stakeholders and begin to develop a range of ideas for research capabilities on the site that could be further supported by development grants. The development costs of potential projects coming out of this stakeholder engagement are unknown.

Beyond these facility-specific efforts, NSF is also actively exploring efforts to strengthen and expand the important role AO has played in the Puerto Rican community through its educational, outreach, and diversity programs. Beyond continued collaboration with the Ángel Ramos Foundation to recover the programs supported by the Visitors Center and related educational outreach, discussions are underway regarding potential programs to support the development of faculty, staff, and students pursuing research in astronomy, planetary studies, and geosciences at universities in Puerto Rico in order to strengthen the local scientific, technical and community engagement in the future of AO.

NSF will continue to keep the Committees informed of developments in each of the aforementioned areas.