

result was expected because Ho^{165} is a deformed nucleus. They also find that dependence of total cross section on relative orientation of neutron spin and nuclear spin is less than 0.2%, about the limit they can observe. Although holmium nuclei are

particularly susceptible to orientation, the Stanford researchers expect that by lowering the temperature they can produce other targets of oriented nuclei suitable for fast-neutron experiments.

Earlier work on aligned Ho^{165}

was done by Harvey Marshak and Allan Richardson of the National Bureau of Standards, collaborating with R. Wagner, Philip D. Miller and Taro Tamura of Oak Ridge National Laboratory (*Phys. Rev.* **139**, B29, 1965 and *Phys. Rev.* **150**, 996, 1966).

A Visit to Arecibo Finds a Telescope Seeking Improvement

The cable car looks not on white slopes and prancing skiers but on the tropical green and brown of Puerto Rican forests. At the top terminus you can look straight down a distance equal to the height of the Washington monument. You look into the center of the world's largest dish—18 acres of wire mesh on a carefully positioned spherical network of supporting cables. You walk around on a 500-ton assembly that supports two carriage houses, a workshop, cables, waveguides and motors to turn and slide its various parts. Below extend the horns, snouts and Yagi antennas that can transmit and receive radio frequencies between 20 and 600 megahertz. A few miles south of the northern coast of Puerto Rico, this is the radar and radio telescope of the Arecibo Ionospheric Observatory. It was dedicated in 1963 (*PHYSICS TODAY*, January 1964, page 66).

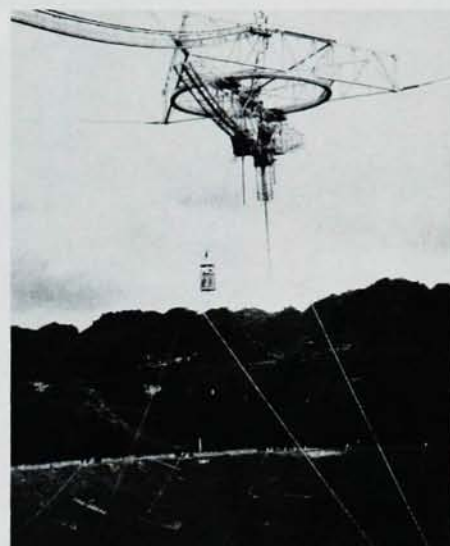
We talked there recently with Gordon Pettengill, who is on leave from MIT to be AIO director for the next few years. He spoke with some pride of the present installation and its important discoveries. He described the program and the way the installation is scheduled and operated, and he told about history and sponsorship. Particularly on his mind, however, is a projected improvement of the reflector and radar that would make

them about 30 decibels better at highest frequencies and at least 200 times as sensitive as the two other leading contenders, Haystack at the MIT Lincoln Laboratory and the Jet Propulsion Laboratory instrument at Goldstone, Calif. Pettengill, who was associate director at an earlier stage of observatory history, is the fourth director. His predecessors have been William E. Gordon (1960–65), John Findlay (1965–66) and Frank Drake (1966–68). Rolf B. Dyce has been associate director since 1965.

Hoped-for improvement would essentially raise the accuracy of the 1000-foot-diameter (300-meter) reflector to a level matching the positioning accuracy of the feed support. Arecibo would become as good at 5-cm wavelength as it is now at 50. An estimated \$3.5 million would improve by a factor of 10 the shape of the reflector which, in places, now departs from the true sphere by a little more than an inch. A new 10-cm transmitter, new feeds, a larger computer and similar equipment to take full advantage of the improved reflector might cost another \$2.5 million. Pettengill estimates the present value of AIO at \$12–15 million. Annual budget is currently \$1.8 million. The new sensitivity would enable radar observation of the four largest moons of Jupiter as well as extending the range of possible pulsar measurements.

To make the present installation, engineers cut away parts of a natural hollow in the mountains until they had a 300-meter circle and a roughly spherical bowl inside it. On the circle are anchors that hold 3.2-cm-diameter north-south oriented cables separated by 30 meters. Each north-south cable is tied down to a series of anchors along its length so that it hangs in a nearly perfect circle instead of a catenary.

Crossing the north-south cables are smaller east-west cables at 1-meter intervals, and on the resulting criss-cross are 1.5×6 -meter panels of wire mesh that has about a 1-cm gauge. Wrinkles in the mesh contribute to



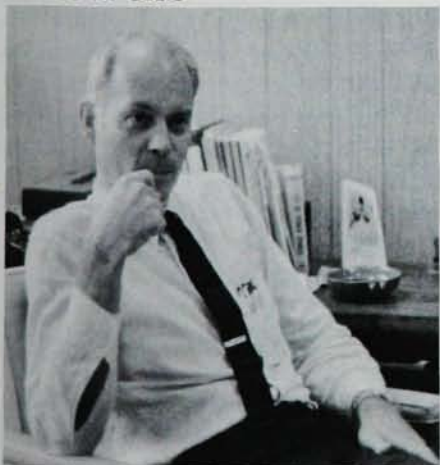
LARGE SIZE of installation is shown by passengers in cable car.

the departure from a true sphere; these are somewhat improved by a crimping tool that will pull in some of the parts of the mesh where unusual departures from the perfect surface exist. The basic north-south supporting cables already have a spherical shape within tolerances suitable for operation at 5-cm wavelength.

Three cement towers on hills outside the 300-meter ring support cables, which, in turn, support the feed assembly over the center of the antenna. A fixed triangular structure hanging from the cables supports a circular track on its lower surface; from this hangs a 120-meter horizontal arm, and rf feeds project downward from two carriage houses that move along the bottom of the arm. Among the feeds long line feeds are designed to correct for the difference between a parabolic reflector and the actual spherical one. Portions of a signal that arrive too soon from parts of the sphere that are nearer than the equivalent parabola are received on the line feed below its base and appropriately delayed to be in phase with later arriving portions that are intercepted closer to the base.

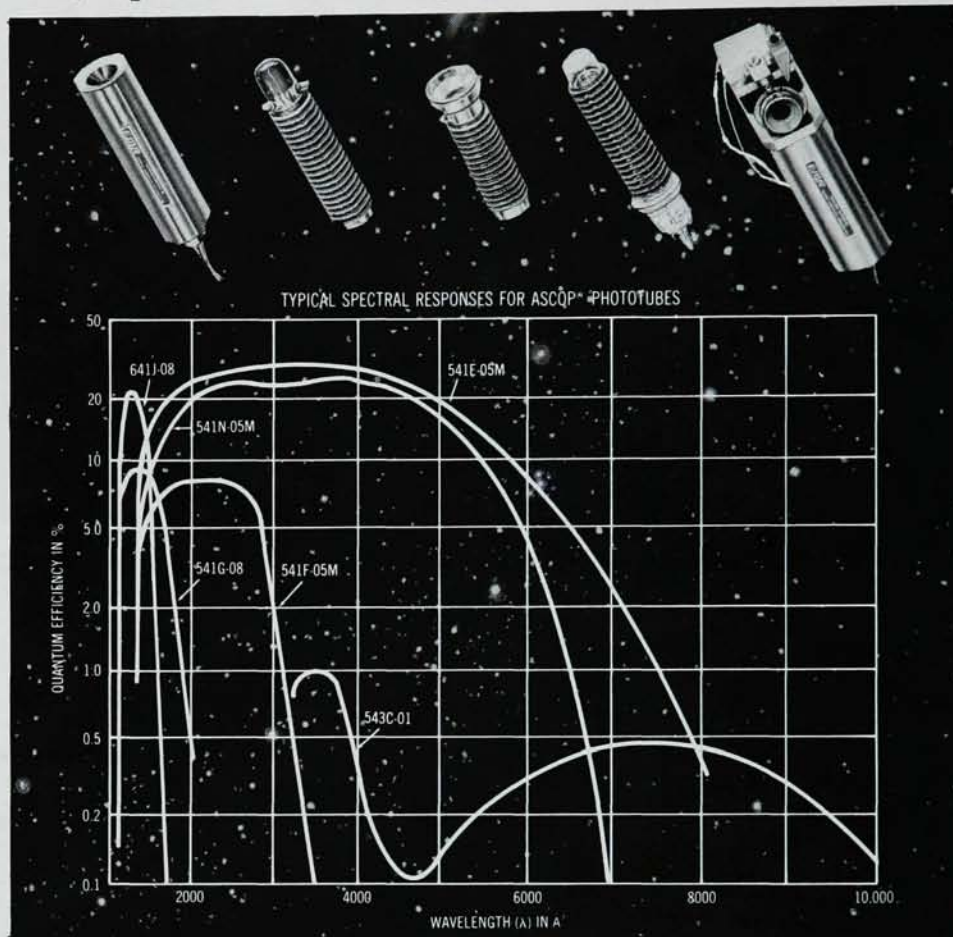
Movement of the various feeds permits experimenters to sweep over a

PHOTOS BY ELLIS



GORDON PETTENGILL, on leave from MIT, is present director at Arecibo.

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The program at Arecibo is in three parts: ionospheric studies, radar astronomy and radio astronomy. The ionospheric studies came first, and the original plan was a big dish with a fixed feed just to look at the ionosphere. The work, funded by the Advanced Research Projects Agency through an Air Force contract with Cornell, still represents nearly half the total effort. When the importance of radar and radio astronomy at Arecibo were recognized, the National Science Foundation added its support to that of ARPA.

Purpose of ionospheric studies is to find ion and electron densities and populations as functions of height, time and atmospheric conditions. With low-frequency radar one can find the bottom profile, but probing into the ionosphere is impossible because the frequencies you want to use are totally reflected at the bottom layer. One way to approach the problem of measuring the upper profile is with a topside sounder, the Alouette satellite passing overhead and transmitting its own radar pulses.

Much more useful, though, is Thomson scattering of much higher (UHF) frequencies. At Arecibo, in fact, the full possibilities of Thomson scattering have become apparent. With the transmitter at a constant frequency, experimenters plot reflected power as a function of frequency and time delay. The area under the curve at a given delay measures electron density. The full width of the spectral curve gives ion temperature. At the ends of the curve appear two humps ("wings"), and the wing height above the rest of the curve gives the ratio of electron to ion temperature. With a little more refinement you might hope to define different ion species by their contributions to different parts of the curve.

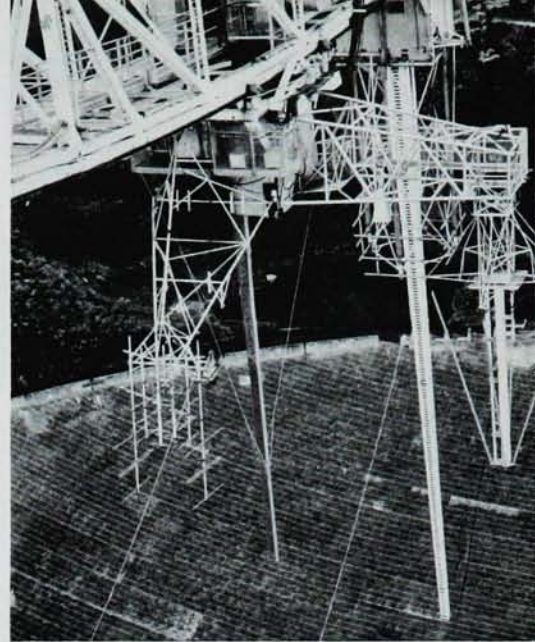
A pleasant redundancy is possible in such work. Acoustic waves in the ionosphere plasma create sidebands on the echo, and the frequencies of the sidebands are related to electron density. Then you play games with the data to wring ever more information from it. If you want still a third measure of electron density you observe Faraday rotation of the polarization of the echo due to the earth's magnetic field.

In addition to these matters, Arecibo investigators have been studying waves due to gravity and other motions in the ionosphere, solar flares, appearance of photoelectrons when sunrise occurs at the point of the southern hemisphere that is conjugate to Arecibo in the earth's field and variations of all these quantities with altitude, time of day, time of year and sunspot cycles.

Radar astronomy explores the planets during the portion of the year when they come into the beam. In 1965, for example, Arecibo correctly determined the rotation of Mercury (once in 59 days) from the Doppler spread in its radar echoes. Other projects involve radar mapping of the moon and Venus, measurement of interplanetary distances with radar and observations of electron populations in space.

Pulsar observations have been the big thing for radio astronomy in the past year. The most significant Arecibo discoveries were the short (33-millisecond) period of the Crab pulsar and the decrease of its rate with time. By watching such objects as the quasars disappear behind the moon and studying the occultation pattern, astronomers can measure sizes as small as a fraction of a second of arc, and they hope to be able to do a cosmological count of source numbers as a function of intensity. Scintillation in the solar corona and long-baseline interferometers explore even smaller sizes. Arecibo is taking part in long-baseline interferometry, working with Jodrell Bank. With increase of its working frequency it could also connect effectively with Green Bank.

We asked Pettengill whether Arecibo is being used to its ultimate capacity. It is not; the program is now limited by budget, not by time. The director is always eager to entertain proposals for good experiments. So far almost all proposals have been good enough to pass. In the last quarter of last year, for example, experiments were done by investigators from Rice, Stanford, University of Florida, Cambridge (England), University of Colorado, and Penn State as well as Cornell. The governing committee leans toward favoring outsiders and would like to see the site more used by them. When demands become heavy enough, in some cases different experiments can be done simultaneously. For example, a radar feed in one house can be functioning



ANTENNA FEEDS project downward from 500-ton supporting assembly.

while a passive receiver uses a feed at a different frequency in the other. At present, though, although such duplication is possible, it is seldom used because of the slight restrictions on operating convenience.

How many persons are involved? What is AIO doing for the social life and education of Puerto Ricans? The observatory employs about 100 non-scientists and has between ten and 20 scientists in residence at a time. More are involved by being part-timers, supervisors of graduate students and occasional visitors to Arecibo. The observatory suffers the usual difficulties of laboratories in out-of-the-way places. After a while wives get concerned about the quality of schooling for their children, medical services or even the brands of coffee available, says Pettengill. The social impact on Arecibo has been considerable just in the money that comes into the local economy. Educational impact, unfortunately, has not been great because there is as yet no graduate program in Puerto Rico with which AIO can couple.

From the top terminal of the cable lift, where two or three technicians were making adjustments on feeds and connections, we rode down to the control room. One computer, although not at the moment controlling any motions, was keeping in practice by computing and displaying data having to do with beam direction. Scientists were making adjustments on another to make it ready for the next run. The atmosphere was that of a busy present and a challenging future for the world's biggest bowl.

—RHE □