National Astronomy and Ionosphere Center
Arecibo Observatory

Arecibo, Puerto Rico 00613
Cornell University, Ithaca, New York 14853

The following report covers the period July 1995 through July 1996.

1. FACILITIES

The Arecibo Observatory is the primary research facility of the National Astronomy and Ionosphere Center (NAIC). The NAIC is operated as a visitor-oriented national research center by Cornell University under a cooperative agreement with the National Science Foundation. Partial support for the planetary radar program is provided by the National Aeronautics and Space Administration. Typically about 80% of the available observing time is allotted to astronomical research programs. The remaining 20% is devoted to research programs in atmospheric physics.

The Arecibo Observatory is located about 12 km south of Arecibo, a city on the north coast of Puerto Rico about 80 km west of San Juan. The principle instrument of the observatory is a 305-m-diameter spherical radio reflector antenna. Radio sources can be tracked within 20 degrees of the zenith using moveable feeds suspended above the stationary reflector. The observatory latitude of 18°21′N gives a declination coverage of about $-1°39'$ to $+38°21'$. Depending upon their declinations, celestial objects may be within view at Arecibo for up to 2h40m each day.

Other facilities operated by the observatory include an optical facility and a high-power HF transmitting array. The optical and HF facilities are normally used for airglow observations and ionospheric heating experiments, respectively.

Operational support at Arecibo includes a scientific staff, an electronic maintenance and development shop, mechanical engineering and maintenance services, a computing center, technical library, drafting services, living accomodations for visiting scientists, and a cafeteria. Additional support is provided by the NAIC staff at Cornell University in Ithaca, New York, where a small electronics development group, some business functions, and a small scientific group are located.

2. TELESCOPE UPGRADE STATUS

The telescope has been undergoing a major upgrading, funded jointly by the NSF and NASA. This upgrading consists of two phases. Phase 1, construction of a 50-ft-high ground screen to eliminate most spillover noise, was successfully completed in mid-1993. Phase 2, the installation of a Gregorian feed system and a more powerful S-band radar, is scheduled for completion in the Spring of 1997. The Gregorian dome, an 85-foot diameter geodesic radome containing secondary and tertiary reflectors and a feed platform, was raised and attached to the azimuth arm in May 1996. As this report was being written, the S-band radar installation was nearing completion and the first receiver (L-band) had been mounted on the feed platform.

The telescope upgrade work has caused a major disruption in the normal scientific operation of the instrument for the past 2.5 years. Because of the loss of tracking capability and the removal of Carriage House #2, scientific observing programs have been limited to drift-scan searches and surveys at 430 MHz and some ionospheric radar work. Although several of the observing programs designed specifically for the upgrade period were very fruitful (see our BAAS report from last year for a summary), the disruption increased in severity during this report period and results from new observations were very limited (which accounts for the brevity of this report).

3. INSTRUMENTATION

In the past, most observations with the Arecibo telescope used spherical aberration correcting line feeds mounted on one of two ‘‘carriage houses’’ on the azimuth arm. The telescope upgrade has replaced most of the line feeds with a single Gregorian subreflector system. Multiple feed horns at the Gregorian focus will eventually provide continuous frequency coverage between 300 MHz and 10 GHz. Replacing the 40-ft line feeds increases the maximum sensitivity at 1415 and 1665 MHz from 8 K/Jy to 12 K/Jy and lowers the minimum system temperature to 20 K. A new 1-MW S-band radar system has also been installed on the Gregorian; this new radar is more sensitive than the old S-band system by a zenith angle dependent factor of between 10 and 40. Carriage House #1 and its associated systems (including the 318 and 430 MHz feeds and the 430 MHz radar) have been retained, and a 430 MHz transmitting capability is planned for the Gregorian. The 430 MHz line feed has a sensitivity of 18 K/Jy and a beamwidth of 10 arcmin. This feed can be connected to a 2.5 MW peak-power (150 kW average power) radar transmitter; this 430 MHz radar is normally used for incoherent backscatter observations of the ionosphere. Radar observations of planets and other deep-space objects are normally made with the S-band (2380 MHz) radar, although the 430 MHz radar can also be used in cases where a lower radar frequency is desired.

At the time this report was written, new receivers were beginning to be installed in the Gregorian feed room. It is anticipated that four receivers will be available during the Gregorian commissioning phase (Spring 1997); these include L-band (1.1–1.7 GHz), S-band (2.38 GHz), C-band (3.95–5.85 GHz) and X-band (8.0–10.0 GHz) receivers. New UHF receivers will be installed shortly thereafter. Other receivers will be added later depending on time, resources, and demand.

Telescope pointing and realtime data acquisition are controlled using a network of VMEbus single-board computers running the VxWorks operating system kernel. Custom-built data acquisition devices (‘‘backends’’) include (1) a general-

purpose A/D system capable of sampling four analog channels at up to 10-MHz rates with programmable resolutions of 1 to 12 bits per sample per channel, (2) an (interim) 50-MHz, 4096-lag Spectral Line Correlator with programmable bandwidth from 195 kHz to 50 MHz, (3) a 50-MHz Radar Decoder, (4) a 100-MHz Spectral Line Correlator being developed, (5) a 10-MHz bandwidth Pulsar Search/Timing Machine with up to 256 channels, and (6) a wideband continuum/polarimetry instrument being developed. An S2 VLBI system may also become available. Additional real-time signal processing capability is provided by four Skybolt i860-based VMEbus single-board computers with 240 MFLOPS peak combined capacity.

Data are recorded on 8mm tape using helical scan (Exabyte) recorders; short runs may be recorded on disk and accessed over the local area network. The analysis network consists of about forty Sun Microsystems workstations, about 30 GBytes of disk, and several 8mm (one 4mm) helical scan tape drives. Software available includes several interactive data reduction and display packages like ANALYZ, AIPS, IRAF, CLASS, IDL and MATLAB, the IMSL and PORTLIB mathematical subroutine libraries, specialized libraries for ephemeris calculation and data format conversions, and the FrameMaker desktop publishing system. Hardcopy devices include two 600dpi and two 300dpi black-and-white laser printers and one 300dpi dye-sublimation color printer. The Observatory network also includes about fifty IBM-AT compatibles and two Apple Macintosh computers, and is connected to the Internet via a dedicated 56Kbps link.

4. STAFF, VISITORS

The Arecibo Observatory welcomes and encourages research projects by qualified scientists from other institutions. Proposals to use the telescope should be addressed to: Director, Arecibo Observatory, P.O. Box 995, Arecibo, PR 00613. All proposals are reviewed by external referees. Information on proposal submission procedures can be obtained from the director or from the observatory web site (http://www.naic.edu).

The NAIC scientific staff is located in both Arecibo, Puerto Rico and on the Cornell campus in Ithaca, New York. Dr. Paul F. Goldsmith, Director of NAIC, is based in Ithaca.

The observatory's Director of Operations, Dr. Daniel R. Altschuler, is based in Arecibo. NAIC-affiliated scientists and their areas of specialization are listed below.

4.1 Arecibo Staff

D.R. Altschuler - *active radio sources*

W.A. Baan - *molecular lines, interstellar medium*

J. Cho - *radar studies of middle and lower atmospheric dynamics*

M.M. Davis - *pulsars, extragalactic line and continuum*

JoAnn Eder - *extragalactic astronomy, 21-cm spectral line observations*

J. Friedman - *optical observations of ionosphere*

T. Ghosh - *low frequency variability, active galactic nuclei, interstellar scintillation, VLBI*

S.A. Gonzalez - *ionospheric observations*

J.K. Harmon - *planetary radar, solar wind*

P. Hofner - *molecular lines*

B. Isham - *ionospheric radar and modification*

B.M. Lewis - *normal galaxies, interstellar medium, OH/IR stars, circumstellar shells*

M. Nolan - *planetary radar, asteroid science*

C. Salter - *galactic continuum, AGN's, HI absorption in pulsars*

M.P. Sulzer - *atmospheric physics, ionospheric modification*

C.A. Tepley - *airglow, ionospheric radar, lidar studies*

K.M. Xilouris - *pulsars*

Q. Zhou - *ionospheric observations*

4.2 Cornell Staff

D.B. Campbell - *planetary radar*

J.M. Cordes - *pulsars, interstellar medium*

R. Giovanelli - *extragalactic and galactic lines*

P.F. Goldsmith - *molecular clouds and star formation*

M.P. Haynes - *extragalactic and galactic lines, galaxies and clusters*

M.C. Kelley - *ionospheric electrodynamics, atmospheric science*

Y. Terzian - *planetary nebulae, interstellar medium*

4.3 Summer Student Program

The Observatory conducts a Summer Student Program in astronomy and atmospheric sciences. For this program a small number of undergraduate and graduate students are chosen to spend the summer at Arecibo engaged in research programs under the supervision of staff scientists. Applications for the Summer Student Program should be submitted to NAIC by early February.

The Summer Students for the summer of 1996 were: Aomawa Baker, *Mass. Inst. of Tech.* Lymari Castro, *Univ. of Puerto Rico* David Goldbrenner, *Harvard Univ.* Cindy Hancox, *Univ. of Calif., Berkeley* Dona Hertel, *Western Washington Univ.* Rebecca Lamkin, *Rutgers Univ.* Nina Menezes, *Cornell Univ.* Sven Schreker, *San Diego St. Univ.* Matthew Schwartz, *Penn State Univ.* Luis Wilkes-Alicea, *Univ. of Puerto Rico* Cesar Tavarez, *Univ. of Puerto Rico*

5. COMMITTEES

5.1 AU&SAC Committee

The Arecibo Users and Scientific Advisory Committee (AU&SAC) meets annually in Puerto Rico to advise the NAIC on the future needs for instrumentation and facilities. The current committee members are: T. Bania, *Boston Univ.* J. Breakall, *Penn State Univ.* F.H. Briggs, *Univ. of Groningen* C. Fesen, *Dartmouth College* R. Foster, *Naval Research Lab.* K. Groves, *Phillips Lab.* C.E. Heiles, *Univ. of California, Berkeley* P. Horowitz, *Harvard Univ.* F.J. Lockman, *Natl. Radio Astronomy Obs.* P. Schloerb, *Univ. of Massachusetts* Chiao-Yao She, *Colorado St. Univ.*

5.2 NAIC-VC Committee

The National Astronomy and Ionosphere Center Visiting Committee (NAIC-VC), appointed by Cornell to review the management and research programs of the Observatory, normally meets once a year. The current members are: H.C. Carlson, *Phillips Lab.* C.S. Gardner, *Univ. of Illinois* T.L. Killeen, *Univ. of Michigan* G.R. Knapp, *Princeton Univ.* J.M. Moran, *Smithsonian Astrophys. Obs.* P. Palmer, *Univ. of Chicago* P. Schwartz, *Naval Research Lab.* S.C. Solomon, *Carnegie Inst. of Wash.* J.H. Taylor, *Princeton Univ.*

6. PROGRAM HIGHLIGHTS

Telescope upgrade construction prevented tracking-mode observations during the entire reporting period, and only a limited number of drift-mode observations were made as part of continuing spectral-line and pulsar search programs.

6.1 Spectral Line

F. Briggs (Groningen) and collaborators continued their 430 MHz drift-scan survey. This is a very deep search for highly redshifted neutral hydrogen emission (at $z=2.3$) from extragalactic clouds and gas-rich galaxies. Preliminary results from this survey are described in the previous (1994-1995) BAAS observatory report. This program was suspended toward the end of the reporting period due to complications from the upgrade construction.

A meeting on ''Molecular Spectroscopy in the 1 to 10 GHz Range with the Upgraded Arecibo Telescope'' was held at the Observatory on October 19–20, 1995. This meeting was organized by W. Baan and L. Olmi of the observatory staff. Some 20 outside scientists from the USA, Europe and Mexico attended, and a total of 16 contributions were presented. The main conclusion from the workshop was that the upgraded Arecibo telescope will soon be ready to compete favorably in the field of molecular astronomy with other major telescopes planned for the end of this decade. In particular, it will complement the large mm-wave single dishes and interferometers. Furthermore, certain types of observations and studies will gain a huge advantage from using Arecibo given the increased sensitivity and high spatial and frequency resolution of the telescope. One of the main scientific conclusions from the workshop is that maser emission will be among the biggest areas of investigation with the upgraded telescope. H_2CO, CH, OH,CH_3OH and Λ-doubling lines of some $^2\Pi$ species such as SH, HCl^+, and possibly SiH will have transitions observable at Arecibo. OH and CH_3OH seem particularly promising when considering multi-line studies in both HII regions and late-type stars. The study of simple hydrides is valuable as these are considered important building blocks in interstellar chemistry, and many of them are observable at cm wavelengths thanks to their Λ-doubling. Observations of these species can also help our understanding of how C, O, N, etc. are incorporated into more abundant molecules. Asymmetric tops form another class of molecules observable with the upgraded telescope. Many such species have weak, low energy transitions below 10 GHz.

6.2 Pulsar

Drift-scan pulsar searches continued through 1995 but were discontinued toward the end of the reporting period due to complications from the upgrade work. The results of the dec-strip drift-scan search programs were summarized in the last (1994-1995) BAAS observatory report. To date, five separate research groups have discovered a total of 57 pulsars in drift-scan searches during the upgrade construction period. Included in this haul are a half-dozen new millisecond pulsars.

A workshop on ''Pulsar Science with the Upgraded Arecibo Telescope'' was held at the Observatory on October 28-29, 1996. There were 36 participants and 27 contributions which surveyed the community's needs for the best and most efficient use of the upgraded telescope. During the workshop, privately owned pulsar processors were offered as user-owned public access equipment. These include the PennStatePulsar Machine, the Princeton MkIII and MkIV machines and Totally Accurate Clock, and the Arecibo-Berkeley-Pulsar-Processor (to be installed at Arecibo in December 1996).

The AOFTM, a 10MHz multichannel pulsar spectrometer developed by J. Cordes was brought to the Observatory, where further tests proved that it is capable of very efficient pulsar searches with the 430 MHz feed.

The pulsar community strongly recommended the development of a wideband pulsar spectrometer that would make use of the wide bandwidths offered by the Gregorian optics. Arecibo Observatory has proposed an 800-MHz spectrometer based on the NAIC-chip composed of four 200-MHz modules. The first such module is expected to be completed by the end of 1997.

PUBLICATIONS

The following list of publications from NAIC staff and visiting scientists is not necessarily complete. These contributions appeared in the open literature or were in press during the period from July 1995 to July 1996.

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