National Radio Astronomy Observatory
Green Bank, West Virginia

Quarterly Report

January 1 - March 31, 1965

RESEARCH PROGRAMS

85-foot Telescopes

During this quarter the 85-foot telescopes were used for both single telescope observations and in the combined telescope configuration as an interferometer. The tabulation below indicates single dish observations only.

85-1 Telescope		Hours
Scheduled		340.75
Equipment installation and scheduled maintenance		54.50
Time lost due to:	equipment failure	20.00
	weather	43.25
	interference	4.50
	power	0.25

H. Wendker began mapping the Cygnus X complex at 5000 MHz. S. von Hoerner observed one lunar occultation with the 5000 MHz equipment.

85-2 Telescope		Hours
Scheduled		59.25
Equipment installation and scheduled maintenance		11.00
Time lost due to:	equipment failure	0.00
	weather	0.00
	interference	0.00
	power	0.00

S. von Hoerner observed lunar occultations of radio sources at 234, 256, and 405 MHz.

Observations as an Interferometer		Hours
Scheduled		624.75
Equipment installation and scheduled maintenance		350.00
Time lost due to:	equipment failure	33.00
	weather	45.00
	interference	3.00
	power	0.5

Rather extensive modifications in the interferometer equipment resulted in rather extensive delay in making the system operational.

300-foot Telescope

		Hours
Scheduled		1950.00
Equipment installation and scheduled maintenance		133.75
Time lost due to:	equipment failure	126.25
	weather	27.25
	interference	1.25
	power	0.00

During this quarter the following investigations were made with the autocorrelation receiver. G. Westerhout (University of Maryland) observed in and near the galactic plane. C. Heiles (Princeton University) continued thesis observations to determine the distribution at high latitudes of interstellar clouds. M. Roberts observed extragalactic systems. G. Rougoor (Leiden Observatory) concluded a short program to supplement Leiden's galactic high velocity cloud investigations. T. K. Menon observed absorption profiles of neutral hydrogen at positions of strong discrete sources. K. Reigel (University of Maryland) observed a few H II regions.

The autocorrelation equipment was removed and a cross-polarized two receiver system observing at a frequency of 1415 MHz was installed along with a 750 MHz system set off axis to the west. With these systems the following measurements were made: H. Wendker began mapping the Cygnus X complex. M. Kaftan-Kassim observed planetary nebulae and a few selected galaxies. P. Mezger continued work on the survey of the Milky Way and observed a few H II regions. M. DeJong (Rensselaer) mapped the continuum surrounding about five galaxies. P. Palmer (Harvard University) investigated the polarization of radiation from Mars at 1415 MHz. D. Hogg observed the Scorpius x-ray source. G. Swenson (University of Illinois) mapped M 31 to supplement data taken at the University of Illinois. F. Ellis (Louisiana State University) mapped portions of the Galactic Spur.

Millimeter Wave Program (1 millimeter and sub-millimeter)

A field trip to Mount Palomar for use of the 200-inch at 1.2 mm was successfully completed during the period January 11-22, and measurements of the Moon, Jupiter, Mars, and 3C 273 were obtained. Plans now indicate a return to Mount Palomar in May, during the bright of the moon, for additional measurements.

Instrumentation for the 36-foot millimeter telescope now under construction is being developed with special emphasis being placed on adapting and improving existing 1.2 mm receivers. In addition, a detector construction program is being carried forward to develop a backlog of germanium bolometers with a wide range of parameters.

The following programs are being carried out in the sub-millimeter region (6-20 microns):

a) Construction of an infrared spectrometer for the 6-14 micron band was completed, and high resolution spectra of the moon, all the major planets, and one star have been obtained using a 28-inch optical telescope at the University of Arizona. This represents the first stellar spectrum ever obtained in this band.

b) Detection of the Ne^+ line at 12.8 microns in an external galaxy using the 28-inch telescope. This was later confirmed with the 82-inch at the McDonald Observatory.

c) A continuing program of infrared photometry covering several narrow windows in the 6-14 micron band has now been extended to about 70 stars, plus all the planets up to and including Saturn.

d) Detection of what appears to be circumstellar infrared emission from three stars, α Orionis, α Tauri, and μ Cephei in the 7.5 to 14 micron band. Continuing observations over a period of several months indicate a cyclical variation in intensity as well as size.

ELECTRONICS DIVISION - EQUIPMENT DEVELOPMENT

Three receiver systems (two 1400 MHz and one 750 MHz) were installed and are operating on the 300-foot telescope. Some difficulties have been encountered, but the eight astronomers who are time-sharing the 24-hour observing day are obtaining useful data.

The revised interferometer system began operation in March and is quite satisfactory. Continuing improvements and clean-up of details on the new system are now being accomplished. Work on the phase lock system is continuing.

A control computer has been ordered for the 36-foot telescope. If details can be worked out, the computer company will also build the

peripheral equipment, provide maintenance from Los Angeles, and write the basic program. They will also attempt to put NRAO in contact with a programming firm in the Tucson area which is familiar with their computer which can write new programs as needed.

The occultation receiver front-ends are being re-packaged to fit the 140-foot telescope at the center mount instead of the outboard mount. This re-packaging will be ready when the 140-foot telescope begins operation.

The 6 cm receiver for the 140-foot telescope is undergoing final tests and work on the other receivers is progressing.

The following Electronic Division internal reports were issued during the report period.

No.	Title	Author	Date
44	300-Foot Telescope Positioner II	Claude Bare	February 1965
45	Clock and Marker System	Claude Bare	March 1965

CONSTRUCTION

Charlottesville Laboratory Building

Construction on the new laboratory building is progressing according to schedule and no delays are foreseen. If construction continues at the present rate, the building will be ready for occupancy by December 1 as planned.

THE 140-FOOT TELESCOPE PROJECT

During January the NRAO Engineering Division completed design of the declination inductosyn mount and the NRAO shop fabricated the assembly. The shop also fabricated six metal slippers to replace the present brake shoes on the declination brakes. The super-structure was fine-balanced, the declination gear was aligned, and work was substantially completed on the installation of the declination drives and brakes. Optical checks on January 7 were made to check the azimuth of the polar shaft and to check the perpendicularity of the declination shaft to the polar shaft. These indicated the telescope to be satisfactory.

A fire on January 30 destroyed the north derrick winch and other equipment. The insurance company of Pacific Crane and Rigging Company is processing the claim.

In February the alignment of the declination machinery was completed and related work on the hydraulic and electrical systems was finished. The cable tray, junction boxes, and roll drums for the signal cable were installed from the control room to the super-structure. Sixteen accumulators serving the bearing pads were removed from the south passage and were returned to the supplier for replacement.

The erection contractor completed his work and left the site on February 25.

In March, Observatory forces completed the bolting of the declination gear girder, bolted aluminum to steel declination shaft, installed cones on the shaft, installed an additional platform and railings and started adjusting the surface panels. Preliminary work on the signal cables is underway in the control room pending completion of the panel setting, after which cable pulling on the structure will commence.

NRAO INTERFEROMETER PROGRAM

During this quarter only a small amount of time was devoted to observations with the interferometers due to construction and installation of new electronic equipment in the system. In addition to this activity, primary emphasis was given to a detailed analysis and interpretation of the data obtained during almost continuous observations during the preceding quarter.

During the first week of January the 85-2 telescope was moved from observing station 2 to station 5. The antenna separation was thus increased from 1500 m to 2400 m, yielding a baseline of approximately 21,600 wavelengths. A measurement of the alignment of the polar shaft of 85-2 at observing station 5 showed the telescope pads were precisely located by the original baseline survey, as was the case with stations 1 and 2.

A new back-end for the interferometer receiving system was completed, installed and tested during this reporting period. The new equipment features modular construction for ease of maintenance and trouble-shooting. In addition, the individual components were designed to eliminate several specific problems which arose during operation with the first equipment. Two weeks of calibration and observations with the new equipment indicates that is is operating very satisfactorily in most respects. The local oscillator system requires further improvements, however.

In addition to the new equipment for the back-end of the receiving system, several modifications were made in the front-ends. These were designed primarily to facilitate system performance checks and calibrations, and will substantially reduce the time required previously to perform such tests. Additional modifications and additions to the system are planned and in progress.

The computer programs required for the reduction of the source position data obtained at baseline 2 have been written and the analysis of these data is now complete. In all, positions relative to the two calibrators 3C 48 and 3C 147 were determined for twenty sources. The internal error, for a source observed for several hours on each of three days, was about one second of arc in each coordinate. The absolute position of a source is determined by assuming that the optical and radio positions of the two calibrators coincide; with this assumption, the radio positions of nine of the twelve recently identified sources agreed with the optical position to within twice the probable error of the measurement. There appears to be no systematic correlation greater than 1".5 with declination in either coordinate.

The data on the resolved sources have also been reduced, but the synthesis study must await the completion of the observations at other baselines. The accompanying figure shows how the visibility amplitude (i.e., the observed flux as a function of the total flux from the object, Cygnus A) varies as a function of hour angle at each of the two baselines used. The rapid variation is produced by the well-known double structure of the source. The slower modulation of the visibility amplitude suggests the presence of small-scale structure within the two components.

Observations of both source position and source structure are presently in progress at the fifth baseline station.

THE NRAO MILLIMETER WAVE ANTENNA

Progress on the various aspects of the 36-foot telescope project has been steady since the last report. The National Science Foundation gave final approval to the location of the telescope on Kitt Peak in a letter dated February 11, 1965, and completed their review of the Rohr contract by March 8, 1965. The NSF made a press release describing the project on February 17, 1965, and this received fairly wide publicity, particularly in Arizona and California.

(a) Site Selection and Preparation

A foundation survey of the exact location for the telescope pedestal and the dome foundation has been completed. Under the direction of the Heinrichs Geoexploration Company of Tucson a set of five borings were made, in each case taken to bedrock at depths somewhat in excess of fifty feet. A seismic survey was made.

Based on the results of this survey and on discussions with the Kitt Peak National Observatory staff familiar with designing foundations on the mountain, a foundation plan has been prepared by Rohr and offered for bid to various Tucson and nearby contractors.

Preliminary access to the site will be by a temporary road leading from the edge of the Kitt Peak picnic area. KPNO have started to prepare this route so that foundation work can start.

Two NRAO engineers, Mr. Hungerbuhler and Mr. Smith, have worked at Kitt Peak on the planning and laying out of the new electric power line to the site and on the location of the final access road. It appears that about 1100 feet of road, with an average grade of about one in ten will be needed. This will lead to the site from a point on the main KPNO road just below the existing turn-off which leads to the picnic area. The final road needs to be only "one vehicle" width, but it must allow the 36-foot dish to be trucked as one unit to the site. The power-line will be a three-phase overhead line of construction very similar to the existing KPNO main feeder line and will take off from that line via suitable disconnects to a sub-station at the 36-foot site.

Other on-site work which will be needed is the design of the observing room which will be located within the dome on the north side of the telescope, and the provision of simple water and sanitary facilities.

(b) The Telescope and Astrodome

Progress in the fabrication of the telescope and the astrodome at the Chula Vista plant of the Rohr Corporation is about on schedule. The foundation core borings were somewhat delayed, and this has caused an overall schedule slip. However, as nearly as can be estimated at present the instrument and dome should be ready for acceptance tests in August of this year.

Regular visits are being made to the Rohr plant. The most interesting step in the whole fabrication will be the machining of the dish back-up structure and of the dish surface itself. A 50-foot radial arm mill capable of working to $\pm$ .002 inches has been specially designed and built at Rohr. This will be used first to machine the top surface of the back-up structure and then to machine the solid aluminum surface of the dish itself. The surface plates will be stretch-formed before welding into the surface skin. The NSF has arranged that the Rohr machine which is employed on other government work may be used for this task.

The fabrication of other parts of the telescope and of the astrodome is proceeding with no major difficulties or delays at present apparent.

The dish will be transported by truck from Chula Vista to Kitt Peak. Rohr and NRAO are working with a trucking contractor for this task. Special highway permits for such a load will be needed, and the first steps to obtain these have been taken.

(c) Ancillary Equipment

The computer which is needed on-line as part of the drive and control system has been ordered. Designs are being made for a focal point assembly allowing the feeds to be remotely focussed and rotated. A design is being made for a high sensitivity closed-circuit television system, rigidly mounted to the dish axis to be used for optical pointing of the dish. Work is yet to start on the design of the control console, cabling plans and the details of focal point equipment.

Separate from the telescope project, development work on radiometers continues and is reported on elsewhere.

ANTENNA DESIGN STUDIES

The Largest Feasible Steerable Paraboloid

The report of the Westerhout meeting of October 30, 1964, was given in the previous quarterly report. Since that meeting a start has been made on the design study for a large steerable instrument. The study is being led by J. W. Findlay.

An outline plan for the study was drawn up, and several preliminary papers have been written. The interest and criticism of a large number of competent people is essential in such a study, and all study documents are being mailed to a total of 55 scientists and engineers. The mailing list covers the membership of the Whitford Committee, the Westerhout group, others who act in an advisory capacity to AUI or NRAO, as well as engineers and scientists with experience of large telescope construction.

The following papers have so far been circulated:

LFSP/JWF/1	The outline plan of the study
LFSP/JWF/2	The Floating Sphere Antenna
LFSP/JWF/3	Comments and additions taken from several replies to the study documents
LFSP/JWF/4	The Fixed Elevation Transit Telescope

A small working engineering group has been formed to work with JWF on all aspects of the study. The group will soon have its first meeting to start more specific design study work.

The Very Large Antenna Array Project

During the quarter effort has been concentrated on the establishment of a design concept for the array, whose principal parameter is ten seconds (arc) beam width at a wavelength of ten centimeters. Theoretical studies have been directed toward an understanding of the multiple-element correlation array, particularly the variation of sensitivity with number and size of elements, establishment of some type of figure of merit involving cost, observing time, electronic complexity, and so on.

Informal memoranda have been prepared for internal use on the following topics:

"Sensitivity of an N-Antenna Correlated Array"
G. W. Swenson, Jr.

"Cost of Achieving $S_{min} = 2 \times 10^{-28}$ as a Function of N"
G. W. Swenson, Jr.

"On the Apparent Baseline Length of a Correlation Interferometer"
Y. L. Chow

"The Feasibility of Exponentially-Spaced Arrays for Small Sources"
Y. L. Chow

"On the Phase-Center of a Paraboloidal Antenna"
B. G. Clark

A computer program has been written to investigate possible array configurations as an aid to optimizing antenna patterns and observing time.

Personnel of the array project keep in close touch with the NRAO interferometer program, as operational experience in this program provides some of the most essential data for the design of the array. Observing time is available on the interferometer as needed for investigations in connection with the array study.

A purchase order has been issued to the National Bureau of Standards for the development study of a method of phase-stabilization of a tropospherically propagated microwave signal. This system is needed for a portable interferometer system of very long baseline, to be used in investigations of atmospheric properties affecting the design of the array. It will also be used in testing possible sites. If the phase-stabilized system achieves the anticipated success, it will open up new possibilities for very long baseline, phase-coherent interferometry. This investigation is underway at Boulder, Colorado.

Informal inquiries have been made among industrial firms concerning the acquisition of a portable, 40-foot diameter, paraboloidal antenna for use in the very long baseline interferometer investigation. Responses have not been entirely satisfactory, but two firms have been found who may be interested in providing an economical antenna capable of transport over highways. The Observatory's engineering department is also studying the problem.

In order to establish design criteria for the array, two groups of astronomers met at the Observatory to discuss the most important astronomical missions for the array. The first group included representatives from Cal Tech, Illinois, Princeton, and California (Berkeley), as well as a few of the Observatory staff, and met on December 11 and 12. The second group included most of the scientific staff of the Observatory, and met on March 30. A list of priority missions has been compiled. This will be subject to review from time to time.

Mr. Walter J. Weller, who has been working for his Ph.D. in astronomy at Northwestern University, joined the staff as a research associate on January 15.

Dr. G. W. Rougoor, of the Leiden Observatory, Mr. Patrick E. Palmer and Mr. David D. Morrison, graduate students of Harvard University, and Mr. Fred E. Ellis, graduate student of Louisiana State University, have been at the Observatory during the quarter on guest appointments.

Dr. Marc Vinokur, of the Meudon Observatory, arrived on March 5 to spend several weeks on a guest appointment. He is engaged in theoretical studies in connection with the NRAO interferometer program.

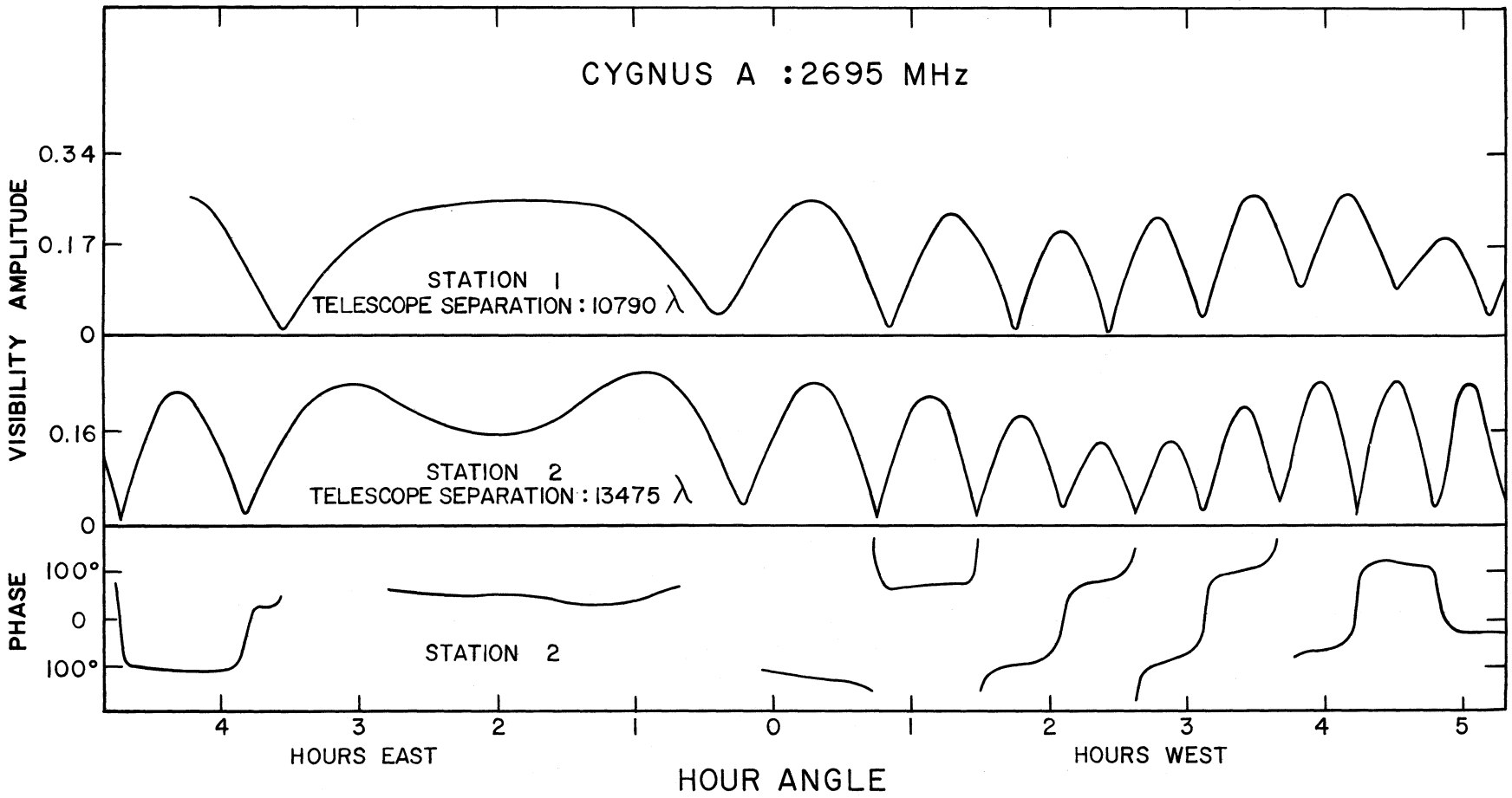
Mr. Yervant Terzian, who did research for his thesis "Radio Emissions from H II Regions" at the Observatory over the past year, received his doctorate in astronomy from Indiana University in January, and has gone to Puerto Rico where he has accepted a position at the Arecibo Ionospheric Observatory.

Appendix A

An Updating of NRAO Reprints

Series A

No.	Title	Author	Journal
32	Determination of the Galactic Rotation Parameters from Cepheid Radial Velocities and their Variation with the Distance Scale	W.E. Howard III and J.G. Kirk	A.J. 69, No. 8 1964
33	Infrared Brightness Temperature of Saturn	F. J. Low	A.J. 69, No. 8 1964
34	Absolute Spectra of the Strongest Nonthermal Radio Sources in the Wavelength Range Between 2 and 100 cm	J.W.M. Baars, P.G. Mezger and H. Wendker	A.J. 69, No. 8 1964
35	Properties of Galaxies: Color-Magnitude Diagram	Craig Chester and Morton S. Roberts	A.J. 69, No. 8 1964


CYGNUS A :2695 MHz
VISIBILITY AMPLITUDE
0.34
0.17
0
STATION 1
TELESCOPE SEPARATION : 10790 λ
0.16
0
STATION 2
TELESCOPE SEPARATION : 13475 λ
PHASE
100°
0
100°
STATION 2
4
3
2
1
0
1
2
3
4
5
HOURS EAST
HOURS WEST
HOUR ANGLE