# Quarterly Report of the

# HAYSTACK OBSERVATORY

## NORTHEAST RADIO OBSERVATORY CORPORATION

**15 JULY 1971**





Operated under Agreement with

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

# QUARTERLY REPORT
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## ACKNOWLEDGMENT

The programs in radio astronomy are conducted with support from the National Science Foundation under Grant GP-25865.

The planetary radar investigations are supported under Grant NGR 22-174-003 from the National Aeronautics and Space Administration.

Radar studies of the moon are conducted under Contract NAS 9-7830 with NASA Manned Spacecraft Center, Houston, Texas.


## FOREWORD

This will be the last Haystack Quarterly Report. In future, work at Haystack will be summarized semi-annually, in accord with a recent decision by the Haystack Observatory Office of Northeast Radio Observatory Corporation.

This decision was based upon a need for economy in publication costs and on the opinion that continuing work will receive more coherent treatment when a longer period is covered by the report.

The first Haystack semi-annual will carry a publication date of 15 January 1972 and will cover the period July through December, 1971.

## ABSTRACT

The end of this quarter marks completion of the first year of operation of Haystack as an observatory under university ownership and direction, and full sponsorship by civilian agencies.

During April through June, radio astronomy observations have used the antenna for 1331 hours as against 292 hours for lunar and planetary radar experiments. Maintenance and improvement activities have accounted for 180 hours.

The 20 radio astronomy investigations that were continuing active at the end of this quarter are summarized in Table I of the text, while Table II lists ten programs that were completed. Spectral line studies and Very Long Baseline Interferometer investigations continue to account for most of the programs at Haystack, though improvements in continuum radiometers reported here should foster additional programs in this area.

In addition to the continuing measurements of lunar topography, detailed analyses of earlier radar backscattering data from the crater Alphonsus and the Apennine-Hadley region were conducted at the request of the Apollo *ad hoc* Site Selection Committee.

In the planetary radar work, one interesting result was the finding of a region on Mars at about 18° South latitude which appeared to be of essentially constant elevation within ± 250 meters over a 1500 km span in longitude.

## NORTHEAST RADIO OBSERVATORY CORPORATION

A nonprofit corporation of educational and research institutions formed in June 1967 to continue the planning initiated by the Cambridge Radio Observatory Committee for an advanced radio and radar research facility. In March 1969, by agreement with MIT and Lincoln Laboratory, its interest was extended to the existing Haystack Research Facility to seek means of increasing its availability for research. Since July 1970, NEROC has directed the research at Haystack and has had the primary role in arranging for support.

### NEROC Institutions

Boston University
Brandeis University
Brown University
Dartmouth College
Harvard University
Massachusetts Institute of Technology
Polytechnic Institute of Brooklyn
Smithsonian Astrophysical Observatory
State University of New York at Buffalo
State University of New York at Stony Brook
University of Massachusetts
University of New Hampshire
Yale University

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| Vice Chairman | Edward M. Purcell |
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| Executive Director | Edward Lilley |
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## I. INTRODUCTION

With the end of this quarter, the Haystack Observatory completes one full year of support to radio and radar astronomy research since it was transferred by the U. S. Air Force to civilian direction under NEROC. Heightened scientific interest among research institutions in the area together with assistance from them in operating and improving the instrumentation has resulted in a fruitful year. Despite the uncertain future in these times, we are fortunate that no key personnel have been lost.

Proposals to NSF and NASA outlining plans for research programs for the coming year were prepared and submitted during the quarter.

The 1 April-30 June period saw the Planetary Radar Box (PR Box) on the antenna from 12 April to 7 May and again from 16 to 28 June. The Radiometer Box (R-Box) was on the antenna for the remainder of the period. It should be recalled that even during PR-Box periods the greater share of antenna time is still devoted to radio astronomy. During the quarter 1331 antenna hours were used for radio observing, while 292 hours were required in radar investigations. Maintenance and improvements occupied 180 hours.

## II. RADIO ASTRONOMY

### A. Summary of Programs

During the April-June period, Haystack Observatory accepted 12 new proposals for observing programs. Ten of these are for spectral line work, of which six involve searches for molecules not previously detected in the interstellar medium. We also accepted one new continuum VLBI proposal and one for continuum observations. Ten programs are continuing from the preceding quarter.

New and continuing programs are listed in Table I. The ten observing programs which were completed this quarter are listed in Table II.

### B. Accounts of Selected Programs

In the following subsections sketches of a few representative programs, edited from the experimenters' notes, are presented in order to provide a more detailed look at some of the research underway at Haystack.

TABLE I

CONTINUING RADIO OBSERVING PROGRAMS

30 June 1971

| PROGRAM | INVESTIGATORS | INSTITUTIONS | THIS QTR. OBS. HRS. | TOTAL HRS. REQUESTED | DESIGNATION |
|---|---|---|---|---|---|
| 4.83-GHz Observations of Formaldehyde | P.C. Myers, A.H. Barrett | Mass Institute of Technology | 67 | 112 | MYERS-1 |
| 1.62-GHz Observations of the H159α Recombination Line Near Sgr A | F.J. Lockman, W.A. Dent | U of Massachusetts/Amherst | 46 | 190 | LOCKMAN-1 |
| 15.5-GHz Mapping of the Galactic Center Region | W.A. Dent, J.E. Kapitzky | U of Massachusetts/Amherst | 15 | 70 | DENT-3 |
| Search for Spectral Lines Around 18.4 and 20.1 GHz | C.A. Gottlieb, H. Penfield<br>A. Penzias | Harvard College Observatory<br>Bell Telephone Laboratories | 78 | 120 | GOTTLIEB-4 |
| 22-GHz Mapping of Galactic Center Region | M.L. Meeks<br>Shelley Rogers | Haystack Observatory<br>MIT Physics Department | 29 | 72 | MEEKS-3 |
| 7.8-GHz Recombination Line Studies (94α) of the Following Sources: Tau A, Ori A, NGC 2024, Sgr A, W49 & Diffuse Background | E.J. Chaisson | Harvard College Observatory | 6 | 216 | CHAISSON-4 |
| 7792-MHz Recombination Lines, Search of Planetary Nebulae | L.E. Goad | Harvard College Observatory | 0 | 72 | GOAD-1 |
| 8- & 15-GHz Monitoring of Quasars & Peculiar Galaxies | W.A. Dent | U of Massachusetts/Amherst | 284 | 50/month | DENT-1 |
| 8.0-GHz Recombination Line Measurements (94α) in the Cygnus X Region | E.J. Chaisson | Harvard College Observatory | 25 | 120 | CHAISSON-3 |

TABLE I, Continued

| PROGRAM | INVESTIGATORS | INSTITUTIONS | THIS QTR. OBS. HRS. | TOTAL HRS. REQUESTED | DESIGNATION |
|---|---|---|---|---|---|
| 30 to 39.6-GHz Search for Molecular Spectral Lines | B.E. Turner, M.A. Gordon<br>G.T. Wrixon | National Radio Astronomy Obs<br>Bell Telephone Laboratories | 0 | 112 | TURNER-1 |
| 7.84-GHz VLBI Observations with Goldstone 210-foot antenna | T.A. Clark, G.E. Marandino<br>*R.M. Goldstein,<br>*D.J. Spitzmesser<br>†H.F. Hinteregger,<br>†C.A. Knight, A.R. Whitney<br>†I.I. Shapiro<br>‡A.E.E. Rogers | U of Maryland<br>* Jet Propulsion Laboratory<br>† Mass Institute of Technology<br>‡ Haystack Observatory | 19 | 60 | VLBI-9 |
| 23.8 to 25.9-GHz Observations of Transitions in Methyl Alcohol | A.H. Barrett, J.W. Waters,<br>P.R. Schwartz | Mass Institute of Technology | 91 | 48 | BARRETT-8 |
| 1.6-GHz Observations of OH in Dark Clouds | P.C. Myers, A.H. Barrett | Mass Institute of Technology | 142 | 80 | MYERS-2 |
| 23.3 to 24.6-GHz Search for Transitions in Methylamide ($CH_3NH_2$) | J.A. Ball, C.A. Gottlieb<br>A.E. Lilley, H. Penfield<br>*H.E. Radford | Harvard College Observatory<br><br>*Smithsonian Astrophys Obs | 0 | 72 | GOTTLIEB-5 |
| 20.2 to 26.7-GHz Search for Transitions in Ethyl Alcohol | J.A. Ball, C.A. Gottlieb,<br>A.E. Lilley, *H.E. Radford | Harvard College Observatory<br>*Smithsonian Astrophys Obs | 0 | 72 | GOTTLIEB-6 |
| 22.7 to 26.6-GHz Search for Transitions in NaCl, $HC_3Cl$, $C_2HCl$ | D.F. Dickinson | Smithsonian Astrophys Obs | 0 | 48 | DICKINSON-5 |
| 15.9 to 17.3-GHz Observations of Recombination Lines 74α, 73α, 72α | G. Papadopoulos, K.Y. Lo<br>B.F. Burke, *E.J. Chaisson | Mass Institute of Technology<br>*Harvard College Observatory | 0 | 72 | PAPADOPOULOS-1 |

TABLE I, Continued

| PROGRAM | INVESTIGATORS | INSTITUTIONS | THIS QTR. OBS. HRS. | TOTAL HRS. REQUESTED | DESIGNATION |
|---|---|---|---|---|---|
| 28 to 38-GHz Mixer System Tests, Continuum Mapping | G.T. Wrixon<br>J.C. Carter | Bell Telephone Laboratories<br>Haystack Observatory | 0 | 16 | WRIXON-1 |
| 7.793-GHz Mapping of H94α Transition in W43 | K.Y. Lo<br>E.J. Chaisson | Mass Institute of Technology<br>Harvard College Observatory | 0 | 50 | LO-1 |
| 23.1 to 24.9-GHz Search for Transitions in Ethylene Oxide, $C_2H_4O$ | A.H. Barrett | Mass Institute of Technology | 0 | 50 | BARRETT-9 |

TABLE II

OBSERVING PROGRAMS COMPLETED

1 April - 30 June 1971

| PROGRAM | DESIGNATION | INVESTIGATORS | INSTITUTIONS | TOTAL OBSERVING HOURS |
|---|---|---|---|---|
| 21 to 26-GHz Search for Solar Recombination Lines | Simon-3<br>Dupree-1<br>Simon/Dupree-1 | M. Simon, P. Burger<br>A.K. Dupree, J.H. [illegible]ack | SUNY/Stony Brook<br>Harvard College Observatory | 63 |
| 22-GHz Search for Extra-galactic water-vapor Sources in NGC 6822 and IC 1613 | Gottesman-1 | S.T. Gottesman | National Radio Astronomy Observatory | 32 |
| 22-GHz Search for water-vapor emission in late-type stars | Barrett-6 | A.H. Barrett, P.R. Schwartz | Mass Institute of Technology | 145 |
| 5.64-GHz Search for Interstellar $HNO_3$ | Dickinson-3 | D.F. Dickinson, C.A. Gottlieb | Smithsonian Astrophys Observatory | 90 |
| 23-GHz Search for small-scale Anisotrophy in the 3° background | Burke-4 | B.F. Burke | Mass Institute of Technology | 57 |
| 22-GHz Search for water-vapor emission in early-type stars | Simon-4 | M. Simon | SUNY/Stony Brook | 14 |
| 25.1-GHz Search for Interstellar $N_2O$ | Barrett-7 | A.H. Barrett, J.W. Waters<br>P.R. Schwa[illegible] | Mass Institute of Technology | 196 |

TABLE II, Continued

| PROGRAM | DESIGNATION | INVESTIGATORS | INSTITUTIONS | TOTAL OBSERVING HOURS |
|---|---|---|---|---|
| 22.234-GHz VLBI with NRL, NRAO, & Soviet Union (Crimea) | VLBI-6 | *B.F. Burke, C. Papa,<br>*P.R. Schwartz, +J.M. Moran<br>†S.H. Knowles, ‡W.T. Sullivan<br>USSR Astronomers (unspecified) | *Massachusetts Institute of Tech<br>+Smithsonian Astrophys Observatory<br>†Naval Research Laboratory<br>‡University of Maryland | 372 |
| 3.8-cm Mapping of Active Solar Regions | AFCRL-2 | J. Aarons, R.M. Straka, D.W. Richards | AF Cambridge Research Laboratory | 52 |
| 23.8-GHz Search for Transitions in the OH Excited State $J = 9/2, \pi_{3/2}$ | Dickinson-4 | D.F. Dickinson | Smithsonian Astrophys Observatory | 23 |

## 1. Continuum Programs

### Measurement of Time Variations in the Flux of Extragalactic Sources at λ=4 and 2 cm

W. A. Dent and G. Kojoian
University of Massachusetts, Amherst

Since the summer of 1969 a regular program for monitoring the flux of extragalactic sources at 4- and 2-cm wavelengths has been underway at Haystack Observatory. Observations were made generally at intervals of two weeks until January 1970 when the interval between observations was shortened to one week. A period of about 24 hours has regularly been scheduled for each observing session, with the observing frequency determined by which of the two equipment boxes (R Box or PR Box) is installed on the antenna. The boxes have been alternated roughly every six weeks so that nearly equal time has been available at the frequencies 7.8 and 15.5 GHz. At 7.8 GHz the measurements have been made with a circular-polarized feed and at 15.5 GHz orthogonal linear polarizations have been employed to obtain the total flux.

Initially about 20 sources were monitored but when the observations became weekly, the number of sources was increased to between 35 and 40. Measurements are corrected for the variation in gain with elevation, for varying values of atmospheric extinction, and in addition since January 1971 for 15.5 GHz observations gain corrections are applied on the basis of differential temperatures over the reflector structure.

### Observations of Sgr A at 22.2 GHz with a Beamwidth of 1.5 Arcminutes

B. G. Leslie, M. L. Meeks, and Shelley Rogers
Haystack Observatory

We have mapped a region centered on Sgr A with the 120-ft Haystack antenna using a mixer radiometer with a system temperature of 1000°K and a bandwidth of 200 MHz. Before each evening's observations of Sgr A we mapped the planet Jupiter, the observations being made, respectively, between elevations of 15 to 18 degrees and between 27 and 28 degrees. Ten repeated sets of drift scans were made across Sgr A with a spacing of 0.7 arcminutes. Data were registered, averaged, smoothed and contour maps prepared automatically by means of a digital computer mapping program. Our map shows that emission from Sgr A has a sharp maximum at the position of $\alpha(1950) = 17^h\ 42^m\ 32.3\ (\pm\ 1.2)^s$ and $\delta(1950) = -28^\circ\ 59'\ 08\ (\pm\ 15)''$ surrounded by a much larger diffuse region. The average diameter of the half-maximum-power contour, uncorrected for our beamwidth, is 2 arc min, and the

0.2-maximum-power contour has an uncorrected width of 3 arc min in right ascension and declination. At a frequency of 22.2 GHz the source appears smaller than the value 2 x 3 arc min reported by Maxwell and Taylor* for 1 GHz on the basis of lunar-occultation measurements. The flux of Sgr A from our measurements is 60 (± 10) flux units on the basis of an assumed average brightness temperature of 120°K for Jupiter at this frequency.

## 2. Spectral Line Programs

### A New Microwave Recombination Line in W3

E. J. Chaisson
Harvard College Observatory

It was recently reported by Gordon and Churchwell** at NRAO that the 10.5-GHz spectrum of W3 possessed an emission feature in addition to the 85$\alpha$ recombination lines of hydrogen, helium, and carbon. With independent observations at 7.8 GHz at Haystack, we have detected the anomalous line and thus have demonstrated that it is furthermore produced by the physical mechanism of electronic recombination. See Figure II-1.

The narrow width of the new line argues in favor of emission from a region similar to that from which the carbon line originates. If the anomalous feature is an additional Doppler-offset carbon line, then it would possess a peculiar radial velocity of ~ 19 $ks^{-1}$ with respect to the region from which the nebular recombination lines originate.

Alternatively, if the cloud from which the anomalous species originates moves with a radial velocity similar to that of the other emission features of this experiment, then the inverted Rydberg formula yields a mass of ~ 5.5 amu. An attempt to associate the anomalous feature with electronic recombination onto $^6Li^+$, for example, would necessitate stimulated enhancement relative to the C94$\alpha$ line by a factor of ~ $10^5$.

Search for an associated hydrogen recombination line arising from an HI region similar to that observed toward Orion B (Ball et al†, Chaisson††) may allow a firm identification of the anomalous emitter.

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* A. Maxwell, J. H. Taylor, Astrophys. Ltrs., 2, 191 (1968).

** M. A. Gordon, E. Churchwell, Astr. and Ap., 9, 307 (1970).

† J. A. Ball, D. Cesarsky, A. K. Dupree, L. Goldberg, A. E. Lilley, Ap. J. Ltrs., 162, L25 (1970).

†† E. J. Chaisson, Ap. J. (in press, 1971).

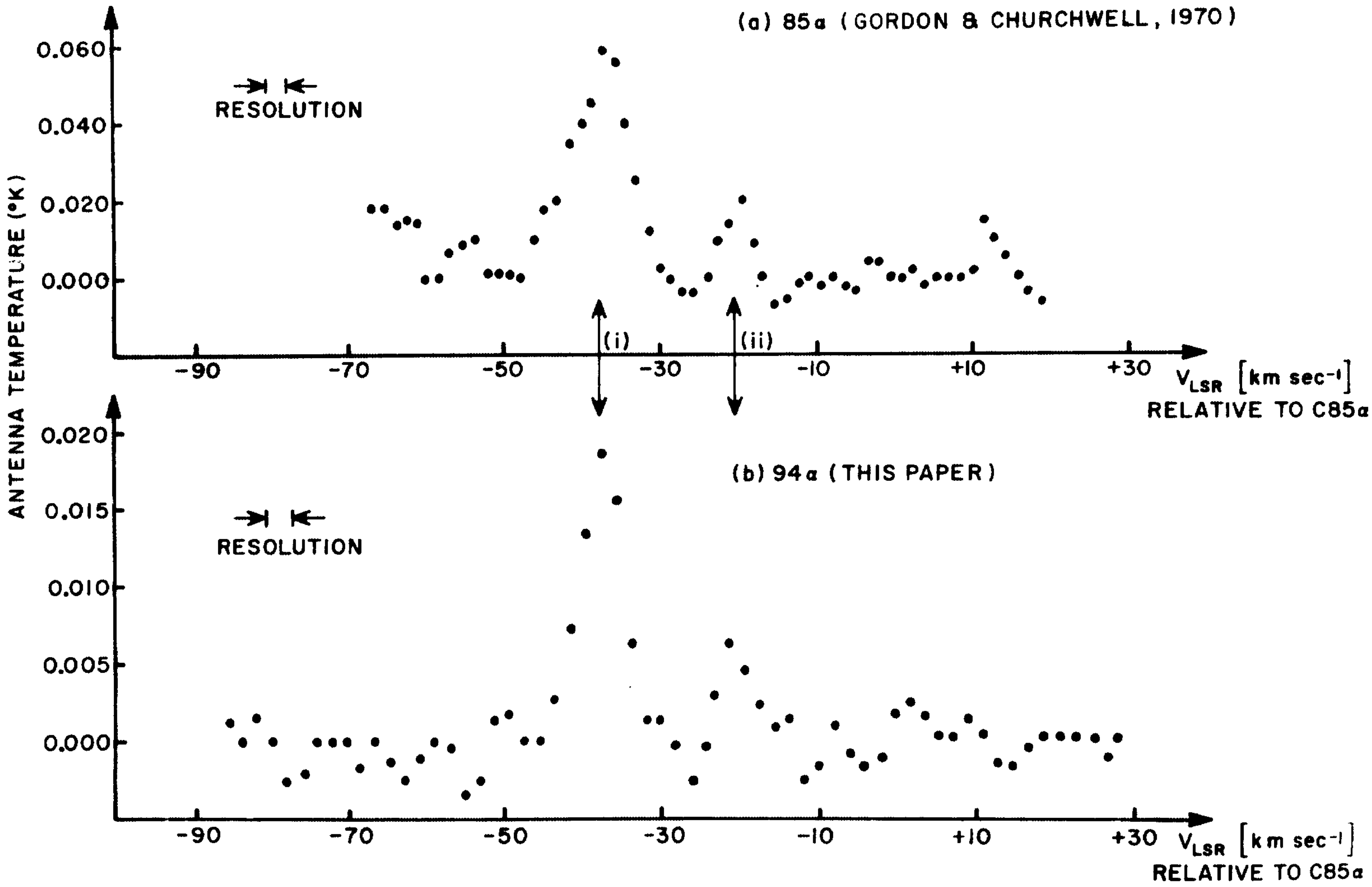


FIGURE II-1: Emission features remaining after subtraction of hydrogen and helium recombination lines at (a) 10.5 GHz and (b) 7.8 GHz; (i) denotes the C85α and C94α lines; (ii) denotes the unidentified recombination line.

## Detection of Methyl Alcohol ($CH_3OH$) in Orion at $\lambda \approx 1$ cm

A. H. Barrett, P. R. Schwartz, and J. W. Waters
Massachusetts Institute of Technology

Five transitions of $CH_3OH$, corresponding to the J = 4,5,6,7, and 8 rotational levels, at frequencies near 25 GHz have been detected in Orion A. The source of emission is less than one arcminute in angular size and appears to be coincident with the IR nebula. Comparison of the emission from these levels shows some departure from local thermodynamic equilibrium, but if the emission originates in the IR nebula then a temperature of about 90°K, a column density of about $5 \times 10^{16}$ $CH_3OH$ molecules/$cm^2$, and a $CH_3OH$ density of 0.25 molecules/$cm^3$ are indicated. Collisional excitation requires a total gas density of roughly $2 \times 10^6$ $cm^{-3}$ and a total mass of gas in excess of 20 solar masses.

The detection of the $CH_3OH$ lines was fortuitous. During an unsuccessful search for the $J = 1 \rightarrow 0$ transition of nitrous oxide ($N_2O$) at 25,123.13 MHz a line was detected in Orion A, but the resulting radial velocity was -11.5 km/sec, which was outside 5 to 20 km/sec velocity range of other molecules in this source. It was noted that the $CH_3OH$, $J = 7$, $\Delta J = 0$, $\Delta K = 1$, line was an alternative identification that gave a radial velocity of 8.5 km/sec. Following up this alternative identification, the four transitions of $CH_3OH$ were detected, establishing the presence of this molecule.

### 3. VLBI Programs

## Further Goldstack Observations of 3C273 and 3C279.

T. A. Clark, R. M. Goldstein, H. F. Hinteregger, C. A. Knight, G. E. Marandino, A. E. E. Rogers, I. I. Shapiro, D. J. Spitzmesser, A. R. Whitney
Haystack Observatory, MIT, Goddard Space Flight Center, Jet Propulsion Laboratory, and University of Maryland

The quasi-stellar objects 3C273 and 3C279 were observed again in June with the Haystack-Goldstone interferometer at 3.8 cm wavelength. This was a follow-on experiment to continue the study of rapid time variations in the brightness distributions of those objects (see Haystack Quarterly Report, 15 January 1971 and 15 April 1971). Very preliminary examination of the new 3C279 data indicate that the null positions in the fringe-amplitude pattern are still present, but moving at a somewhat slower rate than observed earlier (Knight et al,* Whitney et al**). Based on a symmetric double-source model, this suggests that the two brightness components are continuing to move apart but at a somewhat diminished rate (still, however, several times the speed of light, based on the accepted red-shift distance). No definitive choice of mechanisms can yet be made. Data from 3C273 show a drastic deepening of the partial null that was observed in October 1970 and February 1971. This may allow a meaningful interpretation to determine the 3C273 brightness distribution.

Data taken with the Haystack-Goldstone interferometer in October 1970, when 3C273 and 3C279 were close to the sun, have been analyzed to determine fluctuations in the differential radio path length as a function of projected baseline length and distance from the sun. This has enabled apparent settlement of a controversy among scintillation theorists (primarily Hewish of Cambridge and Lovelace of Cornell) as to the shape of the spectra for small-scale ($\gtrsim 10^4$ km) structure of the interplanetary electron density. The data strongly support the Lovelace theory, which predicts phase scintillations several times that of Hewish. The data from the October 1970 experiment are believed to be the first from which electron density irregularities of scale sizes of hundreds to thousands of kilometers near the sun can be studied. The large phase scintillations which were observed incidentally, have greatly contributed to the difficulties in attempting to accurately measure the gravitational bending effect, which was a prime goal of the October experiment.

### C. Radio Astronomy Instrumentation

#### 1. 15.5 GHz Radiometer Improvement

One of the first Haystack radiometers (circa 1964) was a 15.5 GHz continuum radiometer using a tunnel diode amplifier (TDA), with a 1 GHz bandwidth and a 1700° noise temperature. A new TDA with a 1000°K temperature was installed in 1967.

In April of this year another TDA (2 GHz bandwidth and 850° temperature) was combined with the 1967 TDA to form a dual-channel radiometer. Each TDA is alternately switched at a 50 Hz rate between signal and comparison feeds. After synchronous detection their outputs are combined. Thus, sensitivity is

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* C. A. Knight, D. S. Robertson, A. E. E. Rogers, I. I. Shapiro, A. R. Whitney, T. A. Clark, R. M. Goldstein, G. E. Marandino, N. R. Vandenberg, Science, 172, 52 (1971).

** A. R. Whitney, I. I. Shapiro, A. E. E. Rogers, D. S. Robertson, C. A. Knight, T. A. Clark, R. M. Goldstein, G. E. Marandino, N. R. Vandenberg, Science (in press 1971).

improved since the signal feed is always connected to one or the other of the TDA's.

The University of Massachusetts provided much of the support for this most recent improvement, which in turn is proving very valuable in the University of Massachusetts observing program on variable sources.

## 2. 22-24 GHz Continuum Radiometer

A new low-loss (0.2 db) ferrite switch was added to the existing K-band spectral line radiometer in the Radiometer Box (R-Box) to make a Dicke-switched system for continuum observations. Characteristics of the resulting system are as follows:

| | |
|---|---|
| Frequency: | 22-24 GHz (Best range of ferrite switch) |
| First RF Stage: | Mixer |
| IF Bandwidth: | 220 MHz |
| System Temp: | $950^\circ$K |
| Comparison Input: | $300^\circ$K Load or Offset Beam (Polarization switching is planned) |
| Signal Feeds: | Horizontal and Vertical Linear or Right and Left Circular |
| Comparison Feed: | Horizontal Linear; Beam Separated from Signal Beam by $0^\circ.230$ in Azimuth |
| Antenna Beamwidth: | 1.5 arc min ($0^\circ.025$) |
| Effective Aperture: | 250 square meters at $45^\circ$ elevation ($\nu$ = 24% including radome losses). |

## 3. 15.5-18 GHz Spectral Line Radiometer

Harvard College Observatory provided support to package and install in the R-Box a low-noise degenerate parametric amplifier designed and built by MIT Research Laboratory of Electronics. Evaluation at 16.5 GHz, the only frequency tried so far, yielded the following parameters:

| | |
|---|---|
| Noise Temperature: | $500^\circ$K |
| RF Bandwidth: | 50 MHz |
| IF Bandwidth: | 40 MHz |

| | |
|---|---|
| Stability: | Adequate for 5 min. on-source, 5 min. off-source pairs at bandwidths up to 20 MHz. |
| Feed: | Wideband $K_u$-band horn built for 15.5 GHz. Vertical polarization. |

4. K-band Maser Development

A 22-24 GHz maser amplifier is being developed at Haystack with the collaboration of Prof. Sigfrid Yngvesson of the University of Massachusetts, Amherst. University of Massachusetts, Harvard and MIT are each providing some of the required funding for parts, outside shop work and test equipment.

Progress this quarter has centered in two areas:

Magnet

Winding of the superconducting magnet was completed. A test header was also built and the magnet has been transferred to it from the winding machine. The magnetic circuit and test header have been assembled and wired so that the magnet can be evaluated.

Molybdenum Structure

The support for the ruby and microstrip transmission lines is to be made of molybdenum plated with gold over other metals to improve the bond. In the maser constructed by Dr. Yngvesson when he was at Berkeley last year, problems were encountered in roughness and peeling of the plating and high r.f. losses. We have therefore obtained two sample pieces of this structure and are having them plated. A second test header is being fabricated and we will evaluate the performance of these pieces at both room and helium temperatures. Required microwave equipment is already available.

5. Mark I VLBI Recording Terminal

As pointed out previously,* Haystack has not had a digital VLBI recording terminal similar to the "Mark I" developed by NRAO. Instead, the CDC 3300 has

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* Haystack Quarterly Report, p. 13 (15 Jan 1971).

been utilized to record VLBI data in the Mark I format, a trivial task, wasteful of computer time. Similarly, the machine has been inefficiently used in cross-correlating VLBI tapes after the observations.

This quarter, we have completed a Mark I recording terminal which utilizes one of the existing tape drives from the 3300 but otherwise leaves the machine free for other work during VLBI observations. A 7-track 800 bits per inch format is used.

Design of a companion unit which we call the Mark I Processor is also under way. When complete and operating in conjunction with the CDC 3300, it will provide a high speed correlation capability permitting rapid processing of Mark I VLBI tapes at Haystack.

6. Mark II VLBI Recording Terminal

A new wider bandwidth VLBI recording system has been installed in the Haystack control room. This system, known as the "Mk II," was built by Leach Corporation to NRAO specification.* The system records a 2 MHz bandwidth signal by phase encoding the clipped signal samples onto a video tape. Time synchronization is achieved by recording the time of day and frame count in BCD format on one of the audio tracks. Time synchronization on a finer scale is achieved by inserting beginning- and end-of-frame marks as well as the injection of a sync word every 256 recorded bits. The Haystack Mk II installation differs from the other terminals† in that the BCD time code is taken directly from the Haystack BCD clock instead of coming from the Chronalog clock specified by NRAO. The internal timing of the Mk II format unit is synchronized to Haystack time by means of a 1 second "tick" from the Haystack BCD clock.

Support for this development came primarily from MIT and Harvard.

## III. RADAR ASTRONOMY

### A. Lunar Studies

#### 1. Topographic Measurements

A three-hour observing period was scheduled for late June to replace several bad subarea measurements taken earlier in the year. The phase fluctuations in the data were markedly worse than in the February and April observations, with more than $180^{\circ}$ peak-to-peak variation over 5 minutes and a $\pm 20^{\circ}$ short-term

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* Haystack Quarterly Report, p. 13 (15 January 1971).

† NRAO monitored the procurement of a number of Mk II terminals for various observatories. The data recovery system is located in Green Bank and is available to all experimenters using the Mk II system.

noise superimposed. Experiments have been started to determine if the phase fluctuations originate in the inter-site cables and can, therefore, be eliminated or reduced; or if they are a result of atmospheric irregularities. In any event, the number of observations to be made this summer will be kept to a minimum, and measurements will begin again in late autumn to take advantage of the better quality of the data expected during cooler weather.

A one-day set of measurements of the calibration point Pytheas A has been analyzed with the help of the MIT Lincoln Laboratory Planetary Ephemeris Program (PEP). The aims were (1) to obtain a best value for the selenographic position of Pytheas A by fitting the series of range and doppler measurements to the current ephemeris for the lunar center of mass and the lunar librations; (2) to check the consistency of the measurements against the ephemeris, by looking for systematically-varying differences between the measurements and the best-fitted predictions; and (3) to compare the elevation measured by the interferometer against the radius vector calculated during the fitting process.

The consistency of the range-doppler measurements was very good with an rms deviation of only 1.5 mm/sec in the doppler fit and 75 m in the range fit. When the phases of the measurements are converted into absolute elevations, however, there appears a 2 to 3-km variation between observations. In view of the excellent fit of the PEP analysis as well as the internal consistency (better than 0.5 km) of the elevations calculated from a single observation over a 300-km square area,* we conclude that there remains a problem in the data-reduction computer program, almost certainly in the initial introduction of the predicted lunar position and velocity into the three independent coordinate systems (celestial, range-doppler, and interferometer baseline). It is also possible, of course, that the phase differences are the result of an instrumental drift in the interferometer. There is no indication of such drift during the course of one observation, however, which argues against this and also argues for a problem with the initialization.

In the meantime, an alternative way to obtain elevations over an extended area of the lunar surface is to remove the phase uncertainty by least-squares fitting of overlapping parts of different observations. The first such calculation has been successfully completed, with residual errors of much less than 0.5 km in the overlap region. There will be available within the next few weeks an elevation contour map of LAC 41 containing parts of six separate observations. The absolute datum will still be in some question, but the overlap areas from the LAC 41 mosaic will contribute additional information toward the solution of the basic phase-discrepancy problem.

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* Haystack Quarterly Report (April, 1971)

2. Lunar Reflectivity Analyses

Alphonsus

A detailed analysis of the radar data on the crater Alphonsus was recently completed in response to a request by the Apollo ad hoc Site-Selection Committee. Several different geologic units can be distinguished in the 3.8-cm backscatter maps of the floor of the crater that were completed last year. Aside from the well-known dark-halo craters, there is a major difference in both radar albedo and topography between the southern and northern halves of the crater floor. The southern half appears to be flooded with a radar-darker material, topped by the central ridge that extends radially southward from the center of the crater. This material has been thought to be ejecta from the crater Arzachel immediately to the south. It now appears, however, that there is similar elevated material and a ridge in the southern half of Arzachel itself, which is fairly well aligned with the ridge in Alphonsus and also with one of the straight sections of the rim of Ptolemaeus to the north. There is no large crater to the south that would have ejected material into Arzachel. A fault may, therefore, have existed in the lunar crust at an early time. It then may have become the channel for flooding of the southern half of both craters with a viscous lava that did not spread out uniformly over the crater floors before cooling into the present topography. Such a history is, of course, pure conjecture. It would be most interesting, however, to get samples of this flow, in the event that Alphonsus is chosen as the landing site for Apollo 17, since one of the sources for higher viscosity in molten rock is hydration.

Apennine-Hadley

Another investigation was conducted of the Apennine-Hadley region (26°N, 4°E), including the planned site for the Apollo 15 landing.* From a comparison of the 3.8-cm radar map and the Lunar Orbiter optical photograph of the crater Hadley C, it appears that the lava that flooded the floor of the mare Palus Putredinis may have formed only a thin rock layer on top of a much deeper layer of dust (possibly as deep as 1 km). If true, then the dust-producing erosion processes during the $10^9$ years before the mare flooding ($\sim 3.6 \times 10^9$ years ago) were more efficient than is currently accepted.

B. Venus and Mercury

Radar observation of Mercury was concentrated on a favorable inferior conjunction in April, while ranging measurements of Venus were taken on a less

* S. H. Zisk, M. H. Carr, H. Masursky, R. W. Shorthill, T. W. Thompson, Science (to be published, 1971).

concentrated schedule of once per week when the Radar Box was on the antenna. Venus observations will continue on this basis through the superior conjunction in late August.

1. April Mercury Observations

Successful observations devoted to studying surface topography and scattering law were carried out during the interval surrounding the April inferior conjunction of Mercury. Except for two short gaps, daily observations were obtained from 15 through 30 April.

Most of the observations were made using the PRTS (Planetary Real Time System - the designation for the standard ranging mode which uses the CDC 3300 for all data processing functions) with a 24-microsecond effective pulse resolution‡ ranging mode, although a significant number were also made using 60-μsec resolution where signal strength was poor. These were analyzed both for topography and scattering law.

2. Topography and Scattering Analysis

Power versus range delay profiles of 60-μsec PRTS observations were developed by summing all frequency elements of the delay-doppler matrices normally correlated with a "template" to yield precise ranges for orbital determination. The resulting range delay response is a measure of the planetary scattering weighted over a region extending in angle about 10 degrees beyond the subradar point. These profiles are smoothed by the radar delay response and are also modified by the limited frequency coverage available in the PRTS processing.

These known system characteristics were applied to a theoretical scattering model developed by Hagfors.* The resulting signal reflection model was compared with the Mercury measurements obtained in April 1971 (as well as with selected 1968 and 1969 observations). The radar equation was used to scale the observations to a common reference. Figure III-1

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‡ Phase reversal coding is used to obtain range delay measurements with CW transmitter operation. Actual pulsed operation is employed only in the moon work.

* T. Hagfors, J. Geophys. Res., 69, 3779 (1964).

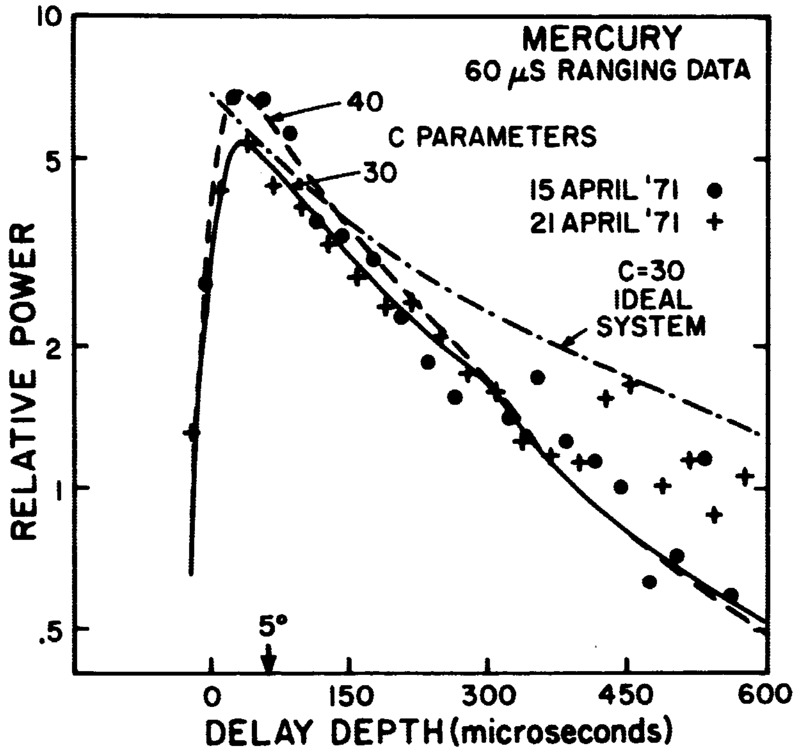


FIGURE III-1: Mercury 60-μsec range delay profiles from 15 April 1971 (circles) and 21 April 1971 (crosses) compared with Hagfors model predictions (curves), including effects of radar system in delay and frequency. Predictions are for C parameters 30 and 40 and for a limb-to-limb frequency spread of 342.7 Hz. Idealized scattering response also emphasizes severe effect of radar system response in modifying the observed delay profiles.

shows the results of two typical observations compared with the Hagfors model for two values of the roughness parameter C and for a particular limb-to-limb frequency spread typical of the conjunction period. The large modification to the model by the radar system response indicates the difficulty in using this technique for precise scattering determination. A further difficulty is that these observations average over a rather large area of the planet; the delay depth of the 60-μsec effective pulse width corresponds to a surface great circle angle of some 5 degrees beyond the subradar point. Thus these delay-profile measurements must be considered as an averaged estimator of scattering characteristics. They did confirm, however, that a C value of 30 to 40 is representative of planetary scattering for Mercury.

The peak value of the delay profile is a measure of both reflectivity and the specularity of the reflection. It is particularly sensitive to the angular scattering spectrum and can be used as an estimate of this quantity if an essentially constant total radar cross section is assumed. Ranging data dating back to 1967 were scaled by the radar equation and plotted against longitude in Figure III-2. (The longitude system adopted by the IAU in 1970 is used to present the data. This differs in both origin and sense of rotation from systems used by Smith and others to present Mercury data.) Three latitude regions are identified by symbol and the intensive 1971 April series are denoted by solid symbols. Noting that early ranging measurements were not as carefully controlled as the 1971 observations and thus may include systematic or random errors not accounted for by the formal error bars, the plot shows a definite longitude-dependent variation in reflection characteristics. Some latitude dependence is suggested for local longitude regions. Analysis of 24-μsec data suggest that the low signal level of some of these points may well be real.

The primary objective of the 24-μsec delay-doppler measurements was an investigation of Mercury's topography. The delay of the earliest signal return for each frequency within the signal was compared with the theoretically-predicted delay for a spherical planet. A least-squares fit in delay and amplitude was made between signal data, scaled by the radar equation, and a theoretical model of the signal generated from Hagfors scattering theory. This model was fitted over a restricted frequency slice which could be identified with planetary longitude. This technique differs from the range delay measurement technique usually employed in that a topography profile along the rotation equator is obtained in contrast to a single range delay point per observation.

A longitude resolution of less than one degree (42.6 km) was obtained, limited by signal-to-noise considerations and by the planetary rotation of .28 degrees per hour which smeared the signal in the longitude dimension. The model fit was made with a frequency resolution of 2.58 Hz, i.e., about .84 degrees in equivalent longitude. Signal-to-noise ratio permitted delay measurements consistent to ± 2.5 μsec in the strongest signal cases. Reflections

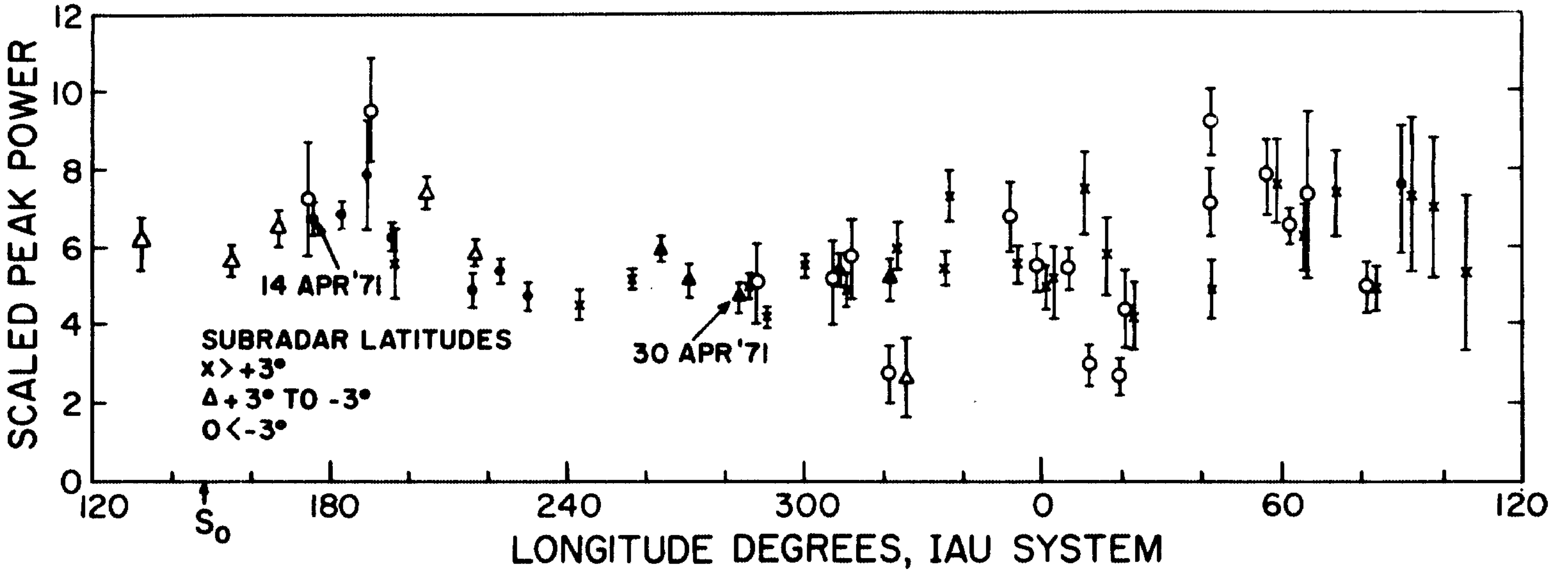


FIGURE III-2; Peak value of 60-μsec Mercury delay profile observations plotted against longitude of subradar point (IAU System 1970). Three subradar latitude bands are identified by symbol and error bars are formal 1σ noise estimates and do not include systematic errors. Data from 1967 through 1971. April 1971 observations identified by solid symbols.

from regions away from the subradar point and from anomalously low reflectivity regions resulted in less accurate determinations. Absolute accuracy of topography depends, of course, on the trial ephemeris used.

The results of the 24-μsec topography observations are summarized in Figure III-3. There was sufficient overlap between the data on adjacent operating days to obtain essentially continuous plots during the three blocks of consecutive daily observations. A rather large variation in reflection on the planet within a relatively small longitude interval is evident. The signal from areas of low reflectivity was not adequate to support the delay measurement, as is evidenced by the two dashed breaks in the delay plot. The generally higher relative power in the region of 180° appeared to result from specular reflection. The model fitting indicated an average C parameter of 40 for the 180° region and a "rougher" value of 30 for the 270° region, consistent with the ranging profile result shown in Figure III-1.

Mercury appears to exhibit topography of the order of 3 kilometers within a relatively small change in longitude as typified by the delay data near 200°. The apparent change in range delay of 30 microseconds between 180° and 220° may in part be a result of the use of a trial ephemeris, but there is certainly strong evidence for a topographic variation. This investigation covered only a fraction of the planetary surface in any detail. Such observations should be continued over a number of favorable periods to build up a full picture of the equatorial region.

C. Mars

Successful radar ranging observations of Mars were carried out on 13 nights during the intervals 15 April - 6 May, and 18-23 June, while the Planetary Radar Box was mounted on the Haystack antenna. The early group concentrated on 120- and 60-μsec effective pulse resolution (with one important exception described below), while the later group (at substantially smaller ranges) took advantage of the increased signal available to shorten the pulse resolution to 10 and 6 μsecs. Most of the short-pulse echo delays were accurate to about 1 μsec.

During the last night (6 May) of the first group of observations, a region of unusually high radar cross section was observed to pass through the subradar point. A quick shift to a 10-μsec effective pulse resolution yielded a series of 3 runs, one of which resulted in a measurement of echo delay accurate to 1 μsec. These runs hold special interest because the highly reflective surface observed will once more pass through the subradar region in mid-August to yield a set of accurately determined "closure" points from which surface topographic variations may be eliminated in the orbital solution.

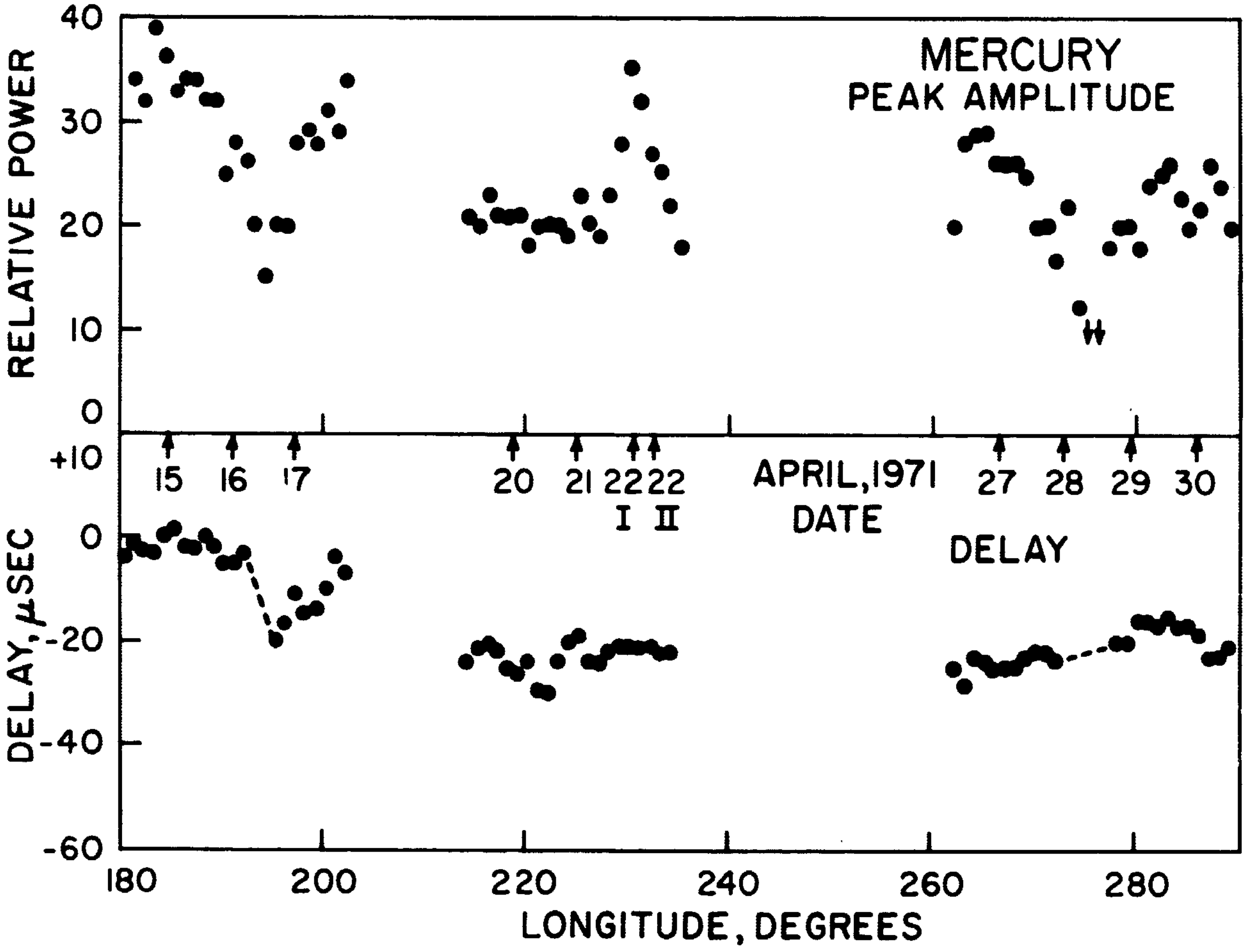


FIGURE III-3: Summary of April 1971 24-μsec Mercury topography results. Delay is relative to trial ephemeris and amplitude is scaled for Hagfors model with C of 40. Longitude system is IAU 1970 with data smoothed to $1^{o}$ quanta. Subradar longitudes of observational dates at epoch are indicated by arrows.

Of particular interest during the later observations (when the subradar latitude was 17.9° S) was a plains-like region extending over 28° in longitude from 307° to 335° (1500 km) which appeared to be at constant elevation to within plus or minus 250 m. No such feature was observed during the oppositions of 1967 or 1969 in the northern hemisphere of Mars, and it thus appears to be atypical of the Martian tropical surface. No simple correlation with a visible surface feature is noted.

During the long observing period beginning on 15 July, it is planned to concentrate on observing using 6-μsec resolution. Two separate objectives are sought: one to measure echo delay to an accuracy approaching 0.5 μsec, the other to map with high resolution a limited region surrounding the sub-radar point. These two objectives can be realized simultaneously from a single set of observations using a new dual-phase program developed recently at Haystack, and discussed in the following section.

## D. Radar Instrumentation

### 1. Hardware

An output display arrangement has been added to the real-time decoder which permits display of decoded signal power on the operating console oscilloscope. Thus, more precise monitoring and control is possible during lunar and certain other coded-pulse operations.

### 2. Computer Programs

#### a. Mars

Programming efforts in support of the 1971 Mars observations included:

- Modification of the real time Partial Decode ranging program to permit recording of 10 sec. blocks of both incoherent and coherent power sums.

- Preparation of a new dual-phase program that performs a zero-frequency sum or low-pass filtering of the raw voltage samples for 4 code intervals before integration in the receive period, followed by a Fourier analysis of a few selected ranges performed in the transmit period. The raw samples, which can be accumulated at intervals as short as 3 μsec, are recorded on tape during receive and read back during transmit in order to accomplish this. The increased efficiency of operation makes possible the decoding of 6-8 additional delay samples.

. Modifications to the "Rogers" Mars reduction program to accept data produced by the new real-time programs.

b. Venus and Mercury

A new real-time Partial Decode program has been produced which will avoid number truncation and the associated problems mentioned earlier.* Use of this program, however, awaits related hardware changes which have not as yet been possible.

c. Moon

A special version of the Haystack Moon Libration program has been written for utilization by Arecibo's Triple-Bounce Moon Experiments. The program produces predictions of range, doppler shift and pointing angles for the triple-bounced signal (Earth-Moon-Earth-Moon-Earth).

A program has been generated to support an overall study of possible errors in the ephemeris of the Moon as utilized in the Moon Mapping Experiments for the period November 1968 to September 1969. The program produces a file of as-used prediction parameters during this period which will be compared to a more recently generated ephemeris.

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* Haystack Quarterly Report, pp. 20-21 (15 April 1971).