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Semiannual Report of the HAYSTACK OBSERVATORY

(NASA-CR-135773) [RESEARCH ON HAYSTACK RADIOMETER, 20-24 GHz MASER, AND RADIO ASTRONOMY PROGRAMS] Semiannual Report of the Haystack Obs. (Massachusetts Inst. of Tech.) 52 p HC $4.75 CSCL 14B G3/11 N73-33152 Unclas 15842

NORTHEAST RADIO OBSERVATORY CORPORATION

15 JULY 1973

Operated under Agreement with

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

SEMIANNUAL REPORT

OF THE

HAYSTACK OBSERVATORY

NORTHEAST RADIO OBSERVATORY CORPORATION

15 July 1973

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I

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ACKNOWLEDGMENTS

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The Planetary radar investigations are supported under Grant NGR-22-174-003 (to NEROC) from the National Aeronautics and Space Administration.

Developments of VLBI techniques for geodetic measurements is supported under ARPA-funded Contract Number F 23601-71-C-0092 Mod 2, between NEROC and the Aeronautical Chart and Information Center, U. S. Air Force.

Incremental support of radar studies of distant satellites is provided by MIT Lincoln Laboratory.

FOREWORD

These reports are intended to summarize typical work at Haystack for the benefit of (a) the NEROC officers and Board of Trustees (b) sponsors, and (c) interested members of the scientific community. They also present engineering developments and other activities of interest which might otherwise not be published.

Suggestions from readers for improvements of these reports are welcome.

Paul B. Sebring

ABSTRACT

During the first half of 1973, the Haystack antenna was utilized 76% of the time. Of this useful time, 72% was devoted to radio astronomy observing, 5% was spent on radar-related research and 23% went into maintenance and system improvements.

Twenty-eight new radio astronomy programs were accepted, eight of which were completed during the period. One new radar program, topographic observations of Mars, was started in June and will be completed early in 1974.

Fourteen programs continued from the previous period were also defined as complete. As of 1 July, 28 radio observing programs were in a continuing status on the Haystack books. Four radar projects were also continuing.

The 20-24 GHz maser development described in the preceding report progressed very well during an on-antenna test phase which began early in the year, but which terminated unfortunately in June with the complete loss of gain in the maser. Investigation of this problem is in progress. During this on-antenna test phase, Professor S. Yngvesson, developer of the maser, was able to demonstrate probably the most sensitive water vapor observing capability which has yet become available. One example of his measurements appears in this report.

Early this year a proposal was prepared and submitted to the NSF for improvements to the Haystack antenna and instrumentation with a goal of achieving radio-astronomy observations at wavelengths as short as 3 mm. Encouragingly, a workup of 2-cm data taken over the past few years in the variable sources observing program of Professor W. A. Dent indicates no observable change in the figure of the Haystack reflector since 1968.

A second Haystack radiometer enclosure ("Box") is under construction. It will provide the alternate "box" to permit improvements and maintenance on one group of radiometers while antenna operations remain in progress using another group. Previously, work on the radiometers has been done while the antenna was operating with the planetary radar box. The use of the planetary radar will, however, be greatly curtailed in 1974.

Radar observations of Mars began in June and will be completed early in 1974. We anticipate that this will be the last major planetary observing project to be conducted with the Haystack radar.

Paul B. Sebring

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.

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Brandeis University
Brown University
Dartmouth College
Harvard University
Massachusetts Institute of Technology
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NORTHEAST RADIO OBSERVATORY CORPORATION

SEMIANNUAL REPORT

of the

HAYSTACK OBSERVATORY

I. INTRODUCTION AND SUMMARY

The utilization of the Haystack antenna and associated equipment is summarized below:

USE	HOURS
Radio Astronomy	2,396
Planetary Radar Studies	74
Radar Observations of Satellites	86
Total Scientific Use	2,556
Maintenance and Improvements	756
TOTAL	3,312
Unused	1,056
Total Hours in 1/2-Year	4,368

Twenty-eight new radio observing programs were approved, of which 8 were completed during the period. Fourteen programs continued from previous periods were completed or terminated. As of 1 July, twenty-eight radio and four radar observing programs were active, with radar observations of Mars getting underway just at the end of the period. Data concerning these programs are presented in Tables I-1 and I-2.

The helium-cooled K-band (20-24 GHz) maser was installed on the Haystack antenna in January 1973. During its initial test periods under the supervision of Professor Yngvesson (University of Massachusetts), its performance was evaluated and several astronomical investigations were successfully conducted as part of the system tests. Performance exceeded expectations, with system temperatures as low as 80°K obtained during clear, cold weather. Unfortunately, the maser lost useful gain in June, apparently due to certain material failures. Every effort is being made to define the problems and restore operation. Many of the proposals now under consideration by the Haystack Schedule Planning Committee have requested time with the maser making its restoration an extremely important matter for the Observatory.

TABLE I-1

NEW PROGRAMS THIS PERIOD

1 January - 30 June 1973

Program	Investigators	Institutions	Hrs. Requested	Hrs. Used This ½ Yr.	Designation
23.8-GHz Search for Excited OH Emission, $^2\pi_{3/2}$, $J=9/2$ State	J.M. Moran, M. Litvak S. Yngvesson, O.E.H. Rydbeck	Smithsonian Astroph. Obs. Univ. of Mass.	76	81 Completed	MORAN-2
22-GHz VLBI Search for Small-Diameter Sources on the Sun (with NRAO 140-ft. and NRL 85-ft. telescopes)	M.R. Kundu	Univ. of Maryland	5	6 Completed	VLBI-15X
8-GHz Observations of Circularly Polarized Emission from Active Solar Regions	M.D. Papagiannis, Kamal Arora Jules Aarons, R.M. Straka	Boston Univ. A.F. Cambridge Res. Lab.	70	41	PAPAGIANNIS-1
15.5-GHz Lunar Brightness Measurements	W.W. Salisbury, D.L. Fernald	Smithsonian Astroph. Obs.	20	17 Completed	SALISBURY-1
8.3-GHz Mapping of M8 and M 17 in Continuum and H92α Emission	C.J. Lada	Harvard College Obs.	90	88 Completed	LADA-2
21.98-GHz Search for HNCO Transitions	D.F. Dickinson S. Yngvesson	Smithsonian Astroph. Obs. Univ. of Mass.	60	66 Completed	DICKINSON-11
22.235-GHz Observations of H_2O in W3(OH) and W75(N)	S. Yngvesson	Univ. of Mass.	28	28 Completed	YNGVESSON-2
22.235-GHz Search for Weak H_2O Sources	A.G. Cardiasmenos, O.E.H. Rydbeck, S. Yngvesson	Univ. of Mass.	144	131 Completed	CARDIASMENOS-1
22.8 to 23.9-GHz Observation of Ammonia Transitions	Ben Zuckerman P. Palmer, M. Morris	Univ. of Maryland Univ. of Chicago	336	0	ZUCKERMAN-1
21.7 to 23.9-GHz Observations of Ammonia Transitions	C.H. Townes, A.C. Cheung, M.F. Chui O.E.H. Rydbeck, S. Yngvesson, A.G. Cardiasmenos	Univ. of Calif. at Berkeley Univ. of Mass.	224	0	TOWNES-1

TABLE I-1

NEW PROGRAMS THIS PERIOD

1 January - 30 June 1973

PROGRAM	INVESTIGATORS	INSTITUTIONS	HRS. REQUESTED	HRS. USED THIS ½ YR.	DESIGNATION
22.7 to 23.9-GHz Observations of Ammonia Transitions	A.H. Barrett, P. Ho P.C. Myers	Mass. Inst. of Tech.	336	0	BARRETT-13
22.235-GHz VLBI Haystack-Green Bank, Maryland Point (140-ft) Observations of H_2O Sources	K. Johnston, S.H. Knowles, S. Mango, P.R. Schwartz B.F. Burke, K.Y. Lo, G. Papadopoulos J.M. Moran	Naval Res. Lab. Mass. Inst. of Tech. Smithsonian Astroph. Obs.	72	0	VLBI-20
22-GHz VLBI Haystack-Maryland Point Measurements of Quasars	B.F. Burke, K.Y. Lo, G. Papadopoulos J.M. Moran K.J. Johnston, S.H. Knowles	Mass. Inst. of Tech. Smithsonian Astroph. Obs. Naval Res. Lab.	24	0	VLBI-19
22.235-GHz Monitoring of Water-Vapor Sources	J.M. Moran O.E.H. Rydbeck, S. Yngvesson, A.G. Cardiasmenos C. Reisz S.H. Zisk	Smithsonian Astroph. Obs. Univ. of Mass. Mass. Inst. of Tech. Haystack Obs.	48 Hrs./month for 6 months	39	MORAN-3
22.235-GHz Search for Extra-galactic Water-Vapor Emission in M33	D.F. Dickinson	Smithsonian Astroph. Obs.	48	0	DICKINSON-12
22.235-GHz Search for Extra-galactic Water-Vapor Emission in M31 & Search for H_2O Sources Near the Ecliptic	A.C. Reisz	Mass. Inst. of Tech.	90	0	REISZ-1
20-24-GHz Search for Various Molecular Transitions	O.E.H. Rydbeck, G.R. Huguenin	Univ. of Mass.	48	0	RYDBECK-1

TABLE I-1

New Programs This Period

1 January - 30 June 1973

Program	Investigators	Institutions	Hrs. Requested	Hrs. Used This ½ Yr.	Designation
22.235 GHz (±2, ±53, ±55MHz) Search for Raman Scattering of Water-Vapor Emission	K.J. Johnston V. Radhakrishnan	Naval Res. Lab. Raman Res. Inst.	96	0	JOHNSTON-1
7.876 & 8.31 GHz Measurements of H92α Line Shape & Recombination in ionized Helium	E.J. Chaisson L.E. Goad	Smithsonian Astroph. Obs. Harvard Col. Obs.	48	0	CHAISSON-15
7.876 & 8.370 GHz Search for 149α & 146α Recombination Lines from ionized Calcium	E.J. Chaisson	Smithsonian Astroph. Obs.	48	0	CHAISSON-11R* *(Reactivated Proposal)
15.5 GHz Observations of Planetary Nebulae	G. Sistla G. Kojoian P. Crane E.J. Chaisson	State Univ. of N.Y. at Albany --- Mass. Inst. of Tech. Smithsonian Astroph. Obs.	48	45 Completed	SISTLA-1
7.956 GHz Search for 74α Recombination Lines of Positronium	G. Kojoian	---	30	0	KOJOIAN-1
7.8 & 15.5 GHz Observation of Markarian Galaxies	G. Kojoian	---	96	62	KOJOIAN-2
17.51, 20.17, & 23.3 GHz Search for Transitions in Methanol (CH_3OH)	R.N. Martin, A.H. Barrett	Mass. Inst. of Tech.	192	0	MARTIN-1
8.00, 8.02, 8.07 GHz Search for Photo Excitation Recombination Lines	P. Blanchard E.J. Chaisson	Tufts Univ. Smithsonian Astroph. Obs.	24	0	BLANCHARD-1

TABLE I-1

NEW PROGRAMS THIS PERIOD

1 January - 30 June 1973

PROGRAM	INVESTIGATORS	INSTITUTIONS	HRS. REQUESTED	HRS. USED THIS ½ YR.	DESIGNATION
21.2 and 23.1-GHz Search for Transitions in Formamide	S. Yngvesson, O.E.H. Rydbeck A.H. Barrett, P. Ho	Univ. of Mass. Mass. Inst. of Tech.	18	18	YNGVESSON-3
16.7-GHz Search for a Microwave Transition in Acetic Acid	B.F. Burke, K.Y. Lo, D. Staelin, G. Papadopoulos	Mass. Inst. of Tech.	48	51	BURKE-6
8.31-GHz Observations of 92α Recombination Lines in W49 and Orion A	E.J. Chaisson	Smithsonian Astroph. Obs.	120	126	CHAISSON-14
Radar Observations of Mars (Topography)	G.H. Pettengill	Mass. Inst. of Tech.	≈300	22	Mars Topography

TABLE I-2

PROGRAMS CONTINUED FROM PREVIOUS PERIOD

PROGRAM	INVESTIGATORS	INSTITUTIONS	HRS. USED THIS ½ YR.	STATUS	DESIGNATION
8.006- and 8.315-GHz Observations of H92α and H117β in NGC 7538	C.J. Lada E.J. Chaisson	Harvard College Obs. Smithsonian Astroph. Obs.	0	Complete	LADA-1
20.0- to 25.0-GHz Further Search for New Methanol Transitions	A.H. Barrett, R. Martin, P. Myers	Mass. Inst. of Tech.	22	Complete	BARRETT-10XX
8.3-GHz Observations of 92α Recombination Lines Toward S 264	J.H. Black, A.K. Dupree E.J. Chaisson	Harvard College Obs. Smithsonian Astroph. Obs.	0	Complete	BLACK-1
22-GHz Search for H_2O Emission from Certain HII Regions	B.F. Burke, K.Y. Lo	Mass. Inst. of Tech.	0	Complete	BURKE-5
7.76-GHz Search for OH Emissions from the J = $3/2, \pi_{1/2}$ State	D.F. Dickinson	Smithsonian Astroph. Obs.	42	Complete	DICKINSON-9
7.9-GHz Continuum Mapping of HII Regions with Large IR Excess	L.E. Goad	Harvard College Obs.	179	Complete	GOAD-4
22-GHz Monitoring & Polarization Measurements of H_2O Sources	K. Bechis, A.H. Barrett	Mass. Inst. of Tech.	115	Complete	BECHIS-1
8.3-GHz Observations of 92α Recombination Lines to Measure the He/H Ratio	E.J. Chaisson	Smithsonian Astroph. Obs.	0	Complete	CHAISSON-13
8- and 15.5-GHz Continuum Observations of Symmetric Nebulae	H.M. Johnson	Lockheed, Palo Alto Research Lab.	0	Continuing	JOHNSON-2
20.2- and 20.4-GHz Further Search for Ketane and Acetic Acid Lines	A.H. Barrett	Mass. Inst. of Tech.	68	Complete	BARRETT-12XX
22.2-GHz Search for H_2O Emission from IR Stars	D.F. Dickinson	Smithsonian Astroph. Obs.	86	Continuing	DICKINSON-10

TABLE I-2

Programs Continued From Previous Period

Page 2

Program	Investigators	Institutions	Hrs. Used This ½ Yr.	Status	Designation
22.2-GHz Further Search for H_2O Emission from Compact HII Regions	K.Y. Lo, B.F. Burke	Mass. Inst. of Tech.	113	Continuing	BURKE-5X
7.6- to 8.4-GHz Further Search for Molecular Spectral Lines	B.E. Turner P.R. Schwartz, S. Mango J.H. Fertel	National Radio Ast. Obs. Naval Res. Lab. ---	99	Complete	SCHWARTZ-1X
8 & 15-GHz Monitoring of Quasars & Seyfert Galaxies	W.A. Dent	Univ. of Mass.	295	Continuing	DENT-1
7.85-GHz VLBI Observations with Goldstone 210-foot Antenna	T.A. Clark, G.E. Marandino R.M. Goldstein, D.J. Spitzmesser H.F. Hinteregger, C.A. Knight, A.R. Whitney, I.I. Shapiro	Univ. of Maryland Jet Propulsion Lab. Mass. Inst. of Tech.	87	Continuing	VLBI-9
7.85-GHz VLBI with Goldstone 210-foot Antenna	K.I. Kellerman, B.G. Clark D.L. Jauncey D. Schaffer	NRAO Cornell Yale University	56	Continuing	VLBI-10
7.8-GHz Geodetic VLBI with Goldstone 210-foot Antenna and Alaska	I.I. Shapiro A.E.E. Rogers, S. Lippincott T.A. Clark D.J. Spitzmesser	Mass. Inst. of Tech. Haystack Obs. Goddard Space Flight Ctr. Jet Prop. Lab.	173	Continuing	VLBI-14
8 & 15.5-GHz Continuum Search for Rapid Time Variation in Extragalactic Sources	E.E. Epstein, W.G. Fogarty	Aerospace Corp	110	Complete	EPSTEIN-1
22.235-GHz Measurements of H_2O Source Positions and Structure with Westford-Haystack Interferometer (Cont'd)	B.F. Burke, K.Y. Lo	Mass. Inst. of Tech.	0	Complete	WESTACK-2X

TABLE I-2

PROGRAMS CONTINUED FROM PREVIOUS PERIOD

Page 3

PROGRAM	INVESTIGATORS	INSTITUTIONS	HRS. USED THIS ½ YR.	STATUS	DESIGNATION
7.8-GHz Radar Measurements of Mercury & Venus Topography	R.P. Ingalls G.H. Pettengill	Haystack Obs. Mass. Inst. of Tech.	67	Continuing	MERCURY/VENUS TOPOGRAPHY (Radar)
7.8-GHz Radar Measurements of Mercury and Venus - 4th Test of General Relativity	R.P. Ingalls G.H. Pettengill, I.I. Shapiro	Haystack Obs. Mass. Inst. of Tech.	0	Continuing	FOURTH TEST (Radar)
7.8-GHz Radar Measurements of Artificial Satellites at Synchronous Altitudes & Beyond	A.F. Pensa; Gp. 96 S.H. Zisk, R.P. Ingalls	MIT Lincoln Lab. Haystack Obs.	86	Continuing	LL-1 (Radar)
28 to 38-GHz Continuum Mapping Observations	G.T. Wrixon	Bell Telephone Labs.	0	Complete	WRIXON-2
7.81-GHz Observations of C118β Recombination Lines	E.J. Chaisson, A.K. Dupree	Harvard College Obs.	0	Complete	DUPREE-2
22-GHz VLBI Observations of H_2O Sources with NRAO 140-ft and NRL 85-ft Antennas	G.D. Papadopoulos, B.F. Burke J.M. Moran K.J. Johnston, S.H. Knowles	Mass. Inst. of Tech. Smithsonian Astroph. Obs. Naval Res. Lab.	68	Continuing	VLBI-15

Design of the 1024-channel digital correlator continues to progress, with a January 1974 goal for initial assembly of the hardware. Owens Valley Radio Observatory is now collaborating on this project with the goal of providing a similar unit for OVRO. Their effort is presently emphasizing software development for the computer-processor which is an integral part of the system.

The Radio Astronomy Operations section is now fully manned with five full-time telescope operator/observers. The previous practice of having outside investigators trained to operate the telescope themselves with only a Haystack "duty officer" present has been abandoned.

Of some interest is the fact that a recent study of 15.5 GHz data taken over the past few years under the DENT-1 Variable Sources program shows no significant change in effective aperture of the Haystack antenna since the surface was readjusted for closer tolerance in 1967. The structural stability indicated is encouraging for future improvements to the antenna. During this period, NEROC submitted to the NSF a program proposal for the improvement of Haystack with a goal of operation at wavelengths as short as 3 mm.

Paul B. Sebring

II. RADIO ASTRONOMY - SELECTED ACTIVITIES

In the interest of providing representative samples of the sorts of work conducted at Haystack, we present in each Report several summaries of selected observing programs. The fact that a program is covered in this section does not mean that it is regarded as more important than others not covered. Emphasis is given to programs not previous described - and ready availability of copy and figures from the investigator also has a positive influence on the Editor's choice!

An apology: In accord with our past practice in some cases, the material on page 11 of the 15 January 1973 Report covering "Precision Map of H_2O Emission from W3 (OH)" was presented as "summarized by I. I. Shapiro", without mention of the research team involved. In this case, the work should clearly have been credited to A.C. Reisz, I.I. Shapiro, J.M. Moran, G.D. Papadopoulos, B.F. Burke, K.Y. Lo, P.R. Schwartz, K.J. Johnston and S.H. Knowles.

P. B. Sebring

A. Continuum Programs

Study of Polarization Oscillations of Solar Active Regions

M.D. Papagiannis, K. Arora, J. Kogut - Boston University

R. Straka - Air Force Cambridge Research Laboratories

The main objective of this experiment is to search at 7.8 GHz for significant changes in the polarization of the radio emission from an active region before the eruption of a flare. Such an effect might be expected both on theoretical grounds, due to the strong build-up and motions of magnetic fields in an active region prior to a flare, and from some preliminary radio and optical observations which indicate temperature fluctuations in the upper chromosphere before a flare. If this polarization effect is observed and confirmed, it could provide a significant new insight in the study of the active sun, and it could serve also as a short-term warning of forthcoming flare activity.

To date, we have conducted test runs which allowed us to become familiar with Haystack operations and to develop successful observing sequences, e.g., calibrations; box-scan mapping of the solar disc, and of active regions, in RC and LC polarization; long-period observations of polarization variations in active regions.

A Map of the Galactic Center Region at a Frequency of 15.5-GHz

J.E. Kapitzky, W.A. Dent - University of Massachusetts

The region of the galactic center has been mapped at 15.5-GHz with an effective resolution of 2.25 minutes of arc. The observations were made during six days in the months of May, July and September, 1971. The radiometer consisted of a dual-channel, tunnel-diode amplifier having a 2-GHz bandwidth and a system noise-temperature of about 1000°K. The radiometer output was recorded digitally with a 2-sec integration time. Data were taken only on days when the sky was clear, or when atmospheric fluctuations were a minimum. The antenna pointing offsets were calibrated each day by measuring the position of the strong small-diameter component of Sagittarius A. To map a region of 8^m in right ascension by 1.5° in declination around the galactic center, a series of 149 drift-scans in right ascension spaced by 36" in declination were made across the region. The observed antenna-temperatures were corrected for atmospheric extinction and variations of gain with elevation angle.

While the outer brightness contours in our map, shown in Figure II-1, are similar to those made with lower resolutions, the inner contours reveal a much more complex structure. Single components in the lower-resolution maps show up as several discrete components. There appears to be a cluster of several weak sources in the region south of Sgr A, and the Sgr B2 region appears to consist of several weaker components around and between the two main components, G 0.5 - 0.0 and G 0.7 - 0.0. The measured flux of Sgr A was found to be 94 ± 8 flux units and the flux of Sgr B2 was 62 ± 6 flux units. No evidence was found of a thermal "extended component" around the galactic center.

A Map of Cas A at 31 GHz

B.G. Leslie - Haystack Observatory

Reduction has been completed on mapping data taken last year at a frequency of 31-GHz with the mixer receiver developed by Dr. Gerald Wrixon of Bell Telephone Laboratories. The observational data were taken with the automatic MULTIPLE DRIFT-SCAN program on the U490 computer that controls the pointing of the Haystack antenna. This program causes the telescope to perform a series of timed drift-scans with each drift scan at a different declination offset so that a raster of data points is built up. The computer simultaneously records the radiometer output and the antenna pointing coordinates on magnetic tape. These data are then processed automatically off-line with the CDC 3300 computer using mapping programs developed by Norman Brenner and M.L. Meeks.

A region centered on Cas A, extending 0.300° in right ascension by 0.196° in declination, was mapped with a scan spacing of 0.008° in declination. This region was covered with 25 scans, each of 72-sec duration, and the radiometer output was recorded with an integration period of 1 sec. The final map, shown in Figure II-2, was prepared by averaging together six complete sets of multiple drift-scans to reduce noise.

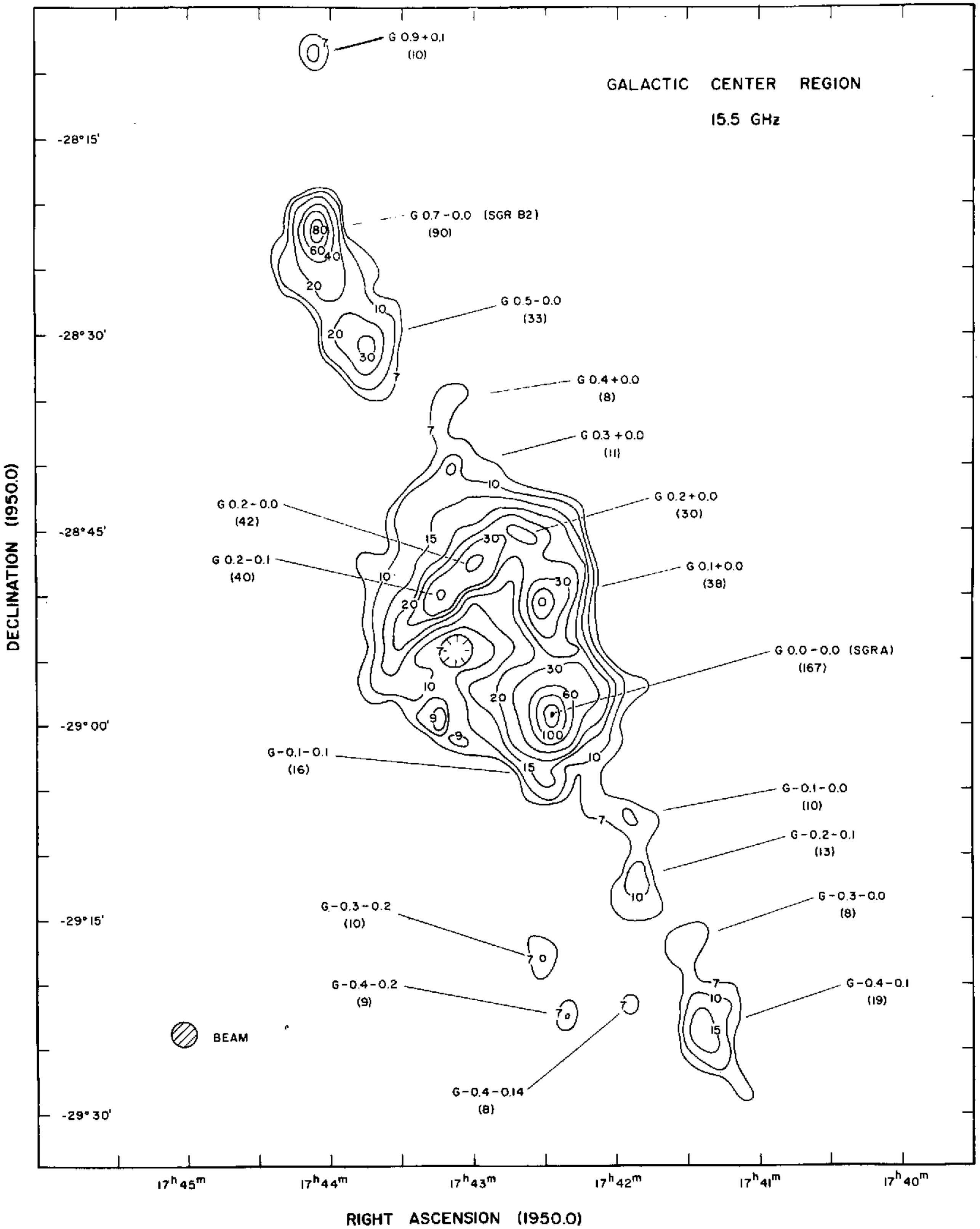

Fig. II-1

A Map of the Galactic Center Region Made at a Frequency of 15.5-GHz with the Haystack Telescope.

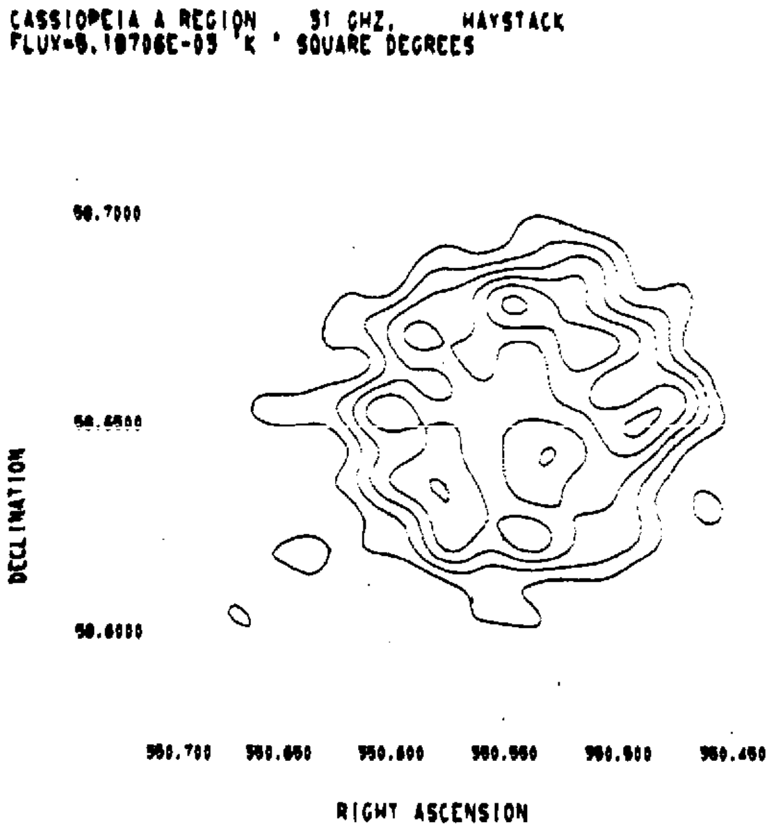

Fig. II-2

Map of Cassiopeia A at a Frequency of 31 -GHz. The antenna beamwidth was 54 arc seconds for these observations.

B. Spectral-Line Programs

Recombination-Line Observations at 23.4 GHz

E.J. Chaisson - Center for Astrophysics (HCO/SAO)

During this report period, the K-band maser system was undergoing on-antenna testing under the direction of Professor Yngvesson and his co-workers from University of Massachusetts. With their cooperation, and as a part of the tests, we made a series of observations of the H65α recombination line from M17. The objective of these measurements was to develop observing techniques and to determine system performance as a preliminary to undertaking formal observing programs involving recombination lines in this frequency range.

The best observing technique appears to be on-source observations followed by off-source measurements, offset in right ascension so that the antenna retraces the same path in azimuth and elevation. Switching against a load is employed at a 5-Hz rate. The off-source spectra are then subtracted from the on-source spectra to minimize baseline curvature.

For the observations reported here, we used the following sequence of operations with the autocorrelation spectrometer:

(1) CALIBRATION

OFF SOURCE	(6^m west) for 5 minutes	Accumulate	NEGATIVE
ON SOURCE	" " "	"	POSITIVE
ON SOURCE	" " "	"	POSITIVE
OFF SOURCE	(6^m east) " " "	"	NEGATIVE

Go to (1)

The spectrometer band was centered at 23,409 MHz, midway between the frequencies for hydrogen and for atoms of infinite mass. The instantaneous bandwidth of the maser was about 20 MHz, and the resolution was 500 KHz (6.4 km/s). The system temperatures we encountered varied between 150 and 240°K, as compared to 100°K obtained without the ferrite switch during the best observing conditions.

Figure II-3 shows the spectrum obtained on M17 with a total of 270 minutes of observing as described above. The raw baseline is seen to be curved, but a simultaneous fit of a parabolic baseline and a Gaussian function gave a reasonable fit. The baseline curvature is definitely a function of the intensity of the continuum source and should be minimized with use of the newly completed noise-injection system. Computed rms error of the fit amounts to 0.014°K as compared with the prediction of 0.010°K based on the system temperature and bandwidth.

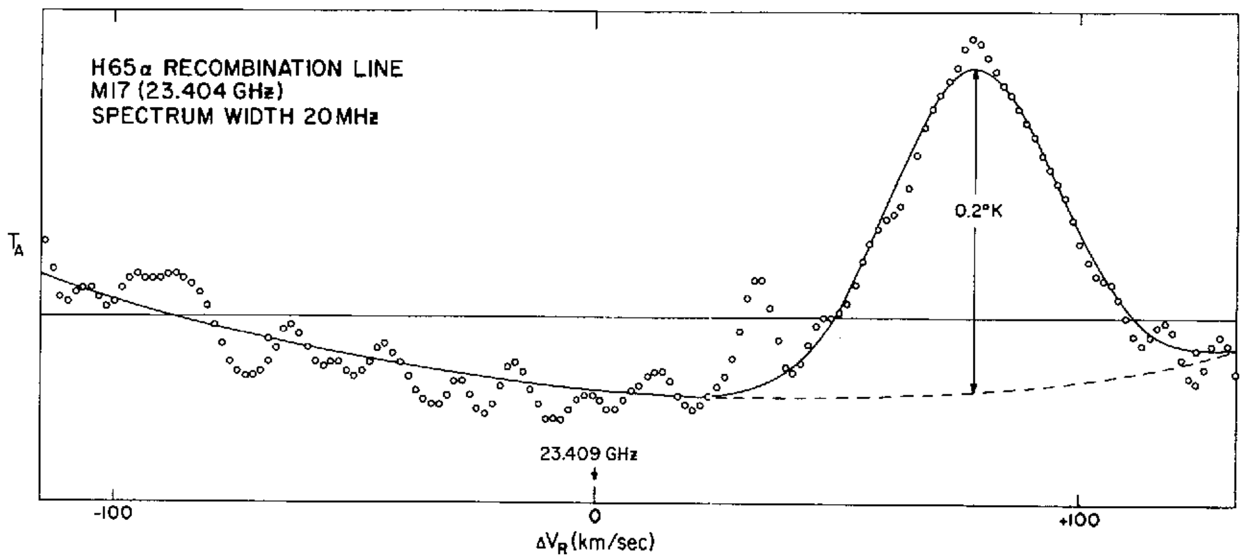

Fig. II-3

The H65α Recombination Line Observed in M17. The open circles represent the observed spectrum after 270 minutes of observing according to the procedure described in the text. The solid line represents a fitted Gaussian with parabolic baseline curvature.

Brief Summary of Results of Measurements on Weak Water Vapor Sources

K. S. Yngvesson, A. G. Cardiasmenos,
O. E. H. Rydbeck* - University of Massachusetts

Another of the several sets of scientific observations made during development tests of the K-band maser at Haystack is outlined below.

Weak water vapor emission was detected in 13 weak sources, most of which are HII-regions (8 of these sources were not previously known to exhibit H_2O emission). Some especially interesting cases are W12 and W41 - simultaneous OH measurements at Onsala Space Observatory indicate that OH is not "masing", whereas H_2O clearly has to be masing. Another very interesting case is NGC 7538, where the H_2O emission is located in the same "bright knot" with which the OH emission is known to be associated.

In common with the well-known strong H_2O-maser sources, the weak ones also generally have H_2O velocities spread over a wider range than the OH velocities (or than the velocities of other molecules, where these have been detected). There are also good indications of time-variations similar to those found in the strong sources.

A further example is W3(C) where the two main water emission peaks are very well correlated with a) OH absorption (including absorption in the first rotationally excited state, recently detected at Onsala Space Observatory) and b) the 4765 MHz OH emission line.

Finally, indications of resolved hyperfine structure have been detected, as exemplified in Figure II-4, which shows a high resolution profile of the main H_2O feature in W75B, recorded with a total system noise of only 84°K ($\Delta T_{pp} \sim 0.08°K$; $\Delta V_r < 0.07$ km/s), at an outside temperature of -8.5°C. It is possibly the most sensitive H_2O recording ever made, and demonstrates the power of the new maser system, especially when taking high-resolution spectra of weak sources. It is interesting to note that the hyperfine H_2O components, $F = 5 \rightarrow 4$ and $F = 7 \rightarrow 6$, appear to be directly visible. We have observed similar features in other H_2O sources during the maser test period. Further confirming measurements are planned for the winter season 1973/1974.

* On leave of absence from Onsala Space Observatory (Sweden).

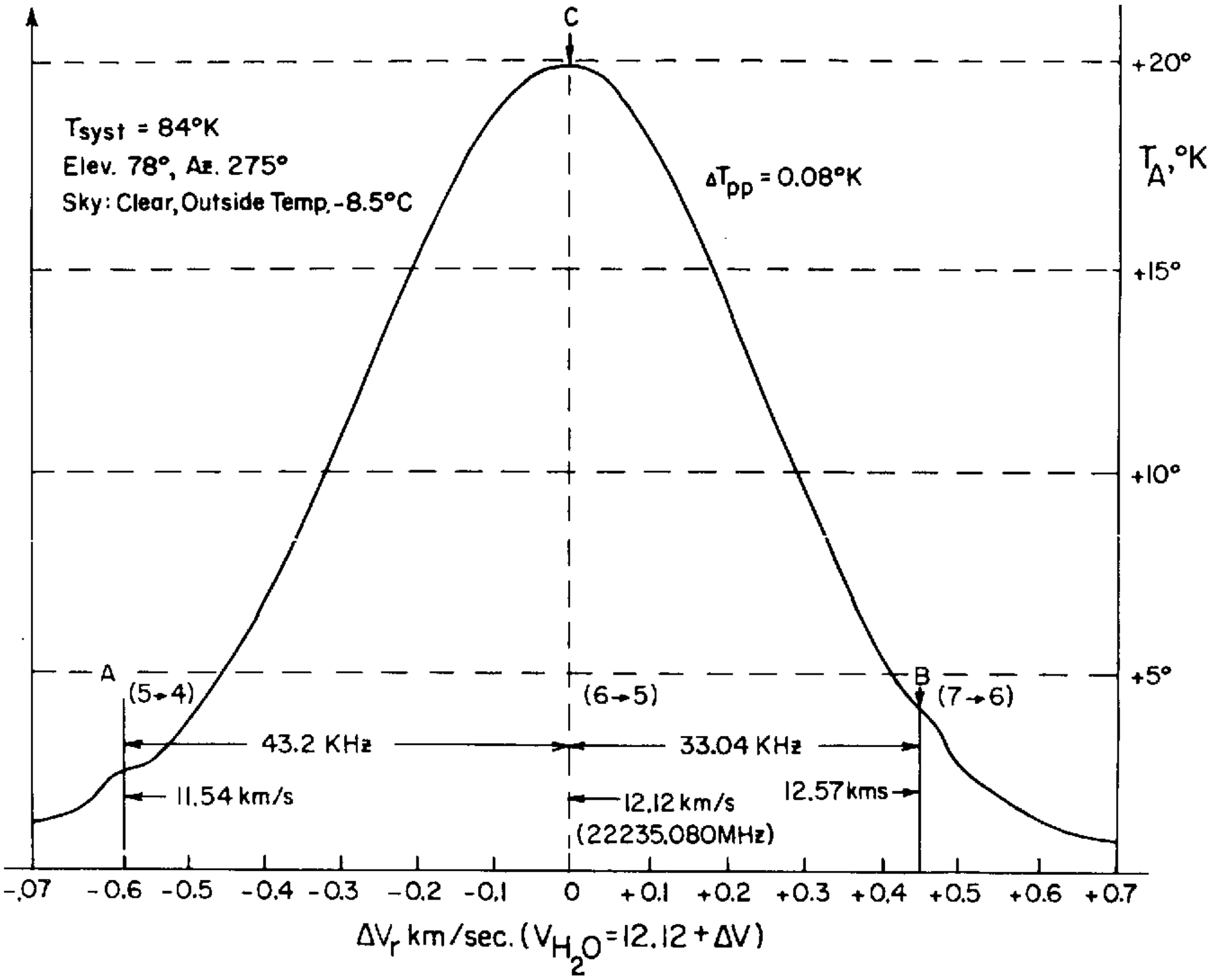

Fig. II-4

High-resolution Spectrum of Main H_2O-Vapor Feature of W75B. Note hyperfine components F = 5 → 4 and F = 7 → 6.

C. Interferometer Programs

Preliminary Report on VLBI-17 and -18[1] (Four-antenna Experiments)

C.C. Counselman III, C.A. Knight, I.I. Shapiro, A.R. Whitney
Mass. Inst. of Technology

T.A. Clark - NASA Goddard Space Flight Center

H.F. Hinteregger, A.E.E. Rogers - Haystack Observatory

In September and October, 1972, two related 8-GHz VLBI experiments (designated VLBI-17 and VLBI-18) were performed with the Haystack and Westford[2] antennas in conjunction with two 85-foot antennas of the N.R.A.O. in Green Bank, West Virginia. The purposes of these experiments were, respectively, to determine the relative positions of a number of quasars, and to measure the effect of the sun's gravitation on the apparent position of quasar 3C279 relative to that of 3C273B. The quasars were observed in pairs, with Haystack and one Green Bank antenna as one long-baseline interferometer observing one quasar, and Westford and the second Green Bank antenna as a second interferometer observing the second quasar. Because both antennas at each end of the long baseline shared a common atomic frequency standard and observed through similar portions of the atmosphere and ionosphere, it was expected that the differential-fringe-phase observable formed by subtracting the phases obtained from the two-baseline interferometers would be relatively free of systematic errors. By means of these observations it is hoped to be able to determine the positions of one quasar relative to the other with particularly good accuracy.

A plot of preliminary post-fit residuals from one day of this experiment is shown in Figure II-5. To obtain this plot, the position of 3C279 was adjusted. The abrupt turnup of these residuals at the end of the day, as the sources set, is probably caused by uncorrected atmospheric effects.

The stability of the fringe phase as a function of time is seen to be such that the phase can be connected with little probability of a $2n\pi$ ambiguity error across gaps as long as one-half hour. (See gap following 16^h U.T.) Nearer to the sun, large phase fluctuations are caused by the solar corona. However, a preliminary reduction of the data seems to show that reliable phase connection has been achieved for 3C279 and 3C273B over spans of several hours, only 4 days before and after the solar occultation of 3C279.

Summarized by C.C. Counselman

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1. Through an oversight, these programs were omitted from Table I of the Semiannual Report of 15 January 1973.

2. 60-ft antenna about 1240 m from Haystack on a bearing 202° true. This antenna is operated as an auxiliary telescope by Haystack Observatory, by agreement with M.I.T. Lincoln Laboratory .

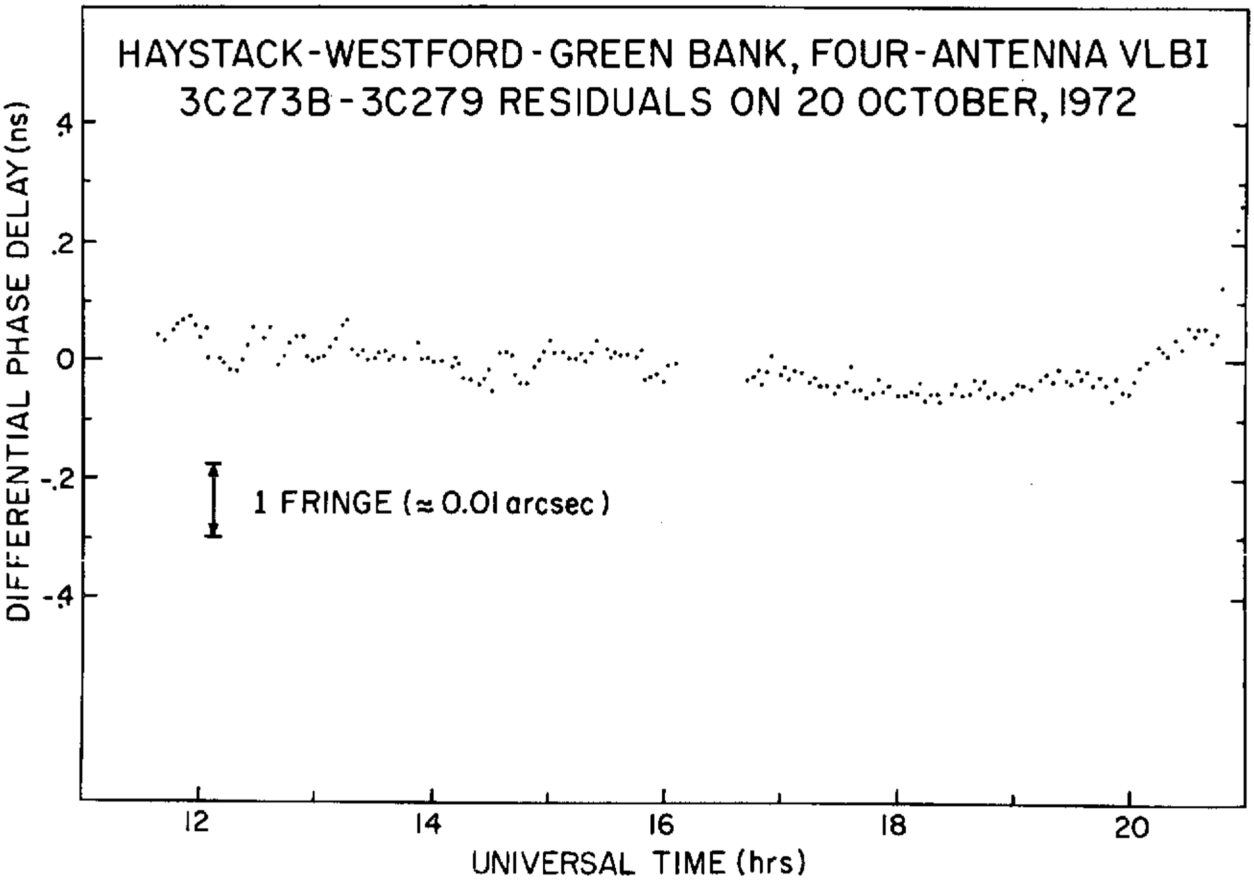

Fig. II-5

The Differential Phase-Delay Residuals for the Haystack-Green Bank, Four-Antenna VLBI Experiment. The position of 3C279 relative to 3C273 was adjusted but no parameter of the atmospheric model was adjusted.

D. Geodetic VLBI Program

Determination of Baselines and Source Positions from 3.8-cm VLBI Observations

A.E.E. Rogers, H.F. Hinteregger, S. Lippincott - Haystack

I.I. Shapiro, D.S. Robertson, A.R. Whitney - M.I.T.

We have repeatedly made observations between Haystack and Goldstone. The baseline results are shown in Table II-1 and refer to the line extending from the intersection of the azimuth and elevation axes at Haystack to the corresponding point on the Goldstone antenna. The consistency of the length determinations is remarkably good and is in accord with the formal standard errors which are based on the postfit residuals. The baseline direction determinations exhibit a substantially larger scatter and indicate the presence of systematic errors which can probably be explained only in part by defects in our model for the earth's rotation and polar motion. The postfit residuals also show systematic trends. Nonetheless it would appear that our goal has been met for the baseline: the weighted average of the separate baseline determinations is very probably within the equivalent of 1 to 2 meters of the true value in all components.

Relative positions for 12 extragalactic radio sources have also been determined. The standard error, based on consistency between results from widely separated periods of observation , appears to be no more than 0".1 for each coordinate of the seven sources that were well observed during two or more periods. The uncertainties in the coordinates determined for the other five sources are larger, but in no case exceed 0".5. Preliminary results are given in Table II-2.

TABLE II-1

Coordinates from Nine Experiments to Determine the Goldstone-Haystack Baseline*

Date	Length (m)	Hour Angle⁺ (hr x 10^{+6})	Declination⁺ (deg x 10^5)
14-15 April 1972	3,899,998.51±0.22	7,051,413.6±0.3	-914,473.4±1.8
9-10 May 1972**	7.61±0.76	4.6±2.8	87.1±5.2
29-30 May 1972	8.64±0.33	5.4±0.8	83.0±1.4
3-6 June 1972	8.60±0.45	3.7±1.1	82.8±2.2
27-28 June 1972	8.56±0.28	2.1±0.7	77.8±1.4
29-30 August 1972	8.77±0.09	5.9±0.3	81.6±0.6
7 November 1972	8.99±0.15	5.5±0.4	82.1±1.1
4-5 February 1973	8.83±0.10	3.7±0.4	81.6±0.4
30-31 March 1973	8.99±0.11	6.1±0.3	84.7±0.5
Weighted Average ± weighted rms spread of solutions about the weighted mean	3,899,998.75±0.23	7,051,414.8±1.3	-914,481.8±2.8

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* The reference point at both Haystack and Goldstone is the intersection of the azimuth and elevation axes of the antenna. The baseline vector points from Haystack to Goldstone. The hour angle is measured from the Haystack meridian, defined by the International Latitude Service mean pole of 1900-05; the declination is measured from a plane that passes through Haystack and is parallel to the equator defined by this mean pole. The uncertainties shown are the formal standard errors, based on a value of unity for the weighted rms of the postfit residuals. The coordinates describing the baseline direction are clearly being affected by systematic errors (see text).

⁺ Note that 10^{-6} hr ≃ 1.0 m and 10^{-5} deg ≃ 0.68 m for this baseline.

** In this experiment, for another purpose, half of the time was utilized for special observations of two source pairs, thus accounting for the relatively large errors.

TABLE II-2

Source Coordinates from VLBI Observations*

Source	α (1950.0)	Elliptic Aberration †	δ (1950.0)	Elliptic Aberratic
3C84	03^h16^m $29^s.539$	$0^s.019$	41°19' 51".75	0".16
3C120	04 30 31.586±0.005	0.019	05 14 59.2±0.1	-0.01
OJ287	08 51 57.232±0.005	0.021	20 17 58.45±0.1	-0.09
4C39.25	09 23 55.296±0.004	0.023	39 15 23.73±0.04	-0.16
3C273B	12 26 33.246 ††	0.002	02 19 43.2±0.1	-0.04
3C279	12 53 35.831±0.004	-0.001	-05 31 08.0±0.1	0.00
OQ208	14 04 45.626	-0.009	28 41 29.4	-0.18
3C345	16 41 17.634±0.004	-0.025	39 54 11.00±0.07	-0.13
PKS2134±00	21 34 05 222±0.005	-0.017	00 28 25.2	-0.03
VRO42.22.01	22 00 39.394±0.007	-0:020	42 02 08.3±0.1	0.15
CTA102	22 30 07.82	-0.013	11 28 22.8	0.03
3C454.3	22 51 29.530±0.009	-0.011	15 52 54.24±0.03	0.05

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* Coordinate determinations for which no uncertainties are quoted were based on only a single set of observations or had formal errors greater than 0".1; the errors in these coordinates are probably no more than a few tenths of an arcsecond.

† The addition of these contributions of elliptic aberration to our results allows direct comparison with positions given in accord with the conventional practice in astrometry.

†† Reference right ascension

E. Radiometric Instrumentation

1. Long-term Stability of the Haystack Reflector

In the fall of 1967 the surface of the 120-foot-diameter Haystack antenna was surveyed and adjusted to an rms tolerance error of 0.027 inches, as determined from radiometric measurements at several frequencies on sources of known flux. No readjustment has been made since this rerigging, and it is of interest to know the degree to which change in the surface tolerance has taken place in the nearly six years which have elapsed since that time.

The observing program DENT-1, which monitors time variations in quasars and peculiar galaxies at frequencies of 8 and 15.5 GHz, was begun in 1968, and the same calibration sources have been used throughout this program. W.A. Dent of the University of Massachusetts at Amherst has given a great deal of attention to the problem of calibration and methods of correction of the data for atmospheric attenuation, and has made his results available to us. We have concentrated our attention on 15.5-GHz measurements of the compact HII region DR 21.

The graph of Figure II-6 summarizes the 15.5-GHz measurements after correction for atmospheric absorption and change of gain with elevation angle. We have performed a least-squares fit to estimate the slope of a straight line through these data points.

The result indicates no significant change over the period of the measurements.

David Stork - M.I.T. Undergraduate Research Opportunities Program

M.L. Meeks - Haystack Observatory

2. K-band (20-24 GHz) Maser Development

For over two years a helium-cooled maser amplifier designed primarily to cover the water-vapor and ammonia lines in the 20-24 GHz region has been under development at Haystack and University of Massachusetts. Professor K.S. Yngvesson designed the maser based on research done while he was associated with Dr. Charles H. Townes at Berkeley. He also supervised its construction, with engineering and technical assistance from Haystack Observatory.

The maser was installed on the antenna in January and was used on an experimental basis under Professor Yngvesson's direction until early June. During this initial test phase, operating techniques were developed, performance was evaluated and several astronomical investigations[1] were successfully conducted. The performance of the maser exceeded our expectations. System noise temperatures as low as 80°K were obtained during periods of best operation in cold, clear weather. The system could be tuned from 20 GHz to

1. See Table I-1. Early H_2O results were communicated to the AAS June meeting, Columbus, Ohio, by University of Massachusetts workers.

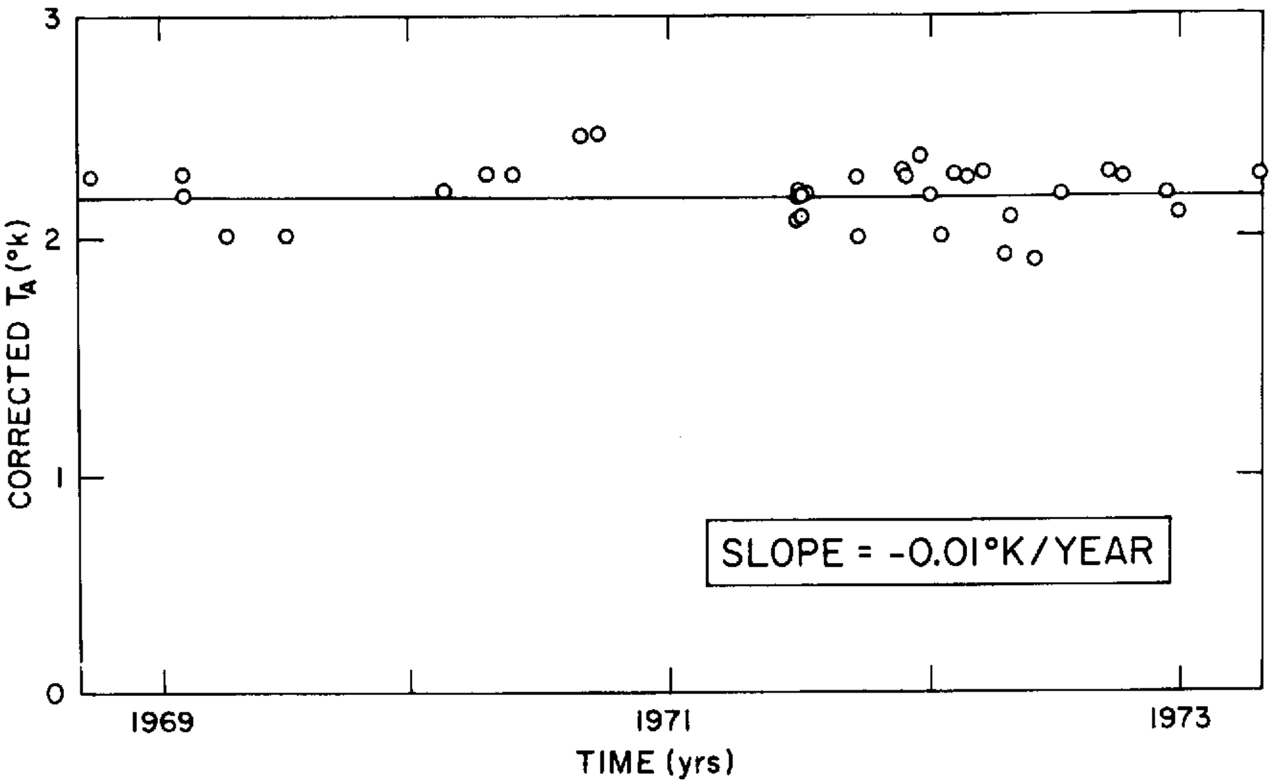

Fig. II- 6

Repeated Measurements of the Compact HII Region DR 21 at a Frequency of 15.5 GHz. The antenna temperature measurements were corrected for atmospheric absorption and for changes in gain with elevation. The data were provided by Professor W.A. Dent.

24 GHz, and cryogenic hold-time was found to be 18 hours following a fill with liquid helium. Although further system improvements were being considered, the maser was working well and a period of highly valuable observing seemed at hand.

Unfortunately, this period of very useful performance came to an abrupt end in June with a nearly complete loss of electronic gain, and it became necessary to postpone until further notice a number of observing programs we were already scheduling in response to many proposals for use of the maser.

Although earlier troubles during the test phase had been traced to a break in the gold wire connecting the comb structure to the input coaxial conductor, this problem had been solved. However, corrosion and diffusion of gold from the ground-plane of the ruby into the Wood's metal solder joints seemed to be in evidence. We believe this deterioration may have caused some increase in passive loss through the device which, though not serious, has been seen. Earlier masers built by Professor Yngvesson have used similar bonding techniques without significant difficulty.

We have, however, found that small bits of the gold plating in the r-f pump waveguide have flaked off. Two comparatively large segments have cracked loose from the waveguide walls and have sprung into the path of the pump signal. This could well have caused the failure of electronic gain, and remedial measures are being taken.

We are optimistic that this maser (No. 1) can be restored to operation without extensive rework. If so, we expect to have it available for use during the Radiometer-Box period which is 6 September - 1 October 1973. In parallel, we are assembling a second maser (No. 2)[1] which will incorporate certain improvements. We hope to have No. 2 ready for the Radiometer-Box period which begins in late November. If tests of No. 2 are successful, No. 1 may be reworked to incorporate similar improvements. Some of the parts for a third unit were also fabricated early in the project. Subject to available manpower and funds, we hope also to complete a third unit which will be kept at Haystack as an alternate.

S. H. Zisk, J.M. Sobolewski - Haystack

3. Phase and Group Delay Calibrator for Interferometer Receiving Terminal

Usually the phase and delay through interferometer terminals is calibrated using "standard" radio sources whose positions are assumed. This method calibrates only the differential phase and delay through the interferometer system and relies on equipment stability to bridge the gap between

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1. Maser No. 2 is ultimately intended for loan to Itapetinga Observatory, Sao Paulo, Brazil.

calibrations. Also, in precision astrometric work, receiver delay variations may be highly correlated with other parameters being estimated. For example, an amplifier whose delay depends on antenna elevation will be correlated with atmospheric delays, while an amplifier whose delay changes with orientation in the earth's magnetic field may be correlated with baseline offsets. Thus, it may be impossible to reduce the residuals[1] in the observations through the use of calibration sources, and there may remain significant errors in the estimates of baseline components and source positions. It is also very useful to be able to calibrate the receiver phase and group delay for each terminal separately to find which components are most unstable, and this is not possible by the "standard" source method.

We have developed a method of calibration by injection of pulses into the receiver through a coupler between the feed and the low noise amplifiers as shown in Figure II- 7 These pulses are generated at a constant repetition rate, and are coherently detected. In our system, a tunnel diode pulse generator is driven from the 5-MHz signal derived from the hydrogen maser frequency standard. The output of the pulse generator is gated by an attenuator driven from a digital divider so that positive pulses emerge with a 1 MHz repetition rate. The spectral lines produced now occur at 1 MHz intervals. This frequency spacing and corresponding 1-microsecond ambiguity is chosen to match the frequency-switching delay synthesis technique used in our interferometer experiments. In this technique[2], we frequency switch our receiver through a sequence of frequencies with minimum spacing of one MHz to synthesize a delay function whose 1 microsecond ambiguity is very large compared with the apriori uncertainties in the measurements. Since the recorded bandwidth is only 360 KHz, there is only one phase calibration "spectral line" within each frequency channel. The "video" signal from the interferometer receiver is clipped and recorded as one bit per sample[3]. The phase calibration signal is extracted from each frequency channel by multiplying the recorded data with quadrature components of a three-level representation of a sine wave. This process is similar to that performed in interferometric data correlation and fringe rotation processing. If the ratio of the power in each spectral componen to the total power in the 360 KHz bandwidth is Tcal/Ts, then the phase can be determined with an rms error of

$$\frac{\pi}{2}\left[\frac{Ts}{Tcal}\right]^{\frac{1}{2}}\left[\frac{1}{2BT}\right]^{\frac{1}{2}}$$

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1. Observed quantity minus theoretical quantities, where the theory includes all known physical effects excluding any parameterization for receiver drifts.

2. H.F. Hinteregger, Northeast Electronic Research Engineer Meet. Rec. 10 66 (1968)

   A.E.E. Rogers, Radio Sci. 5, 1239 (1970).

3. J.H. VanVleck, The Spectrums of Clipped Noise, Rept. #51, Radio Res. Lab. Harvard University, July 21, 1943.

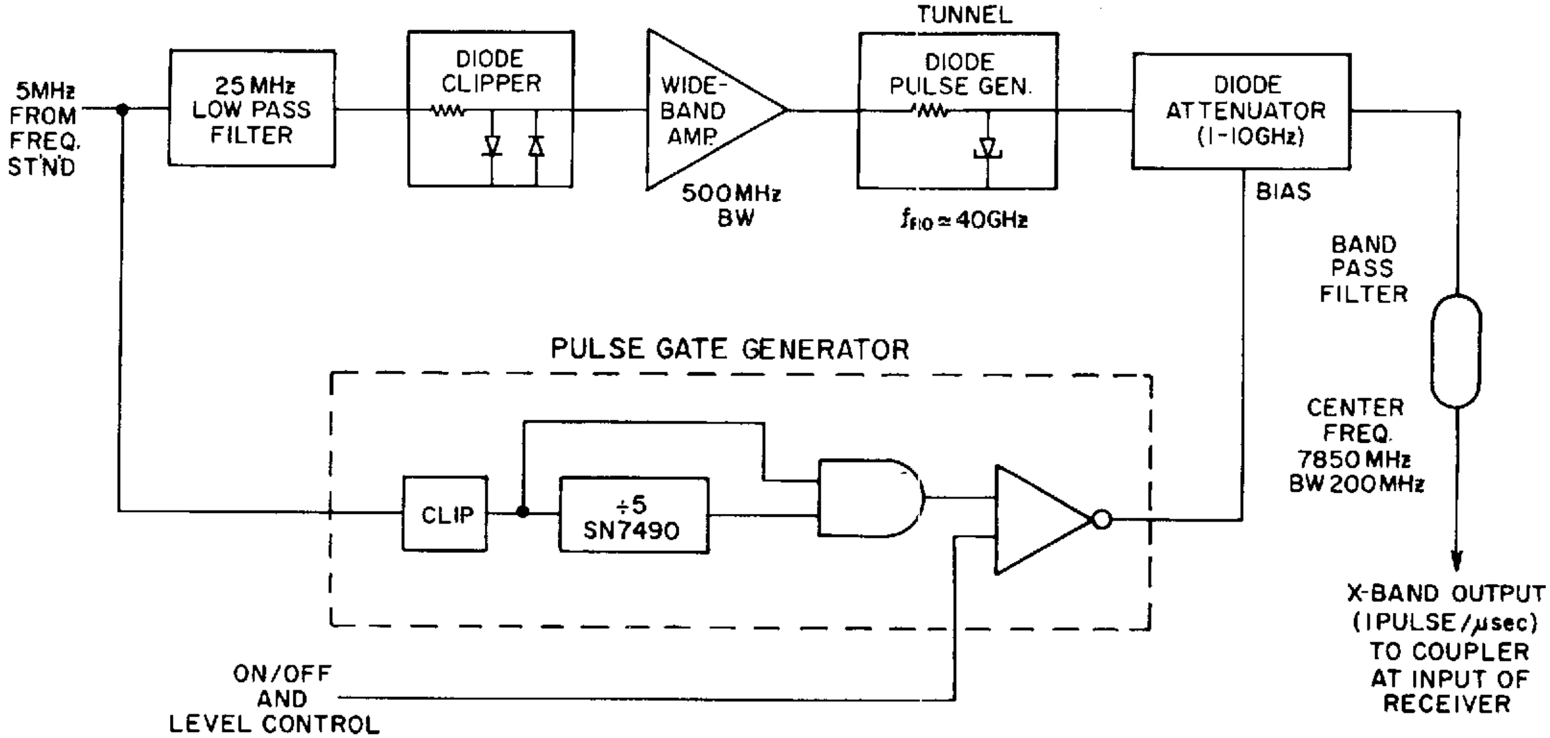

Fig. II-7

Phase Calibrator Block Diagram

where B is the bandwidth (360 KHz) and T is the coherent integration period which has been chosen as one tape record or 0.2 seconds. The above formula shows that the phase can be determined to within 5 degrees for each record with phase calibrator power as low as 1 percent.

This system of continuous low-level phase calibration has now been in operation at Haystack since March 1973 and a similar system is being tested at Goldstone. The signal is low enough in level that it increases the system temperature by less than one percent and thus has little effect on source temperature measurements. Coherent processing allows the calibration phase to be measured continuously throughout each run and displayed as a function of time, for each site separately. The phase calibrators have a measured temperature coefficient of 20 picoseconds per °C and should provide a means of correcting for receiver delay variations not presently calibrated. Figure II-8 shows an example of the printout for one 900-record VLBI run and Figure II-9 the measured delay drift of the Haystack and Onsala receivers during a VLBI experiment performed between Haystack and Onsala, Sweden in May 1973.

Summarized by A.E.E. Rogers - Haystack

4. New Radiometer for VLBI at 14.47 GHz

An operating frequency of 14.47 GHz was desired for certain experiments in the so-called Quasar Patrol (VLBI-10) series with the NRAO 140-ft dish and the Goldstone antenna. A tunnel diode radiometer front end built by NRAO was installed in the R-Box. The feed and phase-locked local oscillator were provided by Haystack. A system noise temperature of about 900°K was obtained.

J. C. Carter - Haystack

5. New Radiometer Enclosure (R-Box #2)

In the past, maintenance and improvements to the radiometric systems have been carried out when the radiometer enclosure (R-Box) has been on the Test Dock on the ground and the Planetary Radar (PR-Box) has occupied the antenna. High utilization of the antenna has thus been possible. However, when radar activity is cut back in 1974 this box alternation will not be possible. In order to achieve a continued high duty factor for the antenna, we are constructing a second R-Box which can be alternated periodically with the present enclosure, so that observations and maintenance/upgrading activities may proceed together. In addition, more radiometric systems can be supported than at present.

Several extra instrument enclosures (the 8' x 8' x 12' "boxes" which mount on the antenna) are available in "bare-bones" form at Haystack. An inventory of large connectors, air handling equipment, racks, etc., left over from the Haystack construction period exists, and a spare-time program has been instituted to outfit one of the spare boxes as an additional R-Box.

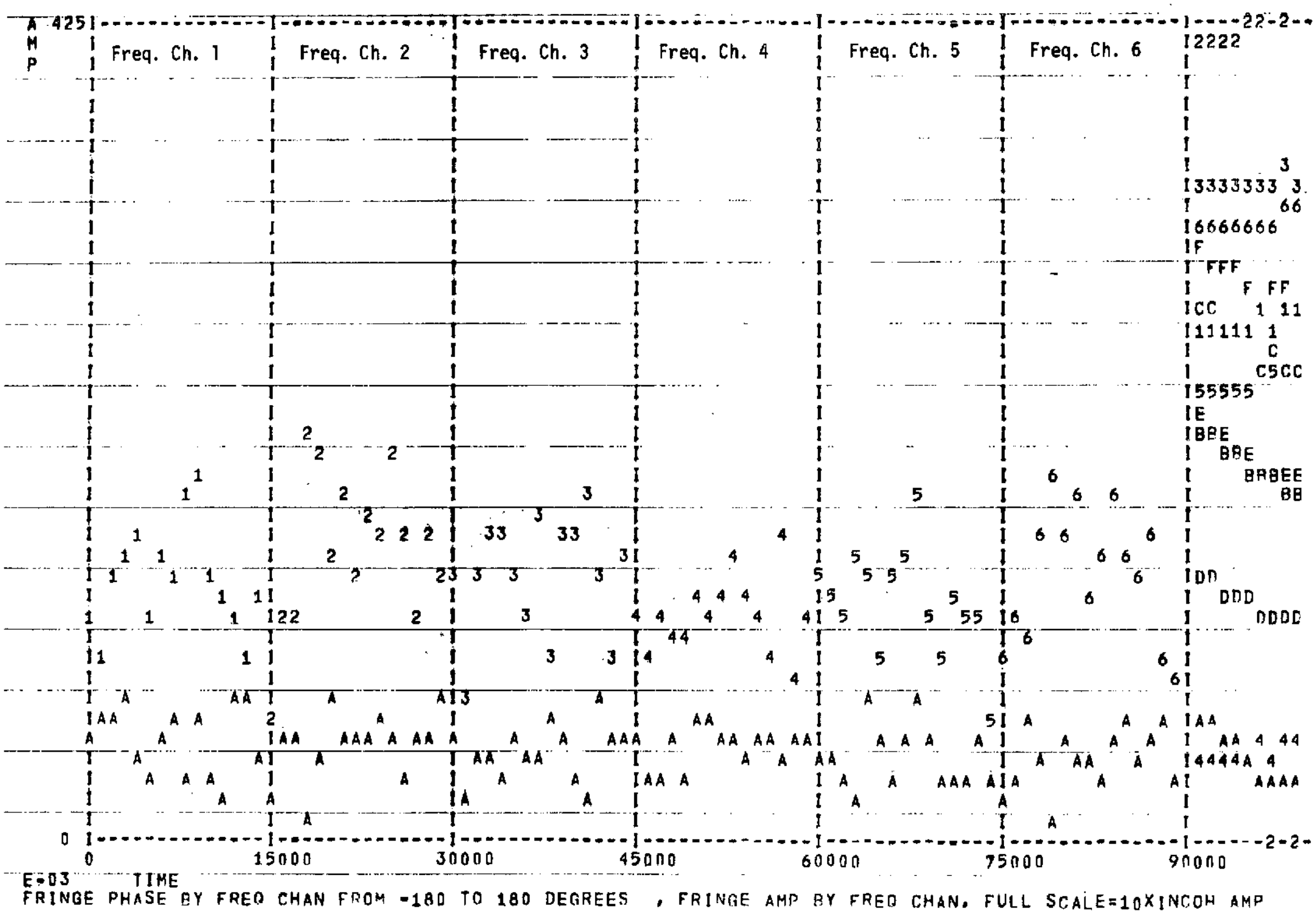

Fig. II-8

Data amplitude, Data Phase Calibration Phases for One 900-record Run. The phases are plotted on a scale from -180° to $+180^{\circ}$. Phase calibration phases for Station 1 (Haystack) are numbered 1 through 6, while those for Station 2 (Sweden) are designated by letters A through F. Each data point represents a 10-record average, while each phase calibrator point represents a 100-record average.

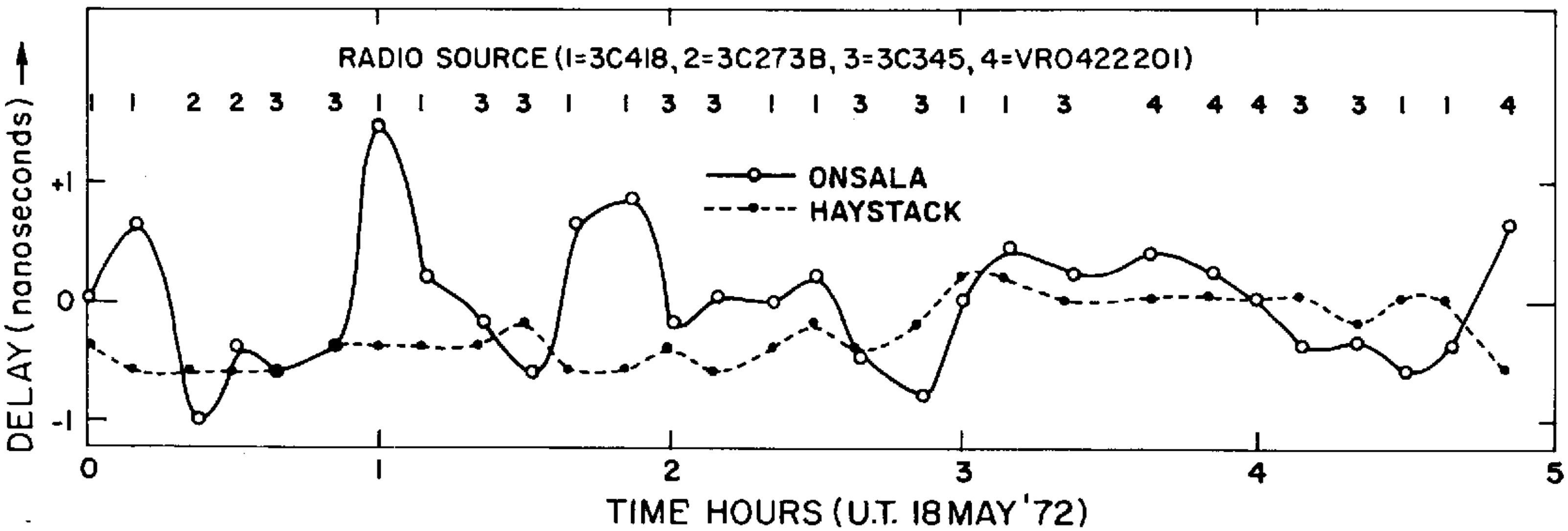

Fig. II-9

Variation of Receiver Delays as Measured During a VLBI Experiment using Haystack and Onsala (Sweden). The variation in receiver delay at Onsala may be correlated with antenna pointing direction.

While it has not yet been decided which radiometers will be incorporated in R-Box No. 2, it seems likely that an OH-line (L-band) system will be installed and that the VLBI requirement for simultaneous S- and X-band reception will also be met in the new arrangement. Each of these applications requires a relatively large feed structure. The L-band system, in fact, has already been removed from the present R-Box in order to increase box flexibility for use at the shorter wave lengths, e.g., installation of the new K-band maser system.

M. H. Leavy - Haystack

6. Haystack 1024-Channel Correlator Spectrometer

The new correlator, now under construction at Haystack, is progressing well and should replace the present 100-channel unit by mid-1974. During an April visit to Haystack by G.J. Stanley and M.S. Ewing of Owens Valley Radio Observatory, it was agreed that OVRO and Haystack would collaborate on correlator development. Basic elements of the OVRO and Haystack correlators will be similar. Haystack is presently emphasizing the hardware design and construction aspects, while OVRO is developing software for the DEC mini-computers which will control spectrometer operation and display results. OVRO may send personnel to Haystack to work directly with Haystack personnel during the construction phase.

The Correlator proper is organized as sixteen 64-channel drawer-type modules with the option of trading channels for bandwidth so as to emphasize either high resolution or wide window-width. The design also incorporates options for multi-level (up to 3 x 5 level) correlation, and provides an overflow-readout capability that allows continuous data processing in non-switched modes.

The importance of VLBI processing at Haystack has led us also to provide for complex cross-correlations, in which the system appears as sixteen separate correlators yielding 32 complex points each.

Design of the basic 64-channel drawer module has been completed. Drawings have been converted to a deck of cards to permit wire-wrapping of the prototype by an outside vendor, *via* automatic machinery. Design of the logic which interfaces the correlator modules to the DEC mini-computers is in progress.

J.I. Levine, W. Rutkowski - Haystack

III. RADAR PROGRAMS

A. Moon

Although NASA Contract NAS9-7830 under which radar studies of the moon (including topographic measurements) have been conducted, terminated at the end of 1972, study of the data continues and the completion report for this contract is still in preparation. Comparison studies of Haystack data, data from Apollo radar and optical observations, and ground-based IR data are also being carried out under Contract 953556 from Jet Propulsion Laboratory. Researchers at JPL, Stanford University, the US Geological Survey and the Boeing Aerospace Corporation, as well as from Haystack, are collaborating in this effort.

Work this period has centered on the last Apollo landing at Taurus Littrow, near the eastern rim of Mare Serenitatis. A comparison of the several earth-based remote-sensor lunar maps, including the 1970 Haystack 3.8-cm radar map, reveals a series of at least five separate components of the surface of Mare Serenitatis, originating either in local volcanic flows or possibly in superficial ballistic deposits from distant violent events. A separate study of the Haystack radar-topography maps has revealed that a shallow trench follows 20 - 30% of the southwestern edge of the mare, at about the location of a "wrinkle ridge" on optical photographs. This suggests very strongly that the original floor of the mare was a thin plate (i.e., kilometers thick, rather than hundreds of kilometers) that has sunk or risen and as a result developed large-scale circumferential fractures.

Without distinguishing cause and effect, these fractures are likely correlated with the fact that there exists a variety of surface units, and are also additional evidence for a late stage of lunar volcanism as proposed last year during our study of the craters Ptolemaeus, Alphonsus and Arzachel.

Another part of the analysis work, undertaken with H. J. Moore of U. S. Geological Survey, is an attempt to improve the theory of radar backscatter at moderate angles of incidence. It appears from our analysis of the results of Apollo 17 photography that radar-bright areas are in fact more closely correlated with dense surface cratering than with dense populations of surface rocks as was previously thought to be the case. Further work will be done on this problem, with an expanded scope to include the results of the Apollo orbital bistatic-radar experiment

S. H. Zisk - Haystack

B. Mars

The first radar observations of Mars in 1973 were obtained on 27 June. Because the red planet was still quite distant at that time (0.92 a.u.), the echoes were relatively weak. It was possible, however, to verify that the new ephemeris for this year was considerably more accurate than that available in 1971/1972. As a further aid, an observing ephemeris will be available shortly which takes into account the major effects of topography.

Intensive observations of Mars will begin in early July, and continue whenever the Planetary Radar Box is mounted on the antenna. Particularly intensive observing efforts are planned on those dates when the Martian coordinates of the sub-earth point closely correspond to those of observations made in 1971. In this way uncertainties associated with surface topography and anomalous radar scattering properties may be minimized, and the full accuracy of the measurements (often better than 75m) brought to bear on the determination of orbital parameters.

An improved data analysis system will also be used, when the echo is sufficiently strong, to permit a better estimate of surface dielectric constant than has previously been possible. In addition, a number of days have been scheduled in common at the Haystack Observatory (3.8-cm wavelength), JPL's Goldstone Facility (12.6 cm) and the NAIC Arecibo Observatory (70 cm), to permit detailed comparison of the same surface areas of Mars at three widely separated observing wavelengths.

G. H. Pettingill - MIT

R. P. Ingalls - Haystack

C. Mercury

A further series of specific Mercury topographic observations were performed during the March, 1973 close approach. This is the fourth series of such topography observations on this planet using the 24-microsecond pulse width mode. Each of these close approach observations has covered a different subradar region on the planet. Resolution in longitude of about a degree is achieved within each observation by using frequency as well as time delay to resolve the planetary echo.

A plot of topographic results from this period is given in Figure III-1. A height range of only about 2 km is evident in this particular set of observations. Currently a program of analysis is in progress to reduce these observations and corresponding measurements made at the Arecibo Observatory by a common orbital ephemeris. Conversely, the observations themselves are of value to the Shapiro group at M.I.T. who are producing the ephemerides, taking account of topography in order to compute the echo time delay.

R. P. Ingalls - Haystack

D. Venus

There were no Venus radar observations during this period, as the planet was near superior conjunction and presented a poor target. Results from study of the data from certain earlier operations are presented below.

The radar reflectivity of Venus has been mapped at 3.8 cm. wavelength from approximately -90° to +10° in longitude and -50° to +50° in latitude.

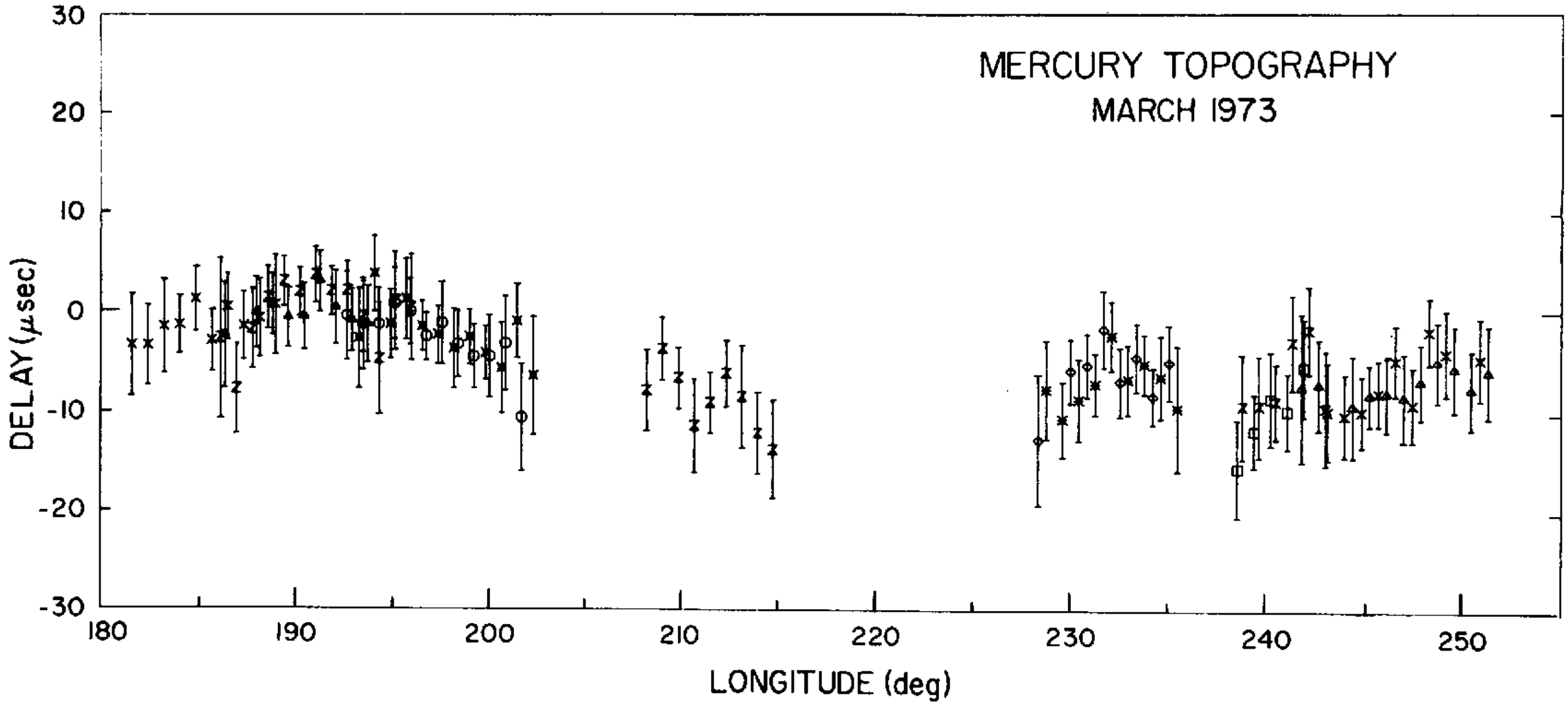

Fig. III-1

Mercury Topographic Delay Results, 12 - 21 March, 1973. Orbital delay was removed with PEP 445 B 10 as a reference. Each symbol identifies an individual observation, with longitude coverage being obtained by frequency resolution within each observation. Most observations were made in daily pairs, so that there was almost complete longitude overlap by two independent observations. Daily longitude change was about 7° and the latitude region covered was near -9°.

Observations made in April 1969 and again in June 1972 both show the same regions of high reflectivity and large regions of low reflectivity. The observations used Haystack and Westford as an interferometer to resolve the range-Doppler ambiguity in the received signal.

The results of mapping in 1969 and 1972 have now been combined and are shown in Figure III-2. The map of the combined results has a better signal to noise ratio and better resolution in the region of the subradar point since some of the 1972 observations were made with a 250 μsec baud length compared with the 500 μsec baud used in 1969, and the subradar region moved from 8 degrees South in 1969 to 2 degrees North in 1972. Contour levels represent the ratio of reflectivity-roughness product to the mean planetary reflectivity of 2 percent and 6.4 degrees r.m.s. slope. One level corresponds to a signal to noise ratio of approximately 4 sigma.

The features seen in the map can be identified with those observed at 12 cm by Carpenter (1966) and Goldstein (1967) and at 70 cm by Campbell (1970). The most probable identifications are made in Table III-1.

TABLE III-1

Probable Identifications of Bright Features with those Observed by Carpenter (1966), Goldstein (1967) and Campbell (1970)

Feature	LONG°	LAT°	Probable Identifications	Lower Limit of Reflectivity, r.m.s. Slope Product*
I	-2±2	-26±2	Carpenter F Goldstein α Campbell-Faraday	5
II	-80±2	25±2	Goldstein β Campbell-Hertz	9
III	-78±2	33±2	Goldstein β Campbell-Gauss	7
IV	-65±2	-5±5	Carpenter C	3
V	-73±3	0±5	Carpenter C2	2
VI	-68±2	25±3	Carpenter D2 Goldstein δ	5

* Expressed as a ratio to a reflectivity of 2% and r.m.s. slope of 6.4 degrees.

References

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Carpenter, R.L., 1966, Astron. J. 71, 142.

Goldstein, R.M., 1967 Moon and Planets, 126, (Dollfus, A., Editor, North Holland, Amsterdam).

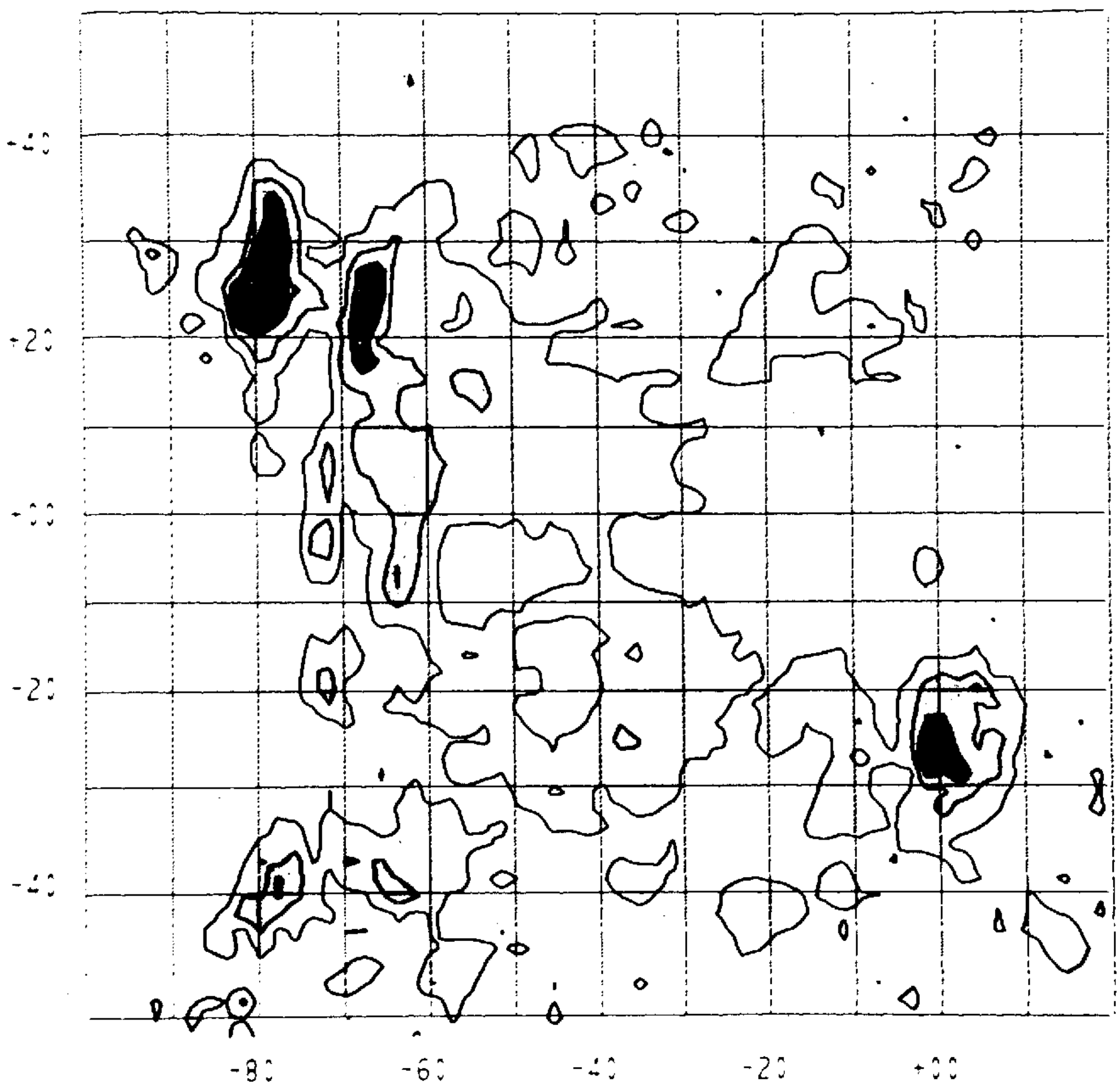

Fig. III-2

Radar Map of Venus from Observations made with Haystack and Westford Interferometer (Hayford) during Concunctions of 1969 and 1972.

E. Satellite Observations

One of the highlights of this period's efforts was the simultaneous radar and optical observation of a near-synchronous satellite. Observatories at Cloudcroft, New Mexico; Maui, Hawaii; and Dayton, Ohio, as well as Haystack, all observed the same target simultaneously. The data from these observations are currently being reduced.

The Haystack radar was also used to observe and measure an apparent coning of Intelsat IV F-3. Information supplied to the Comsat Corporation was subsequently used to correct the coning problem and to re-align the satellite's spin axis.

A. F. Pensa - M.I.T. Lincoln Laboratory

F. Radar Instrumentation

Transmitter

Two new VA-949BM klystrons, S/N 26 and S/N 27, were installed during April in the PR box and checked out to 325 kw on the test dock. They appeared to be well matched, and gave promise of providing a conservative 300 kw transmitter for radar operations. Because of the radio astronomy schedule, there was not available schedule time for really adequate splash plate testing on the ground. When the PR-box was placed on the mount on 25 June, the lower klystron, S/N 26, was apparently in trouble with a dc arcing problem. It appears that we may be forced to change this tube if the problem does not clean up with usage. Currently, the transmitter is usable at 200-kw without excessive arcing. We have the two klystrons S/N 22 and S/N 25 which were taken out and which have useful service life left at a 250 kw level. There is also one klystron, S/N 24, at Varian being repaired for a minute vacuum leak.

Receiver

A new waveguide switch control panel for the PR-box radar system was placed in service, completing those revisions required in the X-band waveguide for the Comtech paramp. This control panel has a much more flexible programming feature that allows presetting of radar or radio astronomy signal path configurations.

Timing System

There were two major upgrading projects associated with the radar timing system. The Radar Sequencer, which is the basic controlling device in the timer system, was modified to operate with a 0.1-microsecond quantum in its delay timing. This permits direct radar delay measurements to a 0.1-microsecond precision, so that runs of this precision can be summed together in real time. Previously, post-run interpolation was required for processing microsecond level of precision. The radar flight time entry in seconds on the timer can now be made to 7 decimal places. This modification was installed principally for the up-coming Mars observations.

The second upgrading project involved the addition of a device called the Satellite Tracking Timer (STT). One major limitation in observing moving satellite targets was the fact that, with high repetition rates, the echo could "disappear" under transmitted pulse as the echo delay became equal to a multiple of the transmitter repetition period. The existing radar timing system for pulse operations had no provision for dynamically changing the repetition period. A new run had to be initiated for each period entry, a situation acceptable for the lunar observations for which the timer had originally been designed, but which presented serious limitations for satellite work.

The STT permits the entry or modification of the radar timer period "on the fly", without breaking track with the sampled data processing in the CDC 3300 computer. The receiver timer period is delayed one round trip flight time before it is changed, a requirement resulting from the fact that the receive timer is used to provide a local analog of the received echo timing. A second major advantage provided by the new unit was the fact that control of the system is now accomplished almost completely from the console area. Only a few switch changes are required to change between the two standard satellite modes-acquisition and pulse. This was accomplished by providing for preset timing entries for both modes with automatic changeover being accomplished by a mode switch at the console.

R.P. Ingalls, M.H. Leavy - Haystack

IV. PROPAGATION STUDIES

M.I.T. Lincoln Laboratory's Millstone Radar group is conducting a program of research aimed at a better understanding of tropospheric and ionospheric refractive effects at very low elevation angles, e.g., $\leq 2°$. To make the required measurements of tropospheric effects, it has been proposed that the Haystack antenna observe the apparent positions of the X-band beacons carried by the Interim Defense Communication Satellite Program (IDCSP) satellites at near synchronous altitudes, using a passive lobe-comparison feed. This approach has several advantages:

(1) At X-band, ionospheric effects are small, so that tropospheric effects may be studied alone.

(2) The near-synchronous satellites appear to move very slowly, requiring several hours to traverse the low-angle region, thus permitting careful observations over a reasonable period.

(3) The narrow (1-milliradian) beam of Haystack at X-band permits low-angle measurements without confusion due to ground reflections (Lloyd's mirror effect).

(4) The precise pointing of Haystack reduces the instrumental error in the measurements.

This project requires the development of a new 4-channel X-band passive lobe-comparison receiving system. In addition to the new feed and receiver to be placed in the R-box, a 4-channel A/D conversion system must be developed for access to the CDC-3300 data-processing computer. The new receiver and conversion equipment design differs fundamentally from the existing 2-channel Direct Data Interface in that it accommodates four signal channels from the receiver and provides 12-bit rather than 8-bit quantizing. In addition, the experimental program requires not only direct logging of antenna position into the CDC-3300, but also requires digital error signal outputs from the processing program to be used for closed-loop tracking on the satellite beacon signals.

Both the analog and digital equipments associated with the interface to the CDC-3300 have been designed and are currently being constructed with a target date of 15 August for completion. Console control equipment has yet to be completely specified, but provision is made in the interface design to transfer control and status signals to the CDC-3300. Full checkout with closed—loop tracking is not expected until later this year.

This new interface system will be valuable for future satellite radar operations, as it provides a means of directly entering such quantities as antenna position and timer period into the CDC-3300.

We anticipate that this program will last a total of two years, with support by M.I.T. Lincoln Laboratory. Antenna time needs will be modest.

J.V. Evans, Millstone
R.P. Ingalls,
P.B. Sebring, Haystack

V. PLANNING FOR FUTURE WORK

A. Antenna Improvement for 3-mm Operation

The Haystack Telescope is of most interest to the astronomy community today because of its unusually good performance at wavelengths from 2 cm to 8 mm. It is perhaps the best available telescope in the region near the wavelengths of water vapor and ammonia.

Clearly, however, larger and better instruments are needed for research at millimeter wavelengths. With this in mind the NEROC community has collaborated in a proposal to the National Science Foundation encompassing the improvement of the Haystack antenna surface and instrumentation to permit radio astronomy observations at wavelengths at least as short as 3 mm. Achievement of this goal would make Haystack a unique instrument for some years to come. The abstract presented in the 3-mm proposal is reproduced below:

ABSTRACT

Improvement of the Haystack Radio Telescope for use at 3 mm wavelength is proposed. The goal is to achieve a 0.006-inch rms surface tolerance for the entire 120-foot aperture, with 0.0005-degree rms pointing accuracy. Achievement of such goals in an instrument of this size requires significant advances in several areas, and the work described here represents our best judgment of the means to be employed. Although full realization of the stated goals cannot be guaranteed, very significant improvements in Haystack are certain and a valuable millimeter-wave instrument will result.

The tasks to be carried out are: (1) Replacement of radome surface panels with new panels optimized for 3 mm operation and rejection of solar radiation, (2) Modification of the reflector surface and back-up structure, (3) Upgrading of the antenna pointing system, and (4) Improvement of control of the thermal environment inside the radome.

The modifications will require a total time of 2 1/2 years, and the Haystack antenna will be out of service for about six months. The program starts with a nine-months organization and study phase, during which a Project Office will be set up, principal tasks will be defined, and engineering approaches selected. The work will be documented in sufficient detail to form a major part of an engineering study of a 200-foot diameter instrument for location at a site optimum for millimeter-wave observations.

A starting date of 1 October 1973 is assumed in order that the discussion and charts can be specific.

B. Satellite Radar Development

In June of this year, NEROC entered into an agreement with M.I.T. Lincoln Laboratory under which the Observatory will support the development and demonstration of a long-range satellite imaging radar. After a development program at Lincoln Laboratory lasting some 3 1/2 years, the radar will be brought to Haystack where it will be periodically installed on the antenna in much the same fashion as the Planetary Radar Box is at the present time. Scheduling will, however, be on a different basis in that radar observations will be concentrated into fewer periods per year than at present, but with intensive, continuous radar work going on whenever the radar box is installed. Thus, no effort need be diverted into providing radio astronomy instrumentation in the radar box - a compromise at best in the case of the present Planetary Radar Box.

Lincoln Laboratory will pay for the consulting effort by the Observatory which will be required to ensure a design that can be successfully used at Haystack, and will defray the full cost of the radar installations, tests and operations at the Observatory.

The Haystack Observatory is near-uniquely-suited to support this important research, and we believe that the Observatory, in turn, will be a stronger organization with better facilities and more flexibility to support astronomy programs because of the presence of this project.

P. B. Sebring, Haystack

APPENDIX

Publications Related to Haystack Research

1 January 73 - 30 June 73

(R) Calibration of Radar Data from Apollo 16 Results
S.H. Zisk, H.J. Moore
Apollo 16 90-Day Preliminary Science Report
NASA SP-315 1972 (Printing Date, February 1973)

(R) Venus: Radar Determination of Gravity Potential
I.I. Shapiro, G.H. Pettengill, G.N. Sherman, A.E.E. Rogers, R.P. Ingalls
Science, Vol. 179, February 1973

7.8 GHz Flux Density Measurements of Variable Radio Sources
W.A. Dent, G. Kojoian
Astronomical Jrnl., Vol 77, Pg. 189, December 1972 (Omitted previously)

(R) Lunar Surface Topography: Computer Generation and Display of High-Resolution Radar Astronomy Maps
S. H. Zisk
Astronomy & Astrophysics, (In Press)

(R) Apollo 16 Landing Site: Summary of Earth-Based Remote Sensing Data
S.H. Zisk, H. Masurski, D.J. Milton, G.G. Schaber, R.W. Shorthill, T.W. Thompson
Apollo 16 Preliminary Science Report
NASA SP-315 1972 (Printing Date, February 1973)

(R) Mare Serenitatis: A Preliminary Definition of Surface Units by Remote Observations
T.W. Thompson, S.H. Zisk
The Moon (In Press)

Absence of Variations in the Nucleus of Virgo A
K.I. Kellermann, B.G. Clark, M.H. Cohen, D.B. Shaffer, J.J. Broderick, D.L. Jauncey
The Astrophysical Jrnl. #3, Vol. 179, February 1973

(R) The Dark Mantling Material of Apollo 17: Its Nature and Aerial Extent as Seen by Earth Based Instruments (Abstract)
C. Pieters, T.B. McCord, S.H. Zisk, J.B. Adams
Transactions of American Geophysical Union, Vol. 54, #4, April 1973

(R) Radar Related Research

(R) Lava Flows in Mare Imbrium: Evaluation of Earth-Based Radar Response (Abstract)
G.G. Schaber, T.W. Thompson, S.H. Zisk
Transactions of American Geophysical Union
Vol. 54, #4, April 1973

(R) Remote Sensing of Mare Serenitatis
T.W. Thompson, K.A. Howard, R.W. Shorthill, G.L. Tyler, S.H. Zisk, E.A. Whitaker, G.G. Schaber, H.J. Moore
Apollo 17 90-Day Preliminary Science Report
(To be published)

Digital Single-Sideband Mixer
C.C. Counselman, III, H.F. Hinteregger
Proc. of the IEEE, Vol. 61, Pg. 478, April 1973

Precision Selenodesy Via Differential Interferometry
C.C. Counselman, III, H.F. Hinteregger, R.W. King, I.I. Shapiro
Science, Vol. 181, Pg. 772, August 1973

Extragalactic Radio Sources: Accurate Positions from VLBI Observations
A.E.E. Rogers, C.C. Counselman III, H.F. Hinteregger, C.A. Knight, D.S. Robertson, I.I. Shapiro, A.R. Whitney
Astrophys. Jrnl. Letters, (In Press)

New H_2O Sources Associated with Infrared Stars
D.F. Dickinson, K.P. Bechis, A.H. Barrett
Astrophys. Jrnl., Vol. 180, #3, Part 1, March 15, 1973

Variations in the Radio Structure of BL Lacertae
B.G. Clark, K.I. Kellermann, M.H. Cohen, D.B. Shaffer, J.J. Broderick, D.L. Jauncey, L.I. Matveyenko, I.G. Moiseev
Astrophys. Jrnl., 182:000-000, June, 1973

(R) Topography & Radar Scattering Property of Mars
G.H. Pettengill, I.I. Shapiro
Icarus 18, 22-28, 1973

Radio Brightness Distribution Over the Crab Nebula at 3.55 and 1.28 cm
L.I. Matveyenko, M.L. Meeks
Soviet Astronomy-AJ, Vol. 16, #5, March/April 1973

(R) The Mapping of Lunar Radar Scattering Characteristics
G.H. Pettengill, S.H. Zisk, T.W. Thompson
The Moon (In Press)

(R) High Resolution Radar Maps of the Lunar Surface at 3.8-cm Wavelength
S.H. Zisk, G.H. Pettengill, G.W. Catuna
The Moon (In Press)

(R) A Comparison of Infrared, Radar and Geologic Mapping of Lunar Craters
T.W. Thompson, H. Masursky, R.W. Shorthill, S.H. Zisk, G.L. Tyler
The Moon (In Press)

Traveling Wave Maser Receivers for 20-24 GHz Using Ruby and Iron Doped Rutile
K.S. Yngvesson, A.G. Cardiasmenos, E.L. Kollberg
Intern. Microwave Symposium, 1973 Digest of IEEE
June 1973

H_2O Sources in Sharpless HII Regions
K.Y. Lo, B.F. Burke
Astronomy & Astrophysics (In Press)

(R) Calibration of Radar Data from Apollo 17 and Other Mission Results
H.J. Moore, S.H. Zisk
Apollo 17 90 Day Preliminary Science Report (Submitted)

A High Resolution Map of the Galactic Center Region
J.E. Kapitzky, W.A. Dent
Astrophys Jrnl. (In Press)