

V. RADIO ASTRONOMY*

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A. PULSAR FACILITY

The feeds for 16 dishes of the pulsar facility have been completed and put in place. All transmission lines from the feeds to the ground are installed.

Four of the dishes in a North-South line have been phased to give a beam at the declination of the Crab Nebula for test purposes. Tests of the phasing errors and impedance matching of the transmission lines are in progress.

RFI tests at the site indicate that frequencies near 142, 146, and 148 MHz will be best for avoiding interference. Modifications to the receiver to allow operation over this frequency range are being undertaken.

B. F. Burke, R. M. Price, M. S. Ewing

B. VARIATION OF SIX RADIO SOURCES AT FOUR AND TWO CENTIMETERS

During 1967 and 1968, an investigation of the variability of continuum radio sources at 4 cm and 2 cm wavelengths was conducted at the Haystack Microwave Facility of Lincoln Laboratory, M. I. T. The flux of 24 radio sources relative to 2 calibration sources was measured at various times using observing techniques designed to eliminate all but the intrinsic secular variation of the objects. The well-known variable sources (Dent,¹ Kellerman and Pauliny-Toth²) were observed on a regular basis between June 1967 and September 1968 at 2 cm, and more sporadically at 4 cm for the entire period.

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(V. RADIO ASTRONOMY)

1. Equipment

The Haystack antenna is a 37-m paraboloid with Cassegrainian optics on an altazimuth mount, enclosed in a radome. The real antenna efficiency, including radome effects, is 45% at 4 cm and 35% at 2 cm, and the system has operated successfully at wavelengths between 18 cm and 0.8 cm. Coordinate conversion, pointing, coordinate precession, refraction, and systematic pointing corrections, and real-time data processing is provided by a Univac 490 computer. The rms antenna tracking error is 0.003° and the real pointing errors are less than this.

The radiometer and feed configurations that were used are summarized in Table V-1. The radiometers were Dicke-switched against a room temperature load with balance noise injection or operated against an off-axis beam separated by 0.25° from the main beam.

Table V-1. Radiometer Configurations.

Front End	Frequency	T_S	Bandwidth	Feed Configuration and Polarization
1. Tunnel Diode	15.5	2500°K	1.0 GHz (1)	Variable linear horn, load switched (3)
2. Tunnel Diode	15.5	900°K	1.0 GHz (1) or 1.2 GHz (2)	Variable linear horn, beams switched (4)
3. Tunnel Diode	8.0	1200°K	1.0 GHz (1)	Variable linear clavin, load switched (3)
4. Maser	7.8	40°K	15 MHz	Left circular horn, load switched

(1) Two 500-MHz channels.

(2) Single channel after June 1968.

(3) June 1967 only.

(4) After November 1967.

2. Observing Techniques and Instrumental Effects

In making absolute flux measurements, the program has been one of making a relatively large number of independent observation of calibration sources, whose flux is well known, and of known or suspected variable sources. If all source sizes are much smaller than the antenna beam, this technique eliminates the need for knowledge of the exact antenna gain and pattern. The major sources of error in this program are fluctuations of radiometer and antenna gain between observations of calibrators, pointing errors, and atmospheric losses.

Radiometer gain fluctuations may be overcome by frequent gas-tube calibrations. It has been the practice to calibrate every time there is a source change, since the maser system gain is sensitive to antenna elevation angle, or every 20 minutes. In practice, typical radiometer gain drifts have been less than 1% for the tunnel-diode amplifiers and less than 3% for the maser. Antenna gain and pattern variations have two origins: position-dependent gravitational deformation, and temperature-dependent thermal deformation of the antenna surface and backup structure. Careful study of the positional dependence of the gain, an effect that reaches 15% with the Haystack antenna, by repeated observations of a number of point sources has resulted in the calibration of the elevation dependence for all angles above 10° and below 80°, and no azimuthal dependence has been found. The thermal effect was found to be much more complex, depending upon the inside temperature of the radome and its time derivatives. Temperature control of the radome seems to eliminate the effect, except during periods of very hot weather or rapid temperature variation. By frequent observation of calibrators, at least every 4 hours, and total avoidance of the worst periods during the summer and near sunrise and sunset, we hope that the thermal effect has been eliminated.

Haystack pointing errors have been well calibrated and are automatically removed by the pointing system. Minor pointing and source position errors are eliminated by manually inserting corrections derived from the use of the Discrete Source Scan (DSS) pointing routine (Allen³). In the usual observation of a source there is a calibration sequence, a DDS, and then a series of "on-offs" comprising a 90-sec source integration, a 30-sec blanking period for antenna repositioning, and a 90-sec comparison integration at the same azimuth and elevation as the "on".

The effects of variable atmospheric loss are countered by hard adherence to a rule of no observations on days with more than 25% cloud cover and no observations below 30° elevation. Also, a serious attempt is made to observe sources and calibrations at the same elevation angles as close together in time as possible. Atmospheric attenuation corrections derived from observations of sea-level temperature, pressure, and water vapor taken every 4 hours are applied to the data in post processing (Allen³).

3. Results

The flux of 6 known variable sources relative to 2 calibration sources, corrected for atmospheric loss and gain variations, is plotted in Figs. V-1 and V-2. The positions and identifications of the 6 sources plus the 2 calibration sources, 3C274 and W75 (DR21), are given in Table V-2. Each data point represents the average of at least 4 sets of observations taken during a two-week period. Each set included measurements at 2 orthogonal polarization angles or in the left circular polarization. The error bars are the rms of the averaging.

The sources represented here serve to illustrate the general characteristics of radio

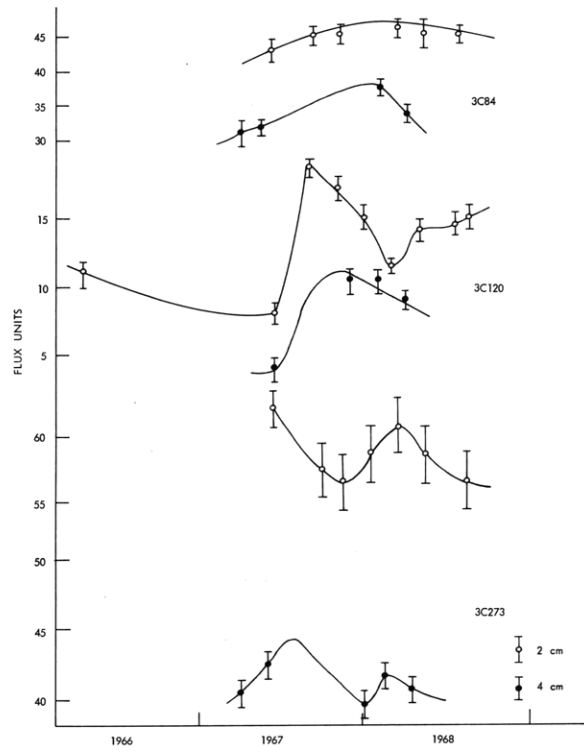


Fig. V-1. Flux of three variable sources relative to calibration sources.

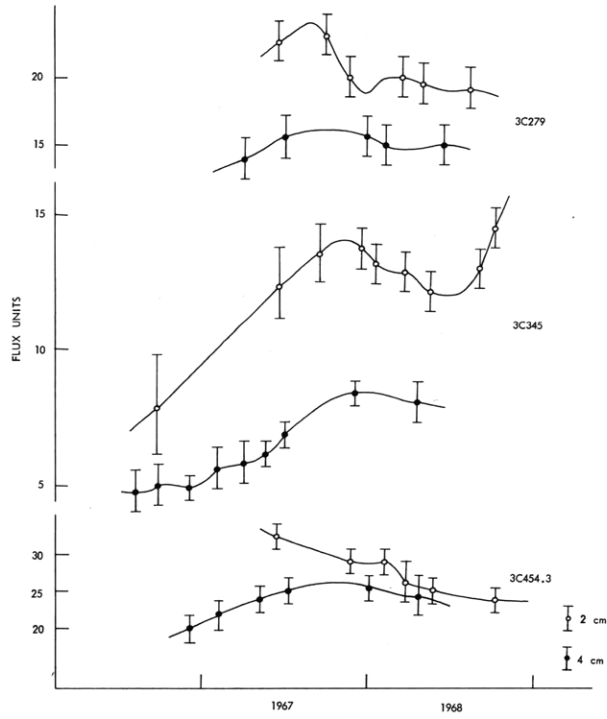


Fig. V-2. Flux of three variable sources relative to calibration sources.

Table V-2. Radio sources observed.

Source	Type	R. A. 1950.0			Dec. 1950			Z (Red Shift)	Flux	
		<u>H</u>	<u>M</u>	<u>S</u>	<u>D</u>	<u>M</u>	<u>S</u>		7.8 GHz	15.5 GHz
3C84	S. G.	3	16	29.4	41	19	59.0	0.02		
3C120	S. G. or N. G.	4	30	30.7	5	14	25.0	0.03		
3C273B	Q. S. O.	12	26	33.3	2	19	42.0	0.16		
3C279	Q. S. O.	12	53	35.9	-5	31	14.0	0.54		
3C345	Q. S. O.	16	41	17.6	39	54	10.6	0.60		
3C454.3	Q. S. O.	22	51	29.5	15	53	11.0	0.86		
3C274		12	28	18.4	12	39	57.6		42.3	28.7
W75 DR21		20	37	14.0	42	9	0		19.5	20.9

S. G. = Seyfert galaxy.
 N. G. = N-type galaxy.
 Q. S. O. = Quasi-stellar object.

(V. RADIO ASTRONOMY)

variability: the relative dissimilarity of the types of objects involved, positive spectral index in the variable region of the spectrum, small angular size, and the amplitude and time scale of the variation. Furthermore, the observed double outburst of 3C120 seems to bear a remarkable similarity to the observed behavior of 3C273, which experienced a spectacular outburst in middle and late 1966, and possibly to the observed variation of 3C345. The sources 3C84, 3C279, and 3C454.3 exhibited more gradual increases to maxima in the period 1965-1968, and have not yet exhibited this multiple burst structure. Thus this "ringing" may be related either to the amplitude or the time scale of variation of the source and, in any case, is strikingly reminiscent of the behavior of a perturbed resonant system with strong damping.

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References

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C. FURTHER OBSERVATIONS OF GALACTIC WATER-VAPOR EMISSION

Observations of water vapor emission sources, begun in February and March, 1969, at the Lincoln Laboratory Haystack facility,^{1,2} were continued in April and May using the 140-ft telescope of the National Radio Astronomy Observatory at Green Bank, West Virginia. Although the reduction of all of the data is not complete, several new results concerning time variation, linear polarization, and spectral dispersion in these sources can be reported.

For the observations, the 140-ft telescope was equipped with a Dicke-switched mixer radiometer and linear horn feed, the IF signal was fed into the 400 N. R. A. O. channel autocorrelation receiver and the resulting power spectra were recorded on magnetic tape, displayed real time on a storage oscilloscope, and post real time on a digital plotter. The system temperature was approximately 2400°K for single-sideband spectral line observations at 22 GHz. The aperture efficiency of the 140-ft telescope was found to be around 10% on the meridian and strongly dependent upon local hour angle; consequently, the observations were usually limited to 3-4 h around source transit. The antenna beamwidth was 1.6 minutes of arc. For polarization measurements, the feed was oriented so that the E plane made an angle of 0, 45°, 90° or 135° to celestial North-South direction; all other observations were made with the E plane North-South.

The H₂O Sources W3OH, G133.7-1.2 (W3 Continuum), W49OH, Orion A, and

VY Canis Majoris were observed on a daily basis with resolutions of 12.5 and 6.25 kHz; the sources W51OH, W75(S)OH, and W24(B2)OH were observed less frequently. Attempts were made to measure the linear polarization of the first seven sources. Two of the sources observed, W3OH and VY Canis Majoris, showed no evidence of variation during the month of observation, nor, for that matter, any significant change from earlier observations in January and February³ and February and March.² Both sources, however, seemed to have small but significant linear polarization. For W51OH and W75(S)OH the analysis is not complete, but the shape of the W75(S)OH spectrum appears changed from February. This source appears to be slightly linearly polarized. W51OH appears to have also changed since February, but this variation may be a result of the higher frequency resolution used at N. R. A. O. The source G133.7+1.2 varied significantly during the month of April and is drastically changed from its appearance in February; in particular, the strong features near 10 km/sec observed in February are completely absent in April. No significant linear polarization could be detected in this source. In Fig. V-3, representative spectra for these 5 sources are shown.

The strongest H₂O source, W49OH, has been shown to be highly variable in time and to possess an extremely high dispersion in radial velocity of features extending from -140 to +140 km/sec.³ In particular, a strong line near 140 km/sec was observed to disappear over the space of three weeks in February-March.² In Fig. V-4 time variations in the main features observed during a one-month period, and rapid and complex changes in line intensity and width are displayed. The high-velocity spectrum of W49OH is shown in Fig. V-5 with the 140 km/sec feature greatly weakened but present, and with even higher velocity features also present. Both the main and the low-velocity features of this source were found to be less than 5% linearly polarized.^{2, 3}

The H₂O source in Orion A has already been shown to be linearly polarized.^{2,3} Time variations of two features of this source were found, including the very rapid appearance of a narrow, isolated, bright line that seems to be analogous to the 140 km/sec feature seen in W49OH in February. It is interesting to note that these two variable features are apparently unpolarized. Time variation and polarization of Orion A are shown in Fig. V-4.

Although it is much too early to make strong generalizations about H₂O emission, the data seem to indicate a tendency for variable features to be unpolarized and slightly narrower than the steady, linearly polarized features, and for variability to be associated with sources with a higher degree of velocity dispersion. If, as has been suggested, H₂O emission is the result of some stimulated emission process in a circumstellar envelope or near a star-formation region, the observed time variations may result from the effects of turbulence on an unsaturated maser process either through small changes in the density or length of the amplifying path or through changes in the orientation of a highly beamed maser with respect to the observer. In any case, two approaches to the

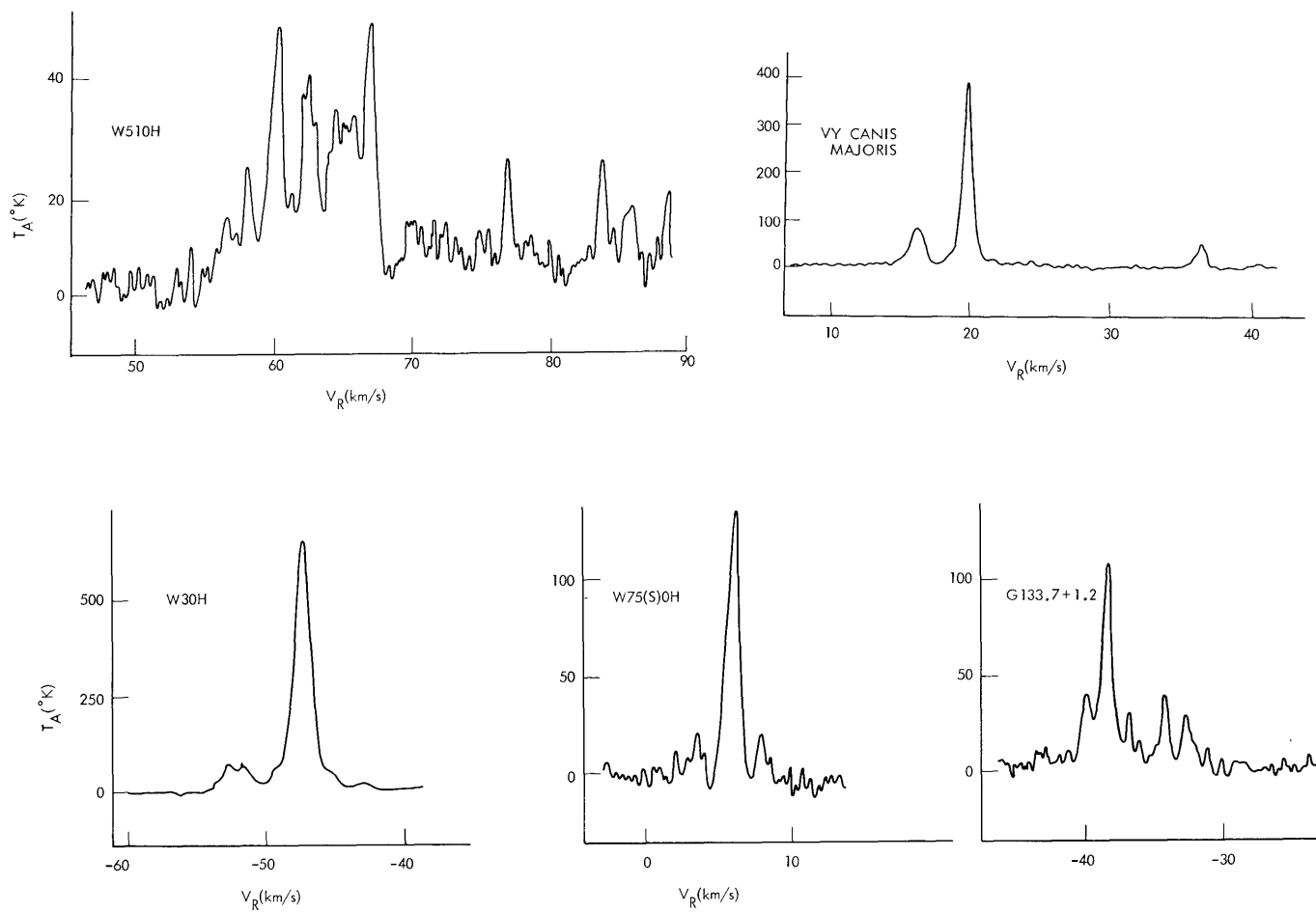


Fig. V-3. Water vapor emission from sources W510H, VY Canis Majoris, W30H, W75(S)OH and G133.7+1.2, N. R. A. O. 140-ft telescope, April 1969.

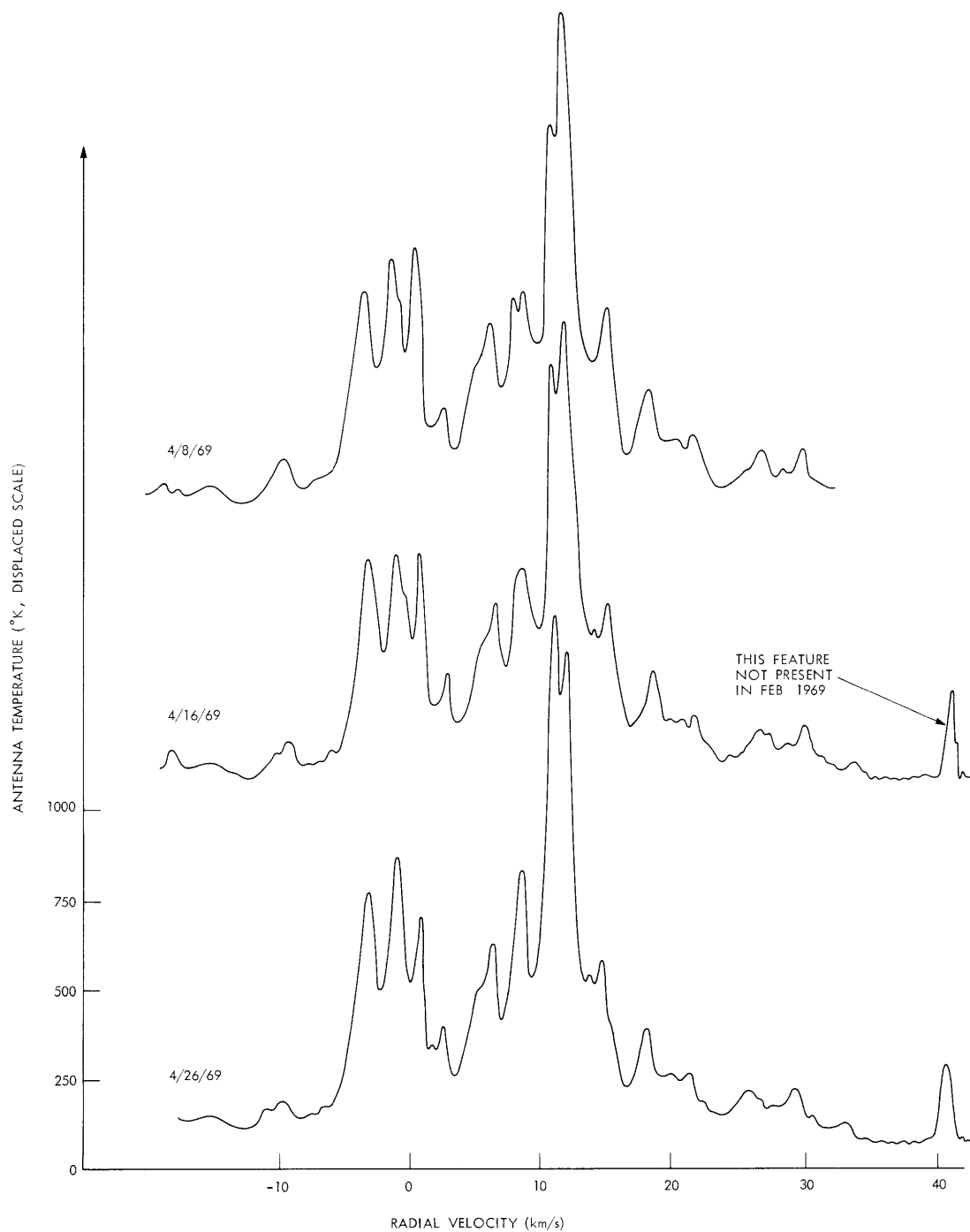


Fig. V-4. Time variation in the H₂O spectrum of W49OH, N. R. A. O. 140-ft telescope, April 1969.

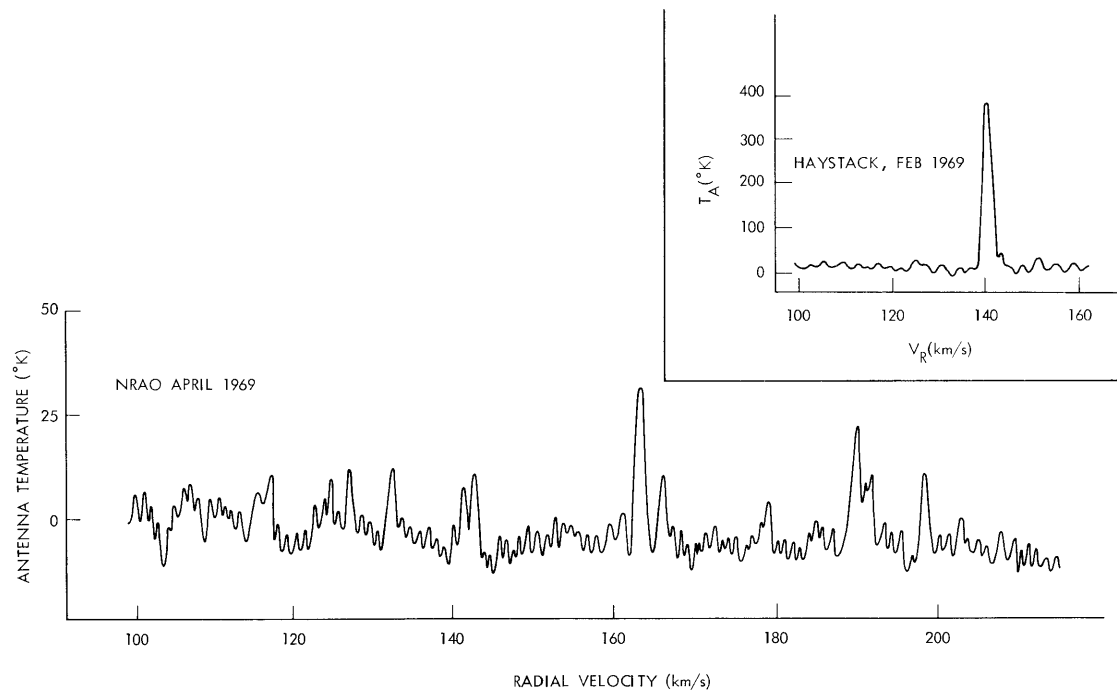


Fig. V-5. High-velocity spectrum of W49OH, in February 1969, at Haystack (small figure) and, in April 1969, N. R. A. O. 140-ft telescope.

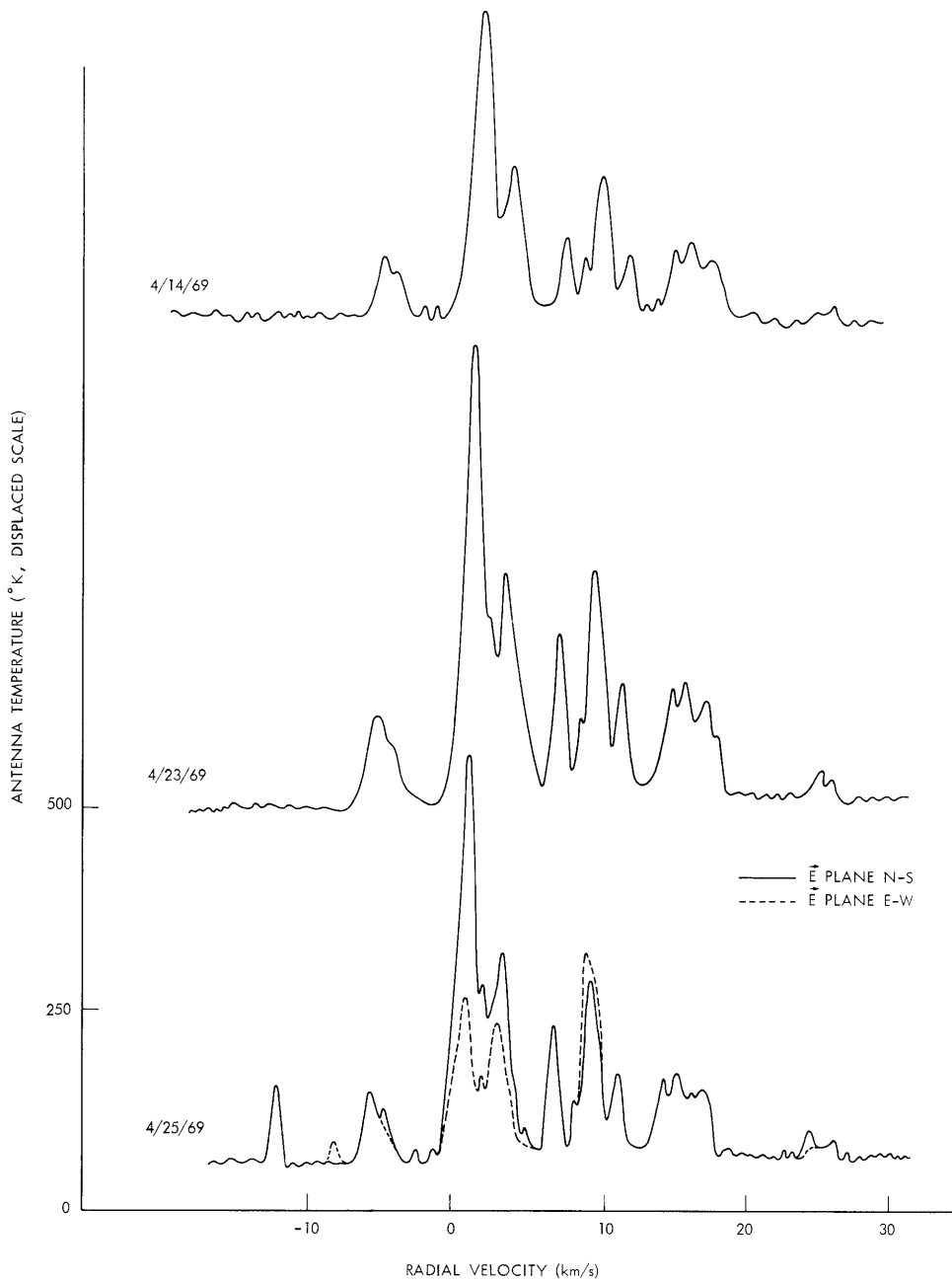


Fig. V-6. Time variation and polarization in the H₂O spectrum of Orion A.

(V. RADIO ASTRONOMY)

H₂O problem are indicated: (i) more careful studies of the relationship between variability and polarization must be carried out, and (ii) the angular size, relative and absolute positions of variable and nonvariable features must be determined, since these quantities might be expected to be markedly different for saturated and unsaturated emission.

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