XIII. RADIO ASTRONOMY

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1. ASTROMETRIC INTERFEROMETER

M. I. T. Sloan Fund for Basic Research

David H. Staelin

A long-baseline Michelson interferometer is being developed for astrometric purposes. In principle, relative stellar positions should be measurable with $\sim 10^{-4}$-10^{-5} arc sec accuracy for stars brighter than ~10-5 mag, respectively, and separated less than ~1°-1 arc min, respectively. A 10-m baseline system with 12-cm optics would be appropriate for such purposes.

A preliminary 1.6-m baseline unit with 1-inch apertures has been operated from October to December 1976 at the M. I. T. Wallace Observatory near Tyngsboro, Massachusetts. The system incorporates two angle trackers, one for each arm of the interferometer, and one fringe-tracking servomechanism. A PDP-8 computer performs all computations; the system averages data in 10-ms units.

Fringes were not observed because of the excessive rate of fringe motion. The system can track only if the white fringe moves less than $\sim 30\ \lambda\ \text{sec}^{-1}$, which is approximately one quarter of the observed rate. Seeing was ~5 arc sec, and the winds were ~10 mi/h. A better site will eventually be needed.

2. ENVIRONMENTAL REMOTE SENSING WITH THE NIMBUS PASSIVE MICROWAVE SPECTROMETER

National Aeronautics and Space Administration (Contract NAS5-21980)

David H. Staelin, Philip W. Rosenkranz

Passive observations of the Earth from space near the microwave molecular resonances of water vapor and oxygen yield information about the atmospheric temperature profile and, over ocean, about the atmospheric water vapor and liquid water content. Two 5-channel microwave spectrometers, the Nimbus 5 (Nimbus E) microwave spectrometer (NEMS) and the scanning microwave spectrometer (SCAMS), were launched on the Nimbus Observatory Satellites in 1972 and 1975, respectively. These spectrometers were fabricated at the Jet Propulsion Laboratory, C. I. T., and most of the scientific analysis has been performed in the Research Laboratory of Electronics, M. I. T. The present emphasis of this research is placed on: improving parameter estimation methods for determining atmospheric parameters, obtaining better methods for computing the propagation of electromagnetic radiation in scattering or inhomogeneous media, such as clouds or accumulations of ice and snow, and utilizing the microwave data for geophysical purposes.

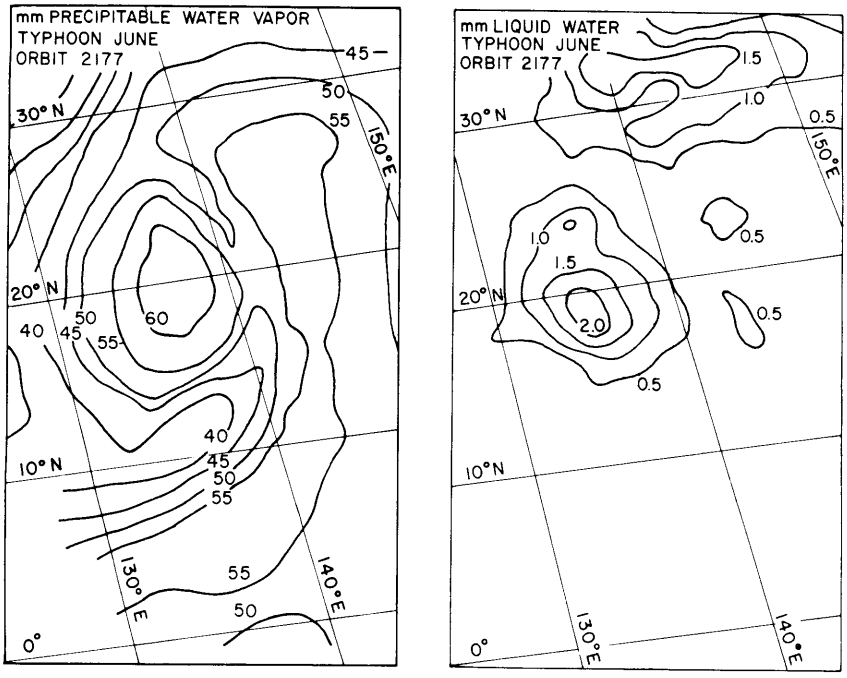

Fig. XIII-1. Retrieved abundances of water vapor and liquid water from SCAMS measurements, November 21, 1975.

The ability of NEMS to sound atmospheric temperature profiles has been determined from comparisons with radiosonde measurements of temperature[1,2] and wind.[3] Measurements with the Nimbus-6 scanning microwave spectrometer SCAMS have been discussed in preliminary fashion.[4,5] Both NEMS and SCAMS are yielding temperature retrieval accuracies close to those expected, 1.5-4 K rms errors. Small systematic residual errors have been attributed to some unknown combination of errors in present atmospheric transmittance expressions, the instrument calibration, and the radiosonde data sets.

Determinations of water vapor and liquid water abundances over ocean have been discussed for NEMS[6] and, in preliminary fashion, for SCAMS.[5,7] The SCAMS observations of Typhoon June, in November 1975, are particularly interesting. Representative maps of retrieved water vapor and liquid water abundances are illustrated in Fig. XIII-1.

Snow and ice observations from NEMS[8,9] revealed strong spectral variations with time and space that are related to subsurface inhomogeneities and loss tangents. A theory for electromagnetic wave propagation for these conditions has been developed and discussed with reference to the SCAMS data.[10,11]

References

1. J. W. Waters, K. F. Kunzi, R. L. Pettyjohn, R. K. L. Poon, and D. H. Staelin, "Remote Sensing of Atmospheric Temperature Profile with the Nimbus-5 Microwave Spectrometer," J. Atmos. Sci. 32, 1953-1969 (1975).
2. K. F. Kunzi, A. G. Piaget, and C. B. Ruchti, "The Accuracy of the Terrestrial Atmospheric Temperature Profile Derived from Nimbus-5 Microwave Spectrometer (NEMS) Data," Proceedings of the Symposium on Meteorological Observations from Space, XIX COSPAR Meeting, Philadelphia, Pennsylvania, June 8-12, 1976, pp. 22-29.
3. R. W. Wilcox and F. Sanders, "Comparison of Layer Thickness as Observed by Nimbus-E Microwave Spectrometer and Radiosonde," J. Appl. Meteorol. 15, 956-961 (1976).
4. P. W. Rosenkranz, D. H. Staelin, R. L. Pettyjohn, and W. L. Ledsham, "Retrieval of Atmospheric Temperature Profiles by a Scanning Microwave Spectrometer," Proceedings of the Symposium on Meteorological Observations from Space, XIX COSPAR Meeting, Philadelphia, Pennsylvania, June 8-12, 1976, pp. 20-21; also RLE Progress Report No. 118, July 1976, pp. 47-51.
5. D. H. Staelin, P. W. Rosenkranz, F. T. Barath, E. J. Johnston, and J. W. Waters, "Microwave Spectroscopic Imagery of the Earth" (submitted to Science).
6. D. H. Staelin, K. F. Kunzi, R. L. Pettyjohn, R. K. L. Poon, R. W. Wilcox, and J. W. Waters, "Remote Sensing of Atmospheric Water Vapor and Liquid Water with the Nimbus-5 Microwave Spectrometer" J. Appl. Meteorol. 15, 1204-1214 (1976)
7. D. H. Staelin, F. T. Barath, E. J. Johnston, W. Ledsham, W. B. Lenoir, R. L. Pettyjohn, P. W. Rosenkranz, and J. W. Waters, "Observations of Atmospheric Water with the Nimbus-6 Scanning Microwave Spectrometer," Proceedings of the Symposium on Meteorological Observations from Space, XIX COSPAR Meeting, Philadelphia, Pennsylvania, June 8-12, 1976, pp. 30-33.

8. K. F. Kunzi, A. D. Fisher, and D. H. Staelin, "Snow and Ice Surfaces Measured by the Nimbus 5 Microwave Spectrometer," J. Geophys. Res. 81, 4965-4980 (1976).

9. K. F. Kunzi and D. H. Staelin, "Measurements of Snow Cover over Land with the Nimbus-5 Microwave Spectrometer," Proceedings of the Tenth International Symposium on Remote Sensing of Environment, Ann Arbor, Michigan, October 6-10, 1975, pp. 1245-1253.

10. A. D. Fisher, "A Model for Electromagnetic Intensity Propagation in an Inhomogeneous Medium," S. M. Thesis, Department of Electrical Engineering and Computer Science, M. I. T., 1976.

11. A. D. Fisher, B. L. Ledsham, P. W. Rosenkranz, and D. H. Staelin, "Satellite Observations of Snow and Ice with an Imaging Passive Microwave Spectrometer," Proceedings of the Symposium on Meteorological Observations from Space, XIX COSPAR Meeting, Philadelphia, Pennsylvania, June 8-12, 1976, pp. 98-103.

3. FEASIBILITY STUDY OF A MICROWAVE SPECTROMETER FOR METEOROLOGICAL OBSERVATIONS FROM SYNCHRONOUS SATELLITES

National Aeronautics and Space Administration (Contracts NAS5-22485 and NAS5-23677)

David H. Staelin, Philip W. Rosenkranz

Certain meteorological phenomena such as tropical and extratropical storms require almost constant surveillance in order to be monitored or possibly controlled properly; this is best accomplished from synchronous satellites. High spatial resolution is desired for rapidly varying phenomena, and this implies short wavelengths if the relatively cloud-insensitive microwave techniques are used for temperature and moisture mapping.

Satellite configurations employing the 118-GHz O_2 resonance and the 183-GHz H_2O resonance are being studied for such applications. The dominant technical problems are nonlinear parameter estimation and electromagnetic propagation in scattering atmospheres. It now appears that clouds will degrade the temperature profile measurements only somewhat more than they do near 60 GHz.

In support of this effort an 8-channel 118-GHz microwave spectrometer is being assembled and adapted to a NASA Convair 990 aircraft for flights in March 1977.

4. NIMBUS-G SCANNING MULTICHANNEL MICROWAVE RADIOMETER

National Aeronautics and Space Administration (Contract NAS5-22929)

David H. Staelin, Philip W. Rosenkranz

This instrument comprises 5 dual-polarized microwave channels at 6.6, 10, 18, 21, and 37 GHz wavelengths. The ground resolution varies from ~120 km to ~20 km, depending on frequency. The swath width for this polar-orbiting system will be ~750 km. Launch is scheduled for 1978.

The theoretical problems involve two-dimensional nonlinear parameter estimation. The problem is compounded because the different frequencies and polarizations have slightly different viewing zones. A preliminary approach to solving these problems has been developed.

5. ATMOSPHERIC MEASUREMENTS NEAR 118 GHz WITH PASSIVE MICROWAVE TECHNIQUES

U. S. Air Force – Electronic Systems Division (Contract F19628-75-C-0122)

David H. Staelin, Philip W. Rosenkranz

The use of the 118 GHz and 60 GHz spectral regions in combination is being studied for the purpose of determining the accuracy with which cloud liquid water can be measured. Theoretical procedures for computing high-order scattering in clouds were developed. The initial evaluations of cloud measurement accuracy were unfavorable because linear estimation techniques were used for the very nonlinear problem of heavy clouds and precipitation. Nonlinear procedures are being developed.

An 8-channel microwave spectrometer at 118 GHz is nearing completion. It incorporates a Gunn-diode oscillator plus doubler for the local oscillator, and a GaAs FET amplifier operating at 500-2000 MHz to yield an ~11-dB noise figure (double sideband). The 8 channels are each ~200 MHz wide and spaced over the band. The local oscillator is centered on the oxygen resonance.

The radiometer utilizes a microprocessor for synchronous detection, system control, and data recording. Limited real-time data reduction can also be performed.

6. GALACTIC AND EXTRAGALACTIC ASTRONOMY

National Science Foundation (Grant AST73-05043-A02)

Bernard F. Burke, Alan Parrish, Aubrey D. Haschick, Thomas S. Giuffrida, Robert C. Walker, Willem A. Baan, Patrick C. Crane, Barry R. Allen, Perry E. Greenfield, J. Antonio Garcia-Barreto, John W. Barrett, D. Cosmo Papa, John D. Kierstead

Our research in galactic and extragalactic astronomy includes the following programs:

(i) Studies of Very-Long-Baseline Interferometry (VLBI) of quasars, active radio galaxies, and interstellar masers.

(ii) Development of a microwave aperture synthesis interferometer for medium-resolution studies of galactic and extragalactic radio sources.

(iii) Studies of time variations of H_2O masers.

(iv) Radio continuum studies of nearby spiral galaxies, using the NRAO 3-element interferometer.

(v) Studies of 21-cm absorption lines in the spectra of quasars, radio galaxies, and Seyfert galaxies, including the effects of intervening high-velocity clouds of our Galaxy. Searches will be made for neutral hydrogen in clusters of galaxies.

(vi) Radio recombination lines in the interstellar medium and H II regions will be observed.

We report the following progress toward carrying out these objectives.

a. Microwave Aperture Synthesis Interferometer

Alan Parrish, Thomas S. Giuffrida, Barry R. Allen, John D. Kierstead, D. Cosmo Papa, Perry E. Greenfield, John W. Barrett, Bernard F. Burke

The electronics development for the M. I. T. microwave interferometer system was essentially completed during the past year. One set of finished components has been installed on two of the three antennas to make a finished interferometer pair. A block diagram of this system is shown in Fig. XIII-2. By using this system, fringes have been obtained on the Sun and on Cas A at 1.3 cm wavelength. We are now testing the equipment under field conditions and shall expand to full operation of the three simultaneous baselines obtainable from three antennas. The radiometer, wiring, and mechanical work for the third antenna are now complete. The additional local-oscillator reference cable length control servo required for this antenna in the system is being constructed, as well as the digital equipment that is necessary to correlate the two additional baselines.

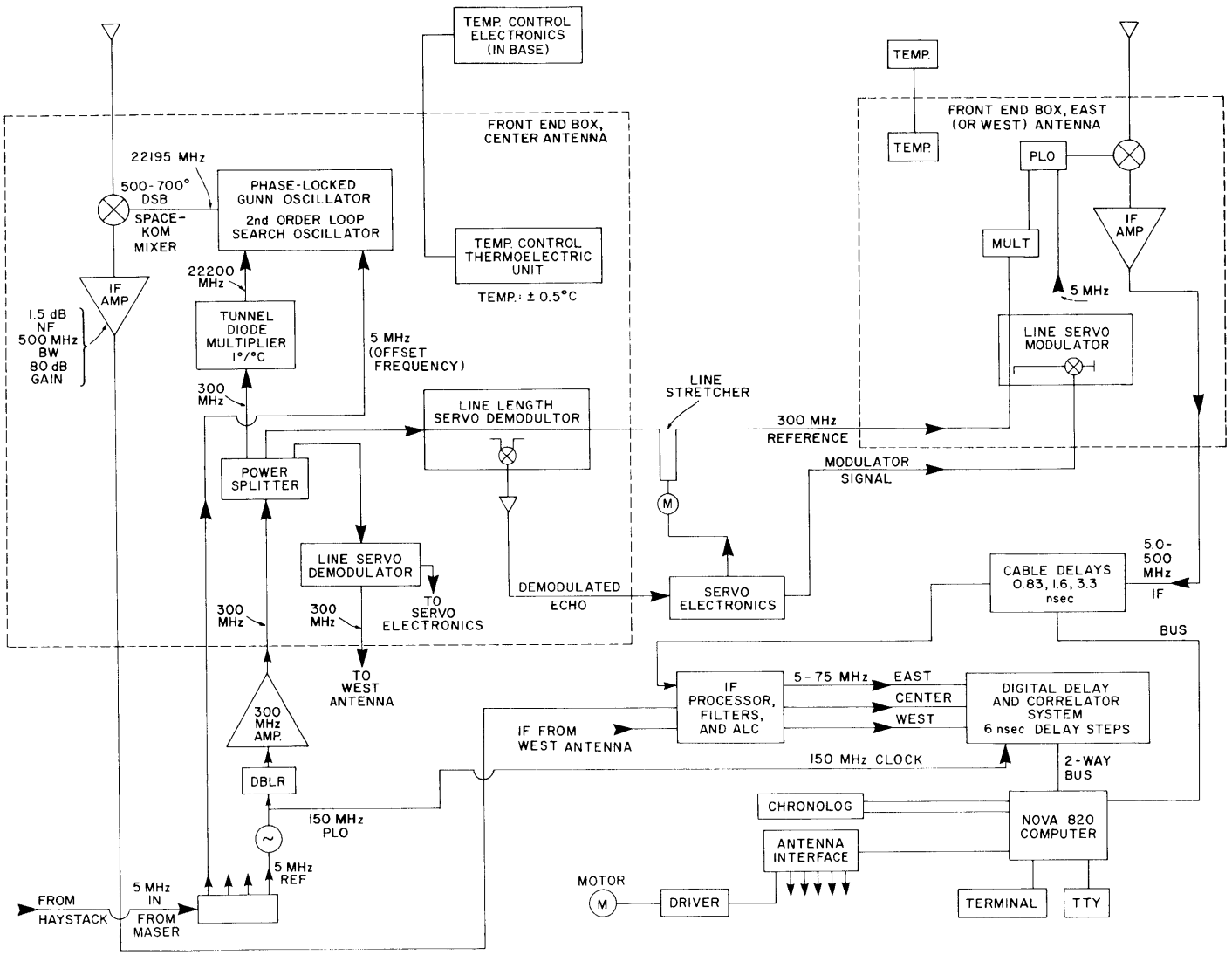

Fig. XIII-2. M. I. T. microwave aperture synthesis interferometer system.

The compactness and relative simplicity of the instrument depend largely on the digital delay and correlator system developed for it in this laboratory. This device, which essentially is a special-purpose digital computer with a cycle time of only 6.6 ns, is capable of crosscorrelating three pairs of noise signals, each of which has a 75 MHz bandwidth.

The components of the installed 2-element system were assembled in the laboratory, and the phase stability of this assembly has been measured to be 3.5° rms. It is expected that this order of phase stability will also be maintained in the field, since the critical variables, the focus box temperatures, are controlled by proportionally controlled thermoelectric systems, and all critical elements are installed in these packages.

The computer system is based on the Nova 820 interrupt system. An external real-time clock generates two interrupt chains, one every eighth second and the other every twelve milliseconds. The eighth-second interrupt causes the computer to perform the following tasks: time and display upkeep, pointing calculations, delay calculations, fringe fitting, and data tape creation. The 12-ms interrupt samples the correlators, pulses the antenna stepping motors, and sets the delays. All software and interfaces have operated successfully in the first phases of testing and are now undergoing system usage tests on site.

The digital sampler, delay lines, and correlator comprise a three-level 2-bit system. The sampler is an ECL system clocked at 150 MHz which gives a 75 MHz bandwidth. Since it would be very difficult to maintain such a clock rate, the high-speed serial data stream is separated into 8 parallel data streams. This allows all except the sampler and serial-to-parallel converter board to be clocked at 18.75 MHz, i.e., TTL logic speeds. The delays are shift registers, multiplexers, and latches that give delays from 6.6 ns to 1.2 μs in 6.6 ns steps. The correlators multiply the samples from each antenna and accumulate these products until the computer requests the accumulation. This system is now operating on site and all tests will soon be completed.

A NRAO program has been adapted to compute the rms surface accuracy of two of the antennas, by using surface measurements made by D. Cosmo Papa. The rms surface accuracy of the two antennas was found to be 0.022" and 0.036", which is in agreement with efficiency measurements, with astronomical sources used. The major fraction of the error is caused by panel setting, and rerigging will be done at a later time.

b. Studies of Nearby Galaxies

Thomas S. Giuffrida

In the thesis research of John H. Spencer[1] virtually no HII regions were detected in M31. Since several detections from observation in our Galaxy would have been predicted, we decided on making further observations of M31 and also of M81 and M101,

using the NRAO 3-element interferometer. Thus far we have detected one large HII region in M31, one HII region in M101, and a supernova in M101. Also, the nucleus of M81 was shown to be quite variable on time scales as short as one day.

References

1. "Interferometric Observations of M31 and M33," Ph.D. Thesis, Department of Physics, M.I.T., March 1973.

c. Neutral Hydrogen Absorption in Clusters of Galaxies

Aubrey D. Haschick, Willem A. Baan

Approximately 20 clusters of galaxies have been surveyed for neutral hydrogen absorption. In all cases, the illuminating radio source was either a background quasar or a radio galaxy within the cluster itself. Each cluster was searched over a 2000 kms^{-1} velocity range centered on the red shift of the cluster, which in all cases was less than 0.035. No absorption features were found down to a limiting antenna temperature ~0.08 K on the 300-ft telescope. This provides a limiting density of $\frac{\eta_H}{T_s} \sim 6 \times 10^{-7}$ cm^{-3} for neutral hydrogen in clusters of galaxies, and implies that the mass needed to bind clusters of galaxies gravitationally is probably not contained in cold HI clouds.

d. Neutral Hydrogen Absorption in the Spectra of Quasars and Radio Galaxies

Aubrey D. Haschick, Patrick C. Crane, Willem A. Baan

Recent observations of the neutral hydrogen spectrum of quasars near spiral galaxies in one case have revealed an absorption feature close to the red shift of a nearby galaxy. The absorbing cloud bears some resemblance to extragalactic HI clouds found by observers in the vicinity of galaxies, such as M81, NGC 55, and NGC 300. This has inspired further observations of radio source galaxy pairs that have revealed three more absorption lines. The absorption feature in the spectrum of the BLLAC-type object 1749+701 has a velocity higher than the velocity of the neutral hydrogen emission from the nearby galaxy NGC 5603. This reveals the presence of high-velocity clouds at distances of ~20 kpc from the nucleus of NGC 5603. The two other absorption lines were found in the spectrum of the nuclear source of the particular galaxy and probably arise from HI clouds either in the disk of the galaxy or in the halo region of the galaxy. Observations of radio galaxies continue in a search for more of these high-velocity hydrogen clouds in external systems. Of particular interest are size, spin temperature, and density of these clouds.

e. Water-Vapor Observations of Hydroxyl Masers in the Galactic Center

Aubrey D. Haschick, Bernard F. Burke

A survey has been conducted of the water-vapor frequency of 22.235 GHz for ~40 regions of OH maser emission in the galactic center. The Haystack 120-ft antenna equipped with a maser amplifier and a 1000-channel autocorrelator was used in the observations. Each position of OH emission was searched, by using a 5-position grid down to a limiting antenna temperature of 0.2 K.

Two new H_2O sources were discovered. One of these sources exhibits a complex spectrum with multiple features spread over a velocity range of ~70 kms^{-1}. The variable nature and multiplicity of the features bears a similarity to H_2O masers found in HII regions as opposed to those found in infrared stars, and hence indicates a possible region of star formation. The second source displays only a single feature that is more characteristic of H_2O masers found in infrared stars.

These observations were made with Dr. James M. Moran of the Smithsonian Astrophysical Observatory.

7. MICROWAVE SPECTROSCOPY OF THE INTERSTELLAR MEDIUM

National Science Foundation (Grant AST73-05042-A03)

Alan H. Barrett, Philip C. Myers

Microwave spectroscopic studies of the interstellar gas have shown that the spectral lines have their origin in regions believed to be intimately associated with star formation. Typical densities are 10^3-10^6 cm^{-3}, kinetic temperatures are in the range 5-100 K, and frequently the molecular clouds contain smaller regions of infrared and/or optical activity which are thought to be embryonic stars. We have studied some of these regions to further our understanding of their physical conditions and gain better insight into the processes involved in the chain of events from formation of a massive cloud to stellar development.

Using the Haystack Observatory, we have observed NH_3, CH_3OH, and H_2O, all of which have transitions in the 22-26 GHz range. We have observed CO and CS at millimeter wavelengths, using the 36-ft NRAO telescope on Kitt Peak, in Arizona. In most cases the angular resolution is ≈1.5 arc minutes. We have also observed the H, OH, and CH_2O lines, using the 140-ft NRAO telescope in Green Bank, West Virginia.

Briefly, the major results of our observations are as follows:

a. NH_3 Results

The NH_3 molecules form a common constituent of many interstellar clouds and the NH_3 abundant hyperfine structure permits the determination of the optical depth, provided it is neither too small ($\ll 1$) nor too large ($\gg 1$). Instances of the latter have never been found; instances of the former are not unusual. NH_3 also has many lines in a narrow frequency range, which allows us to sample a wide range of excitation conditions. We find the optical depth of NH_3 in Orion and in other dense molecular clouds to be ≈ 1-2. In Orion this has led to the conclusion that the NH_3 is nonuniformly distributed, occurring in "clumps" of the order of 0.04 pc in size. In the Taurus dust cloud, the narrow NH_3 lines permit us to set an upper limit of 30 K on the kinetic temperature. Systematic velocities such as would be due to collapse, for example, are less than 0.2 km/s.

b. CH_3OH Results

We have continued to monitor the time variations in the CH_3OH maser emission from the KL nebula in Orion. These observations are made typically every three months. The J = 6 and J = 7 lines are strongest and have continued to show time variations. Also, we now have evidence that the CH_3OH emission is linearly polarized at a level of $\approx 20\%$. Prior to September, 1976, we had set an upper limit of 5% on the linear polarization. The variation in polarization appears to be correlated with the variation in intensity.

c. Millimeter Wavelength Observations

The millimeter wavelength transitions of CO and CS, and their isotopes, have been observed in small, dense globules. OH, H, and CH_2O have also been observed in many of the same clouds. It is feasible to map emission over the entire globules because their angular size is less than 6 arc minutes. Two particularly interesting objects are B163 and CRL 437. The former appears to give evidence of fragmentation into at least two individual clouds. CRL 437 yields strong CO emission which permits detailed studies of the variation of line shape across the object. These have been interpreted in terms of systematic radial and rotational motions within the cloud.

d. Dark Cloud Observations

The Rho Ophiuchus cloud has been mapped in CO, H, OH, and CH_2O lines. The observations appear to indicate that the cloud is surrounded by an HI envelope and the molecular emission originates in a more dense central region. The cloud seems to be undergoing gravitational collapse. The existence of an HI envelope about clouds is apparently quite common but the HI self-absorption is not easy to detect. Continuum emission from dark clouds is less than 0.2 Jy at 5 GHz and 8 GHz, which sets limits on the number and spectral types in such clouds.