XV. RADIO ASTRONOMY

Academic and Research Staff

Prof. Alan H. Barrett	Prof. David H. Staelin	Dr. Philip W. Rosenkranz
Prof. Bernard F. Burke	Prof. Edward L. Wright	John W. Barrett
Prof. James R. Melcher	Dr. Alan Parrish	John D. Kierstead
Prof. Philip C. Myers		D. Cosmo Papa

Graduate Students

Barry R. Allen	Perry E. Greenfield	David F. McDonough
Richard B. Buxton	Aubrey D. Haschick	Matthew H. Schneps
Alan L. Cassel	Steven T. Kirsch	Michael Shao
Rowley L. Cheng	Jeffrey H. Lang	Diane C. Simmons
Arthur D. Fisher	William H. Ledsham	Daniel D. Stancil
J. Antonio Garcia-Barreto	David A. Levitt	Paul Toldalagi
Thomas S. Giuffrida	Terence H. Marshall	Robert C. Walker

1. LONG-BASELINE ASTROMETRIC INTERFEROMETER

David H. Staelin, Michael Shao

Work began this year on a new astrometric interferometer under NSF sponsorship. This is a continuation of a Sloan Fund-sponsored effort to develop a Michelson stellar optical interferometer that can track fringe positions in two colors so as to remove atmospheric effects and permit stellar separations to be measured with up to 10^{-4} arc-sec accuracy.[1]

The first system has one-inch optics and is designed to demonstrate the basic concept of fringe tracking. It is expected to be completed in the spring of 1978 and then moved to a western observatory site for field operations. If successful, it is hoped that an operational instrument with 4-inch optics might be developed.

References

1. M. Shao and D. H. Staelin, "Long-Baseline Optical Interferometer for Astrometry," J. Opt. Soc. Am. 67, 81-86 (1977).

2. CONTROLLED THIN-FILM ANTENNA

David H. Staelin, James R. Melcher

Analysis of a distributed feedback control system for shaping thin-film reflector antennas began in 1977. The concept being studied involves the use of a scanning electron

beam for depositing charge on a semirigid segmented surface parallel to a thin film or mesh that can serve as the reflecting surface for a very large microwave antenna in space. Electrostatic forces between these two surfaces shape the reflector.

Analysis of a particular 1-km diameter antenna showed that there were ~50 unstable modes in the reflector surface if it were suspended only by its rim. The growth time of these modes is sufficiently long ($\gtrsim 20$ s) that a minicomputer appears to be adequate for computing the commands needed by the electron gun assembly.

A scale model is being assembled in the laboratory to test the distributed feedback concept. An assembly for measuring the secondary emission characteristics of thin films is also being constructed.

3. SCANNING MICROWAVE SPECTROMETER EXPERIMENT

David H. Staelin, Philip W. Rosenkranz

The five-channel scanning microwave spectrometer (SCAMS) yielded 10 months of almost continuous data from the Nimbus-6 satellite, launched in 1975.[1]

Analysis of Typhoon June has shown that passive microwave soundings can yield wind information in two ways: The surface wind was inferred for velocities up to ~75 m s^{-1} from the enhanced surface emissivity due to foam and rough seas, and the winds aloft were deduced from the observed horizontal temperature gradients by means of the thermal wind equation.

Kalman filtering was applied to the problem of temperature profile retrievals. By simultaneously operating on data vectors for adjacent image elements, improvements in accuracy were obtained because of the systematic differences between the radiative transfer functions for different viewing angles and the correlations between adjacent atmospheric cells.

The propagation of electromagnetic waves in inhomogeneous media was analyzed for the case where the inhomogeneities can be characterized by the autocorrelation functions of the index of refraction with respect to depth and also radial separation. This model has been successfully applied to interpretation problems for snow and ice data.[2]

References

1. D. H. Staelin, P. W. Rosenkranz, F. T. Barath, E. J. Johnston, and J. W. Waters, "Microwave Spectroscopic Imagery of the Earth," Science 197, 991-993 (1977).

2. A. D. Fisher, "A Model for Microwave Intensity Propagation in an Inhomogeneous Medium," IEEE Trans. on Antennas and Propagation, Vol. AP-25, No. 6, pp. 876-882, November 1977.

4. OBSERVATIONS OF CLOUDS AND ATMOSPHERIC TEMPERATURE PROFILES BY MEANS OF A 118-GHz SPECTROMETER

David H. Staelin, Philip W. Rosenkranz

The 118-GHz spectral region contains a strong molecular resonance of O_2 which can be used for atmospheric temperature sounding and, by combination with 60-GHz channels, for measurement of heavy clouds. A 7-channel 118-GHz spectrometer was developed for studying this spectral region and flown in the NASA/Ames Convair 990 aircraft in March 1977. Measurements near zenith at altitudes from zero to 35,000 ft generally confirmed the theoretical expressions for O_2 absorption. Recent ground-based measurements of the 118-GHz and 60-GHz spectra of clouds passing overhead are still being analyzed. The ability of 118-GHz spectrometers to sound temperature profiles has been determined theoretically to be slightly superior to 60-GHz soundings over ocean and inferior over land. The ability of combined 60-GHz and 118-GHz spectrometers to sound cloud density profiles has been found to be only moderately better than 60-GHz data alone if linear estimation methods are employed. Tsang et al.[1] analyzed theoretically the microwave emission of clouds.

References

1. L. Tsang, J. A. Kong, E. Njoku, D. H. Staelin, and J. W. Waters, "Theory for Microwave Thermal Emission from a Layer of Cloud or Rain," IEEE Trans. on Antennas and Propagation, Vol. AP-25, No. 5, September 1977, pp. 650-657.

5. TIROS-N SATELLITE MICROWAVE SOUNDER

David H. Staelin, Philip W. Rosenkranz

The Tiros-N Operational Weather Satellite carries a microwave temperature-profile sounder (MSU) which has one window channel near 50 GHz, plus three channels at 52-58 GHz; these respond to the average temperatures of atmospheric layers centered near 3, 8, and 12 km altitudes, respectively. The first two such satellites will be launched in 1978. The performance of these instruments will be limited by precipitation, clouds, surface effects, and the mathematical techniques employed to estimate the atmospheric temperature field. This research program focuses on development of an improved understanding of the limits to performance and the development of high-performance estimation procedures. The problem is nonlinear and involves nonstationary, non-Gaussian statistics.

6. SCANNING MULTICHANNEL MICROWAVE RADIOMETER (SMMR) EXPERIMENT

National Aeronautics and Space Administration (Contract NAS5-22929)

David H. Staelin, Philip W. Rosenkranz

The SMMR instrument is scheduled for launch in 1978 on the Nimbus-G and the Seasat satellites; they will scan the Earth at a constant incidence angle at frequencies of 6.6, 10.7, 18, 21, and 37 GHz using dual linear polarization. These data will yield information about the microwave characteristics of snow, sea ice, foam, precipitation, humidity, sea surface, vegetation, soil moisture, etc., and will permit their various parameters to be mapped and monitored.

The parameter estimation problem involves nonlinear phenomena and non-Gaussian and nonstationary statistics. Kalman filtering and pattern classification techniques are being explored for retrieval of these parameters.

The estimation of snow and ice and ocean parameters also requires improved physical models that permit efficient computation of microwave emission characteristics. Such models are being developed.

7. METEOROLOGICAL REMOTE SENSING NEAR 2-mm WAVELENGTH

National Aeronautics and Space Administration (Contract NAS5-23677)

David H. Staelin, Philip W. Rosenkranz, William H. Ledsham

The remote sensing technology developed in the 10-60 GHz spectral region can be applied in large measure to the 100-200 GHz bands because both contain H_2O and strong O_2 resonances, as well as spectral windows which are nearly transparent. The principal difference is that the 100-200 GHz region is 2-20 times more responsive to clouds and precipitation and that the 183-GHz H_2O resonance is quite opaque below a few kilometers altitude. An important advantage of these short wavelengths is that an antenna of fixed size in synchronous orbit can have spatial resolution several times greater than that obtainable at 10-60 GHz. This feature is important for contemplated future weather satellites in geostationary orbit.

The capabilities of meteorological satellites operating at frequencies near 100, 118, 135, and 183 GHz have been analyzed and compared with systems operating below 60 GHz. In general the 100-200 GHz systems perform comparably with the lower frequency systems in clear air or light clouds, but are more easily degraded by precipitation; their performance over land is also slightly degraded for water vapor or temperature profiles at altitudes below a few kilometers. These results were based upon the use of linear estimation procedures; nonlinear estimation should significantly improve the performance of 100-200 GHz sensors in certain situations.

8. MICROWAVE SPECTROSCOPY OF THE INTERSTELLAR MEDIUM

Alan H. Barrett, Philip C. Myers

During the past year our studies of atomic and molecular interstellar gas clouds have continued, with observations of microwave transitions of HI, CO, CS, NH_3, H_2CO, and CH_3OH toward Bok globules, dark clouds, molecular clouds associated with HII regions, and globular clusters. We have used radio telescopes of the National Radio Astronomy Observatory in Green Bank, West Virginia, and at Kitt Peak, Arizona; and of M. I. T. Haystack Observatory.

A search for maser emission from methanol (CH_3OH) in 132 sources confirmed that Orion is a unique source of methanol line emission at $\lambda \approx 1$ cm. A search for CO emission from globular clusters indicates that if mass lost from cluster stars is still trapped in the clusters, no more than ~ 5 $M_\odot$ is in molecular form at $T \approx 100$ K. A study of the NH_3 inversion lines toward molecular clouds associated with Orion A and other HII regions indicates that the gas is highly clumped on a scale of ~ 0.04 pc. In the Taurus dark cloud, extremely narrow NH_3 linewidths were observed, indicating very cold gas with $T < 28$ K. The molecular cloud CRL 437 has CO line shapes with remarkable symmetry properties, suggesting differential rotation of the cloud. A study of the ρ Ophiuchi dark cloud in several molecular lines shows scale lengths which vary from .1 pc to 6 pc. and linewidths increasing with scale length from ~ 1 to ~ 3 km s^{-1}. This effect suggests contracting radial motion. Observation of HI toward dark clouds with an interferometer with resolutions $\sim 3'$ and $\sim 6'$ indicates very strong absorption at molecular line velocities, suggesting very high H densities.

9. VERY LONG BASELINE INTERFEROMETER APERTURE SYNTHESIS OF MASERS

Robert C. Walker, Bernard F. Burke

a. VLBI Aperture Synthesis of Masers

Very Long Baseline Interferometer (VLBI) observations were made in an effort to study the structure of H_2O masers in greater detail than has been possible in the past. A system of programs for aperture synthesis mapping of spectral line VLBI data was developed and applied to data from a five-station experiment. Synthesis maps were produced of the H_2O emission in W51, CRL 2591, and ON2. The emission in many velocity

channels in these sources is spatially complex, demonstrating the value of the synthesis technique over the fringe-rate method of mapping used in most experiments. Fringe-rate maps were made of W3(C)H_2O and W3(OH) which could not be synthesized due to extreme complexity in the sources and instrumental difficulties. In a separate experiment, a new map of the emission from W49N, including much of the high-velocity emission, was made using data from two stations. Intercontinental baselines were used in a third experiment to study the dependence of the apparent size of a maser spot on frequency across single, isolated lines. A dependence, in the sense that the source appears larger in the wings of the line, was found for an extraordinarily powerful line in W49N.

The observations reveal several significant scale sizes in H_2O sources. The apparent size of individual maser spots is on the order of a few times 10^{13} cm. The dependence of source size on frequency supports the "hot spot" idea that the apparent size of maser spots can be much smaller than their real size. The separation of maser spots, which is deduced from the synthesis maps, can be taken as an indication of the actual size of masers: approximately 5×10^{14} cm. Results from the synthesis experiment and the W49N map show that tight clusters of emission lines exist with scale sizes on the order of 4×10^{15} cm. W49N contains several of these tight clusters. The high-velocity emission in W49N was found to be associated with the tight clusters of low-velocity emission. The scale size of the high-velocity emission about a given cluster is on the order of 10^{16} cm. The total extent of many sources is 10^{17} cm or more.

The observations have been discussed in terms of a model for the early evolution massive stars. The important feature of the model is a dust shell and associated region of shocked gas which forms about the star as it begins nuclear burning. The shell is driven away from the star by radiation pressure, and eventually fragments. The H_2O masers occur in the region of shocked gas outside the shell. High-velocity features and extended regions of emission are manifestations of the fragmentation of the shell. The stage of evolution of the dust shell may be determined from the appearance of VLBI maps.

This material, in a thesis, entitled "Observations of the Detailed Structure of Interstellar H_2O Masers," was submitted by R. C. Walker to the Department of Physics on August 12, 1977, in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

10. MASER TIME VARIATIONS

Aubrey D. Haschick, Thomas S. Giuffrida, Bernard F. Burke

The W3(OH)H_2O maser exhibited a well-defined variation in the intensity of one component during May-June 1977. The line rose to maximum intensity over a one-week period, and declined during the following four weeks. A model for the variation has

been constructed that fits the observations accurately. The calculation assumes that the maser is saturated, the pumping mechanism is collisional, the initial source of energy occurs as a pulse localized in space and time, and that the energy is quickly thermalized. A possible geometrical model can be constructed, involving the release of energy through a brief break in the dust cocoon of a young star, which provides sufficient energy for such an event. The model suggests that there is a lack of infrared radiation from the W3(OH) maser because the phenomena are being observed at such an early stage that the infrared radiation has not yet diffused out.

11. FRINGE-RATE MAPPING OF W3(OH)

Thomas S. Giuffrida, Aubrey D. Haschick, Bernard F. Burke

One of the principal methods of reducing spectral line Very Long Baseline Interferometer (VLBI) data is the fringe-rate map. In the current implementation, this method assumes only one source per spectral channel. This assumption is clearly incorrect for many H_2O maser sources, including W3(OH). A series of programs were written avoiding this assumption to reduce VLBI data taken on W3(OH) over one year's time. The data included three experiments run during the rapid turn-on of one feature during May 1977, referred to in Section XV-10.

The resulting maps show that spot positions are repeated surprisingly during the year. Even though some spots disappear and others emerge, most remain. Those that do remain gain complexity in velocity space, something not accounted for in maser models. The maps have been discussed and the possible pump sources enumerated in a thesis, "Interferometric Observations of Astronomical Sources Emitting 1.35 cm Radiation," by T. S. Giuffrida, submitted to the Department of Physics on December 20, 1977, in partial fulfillment of the requirements for the degree of Doctor of Philosophy. The rapid turn-on implies a pump communication speed of .05 times the speed of light. This is difficult to comprehend, except in the hot-dust cold-gas pump model.

12. STUDIES OF H I ABSORPTION IN GALAXIES

Aubrey D. Haschick, Willem A. Baan, Bernard F. Burke

Neutral hydrogen absorption-line studies of external galaxies have continued, using the 300-ft transit telescope of the NRAO.

Neutral hydrogen absorption at 21-cm wavelengths has been detected in the radio

galaxy 1506+34. The absorption feature has a halfwidth of 110 km s^{-1} and midpoint radial velocity $(c\Delta\lambda/\lambda_o)$ of 13,500 km s^{-1} which is coincident with the optical emission line velocity of the galaxy of 13,550 km s^{-1}. The high optical depth of the absorbing H I cloud of $\tau = 0.4$ implies a neutral hydrogen column density of $N_H = 8.5 \times 10^{19}$ T_s H I atoms cm^{-2}. The absorption feature in 1506+34 is comparable both in optical depth and width to features found in the spiral galaxies NGC 253, M82, and NGC 4945.

The 300-ft transit telescope of the NRAO was used for the successful detection of neutral hydrogen absorption at 21-centimeter wavelength arising from within the radio galaxy 3C178. The radial velocity of the most prominent absorption feature of 2460 km s^{-1} lies close to the median velocity of the neutral hydrogen emission profile. An estimate of the optical depth τ of 0.06 for this feature leads to a column density for the absorbing material of 3.6×10^{18} T_s cm^{-2}. Three weak features appear at −34, +12, and +40 km s^{-1} with respect to the central feature. The effect of the continuum radio source on the spin temperature is important, and it appears to be very difficult to locate the absorbing gas close to the nucleus. The low velocity is hard to explain dynamically, and it is possible that the main absorption arises in the galactic halo of 3C178.