

# 13. Radio Astronomy

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## 13.1 Microwave Spectroscopy of the Interstellar Medium

*National Science Foundation (Grant AST79-25075)*

*Alan H. Barrett, Philip C. Myers*

In 1981 the following main objectives were pursued:

1. A search for maser emission from water vapor in the  $\nu_2$  vibrational state, the  $4_{2,3} \rightarrow 3_{3,0}$  transition at 12,008.80 MHz. Sixteen sources of  $H_2O$ , OH, and/or SiO maser emission were searched without detecting any emission in the vibrational state.

2. We have undertaken a detailed study of the Sgr A molecular cloud located about 10 arc minutes from the galactic center. It is generally believed that the Sgr A and B clouds are in close proximity to the galactic center but the evidence for this rests mostly on the radial velocities of the clouds and the small angular separation between the clouds and the Sgr A West continuum source. The Sgr A cloud has been mapped in several lines of  $NH_3$ ,  $HNCO$ ,  $^{13}CO$ , and  $C^{18}O$  at Haystack and Kitt Peak and  $NH_3$  condensations have been detected at the VLA. The  $u$ ,  $b$  maps and  $u$ ,  $v$  maps of the cloud in various molecular lines are surprisingly similar, even in CO, suggesting that the CO data are not contaminated by gas lying between us and the galactic center. The results fit reasonably well with a single temperature and density for the bulk of the cloud, excluding small-scale condensations.

3. In order to identify dense cores in interstellar dark clouds, a survey for the emission of the  $(J,k) = (1,1)$  rotation-inversion line of  $NH_3$  and the  $J = 9 \rightarrow 8$  rotational line of  $HC_5N$  has been

undertaken. The positions were chosen by visually picking the most opaque positions from the red Palomar Sky Survey photographs, primarily in dark clouds known or thought to be less than 500 pc from Earth. This survey has identified 39 dense cores with strong  $\text{NH}_3$  emission. The positions of the dense cores in the Taurus region have been found to correlate with positions of young (emission-line) stars. Stability calculations for these dense cores involving the line widths, densities, and temperatures indicate they are in near critical equilibrium or in early collapse suggesting the probability they are the next generation of low-mass stars.

## 13.2 Research Objectives

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*Bernard F. Burke*

The research program in radio astronomy is primarily centered on the use of interferometric techniques, including hard-wired arrays and Very-Long-Baseline Interferometry (VLBI), to study phenomena on the galactic and extragalactic scale. The principal activities are as follows:

1. Interstellar masers are being studied, using VLBI, to determine their structural, polarization, and time-variation properties.
2. The VLBI technique is being pressed to lower frequencies (300 MHz, 600 MHz, and 1400 MHz) to study the characteristics of quasars and galactic nuclei.
3. The double quasar 0957 + 561, the first observational example of the gravitational lens phenomenon, has been intensively studied, and a definitive lens model produced. We are now following its time variations, which may provide an entirely new class of cosmological information. Both VLA (Very Large Antenna of the NRAO) and VLBI observations will be employed.
4. A computing system for reducing VLA snapshot data has been developed. The basic instrument is our NOVA 800 computer, with added disc and core memory. We can now produce a 256 x 256 VLA map in about 5 minutes of computing time, a cleaning routine has just been completed.
5. Our survey of radio sources under way at the NRAO, using the 300-ft transit telescope at 5 GHz, has been broadened to include a general survey of the entire strip  $-3^\circ$  +  $120^\circ$ , comprising 2 steradians of sky. The survey was completed in late 1981. The 5 GHz Arecibo source survey is in press, and will appear in The Astrophysical Journal Supplements.
6. A new project has been started to look for spatial fluctuations in brightness of the cosmic microwave background. A multichannel receiver is being built, for use with the 140-ft NRAO telescope, to improve statistics and to give better discrimination against spurious effects such as atmospheric fluctuations.

### 13.3 Long-Baseline Astrometric Interferometer

*National Science Foundation (Grant AST79-19553)*

*U.S. Navy - Office of Naval Research (Contract N00014-80-C-0348)*

*National Aeronautics and Space Administration (Grant NAG2-50)*

*MIT Sloan Fund for Basic Research*

*Michael Shao, David H. Staelin, Peter M. Garnavich*

Precise astrometric measurements of the absolute and relative positions of stars to  $10^{-2}$  -  $10^{-4}$  arc sec accuracy will permit improved knowledge of the distances and velocities of stars, the size of the universe, the relativistic deflection of starlight, and the existence and nature of planets circling nearby stars. The last objective is most important because the solar system still is the only planetary system known with certainty to exist. Future versions of the present interferometer are expected to achieve  $10^{-4}$  arc sec relative position accuracy over  $1-2^\circ$  stellar separation, which is adequate to detect a Jupiter near a one-solar-mass star at a distance of several parsecs, with a signal-to-noise ratio of  $\sim 10$ .

During 1981 the Mark-II version of the interferometer was designed, built, and installed at Mount Wilson observatory in California.<sup>1</sup> It occupies an optical table 5 x 12 feet and consists of two two-color interferometers that simultaneously observe two stars separated less than  $\sim 1.8^\circ$ . Only the first interferometer now operates; the second will be completed in 1982. The two interferometers share the same two 10-inch siderostat mirrors, which are  $\sim 3$  m apart. Each interferometer has a  $\sim 2$ -inch aperture and monitors the positions of the red fringe and the blue fringe every  $\sim 4-10$  msec, thus permitting the state of the atmosphere to be estimated and compensated for density fluctuations over time intervals sufficiently short that the atmosphere can be considered "frozen." Unfortunately the local water vapor density has a different dispersion relation and can fluctuate independently of the temperature, and to that extent can confuse the estimates of integrated atmospheric density.

One of the initial purposes of the Mark-II experiment will be to provide estimates of the separate contributions of table motion, water vapor fluctuations, and electronic noise to the observed stellar position errors. A goal of  $10^{-3}$  arc sec rms errors (self-consistency) between adjacent stars is being sought. Stars of  $\sim 5-6$  mag can be observed. Experiments to demonstrate wide angle ( $\gtrsim 10^\circ$ ) and absolute astrometry are also being planned for the Mark-II instrument.

Some effort was devoted during the year to the design and analysis of a 15-m interferometer for space employing main mirrors of  $\sim 50-100$  cm diameter; it should be capable of monitoring  $\gtrsim 19$  mag stars with a precision of  $\gtrsim 10^{-6}$  arc sec, which is nearly sufficient to detect terrestrial planets about nearby stars

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## 13.4 Controlled Thin-Film Antenna

*Joint Services Electronics Program (Contract DAAG80-C-0104)*

*Lockheed Aircraft Corporation (Contract LS90B4860F)*

*Jeffrey H. Lang, Timothy L. Johnson, David H. Staelin, Shih-Ming Shih, Yeung Yam*

The use of electrostatic charges for rapidly manipulating a thin elastic membrane is being studied as a method for precisely controlling the shape of reflector antennas of ~10-300-meter diameter in space; beamwidths of ~1-10 arc sec are sought.<sup>1,2,3</sup>

This year a 5-ft diameter rubber-membrane mirror was constructed with 7 control elements; initial operation and extension to ~60 elements is expected in 1982. Theoretical studies showed that ~100 control elements might suffice to achieve beamwidths of ~1-3 arc sec. More extensive studies have also shown that spillover from unmonitored modes into the monitored and controlled modes can be reduced by proper system design, and that spillover can in fact be used to increase the system stability. This useful result is applicable to other control problems as well.

### References

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2. J.H. Lang and D.H. Staelin, "The Computer-Controlled Stabilization of a Noisy Two-dimensional Hyperbolic System," IEEE Trans. on Automatic Control, 27, October, 1982, in press.
3. J.H. Lang, "Experiments on the Electrostatic control of a Flexible Membrane and their Relation to Membrane-antenna Figure Control," Proc. of the AIAA Guidance and Control Conf. 187-191, Albuquerque, N.M., August 19-21, 1981.

## 13.5 Improved Microwave Retrieval Techniques

*National Aeronautics and Space Administration (Grant NAG5-10)*

*Philip W. Rosenkranz, David H. Staelin, Michael J. Komichak, S. Krishna Nathan*

This program is directed toward development of improved techniques for retrievals of atmospheric temperature, wind, and humidity fields from passive microwave spectral images of the earth, as observed from satellites. Four efforts were undertaken in 1981; these were 1) development of a robust scheme for retrievals of water vapor profiles from 183-GHz spectral data, 2) evaluation of lapse rate as

a possibly superior retrieval variable because of its potentially non-gaussian probability distribution, 3) transfer of almost all computations to a new, much less expensive computer, and 4) initiation of an effort to perform three-dimensional linear statistical retrievals of atmospheric temperature fields using passive microwave spectral maps observed from satellites.

The 183-GHz water vapor retrievals employ an opaque part of the spectrum, and thus the retrievals can be singular if the temperature profile is non-monotonic. The procedure that was developed combines the two statistically-retrieved temperature profiles obtained from each of the opaque 60-GHz oxygen band and the opaque 183-GHz water vapor band; the resulting nonlinear estimate of the water vapor profile is then statistically combined with a profile estimated using only linear statistical procedures. The results are superior to either technique alone and prior techniques.

Statistical studies of atmospheric lapse rates for NMC global analysis fields revealed that the hemispheric probability distributions did not depart sufficiently from gaussians to permit useful improvement in retrieval accuracy by utilizing these departures.

During the year the software for this and other research programs was transferred to a Nova-4s computer with a 12-Mbyte disk, fast floating-point multiply and divide hardware, 96K-word memory (16-bit words), a 9-track tape device, two time-sharing consoles, and one printer. This change has significantly reduced the marginal cost of computation for all of these research programs.

A three-dimensional retrieval scheme, using multiple two-dimensional Fourier transforms of the data field, is being adapted to the retrieval of temperature fields from remote sensing data. These three-dimensional techniques are statistically optimum in a rather general sense, and should help remedy one of the principal deficiencies of present aggregates of one-dimensional retrievals, i.e. the tendency to underestimate the amplitudes of troughs or ridges. The general method is that described by Rosenkranz.<sup>1,2</sup>

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## 13.6 Communications Satellites

*David H. Staelin, Ali D.S. Ali*

A previous study of architectural options for future large broadband switched satellite communications networks<sup>1</sup> was extended to include a more realistic model for costs per terrestrial

circuit mile; this new model includes strong economies of scale. A second new model was developed for the case of FDMA architectures; this was based on work by Omiya.<sup>2</sup> During 1982 these models will be explored under INTELSAT sponsorship to improve understanding of minimum-cost configurations for large integrated satellite and terrestrial communications networks appropriate for the period 1990-2000. Optimum architectures are being determined as a function of the system traffic capacity (typically 0.5-30 Gbps), the total area of coverage (typically  $1-64 \times 10^6 \text{ km}^2$ ), and other variables.

#### References

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2. Y. Omiya, "Analysis of Large FDMA Satellite Systems for Telephone Services," S.M. Thesis, Dept. of Aeronautics and Astronautics, Mass. Inst. of Tech., 166 pp, 1980.

## 13.7 Video-Bandwidth Compression Techniques

*David H. Staelin, Ali D.S. Ali, B. Ghosh, J.M. Sulecki*

Work began this year on design of a video input-output port for the Nova-4 computer. It should be capable of displaying 8-bit monochrome video images at 60 frames per sec for up to  $128 \times 240$  pixels; the frame-store system can be refreshed at  $\sim 10$  frames per sec for images of  $128^2$  pixels, or more rapidly for smaller images. The recording rates are comparable. A 4-bit option permits up to  $256 \times 240$  pixels per frame, and data transfers at twice the normal rate.

This facility will permit various methods for coding video images to be simulated and evaluated. The class of images of initial interest are head- and-shoulders images or other scenes appropriate for video-phone applications.

## 13.8 Scanning Multichannel Microwave Radiometer (SMMR)

*National Aeronautics and Space Administration (Contract NAS5-22929)*

*Philip W. Rosenkranz, David H. Staelin*

On October 24, 1978 the Nimbus-7 Satellite was launched into polar orbit carrying the Scanning Multichannel Microwave Radiometer (SMMR) and other instruments. SMMR separately measures vertically and horizontally polarized terrestrial thermal radiation at wavelengths of 0.81, 1.4, 1.7, 2.8, and 4.6 cm. The microwave beams intersect the terrestrial surface with a zenith angle of  $50.2^\circ$  and view approximately circular spots on the ground ranging in diameter from  $\sim 30$  km at 0.81-cm wavelength to  $\sim 150$  km at 4.6-cm wavelength; the mechanically-scanned antennas map all 10 channels completely over a 780-km wide swath beneath the spacecraft.

This experiment, which has been operating continually since launch, is unique in the number of microwave frequencies and polarizations with which it observes the terrestrial surface. The initial purpose of this research effort is to develop parameter retrieval methods for interpreting this data, and then to use these parameters for various scientific purposes.

A linear three-dimensional retrieval scheme was developed for interpreting this data and has the important advantage of optimality, in a limited sense, even though different frequencies have antenna beamwidths that are significantly different. This method of retrieval and the results for a typhoon have been presented by Rosenkranz.<sup>1,2</sup>

### References

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## 13.9 Tiros-N Satellite Microwave Sounder

*U.S. Department of Commerce, National Oceanic and Atmospheric Administration (Grant 04-8-M01-1)*

*Philip W. Rosenkranz, David H. Staelin, R.H. Lamb, J-S Jin*

The National Oceanic and Atmospheric Administration (NOAA) routinely reduces data from one or two operational polar orbiting weather satellites; these now carry infrared spectrometers and a four-channel passive microwave spectrometer (MSU) for the purpose of mapping the three-dimensional temperature field of the atmosphere at six- or twelve-hour intervals. The purpose of this research program is continued improvement in the utilization of the passive microwave data produced by these NOAA satellites.

During 1981 the detectability of precipitation using MSU data was studied. It was found that heavy precipitation over land or sea could be detected, but that high snow-covered mountains and lakes could sometimes exhibit the same radiometric signature. The geographic stability of these false responses provides an easy method for ignoring them.

The remainder of the major computer programs used in this project have been converted to the Nova-4 computer, which was expanded to two time-sharing consoles and 96K-words of memory during the year. MSU data from the periods February 25-26, 1979; July 1-7, 1979; October 10-19, 1979; and February 9-13, 1981 are being merged with National Meteorological Center (NMC) temperature analysis fields to provide a statistical data base that can support development and evaluation of new retrieval techniques for meteorological parameters.

Work began on development of a model for the growth of errors in the Australian Region Primitive

Equations (ARPE) model for numerical weather prediction. The ARPE model is operating on the Cray computer at the National Center for Atmospheric Research (NCAR), in Boulder, Colorado. This model for error growth will be used for several purposes, the first being optimization of three-dimensional retrieval techniques by means of a more appropriate error criterion.

We have received approval for use of the Cray computer at NCAR and are preparing to run the ARPE model, first with "exact" initial data fields, and then with fields having carefully chosen error fields superimposed. Analysis of these evolving error fields will permit definition of the desired error-growth model. This model would relate errors in numerical weather predictions to the errors in the initial atmospheric state and to their horizontal and vertical correlations; these initial errors arise from the remote sensing systems being studied.

### 13.10 Advanced Microwave Sounding Unit

*California Institute of Technology Jet Propulsion Laboratory (Contract LZ-72789I),  
Subcontract 956059, Task Order RD-151  
Philip W. Rosenkranz and David H. Staelin*

The Microwave Sounding Unit (MSU) spectrometers now being used on operational polar-orbiting meteorological satellites have four channels, centered at 50.3, 53.75, 54.96, and 57.95 GHz, which lie on the wings of the broad oxygen absorption band centered near 60 GHz. This sounder was originally designed only to support the operational infrared sounders, but has been sufficiently successful that an Advanced Microwave Sounding Unit (AMSU) was designed to be the operational successor to MSU. Its original specifications included 3 channels for surface and, over ocean, atmospheric moisture parameters, plus 12 channels for monitoring atmospheric temperature profiles ~0-45 km; these were to be monitored at 50-km resolution in a wide swath such that all spots over the globe would be monitored at 12-hr intervals by each AMSU in orbit. In addition, a window channel near 90 GHz plus four channels near 183 GHz would monitor ice boundaries and, over land and sea, precipitation, heavy clouds, and humidity profiles ~0-10 km altitude. These high frequency channels would map the same swath as the other channels, but with 15-km resolution.

Analysis of the meteorological objectives and the physics of the problem led to modifications in the system specifications which would improve system performance in most cases, and would permit increased reliability and lower costs. Various system options were evaluated and improvements were made to the system specifications. An AMSU Working Group, with members from various NASA, NOAA, DOD, and other centers, was established with D.H. Staelin as chairman to develop and evaluate these options for AMSU; it met several times and presented its recommendations to NASA and NOAA. It is hoped that AMSU will become operational by the early 1990's, and that an experimental version will be launched in the late 1980's.

## 13.11 Jovian Decametric Radiation

*David H. Staelin and Philip W. Rosenkranz*

In 1977 the Voyager I and 2 spacecraft were launched toward Jupiter, Saturn, and beyond; one of the instruments they carried was the Planetary Radio Astronomy (PRA) Experiment. The PRA receiver included a 195-channel spectrometer that can repetitively sweep from ~1.2 kHz to ~40.5 MHz in 6 seconds, and thus respond to non-thermal radio emission from Jupiter, Saturn, Earth, the Sun, and other bodies.

Analysis of the radio spectra from Jupiter revealed "arcs" in the frequency-time diagram that suggested the strong Jovian decametric radio emission was emitted near the local electron cyclotron frequency with a hollow conical emission pattern, the half-angle of which varied in a systematic way with frequency and Jovian longitude.<sup>1,2</sup> It was discovered that the cone angle is maximum at a frequency that is approximately proportional to the square of the magnetic field strength near the foot of the active flux tube;<sup>3</sup> these flux tubes intersect the Io plasma torus and are presumably energized by the Alfvén waves produced when the Jovian magnetic fields rotate past Io.

Work also began on associating the Jovian S-bursts with cusps in electron density produced by longitudinal velocity modulation of ~5-keV electron beams moving outward from Jupiter along the magnetic field lines.

### References

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