

Section 4 Radio Astronomy

Chapter 1 Radio Astronomy

Chapter 1. Radio Astronomy

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1.1 Extragalactic Radio Source Studies

Sponsor

National Science Foundation
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Project Staff

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There were four principal objectives carried out during 1993. These were: (1) an investigation of possible means of directly detecting exoplanets (planets orbiting other stars); (2) searches for gravitational lenses; (3) a general study of extragalactic radio sources; and (4) an experiment to detect primitive hydrogen concentrations at the epoch before galaxy formation began.

1.1.1 Exoplanets

The investigation of exoplanets is a continuation of work carried out during the previous four years for the Office of Solar System Exploration of the National Aeronautics and Space Administration (NASA). Professor Burke served as chairman of a Science Working Group which studied how NASA could formulate a program to search for and study

the formation and evolution of exoplanets. Professor Burke was the Editor-in-Chief of a report, *Toward Other Planetary Systems*. Since that report was issued by NASA, work has continued on the problem of direct detection of exoplanets. Interferometric methods using aperture-synthesis methods that are commonly used in radio astronomy offer a promising approach to this difficult problem, and preliminary designs for such systems have been studied.

1.1.2 The Search for Gravitational Lenses

The search for gravitational lenses is being carried out by making "snapshot" radio maps with the Very Large Array (VLA) of the National Radio Astronomy Observatory (NRAO). The core source list is the MG (MIT-Greenbank) Survey, and the work is referred to as the MG mapping project. Nearly 10,000 maps of radio sources have been gathered, and approximately 4,000 of these have been reduced by a new procedure that greatly improves the accuracy and signal-to-noise ratios of the final maps. These are then examined to see if morphological structures are evident that are characteristic of gravitational lensing—the distortion of radio signals from distant radio galaxies by foreground galaxies, resulting in the production of multiple images. A new example of the type called an "Einstein Quad" was discovered during the current year and is being readied for publication. Several

¹ Australian National Telescope Facility, Parkes, Australia.

candidates have also been identified as "Einstein Rings," and they are now being scrutinized more closely to verify that they are examples of gravitational lensing. To date, our group has discovered six well-established examples of lensing; this is the largest number found by any group in the world.

1.1.3 The Study of Extragalactic Radio Sources

The collection of radio maps that have been produced are useful for many other purposes. A collection of close double sources, with angular separations of under an arc-second, was studied with the British aperture-synthesis array known as MERLIN. This improves upon the angular resolution of the VLA by a factor of five, and from that work a collection of about 15 "compact steep-spectrum radio galaxies" has been identified. A sample of about 150 close double sources is being observed optically, in collaboration with H. Spinrad of the University of California at Berkeley, to determine the redshifts of the parent object, and about 80 redshifts have been obtained so far. Finally, a collaboration with the Australia Telescope of the Australian CSIRO has resulted in the preparation of the Parkes-MIT-NRAO (PMN) Survey of radio sources at 6 cm wavelength. This survey covers the southern sky, from the equator to the South Celestial Pole, and increases the number of known radio sources in the Southern Celestial Hemisphere by an order of magnitude. Two sections have already been published, the Southern Survey (declinations -36 to -87 degrees) and the Tropical Survey (declinations -9 to -30 degrees).

1.1.4 Detection of Primitive Hydrogen Concentrations

A new observational experiment was started this year, in collaboration with P. Horowitz of Harvard University. The universe is known to us on the largest scale through studies of quasars and galaxies and by the cosmic microwave background (CMB). The CMB is at a redshift of about 1,000 and represents the greatest distance that can be studied by present methods. Galaxies and quasars are more local, having been detected in a limited way out to redshifts of about 4.8. The formation of galaxies and quasars captures most of the primeval hydrogen, which was initially the most common constituent of the universe. It appears that beyond a redshift of about 5, the galaxies were still being formed, and there should be large concentrations of neutral hydrogen still in the process of contracting

to form galaxies. An experiment has been mounted to look for these primeval concentrations, using the Arecibo Observatory in Puerto Rico, where the 1,000-foot radio telescope is ideally suited to this search. A radio spectrometer is now under construction, and a prototype section of the spectrometer has been built and is currently undergoing tests at the Arecibo Observatory.

1.1.5 Publications

Burke, B.F., A. Alberdi, T.P. Krichbaum, J.M. Marcaide, A. Witsel, D.A. Graham, M. Inoue, M. Morimoto, R.S. Booth, B.O. Ronnang, F. Colomer, A.E.E. Rogers, J.A. Zensus, A.C.S. Readhead, C.R. Lawrence, R. Vermeulen, N. Barte, and I.I. Shapiro. "First 7 mm VLBI Observations of the Peculiar Superluminal Radio Source 4C 39.25." *Astron. Astrophys.* 271: 93-100 (1993).

Condon, J.J., M.R. Griffith, and A.E. Wright. "The Parkes-MIT-NRAO (PMN) Surveys: IV. Maps for the Southern Survey (covering -88 degrees<S<-37 degrees)." *Astron. J.* 106: 1095-1100 (1993).

Lehar, J., G.I. Langston, S. Silber, C.R. Lawrence, and B.F. Burke. "A Gravitationally-Lensed Ring in MG 1549+3047." *Astron. J.* 105: 847 (1993).

Wright, A.E., and M.R. Griffith. "The Parkes-MIT-NRAO (PMN) Surveys: I. The 4850 MHz Surveys and Data Reduction." *Astron. J.* 105: 1666-1679 (1993).

Wright, A.E., M.R. Griffith, B.F. Burke, and R.D. Ekers. "The Parkes-MIT-NRAO (PMN) Surveys: II. Source Catalogue for the Southern Survey (-87.5 degrees<S<-37 degrees)." *Astroph. J. Supp.* 90: 179-295 (1994).

Wright, A.E., M.R. Griffith, B.F. Burke, and R.D. Ekers. "The Parkes-MIT-NRAO (PMN) Surveys: III. Source Catalogue for the Tropical Survey (-29 degrees<S<-9.5 degrees)." *Astroph. J. Supp.* 91: 111-308 (1994).

Invited Talks

Burke, B.F. "Searching for Planets of Other Stars." Oort Lecture, Leiden University, May 1993.

Burke, B.F. "The Search For Exoplanets." Pecek Lecture, International Union for Aeronautics and Astronautics, Graz, Austria, October 1993.

1.2 Studies of Gravitational Lenses

Sponsors

Alfred P. Sloan Fellowship
 David and Lucile Packard Fellowship
 Award for Science and Engineering
 National Aeronautics and Space Administration
 National Science Foundation
 Presidential Young Investigator Award

Project Staff

Professor Jacqueline N. Hewitt, Grace H. Chen,
 John D. Ellithorpe, Charles A. Katz, Mark D.
 Messier, Christopher B. Moore

Gravitational lenses provide radio astronomers with the opportunity to re-examine many long-standing problems in astrophysics. Two of these problems, addressed by the work described here, are (1) the nature and distribution of luminous and dark matter in galaxies and (2) the calibration of the age and scale of the universe (i.e., the determination of the cosmological Hubble parameter).

These applications require that the distribution of gravitating matter be inferred from observed imaging properties of the lens. This, in turn, requires that we make detailed measurements of the brightness distribution of the image. Detailed radio maps of two gravitationally lensed extragalactic sources, MG1131+0456 and MG0414+0534, are being compiled from data taken with the National Radio Astronomy Observatory (NRAO) Very Large Array (VLA) radio telescope and the recently completed telescopes of the NRAO Very Long Baseline Array (VLBA). Figure 1 presents a VLA image of MG1131 that shows the polarization properties of the object. The unusual morphology is due to the gravitational lens that distorts the background radio source into a system of arcs that form a ring.

Figure 2 shows MG0414; the four components are believed to be images of the same background quasar. The polarization information of figure 1 and the high-resolution imaging of figure 2 are being exploited to model the mass distribution of the lens. This project is being carried out in collaboration with Professor Christopher Kochanek of Harvard University.

In a gravitational lens system, there are differences in the propagation time in the order of days to months for the different ray paths associated with the images of the background source. Monitoring programs aimed at measuring these time delays are being carried out with the VLA. Analysis of these light curves has shown that their variations

are correlated, providing further evidence that the MG0414 system is gravitationally lensed and indicating that, with increased signal-to-noise, time delays will be measurable. Measurements of the time delays would provide a gauge of the distances involved in the geometry of the gravitational lens system. Such an independent measure of distance would provide a calibration of the cosmological Hubble parameter. The monitoring is continuing.

1.2.1 Publications

Chen, G.H., and J.N. Hewitt. "Multifrequency Radio Images of the Einstein Ring Gravitational Lens MG1131+0456." *Astron. J.* 106: 1719 (1993).

Chen, G.H., and J.N. Hewitt. "Characteristics of the Background Source in MG1131+0456, an Einstein Ring Gravitational Lens System." *Bull. Am. Astron. Soc.* 25: 919 (1993).

Ellithorpe, J.D., and J.N. Hewitt. "VLBI Observations of the Gravitational Lens MG0414+0534." *Bull. Am. Astron. Soc.* 25: 1409 (1994).

Hewitt, J.N. "Gravitational Lenses." Paper presented at the *Proceedings of the 16th Texas Symposium on Relativistic Astrophysics and Third Particle Symposium on Particles, Strings, and Cosmology*. New York: New York Academy of Sciences, 1993.

Katz, C.A., and J.N. Hewitt. "Further Radio Investigations of Gravitational Lensing in MG0414+0534." *Astrophys. J. Lett.* 409: L9 (1993).

Moore, C.B., and J.N. Hewitt. "Time Delay Measurements in Gravitational Lens MG0414+0534." *Bull. Am. Astron. Soc.* 25: 929 (1993).

Invited Talks

Hewitt, J.N. "Gravitational Lenses, Time Delays, and Hubble's Constant." U.S. Naval Research Laboratory; Colloquium, April 22, 1993.

Hewitt, J.N. "Gravitational Lenses, Time Delays, and Hubble's Constant." University of Maryland, Department of Astronomy Colloquium, April 21, 1993.

Hewitt, J.N. "Gravitational Lenses, Time Delays, and Hubble's Constant." Princeton University Department of Physics Colloquium, March 11, 1993.

Hewitt, J.N. "Time Delays in Gravitational Lenses." MIT Haystack Observatory Seminar, March 5, 1993.

Hewitt, J.N. "Gravitational Lenses, Time Delays, and Hubble's Constant." Harvard University Department of Physics Colloquium, March 1, 1993.

Hewitt, J.N. "Measuring the Size of the Universe with Gravitational Lenses" (Harlow Shapley Lecturer). Saint John Fisher College Department of Physics Colloquium, February 25, 1993.

Hewitt, J.N. "Using Gravity as a Lens: A New Tool for Astronomers" (Harlow Shapley Lecturer). Saint John Fisher College Department of Physics Public Lecture, February 24, 1993.

Hewitt, J.N. "Gravitational Lenses, Time Delays, and Hubble's Constant." Boston University Department of Astronomy Colloquium, February 8, 1993.

1.3 Radio Interferometry of Nearby dMe Stars

Sponsors

David and Lucile Packard Fellowship
Award for Science and Engineering
National Aeronautics and Space Administration
Grant NAGW-2310

Project Staff

Professor Jacqueline N. Hewitt, John D. Ellithorpe, Christopher B. Moore

dMe stars are dwarf M stars that show evidence of unusual surface activity. For some time, these dwarf stars have been known to flare strongly at optical and radio wavelengths. More recently, it has been demonstrated that many dMe stars exhibit low-level quiescent emission that is detectable by Very Long Baseline Interferometry (VLBI). The detection of dMe stars on VLBI baselines makes possible measurement of their position with high precision and shows that astrometric detection of planetary companions may be feasible. The astrometric monitoring program has continued with

the analysis of data at three epochs spanning three years.

1.4 The Detection of Astronomical Radio Transients

Sponsor

David and Lucile Packard Fellowship
Award for Science and Engineering

Project Staff

Professor Jacqueline N. Hewitt, John D. Ellithorpe, Charles A. Katz, Christopher B. Moore

The detection of radio transients of astrophysical origin is of interest for a number of reasons. First, some already well studied sources are known to exhibit radio transients, and further characterizing their nature would increase our understanding of the emission processes involved. Examples include the sun, flare stars, and interacting stellar systems. Second, there have been serendipitous discoveries of radio transients, apparently of astrophysical origin, but with no known counterpart at other wavelengths. Since these may represent a new class of object, we would like to establish whether they are natural phenomena and ascertain their frequency of occurrence. Third, transients at other wavelengths are known to exist. The NASA Compton Gamma Ray Observatory is detecting gamma ray bursts at a rate of approximately one per day. X-ray transients have also been detected; some of these are associated with transient radio sources. In the near future, an all-sky monitor will be launched on the X-ray Transient Explorer. An all-sky radio monitor is needed to detect any radio counterparts to the x-ray and gamma ray transients and to put upper limits on their fluence. Finally, because of the confusion with man-made interference, the investigation of radio phenomena on short-time scales is an area that has not been fully explored. As such, there is potential for the discovery of new phenomena.

To address the scientific questions outlined above, we are proposing construction of a network of geographically separated correlating arrays. The technical feasibility of the project depends critically on the levels of man-made radio interference at the sites being considered. Current efforts are geared toward measuring the interference environment, as well as developing a design for the arrays.

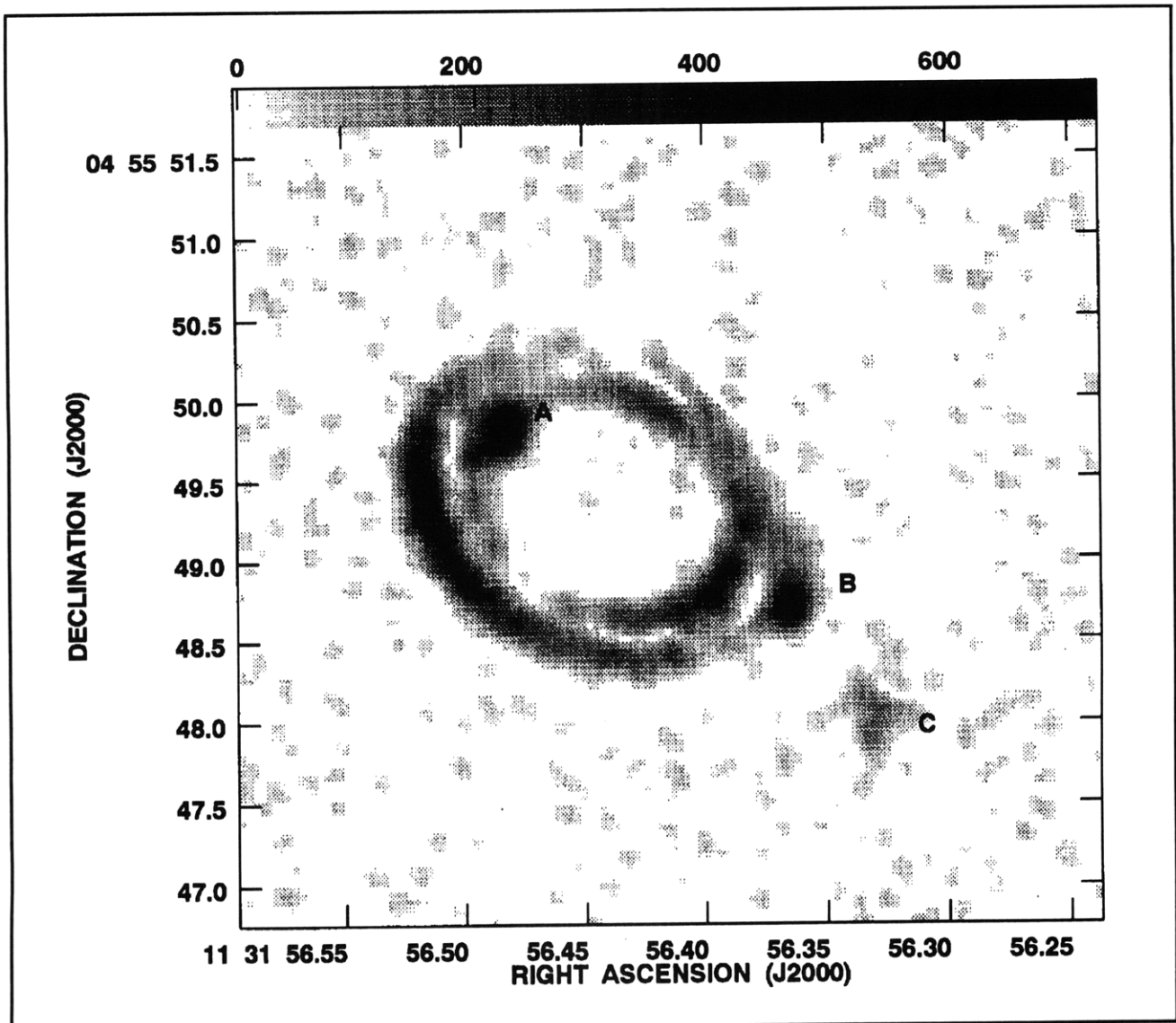


Figure 1. A VLA image of the polarized radio emission in the gravitational lens MG113+0456.

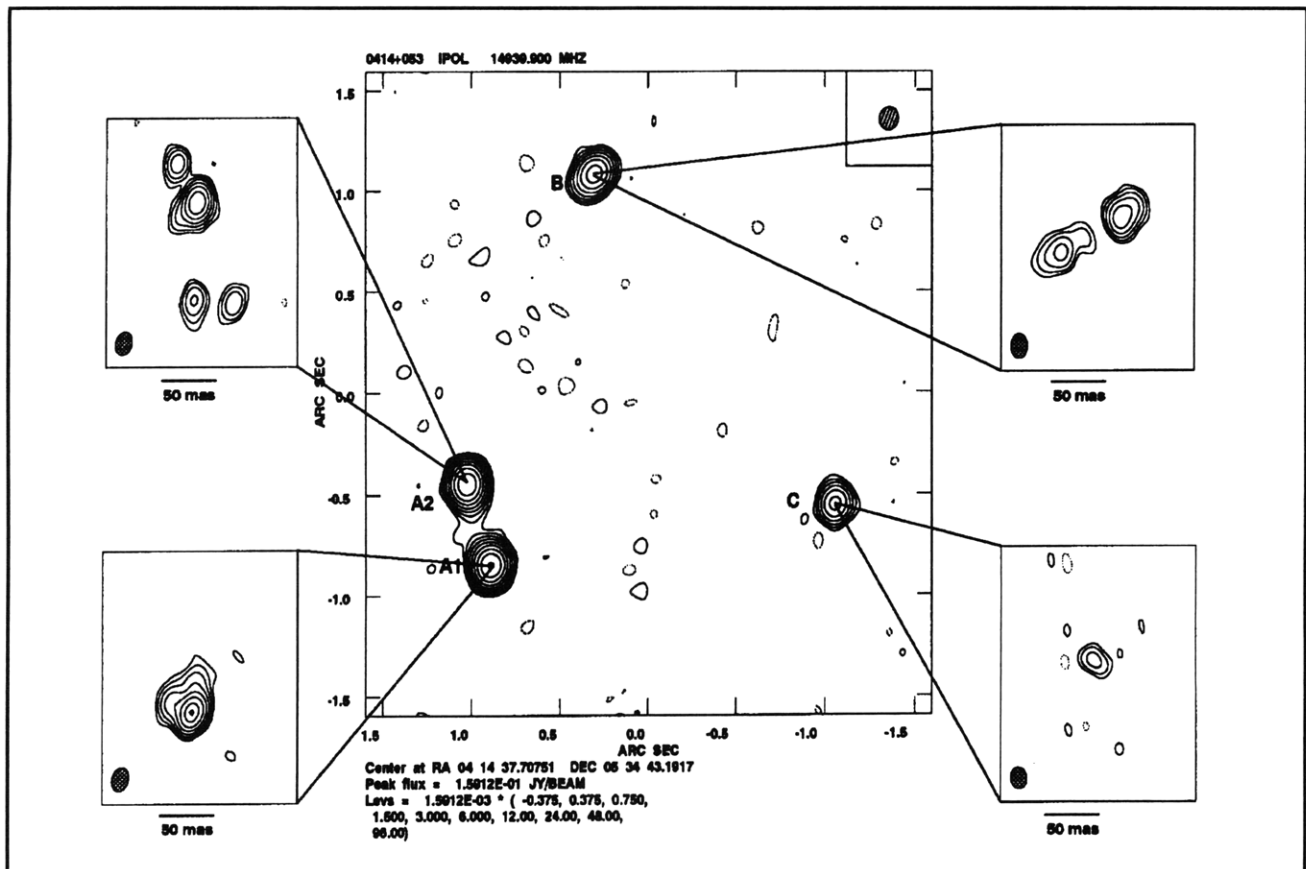


Figure 2. Radio images of the gravitational lens MG0414. The low-resolution image is constructed from data taken with the VLA. The insets show high resolution images constructed from data taken with the newly completed VLBA antennas and correlated at Haystack Observatory.

1.5 Algorithms for Advanced Microwave Sounding Unit Operational Use

Sponsor

MIT Lincoln Laboratory
Agreement BX-4975

Project Staff

Dr. Philip W. Rosenkranz, Michael J. Schwartz

This project provides scientific support to the National Oceanic and Atmospheric Administration (NOAA), for the Advanced Microwave Sounding Unit (AMSU), which is scheduled for launch on NOAA polar-orbiting weather satellites starting in 1995, and also for follow-on instruments. The effort emphasizes development of atmospheric transmittance algorithms, estimation of surface emissivity and precipitation, issues related to instrument design and specification, and general retrieval methods.

Measurements from the MIT aircraft-based Microwave Temperature Sounder and from present satellite radiometers, such as the Microwave Sounding Unit, are used to develop and test prototype algorithms.

A rapid algorithm for computing transmittance in the mesosphere, where the oxygen lines are split by the terrestrial magnetic field, has been developed. This algorithm should prove useful for processing data from future generations of satellite instruments (beyond AMSU).

1.6 Earth Observing System: Advanced Microwave Sounding Unit

Sponsor

National Aeronautics and Space Administration/
Goddard Space Flight Center
Contract NAS 5-31276

Project Staff

Professor David H. Staelin, Dr. Philip W. Rosenkranz, John W. Barrett, Michael J. Schwartz, Michelle S. Spina, Carlos R. Cabrera

The AMSU will provide microwave-band measurements to the Atmospheric Infrared Sounder (AIRS), which will be a facility instrument on NASA's planned Earth Observing System (EOS). This effort is directed toward developing algorithms for the retrieval of temperature and humidity profiles, precipitation, sea ice, land snow cover, and other parameters. The temperature and humidity profiles obtained from AMSU are intended to provide initial conditions for the AIRS infrared cloud-correction and profile retrieval algorithms. Work to date has focused on simulation efforts. A rapid (as distinguished from line-by-line) microwave transmittance algorithm for lower-atmospheric oxygen, water vapor and liquid water was developed.

Artificial neural network techniques have been applied to retrieval of humidity profiles from simulated microwave spectral observations.² At pressures greater than 700 mb over land, an improvement of several percent in relative humidity was obtained in comparison to the statistical iterative technique.³ Preliminary work indicates that neural networks can provide more compact representations of radiometric data than linear methods can.

1.6.1 Publications

Cabrera-Mercader, C.R., and D.H. Staelin. "Passive Microwave Relative Humidity Retrievals using Feedforward Neural Networks." Submitted to *IEEE Trans. Geosci. Remote Sens.*

Thesis

Cabrera-Mercador, C.R. *Neural Network Statistical Retrieval of Atmospheric Water Vapor from Microwave Radiometric Observations*. S.M. thesis, Dept. of Electr. Eng. and Comput. Sci., MIT, 1993.

1.7 High-Resolution Passive Microwave Imaging of Atmospheric Structure

Sponsor

National Aeronautics and Space Administration/
Goddard Space Flight Center
Grant NAG 5-10

Project Staff

Professor David H. Staelin, John W. Barrett, Dr. Philip W. Rosenkranz, Michael J. Schwartz, Paul W. Fieguth

The MIT Microwave Temperature Sounder (MTS) is a dual-band radiometer, incorporating an imaging spectrometer at 118 GHz and a tunable fixed-beam radiometer at 52-54 GHz. This instrument is flown on the NASA ER-2 high-altitude aircraft. In February 1993, we operated the MTS on ER-2 flights based at Townsville, Australia. These flights were an adjunct to the international TOGA-COARE experiment. Two overpasses of tropical cyclone Oliver were made, yielding unique high-resolution images at 118 GHz.

In September and October 1993, we participated in the CAMEX experiment, in which the ER-2 was based at Wallops Island, Virginia. It flew underneath a DMSP satellite and over convective activity near Florida. Besides the MTS, other instruments similar to those that will be on EOS were on board.

On other flights during these two experiments, upward-observing profiles of atmospheric brightness temperature were obtained. These will be used to test atmospheric transmittance algorithms.

1.7.1 Publications

Fieguth, P.W., and D.H. Staelin. "High-Accuracy Profiler that Uses Depth from Focus." Submitted to *Appl. Opt.*

Kuo, C.C., D.H. Staelin, and P.W. Rosenkranz. "Statistical Iterative Scheme for Estimating Atmospheric Relative Humidity Profiles." *IEEE Trans. Geosci. Rem. Sens.* Forthcoming.

² C.R. Cabrera-Mercador, *Neural Network Statistical Retrieval of Atmospheric Water Vapor from Microwave Radiometric Observations*, S.M. thesis, Dept. of Electr. Eng. and Comput. Sci., MIT, 1993; C.R. Cabrera-Mercader and D.H. Staelin, "Passive Microwave Relative Humidity Retrievals using Feedforward Neural Networks," submitted to *IEEE Trans. Geosci. Remote Sens.*

³ C.C. Kuo, D.H. Staelin, and P.W. Rosenkranz, "Statistical Iterative Scheme for Estimating Atmospheric Relative Humidity Profiles," *IEEE Trans. Geosci. Rem. Sens.*, forthcoming.

Rosenkranz, P.W. "Absorption of Microwaves by Atmospheric Gases." Chapter 2 in *Atmospheric Remote Sensing by Microwave Radiometry*. Ed. M.A. Janssen. New York: John Wiley, 1993.

1.8 Rapid Precision Net-Form Manufacturing

Sponsor

MIT Leaders for Manufacturing Program

Project Staff

Professor David H. Staelin, Paul W. Fieguth

An active CCD-based imaging system developed in 1992 was further documented.⁴ It can measure shapes optically within a scannable volume of ~20 cubic inches with rms accuracies of as little as 50 nm for mirror-like surfaces, and ~1-2 micrometers for surfaces like chalk, plastic, and copper.

1.9 Conformal Experiment Design

Sponsor

MIT Leaders for Manufacturing Program

Project Staff

Professor David H. Staelin, Paul W. Fieguth, Rizwan R. Koita, Michelle S. Spina

We continued our work on the development of a user-friendly program to assist engineers with both experiment design and analysis of results. The program accepts a list of control parameters and interactions between them in their *a priori* estimated order of importance so that orthogonal experiment arrays can be designed to minimize confusion when experimental results are interpreted.

This program and its experiment design were applied to the design of automotive fuel pumps to improve their pressure, flow, efficiency, and other characteristics. From eight trial pumps with three control variables, it was found that simple modifications to a minor part could profitably increase the manufacturing yield of certain products.

1.10 Recognition of Natural Nearly Repetitive Signals

Sponsor

MIT Leaders for Manufacturing Program

Project Staff

Professor David H. Staelin, Kevin G. Christian

Dolphins (and some machinery) emit nearly repetitive whistles resembling bird song. A database of 1169 dolphin whistles from 22 animals was compressed by converting them to single frequency-versus-time traces and then to a 16-dimensional coding space where each dimension is a linear or nonlinear operator on the trace. Consideration of the accuracy with which dolphins could repeat their own whistles within this 16-D space suggests their vocabulary could potentially exceed a billion distinguishable whistles. However, when the accuracy with which one dolphin could reproduce the signature whistles of another was considered, the potential shared distinguishable signature-whistle vocabulary of dolphins appeared to be limited to less than a few hundred whistles. This result is based on sufficiently limited copying data that extending these experiments is important if definitive results are to be obtained.

This database of 1169 whistles was also used in whistle-retrieval experiments in which the whistle in the database nearest to a new input whistle was to be retrieved in minimum time. It was found that ~35-53 msec was the average retrieval time for a non-optimized program on a SparcStation 2 when only the six dimensions with the highest signal-to-noise ratios were employed for retrievals. The algorithm employed was slower if other than six dimensions were used for the initial addressing step.⁵

Thesis

Christian, K.G. *Generic Compression and Recall of Signals with Application to Dolphin Whistles*. Ph.D. diss., Dept of Electr. Eng. and Comput. Sci., MIT, 1993.

⁴ P.W. Fieguth and D.H. Staelin, "High-Accuracy Profiler that Uses Depth from Focus," submitted to *Appl. Opt.*

⁵ K.G. Christian, *Generic Compression and Recall of Signals with Application to Dolphin Signals*, Ph.D. diss., Dept. of Electr. Eng. and Comput. Sci., MIT, 1993.