Section 4 Radio Astronomy

Chapter 1. Radio Astronomy

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1.1 Galactic and Extragalatic Research

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1.1.1 Completion of the MG Survey

During the 1980s, the Radio Astronomy group was engaged in a survey of radio sources in the northern sky, using the 300-foot transit radio telescope of the National Radio Astronomy Observatory (NRAO), with its 7-feed, 14-channel radiometer. The first two sections of the MIT Green Bank catalog were published in earlier years; sections III and IV have been published in the current year. The northern sky has now been covered completely between the declinations −0.5 and +39.15, and up to +50.98 declination from right ascensions 15.5−2.5. The survey containing over 10,000 new radio sources, terminated with the collapse of the 300-foot Green Bank telescope in November 1988. Fortunately, a successor survey will start, taking up the slack. This survey, the Parkes-MIT-NRAO (PMN) Survey, uses the Parkes 210-foot telescope in Australia (see section 1.1.5 for details).

1.1.2 The MIT VLA Gravitational Lens Search

The radio astronomy group at MIT has completed a VLA search for gravitational lenses at 6 cm,[2] using as a source list the MGI 5 Ghz radio survey[3] down to 100 mJy. This sample of 4000 sources, extending between 0 and 20 degrees in declination, has produced three established lens systems:

[1] Jet Propulsion Laboratory, California Institute of Technology.

[2] J. Hewitt, Ph.D. diss., MIT, 1986.

[3] Lawrence et al., *Astrophys. J. Suppl.* 61:105 (1986).

2016+112,[4] MG1131+0456,[5] and MG1654+1346.[6] Three more candidates, MG0414+0534, 0023+171, and MG1045+1735 need further work, but are very likely to be gravitationally lensed. There may be more lensed systems in the MGI sample, and about 200 more promising sources are being pursued optically.

We are currently continuing the search using 4000 additional sources drawn from the MGII and MGIII 5 GHz radio surveys,[7] which cover 20 to 40 degrees in declination. The observations are being carried out at 3.6 cm for improved angular resolution and to take advantage of the sensitive X band receivers at the VLA. Kochanek and Lawrence[8] point out that most multiply imaged compact sources have image separations of less than 0.5 arcseconds and suggest that many more gravitational lenses might be discovered with higher resolution searches.

The first part of this survey, which has been completed, consists of a complete sample of about 360 radio sources in a narrow strip ($\alpha = 8^h \rightarrow 18^h, \delta = 28^\circ \rightarrow 32^\circ$), to a limiting flux of 50 mJy. VLA maps were made for each source, followed by Palomar plate identifications, using the Minnesota Automated Plate Scanner, which found counterparts for about half the sources. CCD images have been made for about 40 of the most interesting sources using the 1.3 m McGraw-Hill telescope at Kitt Peak. The most promising candidate for lensing from this first sample is 0956+300, which is discussed below. There also are 18 compact double sources with a separation of less than 1 arcsecond. They have predominantly steep spectra and about half of them have faint optical identifications ($m_R \approx 21$) on the CCD images. Two of them have flat spectra and stand out as promising candidates for multiply imaged quasar cores, although the double structure could not be discerned in the CCD images. These close compact doubles might also be ordinary double lobed radio galaxies, in which case they represent either a very distant sample, or a population of intrinsically small radio galaxies.

The number of available sources will increase as the 3.6 cm VLA survey continues. We have since observed another 1000 sources, which are currently being reduced at MIT, and we expect to obtain another 48 hours of observations this summer during the coming A configuration.

1.1.3 The Close Pair of Quasars 0956+300

One of the most interesting sources to result from the 3.6 cm VLA search for gravitational lenses so far is 0956+300,[9] which consists of a pair of quasars separated by only 8 arcseconds which are at different redshifts. Both have radio emission at 40 mJy and 4 mJy (8.4 GHz) and have 19th magnitude blue optical counterparts. Their spectra were measured using the 200-inch Palomar telescope by Dr. D.P. Schneider (Institute for Advanced Study). Strong emission lines have been found in both cases, though the brighter quasar, A, has a redshift of 2.1, while the fainter, B, has a redshift of 2.8. At 1.4 GHz, both quasars have extended lobes in addition to a compact core, although the southern quasar appears to be one-sided.

Due to the close separation of the two quasars, B is certainly magnified by A. If B has a second lobe, it would probably fall in the region behind A, and there is some likelihood of multiple imaging or the formation of a "ring" or "arc," due to the distortion of the extended lobe. Since the lobes have a steep spectrum, we expect that their structure will be most evident at low frequencies, and there is indeed a peculiar northward extension from the A quasar at 1.4 GHz. If this is a distorted image of a second radio lobe associated with the B quasar, it would be even more evident at lower frequencies. This would be the first case of a quasar as the lensing object as well as the most distant gravitational lens yet observed and would provide a direct constraint on the mass distribution of the A quasar.

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4 Lawrence et al., *Sci.* 223: 46 (1984).

5 Hewitt et al., *Nature* 333: 537 (1988).

6 Langston et al., *Astron. J.* 97: 1283 (1989).

7 Langston et al., *Astrophys. J. Suppl.* 72: 621 (1989); Griffith et al., *Astrophys. J. Suppl.* 74: 129 (1990).

8 *Astron. J.* 99: 1700 (1990).

9 Lehár et al., in preparation.

1.1.4 A New Measurement of the Hubble Constant

The gravitational lens effect manifests itself as a splitting of a quasar image into multiple images. A foreground mass, such as a galaxy or a cluster of galaxies, deflects the radiation from the quasar by the action of its gravitational field. The observed image is displaced from the location of the true image and may appear as several images in various locations around the deflecting mass. We have been studying the lens system 0957+561 intensively for the past ten years, using the VLA at 6-cm wavelength. There are two principal images designated A and B (A being the brightest and the northernmost). Quasars generally fluctuate in intensity, both at optical and radio wavelengths, but the ray paths across the universe have different lengths for these two images. The background quasar is at a redshift of 1.4, and the foreground lens (a composite of a cluster and a massive galaxy) is at a redshift 0.36. Model calculations have shown that a difference of about 1.4 years should be observed in the fluctuations of the two images. The flux curves of the two images constructed from the VLA data are presented in figure 1. The best fit time delay, illustrated by the delayed and superimposed plot in figure 2, is 1.4 $\pm$ 0.1 years (513 $\pm$ 40 days, A leading), and the magnification ratio (B/A) is 0.697 $\pm$ .003.

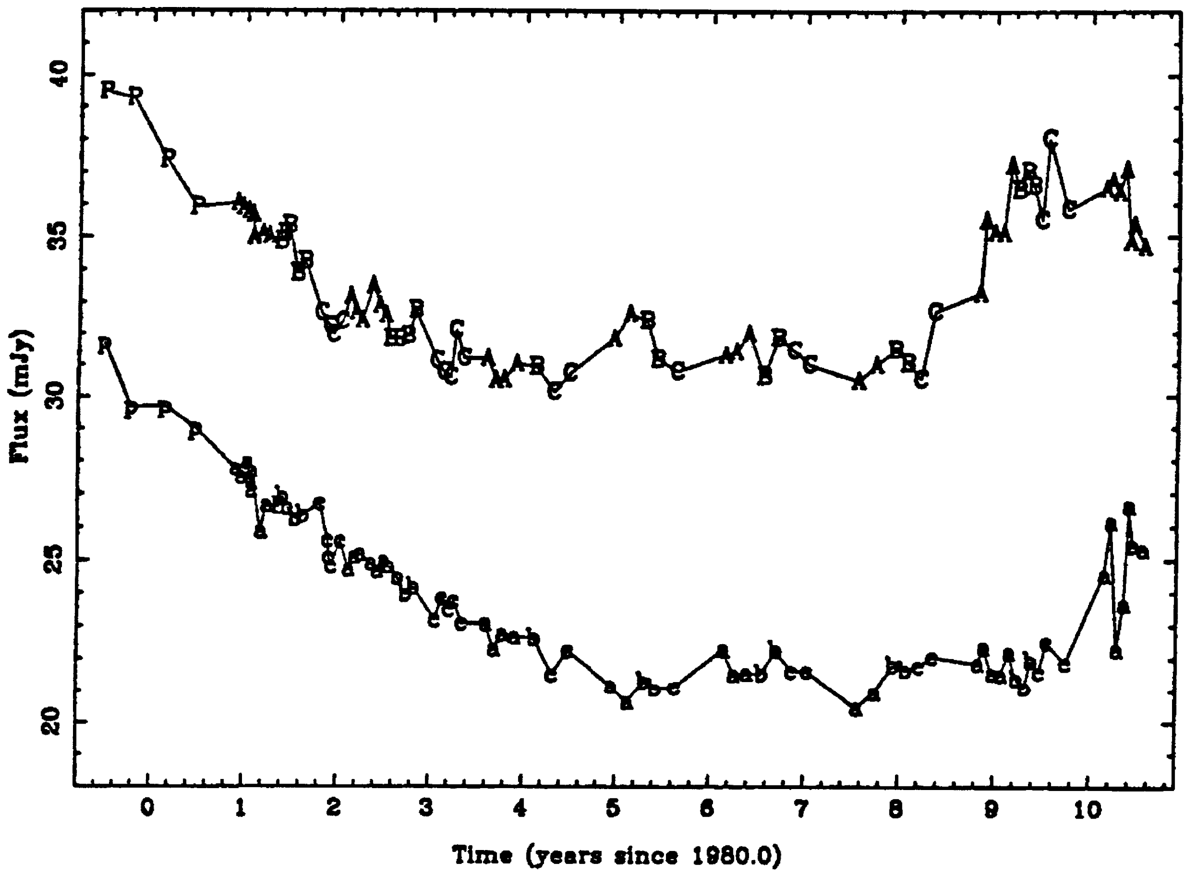

Figure 1. 0957+561 VLA quasar image light curves.

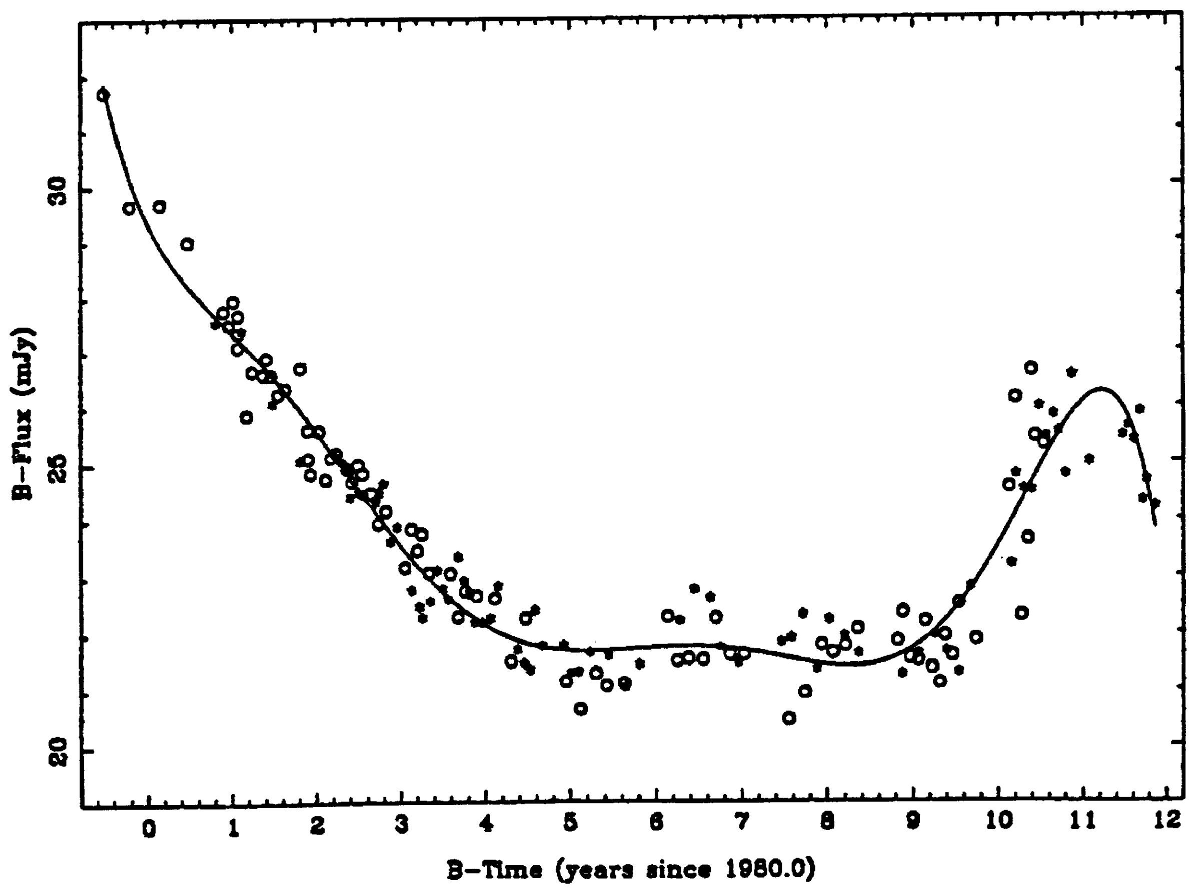

Figure 2. Best fit 7th order polynomial and shifted VLA data.

The time delay can be used to make a model dependent estimate of Hubble's constant. Using the model of Falco, Gorenstein and Shapiro, in combination with recent estimates of the velocity dispersion in the principal lensing galaxy G1, we find that $H_0 = 46 \pm 14$ [42 ± 14] kms^{-1} Mpc^{-1} for $\Omega = 0$ [$\Omega = 1$]. The presence of dark matter in G1 can strongly affect the interpretation of optical velocity dispersions. A reasonable model for a massive dark halo in G1 increases H_0 to 90 [84] kms^{-1} Mpc^{-1}. Since this technique relies on angular size distances, it is free of the uncertainties of traditional methods which use standard candles. This estimate, however, is strongly affected by the mass distributions in the lensing system, which is as yet poorly known. It appears that the information in the radio image has not been fully utilized and efforts are under way to place more stringent conditions on the nature of the lens.

This work is being done in collaboration with Professor Jacqueline N. Hewitt.

1.1.5 The Parkes-MIT-NRAO (PMN) Survey

The Parkes-MIT-NRAO (PMN) Survey was carried out at the Parkes 210-foot telescope in Australia, using the multichannel NRAO 6 cm receiver that had been used for the earlier MG Surveys. The collaborators include Bob Duncan and Ron Ekers (AT/CSIRO), Professor Bernard Burke and Mark R. Griffith (MIT), Ann Burgess (University of Sydney), Phil Randall, Mark Suters, Bill Zealey (University of Wollongong), Graeme White (University of Western Sydney, Neapean), Alan Vaughan (Maquarie University), Ann Savage (Anglo-Australian Observatory), and Dave Jauncey (Australian National University).

Observations were taken during the month of June 1990 and for three weeks in October 1990. The entire southern sky from the south celestial pole to +9 degrees declination was surveyed. An indication of the increase in knowledge is illustrated in figure 3. On the left are plotted the radio sources known to exist in the southern sky from −36 degrees to the south celestial pole. A preliminary map of the new sources discovered in the same region is shown on the right side. The survey has increased by nearly a factor of ten the known number of radio sources in the Southern Hemisphere.

Detailed reduction of the data is expected to take most of 1991. The collaboration will continue, using the new Australia telescope to determine accurate radio positions and to determine source structure. This data will have many uses, although our immediate interest is to discover new examples of gravitational lenses in the Southern Hemisphere.

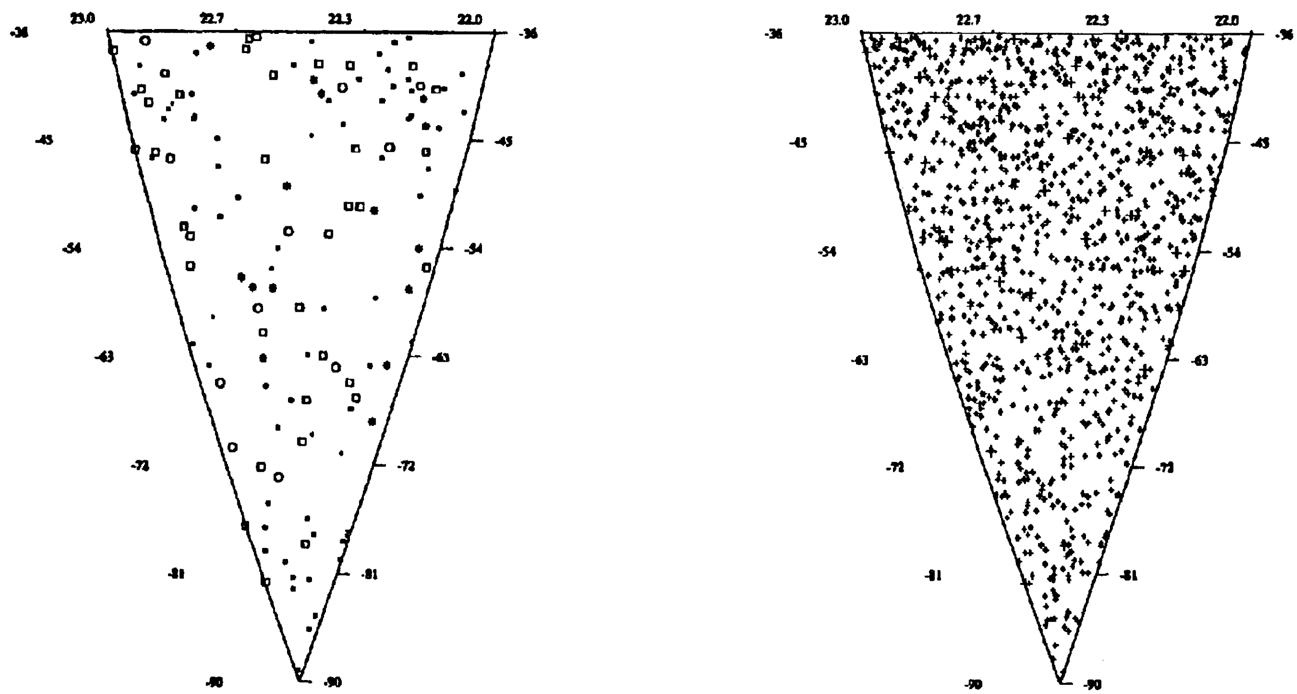

Figure 3.

1.2 Radio Interferometry of Nearby dMe Stars

Sponsor

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Goddard Space Flight Center
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Project Staff

Professor Jacqueline N. Hewitt, John D. Ellithorpe

dMe stars are dwarf M stars that show evidence of surface activity. For some time, they have been known to flare strongly at optical and radio wavelengths and, more recently, it has been demonstrated that many dMe stars exhibit low level quiescent emission that is detectable in Very Long Baseline Interferometry (VLBI). The detection of dMe stars on VLBI baselines makes possible the measurement of the position of these stars with high precision, and the astrometric detection of planetary companions may be feasible. We are currently investigating the nature of the radio emission, and we have identified extragalactic radio sources suitable as positional references for the stars AD Leo, EV Lac, and YZ CMi. Last June we carried out first-epoch VLBI astrometric measurements, using a VLBI array composed of telescopes in the United States, Spain and Germany. The analysis of the data is in progress.

This work is being done in collaboration with colleagues at Haystack Observatory, the Jet Propulsion Laboratory, and the Bureau des Longitudes (France).

1.3 Tiros-N Satellite Microwave Sounder

Sponsor

SM Systems and Research, Inc.

Project Staff

Professor David H. Staelin, Dr. Philip W. Rosenkranz

This effort involves scientific support of the Advanced Microwave Sounding Unit (AMSU) scheduled for launch on polar-orbiting weather satellites in the mid 1990s. Support of this passive microwave spectrometer program emphasizes atmospheric transmittance spectra, retrieval methods, and instrumentation issues.

Knowledge of the surface microwave emissivity at the AMSU observing wavelengths is important for accurate interpretation of the data. An approach using window channels to estimate it accurately was developed. This involves use of a multistate emissivity model to structure the estimation process.

A manuscript concerning estimation of atmospheric humidity profiles was prepared and submitted for publication.[10] Improved methods for estimating precipitation rates using AMSU data are also being developed.

1.4 Non-Thermal Radio Emission from the Jovian Planets

Sponsor

National Aeronautics and Space Administration
Goddard Space Flight Center
Grant NAG 5-537

Project Staff

Professor David H. Staelin, Stephen S. Eikenberry

The Planetary Radio Astronomy (PRA) experiment on the Voyager-2 spacecraft observed radio emission from five planets in 198 channels distributed over the band from 1.2 kHz to 40.5 MHz.

During August 1989, Voyager 2 encountered Neptune. Initial studies of emission with high spectral resolution reveal frequency structures that evolve in a manner reminiscent of emission seen on the other three Jovian planets. One interesting feature is the presence of a slowly drifting spectral region of little or no emission, bounded on both sides by emission that varies relatively smoothly with time and frequency. These frequencies of reduced emission correspond to radii where several Neptunian satellites are located, but this association could be coincidental.

1.5 High-Resolution Passive Microwave Imaging of Atmospheric Structure

Sponsor

National Aeronautics and Space Administration
Goddard Space Flight Center
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Project Staff

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Additional scientific results obtained from passive microwave observations of clear air and storms by the MIT imaging microwave spectrometer on the NASA ER-2 high-altitude aircraft were published. One paper described the instrument (MTS), which employed eight double-sideband channels centered around the 118.75-GHz O_2 resonance. This paper also summarized the results from 32 aircraft flights during the 1986 wintertime Genesis of Atlantic Lows Experiment (GALE) and the summertime COoperative Huntsville Meteorological EXperiment (COHMEX).[11] A nadir-viewing single-beam 53.6-GHz radiometer and a video camera made simultaneous co-located observations.

Comparison of the 118-GHz COHMEX spectral data with theoretical predictions of microwave emission spectra yielded good agreement, within 10%, over the opaque mature centers of cells despite the approximations made. Liquid and frozen hydrometers were modeled as spherical Marshall-Palmer and Sekhon-Srivastava distributed Mie scattering polydispersions, respectively, with Henyey-Greenstein phase functions. Comparisons over the partially transparent anvil regions of the precipitation cells were highly sensitive to the assumed mean ice particle size. The retrieval of cell water densities was facilitated by observations at both 53 and 118 GHz, where the

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[10] C.C. Kuo, P.W. Rosenkranz, and D.H. Staelin, "Statistical Iterative Scheme for Estimating Atmospheric Relative Humidity Profiles," submitted for publication.

[11] A.J. Gasiewski, J. Barrett, P.G. Bonanni, and D.H. Staelin, "Aircraft Based Radiometric Imaging of Tropospheric Profiles and Precipitation Using the 118.75 GHz Oxygen Resonance," *J. App. Meteor.* 29: 620-632 (1990).

transmittances are similar but the sensitivities to hydrometeors are different; again the assumed mean ice particle size was a source of discrepancy.[12]

In preparation for aircraft flight experiments in 1991, further improvements are being made to the MTS 53.6-GHz radiometer. In addition, a 16-channel 2-bit autocorrelation unit was constructed for observations of Zeeman-split oxygen lines and was tested in the laboratory. The ability of such ground-based observations of Zeeman-split lines to yield estimates of atmospheric temperatures near 50-km altitude was analyzed further and presented.[13]

1.6 Characterization of Dolphin Whistles

Project Staff

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Dolphin communication is characterized by sequences of repetitive whistles resembling birdsong. This project involves substantial compression of these signals followed by development of methods for organizing these compressed signals in a database so as to facilitate rapid identification of repetitious song elements. One anticipated result of this research is improved understanding of how various songs are created and evolve in dolphin communities. The results of this research should also lead to signal analysis tools useful for acoustic diagnosis of machinery and other devices.

This year a dolphin song database was assembled and methods for song compression were developed. One problem involves the requirement that similar whistles be coded similarly, despite uncertainties in the initiation and termination times of the whistles due to fading. One promising approach is to code segments internal to the song, where these segments are bounded by inflection points in pitch.

1.7 Rapid Precision Net-Form Manufacturing

Sponsor

Leaders for Manufacturing Program

Project Staff

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This project has three interrelated elements: (1) development of methods and apparatus for measuring the shape of arbitrary three-dimensional objects with sub-mil accuracy, (2) development of methods and apparatus for forming such objects in metal, ceramics, or plastics rapidly with sub-mil precision, and (3) development of new methods for adaptive experimental design that could facilitate process characterization and help achieve desired levels of precision by iteration of elements (1) and (2).

Most of the work has involved development of a 4-axis stage with a scannable volume of ~ 20 cubic inches; its open loop accuracy is better than 25 microns. A 512^2 pixel CCD camera has been linked to a telescope with an adjustable field of view down to 1-mm^2, and to a computer capable of receiving up to 30 frames per second. Holographically generated illumination patterns provide the signal which permits object shape to be measured at high data rates. Initial tests yielded measurements of surface position with $\sim 12\ \mu m$ rms accuracies.

Work on improved methods for parameter design and for materials forming are still in the formative stages. Preliminary analyses of new methods for experiment and parameter design are encouraging, however, and are expected to be more general and to perform better than methods now commonly used.

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[12] A.J. Gasiewski and D.H. Staelin, "Numerical Modeling of Passive Microwave O_2 Observations over Precipitation," *Radio Sci.* 25: 217-235 (1990).

[13] P.W. Rosenkranz, "Oxygen Line Emission as a Measure of Temperature in the Upper Stratosphere and Mesosphere," *Proceedings of the Tenth Annual International Geoscience and Remote Sensing Symposium,* College Park, Maryland, May 20-24, 1990, pp. 1185-1188.

1.8 Earth Observing System: Advanced Microwave Sounding Unit

Sponsor

National Aeronautics and Space Administration
Goddard Space Flight Center
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Project Staff

Professor David H. Staelin, Dr. Philip W. Rosenkranz

A copy of the Advanced Microwave Sounding Unit (AMSU) will provide the microwave-band observing capability for the Atmospheric Infrared Sounder (AIRS); these instruments will operate together on the proposed Earth Observing System Platform A, a polar-orbiting platform to be launched late in this decade. AMSU and AIRS will infer atmospheric profiles of temperature and humidity and also numerous other geophysical parameters characterizing clouds and the terrestrial surface. Our effort in support of this project will develop algorithms for temperature and humidity profiles, precipitation, sea ice and land snow cover, and other parameters.