Section 4 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

Professor Bernard F. Burke, Ian M. Avruch, Deborah J. Becker-Haarsma, Fronefield Crawford, André B. Fletcher, Lori K. Herold-Jacobson

The research during the third year of the grant "Extragalactic Radio Astronomy" has been concentrated on (1) mapping and analysis of radio sources from the MIT-Green Bank (MG) and Parkes-MIT-National Radio Astronomy Observatory (PMN) surveys, (2) a statistical analysis of radio sources over the entire sky, (3) analysis of gravitational lensing, (4) a search for distant neutral hydrogen concentrations beyond redshift 5, and (5) the construction of a near-real-time correlator for the Japanese VSOP space VLBI mission in part with NASA support.

The radio source mapping and analysis has been carried out by Mr. Fletcher and Ms. Herold-Jacobsen, utilizing the extensive MIT database from VLA observations. Radio maps of approximately 4500 radio sources have been completed, and complementary optical observations of over 250 of these objects have been made with the MDM 1.3 m telescope. In the body of data so far, at least eight candidates for gravitational lensing have been identified.

Mr. Crawford has been investigating the isotropy of radio source distribution over the entire sky, using the 87 GB and PMN surveys. In particular, we are interested in seeing whether a dipole anisotropy appears in the distribution of radio sources on the sky. A dipole anisotropy would indicate local motion with respect to the rest frame of radio sources and would complement dipole detections at other wavelengths (e.g., COBE). We have been investigating this possibility by splitting the sky into patches and measuring the source number density on these patches. We then compare the observed source number densities with the predictions of dipole models with various dipole directions and velocities. With this method we hope to statistically rule out the zero-motion (velocity = 0) model, thereby indicating that the Earth must be in motion with respect to a radio source rest frame.

In 1995 we made significant progress in the search for the time delay of gravitational lens 0957+561. This delay in the arrival time between the two images, when combined with knowledge of the lens geometry, is a measure of the angular diameter distance to the lens. The angular diameter distance can in turn be combined with a model of the lens structure and its redshift to yield a value for the Hubble constant. The time delay is found from the light curves of the A and B images, shown in the figure.

Monitoring observations continued at the VLA last year, making a total of 134 good quality observations at 5 GHz since we began the project in 1979. The monitoring has also included 8 GHz observations since 1990. During the summer of 1995, the B image increased in flux, following the increase of the A image flux in 1994. With the addition of this new feature to the light curves, we have increased our understanding of the structure function and other statistical properties of the underlying variation, and this has aided our search for the time delay.

Several types of statistical analysis have been done on the light curves, in an effort to resolve discussion in the literature of the best techniques for determining the delay from the data. Our best

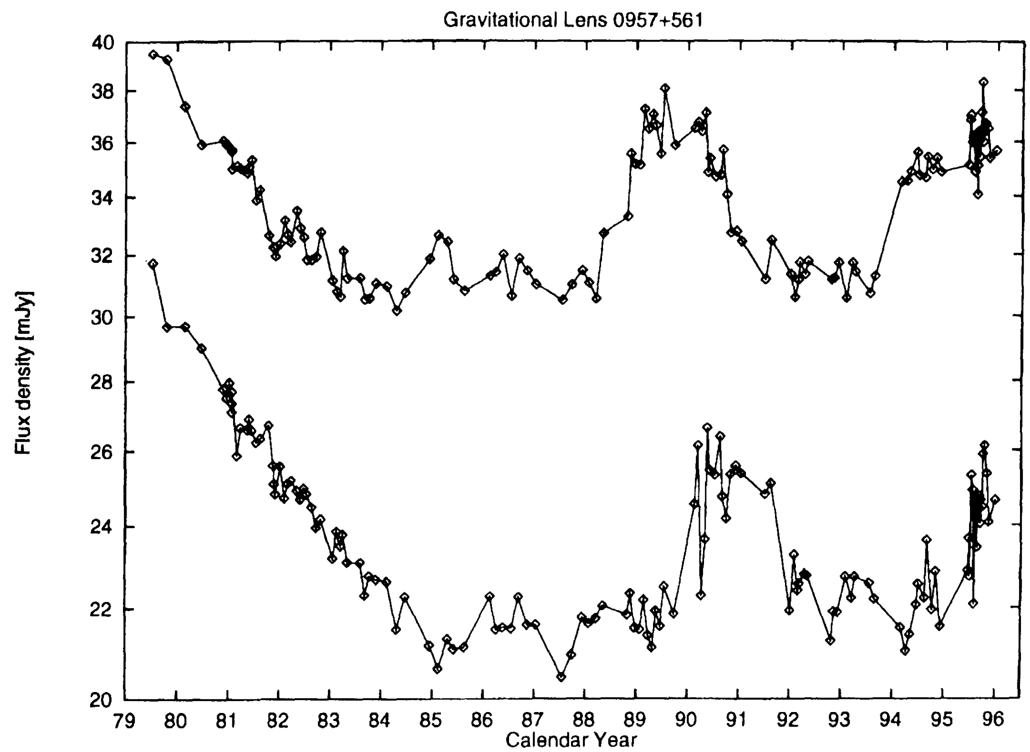

Figure 1.

result is from analysis of the data through December 1994 using the structure function method of Press, Rybicki, and Hewitt, yielding a time delay of 455 ± 16 days (68 percent confidence interval). While doing the analysis, we have learned that a poor choice of structure function can significantly alter the confidence interval but has little effect on the best-fit time delay. We now have a good fit for the structure function and feel that our confidence interval is a good measure of the uncertainty in our result. When this time delay is combined with mass models of the lens, we obtain H_0 in the range 25 to 85 km s^{-1} Mpc^{-1}, depending on the model and the measured velocity dispersion of the lensing galaxy.

The early hydrogen search is a collaboration between MIT, NAIC, and Harvard, in which we hope to observe neutral hydrogen λ21 cm emission from massive proto-cluster clouds at redshift $z \sim 5$, the era of galaxy formation.

The search system, consisting of a dedicated feed on the world's largest radio telscope, a 4000 channel hybrid spectrometer, and control PC, has been running and gathering data since January 1995, although operation was interrupted for a few months during the very active hurricane season. Sensitivity is high compared to other radio telescopes, but the radio-frequency interference (RFI) environment has deteriorated since the initial survey and limits our effective sensitivity. Some of this deterioration may be due to the extensive observatory upgrade underway, and some to the general increase in civilian and military traffic in the Caribbean. An assessment of the data indicates about 25 percent of our observing band is RFI-free most of the time, 10 to 30 percent is very strongly affected, and the balance is time-variable. We expect to salvage most of our data in post-processing and, with more integration time, make a detection.

In addition, members of this group have been planning for the design and construction of a near-real-time correlator for the upcoming VSOP space VLBI mission. This correlator will play a role in debugging the satellite before astronomical observations begin in January 1997.

The correlator will acquire digitized signals directly from both the ground radio telescope and the VSOP tracking station and store them on a PC. Once the data is stored, we will correlate the two streams quickly to see if there has been a detection of a test astronomical source. This will enable us to present feedback about the state of the satellite quickly, and any necessary adjustments can be made before the next satellite pass. The correlator is expected to be completed in September 1996, close to the launch date of the satellite.

Presentations have included a talk at the URSI meeting in Boulder and displays at the AAS meeting in San Antonio, both in January 1996.

1.2 Algorithms for Advanced Microwave Sounding Unit Operational Use

Sponsor

MIT Lincoln Laboratory
Agreement BX-4975

Project Staff

Dr. Philip W. Rosenkranz, William J. Blackwell, Michael J. Schwartz

This project provides scientific support to the National Oceanic and Atmospheric Administration (NOAA) for the advanced microwave sounding units A and B (AMSU-A, AMSU-B) which are scheduled for launch on NOAA polar-orbiting weather satellites starting in 1996 and also for improved 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.

Possible designs for a microwave sounder on a geosynchronous satellite are being explored. The absorption lines of atmospheric oxygen and water vapor between 118 and 425 GHz could be used to measure temperature and moisture profiles. With a two-meter diameter antenna, horizontal spatial resolution would range from 20 to 65 km at the subsatellite point, depending on the frequency. However, the lines near the high end of this frequency band would be obscured by the water vapor absorption continuum within a few kilometers of the surface.

1.2.1 Publication

Rosenkranz, P.W. "A Rapid Atmospheric Transmittance Algorithm for Microwave Sounding Channels." *IEEE Trans. Geosci. Rem. Sens.* 33(5): 1135-1140 (1995).

1.3 Earth Observing System: Advanced Microwave Sounding Unit

Sponsor

National Aeronautics and Space Administration/
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Project Staff

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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.

Uncertainty about the availability of a microwave moisture sounder for EOS motivated a study of low-cost alternative designs. One possible configuration would have two local oscillators at 118.75 and 183.31 GHz, with a total of seven channels derived from the IF passbands. Simulations of the retrieval performance showed accuracy comparable to the three-local-oscillator AMSU-B instrument. An added attractive feature of this design is the possibility of inferring the height of precipitation cells.

The possibility of combining AMSU and AIRS measurements in an optimum cloud-clearing algorithm was studied. The approach is to characterize the impact of clouds on the IR radiances by using both IR and microwave radiances to estimate cloud parameters. A weighted combination of nine AIRS spots is taken, with optimally chosen weights, to represent cloud-cleared radiance at 50-km resolution. It was found that reduction of noise through spatial averaging and use of all channels in profile retrievals were very desirable for good results.

1.3.1 Publications

Cabrera-Mercader, C.R., and D.H. Staelin. "Passive Microwave Relative Humidity Retrievals using Feedforward Neural Networks." *IEEE Trans. Geosci. Rem. Sens.* 33(6): 1324-1328 (1995).

Rosenkranz, P.W. "A Rapid Atmospheric Transmittance Algorithm for Microwave Sounding Channels." *IEEE Trans. Geosci. Rem. Sens.* 33(5): 1135-1140 (1995).

1.4 High-Resolution Passive Microwave Imaging of Atmospheric Structure

Sponsor

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Project Staff

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The major effort has involved evaluation of the atmospheric microwave transmittance spectrum. The data was obtained with the MIT Microwave Temperature Sounder (MTS), which is a dual-band radiometer incorporating an imaging spectrometer at 118 GHz and a tunable fixed-beam radiometer at 52-54 GHz. This instrument was flown on the NASA ER-2 high-altitude aircraft on a number of missions in 1993 and earlier.

The major challenge has been precise calibration of the MTS, partly because of the effects of radio frequency interference and other instrument irregularities. RF interference was removed from the images by taking advantage of its similar form in all frequency bands. In particular, the high-spatial-frequency structure of the interference contrasted strongly with the smooth character of the geophysical data in the most opaque channels. Calibration errors were removed by using external ambient temperature and liquid-nitrogen cooled black bodies, as well as the *a priori* brightness temperatures for zenith observations at high altitudes ($\sim$ 20 km) where the atmosphere is nearly transparent. Dual-mode behavior associated with an intermittent RF connection was calibrated by estimating the system state and then using appropriate coefficients. The two system states exhibited different channel band-pass characteristics, and this was also incorporated in data interpretation.

Preliminary examination of the data near 54 GHz and 118 GHz suggests that recent theoretical expressions based on laboratory data approximate true atmospheric transmittances within several percent, despite indications to the contrary published by others based on satellite data.

In addition, prior work was prepared and submitted for publication.

1.4.1 Publications

Schwartz, M.J., J.W. Barrett, P.W. Fieguth, P.W. Rosenkranz, M.S. Spina, and D.H. Staelin. "Observations of Thermal and Precipitation Structure in a Tropical Cyclone by Means of Passive Microwave Imagery near 118 GHz." *J. Appl. Meteorol.* 35(5): 671-678 (1996).

Spina, M.S., M.J. Schwartz, D.H. Staelin, and A.J. Gasiewski. "Application of Multilayer Feedforward Neural Networks to Precipitation Cell-Top Altitude Estimation." Submitted to *IEEE Trans. Geosci. Rem. Sens.*

1.5 Reduction of Variation

Sponsor

MIT Leaders for Manufacturing Program

Project Staff

Professor David H. Staelin, Timothy J. Derksen, Mark A. Rawizza

In a collaboration involving General Motors, Intel, and Kodak, Research Group 4 of the MIT Leaders for Manufacturing Program has defined a collaborative project focused on new methods for using data from data-rich manufacturing processes to better characterize the multivariate nature of those processes and their evolution, including sensitive detection of any erratic departures from normalcy. An efficient generic tool set and protocols for its use are being developed and tested on representative manufacturing processes.

The General Motors process is body-in-white assembly, and the metrics involve body shape. At Intel, the data involves integrated circuit manufacturing process parameters and the resulting circuit characteristics and dimensions. At Kodak, continuous film base manufacturing processes are being studied, and the metrics involve dimensions and optical properties. In all three cases, the number of measured parameters ranges from tens to hundreds, where each measurement set might be repeated hundreds of times or more, typically in a time sequential fashion. To protect the proprietary character of this manufacturing data, it has been encrypted for use on campus by removal of mean values, normalization of variances, and elimination of parameter labels. Since the objective of the research on campus is to develop efficient methods for uncovering hidden behavior, these steps are of no consequence. The implications of the uncovered hidden behavior to the manufacturing process are explored within the proprietary envelope of each of the separate companies, often by their own employees.

This year, the focus has been on dimensionality reduction, accommodation of missing data, detection of outliers, and detection of surprises in time series data. The initial steps with each data set involve Karhounen-Loéve transforms followed by process characterization in the resulting reduced-dimensionality space. Next, methods for removing predictable elements are explored, and the residuals are studied with linear and nonlinear techniques. Initial results indicate that many important process variations hidden in the raw univariate data become evident in the reduced-dimension representations and reveal useful information.

Earlier work concerning sequential block design of experiments[1] was submitted for publication.

1.5.1 Publication

Koita, R., D.H. Staelin, and M. Rawizza. "Sequential Block Design Strategy for Two-Level Factorial Experiments." Submitted to *The 1995 Proceedings of the Section on Quality and Productivity*, American Statistical Association, 1995.

[1] R. Koita, *Strategies for Sequential Design of Experiments.* M.S. thesis, MIT, 1994.