Section 4   Radio Astronomy

Chapter 1 Radio Astronomy

Chapter 1. Radio Astronomy

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1.1 Extragalactic Radio Source Studies

Sponsor

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1.1.1 Measurement of the Hubble Constant

A definitive measurement of the time delay difference between quasar images in the gravitational lens system 0957+561 has been carried out. The time delay, reported provisionally in *RLE Progress Report Number 133*, is 513±40 days and leads to an evaluation of the Hubble Constant.[3] The apparent discrepancy with optical determination by other authors has been resolved in favor of the radio data. A complete account of the data has also been published.[4] The derived value of the Hubble Constant depends upon lens model and mean matter density in the universe. Our derived values fall between 42 and 69 km/sec/Mpc. The method is completely independent of traditional techniques, but the range of values is consistent with the optical determinations. Agreement of the various methods gives us some confidence that the scale of the universe is known to within a factor of two. Similar measurements of other gravitationally lensed quasars will lead to a better determination

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of the scale of the universe, as inferred from the Hubble constant.

1.1.2 Gravitational Lens Studies

A new example of an "Einstein ring," the source MG1549+3047, was discovered by Lehár in the course of his Ph.D. dissertation work at MIT.[5] The radio map is illustrated in figure 1. An Einstein ring is produced when a background source is well-aligned with a foreground symmetrical mass distribution that deflects the rays to form a ring-like image about the lens. Three of the five known examples of Einstein rings have been discovered in

the course of National Science Foundation research under this grant and those preceding it. The ring phenomenon is not rare and leads to interesting astrophysical conclusions about distribution of matter in the universe. The size of the ring determines mean surface density of matter in the foreground lensing galaxy. All matter within the ring contributes to the observed image whether it is in the form of stars or "dark matter." For two of the three rings, system parameters are completely measurable, and mass-to-light ratio can be determined completely. MG1654+1346 and MG1549+3047 have values of M/L^B equal to 15.9 ± 2.3 and 16 ± 3. These are probably the best values ever determined for elliptical galaxies.
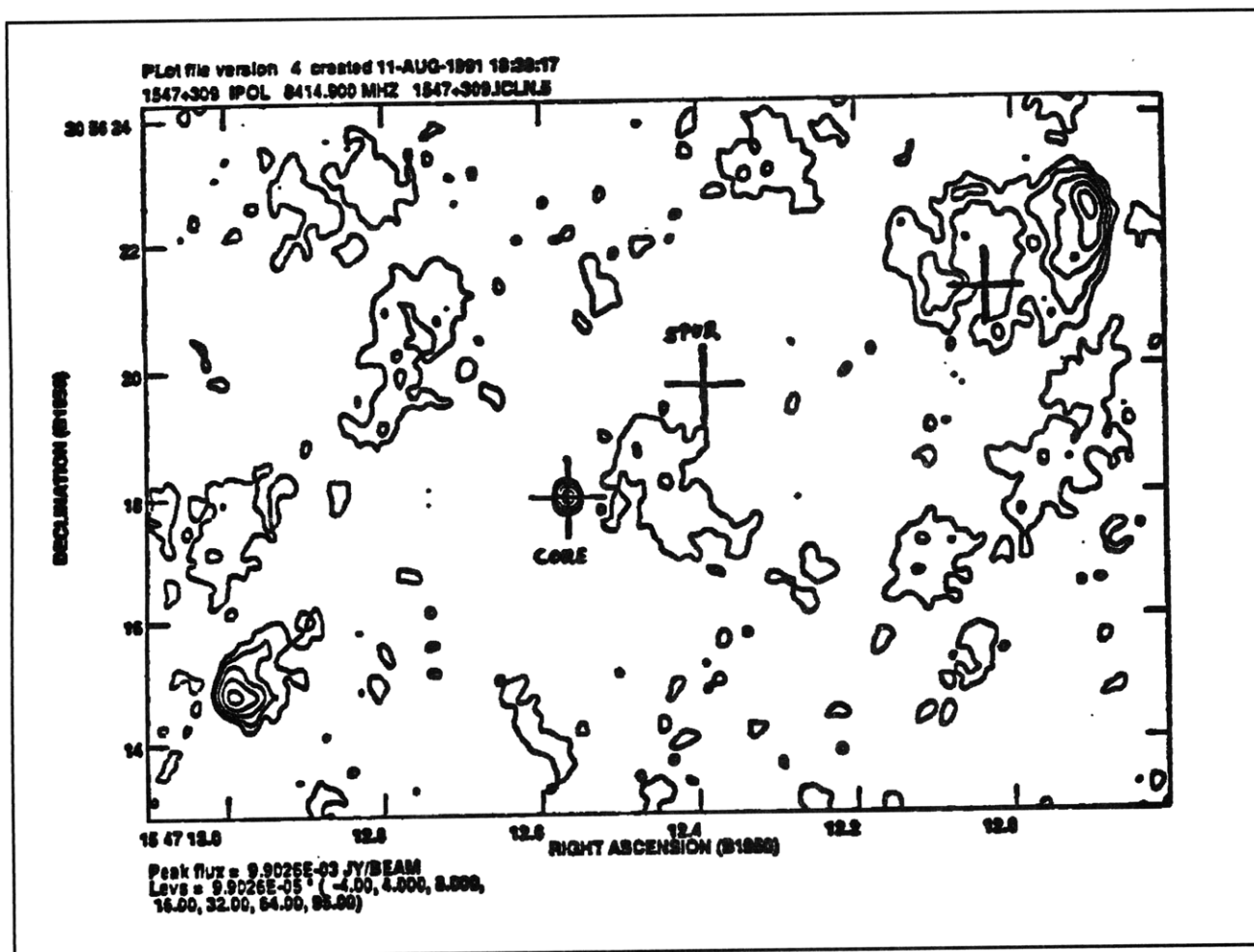

Figure 1. VLA Map of MG1549+3047. There is a bright galaxy at the position of the upper right hand cross, and the ring is roughly centered on the galaxy. The radio source is of the core-double type, and one lobe lies behind the lensing galaxy.

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5 J. Lehár, Ph.D. diss., Dept. of Phys., MIT, 1991.

1.1.3 Search for New Lenses

The systematic lens search project, carried out jointly with Professor Jacqueline Hewitt of MIT and Professor Edward Turner of Princeton University, is continuing. The Very Large Array (VLA) mapping of MG sources is the raw material, and the 4000 maps obtained in previous years have been used for the search. A new complex of Sun work stations, operated jointly with Professor Hewitt, is producing a final map catalog, with each map being cleaned and self-calibrated. S. Conner is coordinating the work. An additional 2000 sources were mapped by the VLA, and data reduction is progressing. J. Lehár's 1991 thesis[6] described the first 500 of these sources, from which his new Einstein ring was later discovered. A closely-related class of gravitational lens has been recognized for some time: quadruple sources. These have essentially the same morphology as the rings, and similarly, the characteristics of the foreground galaxy can be studied. Professor Hewitt has used the material from the MG survey to demonstrate that the source MG0414+0354 belongs to the same class. Our estimate that approximately one in 400 MG sources is measurably lensed continues to be valid.

1.1.4 The Parkes-MIT-NRAO (PMN) Southern Hemisphere Survey

During 1990, a completely new radio survey of the Southern Hemisphere was completed, using the Parkes Telescope, the National Radio Astronomy Observatory (NRAO) multifeed 6-cm receiver, and carried out under the principal leadership of Mark Griffith, an MIT graduate student, with the vital collaboration of Dr. Alan Wright of CSIRO. The first preliminary results were illustrated in the previous *RLE Progress Report Number 133.* A far more complete survey is now in the final stages of preparation, and an example of the radio source distribution for the Southern Hemisphere is illustrated in figure 2. The survey will increase the number of known Southern Hemisphere radio sources by an order of magnitude. The observations have been processed by the MIT Cray computer, and the completed survey should be finished by early summer 1992.

At the same time, we are planning to search this body of data for new examples of lensing. The southernmost sources would have to be studied by the Australian telescope, but there is a large part of the southern sky which is accessible to the VLA. We have carried out an initial investigation of over 1000 sources from the PMN survey using the VLA in the A configuration at X-band. The observations were carried out in the summer of 1991 and are now being reduced.

1.1.5 Search for Highly Redshifted, Pregalactic Hydrogen Clouds

Hydrogen complexes, located at great distances and from an earlier age when galaxies and clusters of galaxies had not been formed, may be observable. This was a project of speculative nature, but the Arecibo Observatory was interested in pursuing the work which could be carried out simultaneously along with its other observations. Initial calculations are encouraging. Fortunately, we have found that the multichannel receiver that is needed for this task can be copied from an existing design by Professor Paul Horowitz at Harvard University. We have proposed that a prototype should be built and tested at Arecibo and that construction of a full-scale receiver should follow. The 1.5 meter band, corresponding to a redshift of 6, would be an optimum area to search. The proposal has gained credibility from Uson's recent announcement that a large hydrogen complex has been discovered by the VLA at a redshift of 3.3.

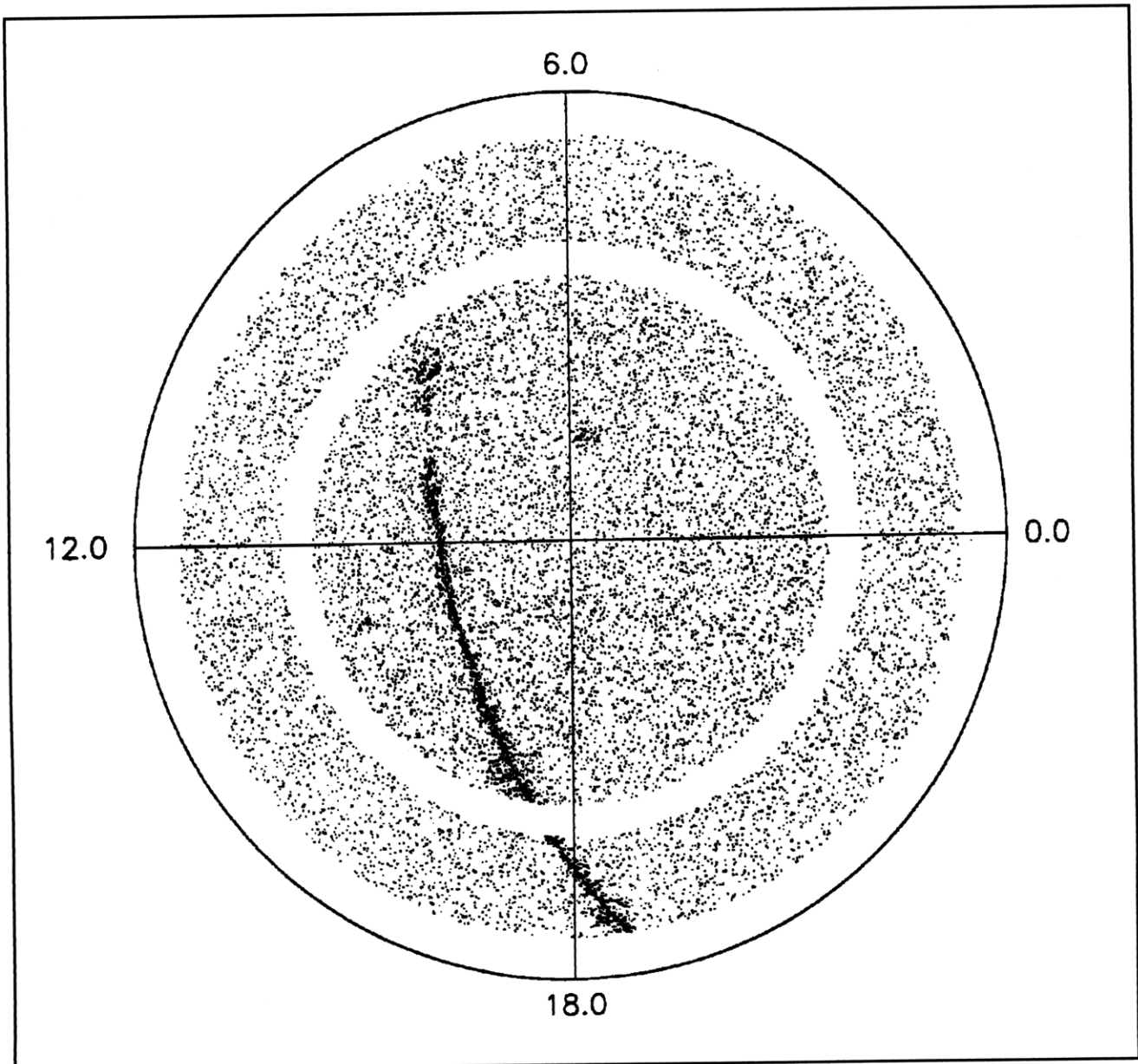[6] J. Lehár, Ph.D. diss., Dept. of Phys., MIT, 1991.

Figure 2. A map of 18,524 sources in the Southern Sky. The plane of the Milky Way is clearly visible. The large Magellanic cloud is the small cluster of sources in the upper right-hand quadrant. The empty circle marks the zenith strip as seen at the Parkes Telescope, and these observations have not yet been analyzed.

1.2 Studies of Gravitational Lenses

Sponsors

Alfred P. Sloan Fellowship
National Science Foundation
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Project Staff

Professor Jacqueline N. Hewitt, Grace H. Chen, Charles A. Katz

Gravitational lenses provide radio astronomers with the opportunity to examine many long-standing problems in astrophysics. For example, through modeling the light-bending effects of a gravitational field, one can infer the quantity and distribution of matter responsible for gravitational lensing. Because dark matter in the universe is not well understood, these independent measurements are proving to be helpful. However, the robustness of this technique is strongly dependent on the degree to which one can reconstruct the mass distribution reliably. Reliable reconstruction is possible if sufficient structure in the lensed image can be measured, and it is facilitated if the mass distribution is highly symmetric. These conditions are met by several gravitational lens systems including MG1131+0456 and MG0414+0534, both radio sources whose lensed properties were discovered in the VLA gravitational lens search described in Section 1.1.3.

An Einstein ring is a particularly symmetric case of gravitational lensing in which the background source is imaged into a ring. MG1131+0456 was the first "Einstein ring" discovered.[7] In MG1131+0456, an intrinsically normal radio source consisting of two radio lobes and a compact object, possibly the active galactic nucleus, is lensed in such a way that one of its lobes is imaged into a ring, and the compact object is doubly imaged. We are continuing our analysis of this object by measuring its polarization and spectral properties. Figure 3 shows a radio image (8 GHz frequency) in which complex polarization structure is evident. We will use these data to reconstruct the gravitational potential that is responsible for imaging.

MG0414+0534 consists of multiple images of a background object, with a configuration that is typical of an elliptically symmetric gravitational lens. Data collected at optical and radio wavelengths provide compelling evidence that the source is lensed and, furthermore, that the background source appears to have unusual properties.[8] Figure 4 shows an 8 GHz radio image that demonstrates that there are four components. Previously collected data with lower resolution could only prove unambiguously the presence of three components. Models of gravitational lenses predict that four components should be present, and this prediction is supported by the image shown in figure 4.

The radio images presented here were computed from data acquired with the National Radio Astronomy Observatory's Very Large Array telescope.

1.3 Radio Interferometry of Nearby dMe Stars

Sponsors

National Aeronautics and Space Administration
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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 measurement of the position of these stars with high precision, and astrometric detection of planetary companions may be feasible. The astrometric monitoring program was continued with second-epoch measurements of the dMe stars AD Leo, EV Lac, and YZ CMi.

[7] J.N. Hewitt, E.L. Turner, D.P. Schneider, B.F. Burke, G.I. Langston, and C.R. Lawrence, *Nature* 333: 537 (1988).

[8] J.N. Hewitt, E.L. Turner, C.R. Lawrence, D.P. Schneider, and J.P. Brody, *Astronom. J.*, forthcoming.
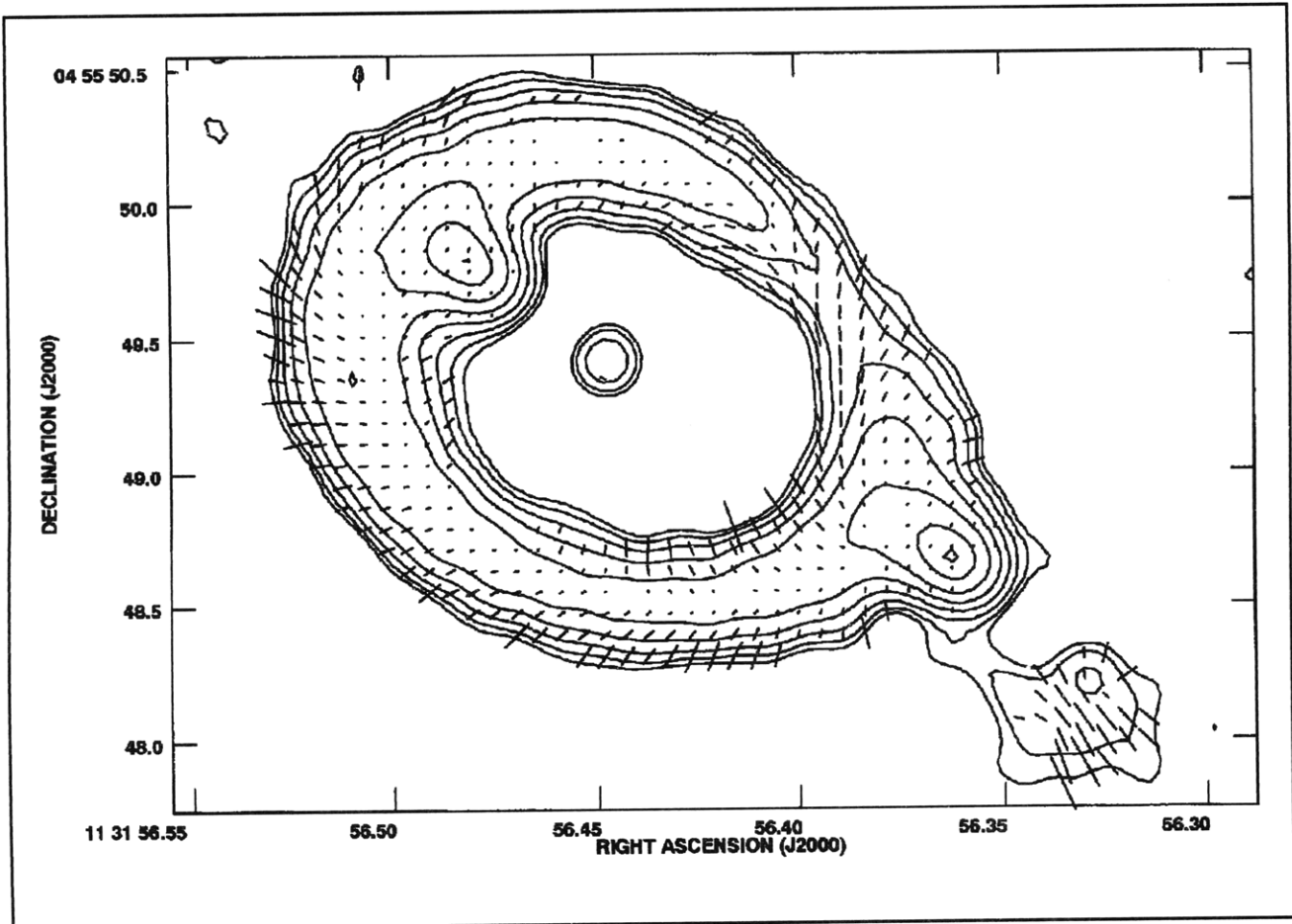
Figure 3. 8 GHz radio image of the Einstein ring gravitational lens MG1131+0456. The contours trace the surface brightness of the source, and the line segments represent its linear polarization. The length of each line segment is proportional to the percentage polarization, and the position angle of each line segment gives the orientation of the electric field vector.

1.4 Tiros-N Satellite Microwave Sounder

Sponsor

SM Systems and Research Corporation

Project Staff

Professor David H. Staelin, Dr. Philip W. Rosenkranz, Michael S. Ho

This project provides scientific support to the National Oceanic and Atmospheric Administration (NOAA) for its Advanced Microwave Sounding Unit (AMSU). The AMSU is scheduled to be launched on NOAA's polar-orbiting weather satellites in the mid-1990s and also on follow-on satellites. In our research effort, we emphasize development of atmospheric transmittance algorithms, estimates of surface emissivity and precipitation, and issues related to instrument design and specification.

A study of measurements made by an existing satellite radiometer, the Special Sensor Microwave Imager (SSM/I), has yielded information on the sensitivity of ocean surface emissivity to wind stress at 19 and 85 GHz.[9] This information will be used to design algorithms for the AMSU, which has an 89-GHz channel.

Measurements made by H.J. Liebe at the Institute for Telecommunication Sciences in Boulder, Colorado, of microwave attenuation in dry air have been analyzed to extract coefficients describing the

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9 P.W. Rosenkranz, "Rough-Sea Microwave Emissivities Measured with the SSM/I," 1992, forthcoming.
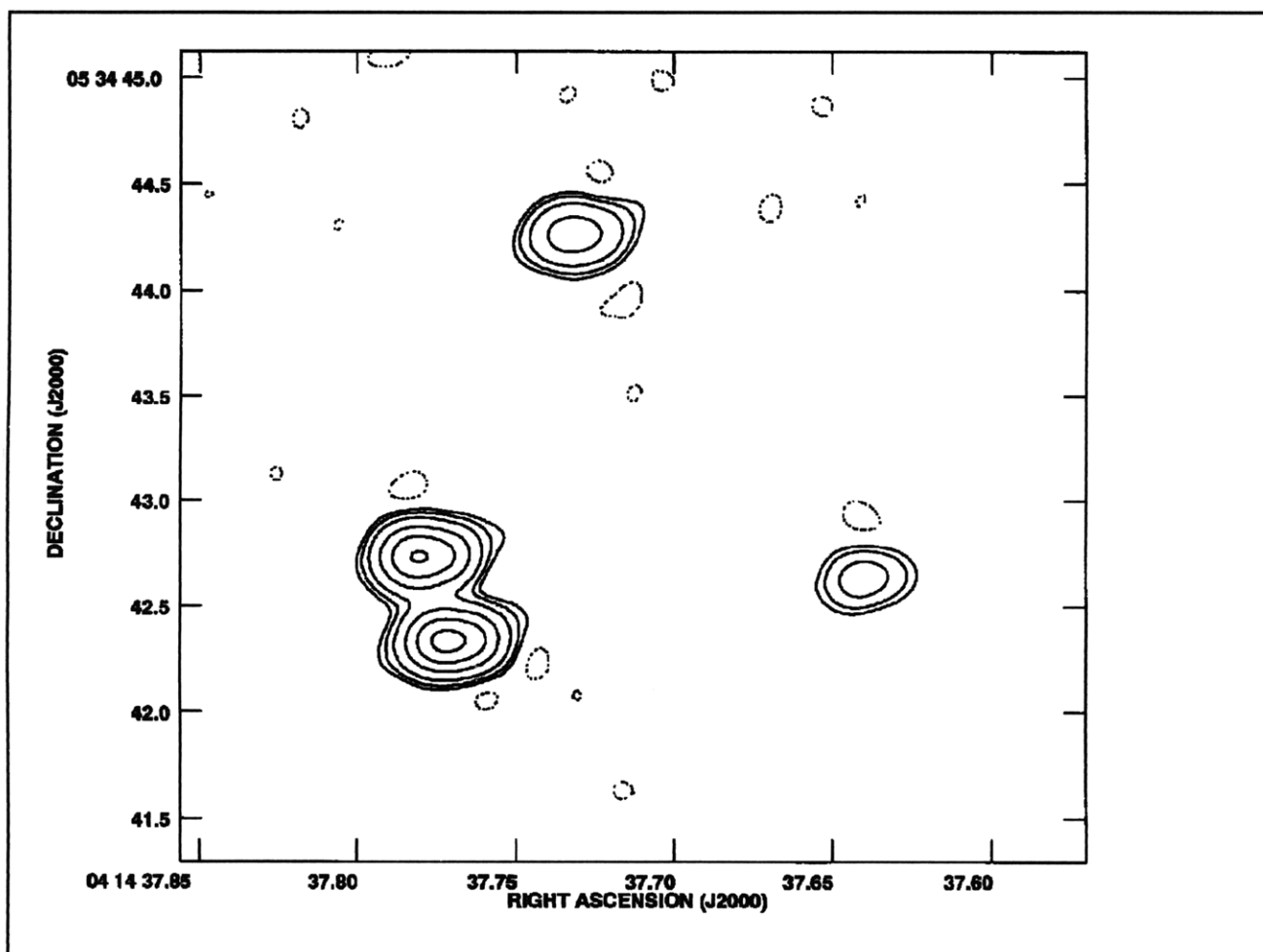
Figure 4. 8 GHz radio image of the four-image gravitational lens MG0414+0456. The contours trace the surface brightness of the source.

mixing of overlapping oxygen lines.[10] These coefficients will improve the accuracy of atmospheric transmittance models, particularly with respect to temperature dependence.

1.5 Earth Observing System: Advanced Microwave Sounding Unit

Sponsor

National Aeronautics and Space Administration/
    Goddard Space Flight Center
    Contract NAS 5-30791

Project Staff

Professor David H. Staelin, Dr. Philip W. Rosenkranz, Michael J. Schwartz

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). In this effort, we are developing algorithms for retrieval of temperature and humidity profiles, precipitation, sea ice, land snow cover, and other parameters. Presently, we are planning that temperature and humidity profiles obtained from AMSU will provide initial conditions for the AIRS infrared retrieval algorithm. Currently, our work is focused on simulation efforts and on developing a rapid (as distinguished from line-by-line) microwave transmittance algorithm.

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[10] H.J. Liebe, P.W. Rosenkranz, and G.A. Hufford, "Atmospheric 60-GHz Oxygen Spectrum: New Laboratory Measurements and Line Parameters," submitted for publication.

1.6 High-Resolution Passive Microwave Imaging of Atmospheric Structure

Sponsor

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Project Staff

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

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. During July and August 1991, we participated in the Convection and Precipitation/Electrification (CaPE) experiment which observed subtropical convective systems.

The data taken during this series of flights, which included two overpasses of Hurricane Bob, provided the highest resolution observations in these frequency bands of a hurricane. On other flights, upward-observed profiles of atmospheric brightness temperature were obtained. These data will help us to resolve apparent discrepancies with theoretical calculations of brightness temperatures that had been observed in previous experiments.

1.7 Characterization of Dolphin Whistles

Project Staff

Professor David H. Staelin, Kevin G. Christian

Dolphins emit whistles resembling bird song. In this project, we are exploring methods for compressing these signals so that repetitious song elements can be rapidly identified. Identifying song elements rapidly with minimal training presents the most challenging aspect of the project.

This year the dolphin song database was expanded, and a broad class of robust measures of whistle parameters was designed. Our current research involves developing methods for selecting combinations of measures which most efficiently capture unique elements in these whistles and permit compact representation and efficient recall from a computer database. These algorithms should also be useful for diagnosing acoustic and other signals produced by machinery, manufacturing processes, and other environments.

1.8 Rapid Precision Net-Form Manufacturing

Sponsor

Leaders for Manufacturing Program

Project Staff

Professor David H. Staelin, John T. Delisle, Darren L. Leigh, Paul W. Fieguth

Algorithms were improved for estimating the shape of manufactured objects with a precision of microns at very high data rates.[11] The experiment involves use of a previously developed four-axis stage with a scannable volume of $\sim$ 20 cubic inches. A 512^2 pixel CCD camera was used with a field of view adjustable down to 1 mm^2. The system is fully computer controlled and can receive up to 30 frames per second.

1.9 Conformal Experiment Design

Sponsor

Leaders for Manufacturing Program

Project Staff

Professor David H. Staelin, Ashraf S. Alkhairy

Optimization of operating parameters for products and manufacturing processes are often determined by experiment in cases where theoretical analysis is inadequate. The performance of these products and processes is often limited because of the high cost of these experiments; experimentation simply ceases when the allocated budget is depleted or the allotted time period ends. With most conventional techniques for experiment design, such as those of Taguchi and Box, on the order of N^2 experiments are required, where N is the approximate number of important parameters. Using

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[11] J.T. Delisle, *Three-dimensional Profiling Using Depth of Focus,* S.M. thesis, Dept. of Physics, MIT, 1991.

newly developed techniques, Dr. Ashraf Alkhairy[12] has shown that in many cases of practical interest, only the order of N experiments is sufficient to get excellent results.

These new techniques, called "conformal experiment design," are used to probe the complexity of the product or process space and guide definition of efficient sets of experiments. This new approach conforms to the process or product of interest by taking advantage of any intrinsic simplicity and by better matching the chosen quality cost functions and statistical models to the problem at hand. This involves performing a series of experiments which ends when those experiments suggest that all unaccounted second-order interactions are negligible; the implication is then that all higher-order interactions are probably negligible too. Previously existing methods often overlooked some of these interactions, even with N^2 experiments, and thus yielded inferior results.

The impact of these new, more efficient methods for experiment design can be enormous when processes and products are characterized by too many significant parameters for N^2 experiments to be practical. Experimental optimization can therefore now be employed for larger and more complex systems or subsystems with larger values of N, leading to significantly superior performance over cases where sequential optimizations of subsets of the same N parameters are performed.

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[12] Alkhairy, A.S., *Optimal Product and Manufacturing Process Selection—Issues of Formulation and Methods for Parameter Design,* Ph.D. diss., Dept. of Electr. Eng. and Comput. Sci., MIT, 1991.