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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Project Staff

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Three major areas of research were covered by the program under Professor Burke's direction. Two of these were in the field of radio astronomy: the search for gravitational lenses (two new examples have been discovered by our group) and a survey of radio sources in the Southern Hemisphere that increased the number of known radio sources there by nearly an order of magnitude. The third is the opening of a new field of research: the search for and study of planets of other stars known as "exoplanets."

1.1.1 Gravitational Lens Studies

The study of the gravitational lensing phenomenon, which occurs when a distant object such as a quasar has its image distorted by a foreground mass such as a galaxy, presents a new tool for investigating gravitational interaction and cosmology. In particular, the distribution of all matter in a galaxy can be studied, whether it is luminous or dark, baryonic or non-baryonic. Two new examples of gravitational lensing were discovered during the past two years of the program. In the course of this work, it has become clear that there are systematic classes of lensing which may be called "Einstein rings" and "Einstein quads." (The first example of an Einstein ring was discovered earlier by Professor Jacqueline Hewitt of the MIT Physics Department and RLE.)

The work uses the MIT-Green Bank (MG) Survey as a finding list, mapping a large number of these radio sources at high angular resolution with the Very Large Array (VLA) and then pursuing promising examples with further optical and radio studies. In our program, over 6000 radio sources have been mapped with the VLA. This collection is the largest sample of sub-arcsecond radio source maps in the world, and it can be used for numerous astronomical investigations.

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[1] Australian National Telescope Facility, Parkes, Australia.

Publications

Burke, B.F. "Introduction to Orbiting VLBI." *Adv. Space Res.* 11(2): 349-353 (1991).

Burke, B.F., D.H. Roberts, J. Lehár, and J.N. Hewitt. "The Hubble Constant from VLA Measurement of the Time Delay in the Double Quasar 0957+561." *Nature.* July 1991.

Burke, B.F., M.B. Heflin, M.V. Gorenstein, and C.R. Lawrence. "First and Second Epoch VLBI Observations of the Gravitational Lens System 2016+112." *Astrophys. J.* 378: 519-536 (1991).

Burke, B.F. "Summary of the Issues." In *Frontiers of VLBI: Proceedings of the International VSOP Symposium and the mm-Wave VLBI Workshop,* Eds. H. Hirabyashi, M. Inoue, and H. Kobayashi. Chapter 5: Management Plan. Tokyo: University Academy Press, 1991.

Burke, B.F. "A View of the Universe Through Imperfect Lenses: A Tribute to David Heeschen." Talk presented at the Heeschen Retirement party, December 16, 1991.

Burke, B.F., J. Lehár, and S. Conner. "Einstein Rings and Related Phenomena." Paper presented at the International Conference on Gravitational Lenses, Hamburg, Germany, September 1991.

Burke, B.F., J. Lehár, J.N. Hewitt, and D.H. Roberts. "The Radio Time Delay in the Double Quasar 0957+561." *Astrophys. J.* 384:453-466 (1992).

Burke, B.F., S.R. Conner, and J. Lehár. "Reconciling the Image Brightness Ratios in the Gravitational Lens System 0957+561." *Astrophys. J. Lett.* 387 LC: 61-64 (1992).

Griffith, M., G. Langston, M. Heflin, and S. Conner. "The Fourth MIT-Green Bank 5 GHz Survey." *Astrophys. J. Suppl.* 75: 801-833 (1991).

Invited Talks

Burke, B.F. "Gravitational Lenses." Arecibo Radio Observatory, Puerto Rico, March 1992.

Burke, B.F. "Gravitational Lenses in the Ultraviolet." University College, London, June 1992.

Burke, B.F. "Einstein Rings and Einstein Quads." IAU Colloquium, Manchester, England, July 1992.

1.1.2 The Parkes-MIT-NRAO Southern Hemisphere Survey

The Parkes-MIT-NRAO survey of radio sources was concluded. The work was carried out with the Parkes 210-foot radio telescope using the National Radio Astronomy Observatory (NRAO) 14-channel 6 cm receiver by Dr. Alan Wright of Australia and Mr. Mark Griffith, an MIT graduate student. We have published a first general overview paper, and a detailed technique paper will be published in May 1993.

The detailed catalogue is ready for submission and contains a list of approximately 60,000 radio sources in the southern sky. This is an increase by nearly an order of magnitude in the number of known Southern Hemisphere radio sources, and follow-up work is continuing with our Australian colleagues.

1.2 The Study of Exoplanets

Sponsor

National Aeronautics and Space Administration
Grant NAGW 1386

Project Staff

Professor Bernard F. Burke, Ian M. Avruch, Deborah J. Becker, Samuel R. Conner, André B. Fletcher, Mark R. Griffith, Lori K. Herold

The search for and study of exoplanets, including the study of their origin and evolution, is a new research area that has become a NASA program known as the Toward Other Planetary Systems (TOPS) program. In 1988, Professor Burke was appointed Chair of the NASA science working group that formulated this program. In 1992 NASA published the report *TOPS: Toward Other Planetary Systems.* During the past decade, Professor Burke published several papers that treated the possibility of searching for exoplanets.

Publications

Burke, B.F. "Concluding Remarks: Prospects for the Study of Planetary Radio Emission." Third International Workshop on Radio Emissions from Planetary Magnetospheres, Graz, Austria, September 1991.

Burke, B.F. "Searching for Exoplanets." In ESA Publications for the Symposium on Targets for

Space-Based Interferometry, Beaulieu, France, October 1992.

Meetings and Talks

Burke, B.F. "Searching for Exoplanets." University of Massachusetts, Amherst, Massachusetts, April 1992, and University of Manchester, Manchester, England, November 1992.

Burke, B.F. "The Search for Other Planetary Systems." Talk presented at the Royal Astronomical Society, London, December 1992.

Burke, B.F. "The TOPS Program." California Institute of Technology Summer School, Pasadena, California, August 1992.

1.3 Studies of Gravitational Lenses

Sponsors

National Science Foundation
  Presidential Young Investigator Award
David and Lucile Packard Fellowship
  for Science and Engineering

Project Staff

Professor Jacqueline N. Hewitt, Grace H. Chen, John D. Ellithorpe, Matthew K. Gray, Charles A. Katz, Pauline McMahon, Mark D. Messier, Christopher B. Moore, Jie Sun

Gravitational lenses provide radio astronomers with the opportunity to reexamine many long-standing problems in astrophysics. Two of these problems, addressed by the work described here, are the nature and distribution of dark matter in galaxies and the calibration of the age and scale of the universe (i.e., determination of the Hubble constant). Both applications require that the distribution of gravitating matter be inferred from the observed imaging properties of the lens. This, in turn, requires detailed measurements of the brightness distribution of the image. Extensive radio maps of

two gravitationally lensed extragalactic radio sources, MG1131+0456 and MG0414+0534, are being compiled from data taken with a Very Large Array radio telescope. Figure 1 shows high-frequency images that highlight the multiple images of the active galactic nuclei in the two systems. The configuration of these images provides constraints on models of the mass distribution in the lens; other information is derived from mapping at lower frequencies where other structure is evident.[2] There are differences in the propagation time, of order days to months, for the different ray paths associated with the images of the active galactic nucleus. Monitoring programs aimed at measuring these time delays are being carried out with the Very Large Array telescope. Preliminary plots of 15 GHz flux density as a function of time for the four images of MG0414+0534 are shown in figure 2. Simulations of time delay estimation techniques indicate that, with the variability displayed by the data of figure 2, the time delays in this system should be measurable.
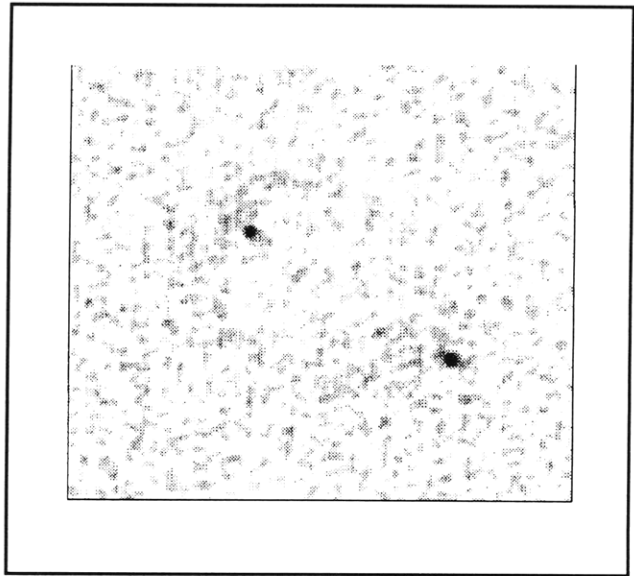

Figure 1a. 22 GHz radio image of the gravitational lens MG1131+0456. The two bright sources are two images of the same background galactic nucleus.

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2 C.A. Katz and J.N. Hewitt, *Astrophys. J. Lett.*, forthcoming; G.H. Chen and J.N. Hewitt, "Multifrequency Radio Images of MG1131+0456," in *Sub-Arcsecond Radio Astronomy,* ed. R.J. David and R.S. Booth (Manchester, England: CVP), forthcoming.
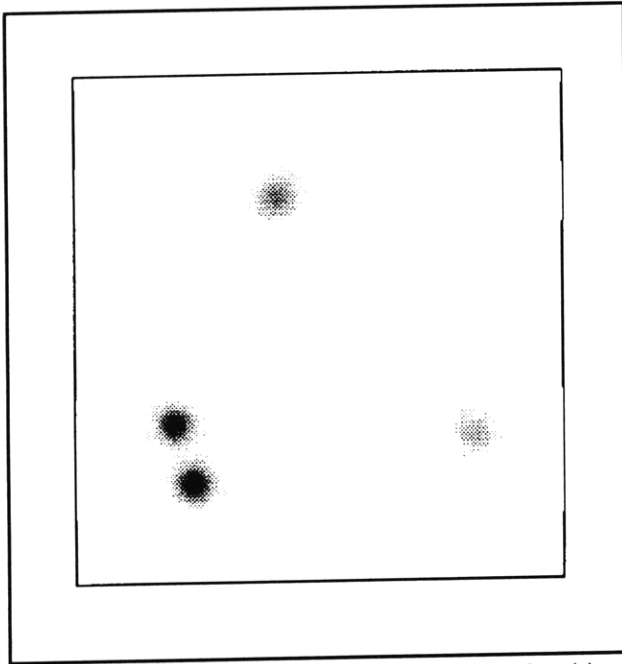
Figure 1b. 15 GHz radio image of the gravitational lens MG0414+0534. In this case, there are four images of the background action galactic nucleus.
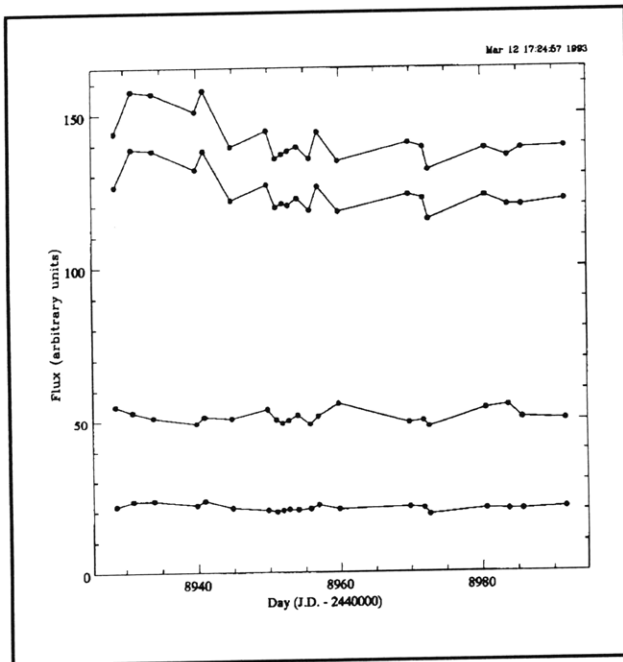

Figure 2. Plots of radio flux density at 15 GHz as a function of time for the four components of MG0414+0534. All four components display variability at a level not uncommon in active galactic nuclei.

1.4 Radio Interferometry of Nearby dMe Stars

Sponsors

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

Project Staff

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dMe stars are dwarf M stars that show evidence of 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 in Very Long Baseline Intererometry (VLBI). The detection of dMe stars on VLBI baselines makes possible measurement of the position of these stars with high precision. In addition, it shows that astrometric detection of planetary companions may be feasible. The astrometric monitoring program has continued with third epoch measurements of dMe stars.

1.5 Algorithms for Advanced Microwave Sounding Unit Operational Use

Sponsors

MIT Lincoln Laboratory
SM Systems and Research Corporation

Project Staff

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

This project provides scientific support to the National Oceanic and Atmospheric Administration (NOAA) for the Advanced Microwave Sounding Unit (AMSU). The AMSU is scheduled for launch on NOAA polar-orbiting weather satellites in the mid-1990s and also for follow-on instruments. Our effort emphasizes development of line-by-line atmospheric transmittance algorithms,[3] estimation of

3 P.W. Rosenkranz, "Emission and Absorption of Microwaves by Atmospheric Oxygen and Water Vapor," paper presented at the Specialist Meeting on Microwave Radiometry and Remote Sensing Applications, Boulder, Colorado, January 14-16, 1992; H.J. Liebe, P.W. Rosenkranz, and G.A. Hufford, "Atmospheric 60-GHz Oxygen Spectrum: New Laboratory Measurements and Line Parameters," *J. Quant. Spectrosc. Radiat. Transfer* 48(5/6): 629-643 (1992).

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 Special Sensor Microwave Imager[4] and the Microwave Sounding Unit are used to develop and test prototype parameter-retrieval algorithms.

1.6 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, John W. Barrett, Michael J. Schwartz, Carlos R. Cabrera

The Advanced Microwave Sounding Unit (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.[5] According to our present plans, the temperature and humidity profiles obtained from AMSU will provide initial conditions for the AIRS infrared cloud-correction and profile retrieval algorithms. Current work is focused on simulation efforts and on a rapid (as distinguished from line-by-line) microwave transmittance algorithm.

1.7 High-Resolution Passive Microwave Imaging of Atmospheric Structure

Sponsor

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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 and March 1992, we participated in the STORM Fronts Experiment Systems Test (STORM-FEST), which was a national field experiment to provide research background and experience with new weather observing systems. Several winter storms in the Kansas-Oklahoma region were overflown. These measurements will be used to study the response of microwave radiometer measurements to precipitation and weather fronts.

In May, July, and August 1992, the MTS was flown along with the Microwave Imaging Radiometer, a NASA instrument, under the orbital track of a satellite carrying the new DMSP SSMT-2 instrument, a microwave humidity profiler. These flights will be used to validate satellite measurements.

On other flights, upward-observing profiles of atmospheric brightness temperature were obtained. These will be used to test recently developed atmospheric transmittance algorithms.

1.8 Rapid Precision Net-Form Manufacturing

Sponsor

MIT Leaders for Manufacturing Program

4 P.W. Rosenkranz, "SSM/I Measurements as Predictors of the Response of AMSU-A to Surface and Atmospheric Phenomena," paper presented at the First NMC/NESDIS/DOD Conference on DMSP Retrieval Products, Washington, DC, April 14-15, 1992; P.W. Rosenkranz, "Rough-Sea Microwave Emissivities Measured with the SSM/I," IEEE Trans. Geosci. Remote Sens. 30(5): 1081-1085 (1992).

5 D.H. Staelin, "Passive Microwave Observations of Atmospheric Parameters from Space," paper presented at the Specialist Meeting on Microwave Radiometry and Remote Sensing Applications, Boulder, Colorado, January 14-16, 1992.

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Algorithms were improved for estimating the shape of manufactured objects with a precision of microns at very high data rates.[6] The technique is to estimate in optimum fashion the distance at which minimum defocusing blur is encountered at each point on the object; multiple images are viewed (typically four or five) at different ranges while the object is illuminated with a fine grid of illuminated points of light (approximately 600 were observed). The experiment involves use of a previously developed four-axis stage with a simultaneously scannable volume of ~ 20 cubic inches. A 512^2 pixel CCD camera is employed with an adjustable field of view down to 0.5 mm². The system is fully computer controlled and can receive up to 30 frames per second.

Rms accuracies of 50 nm were obtained for ideal mirror surfaces for the 0.5-mm field and a stand-off distance of a few mm; this accuracy degraded to 100 nm when faster and simpler algorithms were employed. These accuracies were higher than those expected, partly because the nature of the blur function is strikingly asymmetric, as can be seen from thick lens ray tracing (but not thin lens or diffraction optics). For rougher materials—chalk, black plastic, and copper—accuracies of 1000-2000 nm were obtained. Chalk and plastic are difficult to test because light diffuses inside them on this spatial scale; copper exhibits strong glint from its microcrystalline surface. The system scaling laws derived reveal that these results might be useful in applications to much larger systems.

1.9 Conformal Experiment Design

Sponsor

MIT Leaders for Manufacturing Program

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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 such experiments; experimentation simply ceases when the allocated budget or time ends. Using 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 newly developed techniques, Dr. Ashraf Alkhairy[7] has shown that in many cases of practical interest, on the order of 2N experiments are sufficient to yield excellent results.

The coined phrase "conformal experiment design" suggests the way in which these new techniques 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 a priori knowledge and by matching more closely 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 enough or all unaccounted second-order interactions are negligible; the implication is that all higher-order interactions are then probably negligible too. Other methods often overlook some of these interactions even with N^2 experiments, and thus can yield inferior results.

The impact of these new, more efficient methods for experiment design can be substantial when studying processes and products that are characterized by so many significant parameters that N^2 experiments are not practical. Therefore, experimental optimization can be employed now for larger and more complex systems or subsystems with larger values of N. This could lead to significantly superior performance in cases where sequential optimizations of subsets of N parameters must otherwise be performed.

Initial comparisons of these methods with more traditional Taguchi and response-surface methods

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6 P.W. Fieguth, *Range Estimation Accuracy Using Depth-from-focus Methods—Theory and Experiment*, S.M. thesis, Dept. of Electr. Eng. and Comput. Sci., MIT, 1992.

7 A.S. Alkhairy, *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. Also RLE TR No. 572.

(RSM) by J.E. Glancy[8] and F.J. MacDonald, Jr.,[9] revealed that the conformal design technique yielded both better performance and process characterization and required fewer experiments for these cases (MacDonald did not test RSM). Glancy obtained a 68% increase in mean process performance for a heat sealing manufacturing operation and tripled process capacity with only eight conformal experiments. After 16 experiments, MacDonald reduced marginal manufacturing costs for a fiber drawing process by 30% and more than doubled the capacity of the existing drawing equipment while improving quality sufficiently to establish a new premium product line.

Our recent work has been directed toward generation of a simple user-friendly program to assist engineers with both experiment design and analysis of the results. This program accepts a list of control parameters and another of the most likely nonlinear interactions between them. The program then recommends sets of 8, 16, 32, 64 or more experiments, as selected by the user. These experiment sets are orthogonal arrays designed to evaluate preferentially those interactions of greatest concern. The analysis portion of the initial version will accept the experiment results, expressed as a user-chosen quality metric that incorporates errors in both mean and variance. It outputs an equation relating the input parameters to the quality and a list of parameter values that should yield maximum quality; this recommendation can readily be checked with only one or a few more experiments using these values. Once its development is complete, the program will be tested in industry and then improved further.

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. This project is exploring methods for compressing such signals so that the repetitious elements might be rapidly identified. The challenge is to maximize performance with minimal (perhaps zero) training with the system.

This year a broad class of robust measures of whistle parameters was applied to a database of approximately 1160 dolphin whistles collected for 22 animals. We used contact hydrophones to reduce the effects of environmental noise and propagation variations. Our current research involves developing methods for compact representation of the whistles and their efficient recall from a computer database. Preliminary search algorithms for a 16-dimension space require searching roughly five percent of the total data base, and sometimes more, to find the best Euclidian match. The reductions in search time obtained by less perfect searches are being explored. These same algorithms should also be useful for diagnosing acoustic and other signals produced by machinery, manufacturing processes, and other environments.

Studies of these dolphin whistles using these same whistle metrics have revealed a dolphin has much better control over frequency when reproducing its own signature whistles than when copying that of another dolphin.

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8 J.E. Glancy Jr., *Manufacturing Cost Modeling and Robust Process Design*, S.M. thesis, Dept. of Mech. Eng. and Dept. of Manage., MIT, 1992.

9 F.J. MacDonald, Jr., *An Integrative Approach to Process Parameter Selection in Fused-Silica Capillary Manufacturing*, S.M. thesis, Dept. of Electr. Eng. and Comput. Sci. and Dept. of Manage., MIT, 1992.