Section 4   Radio Astronomy

Chapter 1 Radio Astronomy

Chapter 1. Radio Astronomy

Academic and Research Staff

Professor Bernard F. Burke, Professor Jacqueline N. Hewitt, Professor David H. Staelin, Dr. Philip W. Rosenkranz, John W. Barrett

Visiting Scientists and Research Affiliates

Dr. Ann B. Saust-Rossi

Graduate Students

Ian M. Avruch, William J. Blackwell, Carlos R. Cabrera, Grace H. Chen, John D. Ellithorpe, Charles A. Katz, Deborah J. Becker-Haarsma, John K. Cartwright, Samuel R. Conner, Fronefield Crawford, André Fletcher, Lori K. Herold-Jacobson, Rizwan R. Koita, Christopher B. Moore, Mark A. Rawizza, Michael J. Schwartz, Michelle S. Spina

Undergraduate Students

Lauren B. Klatsky, Mark D. Messier

Technical and Support Staff

Anne E. Conklin

1.1 Extragalactic Radio Source Studies

Sponsor

National Science Foundation
Grant AST 92-24191

Project Staff

Professor Bernard F. Burke, Ian M. Avruch, Deborah J. Becker-Haarsma, John K. Cartwright, Samuel R. Conner, Fronefield Crawford, André Fletcher, Lori K. Herold-Jacobson

The research during the second year of the grant, "Extragalactic Radio Astronomy," has continued to focus on five general areas: (1) analysis of gravitational lensing by galaxies, (2) searching for new examples of gravitational lensing by galaxies, (3) studies of individual radio sources in our extensive VLA mapping study of MG radio sources, (4) completion of the Parkes-MIT-NRAO (PMN) survey of radio surveys in the southern sky, and (5) a search for distant neutral hydrogen concentrations beyond redshift 5.

This year, our study of gravitational lensed systems has concentrated on reducing our extended synoptic data on the twin quasar, B0957+561. We have published a value for the radio time delay between the two quasar images—a quantity of some cosmological significance because it gives a value for the Hubble constant that is based on entirely different assumptions from the traditional optical methods. Since we have continued to observe the system with the VLA during the four years that have elapsed since the previous value was published, we can now refine the propagation delay significantly. A major change has occurred in the fluxes of both components, and a new value for the time delay will be determined soon. The reduction is being carried out by Ms. Deborah Becker-Haarsma.

The gravitational lens search is proceeding along the same lines as in the previous year. The search starts with VLA snapshots of radio sources from the MIT-Green Bank (MG) survey, taken with the VLA and reduced to well-calibrated maps. The work this year is concentrated on optical observations that are needed to provide the verification that radio sources, having promising structures that suggest lensing, have multiple structure at optical wavelengths. The radio reductions have been carried out by Mr. Samuel Conner, and the optical observations are being made by Ms. Lori Herold-Jacobson and Mr. André Fletcher. The MDM 1.3 m telescope on Kitt Peak was used to observe 160 sources at r-band, and the identifications support both the lens search and the studies of individual sources.

Compact radio double sources form one particularly interesting subsample of the MG collection of VLA snapshots. We observed a collection of 24 of these objects, using the Jodrell Bank MERLIN array to gain higher angular resolution. This study shows

polarization asymmetry between the radio lobes as a frequently-occurring phenomenon (the Laing effect), and a publication is in preparation. The optical studies of the compact double sources, noted earlier, are being reduced at the present time and will form the Ph.D. dissertation of Ms. Herold-Jacobson. A second set of individual source studies is being worked on by Mr. Fletcher, as a part of his Ph.D. dissertation. The sources are taken from either the equatorial or tropical section of the PMN survey and will form a link between identification work in the northern and southern hemispheres.

The Parkes-MIT-NRAO (PMN) survey of the southern sky has been completed. Three sections, the southern, tropical, and equatorial surveys, have been published; and the final section, the Zenith survey, is being prepared for publication.

The survey for pre-galactic condensations of neutral hydrogen, beyond redshift 5, is underway. Preliminary observations were made in the fall of 1994, using the 4000-channel spectrometer developed in collaboration with Professor Paul Horowitz of Harvard University. The particular feed structures that were used turned out to be vulnerable to interference received in their far sidelobes, and a new feed is under construction. The system must contend with terrestrial interference in the 200-250 MHz band that we are using. However, we are optimistic that enough clear spots in the spectrum can be found to yield results that should give information on the state of the medium after the recombination era (z=1000) and before the galaxy formation era (after z=5).

1.1.1 Publications

Fletcher, A., S.R. Conner, and B.F. Burke. "First Results from 8.4 GHz VLA Imaging of 1800 Southern Sky Parkes-MIT-NRAO (PMN) Radio Sources." *Bull. A.A.S.* 26: 1503 (1994). (abstract)

Griffith, M.R., A.E. Wright, R.D. Eckers, and B.F. Burke. "The Parkes-MIT-NRAO (PMN) Surveys: VI. Source Catalogue for the Equatorial Survey (covering -9.5 degrees<gamma<+10 degrees)." *Astrophys. J. Suppl.* 97: 347 (1995).

Tasker, N.J., J.J. Condon, A.E. Wright, and M.R. Griffith. "The Parkes-MIT-NRAO (PMN) Surveys V: Maps for the Tropical Survey (covering -29 degrees<gamma<-9 degrees)" *Astron. J.* 107: 2115 (1994).

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 (covering -87.5 degrees<S<-37 degrees)." *Astrophys. J. Suppl.* 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 (covering -29 degrees<S<-9.5 degrees)." *Astroph J. Supp* 91: 111-308 (1994).

1.2 Studies of Gravitational Lenses

Sponsors

MIT Class of 1948/Career Development
   Chair
National Science Foundation
   Presidential Young Investigator Award
David and Lucile Packard Fellowship

Project Staff

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

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 the nature and distribution of luminous and dark matter in galaxies, and the calibration of the age and scale of the universe (i.e., the determination of the present value of the cosmological Hubble parameter).

Both applications require the inference of the distribution of gravitating matter from the observed imaging properties of the lens. This, in turn, requires 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). The high resolution data of figure 1 have been analyzed by an application of the LensClean algorithm developed by Professors Christopher S. Kochanek and Ramesh Narayan of Harvard University. The figure shows the 8 GHz VLA image, model background source, model gravitationally lensed source, and residuals of the model fit. The model, which is a good fit to the data, is highly con-

strained. However, a signficant number of residuals remain, and our effort to reconstruct the mass distribution in this lens is continuing.

The analysis depicted in Figure 1 was carried out using the images generated by the VLA. The image reconstruction techniques introduce errors into the process. To eliminate this source of error, we have developed a modified version of the LensClean algorithm, Visibility LensClean, that operates directly on the interferometer data. This algorithm is being tested and applied to VLBA data. We anticipate that it will be a critical resource in the interpretation of data from sparse antenna arrays such as the VLBA.

In a gravitational lens system, there are differences in the propagation time on 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 the light curves has shown that the variations of the images of MG0414+0534 are correlated, providing further evidence that the MG0414 system is indeed gravitationally lensed. Furthermore, the monitoring data suggest that the third brightest of the four gravitationally lensed images leads the rest, a result that excludes certain models for the lensing mass distribution. Monitoring of the gravitational lens MG1131+0456 (at radio wavelengths) and PG1115+080 (at optical wavelengths, in collaboration with R. Schild of the Harvard-Smithsonian Center for Astrophysics) has detected significant variability in these objects, indicating that time delay measurements should be pursued. Measurements of the time delays would provide a measurement of
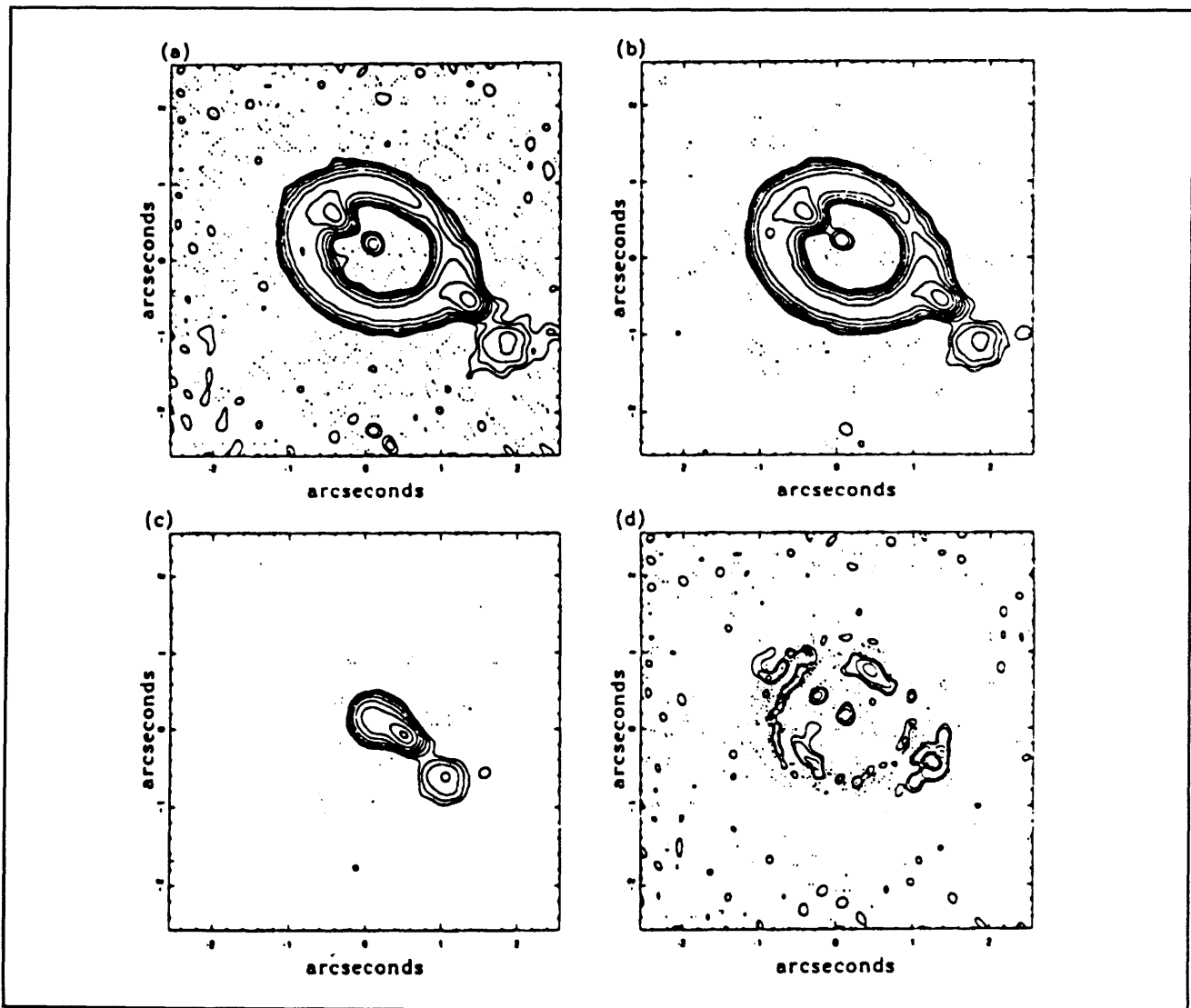
Figure 1. The 8 GHz VLA image, model background source, model gravitationally lensed sources, and residuals of the model fit.

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the distances involved in the geometry of the gravitational lens system. Such an independent measure of distance provides a calibration of the present value of the cosmological Hubble parameter.

The time delay measurement techniques used in these investigations are general, so they have also been applied to the multifrequency monitoring data for the BL Lac object PKS2155-304.

1.2.1 Publications

Chen, G.H., C.S. Kochanek, and J.N. Hewitt. "The Mass Distribution of the Lens Galaxy in MG1131+0456." *Astrophys. J.* Forthcoming.

Edelson, R., J. Krolik, G. Madejski, L. Maraschi, G. Pike, C.M. Urry, W. Brinkmann, W., T.J.-L. Courvoisier, J. Ellithorpe, K. Horne, A. Treves, S. Wagner, W. Wamsteker, R. Warwick, H.D. Aller, M.F., Aller, M. Ashley, A. Blecha, P. Bouchet, P. Bratschi, J.N. Bregman, M. Carini, A. Celotti, M. Donahue, E. Feigelson, A.V. Filippenko, H. Fink, I. George, I. Glass, J. Heidt, J.N. Hewitt, P. Hughes, R. Kollgaard, Y. Kondo, A. Koratkar, K. Leighly, A. Marscher, T. Matheson, P.G. Martin, H.R. Miller, J.C. Noble, P. O'Brien, E. Pian, G. Reichert, J.M. Saken, J.M. Shull, M. Sitko, P.S. Smith, W.-H. Sun, and G. Tagliaferri. "Multi-Wavelength Monitoring of the BL Lac Object PKS 2155-304. IV. Multi-Wavelength Analysis." *Astrophys. J.* Forthcoming.

Hewitt, J.N., G.H. Chen, and M.D. Messier. "Variability in the Einstein Ring Gravitational Lens MG1131+0456." *Astronom. J.* Forthcoming.

Moore, C.B., and J.N. Hewitt. "Time Delay Observations and Variability of the Gravitational Lens MG0414+0534." Submitted to *Astrophys. J.*

Invited Talks

Hewitt, J.N. "Gravitational Lenses: A New Tool for Astrophysicists." U.S. Coast Guard Academy, Lecture, February 15, 1994.

Hewitt, J.N. "Gravitational Lenses and Cosmology." Argonne National Laboratory Physics Division Colloquium, April 1, 1994.

Hewitt, J.N. "Gravitational Lenses, Time Delays, and Hubble's Constant." University of California, Berkeley, Department of Astronomy Colloquium, April 7, 1994.

Hewitt, J.N. "Gravitational Lenses, Time Delays, and Hubble's Constant." Lawrence Livermore National Laboratory Colloquium, April 8, 1994.

Hewitt, J.N. "Gravitational Lenses - Observations." Fourth New England Regional Quasar/AGN Meeting, Brandeis University, review talk, May 6, 1994.

Hewitt, J.N. "Gravitational Lenses, Time Delays, and Hubble's Constant." California Institute of Technology Colloquium, May 25, 1994.

1.3 The Detection of Astronomical Radio Transients

Sponsors

MIT Class of 1948/Career Development
    Chair
National Science Foundation
    Presidential Young Investigator Award
David and Lucile Packard Fellowship

Project Staff

Professor Jacqueline N. Hewitt, John W. Barrett, Charles A. Katz, Lauren B. Klatsky, Christopher B. Moore, John D. Ellithorpe

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 to determine how frequently they occur.

Third, transients at other wavelengths are known to exist. The Compton Observatory is detecting gamma ray bursts at a rate of approximately one per day. X-ray transients have also been detected, many associated with radio outbursts. In the near future, all-sky monitors will be launched on the X-ray Transient Explorer and the High Energy Transient Experiment. An all-sky radio monitor is needed to detect any radio counterparts to the x-ray and gamma ray transients and to place 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 the construction of a network of geographically separated correlating arrays. Proto-type receivers, antennas, and data acquisition systems have been designed and constructed and are currently undergoing testing. The design of correlating arrays has begun.

This project is being carried out in collaboration with Alan E.E. Rogers and Brian E. Corey of MIT's Haystack Observatory.

1.3.1 Publications

Katz, C.A., J.N. Hewitt, C.B. Moore, and J.D. Ellithorpe. "The STARE Project: A Search for Transient Astronomical Radio Emission." *Bull. Am. Astronom. Soc.* Forthcoming.

Invited Talks

Hewitt, J.N. "Detecting Astronomical Radio Transients." Talk presented to the Radio Astronomy and Geodesy Group, Harvard-Smithsonian Center for Astrophysics, March 5, 1994.

1.4 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 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 instrument improvements. 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.

1.4.1 Publications

Rosenkranz, P.W. "A Rapid Transmittance Algorithm for Microwave Sounding Frequencies," *Digest of the International Geoscience and Remote Sensing Symposium*, Pasadena, California, August 8-12, 1994.

Rosenkranz, P.W. "A Rapid Atmospheric Transmittance Algorithm for Microwave Sounding Frequencies." submitted to *IEEE Trans. Geosci. Rem. Sensing.*

Schwartz, M.J., J.W. Barrett, P.W. Rosenkranz, and D.H. Staelin. "Atmospheric Transmittance Measurements Near 118 GHz." *Digest of the International Geoscience and Remote Sensing Symposium*, Pasadena, California, August 8-12, 1994.

1.5 Earth Observing System: Advanced Microwave Sounding Unit

Sponsor

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

Project Staff

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

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.

Artificial neural network techniques have been applied to retrievals of humidity profiles from simulated microwave spectral observations; to estimation of the altitudes of precipitation cell tops using data from the Microwave Temperature

Sounder; and to compact representation of radiometric data.

1.5.1 Publications

Cabrera-Mercader, C.R., and D.H. Staelin. "Passive Microwave Humidity Profile Retrievals Using Neural Networks." *Digest of the International Geoscience and Remote Sensing Symposium,* Pasadena, California, August 8-12, 1994.

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

Kuo, C.C., D.H. Staelin, and P.W. Rosenkranz. "Statistical Iterative Scheme for Estimating Atmospheric Relative Humidity Profiles." *IEEE Trans. Geosci. Rem. Sens.* 32(2): 254-260 (1994).

Rosenkranz, P.W. "A Rapid Transmittance Algorithm for Microwave Sounding Frequencies." *Digest of the International Geoscience and Remote Sensing Symposium,* Pasadena, California, August 8-12, 1994.

Rosenkranz, P.W. "A Rapid Atmospheric Transmittance Algorithm for Microwave Sounding Frequencies." submitted to *IEEE Trans. Geosci. Rem. Sensing.*

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." *Digest of the International Geoscience and Remote Sensing Symposium,* Pasadena, California, August 8-12, 1994.

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.*

Thesis

Spina, Michelle S. *Application of Multilayer Feedforward Neural Networks to Precipitation Cell-Top Altitude Estimation.* M.S. thesis. Dept. of Electr. Eng. and Comput. Sci., MIT, 1994.

1.6 High-Resolution Passive Microwave Imaging of Atmospheric Structure

Sponsor

National Aeronautics and Space Administration/
    Goddard Space Flight Center
    Grant NAG5-10

Project Staff

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

High-resolution 118-GHz measurements of tropical cyclone Oliver (obtained in 1993) were processed. They show warming of approximately 10K in the eye relative to the environment, and the convective cloud structure of the eyewall and cloud bands. Cloud-top altitudes were inferred from the data using a neural-network algorithm.

Upward-observing profiles of atmospheric brightness temperature at 52-54 and 118 GHz are being used to test atmospheric transmittance algorithms.

1.6.1 Publications

Schwartz, M.J., J.W. Barrett, P.W. Rosenkranz, and D.H. Staelin. "Atmospheric Transmittance Measurements Near 118 GHz." *Digest of the International Geoscience and Remote Sensing Symposium,* Pasadena, California, August 8-12, 1994.

Schwartz, M.J., J.W. Barrett, P.W. Fieguth, P.W. Rosenkranz, M.S. Spina, and D.H. Staelin. "Passive Microwave Imagery of a Tropical Storm Near 118 GHz: Thermal and Precipitation Structure." *Digest of the International Geoscience and Remote Sensing Symposium,* Pasadena, California, August 8-12, 1994.

1.7 Reduction of Variation

Sponsor

MIT Leaders for Manufacturing Program

Project Staff

Professor David H. Staelin, Rizwan R. Koita, Mark A. Rawizza, Michelle S. Spina

Reduction of process and product variation is a primary economic goal in most manufacturing operations. Progress this year has centered in two areas: 1) continued development of "conformal experiment design" techniques which seek to optimize and characterize processes with as few as 2N experiments, where N is the approximate number of important parameters, and 2) development of "data-rich" data analysis techniques which most efficiently identify the nature and origin of the principal sources of variation in products and processes.

A previously developed software tool proposed sets of experiments which preferentially evaluate potential two-parameter interactions of greatest concern, based on the user's a priori knowledge about the process. If analysis of that block of experimental results suggests not all process variables or interactions have been identified, a second set of experiments is often desirable. Two methods for generating such a second block of experiments were developed. One method generates a set of experiments half the size of the original block, and the other method generates a second set of size equal to the original set. These new methods thus supplement the design software developed previously. This new method produces new factorial experiment designs with confounding patterns maximally different from those of the first block of experiments. These subsequent designs can be directed to focus on certain interactions of potential interest. The power of these new methods for sequential block design is limited, however, to identifying only one or a few new interactions per block of experiments.

A new method for sequentially designing experiments one-at-a-time was also developed. After an initial block of experiments has been performed, certain columns in the experiment matrix may be significant and also contain more than one potentially significant contributing interaction. The one-at-a-time method can be used to identify which interactions are dominant in each column, and permits optimization of the process with a minimum number of experiments, typically on the order of the number of significant variables. The method involves iteratively hypothesizing on the basis of all prior data the most probable process model consistent with prior experiments, and then designing and performing that one experiment which should yield maximum quality. If the recommended experiment has been previously performed, then the next most likely process model is selected and its corresponding optimum process parameters are tested experimentally. This process is iterated until the process model predicts with adequate accuracy the outcomes of all experiments performed to date. These methods are particularly important when experiments can be conducted one at a time efficiently, and each experiment is costly in time or money.

Methods for identifying and controlling principal sources of variation in manufacturing processes are being developed by testing them on actual manufacturing data from LFM partner companies, including Alcoa, General Motors, Intel, Kodak, and potentially others. The commercially significant processes examined to date are typically characterized by multi-variant linear relationships between process observations and the resulting product characteristics. These relationships exhibit systematic drifting and discontinuities in process characteristics which are often hidden in superficial process noise and which, when identified, should permit improved process control and reduction in variation.

1.7.1 Thesis

Koita, Rizwan R. Strategies for Sequential Design of Experiments. M.S. thesis. Dept. of Electr. Eng. and Comput. Sci., MIT, 1994.