NASA-CR-200735

FINAL

FINAL TECHNICAL REPORT

NASA Grant NAGW-4187

March 29, 1996

37293

TITLE PAGE

Type of Report ..... Final Technical Report

Period Covered ..... July 1, 1994 — January 31, 1996

Grant Number NAGW-4187

Title of Grant ..... "International Conference on Interstellar Polarization"

Principal Investigator ..... Dr. Wayne G. Roberge

Grantee's Address

Physics Dept.
Rensselaer Polytechnic Institute
Troy, NY 12180-3590
Tel. (518)-276-6454
Internet: roberw@rpi.edu

FINAL TECHNICAL REPORT

The objective of this grant was to support an international conference, *Polarimetry of the Interstellar Medium*, to be held at Rensselaer Polytechnic Institute. We have the following results to report:

- The conference attracted over 100 participants from around the world and was a great success. A list of the participants is attached.
- We have published the proceedings in *Polarimetry of the Interstellar Medium*, ASP Conference Series, vol. 97, in press. The table of contents and preface are attached. This proceedings will be a valuable tool for researchers and beginning grad students for years to come.

We are deeply grateful for NASA's support at an early stage of the planning, which catalyzed our successful fund-raising efforts for the meeting.

Participant List

Andrew J. Adamson	a.j.adamson@uclan.ac.uk	U. Central Lancashire
Nancy Ageorges	nageorge@eso.org	ESO, Garching
David K. Aitken	dave@phadfa.ph.adfa.oz.au	Univ. of Hertfordshire
Richard G. Allen	rallen@as.arizona.edu	Steward Observatory
Christopher M. Anderson	anderson @madraf.astro.wisc.edu	Univ. of Wisconsin
Pierre Bastien	bastien@physcn.umontreal.ca	Univ. de Montréal
Rainer Beck	rbeck@mpifr-bonn.mpg.de	MPI, Bonn
Simone Bianchi	sbianchi@arcetri.astro.it	Univ. di Firenze
Karen S. Bjorkman	karen@sal.wisc.edu	Univ. of Wisconsin
Vitor Hugo R. Bonifacio	V.Bonifacio@qmw.ac.uk	Univ. of London
Janet E. Bowey	j.e.bowey@uclan.ac.uk	U. Central Lancashire
Sean J. Carey	carey@charon.phys.rpi.edu	Phillips Lab/GPOB
Andrew W. Chen	awc@orphee.phys.columbia.edu	Columbia Univ.
Jean E. Chiar	chiar@charon.phys.rpi.edu	Rensselaer
Antonio Chrysostomou	acc@star.herts.ac.uk	Univ. of Hertfordshire
Glenn E. Ciolek	ciolek@jets.uchicago.edu	Univ. of Chicago
Geoffrey C. Clayton	gclayton@fenway.colorado.edu	Univ. of Colorado
Dan Clemens	clemens@protostar.bu.edu	Boston Univ.
Cecilia Colomé	cc@astro.as.utexas.edu	Univ. of Texas
Mark A. Creese	creese@astro.spa.umn.edu	Univ. of Minnesota
Mary A. Dahm	mdahm@mercury.cair.du.edu	Univ. of Denver
Jacqueline A. Davidson	davidson@cma.arc.nasa.gov	NASA/Ames
Steven J. Desch	desch@sirius.astro.uiuc.edu	Univ. of Illinois
Susan A. DiFranzo	difras@rpi.edu	Rensselaer
Jessie L. Dotson	jdotson@nwu.edu	Nortwestern Univ.
Bruce T. Draine	draine@astro.princeton.edu	Princeton Univ.
Andreas Efstathiou	a.efstathiou@ic.ac.uk	Imperial College
Michael P. Egan	egan@pldac.plh.af.mil	Phillips Lab/GPOB
James P. Emerson	j.p.emerson@qmw.ac.uk	Univ. of London
Andrea Ferrara	ferrara@arcetri.astro.it	Arcetri Observatory
Michael E. Fogel	fogel@charon.phys.rpi.edu	Rensselaer
Stephen R. Fullerton	S.R.Fullerton@durham.ac.uk	Univ. of Durham
Frederick J. Gellert	hf1272@usma6.usma.edu	USMA, West Point
Perry A. Gerakines	gerak@charon.phys.rpi.edu	Rensselaer
Jason Glenn	jglenn@astro.as.arizona.edu	Steward Observatory
Alyssa A. Goodman	agoodman@cfa.harvard.edu	CfA/Harvard
Jane S. Greaves	jsg@jach.hawaii.edu	JAC, Hawaii
James C. Green	jgreen@casa.colorado.edu	Univ. of Colorado
Roger Hajjar	hajjar@astro.umontreal.ca	Univ. of Montréal
Keith E. Hartman	hartman@charon.phys.rpi.edu	Rensselaer
Lida He	lida@charon.phys.rpi.edu	Rensselaer
Carl Heiles	cheiles@astro.berkeley.edu	UC Berkeley
Toshihisa Hibarino	hibarino @zlab.phys.nagoya-u.ac.jp	Nagoya Univ.

Roger H. Hildebrand	roger@oddjob.uchicago.edu	Univ. of Chicago
Keiko Honda	kei@zlab.phys.nagoya-u.ac.jp	Nagoya Univ.
James H. Hough	JHH@star.herts.ac.uk	Univ. of Hertfordshire
Busaba Hutawarakorn	BH@JB.MAN.AC.UK	Univ. of Manchester
David A. Joiner	joiner@charon.phys.rpi.edu	Rensselaer
Terry J. Jones	tjj@astro.spa.umn.edu	Univ. of Minnesota
Brian D. Kane	kane@buast1.bu.edu	Boston Univ.
John S. Karcz	karczj@rpi.edu	Rensselaer
Joel H. Kastner	jhk@juggler.mit.edu	MIT
Koji Kawabata	kawabata @astroa.astr.tohoku.ac.jp	Tohoku Univ.
Dimitri I. Klebe	dklebe@mercury.cair.du.edu	Univ. of Denver
Naoto Kobayashi	naoto@merope.mtk.nao.ac.jp	NAO, Japan
Jan Koornneef	koornneef@sron.rug.nl	SRON, Groningen
Monika E. Kress	kress@dusty.arc.nasa.gov	NASA/Ames
Kristen A. Larson	kal@charon.phys.rpi..edu	Rensselaer
Alex Lazarian	lazarian@astro.princeton.edu	Princeton Univ.
Dawn Leeber	leebed@rpi.edu	Rensselaer
Chun Ming Leung	leung@charon.phys.rpi.edu	Rensselaer
Antonio M. Magalhães	mario@argus.iagusp.usp.br	Univ. of Sao Paulo
Nadine Manset	manset@astro.umontreal.ca	Univ. de Montréal
Peter G. Martin	pgmartin@cita.utoronto.ca	Univ. of Toronto
John S. Mathis	mathis@madraf.astro.wisc.edu	Univ. of Wisconsin
Masafumi Matsumura	matsu@ed.kagawa-u.ac.jp	Kagawa Univ.
Gordon C. McIntosh	mcintogc@caa.mrs.umn.edu	U. Minnesota, Morris
François Ménard	menard@gag.observ-gr.fr	Obs. de Grenoble
David W. Messinger	mess@charon.phys.rpi.edu	Rensselaer
Alexander G. Murray	a.g.murray@qmw.ac.uk	Univ. of London
Tetsuya Nagata	nagata @zlab.phys.nagoya-u.ac.jp	Nagoya Univ.
Ramon Nartallo	R.Nartallo@qmw.ac.uk	Univ. of London
Nikolaus Neininger	p086nei@mpifr-bonn.mpg.de	MPI, Bonn
Kenneth H. Nordsieck	khn@sal.wisc.edu	Univ. of Wisconsin
Giles Novak	g-novak@nwu.edu	Northwestern Univ.
Akira Okazaki	okazaki@la.gunma-u.ac.jp	Gunma Univ.
Takashi Onaka	onaka@astron.s.u-tokyo.ac.jp	Univ. of Tokyo
Bryan E. Penprase	penprase @shanti.pomona.claremont.edu	Pomona College
Joan Perras	perraj@rpi.edu	Rensselaer
Stephen R. Platt	srp@hale.yerkes.uchicago.edu	Yerkes Obs.
Read Predmore	predmore @fcrao1.phast.umass.edu	FCRAO, UMass
Ramprasad P. Rao	ramp@astro.uiuc.edu	Univ. of Illinois
Mark G. Rawlings	rawlings@draco.phys.rpi.edu	Rensselaer
Marty D. Reese	mreese@physunc.phy.uc.edu	Univ. of Cincinnati
Wayne Roberge	roberw@rpi.edu	Rensselaer
Douglas A. Roberts	droberts@astro.uiuc.edu	Univ. of Illinois
Patrick F. Roche	p.roche@physics.ox.ac.uk	Oxford Univ.
Scott A. Sandford	sandford@ssa1.arc.nasa.gov	NASA/Ames

David A. Schleuning	david@oddjob.uchicago.edu	Univ. of Chicago
Munezo Seki	seki@astroa.astr.tohoku.ac.jp	Tohoku Univ.
Russell F. Shipman	shipman@plh.af.mil	Phillips Lab/GPOB
Jeffrey T. Shykula	jshykula@charon.phys.rpi.edu	Rensselaer
William B. Somerville	wbs@star.ucl.ac.uk	Univ. College London
Wilfred H. Sorrell	swsorre@slvaxa.umsl.edu	U. Missouri, St. Louis
Kate Spilker	spilkc@rpi.edu	Rensselaer
Motohide Tamura	otamura@c1.mtk.nao.ac.jp	NAO, Japan
Susan R. Trammell	srt@oddjob.uchicago.edu	Univ. of Chicago
Peter G. Wannier	wannier@jplsp.jpl.nasa.gov	JPL
David A. Weintraub	david@ttau.phy.vanderbilt.edu	Vanderbilt Univ.
Anthony J. Weitenbeck	ajw@sal.wisc.edu	Univ. of Wisconsin
Doug Whittet	doug@whittet.phys.rpi.edu	Rensselaer
Michael J. Wolff	mwolff@casa.colorado.edu	Univ. of Colorado
Kenneth Wood	kenny@madraf.astro.wisc.edu	Univ. of Wisconsin
Ellen G. Zweibel	zweibel@lepton.colorado.edu	Univ. of Colorado

Table of Contents

Preface xvii

Conference participants xix

Part 1. Optical and Magnetic Properties of Dust

Observational Constraints on Dust Models* 3
J. S. Mathis

Optical and Magnetic Properties of Dust Grains* 16
B. T. Draine

The Composition of Interstellar Grains and Ices* 29
S. A. Sandford

Of Scattering Properties and Approximation Techniques: To EMT or Not to EMT 48
M. J. Wolff, S. J. Gibson and G. C. Clayton

Calculation of the Polarization in Scattering from Core-Mantle Grains . 58
S. R. Fullerton and S. M. Scarrott

Properties of Extinction and Polarization by Ellipsoidal Particles 63
M. Matsumura and M. Seki

Using a PC to Model Radiation Transport in a Dusty Medium 67
D. A. Joiner and C. M. Leung

Polarized Thermal Emission of Aligned Dust Grains in an Anisotropic Radiation Field 72
T. Onaka

Part 2. Instrumentation

A New Camera for the 10 and 20 μm Region 79
D. I. Klebe, M. A. Dahm and R. E. Stencel

Near-Infrared Two Dimensional Speckle Polarimetric Imaging 85
N. Ageorges, A. Eckart, R. Hofmann and B. Stecklum

Beauty and the Beast: The Polarimeter of the Université de Montréal . 90
N. Manset and P. Bastien

*Invited review.

Middle Explorers, Small Explorers, and the Polarimetric Infrared Explorer (PIREX) 95
D. Clemens

Future UV/Visible Spectropolarimetric Studies of Interstellar Polarization at the University of Wisconsin 100
K. H. Nordsieck and W. Harris

A Newly-Developed Near-Infrared Prism Spectrophotopolarimeter for 1.4 – 4.2 micron Simultaneous Observation 106
N. Kobayashi, T. Nagata, T. Takeuchi, H. Takami and S. Sato

Submillimeter Observations from Antarctica – Polarimetry and Photometry 111
G. Novak, J. Dotson, T. Renbarger, S. R. Platt and M. Dragovan

Development of Achromatic Waveplates for Submillimeter Polarimetry . 116
A. G. Murray, P. A. R. Ade and M. J. Griffin

High Precision CCD Imaging Polarimetry 118
A. M. Magalhães, C. V. Rodrigues, V. E. Margoniner, A. Pereyra and S. Heathcote

Part 3. Diffuse ISM, Circumstellar Matter

Continuum Polarization of Starlight* 125
D. C. B. Whittet

Spectropolarimetry of Optical and Ultraviolet Extinction Features* . . . 143
W. B. Somerville

The General Galactic Ultraviolet Interstellar Polarization Program of the Wisconsin Ultraviolet Photo Polarimeter Experiment 159
C. M. Anderson, A. J. Weitenbeck, A. D. Code, the WUPPE Team and Guest Investigators

Polarization by Dust in High Latitude Clouds 168
M. Seki and M. Matsumura

Ultraviolet and Visible Spectropolarimetry of HD 44179 and the Red Rectangle 173
M. D. Reese, M. L. Sitko and R. G. Allen

Multichannel Polarimetry of Nova Cassiopeiae 1993 178
A. Okazaki, J. Kurihara, R. Hirata, S. Kikuchi, H. Satoh, K. Yoshioka, K. Saijo, M. Seki, K. Kawabata, K. Hayashi and M. Matsumura

Interstellar Polarization in the Direction of NGC 1502 183
A. J. Weitenbeck, C. M. Anderson, A. D. Code, the WUPPE Team and Guest Investigators

Large Variations in the Polarization Properties of Nova Cassiopeiae 1993 186
K. Kawabata, M. Seki, M. Matsumura, A. Okazaki, S. Kikuchi and R. Hirata

The Effect of Multiple Scattering on the Polarization and IR Excess of Be Stars: Constraints on the Disk Geometry 191

K. Wood, J. E. Bjorkman, B. A. Whitney and A. D. Code

Probing the Circumstellar Environment with Spectropolarimetry in the Optical and Ultraviolet 197

K. S. Bjorkman, O. L. Lupie, M. R. Meade, B. L. Babler, C. M. Anderson, A. D. Code, G. K. Fox, J. J. Johnson, K. H. Nordsieck, A. J. Weitenbeck, N. E. B. Zellner, R. J. Edgar, W. T. Sanders, R. E. Schulte-Ladbeck, G. C. Clayton and the PBO Science Team

Dust in a Hostile Environment: Interstellar Dust in the Line of Sight to HD 62542 202

A. M. Magalhães, C. V. Rodrigues, M. Meade, A. D. Code, K. H. Nordsieck, C. M. Anderson, J. Bailey, J. H. Hough and P. J. Wheatley

Linear Polarization of Isotopic SiO Masers 207

G. C. McIntosh and C. R. Predmore

Dust Envelopes of Evolved Stars: Lessons Learned from Near-Infrared Polarimetric Coronagraphic Imaging 212

J. H. Kastner and D. A. Weintraub

Optical Imaging Polarimetry of the Young Planetary Nebulae GL 618, M1-92, and M1-91 217

S. R. Trammell, J. F. Kartje, G. J. Hill and H. L. Dinerstein

Part 4. Dense ISM, Young Stellar Objects I.

Spectropolarimetry of Solid State Features in the Infrared* 225

D. K. Aitken

3 μm Spectropolarimetry of H_2O Ice in Young Stellar Objects 243

A. Chrysostomou, J. H. Hough, D. W. Messinger, D. C. B. Whittet, D. K. Aitken and P. F. Roche

Modeling New Spectropolarimetry Data for the BN Object 249

D. W. Messinger, W. G. Roberge, D. C. B. Whittet, A. Chrysostomou and J. H. Hough

Problems in Far-Infrared Polarimetry* 254

R. H. Hildebrand

Investigating Correlations in the Kinematics and Magnetic Fields of Quiescent Bok Globules 269

B. D. Kane and D. P. Clemens

Optical Polarimetry and High Resolution Spectroscopy of Stars toward the Chamaeleon I Dark Cloud 274

B. E. Penprase, E. Covino, L. Terranegra, E. Palazzi and H. Schwarz

Ultraviolet Extinction and Diffuse Interstellar Bands in Chamaeleon I . 279

A. J. Adamson, D. C. B. Whittet and W. W. Duley

Array Polarimetry of the Orion Nebula from the Caltech Submillimeter Observatory 285
D. A. Schleuning, C. Darren Dowell and S. R. Platt

Polarization of the Far-Infrared Emission of M17 290
J. L. Dotson

Part 5. Dense ISM, Young Stellar Objects II.

Polarization of Young Stellar Objects* 297
P. Bastien

Can the Geometrical Parameters of YSOs' Accretion Disks be Evaluated by Polarimetry? 315
F. Ménard, G. Duchène, E. Viard and L. Colombet

Near-Infrared Spectropolarimetry of L1551 IRS 5, HL Tau, and T Tau . 321
N. Kobayashi, M. Tamura, T. Nagata, S. Sato and T. Takeuchi

The Interpretation of Polarization Position Angle Measurements* 325
A. A. Goodman

Betrayed: Using Near-Infrared Imaging Polarimetry to Locate the Sources of YSO Molecular Outflows 345
D. A. Weintraub and J. H. Kastner

Near-IR Imaging Polarimetry of L1489, a YSO in Taurus 350
J. P. Emerson and T. J. T. Moore

Imaging Polarimetry of Young Stellar Objects 355
R. Hajjar and P. Bastien

Prism Spectropolarimetry of Highly-Reddened Stars at 1–2.5 μm 360
T. Nagata, S. Sato, N. Kobayashi, Y. Kobayashi and K. Mizutani

Modelling the Probability Distribution of the Angle Between the Linear Polarization and Outflow Directions in the Plane of the Sky . . . 363
V. H. R. Bonifácio and J. P. Emerson

Discovery of A Second Reflection Nebula within the Protostellar Cluster S140 367
C. Colomé and P. M. Harvey

Magnetic Fields in Star Forming Regions - Near-Infrared and Submillimeter Approaches 372
M. Tamura, S. Hayashi, Y. Itoh, J. H. Hough and A. Chrysostomou

Part 6. Grain Alignment

Observational Constraints on Grain Alignment Mechanisms* 381
T. J. Jones

Grain Alignment in Dark Clouds: New Results for Taurus 396
P. A. Gerakines and D. C. B. Whittet
Grain Alignment in Molecular Clouds* 401
W. G. Roberge
Purcell Pinwheels in Cold Dark Clouds 419
W. H. Sorrell
Mechanical Alignment of Suprathermal Grains 425
A. Lazarian
Infrared Polarimetry of Highly Reddened Stars in the Galactic Plane . . 430
M. A. Creese and T. J. Jones
Gold Alignment 433
A. Lazarian
Paramagnetic Alignment 438
A. Lazarian
Grain Alignment by Ambipolar Diffusion in Molecular Clouds 443
D. W. Messinger, W. G. Roberge and S. Hanany
Paramagnetic/Superparamagnetic Alignment of Molecular Cloud Grains 444
W. G. Roberge, T. A. DeGraff and J. E. Flaherty
Implications from Spectropolarimetry of the 2175 Å Extinction Feature 445
J. S. Karcz and W. G. Roberge
Infrared Polarization in the Molecular Disk at the Galactic Center . . . 450
S. J. Desch and W. G. Roberge

Part 7. Magnetic Fields

A Comprehensive View of the Galactic Magnetic Field, Especially near the Sun* 457
C. Heiles
The Structure of Interstellar Magnetic Fields as Derived from Polarization Observations in Radio Continuum 475
R. Beck
Polarimetry and the Theory of the Galactic Magnetic Field* 486
E. G. Zweibel
The Magnetic Field Structure in the Galactic Center* 504
J. A. Davidson
Multi-Band Photo-Polarimetry: A Study of Two Nearby Dark Clouds . 522
P. G. Wannier and B. -G. Andersson
Comparison of Zeeman and Infrared Polarization Maps toward Star Forming Regions 527
D. A. Roberts, R. M. Crutcher and T. H. Troland

Magnetic Fields in the Cloud Core W75N: MERLIN Spectral Line Results 532
B. Hutawarakorn and R. J. Cohen

Flux Tubes in the Interstellar Medium 537
A. Lazarian and E. Vishniac

Effects of Grains and the Structure of Magnetic Fields in Collapsing Protostellar Cores 542
G. E. Ciolek

Part 8. Galactic Structure, External Galaxies

Near- and Mid-Infrared Polarimetry of the Galactic Centre* 551
P. F. Roche

Polarimetry of External Galaxies* 569
J. H. Hough

Extinction and Polarization in Spiral Galaxy Models 587
S. Bianchi, A. Ferrara and C. Giovanardi

High Resolution Radio Continuum Polarization of M51 592
N. Neininger and C. Horellou

Submillimetre Polarimetry of Blazars 598
R. Nartallo, W. K. Gear, A. G. Murray, E. I. Robson and J. H. Hough

A Model for the Infrared Polarization of NGC 1068 602
A. Efstathiou, J. H. Hough, A. McCall and S. Young

Dust in the Small Magellanic Cloud 607
C. V. Rodrigues, G. V. Coyne, S. J. and A. M. Magalhães

Astro-2 Observations of Ultraviolet Polarization and Extinction by Interstellar Dust in the LMC 612
J. Green, G. C. Clayton, M. J. Wolff, N. E. B. Zellner, A. D. Code, A. F. Davidsen, The WUPPE and HST Teams

Conference Summary

Polarimetry of the Interstellar Medium: Concluding Summary 618
G. C. Clayton

Author index 623

Subject index 625

Object index 631

Preface

It is almost half a century since Hall and Hiltner showed that the light from reddened stars is partially plane polarized. Almost simultaneously, Davis and Greenstein provided the first model to interpret this phenomenon in terms of extinction by aligned dust grains in the interstellar medium. In the years since then, an enthusiastic subset of the astronomical community has come to realize the potential of polarimetric techniques for the study of, amongst other things, the nature of interstellar and circumstellar dust, and the structure of the magnetic field, in our own and other galaxies.

This volume documents the proceedings of *Polarimetry of the Interstellar Medium*, a comprehensive meeting on polarization by interstellar and circumstellar dust held at Rensselaer Polytechnic Institute during June 4–7, 1995. We felt that the time was right for such a meeting. On the one hand, it has been more than 20 years since the last conference devoted exclusively to this subject and a single volume recording the remarkable progress of the past few years seemed warranted. Thus, the following pages describe recent developments in continuum polarimetry, spectropolarimetry, polarimetric imaging, numerous applications to the interstellar medium of our Galaxy and external galaxies, and related theoretical work. On the other hand, it seems inevitable that the next few years will see rapid growth in the exploitation of polarimetry, especially by nonspecialists interested primarily in its applications to star formation, Galactic structure, and related fields. Accordingly, the volume also includes an unusually large number of review articles on polarimetric observations, the interpretation of polarimetric data, and related topics on the observed properties and fundamental physics of dust grains and magnetic fields. Collectively, these reviews form an up-to-date introduction to the field which should serve the needs of beginning graduate students and other researchers for years to come.

We owe a debt of gratitude to the organizations that supported the conference, and to our colleagues who ensured its success by their enthusiastic participation on the Local and Scientific Organizing Committees. The financial support of NASA (grant NAGW-4187), the Dudley Observatory, and Rensselaer Polytechnic Institute are gratefully acknowledged. Special thanks go to Jan Vrtilek at NASA headquarters, whose enthusiasm catalyzed our successful fund-raising efforts, and to Doyle Daves, Dean of Science at Rensselaer, whose timely support put us "over the top." Our fellow members of the SOC— David Aitken, Jacqueline Davidson, Bruce Draine, Peter Martin, Tetsuya Nagata, Judith Pipher, Robert Stencel, and Ray Wolstencroft— provided valuable suggestions on the content, organization, and many other aspects of the meeting. We are especially grateful to Jackie Davidson for suggesting the special session on instrumentation and to Tetsuya Nagata for vigorously promoting the conference in Japan. The efforts of our fellow LOC members— Jean Chiar, Michael Fogel, David Messinger, Joan Perras, Jeffrey Shykula, and Kate Spilker— evoked numerous compliments from the attendees and our lasting admiration and gratitude. We are indebted to our invited reviewers, without whom this volume could not have been written. We are also grateful to *Astronomy & Astrophysics* and Dr. N. Neininger for permission to reproduce the plate that appears on the front cover of this volume, and to Don Mizuno for the conference participants

photograph. Finally, we thank Mark Rawlings, T-shirt designer extraordinary, whose contribution will serve the typical astronomer for many, many years.

This book was produced as part of the conference series of the Astronomical Society of the Pacific, whose efforts in electronic publishing have set new standards for the timely distribution of proceedings at a modest cost. Virtually all of the papers were composed by the authors in LaTeX, transmitted electronically to our ftp site, and processed with the ASP macro package distributed by NOAO. We are indebted to Chris Biemesderfer and Jeannette Barnes for the excellent software and for technical advice on its use. Finally, we gratefully acknowledge the editorial assistance of our colleagues Jean Chiar, Perry Gerakines, and Lida He, who sacrificed their valuable research time in the process. Of course, the ultimate responsibility for any editorial errors that may occur in the following pages is ours.

Wayne Roberge

Doug Whittet