RECONNECTION OF MAGNETIC FIELDS

Magnetohydrodynamics and Collisionless Theory and Observations

The reconnection of magnetic fields is one of the most fascinating processes in plasma physics, responsible for phenomena such as solar flares and magnetospheric substorms. The concept of reconnection has developed through recent advances in exploring the environments of the Sun and Earth through theory, computer simulations, and spacecraft observations. The great challenge in understanding it stems from balancing the large volumes of plasma and magnetic fields involved in energy release with the physical mechanism which relies on the strongly localized behavior of charged particles. This book, edited by and with contributions from leading scientists in the field, provides a comprehensive overview of recent theoretical and observational findings concerning the physics of reconnection and the complex structures that may give rise to, or develop from, reconnection. It is intended for researchers and graduate students interested in the dynamics of plasmas.

Joachim Birn is a staff member in the Space Science and Applications Group at Los Alamos National Laboratory. He was elected a Fellow of the American Geophysical Union in 2000.

Eric Priest is the James Gregory Professor of Mathematics at St. Andrews University and was elected a Fellow of the Royal Society in 2002.

RECONNECTION OF MAGNETIC FIELDS

Magnetohydrodynamics and Collisionless Theory and Observations

Edited by

J. BIRN
Los Alamos National Laboratory

and

E. R. PRIEST
University of St. Andrews

CAMBRIDGE
UNIVERSITY PRESS

CAMBRIDGE UNIVERSITY PRESS
Cambridge, New York, Melbourne, Madrid, Cape Town, Singapore, São Paulo

Cambridge University Press
The Edinburgh Building, Cambridge CB2 2RU, UK

Published in the United States of America by Cambridge University Press, New York

www.cambridge.org
Information on this title: www.cambridge.org/9780521854207

First published 2007

Printed in the United Kingdom at the University Press, Cambridge

A catalog record for this publication is available from the British Library

ISBN-13 978-0-521-85420-7 hardback
ISBN-10 0-521-85420-2 hardback

Contents

Contributors

Professor Wolfgang Baumjohann
Austrian Academy of Sciences
Space Research Institute
Schmiedlstrasse 6
Graz, 8042
Austria

Professor Amitava Bhattacharjee
EOS Space Science Center
University of New Hampshire
39 College Rd
Durham, NH 03824
USA

Dr. Joachim Birn
MS D466
Los Alamos National Laboratory
Los Alamos, NM 87545
USA

Professor Joerg Büchner
Max Planck Institute for Solar System Research
Max Planck Strasse 2
Katlenburg-Lindau, 37191
Germany

Dr. Gareth Chisham
British Antarctic Survey
High Cross
Madingley Rd
Cambridge, CB3 OET
United Kingdom

Dr. Iain J. Coleman
British Antarctic Survey
High Cross
Madingley Rd
Cambridge, CB3 OET
United Kingdom

Dr. William S. Daughton
University of Iowa
Department of Physics and Astronomy
Iowa City, IA 52242
USA

Dr. John C. Dorelli
EOS Space Science Center
University of New Hampshire
39 College Rd
Durham, NH 03824
USA

Professor James F. Drake
University of Maryland
Institute for Research in Electronics and Applied Physics
College Park, MD 20742
USA

Dr. Lyndsay Fletcher
University of Glasgow
Astronomy and Astrophysics Group
Department of Physics and Astronomy
Glasgow, G12 8QQ
United Kingdom

Dr. Terry G. Forbes
EOS Space Science Center
University of New Hampshire
39 College Rd
Durham, NH 03824-3525
USA

Dr. Mervyn P. Freeman
British Antarctic Survey
High Cross
Madingley Rd
Cambridge, CB3 OET
United Kingdom

Dr. Stephen Fuselier
Lockheed Martin
3251 Hanover St L9-42 B255
Palo Alto, CA 94304-1191
USA

Dr. K. Galsgaard
Niels Bohr Institute for Astronomy,
Physics and Geophysics
Blegdamsvej 17,
DK-2100
Copenhagen Ø,
Denmark

Dr. Paulo Giuliani
University of St Andrews
School of Mathematics and Statistics
St Andrews, KY16 9SS
United Kingdom

Dr. Michael Hesse
NASA Goddard Space Flight Center
Code 696
Greenbelt, MD 20771
USA

Dr. Gunnar Hornig
Dundee University
Division of Mathematics
23 Perth Rd
Dundee, DD1 4HN
United Kingdom

Dr. Masahiro Hoshino
University of Tokyo
Department of Earth and Planetary
Physics
7-3-1 Hongo, Bunkyo-ku
Tokyo, 113 0033
Japan

Dr. Kanya Kusano
Hiroshima University
ADSM
Kagamiyama 1-3-1
Higashi Hiroshima, 739-8530
Japan

Dr. Mark G. Linton
Naval Research Laboratory
Code 7675L
4555 Overlook Ave SW
Washington, DC 20375-5352
USA

Dr. Dana W. Longcope
Montana State University
Physics Department
Bozeman, MT 59717-0350
USA

Dr. Rumi Nakamura
Austrian Academy of Sciences
Space Research Institute

Schmiedlstrasse 6
Graz, 8042
Austria

Dr. Thomas Neukirch
University of St Andrews
School of Mathematics and Statistics
St Andrews, KY16 9SS
United Kingdom

Dr. Steven M. Petrinec
Lockheed Martin
3251 Hanover St L9-42 B255
Palo Alto, CA 94304-1191
USA

Dr. David I. Pontin
Dundee University
Division of Mathematics
23 Perth Rd
Dundee, DD1 4HN
United Kingdom

Professor Eric R. Priest
University of St Andrews
Mathematics Department
St Andrews, KY16 9SS
United Kingdom

Dr. Philip L. Pritchett
UCLA
Department of Physics
405 Hilgard Ave
Los Angeles, CA 90095-1547
USA

Prof. T. Sakurai
National Astronomical Observatory
2-21-1 Osawa, Mitaka
Tokyo 181-8588, Japan
e-mail: sakurai@solar.mtk.nao.ac.jp

Professor Karl Schindler
Ruhr-University Bochum
Faculty of Physics and Astronomy
Institute for Theoretical Physics IV
Bochum, D-44780
Germany

Professor Michael Shay
Department of Physics and Astronomy
223 Sharp Laboratory
Newark, DE 19716
USA

Dr Viacheslav S. Titov
SAIC Corp Headquarters
10210 Campus Point Drive
San Diego, CA 92121
USA

Dr. Karlheinz J. Trattner
Lockheed Martin
3251 Hanover St L9-42 B255
Palo Alto, CA 94304-1191
USA

Dr. Paul D. Wood
University of St Andrews
School of Mathematics and Statistics
St Andrews, KY16 9SS
United Kingdom

Preface

This book grew out of a month-long workshop on Magnetic Reconnection Theory held in 2004 at the Isaac Newton Institute, Cambridge, UK, organized by E. R. Priest, T. G. Forbes, and J. Birn. The focus of this workshop was on the most recent advances in understanding reconnection, particularly its three-dimensional aspects and the physics of collisionless reconnection. These are the two areas where the most rapid development beyond the classical theory of reconnection has taken place in recent years. In addition, it was found desirable to include new observational aspects from the two areas that have initiated the concept of reconnection as well as provided new, unprecedented details in remote and *in situ* observations, the Sun and the Earth's magnetosphere.

This book highlights recent progress and thus it is not a comprehensive overview. Rather it is complementary to recent reviews by Priest and Forbes (2000) and Biskamp (2000), which cover more of the traditional approaches to reconnection. Due to the focus on new results, rather than the classical concepts, about one-third of the citations in this book are from the new millenium, years 2001 to 2005. This makes it plausible that the latest developments have not led to a settled, unified, well-accepted picture, and that some topics are still controversial, even between different authors contributing to this book. We did not try to hide those controversies. Also, we did not try to consolidate various discussions of related topics into single sections or subsections. We found that, at this stage of the research development, different views of the same topic by different authors might actually be helpful to the reader to gain deeper insights.

Acknowledgments

The editors and the section authors gratefully acknowledge the hospitality of the Isaac Newton Institute, Cambridge, UK and its Director, Sir John Kingman, and the financial support provided by the Institute. Editors and authors also acknowledge support by the Institute of Geophysics and Planetary Physics at Los Alamos National Laboratory, which hosted a week-long follow-up workshop in Santa Fe, New Mexico, in 2005, during which the successful open discussion and collaboration was continued.

In addition, editors and authors acknowledge financial support by the following institutions: the US National Aeronautics and Space Administration (NASA), through its Sun-Earth Connection Theory, Living With a Star, and Supporting Research & Technology programs, the US Department of Energy through its Office of Basic Energy Sciences, the US Department of Defense, the US Office of Naval Research, the US National Science Foundation, and the UK Particle Physics and Astronomy Research Council.

Furthermore, the authors benefited greatly from discussions and collaborations with the following colleagues: Spiro Antiochos, Russell Dahlburg, Jean Heyvaerts, Joe Huba, Homa Karimabadi, Dietmar Krauss-Varban, Antonius Otto, Clare Parnell, and Grigory Vekstein, apart from discussions with each other.