PLANETARY RINGS

A Post-Equinox View

SECOND EDITION

Fully updated and expanded, this new edition presents a cutting-edge summary of planetary rings and a wealth of exciting space mission results that have greatly increased our understanding of rings in recent years, including Cassini's initial Saturn System mission and its extended Equinox and Solstice missions, and the New Horizons flyby of Jupiter.

Larry Esposito draws on his 40 years' research experience, including his position as a principal investigator within the Cassini mission team, to present all aspects of planetary rings, emphasizing ring history and evolution. The book introduces basic physical processes and simple mathematical approaches in a clear, accessible manner, including *N*-body and stochastic models of ring dynamics. Further revised chapters present highlighted topics including Saturn's F ring, Uranus' rings and moons, Neptune's partial rings, dusty rings, and Jupiter's ring–moon system, including information from Galileo and New Horizons. Cassini results are fully integrated throughout, including new images in color, and a helpful new Afterword links each of the ring images in the Cassini 'Hall of Fame' gallery to the relevant explanation in the text. The book is also supported by an online cache of selected images and videos from the NASA collection, making it easy to locate the most relevant and beautiful illustrative materials available.

This is a key resource for students studying planetary science, and a thorough overview for researchers and professionals in astronomy and space-mission research.

LARRY ESPOSITO is Professor of Astrophysical and Planetary Sciences at the University of Colorado, and also the principal investigator of the Ultraviolet Imaging Spectrograph (UVIS) experiment on the Cassini space mission to Saturn. He was chair of the Voyager Rings Working Group, and, as a member of the Pioneer Saturn imaging team, he discovered Saturn's F ring. Dr Esposito has participated in numerous US, Russian and European space missions and used the Hubble Space Telescope for its first observations of the planet Venus. His awards received include the Harold C. Urey Prize from the American Astronomical Society, the NASA Medal for Exceptional Scientific Achievement, and the Richtmyer Lecture Award from the American Association of Physics Teachers and the American Physical Society. Dr Esposito has served as chair of the National Academy of Sciences Committee on Planetary and Lunar Exploration (COMPLEX), and is a Fellow of the American Geophysical Union.

Cambridge Planetary Science

Series Editors: Fran Bagenal, David Jewitt, Carl Murray, Jim Bell, Ralph Lorenz, Francis Nimmo, Sara Russell

Books in the series

1. *Jupiter: The Planet, Satellites and Magnetosphere*†
   Edited by Bagenal, Dowling and McKinnon
   978-0-521-03545-3
2. *Meteorites: A Petrologic, Chemical and Isotopic Synthesis*†
   Hutchison
   978-0-521-03539-2
3. *The Origin of Chondrules and Chondrites*†
   Sears
   978-1-107-40285-0
4. *Planetary Rings*†
   Esposito
   978-1-107-40247-8
5. *The Geology of Mars: Evidence from Earth-Based Analogs*†
   Edited by Chapman
   978-0-521-20659-4
6. *The Surface of Mars*
   Carr
   978-0-521-87201-0
7. *Volcanism on Io: A Comparison with Earth*
   Davies
   978-0-521-85003-2
8. *Mars: An Introduction to its Interior, Surface and Atmosphere*
   Barlow
   978-0-521-85226-5
9. *The Martian Surface: Composition, Mineralogy and Physical Properties*
   Edited by Bell
   978-0-521-86698-9
10. *Planetary Crusts: Their Composition, Origin and Evolution*†
    Taylor and McLennan
    978-0-521-14201-4
11. *Planetary Tectonics*†
    Edited by Watters and Schultz
    978-0-521-74992-3

12. *Protoplanetary Dust: Astrophysical and Cosmochemical Perspectives*†
    Edited by Apai and Lauretta
    978-0-521-51772-0
13. *Planetary Surface Processes*
    Melosh
    978-0-521-51418-7
14. *Titan: Interior, Surface, Atmosphere and Space Environment*
    Edited by Müller-Wodarg, Griffith, Lellouch and Cravens
    978-0-521-19992-6
15. *Planetary Rings: A Post-Equinox View* (Second edition)
    Esposito
    978-1-107-02882-1

†Reissued as a paperback

PLANETARY RINGS

A Post-Equinox View

SECOND EDITION

LARRY W. ESPOSITO
Laboratory for Atmospheric and Space Physics,
University of Colorado

CAMBRIDGE
UNIVERSITY PRESS

CAMBRIDGE
UNIVERSITY PRESS

University Printing House, Cambridge CB2 8BS, United Kingdom

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

Cambridge University Press is part of the University of Cambridge.

It furthers the University's mission by disseminating knowledge in the pursuit of education, learning, and research at the highest international levels of excellence.

www.cambridge.org
Information on this title: www.cambridge.org/9781107028821

First published 2006
Second edition 2014

Printed in the United Kingdom by TJ International Ltd., Padstow, Cornwall

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

Library of Congress Cataloguing in Publication data
Esposito, Larry, author.
Planetary rings : a post-equinox view / Larry Esposito. – Second edition.
pages cm
Includes bibliographical references and index.
ISBN 978-1-107-02882-1 (hardback)
1. Planetary rings. I. Title.
QB603.R55E875 2014
523.9′8 – dc23 2013044085

ISBN 978-1-107-02882-1 Hardback

Additional resources for this publication at www.cambridge.org/esposito

To my wife, Diane, and daughters, Rhea and Ariel

Contents

Preface: A personal view of planetary rings

I have spent most of my professional life trying to understand the rings around the giant planets. What do the observations tell us? What are the key phenomena, processes, and principles? What is the history of planetary rings?

My colleagues in planetary sciences and I have developed excellent, although still incomplete, answers to these important questions. These results are printed in a large number of journal articles, reviews, and books intended for graduate students and professionals. Unfortunately, we have no up-to-date books suitable for the beginning graduate student or interested undergraduate. It is my purpose to provide a summary of this broad area, including the latest results from the international Cassini mission. Cassini has been orbiting Saturn since 2004. In August 2009, the Sun set on the rings at the time of its vernal equinox. At that time, objects in the ring were spectacularly visible as they cast long shadows. Cassini provided images of small bodies embedded in Saturn's rings and spectacular views of vertical excursions at ring edges and other locations. Along with other Cassini observations, such as high-resolution measurements from star occultations and from spectroscopy of the dimly lit rings, these equinox findings have given a new perspective on planetary rings that is even more dynamic. Comets strike the rings; impacts destroy small moons; embedded transient objects appear. Particularly, the equinox observations may indicate that new objects are forming at the present time.

This book has several objectives. I have endeavored to produce a book that is accessible to the general reader; is suitable for a companion book to undergraduate astronomy electives and courses in general astronomy; and which can provide an entry point for research and reading by graduate students and professionals through an extensive bibliography. Although I cover all the major topics related to planetary rings, I admit an emphasis on some topics that have caught my own attention, particularly the origin of planetary rings and explaining the structure of the ring systems. The reader will indulge me where I discuss these examples in the latter part of the book.

The overall plan is as follows: all interested readers may read Chapters 1, 2, and 3, which provide a historical and descriptive overview, and a summary of the major results and big questions in Chapter 17. My discussion of the basic physics of the rings is covered in Chapters 4–7. This is accessible to undergraduate students in the physical sciences, with some small exceptions. A more in-depth treatment of modeling (Chapters 8 and 9), and some hot topics (Chapters 10–16) will reward the dedicated reader. Extensive references to the original papers allow a number of stepping-off points for term papers or deeper investigation. The most recent Cassini findings are highlighted in newly revised Chapters 7, 11 and 16.

I appreciate helpful discussions on the first edition with Glen Stewart, Tom Brophy, Robin Canup, Mihaly Horanyi, Mark Lewis, Joshua Colwell, Shawn Brooks, Jim Howard, Dimitri Veras, and Andre Brahic. Dick French read the entire draft manuscript of the first edition, and made many helpful suggestions. Phil Nicholson answered some particular questions. For the second edition, Doug Hamilton supplied the latest version of the pie chart in Chapter 3. Mihaly Horanyi and Matt Tiscareno reviewed several chapters each. I thank Jeff Cuzzi and Frank Spahn, who hosted my sabbatical visits while I worked on the second edition of this book. Laura Bloom again produced the final product. I thank the NASA Planetary Geology Program and Outer Planets Data Analysis Program, the Outer Planets Research Program, Jupiter System Data Analysis Program, and the Voyager, Galileo, and Cassini projects for supporting my research on planetary rings over the past 40 years. Of course, any errors are my own responsibility.