HELIOPHYSICS

Space Storms and Radiation: Causes and Effects

Edited by Carolus J. Schrijver and George L. Siscoe

Heliophysics is a fast-developing scientific discipline that integrates studies of the Sun's variability, the surrounding heliosphere, and the environment and climate of planets. Over the past few centuries, our understanding of how the Sun drives space weather and climate on the Earth and other planets has advanced at an ever increasing rate. The Sun is a magnetically variable star and, for planets with intrinsic magnetic fields, planets with atmospheres, or planets like Earth with both, there are profound consequences.

This volume, the second in a series of three heliophysics texts, integrates the many aspects of space storms and the energetic radiation associated with them – from their causes on the Sun to their effects in planetary environments. It reviews the physical processes in solar flares and coronal mass ejections, interplanetary shocks, and particle acceleration and transport, and considers many of the space weather responses in geospace. Historical space weather observations, *in-situ* particle measurement techniques, radiative emissions from energetic particles, and impacts of space weather on people and technology in space are also reviewed. In addition to its utility as a textbook, it also constitutes a foundational reference for researchers in the fields of heliophysics, astrophysics, plasma physics, space physics, solar physics, aeronomy, space weather, planetary science, and climate science. Additional online resources, including lecture presentations and other teaching materials, can be accessed at www.cambridge.org/9780521760515.

CAROLUS J. SCHRIJVER is an astrophysicist studying the causes and effects of magnetic activity of the Sun and of stars like the Sun, and the coupling of the Sun's magnetic field into the surrounding heliosphere. He obtained his doctorate in physics and astronomy at the University of Utrecht in the Netherlands in 1986, and has since worked for the University of Colorado, the US National Solar Observatory, the European Space Agency, and the Royal Academy of Sciences of the Netherlands. Dr Schrijver is currently principal physicist at Lockheed Martin's Advanced Technology Center, where his work focuses primarily on the magnetic field in the solar atmosphere. He is an editor or editorial board member of

several journals including *Solar Physics*, *Astronomical Notices*, and *Living Reviews in Solar Physics*, and has co-edited four other books.

GEORGE L. SISCOE received his Ph.D. in physics from the Massachusetts Institute of Technology (MIT) in 1964. He has since held positions at the California Institute of Technology, MIT, and the University of California, Los Angeles – where he was Professor and Chair of the Department of Atmospheric Sciences. He is currently a Research Professor in the Astronomy Department at Boston University. Professor Siscoe has been a member and chair of numerous international committees and panels and is on the editorial board of the *Journal of Atmospheric and Solar Terrestrial Physics*. He is a Fellow of the American Geophysical Union and the second Van Allen Lecturer of the AGU, 1991. He has authored or co-authored over 300 publications that cover most areas of heliophysics.

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Edited by

CAROLUS J. SCHRIJVER
Lockheed Martin Advanced Technology Center

GEORGE L. SISCOE
Boston University

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Preface

Over the past few centuries, our awareness of the couplings between the Sun's variability and the Earth's environment, and perhaps even its climate, has been advancing at an ever increasing rate. The Sun is a magnetically variable star and for planets with intrinsic magnetic fields, planets with atmospheres, or planets like Earth with both, there are profound consequences and impacts. Today, the successful increase in knowledge of the workings of the Sun's magnetic activity, the recognition of the many physical processes that couple the realm of the Sun to our galaxy, and the insights into the interaction of the solar wind and radiation with the Earth's magnetic field, atmosphere and climate system have tended to differentiate and isolate the solar heliospheric and geo-space sub-disciplines of the physics of the local cosmos. In 2001, the NASA Living With a Star (LWS) program was initiated to reverse that trend.

The recognition that there are many connections within the Sun–Earth systems approach has led to the development of an integrated strategic mission plan and a comprehensive research program encompassing all branches of solar, heliospheric, and space physics and aeronomy. In doing so, we have developed an interdisciplinary community to address this systems-science. This has raised awareness and appreciation of the research priorities and challenges among the LWS scientists and has led to observational and modeling capabilities that span traditional discipline boundaries. The successful initial integration of the LWS sub-disciplines, under the newly coined term "heliophysics", needed to be expanded into the early education of scientists. This series of books is intended to do just that: aiming at the advanced undergraduate and starting graduate-level students, we attempt to teach heliophysics as a single intellectual discipline. Heliophysics is important both as a discipline that will deepen our understanding of how the Sun drives space weather and climate at Earth and other planets, and also as a discipline that studies universal astrophysical processes with unrivaled resolution and insight possibilities. The goal of this series is to

provide seed materials for the development of new researchers and new scientific discovery.

Richard Fisher, Director of NASA's Heliophysics Division
Madhulika Guhathakurta, NASA/LWS program scientist

Editors' notes

This volume is the second of a three-part series of texts (and an on-line problem set) in which experts discuss many of the topics within the vast field of heliophysics. The texts reference the other volumes by number:

I Plasma Physics of the Local Cosmos
II Space Storms and Radiation: Causes and Effects
III Evolving Solar Activity and the Climates of Space and Earth

The project is guided by the philosophy that the many science areas that together make up heliophysics are founded on common principles and universal processes, which offer complementing perspectives on the physics of our local cosmos. In these three volumes, experts point out and discuss commonalities and complementary perspectives between traditionally separate disciplines within heliophysics.

Many of the chapters in the volumes of this series have a pronounced focus on one or several of the traditional sub-disciplines within heliophysics, but we have tried to give each chapter a trans-disciplinary character that bridges gaps between these sub-disciplines. In some chapters stellar and planetary environments are compared, and in others the Sun is compared with its sister stars or planets are compared with one another; in yet other chapters general abstractions, such as magnetic field topology or magnetohydrodynamic principles, that are applicable to several areas.

The vastness of the heliophysics discipline precludes completeness. We hope that our selection of topics helps to inform and educate students and researchers alike, thus stimulating mutual understanding and appreciation of the physics of the universe around us.

The chapters in this volume were authored by the teachers of the heliophysics summer school following the outlines provided by the editors. In the process of integrating these contributions into this volume, the editors have modified or added segments of text, included cross references, pointed out related segments of text, introduced several figures and moved some others from one chapter to another, and attempted to create a uniform use of terms and symbols, while allowing some differences to exist to remain compatible with the discipline's literature usage. The editors bear the responsibility for any errors that have been introduced in that editing process.

Additional resources

The texts were developed during summer schools for heliophysics, held over three successive years, at the facilities of the University Corporation for Atmospheric Research in Boulder, Colorado, funded by the NASA Living With a Star program. Additional information, including text updates, lecture materials, (color) figures and movies, and teaching materials developed for the school can be found at www.vsp.ucar.edu/Heliophysics. Definitions of many solar–terrestrial terms can be found via the index; a comprehensive list can be found on the web at www.swpc.noaa.gov/info/glossary.html.

Heliophysics

helio-, prefix, on the Sun and environs; from the Greek helios.
physics, n., the science of matter and energy and their interactions.

Heliophysics is the

- *comprehensive new term for the science of the Sun–solar system connection.*
- *exploration, discovery, and understanding of our space environment.*
- *system science that unites all of the linked phenomena in the region of the cosmos influenced by a star like our Sun.*

Heliophysics concentrates on the Sun and its effects on Earth, the other planets of the solar system, and the changing conditions in space. Heliophysics studies the magnetosphere, ionosphere, thermosphere, mesosphere, and upper atmosphere of the Earth and other planets. Heliophysics combines the science of the Sun, corona, heliosphere, and geospace. Heliophysics encompasses cosmic rays and particle acceleration, space weather and radiation, dust and magnetic reconnection, solar activity and stellar cycles, aeronomy and space plasmas, magnetic fields and global change, and the interactions of the solar system with our galaxy.

From NASA's *Heliophysics. The New Science of the Sun–Solar System Connection: Recommended Roadmap for Science and Technology 2005–2035.*