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. It encompasses all the variability that we know as space weather, but also enables us to understand the conditions leading to the relatively stable environment that supports life on Earth: our planet is in an orbit that has kept it within the habitable zone throughout the Sun’s evolution, without overly detrimental effects of flares and coronal mass ejections, shielded well enough from galactic cosmic rays, and with the right amount of dynamo action.

This volume, the fourth in this series, explores what makes the conditions on Earth “just right” to sustain life, by comparing Earth to other solar-system planets, by comparing solar magnetic activity to that of other stars, and by looking at the properties of evolving exoplanet systems. By taking an interdisciplinary approach and using comparative heliophysics, the authors illustrate how we can learn about our local cosmos by looking beyond it, and, in doing so, also enable the converse.

Supplementary online resources are provided, including lecture presentations, problem sets, and exercise labs, making this ideal as a textbook for advanced undergraduate and graduate-level courses, as well as a foundational reference for researchers in the many subdisciplines of helio- and astrophysics.

The four volumes in the Heliophysics series are:

1. *Heliophysics – Plasma Physics of the Local Cosmos*
2. *Heliophysics – Space Storms and Radiation: Causes and Effects*
3. *Heliophysics – Evolving Solar Activity and the Climates of Space and Earth*
4. *Heliophysics – Active Stars, their Astrospheres, and Impacts on Planetary Environments*

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HELIOPHYSICS
Active Stars, their Astrospheres, and Impacts on Planetary Environments

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Contents

Preface page ix

1 Introduction 1
Carolus J. Schrijver, Frances Bagenal, and Jan J. Sojka
1.1 Comparative heliophysics 1
1.2 Exoplanets 5
1.3 Cool stars and their space weather 6
1.4 Atmospheres, stellar winds, and cosmic rays 8
1.5 Astrophysical dynamos and space weather 9
1.6 Heliophysics of planetary atmospheres 11
1.7 Aeronomy and magnetospheres 13
1.8 Dimensionless heliophysics: from heliosphere to dust 14
1.9 Energetic particles as diagnostic tools for heliophysics 16
1.10 Radio signals as diagnostic tools for heliophysics 17
1.11 Chapter outlines 18

2 Solar explosive activity throughout the evolution of the solar system 23
Rachel Osten
2.1 Key parameters important to a discussion of explosive events 24
2.2 Time scales: explosive events on stars, young to old 43
2.3 Take-away points 55

3 Astrospheres, stellar winds, and the interstellar medium 56
Brian E. Wood and Jeffrey L. Linsky
3.1 The spatial extent of the solar wind 56
3.2 Observed properties of the local interstellar medium 57
3.3 Introduction to heliospheric structure 60
3.4 Observational constraints on the global heliosphere 62
3.5 Effects of a variable ISM on past heliospheric structure 67
3.6 Detecting astrospheres 71
3.7 Long-term evolution of stellar winds 72

4 Effects of stellar eruptions throughout astrospheres 80
   Ofer Cohen
   4.1 Astrospheres in time 80
   4.2 Coronal mass ejections in time 89
   4.3 Coronal mass ejections and close-in exoplanets 98

5 Characteristics of planetary systems 104
   Debra Fischer and Ji Wang
   5.1 Overview of Keplerian orbits 105
   5.2 Doppler surveys for exoplanets 106
   5.3 Transit technique 110
   5.4 Direct imaging 115
   5.5 Microlensing 116
   5.6 Astrometry 117
   5.7 Comparative planetology 117

6 Planetary dynamos: updates and new frontiers 126
   Sabine Stanley
   6.1 Dynamo fundamentals 127
   6.2 Planetary dynamos: updates 129
   6.3 Planetary dynamos: new frontiers 138
   6.4 Outlook 145

7 Climates of terrestrial planets 147
   David Brain
   7.1 Current climates of terrestrial planets 147
   7.2 Evidence for climate change 150
   7.3 How do climates change? 152
   7.4 Atmospheric source and loss processes 156
   7.5 Requirements and reservoirs for atmospheric escape to space 158
   7.6 Atmospheric escape processes and rates 161
   7.7 External drivers of escape 164
   7.8 Internal drivers of escape 169
   7.9 Frontiers 172

8 Upper atmospheres of the giant planets 175
   Luke Moore, Tom Stallard, and Marina Galand
   8.1 Thermospheres of the giant planets 176
Contents

8.2 Ionospheres of the giant planets 181
8.3 Ionosphere–thermosphere–magnetosphere and solar wind coupling 187
8.4 Auroral emissions 196

9 Aeronomy of terrestrial upper atmospheres 201
David E. Siskind and Stephen W. Bougher
9.1 Global mean upper-atmospheric structure 203
9.2 How do neutral dynamics affect planetary ionospheres? 211
9.3 Summary and outlook 224

10 Moons, asteroids, and comets interacting with their surroundings 226
Margaret G. Kivelson
10.1 Physics of large-scale processes in space plasmas 226
10.2 Characterizing the plasma that interacts with solar-system bodies 229
10.3 Effects of the electrical properties of an obstacle in the flow 234
10.4 The interaction region and the role of MHD waves 238
10.5 Moons with magnetic fields permanent or inductive 240
10.6 Moons without atmospheres 244
10.7 Moons with atmospheres or other sources of neutrals 245
10.8 Small bodies in the solar wind 246
10.9 Summary and expectations for other planetary systems 249

11 Dusty plasmas 251
Mihály Horányi
11.1 Motivation 251
11.2 Dust charging 255
11.3 Dust in planetary magnetospheres 257
11.4 Waves in dusty plasmas: possible role in comets 265
11.5 Summary and conclusions 267

12 Energetic-particle environments in the solar system 270
Norbert Krupp
12.1 Energetic particles from the Sun 275
12.2 Energetic particles in planetary magnetospheres 278
12.3 Summary 287

13 Heliophysics with radio scintillation and occultation 289
Mario M. Bisi
13.1 Observing radio waves 290
13.2 Astronomical radio sources and spacecraft beacons 292
### Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>13.3 Radio occultation</td>
<td>293</td>
</tr>
<tr>
<td>13.4 Radio scintillation</td>
<td>293</td>
</tr>
<tr>
<td>13.5 Radio occultation, with a focus on planetary occultations</td>
<td>294</td>
</tr>
<tr>
<td>13.6 Interplanetary scintillation in the context of heliophysics</td>
<td>296</td>
</tr>
<tr>
<td>13.7 Faraday rotation in heliophysics</td>
<td>322</td>
</tr>
</tbody>
</table>

**Appendix I Authors and editors** | 327  |

**List of illustrations** | 329  |
**List of tables**         | 334  |
**References**             | 335  |
**Index**                  | 366  |

The plates are to be found between pages 116 and 117
Preface

Anyone who has ever seen a picture of Earth taken from deep space can be forgiven for thinking of these two words: “splendid isolation.” Surrounded by millions of miles of uninterrupted black, the fragile blue globe seems profoundly alone, disconnected from anything else.

Nothing could be further from the truth: Earth is profoundly connected to our star.

The bright blue disk is just the most obvious evidence. A non-stop flood of sunlight warms the planet, simultaneously allowing us to live and to see. Invisible connections are equally profound. Solar radiation puffs up our atmosphere, altering its structure and chemistry. Solar winds buffet our magnetosphere, lighting up polar skies with curtains of light, and driving currents of electricity through the soil below. Solar magnetism deflects cosmic rays, moderating the effect of the Galaxy on our tiny home in space.

Years ago, the study of the Sun–Earth connection was edgy stuff. Big Thinkers held the planet and the star to be a system. From this synthesis emerged many new ideas and a new discipline called “heliophysics.”

Now we know that they weren’t thinking big enough. Like Earth, every world in the solar system is connected to its star. From the surface chemistry of Mercury, to the tattered atmosphere of Mars, to the flowing ices of Pluto, the fingerprints of solar activity may be found in all corners of the heliosphere.

In pop culture, people trace the “seven degrees of separation” between themselves and actor Kevin Bacon. Earth is connected much more closely to alien worlds. The central role of the Sun puts us just one degree of separation away from scores of planets, dwarf planets, moons, asteroids, and comets throughout the solar system. This proximity tells us something important: what we learn about those strange places, we also learn about ourselves.

The connectedness of things is the subject of this book: *Active Stars, their Atmospheres, and Impacts on Planetary Environments*. In 13 graduate-level chapters,
Preface

experts lay out new ideas about how stars carve out a place in the galaxy to shape their own solar systems. The chapters touch on subjects ranging from magnetic reconnection and magnetohydrodynamics to climate and aeronomy. It may be one of the most interdisciplinary textbooks ever written – at least in the physical sciences.

Indeed, the themes laid out in this text are so interdisciplinary that their proper synthesis requires more than one book. This fourth volume of the Heliophysics series implicitly makes the case for a new research discipline: comparative heliophysics. As humans and their robots spread throughout the solar system, we will need this kind of interdisciplinary approach to understand the places we visit and to anticipate the dangers. What is the weather like on Titan today? How will a solar storm affect the ices of Europa? Is it safe to land on that comet?

These questions cannot be answered in “splendid isolation.” Indeed, there really is no such thing... under the Sun.

Madhulika Guhathakurta, NASA/LWS program scientist, Heliophysics Division, Science Mission Directorate

Editors’ notes

The Heliophysics series focuses on the physics of space weather events that start at the Sun and influence the Earth’s environment and society’s susceptibility to these processes. The Sun’s variability affects not only Earth, but also the atmospheres, ionospheres, and magnetospheres of all other bodies throughout the solar system. The solar system offers a wider variety of conditions under which the interaction of bodies with a plasma environment can be studied than are encountered around Earth alone: there are planets with and without large-scale magnetic fields and associated magnetospheres; planetary atmospheres display a variety of thicknesses and compositions; satellites of the giant planets reveal how interactions occur with subsonic and sub-Alfvénic flows whereas the solar wind interacts with supersonic and super-Alfvénic impacts.

Analogous to the use of other environments in our own planetary system to learn more about Earth’s environmental conditions we can look at the variety of other stars to learn more about our own Sun and its magnetism. With the realization that most stars support some form of planetary system, the variety of star–planet interactions to be considered also reaches far beyond our own present-day solar system: we can learn about the history and future of heliophysical processes throughout the life of the solar system by considering exoplanet systems, and we can envision environments elsewhere in the Galaxy by studying our solar system. Hence, the theme of this volume: comparative heliophysics.
Preface

The chapters in this volume, as in the others in this series, generally adhere to common practices in the disciplines that they primarily cover in their uses of symbols and units. We intentionally did not attempt to homogenize these across the contents to make it easier for the reader to connect the various chapters to the more detailed professional literature.

Additional resources

The texts were developed during a summer school series for heliophysics, taught 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 http://www.vsp.ucar.edu/Heliophysics.

An online volume (Heliophysics V) describing the impacts of space weather on society in chapters looking into economic impacts, business opportunities, impacts on the electric power grid, and consequences of space weather for radio waves used in, e.g., navigation, can be accessed freely via the web.¹

Definitions of many solar–terrestrial terms can be found via the index of each volume; a comprehensive list can be found at a web page maintained by NOAA’s Space Weather Prediction Center.²

A note on star names and spectral designations

In this volume, several chapters refer to stars other than the Sun, using a variety of different naming conventions.³ Here is a selective summary that covers most of what the reader will encounter in this volume. Stars that are relatively bright in the sky are often named after the constellation in which they occur, of which the Latin name is commonly abbreviated using three letters taken from the beginning of the word or words in their name, preceded by a Greek letter, starting with α for the brightest (e.g., α Cen for the brightest star in the constellation Centaurus) and continuing through the Greek alphabet, and continuing with numbers after the letters are all used. Alternative names include (1) old Arabic names (modified over time, such as Betelgeuse), (2) catalog numbers (such as the Henry Draper catalog numbers, e.g., HD 114762), (3) a letter combination preceding the constellation abbreviation which often designates a member of a variable star catalog (e.g., EK Dra), or (4) a rather unimaginative but straightforward combination of right ascension and declination that specifies the location in the sky, sometimes preceded

¹ http://www.vsp.ucar.edu/Heliophysics/science-resources-textbooks.shtml
² http://www.swpc.noaa.gov/content/space-weather-glossary
by a group of letters that specifies the type of star (e.g., the pulsar PSR 1257+12). Stars are often known by multiple names (users of, e.g., the Astrophysics Data System, ADS, can hunt through the literature by using databases of synonyms to search for studies on stars using multiple names simultaneously). In case of multiple stars, a capital following the name indicates which component is meant, most commonly differentiating between the brightest and next-brightest one as “A” and “B”. When a lower-case letter follows a star name, the designation refers to a planet orbiting the star.

Spectral types of stars are a measure of their spectral properties, long since resequenced in order of decreasing effective temperature (and thus in order of color from blue to red): O, B, A, F, G, K, M, L, T, Y, followed by a number from 1 to 9 as a subdivision. The Roman numeral that follows it is a measure for stellar radius or surface gravity, and indirectly of relative age: V for a mature main-sequence star (such as our Sun), IV for a slightly evolved star, and then III, II, and I for evolved giant, bright giant, and supergiant stars.

Stellar astronomers characterize spectral lines by the abbreviated Latin name of the element followed by a Roman numeral that designates the ionization stage of the element, e.g., the designation “Mg II” refers to a spectral line (or, if no particular name or wavelength follows, the entire set of spectral lines) of singly ionized magnesium. Sometimes, authors may use the spectral designation to characterize the population of the emitting atoms (e.g., “D I atoms” for neutral deuterium). Particularly strong spectral lines may have names followed by a Greek letter (such as “Lyman α”, the first in the Lyman series), or a capital letter which refers to a strong line identified in the solar spectrum (such as the Ca II H and K lines) or their equivalent transition in another element when indicated in lower case (e.g., for the H and K lines: the Mg II h and k lines).
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.