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Physics of Space Plasma Activity

Space plasma is so hot that the atoms break up into charged particles which then become trapped and stored in magnetic fields. When critical conditions are reached the magnetic field breaks up, releasing a large amount of energy and causing dramatic phenomena. A prominent example is the magnetospheric substorm occurring in the Earth's magnetosphere. It involves plasma and magnetic field structures extending from 100 km to tens of Earth radii, and can be seen as strong intensifications of the northern and southern lights. The largest space plasma activity events observed in the Solar System occur on the Sun, when coronal mass ejections expel several billion tons of plasma mass into space.

Physics of Space Plasma Activity provides a coherent and detailed treatment of the physical background of large plasma eruptions in space. It provides the background necessary for dealing with space plasma activity, and allows the reader to reach a deeper understanding of this fascinating natural event. The book employs both fluid and kinetic models, and discusses the applications to magnetospheric and solar activity.

This book will form an interesting reference for graduate students and academic researchers in the fields of astrophysics and plasma physics.

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To Erika

Contents

Preface

A major motivation for writing this book is the strong fascination that visible signatures of plasma activity are able to generate. This goes along with considerable professional research interest in this area. Also, those who have admired spectacular pictures or video presentations on the internet displaying spacecraft observations of auroral activity or of solar eruptions, are often motivated to learn more about their physical background.

In the early days of spacecraft observations, the understanding of dynamical phenomena such as geomagnetic storms and solar flares was considered as poor and high up on the list of particularly challenging problems. Remarkably, this is still true today. The observational database has increased dramatically and important new phenomena were discovered, such as coronal mass ejections and manifestations of the global nature of magnetospheric substorms involving large regions of the magnetosphere. There are many more aspects than envisaged originally, and today we have good reasons to use the comprehensive notions of *solar* and *magnetospheric activity*, which in this book are combined under the working term *space plasma activity*. The desire to understand these complex phenomena has mobilized considerable research efforts, but due to the overwhelming complexity that one encounters, our present understanding is still far from being satisfactory.

One might ask, whether in this situation it is appropriate to write a book that concentrates on space plasma activity. Would it not be more reasonable to wait until our understanding of the underlying physical processes has settled down more solidly?

The main reason for writing this book at this time is the fact that during past decades a substantial wealth of theoretical tools has been developed, which can be expected to remain useful, even if many of the final answers are still to be found. In fact, good knowledge and further development of those tools could well help to accelerate progress in this field. The situation appears to be similar to that of the Earth's lower atmosphere, where several phenomena associated with atmospheric disturbances are still not well understood; on the other hand, there is little doubt that gas-dynamics methods play an important role in present and future investigations in that area. Regarding that the electrodynamic interactions make plasma dynamics considerably more complicated than gas dynamics, it is obvious that there is a strong need for reviewing and, where possible, for improving the existing tools and for developing new ways of approach. Therefore, after the phenomenological survey given in Part I, the relevant methods and plasma properties are addressed in Parts II and III, starting from basic plasma models. In this way an updated (although necessarily incomplete) *toolbox* for the study of space plasma activity arises. I hope that this will be found useful for research in space plasma activity.

A further aim is to meet the needs of scientists or graduate students trying to enter the field of large-scale space plasma phenomena. They often ask for coherent descriptions of the theoretical methods that would allow them to discriminate between conclusions that can safely be drawn and concepts that are more of a speculative nature.

There are also indications suggesting that the occupation with topics related to space plasma activity have enjoyed increasing attractiveness since it became clear that such phenomena have aspects falling under notions of modern theoretical physics, such as nonlinear dynamics, spontaneous processes or catastrophe theory.

The separation between the theoretical tools (Parts II and III) and the applications (Part IV) was chosen for several reasons. First, this separation allows a systematic and coherent presentation of the theory. Further, it makes it possible to present the applications of Part IV in such a way that, to some extent, they can be understood without detailed knowledge of Parts II and III. Lastly, the separation suggests itself in view of the speculative elements that necessarily play a more important role in Part IV than in Parts II and III.

The reader should have knowledge of physics and basic mathematical techniques, as is commonly available after, say, four years' study of physics or astronomy, mathematics, or engineering. Some knowledge of plasma physics, as drawn from textbooks (e.g., Sturrock, 1994; Boyd and Sanderson, 2003; Cravens, 2004), would help the reader to understand the basic plasma models and to follow the formal developments of Parts II and III. Selected background material, tailored to the requirements of this book, is available on the internet; the addresses are inserted in the text where appropriate. Part IV is more descriptive and needs less background in mathematics and plasma physics.

It is a pleasure to acknowledge the invaluable help and support that I received from many sides before and during the preparation of this book. A substantial part of the material originates from the research carried out before the mid 1990s by our group *Theoretische Physik IV* at the Ruhr-University of Bochum. It still fills me with joy when I remember its lively and creative atmosphere. Particularly, I feel indebted to Joachim Birn and Michael Hesse, with whom fruitful and pleasant collaboration has continued until today. I also profited greatly from discussions with many colleagues of the plasma, space and solar physics communities, too numerous to name all of them. But I wish to mention those with whom I had particularly valuable contacts during my extended struggle with space science, namely Ian Axford, Dieter Biskamp, Jörg Büchner, Peter Gary, Akira Hasegawa, Ed Hones, Jim McKenzie, Eric Priest, Philip Rosenau, Roald Sagdeev, Reinhard Schlickeiser, George Siscoe, Bengt Sonnerup, Ted Speiser and Vytenis Vasyliunas. I am grateful to the space science group of the Los Alamos National Laboratory for their warm hospitality during numerous visits.

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