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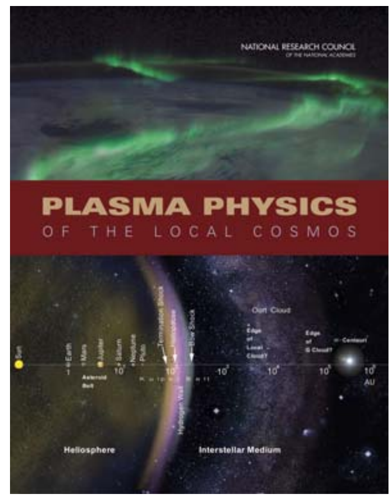
Plasma Physics of the Local Cosmos—*Summary*

SPACE STUDIES BOARD

Background



Solar and space physics is the study of solar system phenomena that occur in the plasma state. Examples include sunspots, the solar wind, planetary magnetospheres, radiation belts, and the aurora. While each is a distinct phenomenon, there are commonalities among them. To help define and systematize these universal aspects of the field of space physics, the National Research Council was asked by NASA's Office of Space Science to provide a scientific assessment and strategy for the study of magnetized plasmas in the solar system. The study was started in 1999 by the Space Studies Board (SSB) Committee on Solar and Space Physics, but was put on hold for 18 months while the committee responded to a request from NASA, NSF, NOAA, and DoD to organize a "decadal survey" in solar and space physics. The report of the decadal study—*The Sun to the Earth – and Beyond: A Decadal Research Strategy for Solar and Space Physics*—met some of the goals of the space plasma study as originally conceived, including the development of priorities and strategies for future program activities. The remaining objectives are covered in *Plasma Physics of the Local Cosmos*, which defines and systematizes the universal aspects of the field of space physics, and analyzes it as "a field that reveals and illustrates the principles of plasma astrophysics as locally manifested."

Report Topics

The plasmas of interest to solar and space physicists are magnetized—threaded through with magnetic fields that are often "frozen in" the plasma. In many cases, the magnetic field plays an essential role in organizing the plasma. In other instances, it is the plasma which organizes the magnetic field. In all cases, the plasma and the magnetic field are intimately tied together and mutually affect each other. The theme of magnetic fields and their interaction with plasmas provides the overall framework for this report.

An important goal of solar and space physics research—one shared with astrophysics, planetary science, and laboratory plasma physics—is to develop an understanding of the **physical mechanisms that control how magnetic fields are generated, maintained, and dissipated**. The report focuses on the topics of dynamo and magnetic reconnection, and identifies several outstanding problems in these areas. For example, understanding the differential rotation of the solar interior is a significant challenge. In addition, there is currently significant debate about what triggers the reconnection process.

The report also presents an examination of some of the **major structures that arise in magnetized plasmas**, including collisionless shocks, current sheets, and tubes of twisted magnetic field known as "flux ropes." These structures have been studied extensively over the past 40 years, and much has been learned about their formation, evolution, and dynamics. Numerous outstanding problems remain, however, such as the formulation of scaling laws to extend the understanding of dissipation and acceleration within the Earth's bow shock to large astrophysical shocks, and questions about the formation, evolution, and destruction of flux ropes.

Magnetohydrodynamic (MHD) turbulence, which exemplifies the tendency of magnetized plasmas to couple strongly across multiple spatial and temporal scales, is also addressed in the report. Turbulence is involved in plasma heating, energetic particle scattering, and particle acceleration. Among the outstanding problems are questions about the detailed structure of heliospheric turbulence, the role of turbulence in transport across boundary layers, and the coupling of microturbulence to large-scale disturbances.

Plasmas throughout the universe interact with solid bodies, gases, magnetic fields, electromagnetic radiation, and waves. Four **classes of plasma interactions** are discussed in the report: electromagnetic interactions, flow-object interactions, plasma-neutral gas interactions, and radiation-plasma interactions. These interactions occur both locally and on large (stellar or galactic) scales. Examples of such interactions include the electromagnetic coupling of a planetary ionosphere and magnetosphere, which is responsible for the energy transfer that powers the aurora at Earth and Jupiter, and the interaction of the solar wind with the atmosphere of Mars, which is thought to have played an important role in that planet's evolution.

The report presents a discussion of **explosive energy conversion**, which is the explosive release of stored magnetic energy in the form of particle kinetic energy and thermal energy. Because of their potentially disruptive influence on both ground- and space-based technological systems, such explosive events are of practical concern in addition to their intrinsic scientific interest. There are several outstanding scientific problems to be addressed including how magnetic energy builds up and is stored in solar corona and how it is converted into flares and coronal mass ejections. The storage and release of magnetic energy occurs in all astrophysical plasmas, and knowledge about those processes gained by study of our solar system should help with the understanding of more complex astrophysical systems.

The **acceleration of charged particles to high energies** is a topic that is also addressed in the report. This discussion reviews the three principal processes that accelerate charged particles in magnetized plasmas: shock acceleration, coherent electric field acceleration, and stochastic acceleration. All of these acceleration mechanisms can occur in the same plasma environment, simultaneously or at different times. For example, direct acceleration of particles by electric fields, particle interactions with ultra-low-frequency

(ULF) plasma waves, and localized, stochastic acceleration may all contribute to the build up of the Earth's radiation belts during geomagnetic storms. Distinguishing among the various acceleration mechanisms as well as determining the role and relative importance of each, however, present observational and theoretical challenges to solar and space physicists.

A number of open questions illustrative of the major scientific issues expected to drive **future research** emerge from the discussions presented in this report. The report provides a broad conceptual framework for the integrated and prioritized set of future research initiatives recommended in *The Sun to the Earth—and Beyond: A Decadal Research Strategy for Solar and Space Physics*. The two reports are thus complementary. *The Sun to the Earth* describes an investigation strategy to study plasma phenomena in a variety of solar system environments from the Sun's corona to Jupiter's high-latitude magnetosphere, while *Plasma Physics of the Local Cosmos* describes the basic plasma physics common to all these environments. Moreover, with its focus on the universal properties of plasmas in the local cosmos, the latter report identifies important links between solar and space physics and plasma astrophysics.

For Further Information

Copies of the complete report, *Plasma Physics of the Local Cosmos,* can be obtained on the National Academy Press Web site <http://books.nap.edu/catalog/10993.html>**.**

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