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Foreword

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The state and evolution of plasmas in the corona and the heliosphere are determined by physical processes that occur over an enormous range of spatial scales, from macroscopic coronal holes and magnetic arcades to kinetic scales where dissipative processes take place. Our progress in solar and heliospheric physics is therefore intrinsically linked to our knowl-

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edge of some of the most fundamental processes of plasma physics, which are expected to be of relevance to all astrophysical plasmas.

A workshop held at the International Space Science Institute (ISSI) in Bern, Switzerland, in January 2010 brought together experts focused on three key driving questions at the forefront of solar and heliospheric physics whose solutions are recognized to be multi-scale in nature. For each of these questions, which will be briefly discussed in this foreword, experts summarized the most recent experimental and theoretical results and also the limitations of our present understanding and approaches. A series of discussions were designed to address these questions and to define the frontiers of research. The key outcome of this workshop is a series of publications in this special volume, summarizing all new research highlights and documenting the current limitations of our understanding of these three basic questions.

(1) What physical process is responsible for heating and acceleration of the solar wind from coronal holes?
(2) What is the relative role of the magnetic topology and reconnection in the release of slow wind and coronal mass ejections?
(3) What processes dominate the thermodynamic evolution of the solar wind in the inner heliosphere?

The first question concerns the heating and acceleration of the solar wind from coronal holes, which are the source of 50–70 % of the solar wind throughout the solar cycle. During solar minimum, coronal holes are the source of the high-latitude heliosphere and extend into the ecliptic plane. Coronal holes remain an important source of solar wind, even during elevated levels of solar activity. Near solar maximum, coronal holes can occur at all latitudes and persist for weeks and months.

The challenge of our understanding of coronal holes and their associated heliospheric plasma is multi-scale in nature. The formation of coronal holes and their extent is well explained by the large-scale properties of the solar magnetic field (Wang et al.). But the temperature and velocity profiles observed by the pioneering observations of space and ground-based observations (Antonucci et al.; Wilhelm; McIntosh) suggest that the heating and acceleration of the solar wind is much more abrupt than expected—reaching supersonic speeds within 2 solar radii (Rs) of the solar surface and not $\sim$10 Rs, as initially thought. There are also strong indications that the energy deposition into the ions is highly dependent on the mass, charge, and energy of these ions and could potentially lead to highly nonthermal distribution functions. The governing processes for such heating must occur on extremely small spatial scales, where kinetic effects are important. Strong experimental indications for the importance of such kinetic processes come from the pioneering inner-heliosphere observations from Helios (Marsch). Since the relevant scales are not currently accessible to experimental investigation, theoretical models have to be used to test the importance of any assumed heating and acceleration mechanism (Cranmer; Malara; Hansteen and Velli). Although much progress has been made in the development of these models and in their application to these important problems, none of the models is generally accepted to be consistent with all relevant experimental constraints from remote and in-situ data (Zurbuchen et al.).

The second question focuses on the release of heliospheric plasmas from the closed corona in the form of slow wind and coronal mass ejections. Slow wind dominates the space environment of the ecliptic plane and therefore of all planets. Its composition is that of the closed corona and it is found in the heliosphere in the vicinity of the heliospheric current sheet, which, at global heliospheric scales, organizes the heliospheric magnetic field. Slow wind is observed to be much more highly structured and variable in pretty much all plasma and compositional quantities.

The study of slow wind and its global structure and evolution is strongly linked to the study of reconnection processes in the corona and the solar wind, reconnection being the prime mechanism for opening the closed coronal field lines. There is in-situ evidence of reconnection in solar wind plasmas (Gosling) as well as remote evidence (Crooker), but their interpretation in the global sense remains the focus of active research. Numerical investigations of the three-dimensional topology of magnetic reconnection provide insights into the temporal evolution and often complex topology of the corona magnetic field (Landi; Edmondson). In fact, the multi-scalar structure of the coronal hole boundary implies that such reconnection processes may indeed be responsible for all of the slow wind (Antiochos et al.).

Due to the fundamental nature of reconnection for the generation of slow wind, coronal mass ejections, and so many other aspects of modern plasma physics, the detailed understanding of this process on a kinetic scale is of crucial interest. Of particular importance is the investigation of reconnection rates under a variety of conditions (Cassak and Shay; Daughton). But there is also an increased understanding that such processes could be the underlying physical reason for the acceleration of ions into the suprathermal energy range (Drake; Mason et al.) and the generation of nearly power-law velocity distribution functions that are observed in many heliospheric plasmas.

The third question focuses on the thermodynamic evolution of the solar wind in the inner heliosphere. The solar wind is a turbulent flow, with energy input from the corona that is structured over a wide range of scales due to solar convective motion, loop interactions, reconnection, etc. The thermodynamics of the collisionless solar wind reflects the evolution of particle distributions and field fluctuations, which is controlled by the large-scale expansion of the solar wind as well as the microscopic kinetic processes responsible for dissipation of the turbulence at small scales. The heliospheric magnetic field is thus structured on all spatial scales, with nonlinear and turbulent interactions leading to a coupling between, for example, the large-scale expansion and kinetic processes responsible for heating ions. Multi-scalar energy transport and dissipation processes are therefore important ingredients in our understanding of the heating and thermodynamic evolution of ions from their origin in the corona throughout their journey through the heliosphere. The turbulent evolution of the solar wind remains an important topic of research and new ideas about the multi-scale flow of energy are being theoretically investigated (Carbone; Camporeale; Horbury). Understanding the precise role of different kinetic processes for the heating of ions and electrons in the corona and the solar wind is a major goal (Araneda et al.; Pierrard; Vocks). Self-consistent modeling of the control of kinetic effects imposed by the global expansion illustrates the important role played by cross-scale coupling in the thermodynamic evolution of the expanding solar wind (Matteini et al.)

It is our hope that this volume will serve as a useful reference for future investigations of the solar corona and solar wind through missions such as ESA's Solar Orbiter and NASA's Solar Probe Plus.

We conclude by thanking all those who have made this successful workshop and its publication possible. We thank the ISSI Science Committee and Directorate for selecting this science theme and sponsoring the workshop. We also thank the workshop participants for writing these important contributions, and the referees for their reports, which have contributed significantly to the quality of the papers. Finally, we thank the ISSI staff for the local organization and support with the same dedication and professionalism that makes each ISSI workshop a memorable experience.