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Editorial
Special issue: Present achievements and new frontiers in space plasmas

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Space plasma physics, pushed by the impressive recent technological developments, is undergoing a period of intense progress. This progress is achieved first at the level of observations, including both remote and *in situ* measurements, but also on the theoretical side, mainly by means of large scale numerical simulations made possible by the dramatic increase of computational resources. In particular, three-dimensional mainly hybrid but also fully kinetic simulations are today feasible, and large intervals in spatial and time scales can at last be accessed by fluid simulations. Addressing fundamental problems such as, e.g. magnetic reconnection, nonlinear dynamics or turbulence development in the kinetic range, are no longer just a heart's desire today.

It is common to assert that the Solar Wind is a laboratory for plasma physics in particular because of the possibility of very accurate measurements of the main fields, but also of the distribution functions. A great success of space plasma physics has been the possibility of exhibiting the collisionless character of plasmas by measuring non-Maxwellian distribution functions more or less everywhere in space. Even further, the terrestrial environment is truly an exclusive laboratory in what concerns the study of turbulence of Alfvénic type, a phenomenon for which experiments are in their infancy due to lack of scale separation. All basic questions about usual fluid turbulence have to be reformulated in the context of Solar Wind turbulence. The physical mechanisms at the origin of dissipation, the typical scales involved, and the link with coherent structures and/or wave particle resonances are among the most difficult problems. Basic issues such as the role or even existence of waves are still debated. Furthermore, in addition to waves, this medium is also affected by macro/micro-instabilities whose nonlinear evolution is still the subject of intensive theoretical investigation because of their role in redistributing in the system the energy injected typically at very large scales. In this sense, micro-instabilities often play a role similar to what one would expect from collisions at much smaller scales.

Great advances in the description of the Alfvénic cascade, its dissipation range and more importantly its 3D spatial structure, were recently made using the four Cluster satellites. Substorms and aurora dynamics were the object of detailed investigation with the five satellite mission THEMIS, while the four satellite mission MMS, to be launched in a near future, should allow for a closer look at reconnection in the

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magnetosphere, one of the leading phenomena for the transfer of the energy injected by the sun via the solar wind toward the Earth. In particular, the MMS mission will be the first experiment able to capture the very small electron scales, to explore the physics of reconnection and, more generally, the plasma microphysics. Despite the smallness of the diffusion region that makes the crossing by satellites rare, space missions have succeeded in measuring important signatures such as, e.g. the Hall quadrupole that characterizes fast reconnection.

New tools such as gyrokinetic simulations, mostly developed for fusion plasmas, are today more and more used in the context of small-scale Solar Wind turbulence, permitting to address questions that would still be out of reach of present day computers with full Vlasov simulations. At the level of modeling, great challenges are being tackled, even if their practical use is still far ahead, such as the implementation of multi-scale physics using a coupling between fluid and kinetic physics. Extended MHD, adding some modeling of low-frequency kinetic physics to multi-fluid formalisms, is another approach being developed and applied to the simulation of these plasmas, enlarging the range of validity of usual fluid descriptions to ion scales. Many fundamental questions are addressed in these studies, such as the role and nature of magnetic reconnection in turbulent environments, the mechanisms at the origin of electron acceleration in auroras, the mechanisms that heat and accelerate the Solar Wind, the physical processes involved in the generation of temperature anisotropy and its self-regulation in the Solar Wind, the interaction of the Solar Wind with the interstellar medium.

Another important motivation for the study of space plasmas and of the physics of the main processes at play, is associated with the development of a Space Weather service, capable of predicting the perturbations caused on Earth, in particular by the arrival of coronal mass ejections. Solar meteorology has become of great importance due to the strong impact of these magnetic storms on our technological platforms. It requires a precise understanding of truly multi-scale phenomena such as those triggering exploding or eruptive events on the Sun, the evolution of CMEs as they propagate in the interplanetary medium, their interaction with the Earth magnetosphere, ionosphere and thermosphere, but also a synergic use of all data sources and a validation of the forecasting models.

Space plasmas are also the site where satellite instruments are capable of detecting different kinds of waves and even coherent structures on the Debye lengths. In particular, the possibility of direct measurement of waveforms using new capabilities of analyses offered, e.g. by the instruments onboard the two STEREO spacecrafts, has provided a complementary way to study the plasma dynamics. In this context, Langmuir and ion-acoustic waves are particularly important because they contain information on the dynamics at small scales, where observations are difficult. Space-plasma measurements combined with analysis of Vlasov numerical simulations have also provided the possibility of demonstrating fundamental nonlinear wave coupling processes as, for example, the parametric decay of a Langmuir wave into a daughter Langmuir wave and an ion-acoustic wave. The detection of the Debye length coherent structures, which can be associated with meta-stable Vlasov equilibria, is, on the other hand, one of the greatest successes of the theoretical Vlasov modeling of collisionless plasmas. These electrostatic structures, also recently observed in the laboratory, are particularly important because of their possible role in replacing collisions at the Debye length.

Several fundamental plasma physics questions, still open, will be addressed experimentally by future space missions and, theoretically, by large-scale simulations.

A non-exhaustive list of such questions concerns the development of turbulence, energy cascade and dissipation at small scales, the microphysics around collisionless shocks, the generation of suprathermal particles and their influence on the global dynamics of the system, up to processes that control Space Weather evolution. No doubt that the heliospheric environment is a laboratory of excellence for plasma physics. This special issue is an open collection whose aim is in particular to stimulate future debate and work in space plasma physics.