MINISYMPOSIUM

TURBULENCE IN THE HELIOSPHERE AND IN THE LOCAL INTERSTELLAR MEDIUM

Convenor: Daniela Tordella • Co-convenor: Federico Fraternale

In the Space Science, Astrophysics and Plasma Dynamics communities, the plasma and magnetic field turbulence is a highly debated topic. Turbulence is believed to be the major player in the conversion of kinetic and magnetic energy of into heat, which occurs via wave-particle interaction occurring at kinetic scales.
It is clear that the fields' fluctuations have an important role in the plasma heating. The interrelationship between turbulence and magnetic reconnection - another major player - is crucial for unravelling the physical processes which underlie the energy transport, conversion and dissipation in space plasmas, and also to understand the transport of energetic particles throughout the heliosphere. In fact, on the one hand magnetic turbulence is capable of generating current sheets which are subject to instability and reconnection. On the other hand, fluctuations due reconnection processes can feed a turbulent energy cascade.
These processes occur on very different scales throughout the heliosphere, from the Solar atmosphere to planetary magnetospheres, interplanetary solar-wind, heliosheath, heliotail, and local interstellar medium.

For what concerns the life on Earth, the properties of solar wind turbulence have direct consequences on space-weather events affecting the functionality of space- and ground-based man-made systems (telecommunication and navigation systems, power distribution networks, etc.) and our health.
The prediction of such extreme conditions in space represents a complicated problem for the interaction of many systems involved such as the Sun, the Earth's magnetosphere, ionosphere and atmosphere. By way of example, it may not be surprising that NASA's and ESA's research programs seek to understand phenomena on a broad range of spatial and temporal scales and how they combine to create extreme events. Investigating the processes that drive these phenomena and their interaction is crucial to advance our capability to predict space-weather events and to advance our understanding of laboratory plasmas as well.

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MINISYMPOSIUM PROGRAM

First Session • Thursday: 14.00 - 15.45 pm
Chair: D. Tordella

14.00 **Observing Solar Wind Turbulence from Fluid to Kinetic Scales**
R. Bruno

14.25 **Turbulence and Dissipation in the Solar Wind**
S. Galtier

14.50 **Simulating Solar Wind Dynamics Across Scales: the Expanding Box Model**
M. E. Innocenti, A. Tenerani, M. Velli

15.15 **Generation of Coherent Structures In MHD and Space Plasmas: Reynolds Number and System Size Effects**
W. H. Matthaeus, T. Parashar, M. Wan, M. Cuesta, A. Chasapis, R. Bandyopadhyay, R. Chhiber, Y. Yang

Second Session • Thursday: 16.15 - 18.00 pm
Chair: N. V. Pogorelov

16.15 **Turbulence and Instabilities at the Heliospheric Interface**
N. V. Pogorelov, F. Fraternale, M. Gedalin, J. Heerikhuisen, T. K. Kim, V. Roytershteyn, M. Zhang

16.40 **Voyager Data from the Heliosheath and Interstellar Medium**
J. Richardson, J. Belcher

17.05 **Statistical Properties of a Local Energy Transfer proxy in Space Plasmas**
L. Sorriso Valvo

ABSTRACTS

OBSERVING SOLAR WIND TURBULENCE FROM FLUID TO KINETIC SCALES

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The first observations by Mariner II of the complex nature of solar wind fluctuations date back to almost six decades ago. Since then, further space missions and more and more sophisticated numerical simulations have considerably augmented our capability of understanding the solar wind dynamics.
In fact, the solar wind is a turbulent magneto-fluid in which the scale of variability of plasma and magnetic field fluctuations extends from the inverse of the solar rotation period to the smallest scales of the order of the ion and electron inertial lengths. Some of these fluctuations are propagating modes but others are simply coherent structures advected by the wind across the observer.

Our heliophysics community pays great attention to study the role that plasma waves/turbulence play in accelerating and heating the wind, fundamental problems of high relevance to astrophysics.
However, new and more accurate in-situ measurements are needed. In this respect, the immediate future of space physics is particularly promising thanks to unprecedented in-situ measurements performed by Parker Solar Probe (PSP) and the future Solar Orbiter (SO) from their orbital vantage points.
I will provide a short overview of our understanding of the solar wind turbulence, going through a phenomenological description of turbulence within different frequency ranges and for different wind speed regimes.

TURBULENCE AND DISSIPATION IN THE SOLAR WIND

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A long-standing problem in the solar wind is its non-adiabatic cooling with a slow decrease of the proton temperature with the radial distance from the Sun. Several scenario have been proposed to explain this behavior, but the candidate that has driven much effort is certainly the local heating of the solar wind via turbulence. Large-scale MHD turbulence is seen as a reservoir of energy that cascades down to the small scales where it can be dissipated by some kinetic effects, which remain to be elucidated. In this type of study, the evaluation of the energy cascade rate plays a central role.

In my talk I will review some recent results in the field of (in)compressible (Hall) MHD turbulence with new theoretical predictions and comparisons with in situ data. At the very fundamental level I will also discuss the possible origin of the anomalous dissipation by extending the well-known results of hydrodynamics to plasmas.

SIMULATING SOLAR WIND DYNAMICS ACROSS SCALES: THE EXPANDING BOX MODEL

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With the launch of the Parker Solar Probe mission (Fox et al. 2016), the direct in-situ exploration of the solar wind plasma will have reached practically the entire heliosphere. From a theoretical point of view, understanding turbulence, wave particle interactions and nonlinearities as they occur in the solar wind requires advanced numerical modeling, given the enormous ranges of scales involved.
Specifically, when describing solar wind dynamics, one cannot forget that solar wind processes (instabilities, magnetic reconnection, turbulence) occur in a plasma which is moving radially away from the Sun, while expanding spherically in the transverse directions. The expansion has a huge impact on solar wind dynamics, making plasma more prone to the development of kinetic instabilities (e.g. Matteini et al. 2006) and even limiting the amount of heating that turbulence can deposit into the wind (e.g. Hellinger et al. 2015).

Competition of plasma processes with spherical expansion can be addressed with direct numerical simulations by including the Expanding Box Model variable change into codes working at different scales (MHD Grappin & Velli 1996; Velli et al. 1992), hybrid (Liewer et al. 2001), fully kinetic (Innocenti et al. 2019), depending on the nature of the processes one wants to investigate.
This talk will provide an introduction to the new views of the heliosphere provided by Parker Solar Probe before focusing on the dynamics controlling the electron distribution function. We will demonstrate via fully kinetic Expanding Box Model simulations done with the EB-iPic3D code (Innocenti et al. 2019) the interplay of spherical expansion and resonant electron firehose instability (EFI) in shaping the bulk properties of the solar wind.

As expected from Helios, Cluster, Ulysses observations (Stverak et al. 2008), the EFI, which self-consistently develops in our simulations as a consequence of the expansion, effectively bounds the increase in electron temperature anisotropy and electron parallel beta that one would expect from a purely expanding plasma.

GENERATION OF COHERENT STRUCTURES IN MHD AND SPACE PLASMAS: REYNOLDS NUMBER AND SYSTEM SIZE EFFECTS

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Spatial and temporal intermittency appear in fluids, magnetofluids and plasmas, with important implications for understanding of heliospheric and astrophysical plasmas [1]. Spatial intermittency is generally associated with formation of sharp gradients and coherent structures. The basic physics of structure generation is ideal, but when dissipation is present it is usually concentrated in regions of strong gradients [2].
This essential feature of spatial intermittency in fluids has been shown recently to carry over to the realm of kinetic plasma, where the dissipation function is not known from first principles [3,4]. This suggests that generalizing the Kolmogorov refined similarity hypothesis to plasmas is a subtle (and unresolved) issue. However, it is established that coherent spatial structures produced in intermittent plasma influence dissipation, heating, and transport and acceleration of charged particles [5,6]. These structures may take on a variety of forms - cores and current sheets in the density, shear layers and quadrupoles in vorticity, as well as near discontinuous density structures [7,8].
A variety of spacecraft observations and numerical simulations will be used to provide examples of these features to guide the discussion.

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TURBULENCE AND INSTABILITIES AT THE HELIOSPHERIC INTERFACE

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The astonishing journey of Voyager 1 (V1) and Voyager 2 (V2) through the heliosphere culminated by their crossings of the heliopause (HP) and penetration into the local interstellar medium (LISM). Physical processes in the SW and LISM are strongly affected by charge exchange between ions and neutral atoms, which leads to the birth of non-thermal (pickup) ions (PUIs) and energetic neutral atoms (ENAs). We discuss the fundamental phenomena occurring in partially-ionized SW and LISM plasmas affected by the presence of PUIs, turbulence, and instabilities of the heliopause. We address the behavior of PUIs and turbulence they generate in four distinctive regions: the supersonic SW, at the heliospheric termination shock, and inner and outer heliosheaths.

This allows us to shed light onto the PUI-related phenomena observed by IBEX, New Horizons (NH), Parker Solar Probe (PSP), SOHO, Ulysses, and Voyagers. We solve the Reynolds averaged MHD equations and show the results of our SW simulations along the NH, PSP, and Ulysses trajectories. The issues are discussed related to crossings of collisionless shocks by non-Maxwellian plasma. We demonstrate a spontaneous transition to turbulence in the inner heliosheath and analyze its consequences for the SW flow. We also show that the heliopause is affected by MHD instabilities and magnetic reconnection. Finally, we show our recent results related to the evolution of PUI distribution functions in the outer heliosheath and relate them to ENA observations by IBEX.

VOYAGER DATA FROM THE HELIOSHEATH AND INTERSTELLAR MEDIUM

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Voyager 1 and 2 are both in the local interstellar medium (LISM). This paper will describe recent data from both spacecraft with emphasis on the recent Voyager 2 crossing of the heliopause. Both spacecraft saw increases in the galactic cosmic ray (GCR) intensities several months before the heliopause.

Voyager 2 is making the first plasma measurements in this region and observed and increase in density and decrease in speed which seems associated with the GCR increase. We give the best estimates for the plasma parameters in the LISM.

We will also discuss similarities and differences between the V1 and V2 heliopause crossings.

STATISTICAL PROPERTIES OF A LOCAL ENERGY TRANSFER PROXY IN SPACE PLASMAS

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In weakly collisional space plasmas, the turbulent cascade provides most of the energy that is dissipated at small scales by various kinetic processes. Understanding the nature of such dissipative mechanisms requires the accurate knowledge of the fluctuations that make energy available for conversion at small scales.

The scaling properties of different energy channels are estimated here using a proxy of the local energy transfer, based on the third-order moment scaling law for magnetohydrodynamic turbulence. In particular, the sign-singularity analysis provides information on the structure and topology of the alternating positive and negative energy fluxes in the different channels.

The group at Politecnico di Torino has been involved in these topics.

In particular, we recently focused on the properties of magnetic field fluctuations in the inner heliosheath and in the local interstellar medium, with the aim of characterizing the energy-injection and inertial scales of turbulence in different heliosheath regions and on a broader range of scales than in previous studies [ApJ 972 (2019); Phys. Scr 91 (2016); J. Geophys. Res. 121 (2016); Eur. J. Mech. B 121 (2016)].

We analyzed *in situ* data from the *Voyager Interstellar Mission*, in collaboration with J. D. Richardson (PI of the Voyager Plasma Experiment, MIT Kavli Institute) and Prof. N. V. Pogorelov (University of Alabama, Huntsville).

In regard to these research themes, we contribute as Co-PI and Guest Investigators to the project "Turbulence as Indicator of Physical Processes at the Heliospheric Interface", H-GI Open Program, 18-HGIO18_2-0029, PI Prof. Pogorelov.