Wigner 121 Scientific Symposium

Wigner Research Centre for Physics
Institute for Particle and Nuclear Physics
Dept. of Space Physics and Space Technology

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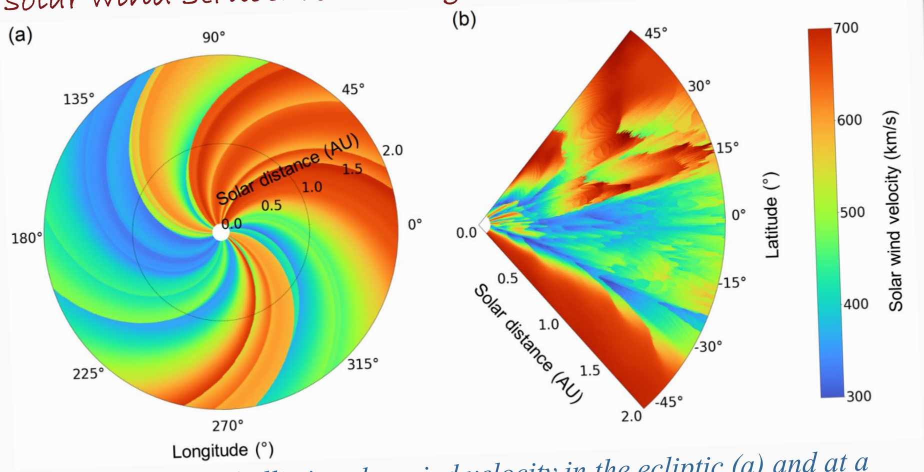
Introduction

The main research interest of our Department is the Solar System and its physical processes. It includes a complex regime of interactions, like the study of the solar interior, its physical processes, and the effect the solar wind and the interplanetary magnetic field on the ionospheres, and/or magnetospheres of planets, moons, and other objects in our Solar System (like comets). We are interested in comparing and finding analogies on the plasma environments of planets as well. Also it is vital to understand how our direct cosmic environment can affect our own planet, so space weather is another important topic that we focus on.

In order to engage in answering these questions we use the science data measured by several different space missions. We are actively participating in the international mission teams, and take part in data analysis and the publication of new results. Our team has been involved in several major space missions from the earliest planning phases through the development, building and testing of onboard instruments and finally the evaluation of the measurements in space. The paper presents some of our current researches and achievements.

Inner heliosphere – Temporal evolution and spatial variation of solar wind structures throughout the heliosphere

We extrapolate solar wind parameters in 3D in the inner heliosphere with an improved ballistic propagation method, using solar corona models as input data. Our enhanced model considers the interaction of slow and fast solar wind by applying a pressure correction during propagation. It also incorporates the differential rotation of the Sun in order to achieve a more accurate prediction at higher heliospheric latitudes (Timar et al. 2023, submitted to JSWSC, Biró et al., submitted to AGU Space Weather).
Furthermore, we also developed a method to analyze the orientation of stream interfaces in corotating interaction regions (CIR), which allows further studies about the interaction of fast and slow solar wind streams (Kobán et al. 2023).



Extrapolated 3D ballistic solar wind velocity in the ecliptic (a) and at a Carrington longitude of 180° (b) in January 2017.

Comet 67P/Churyumov–Gerasimenko – The dynamics of the magnetic field free cavity around comets

The diamagnetic cavity is the innermost region of the magnetosphere of an active comet from which the magnetic field is expelled by the outflowing matter. This phenomenon, first detected around comet 1P/Halley, was extensively studied recently by the Rosetta comet chaser mission. Rosetta observed a surprisingly large diamagnetic cavity around comet 67P/Churyumov–Gerasimenko and revealed an unforeseen structure, rich and highly dynamic. We presented a simple (1+1)-dimensional analytic MHD model of the diamagnetic cavity, which for the first time explained the unexpected size and variability of the cavity (Németh, 2020).

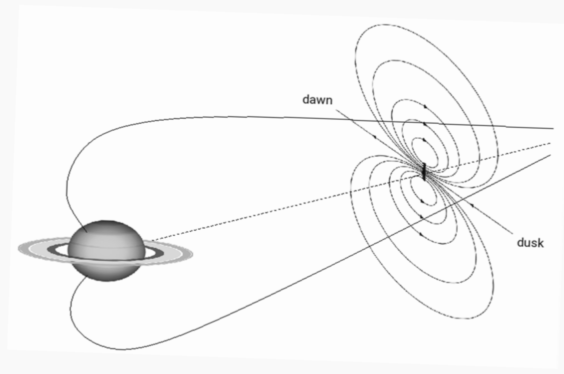

Comet 67P/Churyumov–Gerasimenko and Rosetta (rosetta.esa.int)

Sun – Simulation of the solar dynamo by physics-based models

Nonlinearities and/or stochastic variations in the parameters of solar dynamo models induce cycle-to-cycle variations in the resulting dynamo-generated magnetic field. The study of stochastically perturbed nonlinear dynamos is therefore intimately linked with studies of long-term variations of solar activity. Indeed, the 11-year solar cycle is an irregular, quasi-periodic phenomenon, the lengths and amplitudes of individual cycles varying between rather wide limits. Long-term variations are also present, including the Maunder Minimum and the Modern Maximum. We have performed a systematic analysis of the effects of varying parameters and different types of nonlinearities of the equations describing the evolution of the Sun's large-scale magnetic field. The objective was to find the signatures in the statistical properties of long-term activity variations that correspond to particular types of non-linearities or parameter combinations. (Talafha et al., 2022; Petrovay and Talafha, 2019)

Giant planets I – Closed field line vortices in planetary magnetospheres

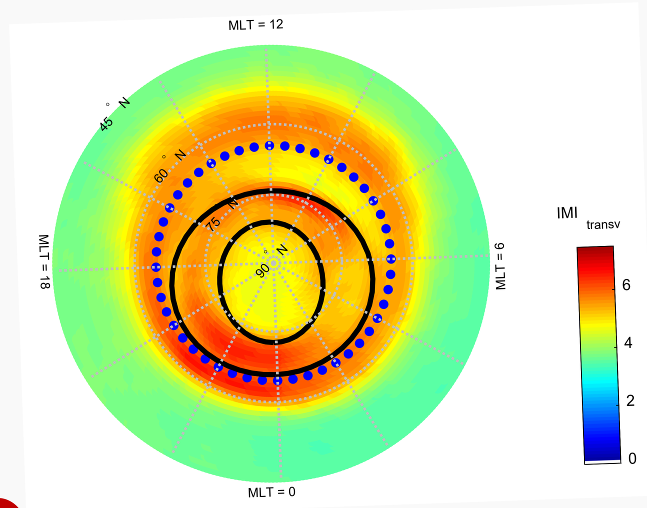
We have recently shown [1] that the magnetosphere of giant planets has a strange new domain, in which the behavior of the plasma and the magnetic field is radically different from any previous expectations. The magnetic field lines of this domain are closed (attached to the planet with both ends) but do not rotate around the planet as expected. The middle points of these field lines are anchored in slowly moving plasma in the far magnetotail, so these points cannot orbit the planet. At the same time the footpoints of the field lines, where they are attached to the planetary surface, rotate together with the planet. Thus, the field lines of this domain are twisted into huge vortices. The plasma here, instead of orbiting the planet, also swirls in vortices. Analysis of Cassini spacecraft data shows that this swirling motion does indeed occur in Saturn's magnetosphere. The new result completely changes the way we have thought about the magnetosphere of giant planets.



Closed field line vortices in planetary magnetospheres, (Nemeth, 2023)

Terrestrial space weather – Plasma irregularities in the upper ionosphere; Study of the Swarm mission magnetic field records

We study the magnetic appearances of small-scale plasma irregularities in the terrestrial upper ionosphere (altitude of about 500 km) by using the high-frequency (50 Hz) magnetic field observations of the Swarm mission triplet. It is argued that the irregularities evolve due to turbulent plasma phenomena exhibiting scale-dependent intermittent magnetic fluctuations. Making use of the non-Gaussian behaviour of the intermittent variations, a so-called intermittency index (IMI) has been developed to statistically reveal those regions in the upper ionosphere that exhibit intermittent fluctuations. It turns out that the most intensive intermittencies are apparent in the auroral oval and near to the ionosphere footprint of the plasmapause. These findings are reinforced by auroral oval boundary and plasmasphere models (see the Figure). Additionally, we also show the intermittent behaviour of the magnetic field fluctuations about the dip equator (near 10° of latitude in both hemispheres), resulted in by equatorial spread F and plasma bubble phenomena. Considering the space weather con-sequences of the irregularities the correlation of the detected irregularities with the propagation of GNSS radio signals is also concerned, via the monitoring of loss of lock events and signal distortions (i.e. scintillations) onboard the Swarm triplet as well as in ground GNSS stations.



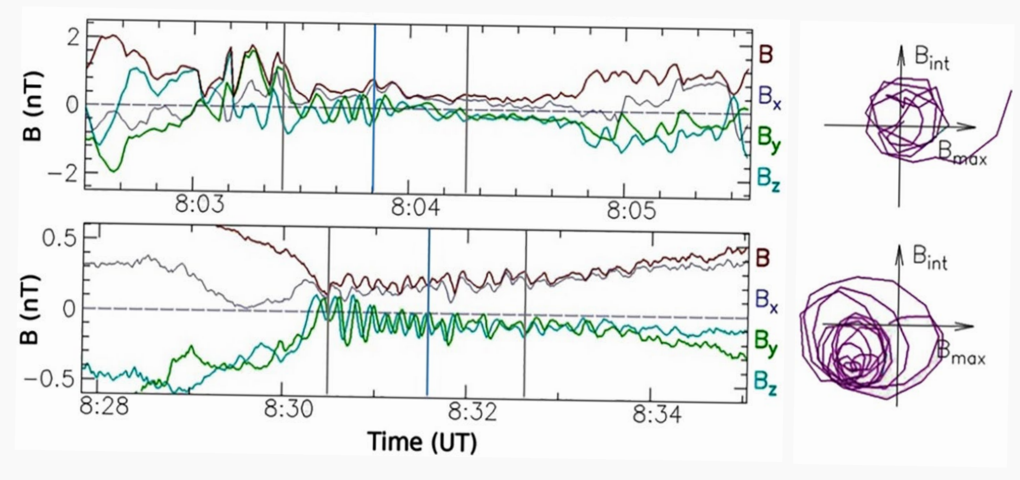
The distribution of the intermittency indices (IMI) in terms of geomagnetic latitude and magnetic local time (MLT), in the upper ionosphere (northern polar region). IMIs were collected for Swarm A & C & B spacecraft, for the period of 2014-2022. Black solid lines show the models of the poleward and equatorward boundaries of the auroral oval (Xiong et al., 2014). Blue dots represent the plasmapause model of Heilig and Lühr (2018).

Contributions in space missions

- **BepiColombo (ESA & JAXA)** ; 2018 – (ongoing)
  Target celestial body: Mercury || Co-I status in the SERENA/PICAM (Planetary Ion CAMera) instrument team.
- **STEREO (NASA)** ; 2006 – (ongoing)
  Target system: Inner-heliosphere, solar wind || Co-I status in the PLASTIC ion plasma, and IMPACT charged particle and magnetic field experiments.
- **Solar Orbiter (ESA & NASA)** ; 2020 – (ongoing)
  Target system: Solar wind in the ecliptic plane and in the southern and northern region of the Sun. || Co-I status in the design and operation of the magneto-meter (MAG) instrument.
- **Rosetta (ESA)** ; 2004 - 2016
  Target celestial body: Comet 67P/Churyumov-Gerasimenko || WRCP participated in the development of the Rosetta Plasma Consortium and the Command and Data Management System of the Philae lander.
- **Cassini (NASA & ESA)** ; 2004 - 2017
  Target celestial body : Saturn, its rings and moons || Co-I status in the instrument teams of Cassini Plasma Spectrometer and Magnetometer instruments
- **Cluster (ESA)** ; 2000 – (ongoing)
  Target system: Terrestrial magnetosphere and partly the solar wind || Co-I status in the FGM magnetometer and RAPID particle instrument teams @ Our department maintains the Hungarian Data Centre which is producing the auxiliary parameters of the Cluster Science Data System.
- **SOHO (ESA & NASA)** ; 1995 – (ongoing)
  Target system: Sun and the solar wind || the Co-I status in the COSTEP/LION low-energy ion and electron instrument team
- **JUICE (ESA)** ; 2023 – (ongoing)
  Target celestial body : Jupiter and its icy moons || The power supply units of the mission were designed by Hungarian ESA partners including WRCP

Giant planets II – Observations of short large amplitude magnetic structures at the Kronian bow shock

Short Large Amplitude Magnetic Structures (SLAMS) are suggested to be the results of the steepening long wavelength magnetosonic waves in the upstream region of magnetized planets, which are generated due to the wave-particle interaction between backstreaming solar ions and nonlinear, compressive ULF waves in the quasi-parallel upstream region. SLAMS have been observed at Earth's quasi-parallel bow shocks (BS) by the CLUSTER probes. In our work we identified and thoroughly analysed four SLAMS events near the BS region of Saturn, by the use of Cassini's plasma and magnetometer records. It was found that formation of SLAMS is possible upstream of Saturn through the same mechanism, like at the Earth, however, the characteristic time scale for the events is longer due to the smaller upstream magnetic field values. ULF wave formation can be observed near the BS , and in several instances the whistler precursor waves were also present. Although with Cassini it is not possible to analyze the spatial distribution of the observed magnetic structures (like with the CLUSTER probes), we can assume that their principal propagation mechanisms and steepening are similar to those observed in the terrestrial upstream regime.
During most of the events the (locally) quasi-perpendicular behavior of the SLAMS fronts were verified, as plasma heating, deceleration, and beam deflection at the structures were all observed. These features are common with the events previously observed in the terrestrial quasi-parallel upstream region (Bebesi et al., 2019).



Magnetic records of SLAMs in the vicinity of Saturn's bow shock and corres-ponding whistler wave signatures centered at 08:03 and 08:31. The hodograms (right) plotted in the B_{max}-$B_{interm.}$ plane of the minimum variance analysis frame refer to the whistler occurrences and show their clockwise circular polari-zation and decreasing amplitudes with time.

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