Workshop on Cross-Scale Coupling in Plasmas

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High kinetic energy density jets in the Earth's magnetosheath: preliminary results.

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Plasma jets in the magnetosheath near the Earth magnetopause are commonly observed and are usually related to magnetic reconnection between the geomagnetic field and the magnetic field carried by the solar wind. However, evidence has been shown in the last years of jets which cannot be explained through reconnection. In this paper we review past observations of high kinetic energy density jets in the magnetosheath and present preliminary evidence of additional similar observations. Finally, we argue that further work has to be done on this matter, as such jets could represent a phenomenon of general occurrence which still needs to be explained.

Advantages of the Cross-Scale Waves Consortium for Plasma Waves Investigation.

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It is well known that plasma waves play a role similar to collisions in a laboratory plasma. Hence, characterisation of the wave processes observed in geophysical plasma provides crucial information regarding the processes occurring within the plasma turbulence. Waves are observed in the frequency range from DC up to a few MHz with both magnetic and electric components. To achieve maximum scientific return across the wave spectrum, the individual wave measurement instruments are controlled by a single DPU. This enable the maximisation of the use of resources such as mass, power and telemetry and also provides a method to obtain coordinated high resolution data across all instruments. This coordinated approach to AC field measurements has led to the formation of the Fields Consortium which coordinates the technical design and integration of the individual units as well as their operations once in orbit.

Optical design of the Ion Composition Analyzer and performances of a multi-channel ASIC for plasma instruments on the Cross-Scale Mission.

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LPP/CNRS

The Laboratory of Plasma Physics (LPP-former CETP) has been developing, building, and exploiting ion mass spectrometers for the last thirty years. It has served as hardware institution for providing the ion optics of ion mass spectrometers on Mars-96 (Dymio), Interball (Hyperboloid), Cassini (IMS), and BepiColombo (MSA). We present the optical design of an Ion Composition Analyzer whose performances would meet the scientific requirements of the Cross-Scale mission in terms of energy/angle resolution, geometric factor, and mass resolution.

The team also provided the detection system of ion instruments on Mars-96, Interball, Polar (Tide), and Rosetta (DFMS). For Bepi-Colombo MPO, LPP is responsible for the development of the TOF detector of the ion mass spectrometer (PICAM) which includes a space qualified ASIC with unique capabilities and performances. This very-low power integrated circuit could be used as the multi-channel front-end electronics of the TOF detector of the Ion Composition Analyzer.

We also present the properties of a multi-channel component that has been optimized for the fast plasma instruments of the Cross-Scale mission. This very low-power ASIC (¡ 1mW/channel) is able to manage very high particle fluxes with pulse pair resolution below 100 ns.

Multi-resolution analysis of two-dimensional free relaxing turbulence in a pure electron plasma.

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Penning-Malmberg traps for the confinement of non-neutral plasmas are suitable devices for the experimental study of two-dimensional (2D) fluid dynamics and turbulence, because the axially integrated dynamics of the particles is well described by the cold fluid drift-Poisson equations, which are analogous to the Euler equations for a 2D ideal fluid. The particle density and the electrostatic potentials are proportional to the vorticity and the stream function of the equivalent fluid, respectively.

The free relaxing 2D turbulence of an electron plasma has been studied in the Penning-Malmberg trap ELTRAP [1] using a charge coupled device camera. After the injection into the trap, the plasma undergoes a strong diocotron (Kelvin-Helmholtz) instability, with the formation of several vortices, which then interact through close encounters and mergers. Inverse cascade processes are observed, characterized by the persistent presence of long-living coherent structures and the formation of a well mixed background.

We have performed a spectral analysis of the flow using a wavelet transform and a multi-resolution analysis [2]: the vorticity (density) field has been mapped onto a set of wavelet coefficients at each length scale. Coherent and incoherent flow fields have been separated using the iterative algorithm proposed by Farge [3]. The procedure is able to disentangle the strong vortices from the background by separating the wavelet coefficients according to a self-consistent Donoho [4] threshold.

Scale contributions to the measured enstrophy and energy distributions are inferred, and the results are compared with recent experiments and theoretical pictures of the 2D turbulence.

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Kolmogorov entropy of magnetic field lines in the percolation regime.

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We report the first numerical computation of the Kolmogorov entropy h of magnetic field lines extending from the quasilinear up to the percolation regime, using a numerical code where one can change both the turbulence level $\delta B/B_0$ and the turbulence anisotropy $l_\parallel/l_\perp$. We find that the proposed percolation scaling of h is not reproduced, but rather a saturation of h is obtained. Also, we find that the Kolmogorov entropy depends solely on the Kubo number $R = (\delta B/B_0)(l_\parallel/l_\perp)$, and not separately on $\delta B/B_0$ and $l_\parallel/l_\perp$. We apply the results to electron transport in solar coronal loops, which involves the use of the Rechester and Rosenbluth diffusion coefficient, and show that the study of transport in the percolation regime is required.

The polar cusp as a natural laboratory to study the multi-scale plasma processes.

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The main goals, among others, for the CrossScale project are studies of the plasma turbulence and acceleration of particles in space plasmas. In this presentation we will give examples of the registration of low frequency waves, which have been sometimes registered in the polar cusp as emissions with extremely high intensity below the electron cyclotron frequency by Interball 1, Magion 4 and CLUSTER. They correlate with strong fluxes of high energetic electrons often observed within the polar cusp by Interball 1 and Magion 4. Similar effects have been registered by Polar satellite. Cluster measurements give new insight into these emissions and the presence of energetic electron fluxes. Recently (December 2007) during special campaign of observation in the low altitude ionospheric part of cusp satellite DEMETER also registered similar effects. Polar cusps are regions particularly turbulent. Observed disturbances show the nonlinear character, and strong wave-particle interactions can lead to the presence of the fluxes of the electrons with high energy. Oppositely these electrons can amplify the emissions due to plasma instabilities like fan instability, horseshoe instability and stream instability. All these instabilities play an important role in the nonlinear wave-particle interactions leading to the isotropisation of the fluxes of the particles and the heating of the plasma. We would like to show in our presentation examples of the correlated measurements indicating, that polar cusps at different altitudes are natural laboratory to study these fundamental processes. A particularly interesting case will be discussed (6 December 2007), when CLUSTER and DEMETER were simultaneously in the cusp, DEMETER in the northern cusp, but CLUSTER in southern one, observing similar phenomena at different altitudes. This event indicates the global character inside one plasma structure (cusp) of small scale (waves) processes.

Study for the Common Payload Processor (CPP) for Particle Experiment

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Given the complexity of Cross-Scale in terms of instruments and number of s/c involved, the problem of optimizing and reducing resources is quite relevant to this mission. A common on-board processing unit or Common Payload Processing (CPP), as indicated on the Preliminary Design Document (PDD), would be the right answer to this problem. The Cross-Scale plasma sensors should be integrated into a suite, and serviced by a common Digital Processing Unit(DPU) - i.e. the CPP in this context - which provides a single power, telemetry, and control interface to the spacecraft as well as power, switching, commanding, data handling and data compression functions for all of the sensors. This would facilitate technical, programmatic and scientific synergies, enable an integrated and coherent approach to correlative plasma measurements, and readily permit to combine these measurements with theory and comprehensive modeling. It clearly offers advantages from the spacecraft resources point of view and potentially also in terms of inter-operation with other instrument suites on the spacecraft. A DPU architecture similar to the proposed CPP is being developed for SERENA particle suite on the Bepi-Colombo spacecraft and proposed for the SWA plasma suite on Solar Orbiter spacecraft.

The multi-scale nature of collisionless magnetic reconnection - Numerical simulation of the observables of the microphysics and turbulence behind.

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Reconnection in collisionless space plasma is an essentially multiscale-coupled process: Its specific macroscopic observables are certain characteristic plasma flow patterns, peculiar magnetic field geometries and topologically distinct field structures and current concentrations at typical magnetohydrodynamic fluid scales. On the other hand reconnection in collisionless space plasma needs localized dissipation which takes place at microscopic, kinetic, i.e. particle scales.

The Cross-scale mission is planned to cover the whole range from large to small scales. But what are the observables of the small scale processes?

We performed forward kinetic numerical simulations of typical reconnection situations starting from turbulent reconnection taking place at kinetic scales. We analyzed the evolution of the turbulence, the dynamical spectra of the fluctuations and of their fractal dimension.

We draw conclusion about the necessity of installing appropriate high time-resolution magnetic and electric field fluctuation detectors on the cross-scale spacraft and to downlink it unchanged to the Earth in order to verify the essentially nonlinear processes linking small scale dissipation in current sheets and collisionless reconnection at large scales by means of in situ measurements in space, since remotely, at more distant astrophysical plasmas like in the solar corona such measurments are impossible.

From macro to micro scales in solar wind turbulence.

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Fluctuations in solar wind are observed at all available scales and are usually described in the framework of fully developed turbulence. However, the understanding of what physical effect plays the role of energy dissipation in a collisionless plasma is one of the outstanding and timely problems of solar wind turbulence theory. We review the state-of-art of investigation of solar wind turbulence, with a particular emphasis on both the energy cascade at large scales, and the cross-scale effects which could establish a link between macroscopic and microscopic scales.

Estimating local gradients and the geometry of magnetic field lines with Cross Scale: a theoretical discussion of physical and geometrical errors.

Gérard M. Chanteur

CNRS/LPP

A multi-spacecraft mission with at least four spacecraft, like CLUSTER, MMS, or Cross-Scales, can determine the local current, and the local geometry of the magnetic field lines when the size of the cluster of spacecraft is small enough compared to the gradient scale lengths of the magnetic field. Reciprocal vectors of the tetrahedron formed by four spacecraft are a powerful tool for estimating gradients of fields and their errors (Chanteur, 1998 and 2000). Shen et al. (2003) and Runov et al. (2003 and 2005) used CLUSTER data to estimate the normal and the curvature of magnetic field lines in the terrestrial current sheet: the two groups used different approaches. Vogt, Paschmann and Chanteur (2008) have presented a compendium of these techniques together with new insights in the determination of the local geometry and the associated errors Considering a thick and planar current sheet model and making use of the statistical properties of the reciprocal vectors allows to discuss theoretically how physical and geometrical errors affect these estimations.

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Wave telescope applicability for cross-scale measurements.

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The wave telescope technique (k-filtering) allows one to obtain the wave vector distribution of a wave field from multi point measurements. The applicability of the technique is strongly dependent on the number and geometrical arrangement of the sensors. Although it is inspired from seismology where it has been applied for various sensor arrays, in space it has only been applied for the CLUSTER tetrahedron formation. Extending the technique to use measurements from sensors separated by different scales is not trivial. We use synthetic data to investigate the extension of the wave length domain where the technique can be applied for each scale and the relation between these domains for various spacecraft configurations.

Rationale for a perigee around 4-5 Re to study the plasmasphere.

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The study of the plasmasphere region might not be a prime objective of the Cross-Scale mission, but it could become one, if the perigee of the orbit would be around 4-5 Re. Such an orbit would allow a higher telemetry rate than with a higher perigee, and it would require less propellant than a lower perigee. It should be noted that also for the CLUSTER mission, the study of the plasmasphere was not a prime objective; in fact, CLUSTER might not have ever observed this region because the initial perigee was around 8 Re. But in view of all the results obtained in the plasmasphere, there are no regrets about this choice. In particular, the fortuitous synergy with the IMAGE mission has turned out to be of scientific interest. A book on plasmaspheric physics with CLUSTER and IMAGE observations will be published by Springer in the coming months. Moreover, the different spacecraft separations (both smaller and larger than CLUSTER), the higher number of satellites, the different configuration, and the equatorial orbit would allow new studies of the plasmasphere, for example concerning small-scale density structures, computation of 10- or 12- spacecraft spatial gradients of middle-scale structures like plumes, study of sub-corotation, electron distribution studies, study of the role of inner magnetosphere electric fields and the role of SAPS, ... An even lower perigee would make radiation belt studies possible.

N-spacecraft computation of gradients.

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The classical gradient computation algorithm (CGC) requires exactly four simultaneous in situ measurements from four non-coplanar points. The curlometer has been based on this CGC. CGC and the curlometer have been used extensively in the context of ESA's Cluster mission. A recent extension of CGC is the least-squares gradient computation technique (LSGC). LSGC has several interesting features. It obtains not only the gradient, but also a realistic error estimate on that gradient. A second feature is the possibility to include constraints; for instance, including the zero divergence constraint leads to an improved curlometer. A third property is that the technique works without any a priori limitation on the number of spacecraft or their configuration: The technique sorts out what data are relevant for computing a particular gradient by itself. These properties make LSGC to a promising data processing tool for the Cross-Scale mission.

Diffusive Shock Acceleration - a mesoscopic theory between plasma physics and MHD.

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I will review our current understanding of diffusive shock acceleration (DSA) emphasising its status as a theory operating on intermediate scales between the microscales of plasma physics and the macroscales of large scale magnetohydrodynamic flows. The importance of heliospheric observations to our understanding of the interface between plasma scales and DSA will be discussed.

Use of multi-point analysis and modelling to address cross-scale coupling in space plasmas: lessons from Cluster.

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It is well known that space plasmas are distinct from laboratory generated plasmas in that they are generally collisionless, so that the magnetic field plays a particular role in space plasmas, affecting the particle distributions. Nevertheless, the outstanding issues of plasma physics often have parallels in both plasma regimes and exhibit common phenomena. The examples given here will illustrate these parallels through comparative theoretical modelling, and explore issues of 'cross-scale' coupling and time stationarity, with existing multi-scale data sets. The proposed aims of the Cross-Scale mission are to determine a complete understanding of behaviour on micro-, meso-, and (MHD-) fluid regimes under conditions of turbulence, during magnetic reconnection and in plasma boundaries. These broad themes map to a number of related, and overlapping, phenomena which play different roles in each theme. The process of magnetic reconnection has a number of directly associated phenomena: FTEs, accelerated flows, energization, or x-line structure. Shock formation and othher boundaries are controlled by entropy and free energy considerations, discontinuity relations and the magnetic geometry. Turbulence operates through a hierarchy of subtle transport mechanisms relating to fundamental scaling relations and requirements on criticality. The analysis of existing, multi-point data sets has lead to a number of data co-ordination methods, such as the four spacecraft analysis tools developed for Cluster and we consider examples of the use of these here. With the addition of theoretical modelling (in the context of particular phenomena, dawing parallels from tokamak theory) and considerations of measurement quality, advanced analysis concepts may be investigated. A particular issue, is how to resolve temporal behaviour across the spatial regimes, so that the data set is suitably coordinated. Moreover, adequate sampling of phenomena (for example, to extract the necessary information on the mechanisms operating) requires suitable spacecraft configurations and directly maps into the measurement quality achievable.

Numerical studies at INAF-IFSI on electrostatic plasma analysers in the context of Cross-Scale.

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We present a numerical study on the response of a Top-Hat type electrostatic analyser which might be suitable for the plasma suite onboard Cross Scale, as proposed in the Payload Definition Document.

The apogee and perigee of each spacecraft will range between 10 and 25-30 earth radii, thus allowing the crossing of different space environments, characterized by different number densities. In principle, in every region visited, a different geometric factor should be used. This was already done in CLUSTER/CIS2, which has $2 \times 180°$ FoV sections parallel to the spin axis with two different geometric factors: one allows detection of the solar wind while the other one operates in the magnetosphere. However, in order to exploit continuously the whole FoV, we propose to use a variable geometric factor obtained varying the polarization of an 'o-ring' located around the entrance of the external plate of the analyser.

Magnetosheath intermittency downstream quasi-parallel and quasi-perpendicular shock.

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The transfer of energy between scales in the terrestrial magnetosheath is turbulent and intermittent. Satellite data evidence non-Gaussian probability distribution functions (PDFs) and multifractal properties of magnetic field fluctuations in the magnetosheath. We discuss observations of intermittent turbulence by Cluster and some preliminary results from THEMIS B and C. During April and May of 2008 the orbits of Cluster and THEMIS B and C are separated by a large distance in the GSE y-direction and form a configuration suited to perform observations downstream the quasi-parallel and quasi-perpendicular shock geometry. The statistical properties of turbulent B-field fluctuations are investigated aided by a package including: PDFs computation, wavelet analysis, rank ordered multifractal analysis and rescaling. We obtain an image of the intermittency over inertial range scales and discuss effects on the threshold-scale for transition from Gaussianity to intermittency, on the moments of PDFs (like the flatness) and the local measure of intermittency (LIM), as well as PDFs rescaling.

Plasma electron instrumentation for Cross-Scale.

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The Cross-Scale mission, proposed for ESA's Cosmic Visions programme, is designed to study fundamental processes that transport, convert or release energy in collision-less plasmas. Recent space plasma physics research has shown that in fundamental plasma physics phenomena such as magnetic reconnection, turbulence and collision-less shocks, processes operating on different scales all participate simultaneously. The mutual interaction of processes operating on different scales is a critical yet little-understood aspect of the phenomena. The Cluster 4-spacecraft mission has been able to explore only one such scale in three dimensions at any one time, for example the time and length scales of ion motion, or the larger scales on which fluid descriptions of the plasma are appropriate. Planned missions such as MMS will begin to address the smallest relevant scale, that on which electron phenomena occur, which requires a new generation of particle instruments capable of very fast measurements. Cross-Scale will simultaneously address all three scales, using up to 12 spacecraft flying in formation in the Earth's magnetosphere and the solar wind. We will review the roles and requirements for electron instruments for Cross-Scale and discuss how the particular constraints of the mission may affect design choices for electron instruments on spacecraft with different roles in the Cross-Scale constellation.

THEMIS Mission Planning and Constellation Maintenance.

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In its exploration of the onset and evolution of magnetospheric substorms NASA's THEMIS mission determines the coupling of space plasma processes on large and disparate scales. The substorm onset signatures in the auroral polar regions are correlated with the interaction of substorm components that can expand over more than 30 Re in the equatorial tail of the magnetosphere. The required synchronized measurements in space and on the ground are achieved by a complex mission design that combines five small space probes on orbits with various multiple day periods and 20 ground observatories along the auroral oval in North America. Since its launch on February 17, 2007 THEMIS has successfully proven its mission design strategies for a constellation-class mission.

In my presentation I want to focus on how we faced the challenges for the orbit design and constellation maintenance. Shortly after approval we developed our own mission planning software to evaluate and maintain science targets through the various stages of the mission and the reliable handling of the thousands of parameters required to repeatedly generate the end-to-end mission trajectories for all five probes. Having the end-to-end mission trajectories early on was crucial for long term mission planning, strategic decisions on data collection modes, and the coordination with other projects using web-based 4D visualization tools and data bases holding multiple data sets from space and ground. I will also address how a high level of automation was key to manage the complex time constraints to bring all five probes into their orbits, maintain satellite and space-ground conjunctions, and improve science return with a very small team. Equipped with this flexible mission planning tool we were able to incorporate the unanticipated pearl-of-string formation of our first few months after launch in almost real time. That greatly enhanced the science during our waiting period, the coast phase, we encountered due to an unexpected launch delay.

The SCOPE Mission.

M. Fujimoto

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In order to open the new horizon of research in the space plasma physics, formation flying spacecraft of SCOPE will perform simultaneous multi-scale in-situ observations of space plasma dynamics in the earth's magnetosphere. In SCOPE, we will combine the observations by mother-daughter spacecraft pair resolving the electron scale dynamics with monitoring by the three daughter spacecraft formation of the surrounding ion/MHD-scale dynamics. This will enable us to inspect from the cross-scale coupling point of view how the key space plasma processes develop, and that, with hands-on-data basis. Key physical processes to be studied are shocks, magnetic reconnection, and turbulence. The SCOPE mission made up of the five spacecraft will be put into the equatorial orbit with the apogee at 30Re (Re: earth radius), making the spacecraft formation to fly through the regions in the near-earth space that host the plasma processes of fundamental importance. There is lively on-going discussion on the fully world-wide international collaboration, which would certainly make the coverage over the scales of interest much better and thus make the mission success to be attained at an even higher level. The common goal here is not only to understand the near-earth space deeper but also to make substantial contribution to our understanding of the Plasma Universe.

Joint effect of stochastic and steady acceleration mechanisms in the Earth's magnetotail.

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Ion beams with energies of the order of several tens of keV are frequently observed in the Earth's magnetotail. Here we consider two possible acceleration mechanisms, the cross tail electric field E_y and the stochastic acceleration due to the electromagnetic fluctuations present in the magnetotail. A test particle simulation has been performed in order to reproduce the interaction between charged particles and electromagnetic fluctuations and the constant dawn-dusk electric field, E_y, in the magnetotail current sheet. Electromagnetic perturbations are generated by random oscillating "clouds" moving in the $x - y$ plane. Protons are accelerated via a stochastic Fermi-like process and, by varying the features of the electromagnetic fluctuations, along with the value of the normal magnetic component and other physical parameters, we can explain a range of energetic ion observations.

Intermittent structures and magnetic discontinuities on small scales in MHD simulations and solar wind.

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In this work we re-examined the statistics of rapid spatial variations of the magnetic field in simulations of Hall magnetohydrodynamic (HMHD) turbulence, using analysis of intermittency properties of the turbulence, and also using methods often employed to identify discontinuities in the solar wind (as in the earlier work of Tsurutani & Smith 1979). The hypothesis is that the statistics of intermittent events might be related to the statistics of classical MHD discontinuities. Indeed, those methods give similar distributions of events, often identifying the same structures. This suggests that observed discontinuities might not be static solutions to the MHD equations, but instead may be related to intermittent structures that appear spontaneously in MHD turbulence. Finally, probability distribution functions of increments in ACE data and in simulations reveal a robust structure consisting of small random currents, current cores, and intermittent current sheets. This classification provides a real-space picture of the nature of intermittent MHD turbulence.

Solar MHD discontinuities as the driving force of the solar wind.

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The main solar MHD discontinuities appearing in the solar corona and in the solar wind are discussed. It is shown that there are specific cases which promote the change of the type of the solar MHD discontinuities inside the solar transition region and at the boundary of the coronal streamer. Often fast shock waves refraction through the contact discontinuity inside the transition region from the solar chromosphere to the solar corona gives us a source for the slow shock waves appearance after the interaction with the stationary contact discontinuity. By the way slow shock waves may appear in the result of similar interaction with the boundary of the coronal streamer described as a tangential discontinuity. Possible dissipation of the solar slow shock waves caused by the Landau damping is discussed for the solar corona. The driving of the magnetic clouds in the solar wind by the solar fast shock waves and the rotational discontinuities is also considered. It is shown that some space data confirm the obtained results and do help to understand better the behaviour of the coronal and solar wind flows. The work was done in the frame of the grant 08-01-00-191 of RFFI and partially due to the Program OFN 16.

Design and Development of the Cross-Scale High Energy Particles (HEP) Instrument.

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The paper describes the current status of the design of the High Energy Particle (HEP) instrument which is being developed by a consortium lead by the Rutherford Appleton Laboratory Space Science and Technology Department. The instrument is being developed for Cross-Scale which is a multi-spacecraft plasma physics mission. Cross-Scale has been selected as a candidate mission within the ESA Cosmic Vision programme for assessment study in the period 2007-2009. The instrument is composed of a set of pin hole detectors which instantaneously map supra-thermal electron and proton fluxes over the entire sky with a series of segmented, event detecting Silicon PIN diode detectors. Each of the individual pixels in the instrument have a field of view of roughly $20^\circ \times 20^\circ$ and simultaneously measure the flux of both electrons and protons in the energy range 20 keV to 1 MeV. The energy of each particle event falling on a particular detector is measured with a maximum rate of 10k (goal 100k) events per pixel per second. A running total is kept for each spatial and energy resolution bin during each integration period and is used to estimate the electron and proton fluxes at a cadence of up to 16 Hz. Bespoke low noise Front-End Electronics (FEE) are being developed to readout and sample the detectors as well as interface with the digital data handling electronics. The FEE will be based on ASIC technology to enable the power, noise and sampling speed requirements of the instrument to be met. The overall design of the instrument are described in the paper including detailed estimates of instrument performance parameters, the electrical, mechanical and thermal design as well as a summary of the interface resource allocations. An outline of the instrument development programme and milestones is also presented.

The role of medium energy particle measurements in CrossScale studies of collisionless plasma processes.

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The CrossScale science requirements have identified the need to measure electron and ion fluxes at energies of thirty to several hundred keV. This is a critical energy range as it gives access to those parts of the energetic particle distributions that show the non-equilibrium nature of collisionless plasmas. Most notably, in-situ measurements in collisionless plasmas across the solar system almost always exhibit kappa-type distributions, that exhibit power law behaviour at high energies — and almost never show simple Maxwellian distributions. This behaviour has significant implications for the bulk properties of the plasma, e.g. the medium energy particles may make a significant contribution to higher order moments such as pressure and heat flux. It may also modify some of the key parameters that we use to characterise plasmas; for example there is considerable discussion in the literature on how the presence of a power law tail modifies electrical shielding in the plasma and hence the Debye length. Medium energy particles also provide vital information on particle energisation by the plasma effects targeted by CrossScale (turbulence, shocks and reconnection). Measurements of the particle distribution will allow us to investigate the energisation process both locally and from vantage points well away from the acceleration site. Detailed analysis of the distributions will help to determine the relative contribution of fundamental processes such as slow mode acceleration, coherent electrostatic structures, betatron, Fermi and pick-up Fermi, turbulent confinement and reflection and electron holes. This talk will review our understanding of the requirements for particle measurements at these energies and will explore how that knowledge can be deepened to build up the specification of the proposed High Energy Particle instrument on CrossScale. In particular, it will stress the need for a deeper identification of plasma wave modes that interact with energetic particles, e.g. electrons and right-circularly polarised modes such as whistler waves. We will also touch briefly on the value of setting CrossScale studies of energetic electrons in a broader astrophysical context, e.g. the various observational techniques that estimate energetic electron fluxes at very distant objects.

Science operation planning: a mandatory component of mission design.

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Both at functional and implementation level, the data handling and operation planning systems are two distinct systems that must not be confused. In this talk, we would like to emphasize that one must start to analyse at mission design level the type of constraints that planning systems will have to deal with. This is because the complexity of the constraints drives the functional architecture (where nodes such as PI teams, ESOC are not relevant) and, subsequently, the implementation (not only at software but also at institutional level). These two designs drive the performance and productivity of the system (i.e. what we can do and at what cost). In the absence of performing "constraint programming" algorithms, constraints have to be transformed into rules. This transformation can be complex as it requires backward reasoning. It is often not full proof. In addition, the expression of the constraints can itself be complex. This means that a good understanding, at mission design level, of the constraints and of their consequences at functional/implementation level can help avoiding bad surprises when it is too late, or too expensive, to change anything; in other words, it can trigger trade-offs. A good example for such a need is the underestimation of the planning of the WBD operations for Cluster. At RAL, we have an extensive experience of payload operations due to our involvement in the Cluster, Double Star and Mars Express missions. We are currently capitalising on that experience by performing an analysis of the planning issues and publishing the results of this work.

CrossScale science operations - some lessons - learned from Cluster.

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The planning of science operations for CrossScale, as with any space plasma mission, will be critically dependent on (a) the capabilities of the various spacecraft and instruments and (b) on the regions that the spacecraft encounter along their orbits. The ideal would be to run the same operations 100little planning would be needed. However this ideal will inevitably be eroded by a variety of practical constraint including instrument performance, on-board data storage available, ground station visibility and availability, data downlink rates, availability of spacecraft power for instruments and downlink, and orbit and attitude maintenance. Some of these constraints will come into play from the start of mission whilst others will become significant as the mission evolves through the usual mix of spacecraft aging, advancing scientific ideas and, not least, the available budget. This talk will review how some of these issues have been handled during the present Cluster mission and highlight lessons that can help CrossScale. The most critical lessons are (a) to keep operations concepts as simple as possible and (b) to ensure that the operations architecture is designed to support a gradual and progressive erosion away from the ideal. The talk will also review current thinking on CrossScale science operations, e.g. the use of autonomy, and suggest how lessons from Cluster can be applied here.

Emission of nonlinear whistler waves versus self-reformation of perpendicular shocks.

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Perpendicular shocks simulated using 1-D codes (both hybrid and PIC) are strongly non-stationary (exhibit the self-reformation process) for a wide range of upstream parameters (e.g., low proton beta and/or high Mach numbers). However, 2-D hybrid and PIC simulations (with the simulation plane in the coplanarity plane) of the perpendicular shocks indicate that the shocks which are self-reforming in 1-D are typically quasi-stationary (but not completely stationary) in 2-D and their shock foot region is dominated by whistler waves which are oblique with respect to the shock normal as well as with respect to the upstream magnetic field. These simulations indicate that these whistler waves inhibit the self-reformation process for a wide range of upstream parameters.

Multi Scale Projective Integration Method for Plasma Simulation

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Currently, there is an upsurge of activities in natural sciences and engineering in a quest to comprehend complex systems with nonlinear interaction involving multiple spatial and temporal scales. Interplay of micro- and macro-scale dynamics has an important role in many kind of plasma phenomena such as magnetic reconnection, plasma shocks, formation of electrostatic potential structures, turbulence with zonal flows, etc. It is important to develop highly-efficient simulation methods to overcome the large difference in time and space scales in nonlinear plasma phenomena.

More recently, a novel simulation framework in plasmas, the so-called Equation Free Projective Integration (EFPI) method [1] has been proposed. Based on a micro-physics kinetic simulator the macro-scale plasma dynamics is determined by repeatedly extrapolating forward macro variables obtained by short bursts of micro-physics simulations [2]. Different schemes for reconstruction and mapping between macro and micro phase space, using moment representation, wavelets [3], and cumulative particle distribution function have been studied.

As a proof-of-principle, we proposed a primal EFPI method to include kinetic effects in ion acoustic wave[4]. In the particle-in-cell (PIC) code, ions are assumed inherently coarse grained as compared to electron-scale dynamics. Ion orbits are tracked and extrapolated in time. The electric potential is averaged over the electron plasma period to extrapolate and project. We further extend EFPI methodology to involve two-dimensional cumulative distribution function (CDF) of the ion phase space [5]. To obtain an inversion of multi-dimensional CDF, marginal and one-dimensional conditional distributions in macro projective integration were attempted. Our calculations indicate that the EFPI simulations can follow the PIC results nicely before strong ion trapping in phase space becomes significant; still, the main characteristics are preserved except for the ion trapping features.

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Development of Medium-Energy Plasma Instruments for the Study of Non-Thermal Particle Acceleration

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One of the most interesting aspects of space plasma is the non-thermality. It is well known that many astrophysical objects emit X-rays/γ-rays as a consequence of the non-thermal plasma process. It is also well established that the planetary magnetospheric (as well as interplanetary) plasma have significant non-thermal components. Among those celestial objects, Earth's magnetosphere has a particular advantage for the investigation of non-thermal acceleration mechanisms; we can obtain in-situ particle data with the best spatio-temporal resolution. In the Earth's case, the medium-energy range (5-200 keV) is generally the transition region from the thermal to the non-thermal component, and thus the detailed analyses of the medium-energy range plasmas are essential. On the other hand, this energy range has been an observational gap; the seamless energy spectrum has rarely been obtained, due to technical problems. Recently, therefore, we have developed medium-energy plasma instruments with a novel electrostatic analyser and state-of-the-art solid-state detectors. Our instruments will be onboard the mother ship of SCOPE, and will acquire three-dimensional distribution functions of medium-energy plasmas inside/around the acceleration regions.

Effects of Heavy Ions on Reconnection in the Magnetotail.

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The CLUSTER mission has provided a considerable number of in-situ observations of the formation of an X-line in the mid-tail region of the Earth's magnetotail. From these observations it has become evident that there are time periods where heavy ion density (mainly O+ of ionospheric origin) exceeds that of the protons. How does the higher mass density of O+ affect the reconnection process in the Earths magnetotail? This topic is currently being investigated theoretically using both fluid and kinetic models. In this study we use observations from the CLUSTER/CIS ion composition instrument in order to identify the observational signatures of the role of O+ in the reconnection process and compare these signatures with results from simulations. The implications of these results on the requirements for the Cross-Scale Mission will be discussed.

Distinguishing physical from pseudo- non time stationarity in finite interval observations of the scaling exponents of turbulence.

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The accurate estimation of scaling exponents is central to the quantitative observational study of scale-invariant phenomena such as turbulence- they allow direct comparison between the data and the predictions of turbulence theories. Stable, time stationary intervals of naturally occurring turbulence, such as that seen in the solar wind, magnetosheath and magnetotail, are unavoidably restricted in space and time. However, methods to quantify the scaling exponents of a stationary stochastic process (time series) can, when applied to finite length intervals of data, also yield apparent time variation in the scaling exponents, suggestive of non-stationarity. This needs to be distinguished from physical non- stationarity that may also be intrinsic to the phenomena under study.

We present the results of a study to determine the optimal number of datapoints (length of timeseries) N required to obtain estimates of scaling exponents to a given precision. We focus on structure function estimates but our results are also applicable to power law power spectral estimates. For power law power spectra, the variance in the computed scaling exponents is known for finite variance processes to vary as $\sim 1/N$ as N goes to infinity, however, the convergence to this behaviour will depend on the details of the process, and may be slow. We study the variation in the scaling of second order moments of the time series increments with N, for a variety of synthetic timeseries and solar wind in- situ observations. We find that in particular for heavy tailed processes, for typical realizable N, one is far from this $\sim 1/N$ limiting behaviour, and propose a semi-empirical estimate for the minimum N needed to make a meaningful estimate of the scaling exponents.

For a given process, once the variance in the computed scaling exponents is known as a function of N, it may be possible for a given dataset to discern 'pseudo' time variation in the exponents due to finite N effects from intrinsic time variation, the prospects for this will also be discussed.

Plasma wave observation system onboard the SCOPE spacecraft.

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The main objective of the SCOPE mission is to investigate the coupling between ion and electron dynamics in the geomagnetosphere. In order to achieve this objective, we need multiple spacecraft, which are located in the different relative distances, and sophisticated observation instruments, which provide the very high time resolution data.

The plasma wave instrument(PWI) proposed for the SCOPE mission observes plasma wave activities in the wide frequency range from the DC to 30MHz for electric field and from 10Hz to 10kHz for magnetic field. The frequency range covered by the PWI corresponds to those of plasma waves which are related to ion and electron dynamics. The PWI also observes the high frequency radio waves beyond 100kHz, which are used for monitoring the solar activities as well as the geomagentic activities.

The PWI is installed in all of the five SCOPE spacecraft. The design and specification of the five PWIs are almost identical. They are basically waveform receivers, which directly collect the observed waves of six component wave fields (three for electric field and three for magnetic field). The waveform receivers allow us to examine the correlation among waves observed by five SCOPE spacecraft with high time resolutions at the different positions. Furthermore, the PWI monitors the spacecraft potentials leading to the knowledge of the in-situ plasma density. On the other hand, the frequency spectra are calculated from the observed waveforms by the digital processing system. They provide the overview of wave features as well as the information on the region identification.

The digital processing unit also has the function of the wave-particle correlato, which operates cooperatively with the onboard plasma instruments. It has the capability to measure the wave-particle interactions quantitatively.

In the present paper, we demonstrate the importance of plasma wave observations in the SCOPE mission and show the current design of the plasma wave observation system.

Investigation of turbulent dynamics inside hot flow anomaly events on the basis of the records of the Cluster mission.

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Hot flow anomalies (HFA) are high-energy plasma population that may evolve near planetary bow shocks due to the interaction between the bow shock and a tangential discontinuity in the solar wind. The events are manifested by increased plasma temperature, low and deflected bulk velocity, and increased magnetic fluctuations. Using these criteria, a series of HFA events have already been identified and investigated using the various records (plasma, magnetic field, velocity, etc.) of the spacecrafts, in the last decade. In some of our previous studies, it has been shown that the PDFs of HFA magnetic fluctuations exhibit exponential wings relying to turbulent signatures inside the phenomena. In this paper the turbulent features of the HFA dynamics are studied further by the investigation of their spectrum and multifractal characteristics. We use the magnetic records of the four spacecrafts of the Cluster mission. When the configuration of the four spacecrafts is advantageous, the physical parameters inside a given HFA are monitored in different time ranges. Using this lucky situation, it is intended to study the evolution of the turbulent dynamics inside the HFA events.

Can multi-scale studies of the Earth bow shock help us understand shock acceleration in astrophysics?

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Astrophysical shocks exist in a very wide range of parameters that at first seem to be far from the parameter range of shocks in the Heliosphere. However some of these shocks have certain characteristics that are rather similar to the shock parameter range of the planetary bow shocks. Some Supernova Remnants (SNR) shocks may have effective Mach numbers as low as several tens, if the interstellar fields are efficiently amplified near shocks. SNR shocks are also inferred to accelerate both electrons and cosmic rays, suggesting that the closest connection can be found between quasiparallel parts of planetary shocks and astrophysical shocks. The unknown mechanisms of magnetic field amplification and particle injection into the acceleration process need detailed comparison between the characteristics of particle distributions and fields. The difficulty in such comparisons, as seen in both simulations and observations, is that the generation of upstream turbulence, particle diffusion and the formation of seed returning particle population develop on disparate spatial and temporal scales, and may not be in a steady state at the time of observation. It can be difficult or even impossible to study with a single shock crossing the processes having temporal/spatial ratio as large as tens to hundreds of thousands. However, Cluster experience shows that there exists the possibility to use statistical approach based on the “age of the shock”. Cluster and the future Cross Scale armada will traverse the shock front that has the “age” determined by the last strong change of the characteristics of the solar wind. This allows one to compare the characteristics of particle distributions and the waves/field structures for different life times of the similar shocks. Such data can give the possibility to study the shock structure “evolution” and to get an idea about the development of different stages of the shock acceleration process. Such detailed study can be used for comparison between similar processes in simulations of the SNR shocks and the only available experimental data set having quite detailed in situ diagnostics.

AC fields measurements: using the experience of Cluster for Cross Scale

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AC and DC magnetic fields are among the key parameters to be measured to achieve the scientific goals of the Cross Scale mission. All three major targets of the project: shocks, reconnection and turbulence are fundamentally dynamic in their nature, and waves are one of the important factors that determine their dynamics. The methods developed using Cluster wave field data to address key issues of collisionless shock physics and plasma turbulence as well as their limits of applicability can help to define the best approach in future planning of the Cross Scale project. Here we present examples of the use of Cluster data set for the characterization of the wave activity in the vicinity of the shock front and in determination of the turbulence statistical properties. We show some results obtained making use of k-filtering and inter-satellite amplitude cross-correlations techniques. We show how the wave data can help in the characterization of the non-stationary dynamics of the shock front and of the structures in the foreshock region.

An important problem is related to the determination of the structures such as vortices, holes or wave packets. We shall show examples of such structures and shall discuss the possibilities related to multi-scale multi-point measurements of electric and magnetic fields. We show that the characteristic of existing instruments, in particular of the search coil, are sufficient to perform the above discussed studies. We shall also evaluate what are the burst mode regimes required to perform these studies.

The importance of heavy ions on the properties of the Earth's bow shock.

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Cluster data in combination with numerical simulations have provided many new insights into the structure of the foreshock region, the local structure of the shock, its downstream region, and the associated physical processes. The theory of downstream plasma thermalization has been revisited. Ion reflection properties of the shock front have been investigated in detail down to the single particle and field level. Reformation has been observed and the link made between how processes such as field aligned ion beams originating at the perpendicular region affect the quasi-parallel foreshock section have been studied. How do heavy ions such as He++ affect these processes and on what temporal and spatial scales? Numerical simulations as well as data from Cluster/CIS both show clear indications that these ions play an important role, but yet their signatures in the observations currently available are not fully resolved. In this study we will focus on role of He++ on ion reflection and downstream thermalization using CLUSTER data and compare with theory and simulations. In this presentation we will demonstrate the implications of the results from this study on the mission requirements for composition sensors and spatial separation strategy of the spacecraft of the Cross-Scale Mission.

Unusual geomagnetic storm of 21-22 January 2005 with main phase during northward IMF and transfer of electromagnetic energy to magnetosphere

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The magnetic storm occurred on 21-22 January 2005 (minimum Dst=-105 nT, maximum Kp=8) was highly anomalous because the storm main phase developed during northward interplanetary magnetic field (IMF); the IMF was northward during ~ 7 hours. It is possibly that this storm is the first event of such type to be reported; as to our knowledge, the storm was analyzed only by Du et al (2008). However, their explanation (based on reconnection with southward IMF during the storm initial phase) that "there is first energy storage in the magnetotail and then a delayed energy injection into magnetosphere" is in contradiction with our results of analysis and interpretation. We use interplanetary ACE and Cluster C1 data for determination of the solar wind parameters. Dst, Kp, AU, AL indeces are used to follow development of geomagnetic activity (GA) for the storm. We attract results of our previous studies. Causes of GA in these studies are divided into temporal changes of the IMF and electric field E in the solar wind (cause is the Sun) and into changes of directions of these vectors relative to the geomagnetic moment M (main cause is annual and daily motions of the Earth). Our study of influence of mutual orientations of the solar wind E vector and the moment M vector on GA (Dst, Kp) obtained on basis of measurements of solar wind velocity V and IMF at ~ 1 AU for the period 1963-2005 showed that GA depends both from module E and angle between vectors of E and M. As result we found a new dependence of the GA rise during northward IMF for constant module of E. We showed that this increase of Kp (Dst) is driven by the Em component (the E vector along the M vector) that is important for understanding mechanisms of the storm. We show that unusual large value of the solar wind Em component (Em ~ 15.7 mV/m) played important role in development of the anomalous storm. Based on calculations of the independent components of the solar wind E vector (taking into account mutual orientation of E and M) we show that the Dst (Kp) temporal variation during the anomalous storm follows the variation of the E components. The result points to the fact that the energy rate supplied to magnetosphere during the storm nearly equals to dissipation rate into magnetosphere (energy storage is not essential). This conclusion is supported by our calculations of the corresponding components of the Poyting flux $P = [E \times B]$ proportional to the energy flux rate (reconnection rate) to dayside magnetopause and polar cap. Based on our analysis we suggest a possible mechanism for the anomalous storm main phase: reconnection of geomagnetic field with northward and azimuthal

IMF in cusps and polar regions of both hemispheres (that leads to intensive convection between hemispheres). Power of the solar wind energy supplied to the magnetosphere during the storm is $\sim 5 \times 10^1 2$ Watt.

Rank-ordered multifractal analysis of magnetic intermittent fluctuations in the cusp based on Cluster observations.

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The Rank-Ordered Multifractal Analysis (ROMA) recently developed by Chang & Wu (2008) is a powerful technique that provides a physically meaningful and a quantitatively accurate description of intermittency in space plasmas. Using magnetic field data from the four Cluster spacecraft, we show that the fluctuations of magnetic energy in the magnetospheric cusp have non-Gaussian Probability Distribution Functions with large extended tails, a clear hallmark of intermittency. We apply the ROMA method on these Cluster data and illustrate the various advantages of this new technique over the traditional multifractal analysis based on structure function calculations. The ROMA method helps us to understand the nature of intermittency in terms of crossover phenomena like random diffusion, anti-persistent states and/or persistently unstable states.
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On solar energetic particles and CME-driven shocks.

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At present, CME-driven shocks are thought to play a crucial role in the acceleration of solar energetic particles (SEPs). The CME-driven shock propagation and the transport of shock accelerated particles in the interplanetary space can be modelled by using, for instance, the Shock-and-Particle model developed by Lario et al. (1998), that assumes a particle source (injection rate of shock-accelerated particles) at the position of the moving interplanetary shock, that develops as a consequence of solar activity associated with particle emission. We exemplify the modelling procedure for the 12-15 September 2000 SEP event. In this case, the particle transport parameters and the evolution of the injection rate were derived through the simulations of the proton differential intensity-time profiles obtained by different experiments onboard 4 different spacecraft (ACE/EPAM, GOES/SEM, IMP8/CPME, SOHO/ERNE), in order to cover a wide range of energy (from 5 MeV up to ¿100 MeV). We show the results of the modelling and discuss on the empirical relation between the injection rate of shock accelerated particles, Q and the plasma speed jump across the shock, VR.

Ion instrumentation for Cross-Scale: studies performed at CESR

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We present recent studies performed at CESR to prepare future ion instrumentation for the Cross-Scale mission, in particular. The baseline ion instruments, as described in the Cross-Scale Payload Definition Document (PDD) are technologically well-defined, with TRL above 7. Nevertheless, given the limited resources of Cross-Scale and its demanding science requirements, it is important to examine how the 'science/mass' and the 'science/power' ratio of the baseline Cross-Scale instruments can be enhanced. We present recent developments and ongoing analyses regarding, for example: (1) the development and the test of new ASIC for the readout electronics, (2) innovative uses of micro-channel plates in mass spectrometry, and (3) the design of fast plasma imagers that could be implemented on Cross-Scale. These studies are part of a more general effort that gathers different institutes in an international consortium intended to improve the ion instrumentation for the mission.

Fast Reconnection of Weakly Stochastic Magnetic Field in MHD regime: Theory and Simulations.

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Recent years have been marked by progress in successful numerical simulations of collisionless reconnection. A lot of astrophysical environments, e.g. interstellar medium, are collisional. Does it mean that the reconnection in these environments is slow? I shall discuss a scheme of reconnection that ensures fast reconnection in MHD regime, thus irrespectively of the collisional state of plasma. The corresponding model proposed by Lazarian & Vishniac (1999) appeals to weak magnetic field stochasticity to enhance the reconnection speed. This model has been recently confirmed by 3D numerical simulations that I am going to discuss. The simulations show that, in accordance with the predictions of the Lazarian & Vishniac 1999 model, the reconnection rates increase with the increase of driving, which stays weak and does not induce any magnetic field reversals. I shall show that the other predictions of the model, i.e. independence of the Ohmic and anomalous resistivities are successfully confirmed. This means that the reconnection is, indeed, fast. The dependence of the reconnection rate on the scale of the turbulence injection is somewhat steeper than it is predicted in the model, but we explain this by the existence of the inverse cascade of the injected turbulent energy. The model entails many implications, including the reconnection instability, which arises from turbulence excited by the outflow of reconnecting matter, as well as efficient First-order Fermi acceleration of energetic particles. These results are very important, for instance, for understanding of solar flares physics. In general, the confirmation of the Lazarian & Vishniac 1999 model provides the justification for many of numerical simulations of the astrophysical environments using MHD codes.

Energy conversion process in an electron dissipation region in a steady state.

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Steady collisionless driven reconnection in an open system is investigated by means of 3D particle simulations. After an initial transient phase, the system relaxes to a steady state with a constant reconnection rate. Meanwhile, a kinetic regime, which consists of electron and ion dissipation regions, appears in the current sheet. The electron dissipation region is inside the ion dissipation region, and it has a dual structure along the downstream direction. In contrast to remarkable growth of ion thermal energy, electron kinetic energies have a clear spatial variation inside the electron dissipation region. The inflow component of electron kinetic energy decreases rapidly when electrons enter electron dissipation region from the upstream.

The out-of-plane component increases there through electron acceleration by reconnection electric field and maximizes at the reconnection point. On the other hand, fast outflow motion is generated in the downstream as a result of reconnection and the outflow kinetic energy reaches its maximum at the edge of inner structure of the electron dissipation region. The detailed energy conversion process will be discussed in our presentation.

Multiscale Multifractal Solar Wind Turbulence.

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The concept of multiscale multifractality is of great importance for the heliophysics because it allows us to look at intermittent turbulence in the solar wind. Starting from Richardsonś (1922) scenario of turbulence, many authors still attempts to recover the observed scaling exponents, using some simple and more advanced fractal and multifractal phenomenological models of turbulence describing distribution of the energy flux between cascading eddies at various scales. In particular, the multifractal spectrum has been investigated using Voyager (magnetic field) data in the outer heliosphere and using Helios (plasma) data in the inner heliosphere. We have also analysed the multifractal spectrum directly on the solar wind attractor and have shown that it is consistent with that for the multifractal measure of a two-scale weighted Cantor set [1].

Further, to quantify scaling of solar wind turbulence, we also consider this generalized Cantor set with two different scales describing nonuniform distribution of the kinetic energy flux between cascading eddies of various sizes. We investigate the multifractal spectra depending on two rescaling parameters and one probability measure parameter [2].

We demonstrate that the universal shape of the multifractal spectrum resulting from the multiscale nature of the cascade is often rather asymmetric. Moreover, we observe the evolution of multifractal scaling of the solar wind in the inner and outer heliosphere [3]

It is worth noting that for the model with two different scaling parameters a better agreement with the solar wind data is obtained, especially for the negative index of the generalized dimensions. Hence we hope that this somewhat more general model could be a useful tool for analysis of the intermittent turbulence in space plasmas also during Cross-Scale Mission.

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Miniaturized Fluxgate Magnetometer Design.

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Miniaturization and simplification of scientific instruments, while keeping the high performance levels of conventional instruments, is a common ambition. In this context the development of an instrument front-end ASIC (Application Specific Integrated Circuit) for magnetic field sensors based on the fluxgate principle was undertaken. It is based on the combination of the conventional readout electronics of a fluxgate magnetometer with the control loop of a sigma-delta modulator for a direct digitization of the magnetic field.

Two such Magnetometer Front-end ASICs (MFA-1 and -2) have been developed and carefully checked for performance compliance and radiation hardness under an ESA development contract. Both MFAs were fabricated in a 0.35μm CMOS technology from austriamicrosystems.

In this paper we shall give a brief overview of the system level design, present the performance which has been achieved with the redesigned MFA-2 (e.g. THD $>$ 95dB, SNDR in field mode $>$ 85dB, offset stability $<$ 10pT/°C and $<$ 0.4nT/250h and TID hardness $>$ 300krad) and discuss the reduced resource requirements.

Furthermore, the application of the MFA as a 4- to 11-channel housekeeping ADC and the status of the third version of the MFA, which will be space qualified for NASA's Magnetospheric Multiscale (MMS) mission in 2009, will be presented.

Study of magnetospheric substorm dynamics and plasmoid structure with Cross-Scale.

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We present signatures of a relatively isolated magnetospheric substorm event observed by a number of Earth-orbiting spacecraft (e.g. Cluster fleet, Polar, GOES) on 27 August 2001. Main features of the event are an X-line progression over the Cluster s/c along with a turbulent magnetic region observed at geosynchronous orbit by the GOES8 satellite. The Cross-Scale mission can provide new results on magnetospheric dynamics during substorms. Particularly, analysis of simultaneous energetic particle, plasma, magnetic field and wave activity observations from various instruments onboard the Cross-Scale spacecraft could help determine the dimensions and characteristic scales of the turbulence region associated with cross-tail current disruption during the expansion phase onset of substorms. The breakdown of the frozen-in condition in this region can also be investigated in detail. Furthermore, we can search with Cross-Scale for magnetic turbulence signatures associated with plasma sheet thinning. We can investigate whether during substorm events there is evidence of Earthward high speed plasma flows accompanied with intense wave activity prior to dipolarization signatures. Another issue to be considered is the analysis of the in-situ wave turbulence and whether its characteristics are consistent with up-to-date kinetic wave models. Furthermore, we present Cluster observations of an earthward flowing plasmoid in the tail in October, 2002. The 4-point measurements provided by Cluster and the separation distance of 1 RE between them provide constraints for the determination of the size and shape of the plasmoid structure. On the other hand, Cross-Scale with its nested individual tetrahedra will provide a set of multi-scale measurements that can be utilized to determine more reliably the 3D geometry of plasmoids, as well as the current density flowing inside these structures.

Cross-scale Coupling: ULF Wave Excitation at the Ion Gyroscale During Substorm Onsets and Ring Current Injection Events.

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We present results from a study of ULF waves using the THEMIS constellation and ground-based magnetometers of the combined CARISMA and THEMIS ground-based observatory (GBO) arrays. We present results from the Pi1 band during the first 10s of seconds of substorm onset, using magnetometer and THEMIS GBO white light auroral imager data. These observations demonstrate the evolution of waves and arc features which begin as periodic arc undulations and beads, and evolve through an inverse spatial cascade into larger scale undulations, and eventually into vortices in advance of the release of the westward travelling surge. When mapped to the plasmasheet, these waves have ion gyroscale and may be the ionospheric signatures of ballooning or other kinetic unstable modes at the ion scale. We further show examples of the growth of Pc4-5 waves which are standing along magnetic field lines in the dusk sector magnetosphere. These waves have a poloidal polarisation and are likely driven by a drift-bounce resonance mechanism which releases energy from unstable ion distributions. In-situ THEMIS field data shows these to be Alfvenic, standing along the background magnetic field, however the ion and electron particle data indicate a clear electron drift signature in the wave electric field, but not in the ions. We believe that this clear evidence verifying the theoretical hypothesis that these are kinetic modes whose growth rates maximise at the ion gyroscale. Observations with constellations such as Cross Scale would enable a detailed understanding of the cross-scale evolution and the role of these wave-particle interactions in plasma energy exchange.

Structure of energy conversion regions: Cluster investigations and Cross Scale prospects

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Energy conversion between its basic mechanical and electromagnetic forms is ubiquitous in space plasmas and can be explored by examining the scalar product of the electric field, E, and current density, J. A systematic examination of $E \cdot J$ in the Cluster plasma sheet data from 2001 resulted in the identification of more than 100 energy conversion regions (ECRs), with both load ($E \cdot J > 0$) and generator ($E \cdot J < 0$) character. We investigate in detail a few of these ECRs, by evaluating quantities relevant for the local energy budget and for the magnetic field topology. We estimate the work of the kinetic pressure, magnetic pressure, and magnetic stress forces, the Poynting flux and its divergence, as well as the curvature of the magnetic field line. The spatial derivatives required are computed by gradient tools developed within the Cluster community. We conclude by addressing possible Cross Scale contributions to a better understanding of energy conversion, based on the enhanced multi-point and multi-scale capabilities of the mission.

Solar wind turbulence: cascade, dissipation and heating.

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In this paper we show that a direct evidence for the presence of an inertial energy cascade, the most characteristic signature of hydromagnetic turbulence (MHD), is observed in the solar wind. A Yaglom-like scaling relation has been found in the high-latitude data samples measured by the Ulysses spacecraft. Moreover, an analogous scaling law, suitable modified to take into account compressible fluctuations, has been observed in a much more extended fraction of the same data set. Thus, it seems that large scale density fluctuations, despite their low amplitude, play a major role in the basic scaling properties of turbulence. The presence of a nonlinear turbulent magnetohydrodynamic energy cascade provides for the first time a direct estimation of the turbulent energy transfer rate, which can contribute to the in situ heating of the wind. In particular, The compressive turbulent cascade seems to be able to supply the energy needed to account for the local heating of the non-adiabatic solar wind.

An Information Theory Approach to Cross-Scale Coupling in Turbulent Space Plasmas

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The study of cross-scale coupling among fluctuations of fields in a turbulent plasma may benefit from the use of information theory tools. In particular, the transfer of information between different scales can be investigated by means of mutual information and of a novel quantity, transfer entropy, introduced by Schreiber (2000): such quantities will be used to characterise the cross-scale coupling, even beyond the linear regime, so to determine the strength of the coupling and the prevailing direction of the information transfer.

Here, the use of these quantities in the analysis of in situ data from a multi-satellite mission is discussed. In particular, the study is done for simulated hydrodynamics and MHD turbulence in shell-models, where the causal relationships between scales is under control, and possibly for actual in-situ measurements.

Multi-scale simulations of the Kelvin-Helmholtz instability at the magnetopause.

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Formation mechanism of the broad plasma mixing layer observed at the low latitude boundary of the magnetosphere (LLBL) has been a long standing issue of the magnetospheric physics. The Kelvin-Helmholtz instability has been considered as one of the promising mechanisms that accounts for the formation of the broad mixing layer. We present recent numerical simulations of the Kelvin-Helmholtz instability characterized by vortex paring processes and secondary induced instabilities. The secondary instabilities involve the secondary Rayleigh-Taylor type instability and the tearing instability both of which couple with large scale vortices. We show that the cross-scale coupling of the secondary instabilities and the large scale vortices is essential for the formation mechanism of the LLBL.

Magnetic and electric field measurements in Japanese Cross-scale/SCOPE mission.

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The electron-scale investigation of the charged particle motion and related parameters is the major objective of the Japanese Cross-scale/SCOPE mission. Magnetic and electric fields are aimed to be measured in accordance with the high-resolution measurement of the plasma. More accurate and perfect three-dimensional measurement of the fields is essential to achieve the science objectives of Cross-scale/SCOPE.

Japanese field measurement technique has been matured by successful projects, Akebono, Geotail, Nozomi, Kaguya, so on. The field instruments have been further refined by the development for BepiColombo MMO. Cross-scale/SCOPE project needs not only the excellent performance of the field instruments, but also the optimization of the satellite system, e.g., electro-magnetic compatibility, magnetic cleanliness, satellite attitude and electric probe along the spin axis. Currently the Japanese SCOPE WG is investigating the instrument and satellite design, collaborating with the colleagues outside Japan.

Proton Cyclotron Heating and Beam Generation in the Solar Wind.

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We present results from hybrid expanding simulations of the solar wind plasma. We investigate the role of kinetic processes in shaping the proton distribution function along the wind expansion in the prensence of an initial spectrum of Alfvn waves. We find that both wave-particle and wave-wave interactions play a role in the ion evolution, in particular waves interact with protons through ion-cyclotron resonace and non-linear trapping due to the growth of parametric instabilities. Cyclotron interactions control the evolution of the temperature anisotropy providing a perpendicular heating which contrasts the adiabatic cooling caused by the expansion. Ion-acoustic modes driven by parametric effects produce a velocity beam in the particle distribution function. We discuss and compare our results with direct solar wind observations between 0.3 and 1 AU, and we find that the resulting proton distribution functions are in reasonable agreement with Helios data.

Self-reformation of the quasi-perpendicular terrestrial shock front evidenced from CLUSTER data.

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Among several mechanisms issued from simulation and theoretical studies proposed to account for the nonstationarity of quasi-perpendicular supercritical shocks, one process - the so-called self-reformation - driven by the accumulation of reflected ions at a foot distance from the ramp has been intensively analyzed with simulations. Present results based on experimental CLUSTER mission clearly evidence signatures of this self-reformation process for the terrestrial bow shock. The study based on magnetic field measurements includes two parts: (i) a detailed analysis of two typical shock crossings for almost perpendicular shock directions where the risk of pollution by other nonstationarity mechanisms is minimal. A special attention is drawn on non appropriate treatment of data which could lead to wrong interpretation. One key signature of this self-reformation is that the ramp width can reach a very narrow value covering a few electron inertial lengths only; (ii) a statistical analysis based evidences the signatures of this nonstationarity versus different plasma conditions and shock regimes. Present results are compared with previous works and implications for the objectives of the cross-scale mission are driven.

Lessons learned from the THEMIS multi-spacecraft mission

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The five-spacecraft THEMIS mission provides an excellent model for low-cost multi-satellite space-plasma-physics missions. This talk will focus on lessons learned from the THEMIS plasma, energetic particle, and electric and magnetic field instruments, including their design and their in-flight calibration. THEMIS spacecraft provide a reasonable baseline for a minimum complement of instrumentation needed to resolve much of the plasma structure. However, there are several measurement limitations that suggest improvements, requiring modest additional resources, in order to meet the requirements of accurate difference measurements between spacecraft for the X-scale and Scope missions. These modifications include adding: 1) an electron sensor viewing the opposite direction to reduce the impact of density fluctuations on electron velocity measurements ($\sim$ 1 kg), 2) additional energetic particle sensors to attain the same angular resolution as plasma sensors ($\sim$ 1.5 kg), 3) a composition sensor ($\sim$ 2 kg), 4) length to the radial antenna ($\sim$ 0 kg, new design), and 5) high frequency electronics to measure the plasma frequency ($\sim$ 0.5 kg). Trade offs in measurement accuracy caused by the lack of such improvements, including some creative analysis techniques to recover lost science, will be discussed as an alternative to this suggested $\sim 20\%$ instrument mass increase. In particular this talk will address the inter-calibration efforts and measurement precisions attained on THEMIS, including various sources of noise and instrumental problems. The talk will also cover issues such as data products and data collection strategies that enhance the science return.

Shock Turbulence and Backstreaming Ion Distributions.

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In an encounter of a charged particle with a shock, this latter is usually treated as a planar surface with length scales over of an ion gyroradius. In this context, it is well known that the quasi-adiabatic reflection of incident solar wind ions off the Earth's bow shock does not account for the backstreaming ion velocity distribution profiles. Shock turbulence is considered to investigate the impact on these distribution functions. Since the shock reflection efficiency is strongly geometry dependent, we first introduce a variability in the local shock normal direction. Assuming a randomly distributed shock normal direction, we derived the probability distribution functions $f(V_\|)$ and $f(V_\perp)$ of ions reflected off the bow shock in a quasi-adiabatic manner. The derived distributions $f(V_\|)$ exhibit second, third and fourth order moments that agree well with the observations. Best agreement is obtained for fluctuations of the normal orientation of a few degrees about the nominal direction. The simple model introduced here predicts a strong correlation between the nominal shock geometry and the moments of $f(V_\|)$. If at some extent, the model provides satisfactory results for $f(V_\|)$, the obtained reduced perpendicular distribution $f(V_\perp)$ strongly disagree with the observations. Finally, this study shows that a dynamical shock structure at ion scales is relevant for accounting the shock-accelerated particles thermal energy.

Canadian Capability in Space-based Magnetometers and Digitisers Relevant to Cross-Scale.

D. Miles, I. R. Mann, D. K. Milling, B. Narod, J. Bennest and others

University of Alberta
University of Alberta
University of Alberta
Narod Geophysics Ltd.
Bennet Enterprises Ltd. and others

The University of Alberta (UofA) is working with experienced Canadian industry to build on flight heritage magnetometer designs to develop a new generation of radiation hardened, space qualified magnetometers and related electronics which could be capable of meeting the mission measurement requirements for Cross-Scale. The UofA is developing both search coil and flux gate magnetometer instruments and digitisation electronics for the Canadian Space Agency (CSA) "Outer Radiation Belt Injection, Transport, Acceleration and Loss Satellite" (ORBITALS) small satellite mission. Such radiation hard technology may also have utility on other future Canadian and international science and space exploration missions, including Cross-Scale. The fluxgate sensor has more than two decades of heritage through CARISMA/CANOPUS, POLARIS, EMScope/EarthScope USArray on the ground, and the ePOP payload on the CASSIOPE satellite mission due to be launched in 2009. The radiation hardened ORBITALS instrument will sample the DC magnetic field at 128 samples per second with a resolution of 0.1 nT. A newly developed fast slewing architecture maintains this resolution on a spinning platform. The AC search coil magnetometer is designed by the University of Alberta, using a flux feedback design based on that used for the DEMETER mission . Flux feedback flattens the high frequency response of the instrument over 0.1 to 10,000 Hz. A radiation hardened electronics package provides analog filtering, an offsetting mechanism for 23 bit digitisation of low frequency (flux-gate) signals and microprocessor resources for data digitisation, processing, and packaging. The payloads are built from 100 krad minimum TID components, are designed to mitigate deep dielectric charging, to survive and recover from single event upsets, and are optimised for mass, power and volume efficiency on a small-satellite platform. The fluxgate sensor could provide a contribution to an optimal approach to magnetometer measurements on Cross-Scale; the UofA continues to examine this opportunity as part of the Cross-Scale Fluxgate Consortium. Digitisation and search coil packages may also provide an opportunity for the flight of Canadian instrumentation as part of a highly tuned and optimized payload on the Cross-Scale mission, and for Canada to contribute to mission success through international collaboration with the Cross-Scale team.

Nonlinear coupling of kinetic and fluid scales by supra-thermal particles in a collisionless plasma

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Dissipative driven dynamical systems are often found in non-equilibrium quasi-stationary (NESS) states dominated by long-range correlations in space and time. Often NESS states are characterized by the presence of energetic particles that are inherently generated by the system above a certain, nonlinear threshold. Plasmas in geo-space and in the laboratory share this basic property. A particularly clear example of a NESS state is the Earth's distant magnetotail and the peculiar features of self-organization of non-thermal geo-space plasma have been studied and discussed in the literature [1]. An emerging issue is the existence of NESS states in burning toroidal plasmas, where the energetic ions (MeV energies) and charged fusion products constitute a significant fraction of the total plasma energy density [2]. In this work, we discuss how the presence of energetic particles can mediate the nonlinear coupling between kinetic and fluid scales and eventually produce a behavior typical of a dynamical system at the NESS state. Our results suggest that the integrated physics studies of complexity and long-range dependence could be among the major challenges in view of the forthcoming space mission concepts and burning plasma experiments. These issues are presented in connection with the ENEA theory and modeling research program.

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Multi-scale multi-point measurements by Cluster in magnetotail current sheet.

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In summer 2005 and 2007 Cluster 4-sc spacecraft observed magnetotail current sheet simultaneously with two different spatial scales. We present two examples of such multi-scale multi-point observations of reconnection and fast flows associated plasma and field disturbances to demonstrate the importance of the multi-scale observations for understanding the physical processes in these current sheets.

On 20050926, meso-scale structures of reconnection current sheet were observed by C1, C2, and C4 (separted by $\sim$ 10000 km) and thin boundary structure with C3 and C4 (separted by $\sim$ 1000 km). These multi-point observations enable to detect current sheet characteristics at both side of an X-line and to observe simultaneously outflow in the plasma sheet and inflow properties at the lobe. It is shown that a combination of a $\sim$ 10000 km-scale multipoint observation, which allows characterizing the reconnection current sheet geometry, and a more local multi-point observation is essential to follow the electron acceleration process thorough the reconnection current sheet.

On 20071027, when the spacecraft separation distance among C1, C2, and C4 were about $\sim$ 10000 km, and the distance between C3 and C4 were $\sim$ 40 km, Cluster observed multiple dipolarizations associated with bursts of flows near the flow-breaking region. These dipolarizations involve different scales of disturbances such as large-scale (¿ several thousands of km), but relatively thin ($\sim$ 1000 km) current sheet oscillations as well as localized dipolar flux tubes with sharp edges down to several electron scales. It is shown that large scale current sheet changes and localized current disturbance/propagation is essential to monitor simultaneously for studying flow-breaking/particle acceleration.

Cross-scale frequency coupling in complex (dusty) plasmas.

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Complex (dusty) plasmas consist of fine solid particles suspended in a weakly ionized gas. Typical particle sizes range from tens of nanometers to tens of microns. Usually particles acquire a large negative charge, because they collect more electrons than ions from plasma. Due to the mutual interaction of particles and their confinement by electric fields present in plasma they can self-organize in an ordered structure. Characteristic frequencies associated with dust particles are on the order of 1-100 Hz, whereas the ion and electron plasma frequencies are on the order of 1 MHz and 250 MHz, respectively, in a typical laboratory experiment.

In this study, cross-scale frequency coupling was experimentally observed in a complex plasma. A rotating electric field ("rotating wall") was applied to complex plasma. An additional "four-electrode box" was placed on the lower electrode of a capacitively coupled rf discharge in argon. The box consists of four vertical plates made of ITO-coated glass that are mounted on four insulating poles. Polymer microspheres with a diameter of 8.77 um were suspended in the plasma sheath inside the box and formed a monolayer cluster of 20 to 160 particles. The ITO coating on the internal surfaces of the glass plates is conducting yet transparent; this allowed us to apply a certain electric potential to each plate independently to manipulate the particles and simultaneously illuminate and image them through the glass plates. A rotating electric field was created when the phase shift between sinusoidal signals on adjacent plates was set to $\pi/2$. In this configuration, the absolute value of the horizontal component of the electric field at the location of particles is practically constant, but the field direction rotates uniformly in the horizontal plane.

Rotating electric field caused the particle cluster to rotate. Clusters of different sizes rotated roughly as rigid objects. The maximum rotation speed of ~ 0.1 Hz was achieved for the applied frequency of $f_{appl} \sim 10$ kHz. At higher frequencies, $f_{appl} > 20 - 30$ kHz, the cluster rotation reversed its direction and finally stopped at $f_{appl} > 100$ kHz. For all f appl, the cluster rotation direction reversed with the reversal of electric field rotation. As the applied frequency was higher than the dust plasma frequency but lower than the ion (and electron) plasma frequency, electrons and ions responded to the applied (screened) ac field and the particles responded to the time-averaged electric field and ion drag force. We discuss the mechanism of particle cloud rotation and possible applications of rotating electric fields in complex plasmas.

Alignment of Velocity and Magnetic Fields in Fast and Slow Solar Wind

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The earliest measurements of velocity and magnetic fields in the solar wind showed that the turbulence can be strongly Alfvenic in the fast wind. This property is very important as the cross-helicity, that is the correlation between velocity and magnetic field is an invariant of the ideal MHD equations and can inhibit the turbulent energy cascade if it is completely realized.

It is however very important to study the local values of the cross-helicity, and in particular its probability distribution function, to determine the statistics of the local turbulent energy transfer. Indeed, even if there is no global Alfvenicity, the fluctuations of the local correlation can be very strong and, as they are related to the cosine of the angle between the velocity and the magnetic field, their distribution will depend on the dimensionality of these vector fluctuations.

We have determined the probability distribution of the angle and its cosine between random vectors for different values of the cross-correlation, and we have compared these distributions with those observed at different distances by the Ulysses spacecraft in high-latitude fast solar wind, and those measured by the Helios satellite in fast and slow wind in the ecliptic. The distributions are found to always differ from the casual ones, but to be closer to two-dimensional distributions in the fast solar wind, suggesting a possible link between Alfvenicity and dimensionality of the fluctuations.

New approach to full comprehension of magnetic reconnection by multi-scale simulation.

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Collisionless magnetic reconnection is widely considered to play an important role in energetically active phenomena in high temperature plasmas. In spite of intensive research, many basic questions about the detailed mechanism of collisionless reconnection still remain poorly understood. One of reasons why it is difficult to make progress in understanding the mechanism is that magnetic reconnection is controlled by multi-scale physics. The change in magnetic topology is global phenomenon, while microscopic kinetic process is needed to trigger magnetic reconnection. In order to understand the magnetic reconnection phenomenon as a whole, it is demanded to develop a multi-scale simulation model to solve both microscopic and macroscopic physics consistently and simultaneously. We assume that non-ideal effects leading to the generation of electric resistivity and viscosity are generated by microphysics in the vicinity of reconnection points. Our multi-scale simulation model is based on the domain decomposition and multi-time-step methods. In the area around the reconnection points, microscopic kinetic effects play important roles. Dynamics in that domain are solved by the particle (PIC) simulation method. In the periphery of the microscopic domain, on the other hand, dynamics is controlled by macrophysics, where ideal MHD equations are applicable. Between the PIC and MHD domains, an interface domain with a finite width is inserted in order to smoothly connect the PIC and MHD domains. In the advance of time in our multi-scale simulation, MHD time step is larger than PIC time step. The applicability of our simulation model has been examined with simulations of linear wave propagation and plasma inflow from MHD to PIC domains. In our presentation, we will demonstrate these simulation results and discuss our strategy to develop multi-scale simulation model in the future.

Magnetic Reconnection and Electron Acceleration by a Self-Retreating X-Line.

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Particle-in-cell simulations of collisionless magnetic reconnection are performed to study asymmetric reconnection in which an outflow is blocked by a hard wall while leaving sufficiently large room for the outflow of the opposite direction. This condition leads to a slow, roughly constant motion of the diffusion region away from the wall, the so-called "X-line retreat". The typical retreat speed is ~ 0.1 times the Alfven speed. At the diffusion region, ion flow pattern shows strong asymmetry and the ion stagnation point and the X line are not collocated. A surprise, however, is that the reconnection rate remains the same unaffected by the retreat motion. We will also present preliminary results of electron acceleration associated with the asymmetric magnetic reconnection.

Electron acceleration at the Earth's Bow Shock: Geotail Observation.

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The Earth's bow shock is known to produce non-thermal electrons. In this paper, we present an overview of Geotail observations of non-thermal electrons at and around the bow shock. By performing statistical analysis of spectral index, we found that the so-called the critical whistler Mach number seems to regulate the electron acceleration efficiency. The spectral index G of electron energy spectra defined by $f(E) \propto E^{-G}$ is distributed between 3.5 and 5.0 in the sub-critical regime while the hardest energy spectra with $G = 3.0 - 3.5$ are detected in the super-critical regime. We then analyzed some particular events in detail to discuss acceleration mechanism of the energetic electrons.

Spectral anisotropy produced by the nonlinear evolution of three-dimensional magnetic reconnection

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The nonlinear evolution of three-dimensional reconnection instabilities are studied through magnetohydrodynamics magnetic simulations in a current sheet with a sheared magnetic field. The nonlinear evolution produces the development of anisotropic magnetohydrodynamic turbulence. Far from the current sheet the energy spectrum develops perpendicularly to the local magnetic field, as in homogeneous configurations. Within the current sheet the spectrum anisotropy is also affected by the structure of unstable modes. With increasing time the configuration becomes more turbulent, the former effect disappears and the energy cascade takes place perpendicularly to the local magnetic field. The local spectrum becomes increasingly anisotropic while the spatially integrated spectrum tends to isotropize.

Effects of current system scale size and location on the curlometer.

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Using infinitely long current tubes, we investigate the response of the curlometer for range of scale sizes and positions of the current system relative to the tetrahedron. It is shown that for sheets with a Gaussian distribution of current intensity in the directions perpendicular to the length of the tube, the curlometer over-estimates the currents when the tetrahedron scale size is greater than 3/5 the width of the Gaussian and under estimates the currents when the tetrahedron scale size is smaller than this. For relatively small current systems, the position of the current within the tetrahedron strongly affects the values returned by the curlometer. Also, the direction of the current vector is shown to be at least 10 degrees from the true direction of the current and this deviation increases with decreasing Gaussian with of the current system scale size in the normal direction. Furthermore, it is shown that for perfectly measured magnetic field and spacecraft separations, $|\nabla \cdot B/\nabla \times B|$ is much smaller than the values typically observed by Cluster, supporting the idea that the measurement uncertainty in the magnetic field vector and the relative spacecraft locations has a far greater effect on the validity of the curlometer measurements than the assumption of linear magnetic field gradients for the current systems examined.

Dust acoustic solitary and shock waves in a coupled dusty plasmas with nonthermal ions.

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The Korteweg-de Vries-Burgers (KdV-Burgers) equation and modified Korteweg-de Vries-Burgers equation are derived in strongly coupled dusty plasmas containing nonthermal ions and Boltzmann distributed electrons. It is found that solitary waves and shock waves can be produced in this medium.

At first, we studied propagation of nonlinear waves in unmagnetized and strongly coupled dusty plasma containing nonthermal ions and Boltzmann distributed electrons. We have shown that if the dissipation is negligible, the solitary waves will appear in the medium if the dispersive and the nonlinear terms are balanced. On the other hand when dissipative term is noticeable and dissipative, nonlinear and dispersive terms are balanced we will have shock waves (both monotonic and oscillatory types). With the stronger dissipation, the shock wave structure becomes steeper (monotonic shock wave) and for weaker dissipation the shock wave has an oscillatory behavior (oscillatory shock wave). Dependency of monotonic and oscillatory shock waves on the medium parameters has been represented by the numerical simulation. Neither solitonic solution nor shock waves can be established when the nonlinearity parameter becomes zero. But in this case we derived mKdV-Burgers equation. The mKdV-Burgers equation has stable solitonic and also shock wave solutions.

Turbulence in driven dispersive MHD models.

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Observatoire de la Côte d'azur

The existence of a turbulent cascade is discussed in the context of one and two dimensional simulations of driven dispersive MHD models, aiming at understanding the small-scale dynamics of collisionless plasmas such as the solar wind or the magnetosheath. Both Hall-MHD and FRL-Landau fluid descriptions are considered. The influence of the spatial scale of the white-in-time random forcing relatively to the ion inertial length is studied. Special attention is paid to the type of modes that dominates the turbulent dynamics.

Sign-singularity of the reduced magnetic helicity by Cluster data.

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We investigate the scaling law of the reduced magnetic helicity obtained through measurements of the Cluster spacecraft in the solar wind. We calculate a signed measure which is related to the polarization (right-hand or left-hand) of magnetic field fluctuations. This quantity behaves as a power law, namely the measure is sign-singular. In variance to what happens for the energy spectrum, we do not observe scale dependence effects at the ion-cyclotron scale, that is cancellations between right-hand and left-hand polarizations go on inside the dispersive/dissipative range. The physical significance of the sign-singularity of the reduced magnetic helicity for the generation of the dispersive/dissipative range in solar wind turbulence is discussed.

Energetic Particle Instrument for the ESA Cross-Scale mission.

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Collisionless plasmas frequently exhibit strong fluxes of electrons and ions at energies well above the mean plasma energy. These suprathermal particles play an important role in the identification and interpretation of the fundamental properties and physical processes within space plasmas. Investigations of these energetic populations require both good angular and temporal resolution measurements. Large geometric factors and fast electronics are vital to ensure adequate sampling of the tail of the particle distribution.

We present an overview of the science drivers and instrument concepts for a proposed HEP (High Energy Particle) instrument for the Cross-Scale mission, which is currently undergoing assessment for ESA's Cosmic Vision programme. The instrument builds on the heritage of experiments already successfully flown on the NASA/Polar and ESA/Cluster spacecraft. The design consists of a simple 'pin-hole' aperture and segmented silicon solid state detector array capable of measuring energetic particle distributions in the range 20-1000 keV. A modular design supports different spacecraft accommodation constraints and scientific requirements. This is vital for the Cross-Scale concept where the measurement priorities and available spacecraft resources will need to be optimized for the different spatial scales.

A Science Data System for Cross-Scale.

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The proposed ESA Cross-Scale mission will consist of a large number of spacecraft with payloads optimized for each of the characteristic scales. In addition there are expected to be close programmatic links with related missions from other agencies. In order to realise the mission science goals the data from the different spacecraft and instruments will need to be processed, combined and manipulated. Fast availability of high quality science data is a key mission objective. It is therefore vital to have a clear vision on how the science data collection, processing and distribution activities will be handled and streamlined at an early stage in the mission definition. Standardisation will be critical both for exchange of data within the mission but also in providing the links to related missions. The operations scenario relies on fast availability of science products in order to select periods of interest and important tasks such as inter-instrument and inter-spacecraft calibration will need to be identified and coordinated at the mission level.

Using lessons learnt from previous missions, we consider some of the key issues that must be addressed during this early assessment of a Cross-Scale Science Data System (CSSDS). The primary goal of the CSSDS will be to ensure fast, open availability of the high-quality data produced by Cross-Scale. The CSSDS will need to support a full range of data products including raw data, auxiliary, quick look and survey products as well as high-resolution science data. In addition the CSSDS will have to provide the services, standards, tools and high-level system architecture that are needed to provide these products to the science community.

Nonlinear dependence of anomalous ion-acoustic resistivity on electron drift velocity.

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Collisionless magnetic reconnection requires the violation of ideal MHD by various kinetic-scale effects. Recent research has highlighted the potential importance of wave-particle interactions by showing that Vlasov simulations of unstable ion-acoustic waves predict an anomalous resistivity that can be significantly higher in the nonlinear regime than the quasi-linear estimate. Here, we investigate the dependence on the initial electron drift velocity of the current driven ion-acoustic instability and its resulting anomalous resistivity. We examine the properties of statistical ensembles of 10 Vlasov simulations with real mass ratio for a range of drift velocities and for electron to ion temperature ratios 0.9, 1 and 2, relevant to both solar and magnetospheric physics. We show that the ion-acoustic anomalous resistivity depends nonlinearly on the electron drift velocity for the low temperature ratios examined, in contrast to the linear dependence predicted by theory and commonly assumed in models of magnetic reconnection. Specifically we find that a) anomalous resistivity is a power law function of the electron drift velocity, approximately with exponent $\sim 8-10$, and b) anomalous resistivity is a power law function of the normalized drift velocity, approximately with exponent $\sim 2.5-6$. An anomalous resistivity model consistent with our results could be important for simulations of magnetic reconnection in astrophysical plasmas.

The Hot Plasma Composition Analyzer (HPCA) on the Magnetospheric Multiscale Mission.

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The Hot Plasma Composition Analyzer (HPCA) measures magnetospheric plasma composition between 1 eV and 40 keV. With it's exceptionally high dynamic range of 10^9 and mass resolution ($M/\delta M$) of 8, the HPCA is ideally suited for separation of all ion species found in Earth's magnetosphere (H+, He++, He+, O++, O+) at all locations (e.g., hot magnetosheath or low density magnetotail) and under all conditions of magnetic activity. HPCA achieves this exceptional performance by employing tandem mass spectroscopy: the energy analyzer uses a novel radio-frequency electric field technology to attenuate the often very intense and dominant proton plasma component, while the time-of-flight analyzer provides high-resolution separation of protons and all minor ion species. A prototype of the HPCA has been used to demonstrate all performance requirements and all instrument technology is currently at Technical Readiness Level (TRL) 6 or above. The HPCA is in Phase B development for NASA's Magnetosphere Multiscale mission (MMS).

Observational techniques for high flux environments.

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Measurements of magnetospheric low energy particles very often require performing those measurements in a very high flux environment. State of the art micro-channel plate systems are limited by the counts per unit area the plates can sustain, as well as the total current through the detector. These limiting factors are examined and characterized, and mitigation measures described. Specific focus is placed on design techniques that have the potential of extending the counting rate of particle detectors by one or two orders of magnitude.

Multi-scale Cluster observations of the dipolarization/jet braking region in the near-Earth magnetotail

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The dipolarization/jet braking region is a key region in the near-Earth magnetotail where the interaction of fast reconnection jets with the dipolar magnetic field triggers important plasma processes such as magnetic field reconfiguration, electromagnetic energy conversion and energetic particle acceleration. Studying the dipolarization/jet braking region is crucial for substorms occurring in the Earth's magnetosphere and in other planetary magnetospheres. Furthermore the plasma processes in this region might be also similar to those occurring in other astrophysical environments where in-situ spacecraft measurements are not available, e.g. in the solar corona during flares. Plasma processes in the dipolarization/jet braking region affect large volumes of space however important physics occurs at non-MHD scales (ion scales and below). It is then crucial to study the dipolarization/jet braking region simultaneously at different scales. Cluster spacecraft observations in the magnetotail during 2007 are ideal for such multi-scale investigation since measurements of particles and electromagnetic fields are available simultaneously at scales ranging from electron (spacecraft separation $\sim$ 40 km) to fluid (spacecraft separation $\sim$ 10000 km). Here we present Cluster observations during one substorm event on October 27, 2007. The observations indicate that the dipolarization/jet braking region is a turbulent region comprised of magnetic structures that have a typical size $\sim$ few ion scales and are edged by thin current sheets with size $\sim$ few electron scales. Strong electric fields and waves are observed within such structures together with non-thermal electron acceleration up to $\sim$ 400 keV.

Analysis of phase coherence in turbulent signals.

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In Fourier analysis of any signal, two parts of information are obtained: The amplitudes give the power spectrum, and in the phase lies the information on coherence, which is fundamental to diagnose turbulent signals. Specific tools have therefore to be used to understand what the role of the phase is, since a power law is not a proof of a non-linear cascade. We will review and test a few tools existing in the literature that allow one measuring directly the phase coherence (based upon statistics on structure functions of surrogate data or statistics on phase increments) and present a new method, called "phase gradient analysis".

These methods will be tested on natural signals (Cluster measurement of magnetosheath turbulence) and numerical simulations of mirror structures. Presently they are not based on multi-spacecraft analysis, we will discuss how one can make them multi-point measurements techniques.

Effects of sub ion scales in shocks and reconnection regions.

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Formation of quasi-stable, inhomogeneous electromagnetic structures with sharp gradients in density and magnetic field is commonly observed in heliospheric magnetized plasmas. The resulting configuration may serve as a source of non-thermal particle distributions: (a) Coronal relaxation results often in an emergence of a shock wave which may traverse significant parts of the heliosphere. The observationally deduced intense ion acceleration close to the Sun, at low Mach numbers and low turbulence levels, poses a dilemma regarding the energization mechanism. When the magnetic ramp of an obliquely propagating electromagnetic substructure narrows to a size of a fraction of ion skin depth, as conjectured during merging of successively propagating shocks, the trajectories of some ions exhibit strongly non-adiabatic characteristics. Subset of ions and heavy elements is energized while surfing along the shock due to the combined forces of magnetic fields and cross-shock electric potential, forming a high-energy tail. (b) Recent experimental observations in the reconnection regions reveal formation of magnetic structures on spatial scales below the ion skin depth. The behavior of the plasma is controlled mainly by the electrons, and the MHD description undergoes modification. While in the ideal MHD the flux is frozen in the plasma flow, in electron-MHD the flux is frozen in the electron flow in. Density gradients, compressibility, and thermal effects may have a significant effect on the electron vorticity, which determines the slipping of the magnetic field with respect to the electrons. These effects modify the structure of the magnetic field in the short-scale electron dominated diffusion region, allowing formation of parallel electric fields, with important implications for the breaking of frozen-in condition and electron heating.

Recent results on small scale/dispersive solar wind turbulence and new requirements for the Cross-Scale mission.

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Most of observational work on solar wind (SW) turbulence has been devoted to large-scale/MHD scales where the Kolmogorov scaling $k^{-5/3}$ is frequently observed. Turbulence at frequencies above the proton gyrofrequency ($f_{ci} \sim 0.1$Hz) has not been thoroughly investigated and remains far less well understood. Above f_{ci} the spectrum steepens to $\sim f^{-2.5}$ and a debate exists as to whether the turbulence has become dominated by dispersive kinetic Alfvén waves and is dissipative, or has evolved into a new dispersive turbulent cascade dominated by whistler waves. Here we present recent results on the nature of this small-scale turbulence (up to 100 Hz) using the high resolution Cluster STAFF-SC data (Sahraoui & Goldstein, submitted). These studies are made using two complementary methods: the k-filtering technique (to calculate the 3D k-spectra of the turbulence, Sahraoui et al., PRL, 2006) and the surrogate data method (to investigate coherent structures and intermittency through Fourier phases of the turbulence, Sahraoui, PRE, 2008). Applying the k-filtering technique to large scale SW turbulence has revealed new constraints on the scales accessible to interferometric methods using multi-point measurements that are imposed by the supersonic/super Alfvnic nature of the SW flow. Investigating electron-scale SW turbulence has also exposed the need for magnetometers with higher sensitivity than those, for instance, now onboard Cluster. Some suggestions regarding these new requirements will be discussed.

SCOPE : Formation-Flight Magnetospheric Satellite Mission

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A formation flight satellite mission "SCOPE" was proposed to the Steering Committees for Space Science in Japan aiming at launching in 2017. "SCOPE" stands for "cross Scale COupling in the Plasma universE". The main purpose of this mission is to investigate the dynamic behaviors of plasma in the terrestrial magnetosphere that range over magnitudes of both temporal and spatial scales. The basic idea of the SCOPE mission is to distinguish temporal and spatial variations of physical processes by putting five formation flight spacecraft into the key regions of the Earth's magnetosphere. The formation consists of one large mother satellite and four small daughter satellites. Three of the four daughter satellites surround the mother satellite 3-dimensionally maintaining the mutual distances of variable ranges between 5 km and 5000 km. The fourth daughter satellite stays near the mother satellite with the distance between 5 km and 100 km. By this configuration, we can obtain both the macro-scale (1000 km - 5000 km) and micro-scale ($\lesssim$ 100 km) information about the plasma disturbances at the same time. SCOPE's predecessor "GEOTAIL", launched in 1992, played a big role for understanding the ion behaviour in the Earth's magnetotail and triggered interests toward further microscopic scale (electrons scale) phenomena. Following this successful work of GEOTAIL, SCOPE aims at observing the Earth's magnetotail where the ion scale phenomena and electron scale phenomena interact with each other, with 5 satellites flying in formation. To fully resolve the time domain behaviour from spatial distribution of the magnetospheric phenomena, simultaneous observations by spatially distributed spacecraft are essential. The launcher for SCOPE is assumed to be H2A. The orbits of SCOPE are all highly elliptical with its apogee between 25 Re and 30 Re from the Earth center. The inter-satellite link is used for telemetry/command operation as well as ranging to determine the relative orbits of the 5 satellites in small distances, which cannot be resolved by the ground-based orbit determination. The model science instruments onboard SCOPE satellites includes high performance plasma/particle sensors including medium energy range ion/electron sensors and super high time resolution electron sensors and DC/AC Magnetic and Electric field sensors including wave particle correlator. All the SCOPE satellites have two 5m spin-axis antennas. The spin-axis antenna must have high specific rigidity for the attitude stability of spinning satellites. We are now developing new lightweight inflatable antenna, having sufficient rigidity for the SCOPE satellites' spin rate of 20[rpm].

Electron temperature measurements by electron cyclotron emission (ECE) diagnostic system and its calibration on HT-7 tokamak.

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Recently a broadband heterodyne radiometer has been installed on HT-7 tokamak to measure second harmonic X-mode electron cyclotron emission (ECE) at frequency range 98-126 GHz, which is the only ECE detectable mode with optical depth ¿ 1 in the present study. The high temporal resolution (4ms) diagnostic system is now operational with 16 detection channels separated by approximately 2 cm on radial axis for measuring electron temperature (Te) on the low field side for typical machine operation at toroidal magnetic field (BT) 1.0-2.5 T. The results of electron temperature measurements are presented along with the calibration of the diagnostic system. In order to cross calibrate the ECE system, the electron temperature data obtained, has been compared to other Te measuring diagnostics i.e. Thomson scattering and soft X-rays Pulse height analysis (PHA). A radial electron temperature profile during ohmic heating phase has been presented and analyzed. Future plans for the diagnostics of temperature fluctuations and measurements are also discussed.
Keywords: electron cyclotron emission, heterodyne radiometer, electron temperature, optical depth.
PACS: 52.55.Fa, 52.25.Os, 52.70.-m, 52.70.Gw

Intermittent turbulence in boundary layers of space and laboratory plasmas: extended self-similarity and superdiffusion.

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The turbulent fluctuations observed in boundary layers near the magnetopause and in edge plasma of fusion devices are self-similar, suggesting the universality of fractal properties in plasma turbulence. In space plasma, analysis of data from Cluster and Interball-1 revealed the scale-invariance and intermittency of magnetic field and plasma flow fluctuations at frequencies below 10 Hz in the disturbed magnetosheath downstream the parallel and oblique bow shock and above polar cusps. Experimental measurements in tokamaks, stellarators and linear plasma machines have shown a spiky rather than random behavior of turbulent fluctuations in the edge magnetized plasma.

To characterize the intermittency, higher order moments (structure functions, $S_q(t)$) of the data at different time scales t have been analyzed. Turbulent fluctuations demonstrate multifractal statistics both in space and in fusion devices, i.e. the scaling behavior of absolute moments with the extended self-similarity $S_q(t) \sim t^{(\zeta(q)/\zeta(3))}$, where $\zeta(q)$ is described by a convex function. It reflects generalized scale invariance of the developed turbulence. The multifractality is related to an underlying multiplicative cascading process. The experimental scalings $\zeta(q)$ deviate from the Kolmogorov's K41 and other standard models of the developed turbulence.

Nonlinear scaling of the structure function observed in experiments is interpreted in frame of the log-Poisson model of intermittent turbulence. The time scalings for the diffusion coefficient are derived from the log-Poisson model parameters. From this scalings, both space and edge fusion plasmas are characterized by superdiffusion. Qualitatively, the superdiffusion is confirmed by fitting the probability distribution functions by the truncated Levy- flight distributions, while for the monofractal model the deviation from the classical diffusion is smaller.

The observation of multifractality in experimental data supposes long-range spatial correlations in turbulent field suggesting a coupling of small-scale fluctuations with global MHD ones. I.e. the microscales are coupled not only with the neighbor fluid scales, but also with the larger ones. We discuss an implementation of this turbulence peculiarities for the strategy of multiscale measurements.

The revealed turbulence features seems to be typical for the boundary layers in space and laboratory plasmas as well as in the astrophysical plasma.

Multi-scale energy and momentum coupling in plasmas: microphysics impact on MHD- scale flows.

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On the basis of Cluster, Interball, Double Star and Geotail data, we discuss the scientific tasks for multi-scale measurements in outer magnetosphere, along with the respective strategy for the spacecraft orbits and ranging.

We display extremely disturbed magnetosheath (MSH) regions either closer to the bow shock (BS), or ahead of magnetopause (MP), which provide an evidence for unprecedented kinetic energy concentration either in spikes ('plasma jets' with the energy density up to several times above that of the unshocked solar wind (SW)), or in average - in extended super -turbulent zones with several tens of the jets. These zones have duration up to 2 hours and require further search for an energy and flow source as its duration far exceeds the period of eigen MSH waveguide modes. As the kinetic energy rising in the jets is opposite to the predictions of MHD for the local transformation of SW kinetic energy into thermal energy at the BS, we discuss the dynamic feature of non-equilibrium processes due to the single jets, along with global energy and flow re-distribution in the dayside MSH for the extended super-turbulent zones. The latter cannot be attributed to a transient MSH process, we suggest a collisionless interference wave- pattern instead. To solve the problem of a the cross-scale linkage from ion gyroradius (the scales of jets' boundaries' and gradients') till global magnetospheric scales, and to draw the physical picture with the total energy and flow balance, the spacecraft constellation should trace plasma streamlines in MSH from foreshock to the near-tail magnetospheric boundaries, including cusp, mantle and low- latitude boundary layers. The latter should shed the new light on the magnetosphere filling by the solar plasma and on the magnetospheric particle losses. Both post-shock and near-MP streamlines' parts should be monitored from electron till fluid scales simultaneously.

We outline the importance of the high- latitude monitoring as: (a) namely there most of solar plasma is believed to enter the dayside magnetosphere and mantle; (b) the stagnant solar plasma above/ inside the outer cusp which has high thermal pressure, interacts in different way with the incident flow compared with that at low latitudes with a magnetic barrier at MP; e.g. the cusp-like neutral points could be crucial for laboratory plasma losses (in tokamaks etc.); (c) only in the course of this interaction the extended turbulent boundary layers can be studied, representing the unique natural “laboratory” for exploration of turbulence, diffusion/ super-diffusion, fusion plasma confinement etc.; (d) namely at the border of the 3D cusp throat the field line over-turning - Alfvenic collapse of magnetic field - has been detected by Cluster and Interball; it is a new way for effective separation of the moving plasma from the stagnant one by the structured (at ion gyroradius scale) magnetic barriers, which in turn could change the streamlining pattern at the MHD scales; (e) the MSH plasma jets can penetrate deep into the high- latitude magnetosphere (especially across the tailward wall of the cusp throat) and populate mantle, lobes and low- latitude boundary layers, resulting even in geomagnetic disturbances including a kind of driven substorms.

Depending on the total number of spacecraft cooperating within Cross-Scale, we propose either aim 4-6 spacecraft on the high latitudes (for > 13 ones), or choose compromised orbits for the total constellation, which allows to trace both equatorial plane and summer outer cusps (using slow evolution of the orbit major axis due to the Moon influence).

ROY project in collaboration with Cross-Scale.

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The key feature of the project ROY is the multi-point synchronous measurements of plasma inhomogeneities in the regions of strong plasma turbulence and magnetic field annihilation at the scales from electron inertial length till MHD dimensions.

The ROY scientific tasks in future multi-scale studies are: (a) turbulence on a non-uniform background as the keystone for transport processes; (b) flow structuring/ jetting with anomalous concentration of kinetic energy over that in the solar wind: impact on flow balance and boundary formation; (c) Alfvenic collapse of magnetic field lines and magnetic field generation; (d) spontaneous versus forced reconnection, (e) shock transitions and particle acceleration.

In the case of an autonomous operation, four mobile spacecraft of about 200 kg mass with 60 kg payload equipped by plasma engines, will provide simultaneous 3D measurements at scales 100-10000 km and 1D ones - at 10-1000 km. The latter will be executed by the usage of radio-tomography: plasma density determination from phase- shift measurements along 3 rays between one irradiating and 3 receiving spacecraft. Understanding strong constraints for this experiment following from the environment conditions, we performed the careful estimation of the experiment parameters. Simulation of tomographic reconstruction was carried out, which demonstrated that even for the three projections it is possible to recover global structure of irregularities, moving in the measurement plane transverse to the rays.

Combined influence of intermittent turbulence and reconnection on the geotail and on the intrinsically nonlinear dynamics of boundary layers should be explored also in situ, for the first time with adequate techniques, including fast particle devices under development, providing plasma moments down to 30 ms resolution.

We propose different options for common measurements in conjunction with the Cross-Scale mission:

- One of the options would be a common constellation, in which ROY provides monitoring of fluid or MHD scales with one mobile spacecraft scanning across the constellation for the continuous tracking throughout the total scale range.
- In a case of available 10-12 ESA, JAXA etc. spacecraft, ROY will be targeted on the multi-scale tracking of high latitudes.

We also hope that the ROY prototype spacecraft STRANNIK (Pilgrim), planning for launch at 2013-2014, would be able coordinate its operation with Resonance, MMS and ROY missions at its early operation phase.

The orbit options and scientific payload of possible common interest are also discussed.

Observational study of non-stationary shock structure.

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The dissipation processes at collision-less plasma shocks are one of the most interesting issues in space plasma physics. Due to the collision-less nature of the plasmas, in the course of the dissipation processes non-thermal particle are generated in association with the bulk heating of the main body populations. Recent numerical simulation results imply that non-stationary behavior of a shock front has a strong impact on the dissipative processes and thus on the particle acceleration mechanism. Observational support for this issue, however, has been rather scarce. One of the obvious reasons is that it is difficult for single spacecraft observations, which is notorious for its inability to distinguish a spatial variation from a temporal one, to unambiguously identify the non-stationarity of a shock front. The multi point measurements by Cluster-II enable us to investigate the non-stationary behavior with temporal and spatial variations being discriminated. We show the non-stationary structures (self-reformation) of quasi-perpendicular and oblique shocks obtained from formation flying observations by Cluster and discuss the particle dynamics under the non-stationary structures. In addition, a simulation result with parameters based on the observation of the quasi-perpendicular shock is shown.

Recent results and future perspective of large scale full particle simulation on magnetic reconnection.

Iku Shinohara, Kenny G. Tanaka, Masaki Fujimoto

Institute of Space and Astronautical Science / Japan Aerospace Exploration Agency

Recent progress of super-computer performance enables us to carry out large scale (dealing with ion and fluid scale beyond electron scale) full particle simulation. We have carried out 2D and 3D simulations on magnetic reconnection with various boundary conditions and have studied several problems like, reconnection triggering process, electron acceleration, response of diffusion region to change of boundary condition, etc. In this presentation, we will show a summary of recent results and will discuss future perspective of reconnection simulation with the full particle code.

WAXS - wave analyzer suite for the Cross-Scale mission.

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To fulfill its science objectives, the Cross-Scale mission will require high quality wave measurements to be available on all spacecraft. The payload therefore needs to include a comprehensive suite of wave instruments covering a frequency range from DC to 100 kHz. We present a preliminary design of wave analyzer modules proposed within the framework of Cross-Scale fields consortium. The Low Frequency Receiver (LFR) will digitize 3 components of magnetic fields and 2 components of electric field provided by E2D and ACB sensors. In addition to waveform measurements, full spectral matrices covering frequencies up to 4 kHz will be calculated on board by the LFR analyzer. The High Frequency Receiver (HFR) is responsible for digitization and spectral analysis of electric and magnetic field data between 1 kHz and 100 kHz as well as identification of plasma resonances excited by the relaxation sounder. The wave analyzer suite may also includes a hardware based thermal noise analyzer (TNR) dedicated to measurements of basic plasma parameters by analysis of plasma thermal noise spectrum. All the above wave analyzer modules will be implemented as electronics cards integrated within the ACDPU instrument box.

Simulation and modeling of nonlinear mirror modes.

P.L. Sulem and T. Passot[1], *P. Hellinger and P.M. Trávníček*[2], *E. Kuznetsov*[3], *F. Califano*[4]

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Pressure balance structures in the form of magnetic depressions (holes) or enhancements (humps) anticorrelated with density fluctuations have been reported in various space plasma environments, such as the solar wind and the magnetosheath of solar system planets, in regions with a high beta (ratio of thermal to magnetic pressures) and a strong anisotropy of the proton temperature (dominant in the transverse direction). They are often related to the nonlinear evolution of the mirror instability, but the understanding of the processes involved in the saturation of this instability remains very incomplete. After presenting a few observational results, this talk will describe particles-in-cell and Eulerian numerical integrations of the Vlasov-Maxwell equations, together with asymptotic developments aimed to model the observed dynamics.

Development of Huge data Storage system with intelligent time search functinos for SCOPE mission.

T. Takashima, S. Fukuda, T. Seki, S. Ichikawa, SCOPE team

ISAS/JAXA
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Time resolution of scientific observation is getting higher and higher, and then instrument data product volume is getting larger and larger. We will develop a new large volume data recorder for SCOPE missions to success and achieve big goals. Nominally we have been developing Solid State Memory (SDRAM) recorder. It is stable technology but it uses large resources such as power, mass, bagged. Now we start to develop Magnetic recorder and Flush memory to use on spacecraft for SCOPE missions. We make tasks for HDD space applications, such as Vibration on rocket launch; thermal control to keep operation temperature for HDD, pressure has been controlled in atmospheric pressure which depends on thermal control, and radiation protection. Especially magnetic record is robust to SEU. It is large merit on HDD. On the other hand, recently, the reliability of Flush Memory is improving. It is possible to expect that it manufactures a very compact recorder system. The rest problems are the writing number of times limitation and a radiation-resistance. It continues to be developed about that point.

The stored science data must be efficiently sent to the ground station. Therefore, it makes the specification to use a file system method on the data recorder and to make have a time search function for data recorder in SCOPE mission. It is possible to send selected data by time interval commands (ex; from 20180101 10:00:00UT, 10 minutes) from the ground station and to delete data from data recorder in order to use storage area efficiently.

We will report those statuses of developments for SCOPE mission.

Three-dimensional global hybrid simulations of a small magnetosphere.

Pavel Trávníček[1,2], *Petr Hellinger*[2], *David Hercik*[2]

[1] UCLA
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We present results from three global numerical experiments of the interaction between the solar wind and a planet with small magnetosphere, namely for north-wardand south-ward orientation of IMF and also for the IMF in the equatorial plane. We will illustrate the capabilities of global kinetic modelling for the interpretation of in-situ observations. The IMF orientation clearly determines the formation of the proton foreshock and the position of quasi-parallel and quasi-perpendicular bow shock. South-ward orientation of IMF causes the current sheet being thinner and supports formation of plasmoids in the magnetotail. Kinetic nature of our model allows us to determine which temperature anisotropy driven instabilities constraint the anisotropy at given place, and which waves are likely to be observed at given location of the studied system. We will show, that the wave-particle feedback is sufficiently resolved by our model, which allows energy transfers between particles and waves (phenomena not resolved by MHD models). To simulate the full size Earth's magnetosphere is beyond computational capabilities of today's computers, however, some of results obtained by our method are qualitativelly relevant to Earth, especially on bow-shock, ion-foreshock, magnetosheath, magnetopause and magnetotail. We are not able to address the phenomena in the magnetosphere closer to the Earth's surface.

Electron acceleration associated with ion dynamics at a perpendicular shock.

Takayuki Umeda, Masahiro Yamao, Ryo Yamazaki

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A full particle simulation study is carried out on the electron acceleration at a collisionless, relatively low Alfven Mach number of M A=5, perpendicular shock. Recent self-consistent hybrid shock simulations have demonstrated that the shock front of perpendicular shocks has a dynamic rippled character along the shock surface of low-Mach-number perpendicular shocks. In this paper, the effect of the ripping of perpendicular shocks on the electron acceleration is examined by means of large-scale (ion-scale) two-dimensional full particle simulations. It has been shown that a large-amplitude electric field is excited at the shock front in association with the ion-scale rippling, and that reflected ions are accelerated upstream at a localized region where the shock-normal electric field of the rippled structure is polarized upstream. The current-driven instability caused by the highly-accelerated reflected ions has a high growth rate to large-amplitude electrostatic waves. Energetic electrons are then generated by the large-amplitude electrostatic waves via electron surfing acceleration at the leading edge of the shock transition region. The present result suggests that the electron surfing acceleration is also a common feature at low-Mach-number perpendicular collisionless shocks.

New Vlasov simulation techniques for scale coupling in the plasma universe.

Takayuki Umeda, Keiichiro Fukazawa, Yosuke Matsumoto, Kentaro Togano, Takuma Nakamura, Iku Shinohara

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In recent days, MHD simulations are widely used for numerical modeling of the solar wind, solar flares, global planetary magnetospheres, and other global and macroscopic phenomena. However, the MHD simulations need artificial resistivity, conductivity, adiabatic index, and diffusion coefficients. These quantities are essentially due to first-principle kinetic processes that are eliminated in the framework of conventional MHD approximation. Recently it has been suggested that the macroscopic, mesoscopic and microscopic processes in space plasma are strongly coupled with each other, which is called cross-scale coupling. To go toward the cross-scale coupling in the solar-terrestrial system, it is important to include full-kinetic dynamics of plasma particles in the global and macro-scale simulations.

In the present study, we regard the Vlasov model as a potential candidate for the first-principle simulation of all space plasma processes, which will be a final goal of the computational space plasma science. We are now developing a new Vlasov simulation code to go beyond the conventional MHD framework toward the cross-scale plasma science. Our new two-and-half dimensional (2.5D) full-electromagnetic Vlasov code is successfully applied to macro-scale phenomena such magnetic reconnection or Kelvin-Helmholtz instability. Here we discuss the current status of the Vlasov model and future prospects of their application to scale coupling in the plasma universe.

An Electric Field Experiment for Cross-Scale.

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According to the Science Requirement Document, the Cross-Scale mission requires high quality measurements of the electric field on all the electron- and ion-scale spacecraft and on at least one fluid-scale spacecraft. We present an overview of a possible design of an electric field instrument (E2D) that is based on the double probe design and would be able to measure two components of the electric field in the satellite spin plane in all the required frequency range. Such an instrument has a very high technology readiness level, with direct heritage from Cluster, MMS, BepiColombo and other missions. In addition to the electric field, the instrument also measures the satellite potential that can be used for high time resolution measurements of plasma density fluctuations as well as for calibration of the particle instrument measurements. The E2D instrument would be a part of a consortium of fields instruments. We also discuss, based on the recent special operation modes of the Cluster spacecraft, the possibility of using electric field data from two tilted spacecraft to estimate all three components of the electric field.

Suprathermal particle energization in reconnection jet braking regions.

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One of the main properties of magnetic reconnection is its capability to convert magnetic energy into plasma energy. Of particular interest is how charged particles with the highest energies (suprathermal particles) are produced. While much of the energization occurs close to the reconnection site, there is significant energization occurring in the reconnection jet braking regions where the jet interacts with the ambient magnetic field. Understanding energetic particle energization in such regions is important for substorms in planetary magnetospheres, flares in solar/stellar coronae and for similar plasma processes in distant astrophysical objects. Here we use Cluster in-situ measurements to show observational details of particle energization within jet braking regions in the Earth's magnetotail and we discuss possible energization mechanisms. Basing on our observational results, we suggest which Cross-Scale spacecraft configurations and instrumentation would be needed to improve our understanding of these energization mechanisms.

Cross-scale effects in solar wind turbulence: multi-dimensional Vlasov simulations.

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The role of kinetic effects on the development of turbulence spectra in solar wind plasmas is numerically investigated in the range of wavelengths around and beyond the ion inertial length, through a recently developed hybrid-Vlasov code [1]. In our numerical model, ions are considered as kinetic particles, while electrons as a massless fluid. This zero-noise Vlasov algorithm is particularly efficient in the analysis of the short-scale termination of turbulence and especially in the description of the link between macroscopic and microscopic scales along the turbulent cascade.

In our simulations [2], nonlinear wave-wave coupling processes at large wavelengths produce a turbulent cascade that transfers energy towards scales of the order of the ion skin depth. In this range of wavenumbers, proton cyclotron resonance with left-handed cyclotron waves self-consistently generates perpendicular temperature anisotropy in the ion distribution function. For hot electrons, a significant level of electrostatic activity is observed at short wavelengths. The careful analysis of the numerical kappa-omega spectra [2] showed that ion-acoustic waves, propagating parallel to the ambient magnetic field, are produced as the result of the nonlinear cascade of energy. Besides these ion-acoustic waves, in agreement with spacecraft observations in solar wind, new short-wavelength fluctuations of the acoustic form, and with phase velocity close to the ion thermal speed, were recovered in the simulations. The analytical solution of the hybrid Vlasov-Maxwell equations shows [3] that these fluctuations are Berstein-Green-Kruskal structures, driven by particle trapping kinetic effects and usually associated with the generation of double-beam proton velocity distributions. The presence of fast beams in the proton velocity distributions is a feature frequently observed in solar wind plasmas, usually in presence of short-scale electrostatic activity.

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X- Ray emission from laser heated clusters.

Updesh Verma and A.K.Sharma

IIT Delhi

An intense short pulse laser impinged on a cluster imparts large oscillatory velocity V_{os} to electrons and heats them. As the cluster expands, electron density falls and at some instant plasma frequency of cluster electrons ω_p, equals $\omega/(3)^{1/2}$ (where ω is the frequency of the laser), giving a resonant enhancement to V_{os} . At this instant the electron radiate strong bremstrahlung radiation in the x-ray band. The self focusing of the laser extends the length of the x-ray existing channel, hence the yield of x-ray generation.

Current filament structures detected in the edge region of a magnetically confined plasmas.

Nicola Vianello, Monica Spolaore, Emilio Martines, Roberto Cavazzana, Gianluigi Serianni, Emanule Spada, Matteo Zuin

Consorzio RFX, Associazione Euratom-ENEA sulla Fusione, Padova

Coherent structures emerging from turbulent background have been detected in the edge region of all magnetically confined plasma configurations, and are believed to significantly contribute to particle transport both through a direct convection toward the edge and through an increase of particle diffusivity. These structures have been widely described in the perpendicular plane, but recently a great effort is devoted to their characterization in the direction parallel to the guiding magnetic field.

In the RFX-Mod Reversed Field Pinch device a new and original insertable diagnostic allows the measurements of both magnetic and electrostatic fluctuations on the same location with high space and time resolution. In particular, the system consists of two sets of electric and magnetic probes 88 mm spaced in the perpendicular direction. Each set is equipped with a 2-D array of Langmuir probes and a radial array of 3-axial magnetic coils. The probe arrangement allows the simultaneous measurements of velocity and relative vorticity, of density and pressure and relative gradients, and of current density.

Coherent fluctuations, responsible for signal intermittency, are found to correspond to pressure structures with a vortex-like velocity pattern in the perpendicular plane, associated with a current filament mainly oriented along the parallel direction. The associated diamagnetic current, due to the pressure gradient fluctuations, will also be provided together with a complete characterization of these structures in terms of current density, pressure and vorticity.

Multi-scale observations of fast flows, dipolarizations and oscillations in the current sheet

Martin Volwerk, Rumi Nakamura, Alessandro Retinò, Wolfgang Baumjohann

Space Research Institute, Austrian Academy of Sciences

The cross-scale mission's objective is to study magnetotail plasma processes such as turbulence, reconnection and oscillations at various scales using near Earth space as a laboratory. During summer 2007 the Cluster spacecraft were placed in a multi-scale configuration, in which C3 and C4 were only separated by several 10s of kilometers, whereas C1 and C2 were over 10.000 km separated from this pair in the night side magnetotail. This constellation brings the possibility to look at the current sheet at different scales.

On 2 September 2007, after $\sim$ 1630 UT, the spacecraft move from the lobe into the current sheet, whereas at the same time there is Earthward plasma flow, magnetic field dipolarizations and wave activity observed. Similar structures in the magnetic field can be seen moving between the spacecraft, but with, most likely, a temporal development in between. On the small scale of the C3-C4 separation, the micro physics can be observed. With an average magnetic field strength of $\sim$ 15 nT and an electron energy of several keV, this means that C3-C4 is sampling the tail at a few times the electron scale.

The view of plasma processes (reconnection, turbulence, waves, etc.) on different scales will lead to a better understanding and to better models of these processes. In this presentation we will discuss the physics on the different scales of Cluster and relate this to how Cross-Scale will improve on these kinds of measurements.

Multi-Scale Observations of Bursty Bulk Flows & Plasma Bubbles: What will we learn from Cross-Scale?

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The concept of a plasma bubble (Pontius & Wolf, 1990) has been suggested as one possible model of the Bursty Bulk Flows (BBFs) often observed in the magnetotail plasma sheet and thought to transport a significant amount of magnetic flux during substorms. They are flux tubes that have been depleted of entropy and as such convect Earthwards more quickly than the ambient plasma. Plasma bubbles have both large-scale and fine-scale structure. We review two separate observations of plasma bubbles made by Cluster at two different tetrahedron scale sizes. Forsyth et al. (2008) provided the first quantitative determination of the field-aligned currents along the edge of two plasma bubbles, comparing with ionospheric observations. Walsh et al. (2009) reported the first direct observations of the expected return flows around the flanks of a plasma bubble and presented a detailed study of its large-scale morphology.

Using Cross Scale it will be possible to investigate the link between the smaller-scale current systems and the gross bubble morphology, which has not been possible using the single-scale measurements provided by Cluster. This will potentially reveal the process responsible for initial entropy depletion, which currently remains a mystery.

Small-scale anisotropy of the solar wind turbulence as observed by Cluster.

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We study the anisotropy of the small-scale turbulence of the solar wind magnetic field. The classical Kolmogorov theory assumes statistical isotropy of the small-scales in a turbulent fluid. However, recent experiments and simulations show that in magnetohydrodynamical fluids the anisotropy of turbulence due to a background magnetic field increases down to fairly small scales. Conventionally, turbulence is studied by looking at the scaling properties of the structure functions, i.e. the moments of the magnetic field or velocity differences measured at two points separated by some distance. So far, the single spacecraft measurements allowed their calculation in only one spatial direction. Using pairs of Cluster spacecraft we can obtain and analyze the tensorial nature of the structure functions of the solar wind magnetic field. This allows investigating the degree to which small scales are isotropic or anisotropic in different spatial directions.

Heavy ion reflection and heating by collisionless shocks in solar corona: Cross Scale contribution.

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The heating of the solar corona to temperatures of the order of 10^6 K and more is one of the fundamental problems of solar physics. Beside the high temperatures, Soho/UVCS observations have shown that heavy ions in polar corona, like O^{5+} and Mg^{9+}, are heated more than protons, and that heavy ion heating is more than mass proportional; further, the perpendicular temperatures are much larger than parallel temperatures.

Shock waves are common in the corona. Here, we propose that the more than mass proportional heating of heavy ions in coronal holes is due to the ion reflection at supercritical quasi-perpendicular shocks and to the ion acceleration by the $\mathbf{V} \times \mathbf{B}$ electric field in the shock frame. We assume that small scale plasma jets are formed in the reconnection regions in the solar corona and chromosphere. On the terrestrial bow shock, the quasi-perpendicular and the quasi-parallel portions of the supercritical shock are routinely observed by spacecraft. Ion reflection can be considered to be the main mechanism by which collisionless shocks convert the flow directed energy into heat, while the electrons are heated much less.

A crucial point is the mechanism at the origin of reflected ions. The conventional wisdom is that ion reflection is due to an electrostatic potential barrier $\Delta\phi$, which slows down the incoming ions, and which has an order of magnitude corresponding to the proton kinetic energy, since protons are the major species.

Cross shock electric field measured by the Polar spacecraft at Earth's bow shock show that the potential $\Delta\phi$ =800 Volts is strongly spiky and fluctuating. The strong fluctuations can allow for heavy ion reflections, even if in an intermittent way. Further, quasi-perpendicular shocks also exhibit cyclic reformation, which implies variable potential barriers and reflection rates.

Experimental evidence of cyclic reformation was recently obtained from Cluster data, so that the strong variations in the shock structure can also allow for heavy ion reflection. Clearly, a mission like Cross-Scale could give invaluable insight on the processes which actually lead to heavy ion reflection under variable solar wind conditions. This would give a prime contribution to the understanding of heavy ion heating in the solar corona.

Magnetic Reconnection in the Interstellar Medium.

Ellen G. Zweibel

U. Wisconsin-Madison

Magnetic reconnection plays an important role in the evolution of galactic magnetic fields, in star formation, and possibly in the energy balance of the interstellar medium, and may accelerate particles to high energies. Interstellar reconnection differs from laboratory reconnection because the plasma beta is order 1, cooling may be important, and neutral particles, charged dust grains, and cosmic rays may all play a role. I will discuss interstellar reconnection theory and compare it to reconnection in space plasmas.

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