Solar–Terrestrial Interactions from Microscale to Global Models II

Sinaia, Cota 1400
June 12 – 16, 2007

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Dear Guests,

We are glad to welcome you again in Sinaia, to STIMM2. We hope that our meeting will be again an open forum for discussions and reviews related to Auroral Physics and Magnetospheric Boundary Layers and Discontinuities. This year STIMM is enriched with two focus groups devoted to an in-depth analysis of space plasma models and advanced methods for in-situ data processing and interpretation. You will also have the opportunity to interact with students and lecturers attending the 6th COSPAR Capacity Building Workshop 'Solar Terrestrial Interactions: INstrumentation and TEchniques' (STIINTE). We wish you a pleasant stay in Romania and hope to enjoy the lectures, discussions and the get-together with the colleagues.

Octav Marghitu, Marius Echim, Adrian Blăgău,
Dragoş Constantinescu, Horia Comişel

Contents

Foreword

Aurora borealis is crucially important for understanding the interaction between the stream of plasma of solar origin and the Earth's plasma and magnetic field. Explaining the physical mechanisms that govern the auroral break-up is still an open debate. Stationary, electrostatic models, build on assumptions concerning the kinetics of magnetospheric / ionospheric plasma populations, are advocated with the same enthusiasm as magnetohydrodynamic time dependent models, where the energy is transferred through wave activity specific for magnetized plasmas. The physical processes that intermediate the energy transfer are not completely elucidated.

On the other hand, increasingly sophisticated experiments on-board spacecraft contribute to refine our view on the terrestrial magnetosphere. The experimental data show that space plasma is discontinuous and dynamic boundary layers separate different plasma regimes (like the magnetopause separating the Earth's plasma from the solar wind plasma). Although significant advances have been made during the recent years, there is still room for progress in modeling and understanding the magnetospheric boundary layers. New data, with better resolution, now enable cross-checking of theoretical models from micro- to global scales. Multi-point missions, like CLUSTER, open a new era in the physics of the boundary layers that may improve our understanding of the solar wind magnetosphere – ionosphere – atmosphere system.

Following suggestions made in 2005 at STIMM-1, we try to make our workshop more interactive, by moving the emphasis from oral presentations to moderated discussions/focus groups. The focus groups devoted to 'Modeling of space plasma plasmas' will be centered on an open discussion about the advantages and limitations of various approaches. Models based on hydrodynamic and moments description and the kinetic ones (exospheric, Boltzmann, Fokker-Planck, Monte Carlo simulations, hybrid codes) will be discussed with respect to modeling the transport in near collisionless gases and plasmas. We expect to bring together colleagues from all horizons to discuss various aspects of different ways to model space plasmas and possibly laboratory plasmas. The focus group devoted to 'Methods for in-situ data analysis' aims primarily to discuss techniques developped to: (a) characterize the boundaries and identify the processes taking place there, emphasizing the macroscopic parameters of boundaries (thickness, speen, orientation), (b) derive wave properties from multi-spacecraft data, (c) analyze 3D quantities from 3 spacecraft data with application to future multi-point missions like THEMIS.

This year STIMM benefits also from the adjacency of the sixth COSPAR Capacity Building Workshop 'Solar Terrestrial Interactions: INstrumentation and TEchniques (STIINTE)'. Target participants are postgraduate students and postdoctoral scientist from Central and Eastern Europe and the surrounding region, in particular, from Armenia, Bulgaria, Czech Republic, Georgia, Hungary, Poland, Romania, Russia and Ukraine, guided by lecturers from Belgium, Czech Republic, France, Germany and Sweden. STIINTE will address practical aspects of Cluster-II and other spacecraft missions to the magnetosphere. The participants will focus on data analysis techniques for single-spacecraft missions and also for multipoint measurements. Selected modeling approaches are discussed to facilitate the physical interpretation of analysis results. STIMM will host a special session where the students of the COSPAR Capacity Building Workshop will have the opportunity to present their results.

Program

Tuesday, June 12

15:00 – 20:00	Arrival and Registration
18:30 – 20:30	Dinner
20:30 – 23:00	Welcome Cocktail

Wednesday, June 13

08:45 – 12:30	**Plenary session**
08:45 – 09:00	Opening word; Info
09:00 – 09:45	**B. Klecker**, Solar-Terrestrial Relations: An Overview
09:45 – 10:30	**J. Vogt**, Paleomagnetospheric processes
10:30 – 11:00	Coffee Break
11:00 – 11:45	**M. Scholer**, Hybrid and full particle electromagnetic simulations of collisonless shocks as applied to the Earth's bow shock
11:45 – 12:30	**T. Karlsson**, Cluster observations of high-beta plasma blobs in the magnetosheath
12:30 – 14:30	Lunch Break
14:30 – 16:00	**Focus group Boundary Layers**
14:30 – 14:40	**G. Parks**, Introduction
14:40 – 15:10	**C. Mazelle**, Ion properties at Earth's foreshock: recent achievements
15:10 – 15:40	**F. Pitout**, Cluster survey of the mid-altitude cusp
15:40 – 16:10	**E. Yordanova**, The evolution of intermittency in the magnetosheath turbulence downstream of a quasi-parallel bow shock
16:00 – 16:30	Coffee Break
16:30 – 17:00	**N. Brenning**, Plasmoid penetration across a magnetic barrier: scaling from laboratory experiments to impulsive penetration into the Earth's magnetosphere
17:00 – 17:30	**H. Nilsson**, The role of centrifugal acceleration near the magnetopause boundary
17:30 – 18:00	**A. Kis** (TBD)
14:30 – 16:00	**Focus group Modeling**
14:30 – 14:40	**J. Lemaire**, Introduction
14:40 – 15:10	**H. Lamy**, Exospheric models of the solar wind
15:10 – 15:40	**N.R. Minkova**, Multiparticle statistical approach to solar wind modeling (TBC)
15:40 – 16:10	**A. R. Barakat**, Monte-Carlo simulations of space plasma outflow
16:00 – 16:30	Coffee Break
16:30 – 17:00	**A. R. Barakat**, Difficulty of Adding Coulomb Collisions in Monte Carlo Simulations
17:00 – 17:30	**V. Pierrard**, Fokker-Planck modeling of the solar and polar wind flow
17:30 – 18:00	**P.-L. Blelly**, Application of multi-moment transport equations to space plasmas simulation
19:30 – 21:00	Dinner

Thursday, June 14

08:45 – 12:30	**Plenary session**
09:00 – 10:30	STIINTE projects (I)
10:30 – 11:00	Coffee Break
11:00 – 12:30	STIINTE projects (II)
12:30 – 14:00	Lunch
14:00 – 22:00	Excursion and Workshop dinner

Friday, June 15

08:45 – 12:30	**Plenary session**
09:00 – 09:45	**C. P. Escoubet**, The mid-altitude polar cusp as seen by Cluster
09:45 – 10:30	**G. Parks**, Plasma sheet observations relevant to THEMIS mission
10:30 – 11:00	Coffee Break
11:00 – 11:45	**M. Roth**, Kinetic modeling of discrete auroral arcs
11:45 – 12:30	**G.T. Marklund**, Auroral investigations by sounding rockets and satellites below, within, and above the auroral acceleration region
12:30 – 14:30	Lunch Break
14:30 – 16:00	**Focus group Aurora**
14:10 – 14:40	**J. Vogt**, Introduction
14:40 – 15:10	**O. Marghitu**, Auroral Electrodynamics on Arc and Oval Scales
15:10 – 15:40	**O. Marghitu**, Investigation of Energy Conversion and Transfer in the Auroral Magnetosphere by Multi-Point Observations
16:00 – 16:30	Coffee Break
14:30 – 16:00	**Focus group Techniques**
16:30 – 16:40	**S. Haaland**, Introduction
16:40 – 17:10	**S. Haaland**, Discontinuity Analysis with Cluster
17:10 – 17:40	**A. Blăgău**, Timing technique for determining the crossing parameters of a 2D, non-planar magnetopause
17:40 – 18:10	**D. Constantinescu**, Extreme Conditions for Wave Detection with Sensor Arrays
14:30 – 16:00	**Focus group Modeling**
14:30 – 15:00	**R. W. Schunk** (presented by **A.R. Barakat**), Generalized Transport Equations and Distribution Functions for Space Plasmas
15:00 – 15:30	**Ø. Lie-Svendsen**, Using kinetic theory to improve fluid equations for fully ionized gases
15:30 – 16:00	**S.W.Y. Tam**, Self-Consistent Hybrid Model: Applications to the Polar and Solar Winds
16:00 – 16:30	Coffee Break
16:30 – 17:00	**N.R. Minkova**, Paired velocity distributions in the solar wind (TBC)
17:00 – 17:30	**M.M. Echim**, Decoupling of a diamagnetic plasma blob from background magnetic field and plasma
17:30 – 18:00	**J. Lemaire** and **M. Echim**, Conclusions
19:30 – 21:00	Dinner

Saturday, June 16

09:00 – 10:30	Closing Session
10:30 – 11:00	Coffee
12:00	Departure

Abstracts

Wednesday, June 13

Solar-Terrestrial Relations: An Overview

B. Klecker

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The term 'Solar-Terrestrial Relations' encompasses the wide field of the effects of solar activity on the Earth, its atmosphere, ionosphere, and magnetosphere. The activity of the Sun includes besides the electromagnetic radiation the solar wind and eruptive phenomena as solar flares and coronal mass ejections (CMEs). The Sun interacts with the near Earth environment in many ways and on many time scales: the solar wind and its embedded magnetic field determine the large-scale structure of the magnetosphere, the plasma clouds of CMEs colliding with high speeds of up to 2000 km/s with the magnetosphere can produce magnetic storms, and a possible influence on weather and climate is also discussed. Furthermore, high energy particles accelerated in the magnetosphere of Earth, in coronal and interplanetary shocks, and in solar flares provide fundamental information on acceleration processes in astrophysical plasmas. These energetic particles are also of increasing interest because they can produce radiation damage in space borne technical systems for communication and navigation, or in biological systems. Presently, solar-terrestrial relations are studied internationally with a large number of research satellites, since early 2007 also with STEREO (Solar Terrestrial Relations Observatory), a mission that will provide for the first time stereoscopic pictures of the Sun and 3D- reconstructions of CMEs, using two spacecraft with identical instrumentation in a heliocentric orbit. In this presentation an overview of Solar-Terrestrial Relations, currently active missions and future perspectives will be provided.

Paleomagnetospheric processes

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On geological time scales, variations of the internal geomagnetic field affect the structure and the dynamics of the Earth's magnetosphere and contribute to what may be called space climate and paleomagnetospheric processes. This presentation is going to summarize the paleomagnetosperic research that was carried out in the context of the DFG Priority Programme SPP 1097 Geomagnetic Variations. We have studied structural aspects of paleomagnetospheres using theoretical concepts of magnetosphere formation, a potential field approach to model magnetopause shielding, and magnetohydrodynamic simulations. The types of geomagnetic variations considered here include changes of the dipole moment magnitude and excursions of the dipole axis. Quadrupolar paleomagnetospheres serve as important examples to assess the rich variety of non-dipolar configurations. Energetic particles in the paleomagnetosphere were studied by means of scaling relations for cutoff energies and differential particle fluxes as functions of a reduced dipole moment. We further quantified how higher- order core fields can open the polar caps and even create new particle entry regions in the equatorial region.

Hybrid and full particle electromagnetic simulations of collisonless shocks as applied to the Earth's bow shock

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The supersonic motion of a fluid around a blunt object leads to the formation of a shock wave standing in front of the object. In space the best known and widely studied example of such a shock wave is the Earth's bow shock in front of the magnetosphere. However, in interplanetary space the simple description of a shock wave is no longer valid: the medium is an ionized gas with several constituents, ions and electrons, and electromagnetic fields. Secondly, the mean free path for collisions between ions and electrons is so large that the medium can be considered collisionless. Using hydromagnetic theory it has been recognized very early that above some critical Mach number (flow speed in units of magnetosonic speed) resistivity alone is not sufficient any more in order to produce the necessary dissipation in the bow shock. Part of the incoming ions are reflected; these reflected ions provide an important portion of the dissipation required to satisfy the Rankine-Hugoniot conservation laws at the shock. As these ions propagate upstream they can excite hydromagnetic waves by ion/ion beam instabilities which in turn scatter the ions back to the shock. This eventually leads to the phenomenon that part of the solar wind ions are accelerated to high energies. Collisionless shocks have been studied by numerical simulations for more than 3 decades. These simulations employ either the hybrid formalism, where the ions are treated as particles and the electrons are a massless fluid, or the particle-in-cell (PIC) method which inludes both ion and electron kinetic effects. We will discuss the advantages and limitations of both of these approaches and will compare results from simulations with recent in situ bow shock measurements.

Cluster observations of high-beta plasma blobs in the magnetosheath

T. Karlsson, N. Brenning

Space and Plasma Physics, School of Electrical Engineering, KTH, Stockholm, Sweden

We use Cluster multi-point measurements to identify localized plasma blobs with a higher density than the background plasma. Several criteria are used to discriminate between blobs convecting together with the plasma flow from signatures associated with motion of the magnetopause or bow shock. Having identified such plasma blobs, we determine their geometry along and perpendicular to the plasma flow. The dynamic beta value (the ratio of the kinetic and magnetic energy densities) and ratio of the scale size perpendicular to the flow to the ion gyro radius are critical parameters for determining the penetrations of such blobs into the magnetosphere during impulsive penetration events. Determination of these parameters enables a comparison with theoretical and laboratory results, showing if typical plasma blobs can penetrate into the magnetosphere, and what type of penetration mechanism will be likely.

Ion properties at Earth's foreshock: recent achievements

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(4) Space & Atmospheric Physics Group, Imperial College, London, UK

Different types of backstreaming ion distributions have been reported in the ion foreshock: field-aligned beams (FABs), gyrating ions and diffuse ions distributions. Contrary to the first type, the two others are always associated with low frequency (ULF) waves. Multi-spacecraft observations by Cluster and the high quality 3-dimensional data obtained by Cluster/CIS has permitted to address specific quantitative questions that could not be resolved previously. Gyrating ions with well-defined pitch-angle and gyrophase organization around the local magnetic field have been frequently observed in association with large amplitude quasi-monochromatic waves. These waves reveal the existence of coherent wave-particle interaction which is an efficient process to dissipate the energy of the particles reflected at the collisionless bow shock. It has been shown recently from a Cluster data set that the gyrophase-bunched ion distributions are mainly produced by such a process from cyclotron-resonant FABs observed just at the edge of both the gyrating ions region and the boundary of ULF waves. New results have also been obtained on the FABs and gyrating ions exhibiting sometimes a high-energy tail likely produced by a local process at the shock which may be micro-turbulence. It has been found that the characteristics of both parallel and perpendicular particle distribution function profiles of field-aligned beams (FABs) are geometry- dependent. Other recent results deal with the properties of ion distributions associated with ULF waves with left-hand polarisation the existence of which has been definitively and unambiguously proven from the four-spacecraft analysis by Cluster. These recent achievements in the properties of ion distributions in the terrestrial ion foreshock will be discussed in the light of theoretical works and recent numerical simulations.

Cluster survey of the mid-altitude cusp

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We have performed a statistical study based on four times three months of Cluster data taken in the dayside magnetosphere, representing 120 orbits. Out of 960 possible cusp crossings only 261 passes were actually identified as cusp crossings according to our criteria. From those crossings and from the 3D capability of the Cluster mission, we have had access to a wealth of information on the dynamics of the cusp, its morphologies and its particle content. For the first time, the multipoint capability of Cluster has allowed us to study in situ the response of the cusp to changes in interplanetary magnetic field (IMF) orientations: the time required for the cusp width to fully adjust is larger than 20 minutes and the motion of the cusp triggered by the rotation of the IMF has a velocity proportional to the variation in Bz: Vcusp = 0.024 Bz, the cusp velocity being in °/min and ΔBz in nT. Regarding the morphology, the occurrence of nicely dispersed ion structures in the cusp is 34%. Not less than 56% of the cusp crossings fall in our "discontinuous" or "irregular" categories. A few cases of discontinuous cusps occurring under stable IMF conditions have been spotted. They all occur when the IMF is dominated by its East-West component, which is expected for both anti-parallel and component reconnection hypotheses but their wide in local time and latitudinal distributions is a priori not compatible with the anti-parallel reconnection hypothesis solely. We have compared the ion densities in the solar wind and in the cusp (right-

hand side figure). It appears that the normalized density in the cusp, η, is around 3 on average. The average density in the cusp is found to be higher under northward IMF while the normalized density is smaller for northward IMF than for southward IMF, suggesting that the efficiency of reconnection is greater under southward IMF.

The evolution of intermittency in the magnetosheath turbulence downstream of a quasi-parallel bow shock

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(2) Swedish Institute of Space Physics, Uppsala, Sweden
(3) Space Research Institute, Graz, Austria
(4) Institute of Atmospheric Physics, Prague, Czech Republic

We study the turbulence downstream of a quasi-parallel bow shock using Cluster multi-spacecraft measurements. We show that turbulence is intermittent and well described by the extended intermittency model, which takes into account the spatial inhomogeneity of the cascade rate. For the first time we use multi-spacecraft observations to characterize the evolution of turbulence, particularly its intermittency, as a function of distance from the bow shock. The intermittency significantly changes over the distance of the order of 100 ion inertial lengths. We speculate on the role reconnection plays in the development of the magnetosheath turbulence.

Plasmoid penetration across a magnetic barrier: scaling from laboratory experiments to impulsive penetration into the Earth's magnetosphere

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Diagnostics, experimental results, and simulations are presented on anomalous electron transport in a laboratory experiment where a plasma blob is shot at and penetrates across a magnetic barrier, into a region where the magnetic field is transverse to the plasma flow direction. Tailor-made diagnostics show that the transport is due to correlated wave structures in the lower hybrid frequency range, driven by a strong diamagnetic current loop that arises around the edge of the plasma blob when it begins to penetrate into the magnetic barrier. The transport mechanism is driven at such a speed that the density fluctuations associated with the transport are approaching 100%, and the wave electric field reaches several kV/m. The resulting transport rate is two orders of magnitude faster than classical, and also far exceeds Bohm diffusion. Macroscopically, the mechanism for penetration is identified as a mixture between self-polarization and magnetic expulsion, where one or the other can dominate depending on the normalized plasma blob parameters: width, speed, and density. A generalization is made from the laboratory results to the proposed impulsive penetration of plasma blobs from the solar wind into the the Earth's magnetosphere. Based on a scaling from the laboratory, parameters of interest (the width, speed, and density of such blobs) in the solar wind and magnetosheath are identified.

The role of centrifugal acceleration near the magnetopause boundary

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The role of the centrifugal acceleration mechanism for ion outflow at high altitude above the polar cap has been investigated. Magnetometer data from the four Cluster spacecraft has been used to obtain an estimate of magnetic field gradients. This is combined with ion moment data of the convection drift and the field-aligned particle velocity. Thus all spatial terms in the expression for the centrifugal acceleration are directly obtained from observations. The temporal variation of the unit vector of the magnetic field is estimated by predicting consecutive measurement- points through the use of observed estimates of the magnetic field gradients, and subtract this from the consecutively observed value. The calculation has been performed for observations of outflowing O^+ beams in January to May for the years 2001-2003. The statistical result is compared to the immediate variation of observed parallel velocities of H+ and O+ ions, and the accumulated acceleration during each orbit is compared with the observed parallel velocities. Finally the observed spatial terms (parallel and perpendicular) of the centrifugal acceleration are compared with the results obtained when the magnetic field data was taken from the Tsyganenko T89 model instead. It is found that the centrifugal acceleration mechanism is significant, but cannot explain all of the observed parallel velocities observed at high altitude above the polar cap, consistent with previous reports based on the same data set. The magnetic field model results underestimate the centrifugal acceleration at the highest altitudes investigated and show some systematic differences as compared to the observations in the lower altitude ranges investigated. It is also suggested that the centrifugal acceleration and associated inertial drift can play a role in forming overlapping cusp injections. The strongest centrifugal acceleration is observed close to the magnetopause, and we bring up to discussion the importance of this acceleration mechanism in relation to boundary layer phenomena.

Exospheric models of the solar wind

H. Lamy , V. Pierrard, J. Lemaire

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Kinetic exospheric models of the solar wind are presented, providing an alternative to the fluid derivation given in most space physics textbooks. This talk will briefly recall the basic ideas behind the exospheric picture and emphasize the role of the electrostatic field in the acceleration of the solar wind. The effects of the non-thermal distributions of electrons observed in the solar wind are also described. We show that current exospheric models are able to reproduce the strong acceleration of the fast solar wind emanating from the coronal holes of the Sun. Limitations and further possible developments will also be discussed.

Multiparticle statistical approach to solar wind modeling

N.R. Minkova

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The two-particle kinetic models [1,2] reproduce the observed acceleration of the in-ecliptic solar wind. At the same time one-particle kinetic models do not provide such acceleration (under the same assumptions: Maxwellian distribution at the exobase, quasineutral currentless plasma flow, etc.). These two models are compared in the frame of the multiparticle statistical approach [3].

The analysis is developed by considering a plasma flow as a system of particles governed by Liouville theorem and assuming that particles coordinates are indistinguishable within instrumental resolution scales. Hence the plasma parameters are defined as statistical moments on the base of multiparticle probability functions. The corresponding relations for density, flux and speed of k-component plasma are derived. In the case of two-component plasma these relations coincide with corresponding results of the two-particle kinetic model [1]. Therefore we can conclude that this model describes plasma also by consideration of instrumental resolution scales.

In contrast, the classical statistical physics operates with distinguishable coordinates of particles. Hence resolution scales of measurements are not taken in account and correspondingly plasma parameters are calculated on the base of one-particle probability functions. Thus the difference between one- and two-particle (multiparticle) models originates from different view of measured macroscopic parameters.

The consistency of theoretical results of the two-particle kinetic model with observational data [1] serves as an argument in favor of multipartical statistical approach [3] and corresponding assumption about indistinguishability of particles coordinates within instrumental resolution scales.

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3.Minkova N.R. Multiparticle statistical approach to the collisionless solar plasma modeling. // Izvestija vuzof. Physics (Russian Physics Journal).-2004. V.47, No.10 (Special issue on Applied problems of mechanics of continua). P. 73-80.

Difficulty of Adding Coulomb Collisions in Monte Carlo Simulations

A.R. Barakat, R.W. Schunk

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In space plasma models, the ion-ion and the electron-ion collisions correspond to Coulomb law. The Coulomb collision model is dominated by the small-angle binary scattering, and therefore, each large-angle scattering consists of a huge number (many millions) of small-angle collisions. In a typical Monte Carlo simulation, many millions of large-angle scatterings are performed. Therefore, a MC simulation that follows the individual binary collisions would not be feasible because it would require performing many trillions of small-angle collisions. Several approaches are suggested in order to overcome this problem. For example, the effects of binary collisions are simulated by diffusion and drag in the velocity space, which in effect lumps many thousands of binary collision in one random process. In another approach, simulation particles are followed as they perform macro-collisions that emulate the effect of collisions during a relatively short time interval. In this presentation, we discuss several difficulties that are associated with applying MC techniques to space plasma problems with Coulomb collisions especially in the collision- dominated regions. Different approaches are presented that help improve the efficiency and accuracy of the simulation models.

Monte-Carlo simulations of space plasma outflow

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The Monte Carlo techniques are used in order to simulate random processes. These simulations use 'pseudo-random' number sequences. Since the MC techniques tend to be computationally intensive, they became more important as computer resources became cheaper and more available. The MC techniques were introduced into space physics since the early 1950's in order to emulate the effects of collisional processes and (later) wave- particle interactions. Here, we present a brief summary of the different applications of the MC technique in the field of space physics. For instance, we consider different problem dimensionality (homogeneous, 1- D, etc.), different collision models (Coulomb, hard sphere, Maxwell molecule, etc.), and different physical problems (solar wind, polar wind, auroral plasma, etc.). The MC technique enjoys several advantages such as: (1) It is valid in the collisionless and the collisional regions as well as within the transition region between them; (2) It is valid for subsonic, transonic, and supersonic flows; (3) The algorithm is simple and the corresponding code could be easily maintained; and (4) It is very robust (e.g. it does not suffer from numerical instabilities). On the other hand, it suffers form some limitations such as: (1) The computationally intensive nature of this technique limits it applicability in the case global models; (2) The inherent residual statistical error limits the precision of the results to few significant digits, and (3) The statistical error can vary widely between the different regions of the simulation domain. We also discuss some methods that could be used to improve the efficiency, and some potential pitfalls that could arise while utilizing the MC techniques.

Fokker-Planck modeling of the solar and polar wind flow

V. Pierrard

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Kinetic models based on the solution of the Fokker-Planck equation have been developed at IASB-BIRA to simulate the solar wind and the planetary polar wind. These models take into account the effects of Coulomb collisions and are adapted to study the wind at any collisional regimes. They are especially useful to study the transformation of the velocity distribution function in the transition region between the collision dominated regions at low altitudes and the collisionless region at large radial distances. The assumptions, methods and results obtained with these collisional kinetic models will be presented, as well as their major differences with exospheric and MHD models.

Application of multi-moment transport equations to space plasmas simulation

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Space plasmas are complex systems with numerous kind of transitions: chemistry/diffusion, collisional/collisionless, subsonic/supersonic, heavy ions/light ions. Moreover, space plasmas interact with electric and magnetic fields, so that the charged particles are affected by the fields while in return they contribute to the magneto/electro-dynamics. There are different ways of tackling the problem of modeling the dynamics of such complex systems, based on the duality fluid/kinetic in the description of the plasma populations: either purely fluid, purely kinetic or hybrid. Among these solutions, an efficient one is given by the multi-moment multi- species approach. This approach is based on a mathematical description that allows using it for describing space plasmas in wide range of regimes, and provides straightforward expressions for couplings with magneto/electro- dynamics or with neutral atmosphere. We will present the application of this approach to model space plasmas in different environments, and we will discuss how, depending on the situation, the different terms contribute to the transport equations, and thus what in the end controls or dominates the dynamics of the plasma. From that, we will show that the approach has inherent limitations and states can be reached where the system of transport equations is no longer hyperbolic and becomes unstable. We will then discuss the loss of hyperbolicity in term 'kinetic behaviour' of the populations and eventually how this may be used to couple such an approach to kinetic models.

Thursday, June 14

The mid-altitude polar cusp as seen by Cluster

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The polar cusp, together with the magnetopause, are the magnetospheric regions in direct contact with the shocked solar wind flowing continuously from the Sun. Therefore any changes in the solar wind plasma induce changes in the polar cusp with a delay of a few minutes to a few tens of minutes. For instance a change of the interplanetary magnetic field (IMF) direction from South to North will displace the polar cusp poleward and at the same time will change the injection of ions from the subsolar magnetopause to the magnetotail lobes. In the mid and low-altitude cusp a spacecraft will then observe a reversal of the dispersion in energy of the ions. We will use Cluster string of pearl configuration in the mid-altitude polar cusp to investigate the temporal variations of ion injections in the polar cusp. In the period from July to September, the Cluster spacecraft follow each other in the mid-altitude cusp with a delay of few minutes up to one hour. A few examples of cusp crossings will be presented to illustrate the influence of solar wind changes in the polar cusp. We will show that a sudden change in the IMF direction from South to North produces a double cusp crossing. By opposition, a change of the IMF from North to South produces a temporal injection on the equatorward side of the cusp and an erosion of the magnetosphere. Finally, we will show that when the interplanetary conditions are stable with the IMF pointing Northward for more than 45 min, the polar cusp ion dispersion stays constant. MHD model runs as well as DMSP spacecraft and ground-based measurements will also be used to complement the Cluster data.

Plasma sheet observations relevant to THEMIS mission

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One of the main purposes of the THEMIS mission is to time substorms. An array of five identical spacecraft equipped with identical instrumentation is slated to determine substorm onset locations. THEMIS will cover a large region of the plasma sheet and have the capability to adopt several separation strategies. The goal of THEMIS is to answer questions about where substorms are initiated. This talk will review what we have already learned from Cluster and Geotail observations and discuss how they are relevant to THEMIS.

Kinetic modeling of discrete auroral arcs

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We show that a magnetospheric DC generator (or electromotive EMF source) is appropriate to quasi-stable discrete auroral arcs. The DC generator results from the potential distribution in a magnetospheric plasma interface of tangential discontinuity type with sheared flows forming a structure embedded in a large-scale convergent perpendicular electric field. We first address the distribution of the potential in the magnetospheric generator. The coupling with the topside ionosphere is made by solving the current continuity equation to obtain the distribution of the ionospheric potential. The contribution of magnetospheric electrons and ionospheric electrons and ions is taken into account into the current- voltage relationship derived for an electric potential monotonically decreasing with the altitude. The model shows that a sheared flow formed between a fast moving plasma and the background plasma at the dusk sector of the LLBL generates current sheets corresponding to upward field-aligned currents, field-aligned potential drops and narrow bands of precipitating energy, as in discrete auroral arcs. When the height-integrated Pedersen conductivity is assumed uniform and constant the following results are obtained: 1) the arc tends to be brighter and wider when the convection in the LLBL is faster; 2) the arc tends to become thinner and more intense when the density of the LLBL plasma increases (and the LLBL velocity remains unchanged); 3) the arc keeps the same luminosity but expands in width when the LLBL electron temperature increases while the LLBL density and velocity remain unchanged; 4) the region where the energy precipitation reaches significant values corresponds to discrete auroral arcs of the order of 1-10 km in latitudinal extent. When the height-integrated Pedersen conductivity is enhanced by the flux of precipitating electrons, we have found that, as a result of the ionospheric feedback, 1) the obtained structures are significantly narrower, on the order of 1 km a thickness never simulated before 2) the peak of the electron energy precipitation and of the field-aligned potential drop (defined as the difference between the ionospheric potential and the magnetospheric potential) decreases; 3) the field-aligned potential drop can reverse sign to become negative in certain portions of the arc that could be associated with return current regions; 4) the flux of precipitating energy and the field-aligned current density take values significantly closer to the values observed experimentally.

Auroral investigations by sounding rockets and satellites below,within, and above the auroral acceleration region.

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Auroral particle acceleration by quasi-static and wave electric fields in the magnetosphere-ionosphere transition region, produces a wealth of phenomena, such as discrete aurora, plasma outflow, wave emissions, and ionospheric modifications. During activity, quasi-static acceleration by an upward parallel electric field takes place at altitudes between 5000 km and 13000 km. A downward parallel electric field, producing upward energetic electron beams, typically forms at altitudes between 1000 km and 4000 km in the auroral return current region. The acceleration structures form natural divisions between high-altitude and low-altitude signatures of the aurora, as will be illustrated by results from sounding rockets and from satellites, including Astrid-2, Freja, Viking, at various altitudes below, through and above the acceleration regions. The main emphasis will be on Cluster results from altitudes well above the acceleration regions. The degree by which high-altitude electric field and potential structures couple to the ionosphere will be addressed. For the quasistatic aurora, this can be estimated by comparing the characteristic energy of upward ion beams, which provides an estimate of the parallel potential drop, with the perpendicular (to B) potential across the structure. This ratio, k, which normally is less than or equal to one, reveals whether the potential couple completely (k=0), is isolated from (k=1), or, which is most common case, partly extends $(0 < k < 1)$ to the ionosphere. For the downward current region, a similar comparison can be made, between the characteristic energy of upward electron beams and the perpendicular (to B) potential. Preliminary results are presented from a selection of intense Cluster electric field events, and compared to results from related studies on the coupling issue.

Auroral Electrodynamics on Arc and Oval Scales

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The auroral arc and the auroral oval are low altitude fingerprints of the magnetosphere iono-sphere (MI) coupling. Although the typical spatial scales of the arc and oval differ by 12 orders of magnitude, the respective standard models share a number of common features:

- azimuthal homogeneity;
- connection to the magnetosphere through a pair of upward / downward field-aligned
- current (FAC) sheets;
- meridional closure of the FACs through ionospheric Pedersen current;
- divergence free Hall electrojet in azimuthal direction.

These features reflect an ideal configuration, and in principle it is easy to agree that the real arc and oval deviate from it. In practice, the symmetry of the ideal configuration is both attractive and convenient, so that the deviations are quite often neglected.

The amount and accuracy of the experimental data nowadays, together with a wide variety of numerical tools, offer the means to check the real arc and oval more thoroughly, and try to answer questions like:

- What methods / techniques do we have to check the real configuration? On what spatial / temporal scales can we use them?
- When / where does the ideal configuration fit the arc / oval? When / where should we expect significant deviations?

- Are the deviations related to the location of the arc within the oval, and to the relative positions of the FAC, precipitation, and convection boundaries?
- How substantial and how typical are the deviations from the ideal configuration? Should we be concerned about them at all?
- Are there significant implications for understanding magnetospheric dynamics and for the MI coupling models?

Investigation of Energy Conversion and Transfer in theAuroral Magnetosphere by Multi-Point Observations

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A comprehensive network of satellites and ground observatories allows nowadays a close investigation of the energy flow in the auroral magnetosphere:

- Satellite formations like Cluster, or the upcoming MMS and (hopefully) Cross-Scale, provide both estimates of the spatial and temporal derivatives of the physical fields, and the increased redundancy needed when the fields are weak. This enables the local examination of the power density, and thus of the energy conversion between its basic mechanical and electromagnetic forms. It also enables the evaluation of the quantities relevant for the local energy transfer bulk flow energy flux, heat flux, and Poynting flux together with their derivatives.
- Conjugate observations between high and low altitude / ground platforms can offer a global view over the energy transfer. In-situ measurements by e.g. Cluster, FAST, Polar, Geotail, Double Star, as well as optical and radar data, have been used to relate energy conversion and transfer between different regions of the magnetosphere, or between the magnetosphere and ionosphere. A systematic effort in this direction is now ongoing through the THEMIS mission.

A wide variety of simulation and modelling tools complement the observations on both local and global scale.

Given the preliminaries above, it may be worthwhile to address the energy conversion and transfer systematically, as a goal in itself. A number of possible questions (biased towards energy conversion) are listed below.

- Are the energy conversion regions rather structured or rather flat?
- Where is the energy conversion located? More in the plasma volume or near / within boundary layers? Like PSBL? LLBL? Neutral sheet?
- What influences the magnitude of the energy conversion? Plasma beta? Other parameters?
- What is the lifetime of the energy conversion regions? Should stable auroral arcs necessarily be associated with steady generators?
- How important are the parallel electric fields for energy conversion? Are they often important, or most of the time the Lorentz force is enough?
- Energy conversion is quite often associated with bulk flow. What are the implications for load versus generator regions?
- Loads are sometimes observed together with temperature anisotropy, with $T_{||} > T_{\perp}$. Is this related to faster thermalization of the plasma in parallel direction?
- Is it possible to identify / quantify irreversible processes associated with energy conversion? Could entropy calculation help in this respect?

- How well can we check the coupling to aurora of magnetospheric generator regions? What about the coupling of load regions?
- What are the dominant energy transfer vehicles in the magnetospheric regions coupled to aurora? How do they depend on the substorm cycle?
- Is it possible to extend (some of) the Cluster techniques to other missions, starting with the three THEMIS satellites in the current disruption region?

Discontinuity Analysis with Cluster

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We present an overview of Cluster's ability to determine the orientation, motion and thickness of boundary layers, and try to identify where and when a particular method is more suitable than another. With Cluster, three different principles can be used for discontinuity analysis; four-spacecraft timing methods, four-spacecraft gradient methods and single-spacecraft residue methods based on conservation laws. Timing methods make use of (and require) data from all four Cluster satellites. Boundary layer orientation, motion and thickness are determined from time differences between the crossings by the four spacecraft and the crossing duration. Variations of the timing methods can be used to take into account non-uniform thickness or non-constant motion of boundaries. Cluster's ability to determine gradients can also be used for discontinuity analysis. The orientation of a discontinuity can in some cases be obtained by examining the gradient of the field or plasma data directly. Alternatively, the gradient operator can be used to determine the electric current via Amperes law, or the time variation of the magnetic field via Faradays law of induction. Variance analysis of these quantities thereafter give the orientation and integration across the discontinuity can be used to determine the velocity and thickness of the layer. Discontinuity analysis methods based on conservation laws and residue analysis may utilize data from one or more of the Cluster satellites, and can be combined with multi-spacecraft methods to improve these or for consistency checks. Constraints, for example by requiring the magnetic field to be tangential to the discontinuity or by requiring zero plasma flow respectively Alfvenic plasma flow across the discontinuity, can be used to improve the stability of the results.

Timing technique for determining the crossing parameters of a 2D, non-planarmagnetopause

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For a multi-point mission like Cluster, the differences in position and time when each satellite detects a discontinuity like the magnetopause (MP) can be used to infer its orientation, thickness and velocity. This so-called timing technique, which assumes a planar MP, proves reliable and offers an independent check for various single-spacecraft techniques like minimum variance

analysis of the magnetic field (MVAB), minimum Faraday residue (MFR) and deHoffmann-Teller (HT) analysis.

We extended the timing method in order to accommodate situations when the MP behaves like a two-dimensional, non-planar discontinuity. This is the case, for example, when the MVAB method provides different individual MP normals, all of them con- tained approximately in the same plane. Such a configuration can be produced by a local bulge/indentation in the MP or by a large amplitude traveling wave on this surface. We illustrate our technique with a test case and compare the results with those provided by the single-spacecraft techniques of MVAB, MFR and HT analysis.

Extreme Conditions for Wave Detection with Sensor Arrays

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There are a number of multi-spacecraft missions already in operation or in planing phase, as well as ground arrays which study wave and wave-like phenomena. The multi-sensor techniques presently in use are based on several assumptions related to the measurement conditions. We propose a discussion to explore the limits of these assumptions. Since the wave telescope / k-filtering technique is representative, we will use it as a test bed. In particular we will focus on the following aspects:

1. Sensor configuration and number. It is generally assumed that we have access to at least four sensors in a three-dimensional (tetrahedral) configuration.

- What happens if the sensors are arranged in a plane (THEMIS ground array) or in a string (THEMIS spacecraft) configuration? - How can we use mixed configurations? An example is Cross Scale which consists of overlapping sensor arrays at different scales. Can we couple them? - How important is the number of sensors in the array?

2. Wave front curvature. Many techniques use a plane waves representation.

- What is the effect of the deviation from planarity? - Can we extract useful information from the wave front curvature? - What happens when the curvature becomes very large? - What happens when waves of comparable power but different curvatures are detected at the same time?

3. Maximum number of waves

- How many waves can we simultaneously detect? - How is this related with the number of sensors?

4. Wave length domain

- What is the minimum and the maximum wave length we can measure? - How does this depend on the wave propagation direction? - How do we treat the special case of mixed configurations (Cross Scale)?

5. Coherency

- What happens when two or more coherent waves are present in the wave field?

Generalized Transport Equations and Distribution Functions for Space Plasmas

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Highly non-equilibrium flow conditions exist in space plasmas, including the solar atmosphere, the solar and polar winds, planetary magnetospheres and ionospheres, and near the termination shock. These highly non- equilibrium flows are typically characterized by Mach numbers greater than one, temperature anisotropies, strong heat flows, long mean-free-paths, and non-Maxwellian velocity distributions. Fortunately, several mathematical approaches have been developed that can be used to describe such flows, including the generalized transport equation approach. With this technique, the species velocity distribution function is expanded in an orthogonal series about a weight factor, the series is truncated, and then the associated set of transport equations is derived. Currently, sets of transport equations exist for Maxwellian and bi-Maxwellian weight factors. For the Maxwellian there 5-, 13-, and 20-moment approximations, while for the bi-Maxwellian there are 6- and 16-moment approximations. The Maxwellian- based 13-moment transport equations are particularly useful because they properly describe processes such as ordinary diffusion, thermal diffusion, thermal conduction, and diffusion-thermal heat flow. However, these processes dominate when collisions are important, and it is less clear what set of transport equations to use when the flow becomes collisionless and the distribution function becomes highly non-Maxwellian. Here, we discuss the convergence of the different sets of transport equations for highly non- equilibrium flows and we compare results obtained from the collisionless transport equations with those obtained from kinetic formulations.

Using kinetic theory to improve fluid equations for fully ionized gases

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Generalized fluid equations are derived by making an assumption for the shape of the velocity distribution function (VDF) and then taking velocity moments of the Boltzmann equation. How well the assumed VDF agrees with the actual VDF determines the accuracy of the resulting moment equations. Based on direct solutions to the Boltzmann equation for a fully ionized gas in the collision-dominated limit, we have assumed a shape for the VDF that is a Maxwellian with a third-order correction term. The resulting isotropic fluid equations for plasmas of arbitrary composition improve the description of collisional processes, particularly heat conduction and thermal forces, while retaining the relative simplicity of "conventional" fluid equations, allowing for easy implementation in numerical models. Expanding about a bi-Maxwellian results in gyrotropic transport equations that provide a good description of both collision-dominated and collisionless flow. We present results for the solar wind, where the equations have been implemented and solved numerically in a model extending from the chromosphere to Earth.

Self-Consistent Hybrid Model: Applications to the Polar and Solar Winds

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We discuss a self-consistent hybrid modeling technique that combines kinetic and fluid calculations. The model is particularly suitable for describing plasma outflow phenomena. The kinetic calculations are in the form of Monte Carlo simulations, which follow the global evolution of the ion velocity distributions along the outflow while taking into consideration the influence due to physical mechanisms of microscopic scales. The fluid equations are used to describe the ambipolar electric field and the properties of the thermal electrons. In the case where there are non-thermal electron features, the evolution of the suprathermal electron velocity distribution is considered as well, based on a Monte Carlo simulation similar to those for the ions. The model utilizes an iterative scheme between the results of the fluid and kinetic calculations, generating self- consistent solution upon convergence. The self-consistent hybrid model has been applied to the ionospheric polar wind and the solar wind. For the polar wind, the model takes into account the global kinetic collisional effects of the photoelectrons and shows that these suprathermal electron effects may drive the polar outflow. For the solar wind, the kinetic effects due to the resonance between ion cyclotron waves and the protons and alpha particles are considered. The wave-particle interaction is found to lead to the preferential acceleration of the heavier ions and the formation of double-peaked proton velocity distributions, two of the features that have been frequently observed in the high- speed solar wind.

Paired velocity distributions in the solar wind

Y.M. Vasenin, N.R. Minkova

Tomsk State University, Russia

The solar wind models based on two-particle velocity distributions [1,2] discussed in the paper describe a plasma flow by joint probability that electrons and protons have velocities in a specified elementary interval of values. This approach is different from the classical ones that consider motion of electrons and protons separately by one-particle distributions. The development of two-particle kinetic models is initiated by observed large scale fluctuations of plasma density in the heliosphere. The sizes of fluctuations exceed significantly Debye length what allow us to consider collective behavior of charged particles.

The two-particle kinetic model [1] is presented in approximation of steady spherically symmetrical collisionless flow of quasineutral currentless plasma. The polarization potential is assumed to be monotonic and the influence of the Suns magnetic field is neglected. The Maxwellian distribution of plasma particles is prescribed at the exobase. The analysis of the model yields the domain of permitted values of polarization potential that provide stationary flows. The corresponding radial dependences of solar wind density and speed covers rather narrow domains of values and are consistent with the in-ecliptic observational data.

The two-particle model is presented also in the neutral approximation [2] that can be interpreted as the statistics of dynamic electron-proton pairs. This approximation excludes the consideration of polarization potential and produces upper estimations for plasma density and speed derived in the frame of the first model. The results of the neutral model are also consistent with observations.

Thus the two-particle kinetic approach reproduces the observed solar wind acceleration that is provided only by energy of thermal motion of particles of the equilibrium plasma at the exobase. This can be achieved in the frame of one-particle kinetic models only by including additional energy sources.

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Decoupling of a diamagnetic plasma blob from background magnetic field andplasma

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Laboratory and numerical experiments with plasmoids impulsively injected in transverse distributions of magnetic field show 'anomalous plasma transport'. The plasma blob is skidding in the direction perpendicular to the magnetic field over distances larger than the average ion Larmor radius and is not 'glued' to magnetic field lines. Similar behavior is observed in space plasma during active experiments or by insitu measurements in magnetospheric regions where the 'frozen-in' condition is violated. This type of transport cannot be described in the framework of the ideal MHD approximation, where the condition E.B=0 must be satisfied everywhere and the 'frozen-in' magnetic field lines are everywhere bent and compressed by the plasma flow. Starting from a 2D stationary kinetic model, I show that the boundaries of a diamagnetic plasma blob impulsively injected across magnetic field lines are the sites of a parallel electric field that disconnects the plasma from the background magnetic field. The strong shear of bulk velocity, $\Delta_{||}V_{\perp}$, driven in the direction parallel to the magnetic field by the excess momentum of the plasma blob, acts like a generator of parallel electric field inside the blob's boundary layers. The model is derived from first principles of classical physics and does not rely on anomalous processes postulated in fluid models. I discuss also the effectiveness of decoupling as a function of the blob's excess velocity, density, temperature and plasma beta.

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Currency

- 1 RON $\approx$ 3.25 Euro

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- 0724 955 218

Cable-car schedule

- Monday: closed for revision
- Tuesday – Friday: 08:30 – 16:00
- Weekend: 08:30 – 17:00