19^{th} Cluster Workshop

Poiana Braşov
May 18 – 21, 2010

Dear Guests,

Welcome to Poiana Braşov! It is a pleasure to see you at the 19th Cluster workshop, inteded as a forum for reviewing and discussing recent achievements in the physics of magnetosphere and ionosphere. We wish you a pleasant stay in Romania and hope you will enjoy the meeting.

Organizing Committee:

Adrian Blăgău (ISS), Costel Bunescu (ISS), Mircea Ciobanu (ISS/GSI), Horia Comişel (ISS), Dragoş Constantinescu (ISS/IGEP), Vlad Constantinescu (ISS), Marius Mihai Echim (ISS/IASB), Philippe Escoubet (ESA), Harri Laakso (ESA), Octav Marghitu (ISS), Arnaud Masson (ESA), Yasuhito Narita (IGEP), Matt Taylor (ESA), Gabriel Voitcu (ISS)

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Foreword

While the beautiful aurora in the arctic region has been attracting people for thousands of years, it was not until a few decades ago before people have realized that the aurora is a manifestation of the complex magnetosphere–ionosphere (M–I) coupling. Since its launch in 2000, the four Cluster satellites collected a rich data base of multi–point particle and field measurements, allowing for the first time a systematic separation of spatial from temporal variations in the magnetospheric plasma. Soon Cluster will celebrate 10 successful years in orbit with its invaluable data.

A couple of years ago Cluster started to probe key regions of the M–I coupling chain, namely the topside auroral acceleration region and the the near–Earth plasma sheet. Together with high altitude spacecraft, most notably THEMIS, low altitude satellites like REIMEI or DMSP, and a dense network of ground based observatories, Cluster provides at present an ideal platform for M–I coupling investigations.

The workshop concentrates on key magnetospheric regions in their interaction with the ionosphere: (1) the polar cap and the cusp, (2) the magnetotail and associated substorm phenomena, (3) the auroral acceleration region, (4) the inner magnetosphere. The recent achievements to be presented cover a broad range of topics, including field-aligned currents and Alfvén waves, acceleration and transport of energetic particles, auroral arc formation, ionospheric signatures of magnetic reconnection.

Program

Tuesday, May 18

13:30 – 14:00 Welcome

14:00 – 15:30 Oral session 1 – Polar cap / Cusp

14:00 **H. Nilsson**, Heavy ion energization, transport, and loss at Earth, Mars, and Venus (invited)
14:30 **S. Haaland**, Estimating the net plasma loss from ionospheric outflow
14:50 **M. André**, Cold plasma and magnetic reconnection at the magnetopause
15:10 **J. Zhang**, Observed variation in ionospheric outflow during the 11 October 2001 moderate storm

15:30 – 16:00 Coffee break

16:00 – 17:30 Oral session 1 – Polar cap / Cusp

16:00 **R. Maggiolo**, Polar cap arcs - FAC and ion outflow – Cluster results (invited)
16:30 **K.S. Jacobsen**, Quasistatic electric field structures and field-aligned currents in the polar cusp region
16:50 **L.M. Kistler**, The cusp outflow as a source of the plasma sheet during storm and non-storm times
17:10 **B. Walsh**, Investigating electron energization in the cusp

19:30 – 22:00 Reception

Wednesday, May 19

09:00 – 10:40 Oral session 2 – Tail / Substorm

09:00 **J. Shi**, Field-aligned currents in the magnetotail observed by Cluster (invited)
09:30 **A. Keiling**, Alfvén waves from the magnetotail to the low-altitude auroral region (invited)
10:00 **E. Grigorenko**, Different types of accelerated ion structures registered in the magnetotail PSBL: their spatial-temporal characteristics and auroral manifestations.
10:20 **T. Burinskaya**, Generation of low frequency oscillations

10:40 – 11:10 Coffee break

11:10 – 12:40 Oral session 2 – Tail / Substorm

11:10 **J. Vogt**, Models of magnetosphere-ionosphere interactions (invited)
11:40 **J.P. McFadden**, Putting together the pieces of the substorm puzzle (invited)
12:10 **G. Haerendel**, The growth phase arcs and substorm onset (invited)

12:40 – 14:00 Lunch

14:00 – 15:40 Oral session 2 – Tail / Substorm

14:00 **C. Forsyth**, BBF / plasma bubble coupling to the ionosphere (invited)
14:30 **O. Marghitu**, On the association between energy conversion regions and high speed flows in the plasma sheet
14:50 **L. Juusola**, Magnetotail reconnection and its signatures in the ionosphere (invited)
15:20 **K. Snekvik**, Reconnection Hall current system observed in the magnetotail and in the ionosphere

15:40 – 16:10 Coffee break

Wednesday, May 19 – Poster session

16:10 – 17:40

A. Blăgău, Timing method for determining the parameters of a 2-D, non-planar discontinuity
C. Bunescu, Cluster/ FAST investigation of two early morning aurora events
H. Comişel, On inferring reformation of the quasi-perpendicular bow shock by multi-Spacecraft data
D. Constantinescu, Low frequency waves in and around energy conversion regions in the plasma sheet
V. Constantinescu, Neural network identification of ECR events – preliminary results based on synthetic data
P. Dobreva, Investigating magnetosphere-ionosphere interactions using magnetosheath-magnetosphere numerical model
M. Echim, Kinetic properties of the interface between the solar wind and the magnetosphere of Venus and Earth: modeling and observations by Venus Express and Cluster
A. Fazakerley, Cosmic Vision M3: a Multi-Spacecraft AAR/MI-coupling mission?
C. Forsyth, Multi-spacecraft observations of auroral electron acceleration by Cluster
S. Grimald, Current density calculation deep inside the ring current, using the curlometer technique
M. Hayosh, Study of the auroral current-voltage relationship using Cluster electric field and particle data
A. Kis, Influence of the field aligned beam on the scattering of diffuse ions at the Earth's quasi-parallel bow shock
P. Kovacs, Study of turbulent phenomena in space plasma exhibiting strong wave activity: Investigation of Hot Flow Anomaly turbulence
O. Marghitu, Magnetosphere-ionosphere coupling in the Harang region
C. Munteanu, Space weather prediction accuracy: improved estimation of arrival times of solar wind phase fronts
Y. Narita, Anisotropy evolution of magnetic field fluctuation through the bow shock
H. Nilsson, Efficient ion heating at high altitude, wave and temperature characteristics
J.-L. Rauch, An interpretation of the wave propagation properties observed on WHISPER passive mode as an estimation of the electron density
G. Voitcu, Test-kinetic simulation of ion energy-dispersed structures and of non-gyrotropic distribution functions formed at the traversal of a plasma interface: two-dimensional solutions

Thursday, May 20

09:00 – 10:30 Oral session 3 – AAR / Topside ionosphere

09:00 **G. Marklund**, Aurora and black aurora viewed by Cluster (invited)
09:30 **M. Echim**, Advances in modeling and understanding in-situ observations and coupling of the magnetosphere and the auroral ionosphere during Cluster-DMSP conjunctions
09:50 **J. De Keyser**, Monopolar and bipolar auroral electric fields and their ionospheric signature
10:10 **I. Christopher**, First WBD results from the winter 2009/2010 auroral acceleration region campaign

10:30 – 11:00 Coffee break

11:00 – 12:20 Oral session 3 – AAR / Topside ionosphere

11:00 **S. Wing**, Field-aligned currents and particle precipitation (invited)
11:30 **T. Karlsson**, Investigation of temporal stability of field-aligned currents in the auroral oval
11:50 **J. De Keyser**, Multi-spacecraft gradient techniques: Applicability for studying magnetosphere-ionosphere coupling (invited)

13:00 – 17:30 Excursion to Postavarul Pub Kanzel and Barbeque

18:00 – 23:00 Visit to Braşov and Workshop Dinner

Friday, May 21

09:00 – 10:40 Oral session 4 – Inner magnetosphere

09:00 **I. Dandouras**, Inner magnetosphere science objectives: some previous achievements with Cluster and new targets for 2011 – 2012 (invited)

09:30 **H. Matsui**, Characteristics of storm-time electric fields in the inner magnetosphere

09:50 **M. Voiculescu**, Use of CLUSTER data in investigating the correspondence between different regions of inner magnetosphere and ionospheric phenomena

10:10 **J.-G. Trotignon**, Electron density measured in the Earth's space environment by the WHISPER relaxation sounder onboard CLUSTER (invited)

10:40 – 11:10 Coffee break

11:10 – 11:30 Closing remarks

Abstracts

Tuesday, May 18

Heavy ion energization, transport, and loss at Earth, Mars, and Venus

Hans Nilsson

Swedish Institute of Space Physics, Kiruna, Sweden

The magnetic field of the Earth acts like a shield against the solar wind, leading to a magnetopause position many planetary radii away from the planet, in contrast to the situation at non- or weakly magnetized planets such as Mars and Venus. Despite this there is significant ion outflow from the cusp and polar cap regions of the Earth's ionosphere. Effective interaction regions form, in particular in the ionospheric projection of the cusp, where ionospheric plasma flows up along the field-lines in response to magnetospheric energy input. Strong wave particle interaction at altitudes above the ionosphere further accelerates the particles so that gravity is overcome. For the particles to enter a direct escape path they must be accelerated along open magnetic field lines so that they cross the magnetopause or reach a distance beyond the return flow region in the tail. Else the Earth's magnetic field will guide the transport of the particles back towards the Earth. This return flow may either be lost to space or returned to the atmosphere. Throughout this transport chain the heating and acceleration experienced by the particles will have an influence on the final fate of the particles. We will present quantitative estimates of acceleration and heating along the escape path from the cusp, through the high altitude polar cap/mantle. Finally we will compare this with the situation at the unmagnetized planets Mars and Venus and discuss to what extent a magnetic field protects an atmosphere from loss through solar wind interaction.

Estimating the net plasma loss from ionospheric outflow

S. Haaland (1,2), E. Engwall (3), A. Eriksson (3), M. Förster (4), B. Lybekk (5), A. Pedersen (5), K. Svenes (6)

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(3) Swedish Institute of Space Physics , Uppsala, Sweden
(4) Helmholtz-Zentrum Potsdam, GFZ German Research Centre for Geoscienses, Germany
(5) University of Oslo, Norway
(6) Norwegian Defense Research Establishment, Norway

An important source of magnetospheric plasma is outflow from the terrestrial ionosphere. Low energy ions travel along the magnetic field lines and enter the magnetospheric lobes and are convected towards the tail plasma sheet. Recent results from Cluster indicate that the field aligned outflow velocitiy is sometimes much higher than the convection towards the central plasma sheet. A substantial amount of plasma therefore escape downtail without ever reaching the central plasma sheet.

In this work, we use a Cluster measurements of the ionospheric outflow and lobe convection velocities combined with models of the magnetic field and plasma composition in an attempt to quantify the plasma loss for various magnetospheric conditions. Preliminary results show that both the circulation of plasma but also the tailward escape of ions increase significantly during disturbed magnetospheric conditions.

Cold plasma and magnetic reconnection at the magnetopause

M. André [(1)], A. Vaivads [(1)], Y. Khotyaintsev [(1)], H. Nilsson [(2)], G. Stenberg [(2)], A. Fazakerley [(3)]

(1) Swedish Institute of Space Physics, Uppsala, Sweden
(2) Swedish Institute of Space Physics, Kiruna, Sweden
(3) MSSL, Dorking, UK

We report on detailed observations of magnetic reconnection and Flux Transfer Events at the magnetopause. We use observations from the four Cluster spacecraft at different simultaneous separations (about 35 km and 8000 km, i. e. the electron/ion and MHD scales, respectively).

We confirm previous observations of cold (eV) plasma in reconnection regions, now using a method based on detection of the wake electric field caused by cold ions streaming past a charged spacecraft. This method allows an estimate of the ion energy, and can reliably indicate changes at boundaries with high resolution. Multi-satellite observations are used to investigate the influence of the cold plasma on the reconnection process. We find that the electric field at the edges of a reconnection jet (in the separatrix region) depends on the mixture of hot and cold plasma. This electric field can cause a potential drop and accelerate the plasma.

Observed variation in ionospheric outflow during the 11 October 2001 moderate storm

J. Zhang [(1)], L. M. Kistler [(1)], C. G. Mouikis [(1)], H. Matsui [(1)], B. Klecker [(2)], I. Dandouras [(3)], M. W. Dunlop [(4)]

(1) Space Science Center, University of New Hampshire, USA
(2) Max-Planck-Institut für extraterrestrische Phsik, Germany
(3) CESR/CNRS, France
(4) Rutherford Appleton Laboratory, UK

The COmposition and DIstribution Function (CODIF) Analyzer on board the Cluster spacecraft frequently observes narrow-energy, field-aligned O+ over the polar caps and in the lobes, particularly during storm times. This population is due to ion outflow from the cusp. During the 11 October 2001 moderate storm, CODIF, located in the southern lobe, 18 RE down the tail, and moving inbound, observed a change in the outflow. A sudden increase in solar wind dynamic pressure at 17:02 led to a sudden increase in the energy of O+ from 200 eV to 4 keV, or a velocity increase from 50 to 220 km/s. This high-energy population gradually decreased in energy over the next 2.5 hours. The energy increase resulted from the effects of the shock on pre-existing outflow. To model the effects of the shock, we first determined how the magnetic field configuration changed, by comparing the local magnetic field before and after the shock with the predictions of the T04s empirical model. We found that the local magnetic field was well reproduced by T04s, and the field experienced a 1.6-RE perpendicular displacement and a 13.4-degree rotation in 13 minutes when the solar wind shock hit. We used local measurements of the magnetic and electric fields to calculate if the observed velocity increase was due to centrifugal acceleration. We found that centrifugal acceleration contributed only about 8%, i.e., 18 km/s, to the sudden parallel velocity increase. We conclude that the increase was actually due to the field displacement, which brought a higher velocity population to the Cluster location. A higher velocity is expected at higher latitudes due to the velocity filter effect that results from higher energy ions moving further along the field line than lower energy ions, as the field line convects over the polar cap and into the tail.

Polar cap arcs - FAC and ion outflow - Cluster results

R. Maggiolo [(1)], M. Echim [(1,2)], D. Fontaine [(3)], A. Teste [(4)], J. De Keyser [(1)], C. Jacquey [(5)], I. Dandouras [(5)]

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(2) Institute for Space Sciences, Bucharest, Romania
(3) Laboratoire de Physique des Plasmas, Velizy, France
(4) Space Sciences Laboratory, Berkeley, United States
(5) CESR, Université Paul Sabatier, Toulouse, France

During prolonged periods of northward IMF, successive current sheets with opposite polarity are detected by the Cluster spacecraft above the polar caps. At Cluster altitude (5-7 RE), the upward part of this current system consists of ion beams accelerated by quasi-static electric fields and with typical inverted-V structure. We review Cluster observations and focus on new results revealed by the statistical analysis of about 200 such polar cap ion beams. Their electrodynamical and statistical properties suggest that these events can be considered as the high-altitude image/signature of polar cap arcs.

One interesting feature of these ion beams is that 40% of them are detected together with hot isotropic ions located inside the magnetospheric lobes. Polar cap ion beams may thus provide insight on processes taking place in the more distant magnetosphere during prolonged periods of northward IMF.

We discuss these beams in the frame of magnetospheric lobes configuration during weak geomagnetic activity periods. We also present a quasi-static magnetosphere-ionosphere coupling model, developed for discrete auroral arcs in the main oval and adapted to describe the electrodynamics of the polar cap arcs and associated ion beams and field-aligned current sheets.

Quasistatic electric field structures and field-aligned currents in the polar cusp region

K. S. Jacobsen, J. I. Moen, A. Pedersen

University of Oslo, Norway

Cluster data have been examined for quasi-stationary electric field structures and field-aligned currents (FACs) in the vicinity of the dayside cusp region.

We have related the measurements to the Region 1/Region 2 (R1/R2) current system and the cusp current system. It has been theoretically proposed that the dayside R1 current may be located on open field lines, and experimental evidence has been brought for R1 currents partially on open field lines. We document that R1 currents may flow entirely on open field lines. The electric field structures are found to occur at plasma density gradients in the cusp. They are associated with strong FACs with current directions that are consistent with the cusp currents. This indicates that the electric field structures are generated by the cusp current system. The electric equipotential structures linking the perpendicular electric fields seen at Cluster altitudes to field-aligned electric fields at lower altitudes falls into one of two categories; S-shaped or U-shaped. Both types are found at both the equatorward edge of the cusp ion dispersion and at the equatorward edge of injection events within the cusp.

Previous studies in the nightside auroral region attributed the S-shaped potential structures to the boundary transition between the low density polar cap and the high density plasma sheet, concluding that the shape of the electric potential structure depends on whether the plasma populations on each side of the structure can support intense currents. This explanation is not applicable for the S-shaped structures observed in the dayside cusp region.

The cusp outflow as a source of the plasma sheet during storm and non-storm times

L.M. Kistler, J. Liao, C.G. Mouikis

University of New Hampshire, Durham, NH, USA

We have used the ion composition data from the CIS/CODIF instrument on Cluster to study ion transport from the cusp to the plasma sheet during storm and non-storm times. The Cluster trajectory, which moves over the polar cap, into the lobe, and then into the plasma sheet on each orbit, allows us to track the changes in O^+ in these regions during different levels of activity. During storms, we find that changes in the O^+ density and pressure in the plasma sheet are similar to those commonly observed in the ring current during a storm. The O^+ is low pre-storm. It increases by about a factor of 10 just prior to or during the early main phase of the storm, and is reduced, but usually not down to pre-storm levels, in the recovery phase. The lobes contain tailward streaming O^+ which originates in the cleft ion fountain. During the storm main phase, this population also increases. A detailed look at the main phase passes shows that a significant increase in the O^+/H^+ ratio is observed when this lobe population reaches the plasma sheet, and this population becomes incorporated into the plasma sheet, scattering and isotropizing as it crosses the neutral sheet. The inward convection of this population is likely a significant contributor to the storm time ring current. During non-storm times, the cusp outflow is still observed in the lobes about 13% of the time, and the non-storm times provide better statistics for determining the transport path. The path of the O^+ to the lobe depends strongly on IMF By. For positive By, the O^+ from the Northern cusp flows predominantly to the dawnside, while O^+ from the Southern cusp flows to the duskside. For negative IMF By, the transport is much more symmetric. A similar lack of mirror symmetry between positive and negative By has been observed in the convection patterns over the polar cap, and has been shown to result from day/night differences in ionospheric conductivity. Finally we find that the cusp outflow that reaches the ≈20 Re plasma sheet is significantly reduced during solar minimum, much more than the outflow itself is reduced, as observed over the cusp and polar cap. This indicates that during solar minimum, a greater fraction of the O^+ escapes down the tail, reducing the ionospheric contribution to the near-earth plasma sheet and ring current.

Investigating electron energization in the cusp

B.M. Walsh , T.A. Fritz , M.M. Kilda

Boston University, USA

The role of ion acceleration up to energies of hundreds of keV in the exterior cusp has been a topic of recent scientific discussion; however the energetic electron populations, also frequently present in the cusp, has received less attention. Properties of the electron population within the cusp are studied and compared with the expected characteristics of several proposed sources to weigh the role each plays in populating this region. The role of pitch angle scattering in the cusps turbulent magnetic field is also modeled to determine the significance of the observed pitch angle distributions. From the observations, it is likely that local acceleration is the primary source of the energetic electrons in the exterior cusp during the selected events that will be prevented.

Wednesday, May 19

Field-aligned currents in the magnetotail observed by Cluster

J. K. Shi (1), Z. W. Cheng (1), T. L. Zhang (2), M. Dunlop (3), Z. X. Liu (1), A. Fazakerley (4), E. Lucek (5), H. Réme (6), M. Taylor(7), I. Dandouras (6)

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(6) University of Toulouse, UPS, CESR, and CNRS, Toulouse, France
(7) European Space Technology Centre, Noordwijk, The Netherlands

We statistically investigated features of the FACs distribution in plasma sheet boundary layers between 17 and 19 RE in the magnetotail using the curlometer technique to calculate the current from 4-point magnetic field measurements taken in 2001. The results show that the FAC distribution in the plasma sheet boundary layers in the magnetotail has dusk-dawn asymmetry, Earthward-tailward asymmetry, and north-south asymmetry. The occurrence and polarities of FACs in the northern hemisphere are different from that in the southern hemisphere. The average density and the standard deviation of the FACs whose are most likely to be Earth connected are 4.90 nAm^{-2} and 2.55 nAm^{-2}, respectively, in the northern hemisphere, and are 4.21 nAm^{-2} and 1.80 nAm^{-2}, respectively, in the southern hemisphere. For investigating the mechanism of the north-south asymmetry, we mapped the FACs along the field line into the polar region. The footprints of the FACs also show a difference between the two hemispheres. These characteristics suggest a north-south asymmetry of the FACs in the magnetosphere. That the FACs densities are different between the hemispheres suggests that an important source of these currents must be a voltage generator.

Alfvén waves from the magnetotail to the low-altitude auroral region

Andreas Keiling

University of California-Berkeley, Space Science Lab, USA

While threading the entire magnetotail, Alfvén waves play many roles in the dynamics of the magnetotail. Many spacecraft missions (including Cluster) contributed to our enhanced understanding of Alfvén waves regarding their generation in the tail, their propagation toward the auroral region, their interactions along the way, and their dissipation in the auroral region and ionosphere. In this talk, I will review the most recent results, including observations and simulations.

Different types of accelerated ion structures registered in the magnetotail PSBL: their spatial-temporal characteristics and auroral manifestations.

E.E. Grigorenko(1), R. Koleva(2), J.-A. Sauvaud(3), L.M. Zelenyi(1)

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(2) Solar-Terrestrial Influences Institute Acad. D. Mishev, BAS, Sofia, Bulgaria
(3) CESR, Toulouse, France

Cluster and Geotail observations in the PSBL of the Earths magnetotail revealed two different types of accelerated ion populations. The first type represents energy collimated field-aligned ions having a rather long duration (up to 20 min) and energies $\leq$ 20 keV. During intervals of their propagation isotropic electron velocity distributions were observed in the PSBL-lobe interface. Multipoint Cluster observations of such type of accelerated ion structures revealed that they represent long-living plasma filaments elongated along the lobe magnetic field (L $\sim$ 60 - 100 RE) and strongly localized ($\sim$ 0.2-0.7 Re) in the direction perpendicular to the main magnetic field. On the basis of comprehensive statistical analysis we have proved that these ion structures were accelerated in the distant CS during quiet geomagnetic intervals. During such intervals of quiet PSBL ion non-adiabatic acceleration occurred simultaneously at several spatially localized sources located in the CS at closed magnetic field lines, i.e. the acceleration processes were not related with the magnetic reconnection. Another type of ion velocity distributions in PSBL represents powerful (with energies up to 100 keV) field-aligned ion beams having rather large parallel temperatures. They were observed together with anisotropic electron velocity distributions formed by cold and hot counterstreaming populations. This feature is peculiar for the magnetic separatrix and indicates that during such active PSBL intervals ion acceleration occurred near the magnetic reconnection region. According to multipoint Cluster analysis the time scale of such acceleration source is of the order of a few minutes, which indicates on the importance of transient effects and the corresponding role of inductive electric fields for the process of ion acceleration. The auroral manifestations during the intervals of quiet and active PSBL were studied.

Generation of low frequency oscillations in the plasma sheet boundary layer

T.M. Burinskaya , M.M. Shevelev , E.E. Grigorenko

Space Research Institute RAS, Moscow, Russia

Multipoint Cluster observations have revealed that during the motion of highly accelerated (up to 2500 km/sec) field-aligned ion flows in the plasma sheet boundary layer the related propagation of magnetic oscillations with a phase velocity of the order of the local Alfven speed is observed. Since the Kelvin-Helmholtz (K-H) instability is a very probable candidate for the excitation of such Alfven type disturbances, a general stability analysis is performed for the K-H instability in a three-layered system, when a background magnetic field is directed parallel to the plasma flow velocity. Solutions of the dispersion equation for the compressible plasma have shown that there is no upper critical sonic Mach number (MS=2) for oscillations propagating along the magnetic field, contrary to the common case of two plasmas moving relative to each other. For sonic Mach numbers higher than 2, the instability arises in a limited range of wave numbers, thus fixing the upper and lower cut off frequencies for the wave spectra. The structure of eigenmode has a damped-oscillatory character in the direction perpendicular to the background magnetic field and a kink-like type along the magnetic field. The comparison of obtained theoretical results with experimental data is discussed.

Models of magnetosphere-ionosphere interactions

Joachim Vogt

Jacobs University Bremen, Germany

Although geospace has been a prime scientific target in the past 50 years of space exploration, it remains a notoriously undersampled dynamical system. Spacecraft observations are mainly in-situ which means that in time they allow to study local processes, and only through repeated measurements of persistent phenomena like the magnetopause, other boundary regions, or quasi-stationary current systems, they contribute to the global picture. Studying the dynamic magnetosphere as a whole remains a challenge that time-resolved and spatially two-dimensional ionospheric data help to address in the context of conjugate events. The key underlying assumption of conjugate studies, however, is the idea that magnetic field lines act as transmission lines, and that we are in control of the various magnetosphere-ionosphere interaction modes. Stationary coupling models are expected to work for phenomena that do not vary significantly on the Alfven transit time scale along the magnetic field lines. To study more dynamic events, the propagation, absorption, and reflection of waves have to be taken into account. As individual plasma compartments connected by a magnetic flux tube exhibit not only linear but also nonlinear behavior, we encounter saturation effects like for the transpolar cap potential in response to strong solar wind forcing. The presentation will emphasize the role of field-aligned currents, discuss the different interaction modes, and address the implications for global dynamical models of the magnetosphere-ionosphere system.

Putting together the pieces of the substorm puzzle

J. P. McFadden

University of California, Berkeley, USA

Substorms are an energy release phenomena characterized by accelerated electron precipitation over broad regions of the night-side auroral oval. These precipitations are the result of parallel electric fields, which result from strong field-aligned currents (FAC) that connect to the ionosphere. To understand substorms, we should therefore focus on what produces these FACs. There are four primary processes that are associated with large-scale FACs: 1) night-to-day (and day-to-night) magnetospheric convection, 2) interchange instabilities, 3) field line twist caused by IMF By which results in local time shifts in magnetic connection between hemispheres, and 4) toroidal field line resonances. Since substorm aurora are localized, the primary processes should be the last three. This paper will outline how these three processes can be driven in the context of the NENL model, and how they play a role in generating the substorm aurora. The paper will also address why other processes (such as current disruption, BBFs, flow braking, and deep-tail double-layers) are not considered a major source of aurora. The paper will describe a two-stage dipolarization process driven by NENL reconnection, where the first stage produces rapid flows with little or no FAC to the ionosphere, followed by a second stage where FACs associated with these three processes generate the bulk of substorm aurora. Satellite observations will be used to support these interpretations of substorm phenomena.

The growth phase arcs and substorm onset

Gerhard Haerendel

Max Planck Institute for Extraterrestrial Physics, Garching, Germany

Key observations of the growth phase arcs are being reviewed. As part of a current system of Type II the electron arc is instrumental in changing the dominantly equatorward convection from the polar cap into a sunward convection along the auroral oval. A quantitative model of the arc and associated current system allows determining the energy required for the flow change. It is suggested that high-beta plasma outflow from the central current sheet of the tail creates the current generator. The equatorward motion of the electron and the hydrogen arcs is interpreted as manifestation of the shrinkage of the near-Earth transition region (NETR) between the dipolar magnetosphere and the highly stretched tail. This shrinkage is caused by returning magnetic flux to the dayside magnetosphere as partial replacement of the flux eroded by frontside reconnection. As the erosion of the NETR is proceeding, more and more magnetic flux is demanded from the central current sheet of the near-Earth tail, until highly accelerated plasma outflow causes current sheet collapse. Propagation of the collapse along the tail triggers reconnection and initiates the substorm. At some occasions, poleward boundary intensifications followed by streamers towards the onset arc may play a role in the triggering process.

BBF / plasma bubble coupling to the ionosphere

Colin Forsyth

UCL-MSSL, Dorking, UK

Bursty bulk flows and plasma bubbles have been shown to be a significant mechanism for the transport of magnetic flux and energy through the magnetotail. Field-aligned currents that flow along the edge of these fast plasma flows couple with the ionosphere, exciting aurora, such as auroral streamers and poleward boundary intensifications, modifying ionospheric conductivity and enhancing ionospheric convection. This talk will review how Cluster, in conjunction with a variety of ground and space-based instrumentation, has increased our understanding of these flows.

On the association between energy conversion regions and high speed flows in the plasma sheet

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(2) Department of Physics, Umeå University, Sweden
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High speed flows are frequently observed in the plasma sheet, providing a significant fraction of the mass, energy, and magnetic flux transport in the coupled magnetosphere–ionosphere system. Numerous studies over the last 20 years showed that much of this transport takes place in the central plasma sheet, by the so-called bursty bulk flows, known also as plasma bubbles. More recently, the Cluster mission allowed a systematic investigation of energy conversion regions (ECRs), identified as concentrated load regions (CLRs, $\mathbf{E} \cdot \mathbf{J} > 0$, with E the electric field and J the current density) and concentrated generator regions (CGRs, $\mathbf{E} \cdot \mathbf{J} < 0$). The ECRs were often found to be associated with high speed flows both in the central plasma sheet, where plasma velocity is mainly perpendicular to the magnetic field, and in the plasma sheet boundary layer, where plasma velocity is mainly parallel to the magnetic field. We present some features of this association, as observed in both regions, and discuss the similarities and differences between CLRs and CGRs. We also compare the findings with recent data analysis and modeling results.

Magnetotail reconnection and its signatures in the ionosphere

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Ionospheric equivalent currents related to bursty bulk flows (BBF) during Cluster and the International Monitor for Auroral Geomagnetic Effects (IMAGE) magnetometer network conjunctions between 2001 and 2006 are studied. A geomagnetically southeastnorthwest aligned, relatively narrow channel of northwestward equivalent current density with downward field aligned current at its northeastward flank and upward field aligned current at its southwestward flank is confirmed as the ionospheric signature of BBFs in the majority of cases, i.e., whenever an ionospheric signature is present. Unlike in previous event studies, all conjugate BBFs between 2001 and 2006 are analyzed and during 19 out of 22 BBFs, the channel is observed in the ionosphere. The mean duration of the BBFs observed when the footprint of Cluster is located close to the poleward boundary of the auroral oval is clearly longer (17 min) than the that of the BBFs observed close to the equatorward boundary of the oval (3 min).

Reconnection Hall current system observed in the magnetotail and in the ionosphere

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On 07 Sep 2001 around 21:40 UT, Cluster was located 19 R_E downtail, and observed earthward fast flows and strong perturbations in the dawn-dusk component of the magnetic field (B_Y). The perturbations corresponded to a sheet of tailward field aligned current close to the neutral sheet and another sheet of earthward field aligned current closer to the lobe. At Cluster footpoint, the ionospheric equivalent current density was monitored by the IMAGE magnetometer network. The observed equivalent current pattern is found to be consistent with a longitudinally extended current out of the ionosphere at $67°$ magnetic latitude and another sheet into the ionosphere 10 km further north. These observations provide evidence that the Hall current system generated in the ion diffusion region of a tail reconnection X-line, can close in the ionosphere.

Wednesday, May 19 – Poster session

Timing method for determining the parameters of a 2-D, non-planar discontinuity

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When Cluster crosses a plasma discontinuity, the differences in satellites' position and time of encounter can be used to obtain the discontinuity local orientation, thickness and motion. This timing technique, commonly assuming a planar geometry, offers an independent check for various single-spacecraft techniques.

We present an extension of the standard timing method, capable of determining in a self-consistent way the macroscopic parameters of a two-dimensional, non-planar discontinuity. Such a configuration is recognized in Cluster data when the single spacecraft techniques provide different individual normals contained roughly in the same plane. The model we adopted for the discontinuity assumes a layer of constant thickness of either cylindrical or parabolic shape, which has one or two degrees of freedom for the motion in the plane of the individual normals.

We applied the method to a magnetopause (MP) transition for which the various planar techniques provided inconsistent results. By contrast, the solutions obtained from the different implementations of the new 2-D method were consistent and stable, indicating a convex shape for the MP. These solutions perform better than the planar solutions from the normal magnetic field variance perspective. The values obtained for the MP parameters, together with the corresponding error estimate, the MP dynamics, and the presence of a non-zero normal magnetic field component in the analyzed event are further discussed.

Cluster / FAST investigation of two early morning aurora events

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We investigate two Cluster / FAST conjugate events, in January 2003 and January 2005, with Cluster crossing the auroral field lines in pearl-on-string configuration at about 3.5 RE altitude, and FAST probing the topside ionosphere at about 0.4 RE altitude. Both events occur in the early morning sector, around 2–4 MLT, during the early / late substorm recovery phase in 2003 / 2005. Cluster data show interesting similarities between the two cases in the magnetic field, electric field, and particle signatures. By comparing different types of data we identify for each event both intervals when the various signatures are in good agreement with each other and intervals with rather poor agreement. This may be the result of space and time variablity, whose analysis is made possible by Cluster. At low altitude, FAST crosses field-aligned current (FAC) structures whose intensity and latitudinal extent appear to be consistent with the mapped characteristics of the FACs observed by Cluster, provided that the FAC motion at Cluster level is properly taken into account. For the event in 2003 Polar optical data are available as well, indicating a structured and time varying luminosity pattern, consistent with the measurements of Cluster and FAST. Although we could not find optical data for the event in 2005, the similarities in the Cluster data suggest as well a complex luminosity pattern. However, the FAST data, in particular the magnetic field, show a less disturbed profile, that we tentatively associate with an increased length scale of the aurora during the late recovery substorm phase.

On inferring reformation of the quasi-perpendicular bow shock by multi-spacecraft data

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Based on Cluster magnetic field and particle data obtained during a quasi-perpendicular bow shock crossing on 24 January 2001 Lobzin et al. (GRL 34, 2007) have concluded that the shock is nonstationary and reforming on the time scale of the ion gyroperiod. The argument for shock reformation is mainly based on the different magnetic field profiles observed by different spacecraft when traversing the bow shock.

We have performed one-dimensional full-particle simulations for parameters appropriate to the 24 January 2001 shock crossing with the physical ion to electron mass ratio (it should be noted that the actual ion beta in the solar wind is ~ 0.6 as compared to 2.0 given by Lobzin et al.). The simulation exhibits large amplitude small wavelength waves in the foot, ramp, and overshoot simultaneously with vortices in the ion phase space of the incoming ions indicating the excitation of the modified two stream instability between incoming ions and electrons. These vortices lead to nonstationarity on a considerably smaller time scale than the ion gyroperiod.

We have flown two closely spaced artificial satellites from upstream through the foot and ramp to downstream and have recorded the magnetic field profile during shock traversal. The two spacecraft measure, after low-pass filtering the data, different magnetic profiles. This is very similar to what has been observed after filtering the data obtained from the actual bow shock crossing. Based on the simulations we suggest that during the 24 January 2001 crossing the bow shock is actually not reforming, but nonstationary on two different time scales: one time scale much smaller than the ion gyroperiod due to mini-cycles involving ion phase space vortices, and a nonstationarity with a time scale of 1 - 2 inverse ion gyrofrequencies due to a periodically changing shock potential, leading to enhanced reflection of ions, and subsequent excitation of waves far upstream. This nonstationarity can also be seen in the filtered spacecraft data. The difference of the large scale magnetic field profiles measured aboard different Cluster spacecraft is probably due to the latter nonstationarity, but not due to large scale reformation.

Low Frequency Waves in and around Energy Conversion Regions in the Plasma Sheet

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Regions in the Plasma Sheet (PS) where the energy is converted between the electromagnetic field and the plasma particles can be identified using the sign of the scalar product between the electric field and the current density. Positive sign indicates transfer from the field to the particles (Concentrated Load Region - CLR) while negative sign indicates the reverse process (Concentrated Generator Region - CGR). These regions may play an important role in the Plasma Sheet (PS) dynamics and in the energy exchange between the tail and the inner magnetosphere.

Here we use the Cluster FGM magnetic field data to study the low frequency waves associated with several ECR's encountered during a PS crossing in July 2003. The close to regular shape of the tetrahedron and the small distances between the spacecraft allowed the use of the source locator technique to determine the waves propagation directions and the proximity of the wave sources for several selected intervals inside and outside the ECR's. We found that the waves were propagating orthogonal to the magnetic field both inside and outside the ECR's. Outside the ECR's the waves always came from large distances and propagate close to parallel with the XY plane. In contrast, the waves detected within CLR's always came from close sources. Inside CGR's both close and distant sources were found.

Neural network identification of ECR events - preliminary results based on synthetic data

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Neural networks (NN) provide a powerful pattern recognition tool, that can be used to search large amounts of data for certain types of 'events'. Our specific goal is to make use of NN in order to identify energy conversion region (ECR) events in the Cluster data, that is regions where $\mathbf{E} \cdot \mathbf{J} \neq 0$ is rather well defined and observed on time scales from a few minutes to a few tens of minutes (E is the electric field and J the current density). The manual examination of the Cluster plasma sheet data from the summer of 2001 provided a start-up set of several concentrated generator regions (CGRs, $\mathbf{E} \cdot \mathbf{J} < 0$) and concentrated load regions (CLRs, $\mathbf{E} \cdot \mathbf{J} > 0$), that we tried to use initially for training a feed-forward back-propagation NN. The input data was divided in intervals of fixed size (e.g. 100 points) and for each interval the target output of the network was an equally long vector, filled with 1 for CLRs, -1 for CGRs, and 0 in rest. However, using Cluster data for training the NN proved to have two disadvantages: first, the training set was limited, and second, the regions marked with 0 in the training set could not be explored later - in a consistent manner - for the presence of CLRs / CGRs. In oder to overcome these problems we considered using synthetic data for training and testing the NN. For the time being each input interval contains one ECR event, with random amplitude, duration, and sign, to which a certain noise level is added. We investigate the results provided by the NN, as used with synthetic data, depending on the size of the training set, the noise level, and the NN configuration.

Investigating magnetosphere-ionosphere interactions using magnetosheath-magnetosphere numerical model

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The numerical magnetosheath-magnetoshere model integrates two parts:model of magnetosheath flow and of the magnetospheric magnetic field. The 3D bow shock and magnetopause shapes are part of self-consistent determination. The position of magnetopause has to satisfy the pressure balance equation. The magnetic field distribution in the magnetosphere is also received as a part of the solution. Input parameters are solar wind conditions, geomagnetic activity and the dipole tilt angle. The model is a convenient tool for mapping the magnetic field lines from magnetopause to the ionosphere. In this study, we use Cluster data with combination of the magnetosheath-magnetosphere model to investigate the magnetopauseionosphere interaction during various conditions.

Kinetic properties of the interface between the solar wind and the magnetosphere of Venus and Earth: modeling and observations by Venus Express and Cluster

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In June 2006 Venus Express crossed several times the outer boundary of the Venus induced magnetosphere, its magnetosheath and the bow shock. During the same interval Cluster spacecraft surveyed the dawn flank of the terrestrial magnetosphere, intersected the Earth's magnetopause and spent long time intervals in the magnetosheath. This configuration offers the opportunity to investigate simultaneously the interface between Venus and Earth's outer plasma layers and the shocked solar wind. We discuss the kinetic structure of the magnetopause of both planets, its global characteristics and the effects on the interaction between the planetary plasma and the solar wind. A quasi-stationary Vlasov equilibrium model is constructed for both planetary magnetopauses when the MP can be described by a tangential discontinuity as is the case for Venus Express and Cluster MP observations from June 27, 2006. The kinetic model provides good estimates of the magnetic field profile across the interface. The model is also in agreement with plasma data and evidence the role of planetary and solar wind ions on the spatial scale and equilibrium of the magnetopause of the two planets: the (Chapman- Ferrraro) current in the MP layer is mainly carried by electrons and protons with properties similar to the solar wind particles in the case of Venus; the terrestrial MP current is carried mainly by particles having kinetic properties consistent with the planetary species. This difference, suggested by model results, results most probably from the particularities of the interaction between the solar wind and an induced magnetosphere in one case and a "proper"/terrestrial magnetosphere in the other case.

Multi-spacecraft observations of auroral electron acceleration by Cluster

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During recent years the orbit of the Cluster spacecraft has evolved such that the spacecraft pass through the auroral acceleration region close to perigee during the dayside season. This presents the opportunity to make multi-spacecraft measurements of this region for the first time.

We present a case study of an upward auroral current region observed by Cluster in December 2009. During this event, Cluster 1 and Cluster 3 were approximately located on the same magnetic field-line but separated by 1000 km. We show that the electron population was accelerated along the fieldline between Cluster 1 and 3. Magnetic field observations confirm the presence of an upward current system. Based on these observations we estimate the size of the length of the acceleration region.

Cosmic Vision M3: a Multi-Spacecraft AAR/MI-coupling mission?

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Its a good time for the space plasmas community to begin to think about possible mission concepts to be proposed to the next ESA Cosmic Visions M-Class opportunity. One option is to build on the Cross-Scale experience, with a modified concept that will fit within the ESA cost cap. Another option is to try something different, perhaps drawing on the heritage of earlier mission studies. Cluster has serendipitously shown the value of multi-point observations in the AAR, but a dedicated mission is likely to provide a more complete set of answers to science questions on AAR and MI-Coupling. A number of possible approaches to this kind of mission have been studied: we illustrate one such concept (a study led by Mark Lester) here, in order to stimulate discussion. Comments please!

Current density calculation deep inside the ring current, using the curlometer technique

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The existence of a ring current around the Earth was established at the end of the 50's. Since then, the calculation of the current density and the study of the changes in the ring current is an active field of research as it is a good proxi for the magnetic activity. In order to calculate the current density, several methods were developed. The most common one is to deduce the perpendicular component of the current from the particle pressure gradient measurement. Another method developed is using four points measurements: the curlometer technique. This method uses the magnetic field data from four satellites located in the same current sheet and was first used by Vallat et al. (2005) using the CLUSTER satellites data at 4.1 RE. This allows a direct measurement of the total current density.

Since 2008, the CLUSTER satellites enter deeper inside the inner magnetosphere. This will allow a calculation of the current density closer to the earthward edge of the ring current. In this presentation, we will use the FGM and CIS data to localize the ring current and to calculate the current density at a CLUSTER perigee pass.

Study of the auroral current-voltage relationship using Cluster electric field and particle data

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In the Earth's auroral zone, currents flow along magnetic field lines in both upward and downward direction. In the upward current region, the field-aligned current (FAC) is often associated with a field-aligned potential drop (FAPD) and, within certain limits, the current-voltage relationship (CVR) can be approximated as linear (Knight, 1973; Lyons et al., 1979). As a preliminary step towards a systematic examination of the CVR based on Cluster and FAST data, we use multipoint measurements of the electric and magnetic fields, combined with particle measurements, to investigate temporal and spatial variations of the upward currents. The influence of different magnetic field models is checked. We also estimate the FAPD and explore its association with ion beams as inferred from Cluster and FAST observations - above and below the FAPD region, respectively.

Influence of the Field Aligned Beam on the Scattering of Diffuse Ions at the Earth's Quasi-Parallel Bow Shock

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We present several simultaneous multipoint measurements of energetic ion events upstream of Earth's quasi-parallel bow shock by Cluster during time periods of large (1-1.5 Re) inter-spacecraft separation distances. The e-folding distances of partial ion densities were determined by using a dynamical model bow shock surface. In the focus of our investigation is the scattering mechanism of diffuse ions by waves which are to be found in the foreshock region. Our results show that during times when the IMF is characterised by substantial directional stability the intensity of the Field Aligned Beam (FAB) is high. This high-intensity FAB generates waves which are convected deep in the foreshock region and strongly affects the scattering of diffuse ions which ultimately results in unusually low e-folding distances in the case of lower energy (10-18 keV) diffuse ions. These new results show that under different interplanetary conditions the scattering of diffuse ions (which leads to ion acceleration at the bow shock) can change significantly and this helps us to understand more the deeply the diffusive acceleration mechanism at the Earths bow shock.

Study of turbulent phenomena in space plasma exhibiting strong wave activity: Investigation of Hot Flow Anomaly turbulence

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In this paper the turbulent dynamics of those space regions is investigated where turbulent phenomena appear together with wave activities, e.g. in the terrestrial foreshock. It is shown that the level of the turbulent intermittency in the foreshock can be monitored in terms of space and time by the fourth statistical moment of the temporal differences of the time-series, i.e. by their flatness. In the analyses, the multi-spacecraft observations have a key role, since with them the intermittency in the plasma fluctuations can be revealed not only in temporal but also in spatial scales. However, in the analyses, it must be taken into account that the dynamics of the foreshock region is governed not only by turbulent fluctuations but also by regular wave phenomena occurring in certain frequencies. From the point of view of the turbulence studies, the wave activities can strongly complicate the interpretation of the results of the analyses, since they can e.g. distort the power-law behavior of the turbulent spectra and influence the shapes of the PDF-s and structure functions of the magnetic records in certain time scales. For this reason, a method based on wavelet filtering is intended to be introduced to discriminate between wave and turbulent components of the analyzed time records. The method is tested in hot-flow anomalies (HFA) that are transient plasma disturbances occurring along the interaction line of the bow shock and a tangential discontinuity plane embedded in the solar wind. The HF anomalies are typical regions where the wave and turbulent phenomena are mutually apparent.

Magnetosphere-ionosphere coupling in the Harang region

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The current configuration in the Harang region (HR), between the evening and morning sectors of the auroral oval, is believed to consist typically of one upward field-aligned current (FAC) sheet, fed from the sides, via meridional Pedersen currents, by downward FAC sheets. We present FAST observations indicating that the ionospheric current closure in the HR is sometimes dominated by the longitudinal coupling of FAC sheets with electrojet currents. The current configuration at ionospheric level suggests azimuthal current closure in the magnetosphere, contributing to the asymmetry of the ring current in the dusk sector, and to the cancellation of the cross-tail current at substorm onset. The auroral current circuit appears to be a mix of the 'Type 1' and 'Type 2' configurations introduced by Boström (1964), and may represent a relevant M-I coupling mode in the HR. In the upward current region, if the divergence of the electrojet is related primarily to the variation of the conductance, the FAC–EJ coupling is realized mainly by Hall currents for a wide energy range of the precipitating electrons. In this case the Joule effect has little contribution to the energy dissipation in the ionosphere, which is achieved mainly by collisions of the accelerated electrons.

Space weather prediction accuracy : improved estimation of arrival times of solar wind phase fronts

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Most space weather phenomena, such as geomagnetic storms and substorms are associated with disturbances in the solar wind, in particular directional changes in the interplanetary magnetic field (IMF). An observational challenge in this connection is that solar wind measurements are usually taken at large distances from the Earth and have to be time shifted to be representative for the upstream conditions, where the interaction takes place. Most methods to time shift the IMF data require knowledge about the orientation of magnetic surfaces in the solar wind. The orientation can be obtained from variance analysis of the IMF. A drawback with this approach is that the variance analysis frequently gives poor results or fails if Alfvénic structures or magnetic islands are embedded in the solar wind plasma. In this paper, we present a wavelet based denoising method to minimize the influence of such structures. Applications of the method shows that a better estimate of magnetic surface orientations and better prediction accuracy of the arrival time of solar wind disturbances at the Earth's magnetopause can be achieved.

Anisotropy evolution of magnetic field fluctuation through the bow shock

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We investigate wave vector anisotropies of magnetic field fluctuations using Cluster magnetometer data and the wave telescope technique. The energy distributions are determined in various regions from the solar wind to the magnetosheath and the cusp region across the bow shock, which allows us to study how wave vector anisotropies of turbulent magnetic field fluctuations evolve as the solar wind encounters the terrestrial bow shock and the magnetosphere. While fluctuations in the solar wind, the magnetosheath, and the magnetospheric cusp regions are characterized by the perpendicular wave vector geometry with respect to the mean magnetic field direction, that in the foreshock region is characterized by the parallel wave vector geometry. These transitions are discussed from the viewpoint of linear instabilities and nonlinear processes.

Efficient ion heating at high altitude, wave and temperature characteristics

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In the high altitude cusp /mantle the oxygen ion perpendicular temperature increase with altitude in spite of the adiabatic cooling effect of the magnetic mirror field. This indicates transverse heating, presumably due to wave particle interaction. In an initial case study we searched for the longest period with significantly enhanced perpendicular to parallel temperature ratio, an expected sign of local transverse heating. It was found that the simultaneously observed waves could not explain the observed perpendicular ion temperatures. We now complement the initial study with a statistical study of the electric and magnetic field spectral densities in the frequency range below 1 Hz, in the general vicinity of the high altitude oxygen gyro frequency. This is further complemented with some new case studies, where we have picked out some of the cases with highest spectral density around the oxygen gyro frequency, in order to see if gyro resonance theory can explain the perpendicular ion temperatures observed in conjunction with the strongest observed wave activity. A preliminary finding is that ion temperatures are often isotropic in regions with strong wave activity, and the more pan-cake like distributions are observed when the wave activity ceases. We try to interpret this in terms of isotropic heating followed by a velocity filter effect.

An interpretation of the wave propagation properties observed on WHISPER passive mode as an estimation of the electron density

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The Wave of High frequency and Sounder for Probing of Electron density by Relaxation (WHISPER) performs the measurement of the electron density on the four satellites of the CLUSTER project. The two main purposes of the WHISPER experiment are to record the natural waves and to make a diagnostic of the electron density using the sounding technique. The various working modes and the fourier transforms calculated on board provide a good frequency resolution obtained in the bandwidth 2-83 kHz and a well instrumental adaptability to determine the electron density in various plasma.

The natural wave recorded by WHISPER/CLUSTER exhibit several kinds of lower and upper frequency cut-off which correspond at local characteristics frequencies of the wave propagation. A careful examination of the natural wave propagation characteristics can give us information about the plasma dispersion. It is well-known that some regions of the frequency/wave number (ω, K) domain are forbidden to wave propagation. The limits of these forbidden regions depend strongly of the magnetic field and the plasma density. Reflection and absorption processes take place close to these limits and point out the plasma properties. So, the identification of these limits allows us to deduce electron density estimation. The determination of the F_{pe} given by the WHISPER/ active mode are used to understand the VLF waves feature. An interpretation is proposed with the aim to determine an estimation of the local electron density using the natural wave in various regions crossed by CLUSTER spacecraft.

Test-kinetic simulation of ion energy-dispersed structures and of non-gyrotropic distribution functions formed at the traversal of a plasma interface: two-dimensional solutions

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In this paper we discuss the formation of ring-shaped and non-gyrotropic velocity distribution functions (VDFs) as well as of energy-dispersed structures at the edges of a proton cloud injected into a non-uniform two-dimensional distribution of the electromagnetic field. The test-kinetic approach is used to compute the velocity distribution function in various regions of a particle cloud moving in the vicinity of a plasma interface with a sharp transition of the magnetic field. The electric and magnetic fields are prescribed and steady-state. Their spatial variation is confined to a transition region whose scale length is an input parameter of the simulation. A sheared distribution of the magnetic field is derived from a one-dimensional model of tangential discontinuities (TD). The two-dimensional electric field is everywhere normal to the magnetic field and is obtained by solving the Laplace equation on a two dimensional rectangular grid, with Neumann boundary conditions compatible with the self-consistent TD solution. We integrate numerically the trajectories of test-protons having the initial velocities distributed according to a displaced Maxwellian. The initial VDF is Liouville mapped along the integrated trajectories and is reconstructed in various spatial regions of the simulation domain, inside and outside the plasma interface. We also illustrate the evolution of the cloud's morphology while traversing the interface. The numerical results show the formation of an energy-dispersed structure at the edges of the cloud, with the energy increasing towards the fringes. Ring-shaped VDFs form inside the velocity-dispersed structure. Gyro-phase restricted velocity distribution functions are obtained in the front-side and trailing edge of the cloud and are likely due to the remote sensing of large Larmor radius particles whose guiding centers rest in the core of the cloud. The test-kinetic solutions show properties similar to the in-situ velocity distribution functions observed by CLUSTER satellites in the magnetotail, close to the neutral sheet, as reported by, e.g., Meziane et al. (2003) and Wilber et al. (2004).

Thursday, May 20

Aurora and black (inverse) aurora viewed by Cluster

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Results are presented from Cluster observations above and within the auroral acceleration region, with special focus on auroral electric fields, potentials, and currents, and their role in particle acceleration and other interaction processes between the magnetosphere and the auroral ionosphere. Measurements from above the AAR have been used to study the evolution, life time, and stability of quasi-static potential structures, how they interact with the ionosphere and assume certain shapes depending on the associated plasma boundary conditions. The growth and life time of a positive potential structure is closely tied to density cavity formation in the associated downward current sheet, which becomes broader and more filamentary, as the cavity becomes deeper. The Cluster data have also been used to identify characteristic spatial scales of intense electric fields and associated currents and density gradients, being co-located with plasma boundaries and peaking at scale sizes of 4-5 km. These and other results on this topic are discussed to address the question whether the arc width distributions are described by one or several peaks (within the range 10 m- several 100 km), or whether the distributions are continuous and non-peaked, as power law distributions. Ionospheric feedback has an important role in auroral particle acceleration as well as in small-scale structuring of the auroral plasma, as shown by comparisons of numerical simulation results with Cluster data. Measurements from crossings of the AAR, at different altitudes, are presented to address some of the open issues concerning the AAR, such as the altitude distribution, and evolution in space and time, of the parallel electric field and associated potential structure.

Advances in modeling and understanding in-situ observations and coupling of the magnetosphere and the auroral ionosphere during Cluster-DMSP conjunctions

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Conjugated observations by Cluster and DMSP connected by the same auroral geomagnetic field lines provide physical insight on the processes actively coupling the magnetosphere and the auroral ionosphere. During the first years on orbit the Cluster spacecraft traversed, close to their perigee, the upper segment of the auroral acceleration region; the DMSP spacecraft survey the auroral ionosphere probing in situ the accelerated downgoing electrons connecting the ionospheric load with the magnetospheric generator. With a quasistationary model developed to describe the coupling between the high-altitude magnetosphere and the auroral ionosphere, we can estimate the state of the magnetospheric generator as well as the electrodynamic properties of the associated auroral arc. The model consists of two modules: (1) the magnetospheric module computes the generator plasma and field parameters (the electric potential, the plasma density and bulk velocity, the current density, the parallel flux of electrons and ions), to be compared with data - from Cluster - at high altitude magnetospheric interfaces and discontinuities; (2) the ionospheric module computes a height integrated solution of the current continuity at the topside ionosphere considering the coupling (via a Knight-type current-voltage relationship) with the generator described by the magnetospheric module. The ionospheric module provides the electrodynamic parameters of the discrete auroral arc (ionospheric potential, field-aligned potential drop, field-aligned current density, flux of precipitating energy, Pedersen conductance enhancement, spatial

scale size of the inverted-V and of the luminous emission) to be compared with DMSP measurements. We illustrate how the model results compare with data collected during the Cluster-DMSP conjunction on April 28, 2001. Both modeling and experimental results provide evidence for the quasi-static acceleration of upgoing ions and downgoing electrons by a parallel potential drop of the order of 3 kiloVolt, corresponding to a discrete auroral arc 15 kilometers wide and generated by a magnetospheric plasma interface with a scale length of the order of 500 kilometers at 4.5 Earth radii, in the dusk flank.

Monopolar and bipolar auroral electric fields and their ionospheric signature

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Most of the quasi-static high-altitude auroral electric fields observed by CLUSTER can be classified into monopolar and bipolar structures. The observations show that monopolar electric fields tend to be associated with polar cap boundary arcs, while bipolar fields are linked to discrete arcs within the auroral oval. We propose an explanation of this association in terms of a simple model of the overall configuration of the magnetotail and the results of kinetic model computations. We propose quasi-electrostatic models of the magnetosphere-ionosphere coupling that describe the auroral current system associated with such high-altitude fields. These models give indications about the location of up- and downward field-aligned current regions, the ionospheric and magnetospheric convection along the arc, the acceleration or deceleration of precipitating particles, and the behaviour of escaping ionospheric ions.

First WBD results from the winter 2009/2010 auroral acceleration region campaign

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In December, 2009 through January, 2010, there was a concerted campaign to study the auroral acceleration region (AAR) by the Cluster mission. This period presented the first, albeit brief, opportunity for a full, multi-spacecraft investigation deep into the nightside AAR. The Wideband Data (WBD) instrument, in coordination with the other Cluster instruments, targeted various wave phenomena for study, including auroral kilometric radiation (AKR), electrostatic solitary structures and auroral hiss, observing at frequencies from 100 Hz to 577 kHz (although not with full coverage). We will present an overview of the first results of these wave investigations. Since multi-spacecraft measurements were made both along the same field lines and along near-identical spacecraft tracks (with minute-scale time lags), we will emphasize the spatial and temporal variation of the observed features. We will also compare to similar AAR observations made in late spring of 2009, when the spacecraft passed through the acceleration region at higher altitudes, but at more poleward latitudinal positions.

Field-aligned currents and particle precipitation

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The source regions of region-0 (R0), region-1 (R1), and region-2 (R2) field-aligned currents (FACs) were statistically determined using DMSP particle precipitation and magnetometer data. Each current within a FAC sheet originates from more than one region in the magnetosphere, depending on the latitude and magnetic local time (MLT). The ion westward and electron eastward drifts may contribute to the prenoon-postnoon asymmetry of the source regions. R2 originates mostly from closed field lines, but near noon, some R2 may originate from LLBL, which is located near the magnetopause and can be open or closed. R1 is located mostly on closed field lines in the morning and the afternoon, but near noon, it maps mostly to LLBL. However, there is some indication that some R1 at the equatorward region is on closed field lines. On the other hand, R0 is located mostly on open field-lines. These should have implications to the FAC generation mechanisms. Within up-flowing R0, sometimes upward field-aligned electric field, which accelerates electron and retards ion precipitation, modifies mantle distribution to look more like those of polar rain and BPS. This electric field has the opposite polarity to the background electric field that maintains charge-quasi neutrality and that limits some solar wind electrons from entering the magnetosphere in the mantle and polar rain regions. These and other relationships between the field-aligned currents, parallel electric field, and the particle precipitation are explored.

Investigation of temporal stability of field-aligned currents in the auroral oval

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The cluster magnetic field data from several years worth of aurora oval crossing is used to quantify the temporal variations of magnetic field signatures of field-aligned currents (FAC). The method used is to study the cross-correlation between pairs of spacecraft as a function of the temporal separation of the auroral crossings of the respective spacecraft. When the method is applied on the large-scale variations associated with the whole auroral pass, it gives results consistent with those of an earlier smaller study using low-altitude measurements of particle fluxes. We then apply the method to study the temporal stability of FAC as a function of latitude, local time, geomagnetic parameters, and the scale sizes of the magnetic field variations. The use of a variation of this method to discriminate between temporal and spatial variations is discussed.

Multi-spacecraft gradient techniques: Applicability for studying magnetosphere-ionosphere coupling

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In this presentation we review different existing techniques for computing gradients from multi-spacecraft data, focussing in particular on least-squares gradient computation. A major question is: are such techniques useful in the context of the study of the coupling between the magnetosphere and the ionosphere in the auroral regions? We discuss the limitations of the methods and suggest where and how gradient computation is possible.

Friday, May 21

Inner magnetosphere science objectives: some previous achievements with Cluster and new targets for 2011 - 2012

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The inner magnetosphere is a region where multiple particle populations coexist and interact (plasmasphere, ring current, exosphere), and where most of the energy is dissipated during magnetospheric storms and substorms. During the first years of Cluster operation the spacecraft orbit, with a 4 RE perigee, allowed an analysis of the westward ring current and the outer plasmasphere. The recent orbit evolution, with a substantial lowering of the perigee, gives access to the more inner part of the magnetosphere, opening the possibility to address some new key science objectives.

Characteristics of storm-time electric fields in the inner magnetosphere

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We study storm-time electric fields in the inner magnetosphere measured by Cluster. First we show two event studies around minimum Dst values. In one event in the eveningside, we have measured subauroral ion drifts (SAID) and/or undershielding. In the other event in the nightside, we have measured large electric fields with or without dipolarization signatures. The spatial coherence of electric field between multiple spacecraft is not high, indicating the variable nature of this event. Next we show statistical results. The electric field is enhanced around minimum Dst at all local times. The electric field decays more quickly than Dst values in the recovery phase. AC components are generally larger than DC components. These results would be useful in future efforts to update the empirical electric field model in the inner magnetosphere.

Use of CLUSTER data in investigating the correspondence between different regions of inner magnetosphere and ionospheric phenomena

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Coincident observations of middle and top ionosphere using satellite tomography, radar measurements and plasmapause observations with IMAGE and/or CLUSTER are used to investigate the relationship between the F region trough and the plasmapause. Several F region troughs observed in tomographic images have been selected in order to study the correspondence with plasmaspheric boundary. There is a very small probability to find CLUSTER data that are both spatially and temporally coincident with a F region trough, however, satellite data available at the moment of trough observations can be used to certify the validity of the plasmapheric model used for evaluating the position of plasmaspheric boundaries. These data are also used to are specifyic characteristics of the trough and specific regions of the inner magnetosphere. The position of the plasmapause can be estimated, presumably, from ionospheric data, as for instance the equatorial border of auroral precipitation, the light ion trough, the occurrence of red auroral arcs or enhancements of subauroral electron temperature. Zonal rapid ion drifts, known as subauroral ion drifts, occurring in the ionosphere in both westward and eastward directions, also indicate a strong coupling with the inner magnetosphere. Possible mechanisms that generate the well-known SAIDs and the recently discovered ASAIDs are analysed. We discuss here the role of background magnetospheric and solar wind conditions (geomagnetic activity, solar wind pressure, IMF orientation, etc) in the coupling between the F region trough and the plasmapause and their relevance for the magnetosphere-ionosphere coupling.

Electron density measured in the earth's space environment by the WHISPER relaxation sounder onboard CLUSTER

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The WHISPER relaxation sounder that is onboard the four CLUSTER spacecraft has for main scientific objectives to monitor the natural waves in the 2 kHz-80 kHz frequency range and mostly to determine the total plasma density from the solar wind down to the Earth's plasmasphere. To fulfil these objectives, WHISPER uses the two long double sphere antennae of the Electric Field and Wave experiment as transmitting and receiving sensors. In active mode, strong and long lasting echoes are usually received whenever the transmitting frequencies coincide with characteristic plasma frequencies. Once these echoes, also called resonances, are identified, the WHISPER relaxation sounder becomes a reliable and powerful tool for plasma diagnosis, and parameters such as the total electron density and magnetic field strength may be determined. When the transmitter is off, WHISPER behaves like a passive receiver, allowing natural waves to be monitored. The paper aims mainly at the resonance recognition process, natural wave signature identification to allow the plasma density to be determined in the various regions encountered all along the CLUSTER orbits around the Earth.

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