COLOGNE 2009

Magnetospheres of the Outer Planets 2009

27 - 31 July 2009

Institute of Geophysics and Meteorology,
University of Cologne,
Cologne
Germany

The Magnetospheres of the Outer Planets 2009 meeting is organized by Joachim Saur (Institute of Geophysics and Meteorology, University of Cologne).

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Sunday 26th July, 2009

18:00 - 20:00 **Registration/Reception (Includes Food)**

Monday 27th July, 2009

08:45 - 09:00 **Welcome by J. Saur**

09:00 - 10:15 **Jupiter**

Time	1st Author	Chair: J. Clarke	Page
09:00	Feldman P. D.	FUSE Observations of Jovian Aurora at the Time of the New Horizons Flyby	3
09:15	Tao C.	Characteristics of coupling current and rotational dynamics in the Jovian magnetosphere-ionosphere-thermosphere model	4
09:30	Alexeev I. I.	Dependence of the Jupiter magnetosphere size on the plasma magnetodisk parameters and on the solar wind dynamic pressure	5
09:45	Steffl A. J.	MeV Electrons in the Jovian Magnetosphere Detected by the Alice UV Spectrograph Aboard New Horizons	6
10:00	Radioti A.	Auroral signatures of flow bursts released during substorm-like events in the Jovian magnetotail	7

10:15 - 10:45 **Break**

10:45 - 12:00 **Io: Flux-tube, Footprints and Torus**

Time	1st Author	Chair: F. Bagenal	Page
10:45	Bonfond B.	Io UV footprint various spots: position and brightness variations	8
11:00	Wannawichian S.	Simultaneous study of plasma torus density near Io and the satellite's magnetic footprint brightness	9
11:15	Jacobsen S.	The morphology of equatorial electron beams at Io	10
11:30	Winglee R. M.	Coupled Simulations of Io, the Io Plasma Torus and the Jovian Magnetosphere	11
11:45	Hess S.	Power transmission and particle acceleration along the Io Flux tube	12

12:00 - 13:30 **Lunch Break**

13:30 - 15:15 **The Rotation Rate of Saturn**

Time	1st Author	Chair: T. Hill	Page
13:30	**Cecconi B.**	**Modulation of Saturn's auroral radio emissions at or close to the planetary rotation period**	**13**
13:50	**Carbary J. F. (by Mitchell D. G.)**	**Energetic Particle Periodicities at Saturn**	**14**
14:10	**Kivelson M. G.**	**Theories of Rotating Periodicities**	**15**
14:30	Gurnett D. A. (by Kurth W. S.)	A North-South Asymmetry In the Rotational Modulation Period of Saturn Kilometric Radiation	16
14:45	Lecacheux A. (by Southwood D. J.)	Observed Magnetospheric Periodicity	17
15:00	Crary F. J.	Dual periodicities in the magnetospheres of Jupiter and Saturn	18

15:15 - 15:45 **Break**

15:45 - 17:45 **The Rotation Rate of Saturn**

Time	1st Author	Chair: T. Hill	Page
15:45	Vasyliūnas V. M.	The puzzle of SKR and magnetic field periodicities in Saturn's magnetosphere	19
16:00	Goldstein J.	Cause of Saturn's Plasma Cam	20
16:15	Khurana K. K.	Why Does Saturn's Magnetosphere Develop Azimuthal Asymmetries?	21
16:30	Brandt P. C.	Rotational Periodicities in Saturn's Magnetosphere	22
16:45	Mitchell D. G.	Saturn's Clock: Concept for Generating and Maintaining Saturn's Observed Magnetospheric Periodicity	23
17:00	Andrews D. J.	Saturn's equatorial magnetic field oscillations	24

17:15 - 17:45 **GENERAL DISCUSSION (ROTATION RATE)**

Tuesday 28th July, 2009

09:00 - 11:00 **Aurora and SKR**

Time	1st Author	Chair: W. Kurth	Page
09:00	**Grodent D.**	**News from outer worlds**	**27**
09:30	**Pryor W. R.**	**Saturn Auroral Images and Movies from Cassini UVIS**	**28**
10:00	Clarke J. T.	The Variability of Auroral Emissions on Jupiter and Saturn	29
10:15	Nichols J. D.	Saturn's equinoctial auroras	30
10:30	Badman S. V.	Location and morphology of Saturn's infrared aurora observed by Cassini VIMS	31
10:45	Stallard T.	Changes in polar ion wind flows during periods of solar wind compression	32

11:00 - 11:30 **Break**

11:30 - 12:45 **Aurora and SKR**

Time	1st Author	Chair: P. Zarka	Page
11:30	**Bunce E. J.**	**Auroral current systems at Saturn: Observations from Cassini and the Hubble Space Telescope**	**33**
12:00	Masters A.	Large-scale vorticity in Saturn's outer magnetosphere as a driver of auroral emissions	34
12:15	Kurth W. S.	In Situ Measurements of a Low-Frequency SKR Source Region at Saturn	35
12:30	Lamy L.	An auroral oval at the footprint of Saturn's radiosources, colocated with atmospheric aurorae	36

12:45 - 13:15 **GENERAL DISCUSSION (AURORA)**

13:15 - 15:00 **Poster Session with Pizza**

15:30 - ca. 17:00 **Sightseeing**

19:00 - 22:30 **Evening Banquet on the Rhine River**

Wednesday 29th July, 2009

09:00 - 10:30 **Saturn's Magnetosphere and Comparison with Jupiter**

Time	1st Author	Chair: M. Kivelson	Page
09:00	**Arridge C. S.**	**Global magnetospheric fields of Saturn and Jupiter**	**39**
09:30	Bagenal F.	Models of the Plasma Sheet at Jupiter and Saturn	40
09:45	Ray L. C.	Effect of Field-Aligned Potentials on Magnetospheric Dynamics at Jupiter and Saturn	41
10:00	Mauk B. H.	Radiation Belts of the Solar System	42
10:15	Sergis N.	Structure, variation and pressure balance in the Saturnian plasma sheet. Combined MIMI, CAPS and MAG measurements from Cassini	43

10:30 - 11:00 **Break**

11:00 - 12:30 **Plasma Properties of Saturn's Magnetosphere**

Time	1st Author	Chair: C. Paty	Page
11:00	**Delamere P. A.**	**Hot electrons and their influence on the Enceladus and Io tori**	**44**
11:30	**Rymer A. M.**	**Saturn's magnetospheric electrons**	**45**
12:00	Schippers P.	A three-dimensional analysis of the electron populations in Saturn's magnetosphere: identification of the source, transport and sink regions	46
12:15	Paranicas C.	Energetic electron asymmetries near Saturn's main rings	47

12:30 - 14:00 **Lunch Break**

14:00 - 15:30 **Properties of Plasma and Neutrals in Saturn's Magnetosphere**

Time	1st Author	Chair: D. Mitchell	Page
14:00	Thomsen M. F.	A survey of plasma properties in Saturn's magnetosphere: Cassini CAPS	48
14:15	Armstrong T.	Comments on the Trapped Energetic Ions in the Inner Saturnian Magnetosphere	49
14:30	**Smith H. T.**	**The influence of neutrals on Saturn's magnetosphere**	**50**
15:00	Dialynas K.	Global neutral gas distribution at Saturn derived from ENA images	51
15:15	Burger M.	The Distribution of Neutral Water in Saturn's Inner Magnetosphere	52

15:30 - 16:00 **Break**

16:00 - 17:30 **Interchange and Dynamics in Saturn's Magnetosphere**

Time	1st Author	Chair: E. Bunce	Page
16:00	**Andre N.**	**Interchange instabilities in the Jovian and Saturnian magnetospheres**	**53**
16:30	Hill T. W.	Saturn Simulations with the Rice Convection Model	54
16:45	Kidder A.	The effect of solar wind dynamic pressure on the centrifugal interchange cycle in Saturn's magnetosphere	55
17:00	DeJong A. D.	Low energy electron peaks due to interchange	56
17:15	Alexandrova O.	Magnetic field fluctuations in Saturn's magnetosphere as observed by the Cassini spacecraft	57

Thursday 30th July, 2009

09:00 - 10:00 **Dynamics and Mixed Saturn**

Time	1st Author	Chair: E. Bunce	Page
09:00	Müller A. L.	Azimuthal plasma flow in the Kronian magnetosphere	61
09:15	Moore L.	The Latitude Dependence of Conductances at Saturn: Cassini Observations and Model Comparisons	62
09:30	Walker R. J.	Vorticity and Magnetic Field Oscillations in Saturn's Morning Magnetosphere	63
09:45	Hansen K. C.	The Response of Currents and Ionospheric Signatures in Saturn's Magnetosphere	64

10:00 - 10:30 **Break**

10:30 - 11:30 **Saturn's Outer Magnetosphere and Foreshock Region**

Time	1st Author	Chair: F. M. Neubauer	Page
10:30	Krimigis S. M.	Energetic Ions and Magnetic Fields Upstream From the Noon-to-Dusk Saturnian Bow Shock: Indications of Periodicity	65
10:45	Went D. R.	Magnetic Field Dipolarization in Saturn's Outer Magnetosphere: Search for a Cushion Region	66
11:00	Jackman C. M.	Properties of the magnetic field and plasma in the kronian magnetotail lobes	67
11:15	Kane M.	Saturn's outer magnetosphere: Convection, Reconnection, and Configuration	68

11:30 - 12:00 **GENERAL DISCUSSION (SATURN MAGNETOSPHERE)**

12:00 - 13:30 **Lunch Break**

13:30 - 15:15 **Satellites (Titan)**

Time	1st Author	Chair: F. M. Neubauer	Page
13:30	**Young D. T.**	**Titan's Ionosphere as a Source for the Magnetosphere and Atmosphere**	**69**
14:00	**Simon S.**	**Titan's highly variable plasma interaction: Global numerical simulations and comparison with Cassini data**	**70**
14:30	Snowden D. S.	Titan at the Edge: 3D Multi-fluid Simulations of Titan near Saturn's Magnetopause	71
14:45	Wellbrock A.	Negative ions at Titan - new results	72
15:00	Sittler E. C.	Saturn's Magnetosphere and Properties of Upstream Flow at Titan: Preliminary Results	73

15:15 - 15:45 **Break**

15:45 - 17:30 **Satellites with Thin Atmospheres**

Time	1st Author	Chair: K. Retherford	Page
15:45	**Khurana K. K.**	**The Interactions of Outer Planetary Satellites with Their Magnetospheres: Non-Magnetized Moons with Thin Atmospheres**	**74**
16:15	Dols V.	A Hybrid Simulation of the Plasma Flow Around Io Coupled to a Multi-species Chemistry Model of Io's Local Interaction	75
16:30	McGrath M.	New Observations of UV Emissions from Europa	76
16:45	Hendrix A. R.	Europa: UV Signatures of Plasma-Surface Interactions	77
17:00	Saur J.	HST observations of Europa's atmospheric UV emission	78
17:15	Schneider N. M.	Discovery of a New High-Speed Atmospheric Ejection Process at Io	79

17:30 - 19:30 **Poster Session with Snacks**

Friday 31st July, 2009

09:00 - 10:45 **Satellites (Thin Atmospheres, Ganymede and Enceladus)**

Time	1st Author	Chair: J. Saur	Page
09:00	**Jia X.**	**Global MHD Simulations of Ganymede's Magnetosphere and Their Comparison with Observations**	**83**
09:30	Volwerk M.	Ganymede's field line resonances revisited	84
09:45	**Paty C.**	**Enceladus' Plume: An Overview of Observations and Interpretation Through Multi-fluid Simulations**	**85**
10:15	Coates A. J.	Electrons at Titan and Enceladus: implications for Ganymede and Europa	86
10:30	Jones G. H.	Electrically charged grains in Enceladus's plume	87

10:45 - 11:15 **Break**

11:15 - 12:00 **Satellites (Enceladus continued)**

Time	1st Author	Chair: J. Saur	Page
11:15	Kriegel H.	Hybrid Simulations of the Enceladus Plasma Interaction and Comparison with Cassini MAG Data	88
11:30	Krupp N.	The Cassini Enceladus encounters in the view of energetic particle measurements	89
11:45	Roussos E.	Motion of equatorially mirroring energetic electrons near Saturn's inner moons	90

12:00 - 12:30 **Rings and Dust**

Time	1st Author	Chair: J. Saur	Page
12:00	Tseng W.-L.	A re-examination on the Mass Budget of the Saturn's Ring Atmosphere and Ionosphere at Equinox	91
12:15	Hsu H. W.	Dynamics of the nanometer-size dusts originated from the Jovian and Saturnian systems, Cassini dust detector results	92

12:30 - 13:00 **Exoplanets**

Time	1st Author	Chair: J. Saur	Page
12:30	**Zarka P.**	**Planet-Star Plasma Interactions and Possible Radio Emission**	**93**

13:00 - 14:30 **Lunch Break**

14:30 - 15:45 **Future Missions/Campaigns**

Time	1st Author	Chair: F. Bagenal	Page
14:30	**Southwood D. J.**	**Outer Planets Program of ESA**	**N/A**
15:00	**Bolton S.**	**JUNO and NASA's Outer Planets Program**	**N/A**
15:30	Kasaba Y.	Latest Perspective for the Jovian Magnetospheric Orbiter	94

15:45 - 16:15 **GENERAL DISCUSSION (SATELLITES AND OVERALL)**

16:15 **Final Words (J. Saur)**

Earth Posters

Jupiter Posters

Jupiter Posters (cont.)

Io Posters

Saturn Rotation Rate Posters

Saturn Aurora and SKR Posters

Saturn's Magnetosphere Posters

Saturn's Magnetosphere Posters (cont.)

Titan Posters

Satellites with Thin Atmospheres Posters

Uranus Posters

Exoplanets Posters

Future Missions/Campaigns Posters

Oral Presentations

Monday 27$^{\text{th}}$ July, 2009

FUSE Observations of Jovian Aurora at the Time of the New Horizons Flyby

Feldman, P. D.[1], H. A. Weaver[2], K. D. Retherford[3], G. R. Gladstone[3], D. F. Strobel[1], and S. A. Stern[3]

(1) *Johns Hopkins University*
(2) *JHU/Applied Physics Laboratory*
(3) *Southwest Research Institute*

Abstract. At the time of the New Horizons flyby of Jupiter on 28 February 2007, there was a five-day window of opportunity during which the Far Ultraviolet Spectroscopic Explorer (FUSE), despite the loss of three of its four reaction wheels, could be stably pointed at Jupiter's position on the sky. FUSE was an orbiting spectroscopic observatory capable of spectral resolution better than 0.4 Å for extended sources in the wavelength range 905–1187 Å, together with very high sensitivity to weak emissions. Three orbits of observations were obtained in a point-and-stare mode beginning at 16:50 UT on 02 March 2007 of which for the first two the FUSE $30'' \times 30''$ aperture was centered on northern polar aurora. During each orbit the count rate was constant with time indicating that the target remained fully in the aperture during the entire exposure. These spectra will be compared with those obtained by FUSE in October 2000, December 2000, and January 2001, in terms of FUV luminosity and derived H_2 vibrational population. We will also compare these results with the auroral luminosity derived from ultraviolet images obtained by the Hubble Space Telescope one Jovian rotation before and one after the FUSE observations, and with corresponding data from New Horizons.

Characteristics of coupling current and rotational dynamics in the Jovian magnetosphere-ionosphere-thermosphere model

Tao, C.[1]**, H. Fujiwara**[1]**, and Y. Kasaba**[1]

(1) *Department of Geophysics, Tohoku University*

Abstract. In order to investigate the coupling processes between the Jovian magnetosphere, ionosphere, and thermosphere, we have developed a new numerical model. The model calculates axisymmetric thermospheric dynamics and ion composition by considering fundamental physical and chemical processes. The ionospheric Pedersen current is obtained from the thermospheric and ionospheric parameters affected by auroral precipitation and solar EUV. The model simultaneously solves the torque equations of the magnetospheric plasma due to radial currents flowing at the magnetospheric equator, which enables us to update the electric field projected onto the ionosphere and the field-aligned currents (FACs) depending upon the thermospheric dynamics. The self-consistently calculated temperature, ion velocity, and FAC are consistent with observations. The estimated neutral wind field captures the zonally-averaged characteristics in previous three-dimensional models. The energy extracted from the planetary rotation is mainly used for magnetospheric plasma acceleration below 73.5° latitude, while it is consumed in the upper atmosphere, mainly by Joule heating, above 73.5° latitude. The neutral wind dynamics contributes to a reduction in the electric field of 22% compared to the case of neutral rigid corotation. About 90% of this reduction is attributable to neutral winds below 550 km altitude in the auroral region. The calculated radial current in the equatorial magnetosphere is smaller than observations. This indicates that the enhancement of the background conductance and/or the additional radial current would be expected to reproduce the observed current.

Dependence of the Jupiter magnetosphere size on the plasma magnetodisk parameters and on the solar wind dynamic pressure.

Alexeev, I. I.[1]

(1) *Scobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia*

Abstract. In the outer jovian magnetosphere the equatorial plasma magnetodisk contribution to the total pressure is essential. The changing of the solar wind pressure and IMF strength and direction results in expansion or collapse the plasma disk. The simple balance between the inner jovian dipole field enhancement by magnetopause currents and solar wind plasma pressure gave a big discrepancy with observations. The proposed model of the outer magnetosphere gave possibility to forecast the magnetospheric field at subsolar magnetopause and to formulate the balance equation. Comparison with Saturn magnetosphere where plasma disk dynamic have been observed by Cassini is presented.

MeV Electrons in the Jovian Magnetosphere Detected by the Alice UV Spectrograph Aboard New Horizons

Steffl, A. J.[1], F. Bagenal[2], M. J. Desroche[2], D. K. Haggerty[3], G. R. Gladstone[1], J. Wm. Parker[1], K. D. Retherford[1], and S. A. Stern[1]

(1) *SwRI*
(2) *CU/LASP*
(3) *JHU/APL*

Abstract. In addition to UV photons, the microchannel plate detector of the Alice UV spectrograph aboard the *New Horizons* spacecraft is surprisingly sensitive to energetic electrons. Electrons with energy of order 1 MeV or greater can easily penetrate the aluminum instrument casing. Laboratory testing of the flight spare for the Alice spectrograph on *Rosetta* (functionally equivalent to the Alice on *New Horizons*) revealed a detection efficiency of 33% for 1 MeV electrons.

Over a 10-day period, during which *New Horizons* flew from 80 R_J upstream of Jupiter through closest approach at 32 R_J to 115 R_J downstream, Alice was on nearly half of the time, often with the aperture door closed. While on, the integrated count rate was recorded every second, resulting in the highest time resolution measurements of Jovian MeV electrons. When both instruments were operating concurrently, the count rate seen by Alice is highly correlated with the flux of electrons in the 25–1000 keV range observed by the PEPSSI energetic particle instrument.

Along with the PEPSSI and SWAP energetic particle instruments, Alice detected the magnetopause boundary crossing on 2007-02-25 18:00 UTC. While inside the magnetopause, Alice observed large variations in the MeV electron flux. Often, the rate of energetic particle events detected exceeded 15,000 per second, causing Alice to enter safe mode. Rapid variations in MeV electron flux were observed, with factor of two changes in flux over 100-second timescales seen frequently. Later as *New Horizons* flew down the magnetotail, strong 10-hour periodicity is seen in the MeV electron flux with 20x increases in flux when *New Horizons* was at System III longitudes of 130° and 280°.

Auroral signatures of flow bursts released during substorm-like events in the Jovian magnetotail

Radioti, A.[1], **D. Grodent**[1], **J.-C. Gérard**[1], **B. Bonfond**[1], **M. Hill**[2], **R. L. Mc.Nutt**[2], **and S. M. Krimigis**[2]

(1) *LPAP, Institut d'Astrophysique et de Géophysique, Université de Liège*
(2) *Applied Physics Laboratory, John Hopkins University, Laurel, USA*

Abstract. Substorm-like processes at Jupiter's magnetotail, have recently been shown to leave their signature in the aurora. The Hubble Space Telescope (HST) observed transient polar dawn spots on the Jovian aurora, with a characteristic recurrence period of 2-3 days. Because of their periodic occurrence cycle and observed location, it had been suggested that the transient auroral features are related to the precipitated, heated plasma during reconnection processes taking place in the Jovian magnetotail. During tail reconnection, bursty flow is directed away and towards the planet. We examine the scenario that the transient auroral emissions are triggered by the inward moving flow bursts released during the process. In our analysis we make use of a model adapted from the terrestrial case, according to which moving bursty flow is coupled with the ionosphere by field aligned currents (FACs), which give rise to spotty transient auroral emissions. Based on magnetic field measurements we estimate the upward FAC at the edge of the flow bursts and we derive the power deposited in the ionosphere. Comparison of the flow bursts properties with those of the auroral spots confirms that the latter are signatures of tail reconnection and strongly suggests an association with the inward moving bursty flow released during the process. This suggestion is additionally supported by a set of simultaneous HST and New-Horizons (NH) observations. During this period HST observes transient auroral spots and NH detects energetic ions exhibiting dispersive events possibly associated with inward moving flow.

Io UV footprint various spots: position and brightness variations

Bonfond, B.[1], D. Grodent[1], J.-C. Gérard[1], and A. Radioti[1]

(1) *Université de Liège, Liège, Belgium*

Abstract. The Io footprint (IFP) is the auroral signature of the electromagnetic interaction between Io and the jovian magnetosphere. The IFP is located equatorward of the main auroral emissions in each hemisphere, close to the feet of the field lines passing through Io. The footprint is composed of three different structures: a main bright spot, secondary upstream and downstream fainter spots and a long tail extending more than 90° longitude in the direction of planetary rotation. The evolution of the inter-spot distances has been found to be an excellent marker for understanding the Io-Jupiter interaction. Here we will show precise measurements of these distances based on the huge UV dataset gathered by the STIS and ACS cameras onboard the Hubble Space Telescope. On the other hand, we will show that the shift between Io's location and the main spot location is not a reliable parameter to diagnose the interaction. The brightness of the different spots and tail also provides valuable information on the nature of the interaction. However, linking the observed brightness to the precipitating electron flux is complicated by the particular 3D structure of the emission region. We will present an innovative method to deal with the limb brightening and other geometrical effects when measuring the brightness of the different spots. This technique, applied to the whole dataset, now allows us to accurately study the spots' brightness variations at various timescales, from minutes to years and to constrain the processes controlling the Io-Jupiter interaction.

Simultaneous study of plasma torus density near Io and the satellite's magnetic footprint brightness

Wannawichian, S.[1], **J. T. Clarke**[1], **W. H. Smyth**[2], **and C. A. Peterson**[2]

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(2) *Atmospheric & Environmental Research, Inc., Lexington, MA, USA*

Abstract. A number of FUV images by HST (Hubble Space Telescope) of Jupiter's auroral regions over more than ten years have shown a large collection of Io's magnetic footprint features. These auroral emissions appear to vary with the satellite's System III longitude. According to previous studies, there are several possible factors that could influence the brightness of Io's magnetic footprint. The magnetic footprint is the observed signature of the field-aligned current carried along the magnetic field lines from the interaction region near Io. Theoretical and observational studies suggested that the plasma density near Io is the main parameter controlling the footprint brightness. Io's magnetic footprint appears to be brightest when the satellite is located in the region of peak density, the plasma equator. Due to the nature of Jupiter's offset-tilted magnetic field, the location of the plasma equator is not aligned with Jupiter's equator or Io's orbital plane. Therefore the brightness of the footprint should vary with the distance of Io from the plasma equator, which mostly agrees well with the observed auroral brightness at Io's footprint. However, additional variations of the footprint brightness have been observed. To determine the cause of these variations, we use a four-dimensional empirical model for the density structure of the Io plasma torus. The model varies with four parameters: Dipole L shell, magnetic latitude, magnetic longitude, and local time. The model plasma density at Io will be directly compared with the satellite's magnetic footprint brightness. This study will therefore investigate the direct connection between Io's magnetic footprint and the nature of Io's plasma torus.

The morphology of equatorial electron beams at Io

Jacobsen, S.[1], J. Saur[1], F. M. Neubauer[1], B. Bonfond[2], J.-C. Gérard[2], and D. Grodent[2]

(1) *Institute of Geophysics and Meteorology, University of Cologne, Germany*

(2) *Laboratory for Planetary and Atmospheric physics, Université de Liège, Liège, Belgium*

Abstract. Io's powerful interaction with the surrounding plasma generates auroral footprints in Jupiter's atmosphere, which emit barely less than the whole UV aurora on Earth, roughly 10^{11} GW. The auroral footprints are assumed to be generated by energetic electrons that are accelerated downward (planetward) and precipitate into Jupiter's upper atmosphere. Associated with Io's interaction, energetic electron beams have also been observed in-situ by the Galileo spacecraft in the vicinity of Io. Their measured pitch-angle distributions suggest that these electron beams originate at high latitudes close to Jupiter where electrons are accelerated upward (anti-planetward) towards Io.

We apply a 3D MHD model of the far-field Io-Jupiter interaction to simulate for the first time the location and shape of equatorial electron beams for the individual flyby scenarios. We compare our results to Galileo observations and find a good agreement. We show that the electron beams reside further downstream from Io depending on the ratio of two crucial parameters: Alfvénic travel time and convection time. For Io both of these vary with Io's position in the plasma torus. Thus it represents a good prime example for our studies. Other moons exhibit similar interaction but of different strength and are therefore likely to display comparable equatorial beam phenomena but with different spatial locations compared to Io.

Coupled Simulations of Io, the Io Plasma Torus and the Jovian Magnetosphere

Winglee, R. M.[1], E. Harnett[1], D. Snowden[1], A. Kidder[1], L. Lerud[1], and C. Paty[2]

(1) *University of Washington*
(2) *Georgio Institute of Technology*

Abstract. Io is the dominant source of plasma to the inner Jovian magnetosphere. However, the plasma outflow from Io can vary due to changes in the plasma and magnetic field that the satellite is actually immersed to the wobble of Jovian magnetic field arising from the displacement of magnetic and rotation axes. To date simulations primarily treat Io as an isolated system and its impact on the Jovian magnetosphere is neglected. Processes associated with these coupled systems are investigated using multi-fluid/multi-scale simulations. The multi-fluid aspects enable the dynamics of the difference ions species relevant to Io/torus interaction to be examined, while the multi-scale aspects allows the investigation of small scale processes at Io to be resolved, along with large scale processes involved with the coupling of Io's plasma to the Jovian magnetosphere and ionosphere. The fluid aspect of the code allows the interaction to be studied for tens of hours as opposed a few minutes typical of local simulations. Due to the wobble of the magnetic field, Io is shown to be immersed in a variable plasma/magnetic field environment. This leads to the bending of the Alfvén wing so that on occasions it can actually point in the upstream direction. The Io plasma under global convection fields is pulled preferentially towards the Jovian magnetic equator so that north-south asymmetries develop in the outflows at Io. In addition, gravity/time-of-flight effects lead to mass separation so that there are distinct regions of plasma with different composition in light and heavy ions. Waves are also set up that cause the flapping of the ion tail from Io. These simulations provide new insight into how the torus plasma is sustained and the processes that lead to Io-related Jovian aurora.

Power transmission and particle acceleration along the Io Flux tube

Hess, S.[1]**, P. Delamere**[1]**, and V. Dols**[1]

(1) *LASP - University of Colorado*

Abstract. Io's motion relative to the Jovian magnetic field generates a power of about 10^{12} W which is thought to propagate as an Alfvén wave along the magnetic field line, until this power is transmitted to the electrons, which will then precipitate and generate the auroral phenomena that are observed from UV to Radio.

That is the general overview of the Io-Jupiter interaction, however a more detailed look at it shows some difficulties: Can the Alfvén waves escape the torus or are they trapped inside? Then where and how are the particles accelerated? In which direction? Is there enough power transmitted to the particles to explain the strong brightness of the auroral emissions in UV, IR, Visible and Radio? In other words : Can we make some global and consistent model of the Io-Jupiter which matches all the observations we have of it?

We will answer to this question by making a review of the models and studies that have been proposed so far and we will show that the Alfvén waves need to be filamented by some turbulent cascade to be able to explain the observations and to form a consistent scheme of the Io-Jupiter interaction.

Invited Talk

Modulation of Saturn's auroral radio emissions at or close to the planetary rotation period

Cecconi, Baptiste[1]

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Abstract. The variable periodicity of the Saturn Kilometric Radiation (SKR), first discovered with Ulysses data, is one of the most puzzling aspect of Saturn's magnetosphere dynamics. Magnetic field as well as plasma particule observations also revealed similar variables periodicities. An empirical system of longitude based on the long term fluctuations of the SKR periodicity modulation (SLS3) has been put together. This longitude system has been successfully used to organize other datasets (magnetic field, plasma particule, ENA...). On top of the long term variations of the periodicity, short term fluctuations were also observed. Their amplitude is as large as that of the long term fluctuations, and they are well correlated with the solar wind velocity (contrarily to the SKR intensity, which is correlated to the solar wind dynamic pressure). Recent observations are also suggesting that several simultaneous periodicities are observed in the SKR.

Two tools can be used to go one step further and directly characterize the radio emissions: (i) Simulation of the visibility of the SKR and (ii) Goniopolarimetric analysis. The visibility simulations provided evidences for sub-corotating radiosources, reminiscent of the UV auroral hot stop as observed by the HST. Goniopolarimetric analysis provides the actual source location and its magnetic footprint for each measurements allowing detailed studies of the SKR source dynamics.

Invited Talk

Energetic Particle Periodicities at Saturn

Carbary, J.F.[1] **and D.G. Mitchell**[1]

(1) *JHU/APL*

Abstract. All energetic charged and neutral particles in Saturn's magnetosphere display some sort of periodicity near the planetary rotation rate, here taken to be 10.80 hours. Essentially the same period appears at energies from 10 keV to over 100 keV, which is for electrons in the relativistic regime. These periodicities endure for many cycles and, with some notable interruptions, can be considered quasi-continuous over many years throughout several Saturnian seasons. Periodicities are recognized from the mid-magnetosphere (8 RS) well into the outer magnetosphere (60 RS). The periodicities do not display Doppler-like shifts expected from relative motions of source and observer, although they may vary over long time spans possibly in response to seasonal or solar wind effects. Furthermore, the particle periodicities do not have a consistent phase relative to other periodicities, such as those of the kilometric radiation. In some instances, charged particle periodicities are manifest as spiral patterns lasting several weeks in the SLS longitude system. The periodicities depend on observer latitude and are curiously similar to periods of zonal winds observed at polar latitudes. Finally, the particles may display two (or more) periodicities at the same time, and the relative strengths of the multiple periodicities can change over time spans of months.

Invited Talk

Theories of Rotating Periodicities

Kivelson, M. G.[1]

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Abstract. Possibly the most puzzling mystery in the study of outer planet magnetospheres arises from evidence that in the surroundings of a very nearly axially symmetric magnetic body, Saturn, properties of particles and fields are modulated at close to the planetary rotation period. The subject is likely to dominate much of the discussion at this 2009 Magnetospheres of Outer Planets meeting. From the first, the issue has generated contention. Some early interpretations proposed that a high order internal magnetic anomaly accounts for the periodic variation of power in Saturn Kilometric Radiation (SKR). However, after the SKR period was found to drift at a rate incompatible with internal convection, numerous, creative proposals for a mechanism have burgeoned. At this stage, little is rigorous and the theories that have been presented are neither complete, nor quantitative, nor self-consistent. This talk will identify some of the contending concepts including those that invoke current systems of various symmetries those that link drift of periods to the solar wind-magnetosphere interaction, those that focus upon plasma non-uniformities in convective flow, density, or energetic particle properties and others that invoke internal mass-loading to produce periodic dynamical responses. As in the classic substorm problem of the terrestrial magnetosphere (how are responses in the magnetosphere and ionosphere coupled and what happens first), the solution of the periodicity problem has two components. The linkages among the multiple observed responses must be understood and then the more fundamental and least understood question of the underlying source of asymmetry in the system must be answered.

A North-South Asymmetry In the Rotational Modulation Period of Saturn Kilometric Radiation

Gurnett, D.A.[1], A. Lecacheux[2], W.S. Kurth[1], A.M. Persoon[1], J.B. Groene[1], S. Ye[1], and J.F. Carbary[3]

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Abstract. It is known from measurements by the Cassini Radio and Plasma Wave Science (RPWS) instrument that the rotational modulation period of Saturn Kilometric Radiation (SKR) has two distinct components, each with a different period. The first, which was initially thought to be the only component, occurs at a period of about 0.451 days, or 799 deg/day. The second, which was first detected in late 2006 by Kurth et al. (2008), occurs at a period of about 0.441 days, or 816 deg/day. Both have slowly varying amplitudes and small variations (fraction of a percent) in the modulation period on time scales ranging from weeks to a year or more. Recent Cassini measurements at high northerly and southerly latitudes, more than 60 degrees from the equator, now show that the first, longer period, component primarily originates from a source in the southern hemisphere, and that the second, shorter period, component primarily originates from a source in the northern hemisphere. Just how the SKR sources in the two hemispheres could have such markedly different rotational periods is not known, but does imply a substantial longitudinal slippage of the plasma along a given L shell, contrary to the expectation of the frozen field model of magnetohydrodynamics. However, a longitudinal slippage is allowed if there are electric fields parallel to the magnetic field, such as are expected to occur along the auroral field lines, where the SKR is believed to be generated. Possible reasons for the north-south difference in the modulation period could include hemispherical differences in the high altitude zonal winds, differences in the solar illumination (hence ionospheric conductivity) in the two hemispheres, differential slippage of the magnetospheric plasma due to the above mentioned parallel electric fields, or some internal dynamical process involving the generation of Saturn's magnetic field.

Studies of high latitude phase pulses in the Saturnian SKR radio and comparison with Cassini magnetic field data

Lecahceux, A.[1] **and D. J. Southwood**[2]

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(2) *ESA HQ, Paris, France, Imperial College London, UK and IGPP, UCLA, Los Angeles, USA*

Abstract. The slow variation in the period of the Saturnian SKR radio signals and its association with the rotating "cam" magnetic field signal are fundamental puzzling features of the Saturn system. The rotating cam field is seen superposed on the rotationally aligned planetary dipole field throughout the dipolar region of the Saturnian magnetosphere, the region where the dipole field is dominant. The radio pulse peak comes at a distinct phase in the magnetic rotation and has been explained as an interaction between the field aligned currents associated with the cam and a separate currents on flux tubes at higher latitude associated with the solar wind interaction. Reports have recently emerged of the presence of more than one frequency in the radio signal. This work confirms this result but also brings the new finding that there is a second period in the magnetic signal. Aliasing complicates the magnetic analysis, but one can firmly state that the observations are consistent with the higher frequency signal having a period about 3 per cent smaller than the dominant period. It is likely that at low and mid-latitudes the signal is normally a mixture of the two whilst at high latitudes in each hemisphere has a preferential period (with currently the longer period dominant in the southern polar region). In the recent past the amplitudes may have become more equal. This report further complicates an analysis of the origin. Mechanisms will be discussed.

Dual periodicities in the magnetospheres of Jupiter and Saturn

Crary, F. J.[1] **and T. W. Hill**[2]

(1) *Southwest Research Institute*
(2) *Rice University*

Abstract. Two distinct periods, both near the rotational period of the planet, have been identified in Saturn's kilometric radio emissions [Kurth et al., 2008]. The first is that of the usual SLS rotation rate, associated with a wide range of periodic phenomena in Saturn's magnetosphere. The amplitude of the second period, at 815^o/day or approximately 2% faster than SLS, is typically lower than that of the SLS amplitude. Unlike the SLS period, the 815^o/day signal appears to have a constant rate. We note that Jupiter's magnetosphere also exhibits two distinct periods. One is the traditional System III period, has an extremely steady rate, is clearly generated by asymmetries in the planet's internal field and corresponds to the rotation rate of the planet's interior. The second, "System IV" periodicity, on the other hand, is 2-3% slower than System III, is relatively faint, has been reported at rates which vary by $\sim$1%, and has been observed to abruptly shift in phase by 100 deg [Brown, 1995.] The origin of System IV periodicity is unknown.

We suggest that these dual periodicities in the magnetospheres of Jupiter and Saturn are related. One period is generated by asymmetries in the planet's internal field, and therefore has a steady rate and reflects the internal rotation rate of the planet. In the case of Jupiter, this is the System III period; in the case of Saturn, this would be the 815^o/day period. The relative amplitudes of these periods result from the relative asymmetry of the planet's internal field: This mode is the dominant source of rotational periodicity at Jupiter because of the strong asymmetries in Jupiter's internal field. In contrast, this mode is faint in Saturn's magnetosphere due to the highly symmetric nature of Saturn's internal field.

The second type of periodicity is not clearly understood at either planet. At Saturn, its source has been described as a m=1 convection system or structure. It has been assumed that this source corotates, with a few percent slippage, and that the disturbance propagates outward into the magnetosphere as a whole. Recent analysis of CAPS data shows that the plasma in the inner magnetosphere does not corotate. We suggest that some process favors the growth of a mode whose phase velocity matches that of the planet's ionosphere. Since this reflects the rotation rate of the thermosphere, it would not necessarily be constant. Seasonal changes and magnetospheric forcing could also cause variability.

The puzzle of SKR and magnetic field periodicities in Saturn's magnetosphere

Vasyliūnas, V.M.[1]

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Abstract. A variety of phenomena observed in the magnetosphere of Saturn exhibit periodic time variations with a period essentially the same as that of the SKR radio emissions. Among them are the magnetic field perturbations of the type sometimes referred to as the "camshaft" field, conventionally interpreted as a corotating azimuthally asymmetric spatial structure (no periodic variation in the corotating frame), with the phase of the apparent modulation varying directly with local time. This is in contrast to the SKR radio emissions themselves, the periodic modulation of which is universally regarded as purely temporal, with the same phase at all local times. The condition of zero phase difference between the SKR and the magnetic modulation defines a special local time, corresponding to a particular orientation of the corotating magnetic field structure (relative to the solar wind direction), presumed favorable for exciting the SKR emissions; the magnetic phase Ψ_M defined by Andrews et al. (2008) and Provan et al. (2009) corresponds to minus the azimuthal angle ϕ of this special local time. Comparison of their results on the long-term variation of Ψ_M with their orbital data shows that much of the time (with one striking exception), the observationally inferred Ψ_M follows approximately the precession of the line of apsides of the Cassini spacecraft, rather than remaining fixed relative to the solar wind direction. How to interpret this poses a genuine puzzle. (Ascribing everything to coincidence would imply that the observations are too variable to constitute confirmation of the hypothesis relating SKR periodicity to the rotating "camshaft" field structure.) A rational explanation requires that, during the time interval when the analysis of Provan et al. (2009) extends beyond the SKR phase model of Kurth et al. (2008), the actual SKR phase agree with the observed magnetic phase (and hence deviate markedly from the extrapolated model); there are also indications that the rotation rate of the "camshaft" field structure may depend on local time. The current assumptions on the relative importance of strobe vs. rotating-beacon types of modulation and on the existence of a well-defined SKR phase may need to be reexamined.

Cause of Saturn's Plasma Cam

Goldstein, J.[1], J. Burch[1], A. DeJong[1], and D. Young[1]

(1) *Southwest Research Institute*

Abstract. Statistical analysis of over two years of plasma ion data from the Cassini Plasma Spectrometer (CAPS) has revealed the presence of a cam-shaped distribution that rotates with the SKR-based SLS3 longitude system. Though the plasma cam's spatial distribution (extending to 25 Saturn radii (RS) between 0-45 degrees SLS3 longitude) is similar to a rotating density feature in plasma wave data observed by Gurnett et al. [2007], its cause is still undetermined. This paper investigates whether the plasma cam can be formed by the creation of a rotating two-cell convection pattern, produced either by an m=1 interchange mode (as suggested by Gurnett et al. [2007]) or by coupling of Saturn's ionosphere to a partial ring current (observed by Mitchell et al. [2005]). A simple analytical model of the proposed two-cell convection is used to estimate the magnitude of associated currents and fields (electric and magnetic).

Why Does Saturn's Magnetosphere Develop Azimuthal Asymmetries?

Khurana, K.K.[1], **M.K. Dougherty**[2], **C.T. Russell**[1], **C. Paranicas**[3], **and P.C. Brandt**[3]

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Abstract. Many in situ and remote sensed field and plasma parameters display evidence of rotating azimuthal asymmetries with a period close to that of the Saturn Kilometric Radiation (SKR). In addition, the magnetospheric current sheet displays a tilt in this rotating frame. Khurana et al. (2009) have shown that the tilt arises from an asymmetric lift of Saturn's magnetosphere in the presence of a rotating partial ring current.

After discussing the pros and cons of several models of plasma asymmetry generation in Saturn's magnetosphere, we focus on a model of self-generation of energetic particles' azimuthal asymmetry from reconnection induced particle injections and bursty-bulk flows launched into inner magnetosphere from the neutral line. We argue that the magnetosphere favors the azimuthal m = 1 mode over m = 0 (uniform ring current) and other higher order and non-integral modes because for a given integrated energy density of particles , this mode produces the most stretched configuration in the reconnection region and thus the strongest feedback reaction from the magnetotail.

ROTATIONAL PERIODICITIES IN SATURN'S MAGNETOSPHERE

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Abstract. A central question for Saturn's magnetospheric dynamics is the origin of periodicities close to the presumed rotational period of Saturn (10.8 h). Periodic oscillations are observed in the magnetic field, particles, Saturn kilometric radiation (SKR) and more. We discuss the possibility that all periodicities are likely to have one common cause: periodic plasmoid release from the night side sector. The rapid magnetic field reconfigurations following the plasmoid release energize charged particles and create the large scale injections that are clearly seen in energetic neutral atom (ENA) images observed by the INCA camera on board Cassini. We further show that the magnetic field oscillations and SKR can be explained by the currents, by necessity driven by the observed injected and energized plasma pressure distribution drifting around Saturn. The evolution of these pressure-driven currents is consistent with the evolution of the SKR. To quantify the magnetic field oscillations we estimate the distribution and strength of the plasma pressure from Cassini/MIMI and CAPS observations of hot and cold plasma. An important constraint is the how the magnetospheric dynamics respond to variations in solar wind dynamic pressure (SWP). In order to quantify this constraint we use SWP measurements from when Cassini is in the solar wind as well as model propagated solar wind properties to investigate how periodicities vary as a function of SWP. We further speculate that the ultimate cause of the periodic plasmoid releases is an effect of the inherent stability of the cold plasma without the need of a longitudinal anomaly tied to the planet's core or ionosphere.

Saturn's Clock: Concept for Generating and Maintaining Saturn's Observed Magnetospheric Periodicity

Mitchell, D. G.[1], P. C. Brandt[1], and A. Ukhorskiy[1]

(1) *JHU/APL*

Abstract. Saturn's 10.X hour periodicity, observed throughout the magnetosphere, remains a mystery. It has been observed in many regions, modulating many phenomena. Multiple periods have been observed, although the most enduring during the Cassini mission has been the period at about 10.8 hours, expressed in Saturn kilometric radiation from the high latitude auroral zone, in magnetic field components (both equatorial and high latitude) from 3 to 12 Rs, in current sheet encounters in the outer magnetosphere and magnetotail, in energetic neutral atom emission, and in plasma and energetic particles in the magnetotail. The cause of this periodicity is still not accounted for. Although loosely associated with Saturn's rotation, the variability in the period precludes a direct connection with Saturn's interior (e.g., a magnetic anomaly). Other candidates that have been discussed by others are an ionospheric source (conductivity anomaly), a perturbation in the cold plasma circulation pattern, a magnetospheric cam, asymmetric ring current particle pressure, and/or a natural frequency of the magnetosphere (cavity mode or traveling wave front of some sort). In this paper we present a concept that may involve some or all of these to-date unconfirmed candidates. The concept would require a particular configuration of the cold plasma density in the current sheet beyond about 15 Rs, and the regular release of plasma, perhaps as plasmoids, on the night side on every cycle of the observed periodicity. In the clock analogy, the centrifugal force on the cold plasma serves as the clock weights, plasmoid release serves as the pendulum, and feedback via the ring current to the ionosphere serves as the escapement.

We have surveyed some of the energetic particle data to search for evidence of such regular plasmoid release, and our results are inconclusive. We have, however, identified compositional dependencies in the energy attained during the acceleration of charged particles in likely candidates for current sheet acceleration on the planetward side of plasmoid release, that is consistent with current sheet acceleration features seen during storm-time substorms at Earth.

Saturn's equatorial magnetic field oscillations

Andrews, D. J.[1], S. W. H. Cowley[1], M. K. Dougherty[2], G. Provan[1], and D. J. Southwood[3]

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(2) *Blackett Laboratory, Imperial College, London, U.K.*
(3) *ESA Headquarters, Paris, France*

Abstract. We present the results of a comprehensive investigation of the amplitude and phase of the magnetic field oscillations seen ubiquitously throughout Saturn's equatorial magnetosphere by the Cassini spacecraft. We employ the phase model of *Provan et al.* [2009] to organise the data, determined over the interval from July 2004 through to January 2008. Throughout this interval we obtain near-complete coverage of the equatorial plane, out to 30 Saturn radii.

We find phase and amplitude behaviour showing the presence of a quasi-uniform field within ∼15 Rs that rotates in the sense of planetary rotation though with evidence of suppression in the inner region. Beyond ∼15 Rs we see evidence for a change of field geometry towards that of a rotating transverse dipole with a substantial region near dawn in which the oscillating field rotates opposite to the sense of planetary rotation. Field amplitudes are typically 1-2 nT and exhibit a significant day – nightside asymmetry, with larger fields on the nightside. A movie has been produced that shows the behaviour of the oscillating field over a complete cycle of rotation.

Using a finite-difference scheme we are able to estimate the electric current flowing north-south through the equatorial plane. A movie has also been produced showing the evolution of the current system over a complete rotation. This shows a rotating four-component system flowing in the outer region centred near 15 Rs that we relate to the current systems proposed by *Southwood & Kivelson* [2007] and *Provan et al.* [2009], together with an inner two-component system centred near ∼7 Rs associated with the inner field suppression effect.

Oral Presentations

Tuesday 28$^{\text{th}}$ July, 2009

Invited Talk

News from outer worlds

Grodent, D.[1]

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Abstract. For more than 15 years we have been cautiously shaping a big picture of the ultraviolet auroral phenomena at Jupiter and Saturn. At present, we are able to recognize the main components of the auroral morphology. However, this interpretation rests on an average view. As we go further into the details of the morphology and take full advantage of the spatial and temporal resolutions offered by present observing instruments, we realize that these "details" bear fundamental information on magnetosphere-ionosphere coupling and on mechanisms giving rise to particle precipitation into the ionosphere of the giant planets. We will review recent results that have been principally inferred from UV images of Jupiter and Saturn obtained with the Hubble Space Telescope and Cassini spacecraft, and get news from these outer worlds.

Invited Talk

Saturn Auroral Images and Movies from Cassini UVIS

Pryor, W. R.[1], L. W. Esposito[2], A. I. F. Stewart[2], A. Jouchoux[2], W. McClintock[2], G. Holsclaw[2], S. Eriksson[2], J. M. Ajello[3], R. A. West[3], C. J. Hansen[3], A. R. Hendrix[3], D. E. Shemansky[4], J. T. Clarke[5], J. Nichols[6], J. Gustin[7], D. Grodent[7], J. C. Gerard[7], J. Colwell[8], G. Hospodarsky[9], and D. Mitchell[10]

(1) *Central Arizona College; Space Environment Technologies*
(2) *LASP, University of Colorado*
(3) *JPL*
(4) *Space Environment Technologies*
(5) *Boston University*
(6) *University of Leicester*
(7) *University of Liege*
(8) *University of Central Florida*
(9) *University of Iowa*
(10) *APL*

Abstract. Cassini's Ultraviolet Imaging Spectrograph (UVIS) has completed five years of study of Saturn's atmosphere and auroras. Two long slit spectral channels are used to obtain EUV data from 56.3-118.2 nm and FUV data from 111.5-191.3 nm. 64 spatial pixels along each slit are combined with slit motion to construct spectral images of Saturn. Auroral emissions are seen from electron-excited molecular and atomic hydrogen. In 2008-2009 UVIS obtained data with the spacecraft well out of Saturn's ring plane, permitting UVIS to obtain a number of short movies of the rotating auroral structures. In some movies a cusp-like feature is present near noon inside the oval. One movie from 2008 day 201 shows parallel linear features on the day side almost at right angles to the main auroral oval that appear, then lengthen, separate in the middle, and then fade away. The same movie also shows one bright "polar flare" inside the oval. A few of the most recent images were obtained at sufficiently close range that 2 spacecraft slews were needed to completely cover the oval. These images provide almost 100 pixels of information across the oval and clearly show multiple arcs of emission on the main oval and scattered emissions inside the oval. We will discuss these features, their locations, and possible interpretations. We also report on a search for an Enceladus auroral footprint on Saturn.

The Variability of Auroral Emissions on Jupiter and Saturn

Clarke, J.T.[1], J. Nichols[2], J.-C. Gerard[3], and D. Grodent[3]

(1) *Boston University*
(2) *Univ of Leicester*
(3) *Univ of Liege*

Abstract. The 4 concentrated HST observing campaigns of the aurora on Jupiter and Saturn in 2007-2008 have provided a large new dataset with comprehensive coverage over month-long intervals. One main goal of this program was to compare auroral power with solar wind parameters, a study now in press in JGR. In general, Saturn's auroral emissions and the radius of the oval correspond with the arrival of solar wind pressure fronts, while some of Jupiter's auroral emissions have been seen to do the same and others did not. These results will be briefly summarized, but in addition there is considerable new information about the variations of different auroral emissions on the two planets. This presentation will go into greater detail on the variations of the different auroral emitting regions at Jupiter and Saturn, the frequency and kinds of storms, and how these compare with the data from other spacecraft.

Saturn's equinoctial auroras

Nichols, J. D.[1], S. V. Badman[1], E. J. Bunce[1], J. T. Clarke[2], S. W. H. Cowley[1], F. J. Crary[3], M. K. Dougherty[4], J.-C. Gérard[5], D. Grodent[5], K. C. Hansen[6], W. S. Kurth[7], D. G. Mitchell[8], W. R. Pryor[9], T. S. Stallard[1], D. L. Talboys[1], and S. Wannawichian[2]

(1) *University of Leicester*
(2) *Boston University*
(3) *Southwest Research Institute*
(4) *Imperial College London*
(5) *Université de Liège*
(6) *University of Michigan*
(7) *University of Iowa*
(8) *Johns Hopkins University*
(9) *Central Arizona College*

Abstract. Saturn's ultraviolet (UV) auroras were observed in January and February 2009 using the Advanced Camera for Surveys (ACS) on the Hubble Space Telescope (HST). During this time Saturn was approaching equinox, such that the sub-Earth latitude was very low. From this near-equatorial vantage point, both the north and south auroras were simultaneously visible for the first time since the advent of high sensitivity planetary auroral imaging. At the same time Cassini was obtaining plasma, magnetic field, radio, and auroral data from a highly inclined orbit, and ground-based infrared (IR) observations were obtained using the Infrared Telescope Facility (IRTF). In this paper movies of the HST images will be presented, and the first results of this campaign will be discussed. We show that the total UV power emitted from both hemispheres is generally similar, however individual auroral features can exhibit distinct hemispheric asymmetries. We also show that the radius of the northern auroral oval is $\sim 1^\circ$ smaller than the southern, a result which independently verifies the multipole nature of Saturn's internal magnetic field.

Location and morphology of Saturn's infrared aurora observed by Cassini VIMS

Badman, S.V.[1], T. Stallard[1], . Cassini VIMS team (PI: R.H. Brown), and U.K. MAG-VIMS collaboration team

(1) *University of Leicester*

Abstract. An unprecedented collection of images acquired by the Cassini VIMS instrument during 2006 – 2009 has been examined to determine the location and morphology of Saturn's infrared auroral emissions. Both the northern and southern hemisphere aurorae have been observed, facilitating comparisons between the two. The occurrence of bright polar emissions and arcs equatorward of the main oval are also studied, with an aim to gain insight to the driving magnetospheric processes. Comparisons with the known characteristics of the UV aurora, including latitudinal position and temporal variability, are also made to identify common features and processes.

Changes in polar ion wind flows during periods of solar wind compression

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(3) *Laboratory for Atmospheric and Space Physics*

Abstract. Previous analysis of Doppler-shifted H_3^+ emission in the auroral region of Jupiter revealed a complex wind system, with ion winds associated with the main auroral oval surrounding a polar region containing three separate wind systems (Stallard et al., 2003). The bright polar region (BPR - on the dusk side) contained near-corotating ions, while the dark polar region (DPR - on the dawn side) appeared to consist of two sub-regions, a central region fixed with a zero velocity in the inertial frame (f-DPR), partially surrounded on the dawn flank by a region returning to corotation (r-DPR). The presence of a zero-inertial-velocity points to an external control on the ionosphere driven by the solar wind, that has been interpreted as a form of Dungey cycle processes at Jupiter (Cowley et al., 2003).

Here, we present new ground-based observations of H_3^+ emission from Jupiter's aurorae made during a solar wind compression of the magnetosphere. These show a dramatic change in the polar ion wind structure, with the f-DPR begin significantly reduced in size relative to the DPR as a whole, indicating a significant effect of the solar wind on this region. These ground-based infrared observations were made simultaneously with Hubble Space Telescope observations of the UV aurorae. We can thus make the first detailed comparison of the ion wind system against the UV aurorae, and one of the first comparisons of the infrared and UV emission morphology. This can then be used to attempt to better understand the effect of solar wind control in Jupiter's ionosphere, and thus solar wind driving of Jupiter's magnetosphere-ionosphere system.

Invited Talk

Auroral current systems at Saturn: Observations from Cassini and the Hubble Space Telescope

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Abstract. New observations of Saturn's high-latitude magnetosphere by the Cassini spacecraft have allowed the first detailed exploration of an extra-terrestrial auroral current system. Combining these in situ measurements with observations of Saturn's UV aurora from the Hubble Space Telescope (HST) has allowed us to enhance our understanding of the processes which drive the main emissions. In this review, the high-latitude measurements of the field-aligned current systems from a variety of Cassini instruments at Saturn will be discussed in relation to specific intervals and general observations of Saturn's dynamic auroral emissions mainly from the HST. We also have auroral images from the Ultraviolet Imaging Spectrometer (UVIS) and the Visible Imaging Mapping Spectrometer (VIMS) instruments from Saturn orbit which will also be briefly discussed here, in particular focussing on opportunities for comparison with the in situ field-aligned current observations. Overall, new observations from Saturn are both confirming and challenging our previous theoretical picture of the auroral current system and some modifications will be suggested.

Large-scale vorticity in Saturn's outer magnetosphere as a driver of auroral emissions

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(4) *University of California, Los Angeles*
(5) *Mullard Space Science Laboratory*
(6) *Johns Hopkins University*
(7) *Los Alamos National Laboratory*
(8) *Max-Planck-Institut*

Abstract. We present the first observations of a Kelvin-Helmholtz (K-H) vortex at the edge of Saturn's boundary layer. The Cassini spacecraft made multiple crossings of the magnetopause on 13 December 2004 at a local time of approximately 10 hrs during the inbound pass of its low-latitude Rev B orbit, repeatedly encountering the boundary layer. The analysis of magnetic field, plasma, and energetic particle data taken during the final crossing from the boundary layer into the magnetosphere reveals that the spacecraft encountered a twisted field topology, disturbed boundary layer and magnetospheric plasmas, and unidirectional, field-aligned beams of high-energy (>20 keV) electrons during an approximately two hour transition. We show that these features are consistent with a spacecraft encounter with a K-H vortex on the edge of the boundary layer. Simple physical arguments suggest that an appreciable field-aligned current was present, and that the vortex scale was greater than 0.8 Saturn radii.We propose that the energy fluxes of the observed beams were sufficient to excite auroral emissions. The potential implications of these results for our understanding of Saturn's aurorae are discussed, including the proposed relationship between K-H instability in the outer magnetosphere and Saturn kilometric radiation.

In Situ Measurements of a Low-Frequency SKR Source Region at Saturn

Kurth, W.S.[1], D.A. Gurnett[1], J.D. Menietti[1], R.L. Mutel[1], M.G. Kivelson[2], E.J. Bunce[3], S.W.H. Cowley[3], D.L. Talboys[3], M.K. Dougherty[4], C.S. Arridge[5], A.J. Coates[5], S. Grimald[5], L. Lamy[4], P. Zarka[6], B. Cecconi[6], P. Schippers[7], N. Andre[8], P. Louarn[7], D. Mitchell[9], and J.S. Leisner[1]

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Abstract. Earth orbiting satellites have routinely traversed auroral kilometric radiation source regions. This radio emission is generated via the cyclotron maser instability at frequencies very close to the electron cyclotron frequency f_{ce}. Hence, an often-used criterion for the identification of a source region is the detection of radio emission at and even below f_{ce}. While Cassini's orbit has taken it to sufficiently high latitudes to cross auroral field lines, the radial distance at auroral latitudes is typically near 5 R_S, generally too high for the analogous Saturn kilometric radiation (SKR) source. However, on Oct. 17, 2008, between ~8:30 and ~9:00 UT the Radio and Plasma Wave Science (RPWS) instrument detected the low frequency extent of SKR between 8 and 9 kHz, at and just below the measured f_{ce}, based on magnetometer measurements. At this time the spacecraft was at a distance of 5 R_S at 0.9 hr local time, at ~65^o S. latitude, and on dipole L-shells in the range of 25 to 30. In the putative source the azimuthal component of magnetic field, B_ϕ, was increasing, indicating motion of the spacecraft from a region in which the field was leading to one which was lagging. Hence, the corresponding current was directed upward, away from the planet. Low energy electron observations by the Cassini Plasma Spectrometer (CAPS) instrument are being analyzed for evidence of electron beams or other features that may drive the cyclotron maser instability. Growth rate calculations will be made to assess the capability of the electrons to support the generation of the radio emissions.

An auroral oval at the footprint of Saturn's radiosources, colocated with atmospheric aurorae

Lamy, L.[1], R. Prangé[2], B. Cecconi[2], P. Zarka[2], S. Hess[3], J. D. Nichols[4], J. T. Clarke[5], W. Pryor[6], T. Stallard[4], and S. Badman[4]

(1) *Imperial College London*
(2) *LESIA, Observatoire de Paris*
(3) *LASP, University of Colorado*
(4) *University of Leicester*
(5) *University of Boston*
(6) *Central Arizona College*

Abstract. Similarly to other magnetized planets, accelerated electrons gyrating around high latitude magnetic field lines generate auroral emissions at Saturn. They divide into Ultraviolet (UV) and Infrared (IR) aurorae, originating from electron collisions with the upper atmosphere, and Saturn's Kilometric Radiation (SKR), radiated from higher altitudes by electron-wave resonance. Whereas spatially resolved UV and IR images of atmospheric aurorae reveal a continuous auroral oval around each pole, the SKR source locus was only indirectly constrained by the Voyager radio experiment to a limited local time (LT) range on the morning side, leading to interpret the SKR modulation as a fixed flashing light. Here, we present resolved SKR maps derived from the Cassini Radio and Plasma Wave Science (RPWS) experiment using goniopolarimetric techniques which reveal radio sources at all longitudes distributed along a high latitude continuous auroral oval. Observations of UV aurorae by Hubble Space Telescope (HST) and Cassini/UVIS, and of IR aurorae observed by Cassini/VIMS have been compared to simultaneous and averaged Cassini-RPWS measurements, revealing that SKR and atmospheric auroral ovals are very similar. The correspondence between radio and UV auroral emissions during the HST observations of January 2004 is used to model the sudden disappearance of SKR high frequencies observed at high northern latitudes, showed to be a consequence of the strong SKR anisotropy.

Oral Presentations

Wednesday 29$^{\text{th}}$ July, 2009

Invited Talk

Global magnetospheric fields of Saturn and Jupiter

Arridge, C. S.[1]

(1) *Mullard Space Science Laboratory, University College London, UK*

Abstract. The Cassini spacecraft has spent over four years in orbit at Saturn and has collected a wealth of information over all local time sectors in Saturn's magnetosphere. In this talk we distil these data and present a global overview of Saturn's magnetospheric field. In particular we will discuss i) various models of Saturn's internal field, ii) the ring current and the development of magnetodisc geometry in the outer magnetosphere, iii) warping of the magnetodisc, iv) bend-back of Saturn's magnetic field lines, v) the field due to magnetopause currents, vi) the location of the open/closed field line boundary, and vii) the impact of global magnetospheric periodicities on Saturn's global magnetospheric field. Recent studies of these features will be described and the most recent empirical and numerical models discussed.

Models of the Plasma Sheet at Jupiter and Saturn

Bagenal, F[1] **and M Desroche**[1]

(1) *University of Colorado*

Abstract. We develop quantitative models of plasma conditions in the magnetospheres of Jupiter and Saturn and evaluate how these properties vary with radial distance, latitude, longitude, local time and time. We combine in situ plasma measurements with models of the magnetic field and of the plasma composition (derived from physical chemistry) to extrapolate the plasma density along flux tubes and map out the density distribution in meridian planes at different local times. We explore the effects of thermal anisotropy and supra-thermal velocity distributions on the density maps. An objective of this study is to derive a quantitative description of the heating necessary to produce the high-beta plasma in the outer magnetosphere which we believe to be a key component of global models of the dynamics of these magnetospheres.

Effect of Field-Aligned Potentials on Magnetospheric Dynamics at Jupiter and Saturn

Ray, L. C.[1], R. E. Ergun[1], P. A. Delamere[1], F. Bagenal[1], and Y.-J. Su[2]

(1) *LASP/University of Colorado*
(2) *AFRL*

Abstract. We present a time-independent model of Jupiter's rotationally driven aurora based on torque balance between the ionosphere and magnetosphere, including the effects of a field-aligned potential and a variable Pedersen conductivity. The field-aligned potential arises from field-aligned current limitation at high-latitudes and changes the mapping of the electric fields between the ionosphere and the magnetosphere. We apply a Vlasov study to determine the location and extent of the field-aligned potential drop along the flux tube. We then adjust the Pedersen conductivity to vary with electron precipitation energy and incident energy flux consistent with the study by *Millward et al. (2002)*. The primary effect of the field-aligned potential is to enhance coupling by increasing angular momentum transfer from the ionosphere to the magnetosphere. The net result is an equatorial mapping location for the main auroral oval at ~ 25 R_J. Our model reproduces many of the observed characteristics of Jupiter's main auroral oval including the energy flux into the ionosphere (2 – 30 mW/m^2), the width of the aurora at the ionosphere (1000 km) and field-aligned potentials consistent with observed electron energies (30 – 200 keV). We apply our model to Saturn and find that the magnetospheric plasma at Saturn may make a significant contribution to Saturn's main auroral oval. Our model at Saturn reproduces the angular velocity profiles determined from Cassini and Voyager data.

Radiation Belts of the Solar System

Mauk, B. H.[1]

(1) *The Johns Hopkins University Applied Physics Laboratory*

Abstract. Motivated by renewed interest in radiation belt physics, with the anticipated launch of the Radiation Belt Storm Probes in 2012, we here compare aspects of the radiation belt processes at Earth, Jupiter, Saturn, Uranus, and Neptune, with a special focus on new Cassini measurements at Saturn. We emphasize evidence that for active magnetospheres, electron spectral intensities are driven towards classical Kennel-Petschek-like limits and that spectral shapes are sculpted by the associated near-saturated wave particle loss processes in a fashion that was predicted by Schulz and Davidson (1988, Limiting Energy Spectrum of a Saturated Radiation Belt, J. Geophys. Res., 93, p. 59).

Structure, variation and pressure balance in the Saturnian plasma sheet. Combined MIMI, CAPS and MAG measurements from Cassini.

Sergis, N.[1], C. S. Arridge[2], S. M. Krimigis[3], D. G. Mitchell[3], A. M. Rymer[3], D. C. Hamilton[4], N. Krupp[5], E. C. Roelof[3], M. K. Dougherty[6], and A. J. Coates[2]

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(6) *Space and Atmospheric Physics Group, Imperial College, Huxley Building, Imperial College, South Kensington,*

Abstract. Combined plasma, energetic particle and magnetic field measurements, obtained by the Cassini Plasma Spectrometer (CAPS), Magnetospheric Imaging Instrument (MIMI) sensors and the magnetometer (MAG) respectively, are used to study the Saturnian plasma sheet as revealed through nearly vertical passes of Cassini during its inclined orbits. Trajectories with such geometry favour the clear detection of plasma sheet boundaries, both in magnetic field and particle data. As the in-situ Cassini measurements offer complete energy coverage (eV to MeV) of the cold plasma and the energetic particle population (where present), the computation of total plasma pressure and density is made possible. In this presentation the extent and temporal variability of the plasma sheet will be examined. We will present scale heights for the plasma and energetic particles (per species/population where possible), calculated using different model profiles (e.g., exponential decay, Harris) and compared with the scale height of the current sheet. Initial results indicate that the dayside energetic plasma sheet is wide in latitude (+/- 45 degrees), the lower-energy plasma sheet is thinner and both sheets extend out to the dayside magnetopause. The plasma sheet pressure is observed to fall with radial distance, while the night side plasma sheet appears to be much thinner in both plasma and energetic particles, with a larger scale height for energetic ions (2 Rs) compared to the cold-warm plasma (1 Rs). Plasma beta is kept close to or above 1 inside the plasma sheet region, outside 8 Rs.

Invited Talk

Hot electrons and their influence on the Enceladus and Io tori

Delamere, P. A.[1]

(1) *University of Colorado*

Abstract. A non-thermal tail to the electron distribution function has been measured in the inner magnetospheres of both Jupiter and Saturn. These "hot" electrons (∼10s - 100s eV) are only a small fraction (<1%) of the total electron density, yet their influence on the gas tori at Jupiter and Saturn is significant. We will review the role of hot electrons in both systems. Hot electrons are a dominant source of energy input into the Io plasma torus. This energy input is required to sustain the $\sim 10^{12}$ W of power radiated in the UV and EUV as well as to sustain the high ionization state of the torus. At Saturn, the energy input is negligible, but the hot electrons dominate ionization (see Fleshman abstract). We propose that the observed azimuthal electron density modulation at Saturn is caused by an azimuthally varying hot electron abundance, consistent with observations and models of the Io plasma torus (see Steffl abstract). Finally, we will discuss the possible origins of these ubiquitous hot electrons and the possible electron heating mechanisms associated with field-aligned current systems.

Invited Talk

Saturn's magnetospheric electrons.

Rymer, A. M.[1]

(1) *Johns Hopkins University Applied Physics Laboratory*

Abstract. In this presentation we will review the sources, losses and energisation of electrons at Saturn. The composition of Saturn's magnetosphere is dominated by the ionization of neutral atoms, which provides a distributed source of electrons through impact and photo-ionisation. Initially cold, freshly produced electrons almost instantaneously experience the planetary electric field and are picked up at the local rotational energy. The energy available in this process is proportional to mass and so is very low for electrons, with the resultant electrons remaining below the lowest energy measured by the Cassini sensors. Despite this, we still clearly observe a dense cold electron component whose energy increases with increasing distance consistent with (but hotter than) the local pick-up energy. Analysis shows that this can happen through Coulomb collisions between the electrons and the much hotter proton and water group ions. This takes time and is therefore indicative that radial transport associated with the cold electron component is slow. Superposed on the cold electron component in the range $5 < L < 11$ is a hotter electron component that is formed from rapid inward radial injection coupled with azimuthal drift. Pitch angle analysis indicates that these electrons move rapidly from the middle magnetosphere conserving the first and second adiabatic invariants, forming "pancake" pitch angle distributions (peaked at 90 degrees with minima at 0 and 180 degrees). Drifting hot electrons display a characteristic "butterfly" pitch angle distribution which arises from a combination of outward transport and equatorial losses. Hot and cold field aligned electrons are also occasionally observed and are associated with field aligned currents; this type of process has been put forward to explain an ostensibly similar hot electron component observed at Jupiter. We will endeavour to summarise the differences in our understanding of electron heating and transport at these two planets.

A THREE-DIMENSIONAL ANALYSIS OF THE ELECTRON POPULATIONS IN SATURN'S MAGNETOSPHERE : IDENTIFICATION OF THE SOURCE, TRANSPORT AND SINK REGIONS

Schippers, P.[1], N. André[1], M. Blanc[1], D. Santos-Costa[2], A.M. Persoon[3], A.J. Coates[4], S.M. Krimigis[5], W.S. Kurth[3], D.A. Gurnett[3], M. Dougherty[6], and D.T. Young[2]

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(2) *SWRI, San Antonio, TX, USA*
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(5) *APL, John Hopkins University, Laurel,MD,USA*
(6) *Imperial College, London, UK*

Abstract. Based on inter-calibrated composite spectra, from the low-energy data (CAssini Plasma Spectrometer, from 0.6 eV to 26 keV) and the high-energy data (Magnetospheric IMaging Instrument, from 12 keV to 1 MeV) , macroscopic fluid parameters of the dominant electron populations co-existing in Saturn's magnetosphere, ie the thermal (a few eV) and suprathermal (100-1000 eV) populations, have been derived. From the radial profiles of both electron population moments, we have identified the existence of three magnetospheric regions characterized by different plasma regimes, separated by two boundaries, at 9 and 15 Saturnian radii. Statistical analysis of the electron moment radial profile has revealed a highly dynamic plasma sheet, and an asymmetry of the thermal and the suprathermal electron populations in longitude. The analysis of the fluid moment evolution inside and between magnetospheric regions allowed identifying the source, the sink and the transport regions of the electron populations on one hand, and the physical processes operating in these regions on the other hand.

Energetic electron asymmetries near Saturn's main rings

Paranicas, C.[1], D. G. Mitchell[1], S. M. Krimigis[1], T. P. Armstrong[2], N. Krupp[3], E. Roussos[3], K. Khurana[4], M. G. Kivelson[4], and M. Burton[5]

(1) *Applied Physics Lab*
(2) *Fundamental Technologies*
(3) *MPS Lindau*
(4) *UCLA*
(5) *JPL*

Abstract. During Saturn Orbit Insertion (SOI), Cassini had a closest approach distance to Saturn that was inward of the A ring, the outermost of the main rings. Near the outer edge of the A ring, LEMMS, one of the energetic charged particle sensors on MIMI, detected asymmetric electron intensities on the inbound and outbound legs of the trajectory. On the inbound trajectory, the MeV or so electron intensities begin to fall off well before the spacecraft reaches the outer edge of the A ring. Then over the ring itself, there is little or no flux above the sensor background, as expected. On the outbound portion of SOI, the spacecraft measures high electron fluxes just after it crosses the outermost edge of the A ring. This asymmetry in local time suggests to us that the drift paths of these particles are not completely circular in the region of the main rings. In this paper, we will present these MIMI data and our interpretation of them as well as the consequences of this signature for the electromagnetic fields close to the planet.

A survey of plasma properties in Saturn's magnetosphere: Cassini CAPS

Thomsen, M. F.[1], R. L. Tokar[1], R. J. Wilson[1], D. Delapp[1], D. B. Reisenfeld[2], D. T. Young[3], F. J. Crary[3], and E. C. Sittler[4]

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Abstract. Using a recently-constructed database of plasma moments derived from numerical integration of measurements from the Cassini CAPS Ion Mass Spectrometer, we present a survey of the plasma properties in Saturn's magnetosphere, from Saturn orbit insertion in 2004 through spring of 2009. The composition of the plasma is identified via the IMS time-of-flight measurements, and the (non-mass-resolved) singles counts are accordingly partitioned into three main species: H+, m/q=2, and W+, where W+ represents water-group ions (O+, OH+, H2O+, and H3O+). Moments (density, temperature, flow velocity) are computed separately for each of the three species. Variations in these plasma properties with respect to radial distance, local time, and latitude are summarized.

Comments on the Trapped Energetic Ions in the Inner Saturnian Magnetosphere

Armstrong, Thomas[1]

(1) *Fundamental Technologies, LLC*

Abstract. Recent observations made with the Cassini MIMI INCA instrument show a lack of energetic neutral atoms originating in the 2.3 to 4.0 RS region. This, coupled with optical observations of neutral gases and derived models showing substantial densities present in this region suggest and energetic charged particles that have significant cross sections for interaction with the neutral gases present must be suppressed. Key questions that arise immediately are what energetic ions of what energies can be resident there and for how long. Ions with energies high enough that charge exchange cross sections are small do appear to present and durable. Mapping out the distributions in energy, pitch angle and species is likely to inform as to sources and losses of energetic trapped ions. Re-evaluation of Voyager 2 LECP observations as well as checks for consistency with Pioneer 11 observations will be used to describe and establish limits on the energetic ions.

Invited Talk

The influence of neutrals on Saturn's magnetosphere

Smith, H.T.[1], R.E. Johnson[2], M.E. Perry[1], A.M. Rymer[1], and T.A. Cassidy[2]

(1) *JHU Applied Physics Lab*
(2) *University of Virginia*

Abstract. The Saturnian system differs from the Jovian system in that its magnetosphere is dominated by neutral particles by a factor >10 over ions. Therefore, magnetospheric plasma source and loss processes are greatly influenced by neutrals. Prior to 2004, knowledge of the Saturnian system was limited to Earth based observations and only three in-situ flybys. The subsequent arrival of the Cassini spacecraft has rapidly changed what we know about the impact of neutrals in the Saturnian system. During this fascinating discovery period we have had to revise our understanding of the physical processes occurring in Saturn's magnetosphere and sources. The very dense, relatively unprotected atmosphere of the large moon Titan, which was once believed to be a dominant source of plasma, has taken a back seat to its much smaller cousin, Enceladus and even to Saturn's ring atmosphere. Recent findings underscore the significance of both source location and the nature of the source (e.g., out-gassing at Enceladus vs. atmospheric stripping at Io) for determining the characteristics of magnetosphere plasma and neutral tori. Neutral particles originate from a wide variety of sources including the Enceladus plumes, Saturn's atmosphere, Titan's atmosphere and the ring atmosphere/ionosphere. These provide distributed (predominantly molecular) neutral sources that are in turn dissociated and ionized affecting the plasma composition and mass loading in the magnetosphere. Additionally, these neutrals also affect the plasma loss rates by charge exchange and by electron-ion recombination. We present a brief overview of the current understanding of Saturn's neutral tori and neutral/plasma sources as well as methods used to indirectly study these particles. We also present recent results examining Enceladus and Titan as neutral particle sources.

Global neutral gas distribution at Saturn derived from ENA images

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Abstract. Energetic Neutral Atoms (ENAs) result from charge exchange collisions between fast ions trapped in planetary magnetic fields and residual neutral gases resident in the magnetosphere. ENAs thus escape and can be detected and imaged by the INCA (Ion and Neutral CAmera) camera on board Cassini to produce a picture of the population in the entire magnetosphere. Using all available INCA images in the time period 183/2004 to 200/2008 and selecting those times during which the INCA imager was looking at Saturn's magnetosphere from approximately the same vantage position, we were able to produce average images of the neutral gas cloud that correspond to 4.6 Saturn rotations. In the present study, we demonstrate a technique to retrieve the global neutral gas distribution in Saturn's magnetosphere using these average ENA images. The neutral gas distribution at Saturn is retrieved by simulating INCA images using ion distributions of combined CHEMS, LEMMS and INCA in-situ measurements that cover several passes from SOI (183/2004) to day 100/2007, at various local times over the dipole L range 5<L<20 Rs. A parameterized neutral gas distribution is then changed until agreement between the simulated and average INCA image is obtained. Our preliminary results on the neutral cloud density distribution and composition up to approximately 10 Rs are consistent with the neutral gas model by Jurac and Richardson [2005], while the calculated total O content is in agreement with the Esposito et al., [2005] results. The OH vertical distribution was found to be more extended than previously thought [e.g. Richardson et al., 1998].

References:

Esposito et al. (2005), Ultraviolet Imaging Spectroscopy Shows an Active Saturnian System, Science, 307, 1251, DOI: 10.1126/science.1105606

Jurac, S., and J. D. Richardson (2005), A self-consistent model of plasma and neutrals at Saturn: Neutral cloud morphology, J. Geophys. Res., 110, A09220, doi:10.1029/2004JA010635.

Richardson, J. D., A. Eviatar, M. A. McGrath, and V. M. Vasiliunas, OH in Saturn's magnetosphere: Observations and implications, J. Geophys. Res., 103, pp 2045-2055.

The Distribution of Neutral Water in Saturn's Inner Magnetosphere

Burger, M[1]

(1) *University of Maryland and NASA/GSFC*

Abstract. More than 100 kg of water is ejected every second from Enceladus' south pole in discrete plumes aligned along fractures that cross the south polar terrain. Because of the high speeds of the venting water gas and Enceladus' low surface gravity, most of this material escapes Enceladus and forms a torus of water around Saturn [Johnson et al. 2006]. This torus has been observed through the detection of water group pick-up ions by the Cassini Plasma Spectrometer (CAPS) as Cassini flies through the torus [Tokar et al. 2008].

Water and its dissociation products originating at Enceladus have been observed throughout the Saturnian magnetosphere in both ionized and neutral states [e.g., Sittler et al. 2006, Shemansky et al. 1993, Melin et al. 2009]. We discuss the transport of neutral H_2O, O, and OH throughout the Saturnian magnetosphere and the interactions between neutrals and the plasma to estimate radial variations in the neutral loss and plasma production rates.

References:

Johnson et al., ApJ, 644, L137, 2006.
Melin et al., PSS, 2009, in press.
Shemansky et al., Nature, 363, 329, 1993.
Sittler et al., PSS, 54, 1197, 2006.
Tokar et al., GRL, 35, L14202, 2008.

Invited Talk

Interchange instabilities in the Jovian and Saturnian magnetospheres

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Abstract. Recent Galileo and Cassini plasma and magnetic field observations indicate that the interchange instability plays a critical role in radial plasma transport in the rapidly rotating magnetospheres of giant planets. These observations have stimulated considerable interest in understanding the development and the properties of the instability.

Motivated by these observations, we will first revisit theoretically the stability criteria of low-frequency waves in plasmas representative of the Jovian and Saturnian magnetospheres. We will examine in particular the implications of non bi-Maxwellian velocity distributions and of pressure anisotropies for the interchange instability. We will then apply our theoretical results to realistic equatorial distributions of plasma and magnetic field in the inner regions of the Jovian and Saturnian magnetospheres, in order to gain new insights on plasma transport in these environments.

A complete description of the interchange instability involves an electric coupling between the magnetosphere and the planetary ionosphere. Using a simplified model, we will show that the Coriolis force does not affect the short-wavelength interchange mode in an axisymmetric, rapidly rotating magnetosphere. We will also confirm that the planetary ionosphere has no influence on the interchange instability criterion, but that it controls the instability growth rate, especially when the ionospheric Pedersen conductivity is large (strong ionosphere/magnetosphere coupling), whereas the magnetospheric dynamics remain local in the opposite limit.

Saturn Simulations with the Rice Convection Model

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(2) *University of Virginia*

Abstract. The Rice Convection Model (RCM) is a numerical simulation code that was originally developed for the study of plasma motion in Earth's inner magnetosphere and its electrodynamic coupling to the ionosphere. It has now been modified for the study of centrifugally driven convection in the magnetospheres of Jupiter and Saturn. Modifications include the incorporation of the centrifugal and Coriolis forces and of a continuously active internal plasma source, as well as an outer boundary condition that allows free escape of the internally generated plasma. The simulation domain is the inner magnetosphere, roughly $2 < L < 12$ for both planets, where the model's assumptions are approximately valid. The most critical assumption is that the flow speed is well below the MHD wave propagation speeds. Other simplifying assumptions, not required by the RCM but made for convenience at Jupiter and Saturn to date, are that the magnetic field is dipolar and the ionospheric Pedersen conductance is uniform. At Saturn, the neutral water vapor source peaks near $L = 4$ (the orbit of Enceladus), but the resulting plasma source peaks farther out ($5.5 < L < 7.5$) because that is where the ambient electron population has sufficient temperature to ionize water vapor. The inclusion of this continuously active distributed plasma source has elucidated many aspects of the resulting interchange plasma transport, including in particular the observed and heretofore unexplained fact that the longitudinal sectors of outflow are broader, and therefore slower, than the interspersed sectors of inflow.

The effect of solar wind dynamic pressure on the centrifugal interchange cycle in Saturn's magnetosphere

Kidder, A.[1]**, R.M. Winglee**[1]**, and E.M. Harnett**[1]

(1) *University of Washington*

Abstract. Measurements by the Cassini spacecraft indicate that the solar wind dynamic pressure may have a greater effect on reconnection and the development of plasmoids at Saturn than the direction of the interplanetary magnetic field (IMF). INCA has measured ENA intensifications ahead of observations of plasmoid formation near the midnight sector, and solar wind pressure has been correlated to auroral power through joint Cassini-HST observations.

To date, our multi-fluid simulations of the Kronian magnetosphere have focused on the extent to which the centrifugal interchange cycle is regulated by the orientation of the IMF. These simulations have shown that both injection and outwelling fingers of the centrifugal interchange cycle are consistent with bulk characteristics observed by Cassini. IMF anti-parallel to Saturn's planetary field or a denser Enceladus ion torus serves to increase the number and length of injection fingers in Saturn's inner magnetosphere. We now examine the effect of a solar wind pressure pulse on these interchange fingers, as well as the formation of plasma bubbles/plasmoids that subsequently move downtail. Single events like plasmoid formation have been observed by Cassini, but it is difficult to determine the local time and solar wind conditions at which they most frequently occur. Multi-fluid simulations enable us to quantify the global effect of a pressure pulse on the frequency with which the tips of interchange fingers get broken off and move downtail, and the local time at which this occurs. This paper seeks to address the location, speed and composition of any plasmoids (if they are primarily composed of hydrogen or water group ions – which would be consistent with an inner magnetospheric source).

Low energy electron peaks due to interchange

DeJong, A.D.[1], J.L. Burch[1], J. Goldstein[1], A.J. Coates[2], and D.T. Young[1]

(1) *Southwest Research Institute*
(2) *University College London*

Abstract. Electron data from the Cassini Electron Spectrometer (CAPS-ELS) are examined from July 14, 2004 to December 31, 2006. When Cassini is within $\pm 10^o$ latitude of the equator a peak in the low energy electrons ($\sim 100eV$) is observed to extend from approximately 7 to 8.5 Rs. We find this low energy peak, which has been reported in total density by Wahlund et al. [2005], to be associated with localized plasma injections. The electron peak intensifies and penetrates deeper into the magnetosphere (5 Rs) from $30^o - 300^o$ SLS3 longitude. A peak in the ion single counts at 25 Rs is also observed in this SLS3 range [Burch, 2009]. This result indicates that there is a large source of interchange instability at this 6 hour SLS3 range. This active interchange sector is likely to be associated with the plasma and magnetic field periodicities that are commonly observed in Saturn's magnetosphere.

Magnetic field fluctuations in Saturn's magnetosphere as observed by the Cassini spacecraft

Alexandrova, O.[1] **and J. Saur**[1]

(1) *Institute of Geophysics, University of Cologne*

Abstract. We study properties and consequences of magnetic field fluctuations in Saturn's magnetosphere. We show that magnetic field fluctuations have a broad band spectrum, following a power-law, that is a clear signature of well developed turbulence. We analyze turbulence properties during the 1st and 2nd Cassini orbits around Saturn, and within $\sim [10^{-3}, 10^{0}]$ Hz frequency range. We show that turbulence reaches its maximum in the equatorial plane and for local time close to midnight. During the corresponding time periods, the spectrum of magnetic fluctuations has a very particular shape, showing signatures of coherent structures, probably related to injection events in the magnetosphere.

Oral Presentations

Thursday 30$^{\text{th}}$ July, 2009

Azimuthal plasma flow in the Kronian magnetosphere

Müller, A. L.[1,2], J. Saur[1], N. Krupp[2], D. G. Mitchell[3], S. M. Krimigis[3,4], and E. Roussos[2]

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(3) *Applied Physics Laboratory, Johns Hopkins University, Laurel, Maryland, USA*
(4) *Academy of Athens, Greece*

Abstract. We study the azimuthal plasma velocity in Saturn's magnetosphere between 2 and 13 Saturnian radii by analysing Energetic Particle Injection Events. High energetic plasma is transported into the inner part of the magnetosphere. Due to the magnetic drifts, the injected particles begin to disperse and leave an imprint in the spectrograms of the Magnetospheric Imaging Instrument (MIMI) onboard the Cassini spacecraft. The shape of these profiles depends strongly on the azimuthal velocity of the magnetospheric plasma and the age of the injection event.
Comparison of theoretically computed dispersion profiles with observed ones enables us to characterize the azimuthal flow of the plasma. The measured flow profile clearly shows that the plasma tends to subcorotate.

The Latitude Dependence of Conductances at Saturn: Cassini Observations and Model Comparisons

Moore, L.[1], A. Kliore[2], I. Mueller-Wodarg[3], M. Galand[3], and M. Mendillo[1]

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Abstract. We present estimates of the Pedersen and Hall conductances in Saturn's ionosphere based on electron density altitude profiles retrieved from Cassini radio occultations (Kliore et al., 2009). Neutral atmospheric and ion fraction parameters are specified using the Saturn Thermosphere-Ionosphere-Model (STIM), a suite of 1D, 2D and 3D models of Saturn's upper atmosphere. In addition, in order to establish upper and lower limits on the conductance estimates, we perform a parameter space study in which a range of neutral atmospheres and ion mixing ratios are considered. Comparisons between conductances derived from the Cassini radio occultation data and those calculated by STIM reveal a shortfall in the modeled Pedersen conductances, particularly at mid-latitude. This discrepancy is indicative of missing mid-latitude ionization sources within the model.

Vorticity and Magnetic Field Oscillations in Saturn's Morning Magnetosphere

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Abstract. We have used a global magnetohydrodynamic simulation of the interaction of the solar wind with Saturn's magnetosphere and Cassini magnetic field observations to investigate vorticity in the morning magnetosphere and magnetic field oscillations within the magnetosphere. We find that large vortices form for northward IMF in a region near the morning magnetopause with large velocity shear. The vortices are associated with strong field aligned currents. Similar vortices do not form in simulations with southward IMF or low velocity shear. For our initial simulations we assumed a source of plasma from the moon Enceladus of $2X10^{29}$ AMU/s. This is near the upper limit on the Enceladus plasma source. For this source rate the vortices lasted throughout the simulation (40 hours), however when we decreased the source to $5X10^{28}$ AMU/s the vortices were shorter lived (15 hours). The vortices cause magnetic field oscillations with periods of 1 to 4 hours on virtual spacecraft placed in the dayside magnetosphere. Cassini magnetic field observations [1] show similar oscillations both within the magnetosphere and at the magnetopause. We will compare the simulated magnetic field oscillations with these observations.

[1] Daugherty, M. K., S. Kellock, A. P. Slootweg, N. Achilles, S. P. Joy and J. N. Mafi, CASSINI MAG CALIBRATED SUMMARY AVERAGED, C-E/SWS/J/S-MAG-4-SUMM-AVERAGED-V1.0, NASA Planetary Data System, 2007.

The Response of Currents and Ionospheric Signatures in Saturn's Magnetosphere

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Abstract. The extent to which the solar wind drives Saturn's magnetosphere-ionosphere system is an ongoing topic of extensive study due to both the Cassini spacecraft presence in the Saturnian system as well as the recent (2007, 2008) Hubble Space Telescope campaign to image the UV aurora. Studies using these data have shown some evidence that solar wind dynamic pressure enhancements influence the aurora as well as the magnetosphere. In this study, we address the solar wind driving using our 3D global MHD model of Saturn's magnetosphere-ionosphere. In order to study the coupled solar wind-magnetosphere-ionosphere system it is necessary to know the upstream solar wind conditions. We have recently published a detailed validation of our MHD model which propagates the solar wind radially outward from the Earth (ACE) to Saturn [Zieger and Hansen, JGR, 2008]. These solar wind values can be used as input to our global, 3D, MHD model of the magnetosphere. From the global model we extract time series that can be compared directly to spacecraft data. These include the total auroral power as well as the locations of both the auroral oval and the open-closed field lines boundary. In addition, we are able to explore the global structure of the magnetosphere including auroral morphology and current structures that create the aurora as well as convection patterns in the magnetosphere. In this paper we will concentrate on the ionospheric response as well as the current structures in the magnetosphere during the two time periods of extensive HST measurements as well as the March 4, 2006 plasmoid event observed by Cassini.

Energetic Ions and Magnetic Fields Upstream From the Noon-to-Dusk Saturnian Bow Shock: Indications of Periodicity

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Abstract. Energetic particle events associated with IMF field fluctuations were first seen by Voyager and Cassini in pre-noon upstream of Saturn. It is possible that such events may appear in a periodic fashion upstream, as some models predict for plasmoids within the magnetosphere, but are observed only if the projected IMF connects the spacecraft to the bow shock. We now report events off the dusk bow shock that exhibit somewhat different characteristics. During days 212 to 214 and 223 to 231, 2007, when Cassini was located beyond the bow shock (60 RS) in the afternoon (1430-1600 hr) local time sector, there were several events in H+ and/or O+ recorded in all MIMI sensors (CHEMS, LEMMS and INCA) with definitive plasma wave activity observed by the Radio and Plasma Wave Science experiment (RPWS). Such Langmuir waves at a few khz are indicative of low energy (a few tens of ev) electrons travelling up from the planetary bow shock. All examined events seemed to strictly appear when the projected IMF connected the spacecraft to the bow shock and some appeared modulated at the planetary rotation period. Further, these were markedly anisotropic, unlike previous cases that tended toward isotropy as the event progressed in time. The events will be presented and the question posed on whether the events are always periodic if the IMF is connected to the proper part of the bow shock, indicative of plasma escape from the dawn-to-noon sector of the magnetosphere.

Magnetic Field Dipolarization in Saturn's Outer Magnetosphere: Search for a Cushion Region

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(2) *University College London*

Abstract. In this study we use data from the magnetometer instrument onboard the Cassini-Huygens spacecraft to search for evidence of a magnetically turbulent, dipolar region between the dayside magnetodisc and magnetopause which may be analogous to the cushion region seen at Jupiter.

The cushion region at Jupiter has been observed at all local times in the dayside magnetosphere and, though probably thicker in the pre-noon sector as opposed to post-noon, is typically of the order 10 RJ thick. The cushion region is thought to be closely related to the return of open flux in the final stages of the Vasyliunas Cycle (Kivelson & Southwood, 2005) and it is the growing body of evidence suggesting that Saturn supports its own version of a Vasyliunas cycle that has motivated this work. Initial results from a survey of all magnetometer data from 2004-2009 suggest that Saturn's cushion region, if present at all, is significantly smaller than that of Jupiter's (even after the appropriate scaling has been taken into account) raising interesting questions as to why this may be the case given the known similarities between other parameters of the systems.

Properties of the magnetic field and plasma in the kronian magnetotail lobes

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Abstract. Knowledge of the properties of the magnetotail lobes is important for understanding the structure, equilibrium and dynamics of magnetotail and magnetosphere as a whole. In this presentation we use Cassini magnetometer and electron spectrometer data to characterize the magnetic field in Saturn's magnetotail lobes throughout the nominal mission, with particular emphasis on the deep tail orbits out to 65 Rs in 2006.

We compare the magnetic pressure in the central plasma sheet with that in the lobes to estimate plasma pressures in the plasma sheet and study the radial, local time and longitudinal profiles of lobe magnetic field strength and pressure. Power-law fits for the magnetic field strength and pressure as a function of radial distance are presented, with a field strength falloff of $R^{-1.11}$. Estimates of the lobe plasma density are used to estimate the Alfvén speed. The effects of hinging of the current sheet on the nightside are observed at increasing radial distances.

Lobe conditions during "quiet" periods are compared and contrasted with disturbed periods where travelling compression regions and other such structures are observed. By comparing the average fitted lobe field strength with observations in the magnetotail, we attempt to investigate the typical length of the "growth phase" of substorm-like events at Saturn, and to quantify the amount of open flux closed during such events. Lastly, we discuss our results in the context of the Earth and Jupiter.

Saturn's Outer Magnetosphere: Convection, Reconnection, and Configuration

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Abstract. The MIMI cluster of instruments, and particularly the Ion and Neutral Camera (INCA), measure intensities of hydrogen and oxygen ions and neutral atoms in the Saturnian magnetosphere. We use the measured intensity spectrum and anisotropy of hot hydrogen and oxygen ions to calculate plasma convection. We find that, throughout a wide region of this magnetosphere, the bulk plasma is capable of nearly rigid corotation within Titan's orbit, but that the bulk flow generally significantly lags the SKR rotation rate. We find evidence of some radial outflow in the nightside region. We discuss the implications of such flow for the ultimate fate of distant nightside current sheet plasma and compare with similar plasma at Jupiter. Our recent work shows that the degree of corotation of plasma within the magnetospheres of Jupiter and Saturn in the midnight to dawn sector decreases with increasing distance from the respective planets in a remarkably similar manner, when scaled to a nominal magnetopause standoff distance. Thus far, we find no evidence for a duskside velocity stagnation region similar to that found within Jupiter's magnetosphere. Current topological models of Saturn's nightside magnetosphere predict the presence of a reconnection X-line associated with internal Vasyliunas-cycle reconnection in the magnetotail and perhaps a Dungey-cycle reconnection X-line on the dawn flank of the magnetotail of Saturn. The INCA instrument is very sensitive, can resolve oxygen and hydrogen ions and can be used in conjunction with other instruments in the MIMI cluster to explore and differentiate such structures. Their convective signatures and pitch angle structure, including signatures detected during events that may be associated with dynamic reconnection, are well sensed and analyzed by this instrument cluster. With the support of magnetic field data, we have identified and analyzed such signatures in the outer magnetosphere and find evidence consistent with Vasyliunas-cycle reconnection, dipolarization, and fast planetward convection. We also report on our search for evidence of plasma layers on the dawn flank associated with return flow from Dungey-cycle reconnection.

Invited Talk

Titan's Ionosphere as a Source for the Magnetosphere and Atmosphere

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Abstract. Analysis of data from Cassini CAPS and INMS has begun to show many interesting features of the interaction of Titan's ionosphere with both the magnetosphere and atmosphere. In this paper we examine the role of Titan's ionosphere as a source of material for both the magnetosphere and, surprisingly, the deep atmosphere. The ionosphere was once thought to be a major source of plasma for Saturn's magnetosphere, but has proven to be something of a flop. Instead, plasma in the vicinity of the Titan "torus" appears to consist mostly of hydrogen with a small admixture of water group ions, the latter originating deep in the magnetosphere. While the strength of the ionosphere as a source of magnetospheric plasma has yet to be established, CAPS has measured abundant heavy positive ions (up to 350 amu/e) and negative ions (up to 13,000 amu/e) below 1500 km. Because of their large masses, these species probably contribute little to plasma stripped from Titan and fed to the magnetosphere. However, in an interesting twist, they do play a significant role in complex organic chemistry leading to formation of aerosols (tholins), which are a source of haze layers deep in Titan's atmosphere.

Invited Talk

Titan's highly variable plasma interaction: Global numerical simulations and comparison with Cassini data

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Abstract. Titan's orbit is located within the outer regions of Saturn's magnetosphere, where the moon is exposed to an at least partially corotating flow of magnetospheric plasma. Since Titan does not possess a significant intrinsic magnetic field, the moon's dense atmosphere and ionosphere interact directly with the impinging plasma flow. This plasma interaction possesses several unique features: Titan's dayside ionosphere is not necessarily located in the hemisphere that is exposed to the impinging plasma. Besides, when Saturn's magnetosphere is compressed due to high solar wind dynamic pressure, Titan can leave the magnetosphere of its parent planet near noon local time and interact with the shocked magnetosheath plasma or even directly with the unshocked solar wind. Another important characteristic of Titan's plasma interaction are the large gyroradii of the newly generated pick-up ions, which can exceed the radius of the satellite by more than a factor of 5.

During recent years, numerous global simulation codes (MHD, multi-fluid and hybrid) have been applied to Titan's highly variable plasma interaction. Since these simulations draw a picture of Titan's plasma environment on a global scale, they provide a valuable tool for the interpretation of Cassini plasma and magnetic field observations. In this talk, we give an overview of the available global models of Titan's plasma interaction and compare their strengths and weaknesses. Special attention will be paid to the recent development of real-time simulation scenarios, allowing to determine the characteristic time scales on which Titan's induced magnetotail is reconfigured during an excursion into Saturn's magnetosheath or the solar wind.

Titan at the Edge: 3D Multi-fluid Simulations of Titan near Saturn's Magnetopause

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Abstract. Cassini has confirmed that Saturn's magnetopause is routinely near the orbit of Titan. However, it is unclear what effect Titan may have on the dynamics of Saturn's magnetosphere during these times. We have used a multi-fluid/multi-scale model of Titan embedded within the Kronian magnetosphere to investigate the effects of mass loading on Saturn's magnetopause for Titan in the pre-noon sector (9:00 local Saturn time). The direction of the interplanetary magnetic field is northward and a solar wind pressure pulse is used to compress the Kronian magnetosphere. Over the several hours modeled we find that the flux of ions from Titan depends on the characteristics of the local environment; which was variable due to intermittent, out-welling centrifugal interchange fingers in Saturn's magnetosphere. A boundary layer exist near the magnetopause because the magnetospheric flow is oppositely directed to the magnetosheath flow. Titan's ion tail flows towards the magnetopause and enters this boundary layer and the tail is broken into clumps that can be seen flowing across the dayside magnetosphere along the inside edge of the magnetopause. Titan enters this boundary layer when the magnetopause moves inwards strongly modulating the characteristics of Titan's induced magnetosphere. The stand-off distance of Saturn's magnetopause appears to be determined by mass loading from Titan and the inward movement of the magnetopause is small compared to a simulation that does not include mass loading from Titan. These results will be compared with data from the T8 and T10 flybys, when Titan was in a similar location in the magnetosphere (SLT= 9.3 and 8.5, respectively).

Negative ions at Titan - new results

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Abstract. The Electron Spectrometer of the Cassini Plasma Spectrometer (CAPS-ELS) revealed the existence of negative ions in Titan's ionosphere (Coates et al, 2007, Waite et al, 2007). These are observed when the instrument points in the ram direction at altitudes between 950 and 1400 km. The ions have masses up to 13,800 amu/q. This indicates that complex hydrocarbon and nitrile chemical processes take place in Titan's upper atmosphere. Groups of masses can be identified because similar peaks are observed in the mass spectra of different encounters. By using spacecraft attitude changes an increased set of data is available which we use to discuss new results such as density trends of different mass groups with altitude, latitude and solar zenith angle.

Saturn's Magnetosphere and Properties of Upstream Flow at Titan: Preliminary Results

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Abstract. Using Cassini Plasma Spectrometer (CAPS) Ion Mass Spectrometer (IMS) measurements, we present the ion fluid properties and its ion composition of the upstream flow for Titan's interaction with Saturn's magnetosphere. A 3D ion moments algorithm is used which is essentially model independent with only requirement is that ion flow is within the CAPS IMS 2π steradian field-of-view (FOV) and that the ion velocity distribution function (VDF) be gyrotropic. These results cover the period from TA flyby (2004 day 300) to T22 flyby (2006 363). Cassini's in situ measurements of Saturn's magnetic field show it is stretched out into a magnetodisc configuration for Saturn Local Times (SLT) centered about midnight local time. Under these circumstances the field is confined near the equatorial plane with Titan either above or below the magnetosphere current sheet. Similar to Jupiter's outer magnetosphere where a magnetodisc configuration applies, one expects the heavy ions within Saturn's outer magnetosphere to be confined within a few degrees of the current sheet while at higher magnetic latitudes protons should dominate. We show that when Cassini is between dusk-midnight-dawn local time and spacecraft is not within the current sheet that light ions (H^+, H_2^+) tend to dominate the ion composition for the upstream flow. If true, one may expect the interaction between Saturn's magnetosphere locally devoid of heavy ions and Titan's upper atmosphere and exosphere to be significantly different from that for Voyager 1, TA and TB when heavy ions were present in the upstream flow. We also present observational evidence for Saturn's magnetosphere interaction with Titan's extended H and H_2 corona which can extend to $\sim 1\ R_S$ from Titan.

Invited Talk

The Interactions of Outer Planetary Satellites with Their Magnetospheres: Non-Magnetized Moons with Thin Atmospheres

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Abstract. Voyager, Galileo and Cassini spacecraft have made close approaches to eleven of the large (radius $>$ 250 kms) satellites of the outer solar system. The field and particle data from these flybys have provided us a wealth of information on the interactions of these satellites, their ionospheres and mass-loading regions with the planetary magnetospheres. In addition, the magnetic field measurements have been inverted to reveal the interior structures of these moons and to ascertain the presence of liquid water oceans in some of these moons.

In this talk, I will first summarize the field and plasma observations from the three non-magnetic Galilean satellites of Jupiter, namely Io, Europa and Callisto. After presenting the evidence of strong Alfvenic interaction from these satellites, I will discuss the discoveries and implications of the induced magnetic fields in Europa and Callisto. It is now well accepted that the induction fields in these satellites arise from eddy currents flowing in the subsurface oceans in response to the rotating field of Jupiter.

The exploration of the icy satellites of Saturn is now underway. Cassini has already made close flybys of Enceladus, Tethys, Dione, Rhea, Titan, Hyperion and Iapetus. Magnetic field observations from Enceladus have led to the discovery of water plumes originating from the south polar region of this moon. It is now believed that a subsurface liquid water aquifer maintains these geysers on Enceladus. The Dione observations also suggest some plasma pick-up in its vicinity but the origin of the plasma source is not yet known. However Tethys and Rhea appear Moon-like (plasma absorption upstream and an empty wake downstream) in their interaction with the corotating plasma. Finally I will discuss the status of induction fields in the Saturnian moons, and the future plans of the Cassini team for additional magnetic field measurements of the Saturnian moons.

A Hybrid Simulation of the Plasma Flow Around Io Coupled to a Multi-species Chemistry Model of Io's Local Interaction.

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Abstract. The Galileo flybys of Io have provided a number of observations that are still not completely understood i.e. the strong asymmetry of the flow and the high plasma density in the center of the wake. Past studies have tackled the problem of the local interaction of Io's corona with the plasma in the torus using different complementary approaches, each of them involving some simplifications: MHD modeling with a parameterization of the sources of ionization and collision (Linker et al., 1998; Combi et al., 1998), 2-fluid approach assuming a constant magnetic field (Saur et al., 1999), hybrid simulation (Lipatov and Combi, 2005) and multi-species chemistry assuming a prescribed flow of the plasma around Io (Dols et al., 2008). We couple a hybrid model of the plasma flow around Io (kinetic ions and fluid electrons) and a multi-species chemistry model (chemistry of SO_2, S and O) to obtain a fully self-consistent model of the local interaction. We present results using this flow calculation, plasma production and charge exchange rates, pickup current as well as contribution of the electron beams detected close to Io and compare these results with the Galileo flyby observations.

New Observations of UV Emissions from Europa

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Abstract. The recent top prioritization of the Europa Jupiter System Mission for the next outer solar system flagship mission is refocusing attention on Europa and the other Galilean satellites and their contextual environments in the Jupiter system. Surface sputtering by magnetospheric plasma generates a tenuous atmosphere for Europa, dominated by O2 gas. This tenuous gas is in turn excited by plasma electrons, producing ultraviolet and visible emissions. Two sets of imaging observations have been published to date, UV images from the Hubble Space Telescope (McGrath et al. 2004; Cassidy et al. 2007; McGrath et al. 2009), and visible eclipse images from Cassini (Porco et al. 2003; Cassidy et al. 2008; McGrath et al. 2009). Three additional sets of HST UV observations were acquired in February 2007 (Retherford et al. 2007 conference presentation), April 2007 and June 2009. The signal to noise ratio in these data are not high, however, given the paucity of data and its increasing importance in terms of planning for EJSM, we have attempted to extract as much new information as possible from these data. This talk will summarize our analysis to date, and discuss them in terms of existing models, which attempt to explain the image morphology either in terms of the underlying source production and loss processes, or in terms of the plasma interaction with the exosphere.

Europa: UV Signatures of Plasma-Surface Interactions

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(2) *Univ. Virginia*
(3) *APL/JHU*

Abstract. The study of ultraviolet spectra of solar system surfaces is often diagnostic of weathering processes. Europa, in its high radiation environment, is a prime example. We investigate observations of Europa by the Galileo Ultraviolet Spectrometer (UVS) to describe the effects of the plasma bombardment on the surface composition and chemistry. This is an important step in separating endogenic and exogenic contributions to the surface composition. Therefore, we revisit the bombardment pattern of cold and suprathermal plasma on the moon and compare with the UV albedo and the measured strength of UV absorption features on the surface, focusing on the 280 nm SO2 feature. We examine here whether or not trends in the UV signatures can be traced to interaction patterns of different particle populations, e.g. cold versus eV versus MeV.

The UVS data show that the overall UV albedo pattern across the surface (i.e., albedo vs. longitude) differs from the trend seen in the 280 nm absorption band strength. The UV albedo is lowest (i.e. the surface is darkest) and the 280 nm absorption band is strongest at the apex of the trailing hemisphere, where the flux of ionizing radiation is highest, and high-energy electrons are absorbed (Paranicas et al., 2001). The longitudinal trend in UV albedo suggests the work of another plasma population: sulfur ions with a variety of energies (eV to MeV) that impact the whole of Europa's surface (with a peak flux at the trailing hemisphere apex).

In addition to the longitudinal trends, we find a correlation between the 280 nm absorption feature and the infrared-measured hydrate; both spectral features are associated with the presence of sulfur. The UV feature agrees spectrally with the presence of SO2 in an ice matrix, consistent with previous work (Lane et al. 1981). The infrared feature has been correlated with dark terrains on Europa's trailing hemisphere (Carlson et al. 2009), suggesting an additional relationship between the UV absorber and the dark terrains on Europa's trailing hemisphere. Carlson et al. (1999; 2002; 2009) describe a sulfur cycle on Europa, whereby endogenic sulfurous material on Europa is exposed to radiolysis at the surface, producing hydrated sulfuric acid, H2SO4*nH2O in the dark terrain on the trailing hemisphere.

The UV signatures thus appear to be the combined result of high-energy electrons impacting the trailing hemisphere, sulfur ions bombarding the entire body, and recent geologic activity.

HST observations of Europa's atmospheric UV emission

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(3) *SWRI, USA*
(4) *University of Liège, Belgium*

Abstract. The Advanced Camera for Surveys on the Hubble Space Telescope observed Europa in June 29, 2008 during five consecutive orbits. Europa was at eastern elongation and crossed the Jovian current sheet during the observing interval. The observations were performed with ACS/SBC with prism PR130L to separate the two prominent FUV oxygen lines OI 1304 Å, OI 135.6 Å and to descriminate reflected solar light from Europa's surface. In our talk we present results of these observations and we discuss how we address the strong red leak contained in the measurements.

Discovery of a New High-Speed Atmospheric Ejection Process at Io

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(2) *Dipartimento di Astronomia, Università di Padova, Italy*

Abstract. High-resolution spectra of Io sodium have identified an unexpected high-speed ejection process operating near Io's wake and Jupiter-facing hemisphere. Observations with the SARG spectrograph on the 3.6-m Telescopio Nazionale Galileo in the Canary Islands targeted Io as it neared eclipse behind Jupiter. The slit was oriented parallel to the jovian equator, capturing spectra ahead of of Io and behind it along the orbit. The region ahead of Io along the orbit is also the downstream wake region in a magnetospheric sense; the Galileo spacecraft showed this to be a region of cold, dense, stagnated plasma. Our spectra of this region in the hour before eclipse show three distinct spectral features. The first two are well known: the slow sodium "banana cloud" and fast sodium "stream" or "jet" ejected in the anti-Jupiter direction and hence highly red-shifted. The unexpected third feature is clearly blue-shifted, indicating an ejection from Io towards Jupiter. The observed directionality and speeds exceeding 10 km/sec indicate a source process involving fields and currents in Io's atmosphere and/or wake, as opposed to the lower speeds and more isotropic ejection expected from collisions. Preliminary analysis indicates that the source process is not active immediately after eclipse, suggesting the mechanism is reduced by atmospheric collapse or the lack of of photoionization. At present there are no known ejection mechanisms that satisfy the observed properties. We will present preliminary analysis of the spatial and velocity distributions of this feature, along with a discussion of plausible source mechanisms. We will also discuss similar observations at the AEOS Telescope on Maui, and plans for followup observations.

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Oral Presentations

Friday 31st July, 2009

Invited Talk

Global MHD Simulations of Ganymede's Magnetosphere and Their Comparison with Observations

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Abstract. Ganymede, the largest satellite in the solar system, is unique among planetary satellites not only because of its great size but also because it is the only satellite in the solar system known to possess an intrinsic magnetic field. The interaction between Ganymede and Jupiter's magnetospheric plasma forms a magnetosphere embedded within the giant magnetosphere of Jupiter. The observations acquired by Galileo, both in different regions of the magnetosphere and under various external particle and field conditions, provide us with a comprehensive sampling of the interaction system. To better understand Ganymede's magnetosphere and the Galileo observations, we have developed a three-dimensional MHD model with a high resolution grid and appropriate boundary conditions to investigate the near-Ganymede environment. As validated by directly comparing with the available observations, our model can provide a realistic description of Ganymede's magnetosphere allowing us to further understand the nature of the interaction in a more comprehensive way. In this paper, we will discuss the general properties of Ganymede's magnetosphere inferred from our simulations, such as the global configuration and the convection pattern, and their comparison with observations. Moreover, Ganymede's magnetosphere provides us with a good opportunity to investigate the reconnection process in a relatively stable external environment. Our time-dependent simulations suggest that under steady external conditions, reconnection is intermittent instead of being steady, a result that is consistent with the presence of magnetic fluctuations near the magnetopause encounters.

Ganymede's field line resonances revisited

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Abstract. The Galileo spacecraft has passed through Ganymede's magnetosphere twice; during the G8 and G28 flyby. Both flybys were at different locations in the Jovian magnetosphere. Around closest approach during the G8 flyby, Galileo remained for three minutes on approximately one L-shell ($L \approx 2$) in Ganymede's magnetosphere and field line resonances were found. From model frequencies it was possible to infer the local plasma density as ~ 2 AMU cm^{-3}. During the G28 flyby Galileo remained, again, on one L-shell ($L \approx 1.5$) for about 3 minutes and the signature of field line resonances in the magnetometer data were found once more, albeit at different frequencies. Also, when crossing the region of $L \approx 2$ with very little varying magnetic field, signatures of field line resonances were found at similar frequencies as for G8. We will discuss these two flybys using magnetometer, EPD, PWS and plasma data, to obtain more detailed information about Ganymede's magnetosphere.

Invited Talk

Enceladus' Plume: An Overview of Observations and Interpretation Through Multi-fluid Simulations

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Abstract. The discovery of the Enceladus' plume raised important questions pertaining to the interaction of Saturn's magnetosphere with this small moon. Here we will focus on some of the striking observations and discoveries made at Enceladus, emphasizing the recent observations made by CAPS during the E3 and E5 encounters. The importance of collisions between ions and neutrals for governing the interaction of Enceladus and Saturn's magnetosphere will also be discussed in the context of the observations.

Finally we will show results from modeling efforts aimed at incorporating elastic and inelastic collisions between ions and neutrals into an existing multi-fluid plasma dynamic framework, allowing for energy and momentum transfer between the neutral and ion fluids. An improved diagnostic tool for directly comparing these simulations to in situ observations made by instruments onboard the Cassini spacecraft has been developed, enabling detailed model comparisons and interpretation of observations from the E3 and E5 encounters.

Electrons at Titan and Enceladus: implications for Ganymede and Europa

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Abstract. Cassini CAPS-ELS measurements at Titan and Enceladus have revealed several new features of outer planet moon interactions. At Titan, where a thick, nitrogen and methane rich, atmosphere interacts with usually subsonic upstream plasma, heavy negative ions were discovered, and ionospheric photoelectrons can be used as tracers of a magnetic connection to Titan's sunlit ionosphere. At Enceladus, water clusters and other negative ions are seen. Ganymede and Europa each have unique plasma interactions with Jupiter's magnetosphere – both have weak oxygen dominated atmospheres and Ganymede has a magnetic field. Here we summarise the results from Titan and Enceladus and examine some possible implications for plasma measurements at Ganymede and Europa.

Electrically charged grains in Enceladus's plume

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Abstract. During two close encounters with Enceladus in 2008, the moon's active south polar plume was traversed while the Cassini Plasma Spectrometer, CAPS, was oriented to sample erupted material directly. The instrument's data show that a major plume component comprises previously-undetected particles of nanometer scales and larger that bridge the mass gap between previously observed gaseous species and solid icy grains. This population is electrically charged both negative and positive, indicating that subsurface triboelectric charging of condensed plume material may occur through mutual collisions within vents. The electric field of Saturn's magnetosphere controls the jets' morphologies, separating particles according to mass and charge. Fine-scale structuring of these particles' spatial distribution correlates with discrete plume jets' sources, and reveals locations of other possible active regions. The observed plume population likely forms a major component of high velocity nanometer particle streams detected outside Saturn's magnetosphere.

Hybrid Simulations of the Enceladus Plasma Interaction and Comparison with Cassini MAG Data

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Abstract. The Cassini Spacecraft has made four close flybys of Saturn's icy moon Enceladus. It became evident that a large water vapour and dust plume is located below Enceladus' south pole. Cassini plasma and magnetic field measurements indicate a source strength exceeding 100 kg/s and show a significant draping of the magnetic field lines. Cassini observations suggest a plume diameter of at least 2 Enceladus radii and a mass loading rate of about 2-3 kg/s. We study the interaction of Enceladus with the Saturnian magnetospheric plasma and magnetic field by using a three-dimensional hybrid model, which treats the electrons as a fluid and the ions as individual particles. Our model includes a self-consistent description of the obstacle's internal conductivity and also considers ion-neutral-collisions. We analyze systematically how the obstacle's internal conductivity as well as the shape and size of the plume contribute to the overall structure of the interaction region. The presence of the plume gives rise to a magnetic cavity downstream of the moon and a magnetic pile-up region, while the field lines are able to pass through the solid body of Enceladus almost unaffected. Our simulation results are in reasonable agreement with observations made by the Cassini magnetometer instrument.

The Cassini Enceladus encounters in the view of energetic particle measurements

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Abstract. During the Cassini prime mission 2004-2008 the spacecraft flew by the moon Enceladus six times. This moon embedded in the radiation belts of Saturn plays a very important role for the magnetosphere as it is the primary plasma source of the system. Energetic particle measurements performed during those flybys showed the influence of the Enceladus plume on the properties of the magnetosphere. Features in the data indicated that the spacecraft was connected to the plume material along field lines way before the entrance into the high density region. Absorption signatures in the loss of energetic electrons bouncing along those field lines clearly show an energy dependence from which density calculations might be possible. During one of the flybys the presence of dust in the energetic particle data offers the opportunity to nicely correlate those results with onboard dust measurements of the CDA instrument. In this paper we give an overview of the energetic particle response in the vicinity of the moon, during the closest approaches and during the crossings of the L-shell of Enceladus.

Motion of equatorially mirroring energetic electrons near Saturn's inner moons

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Abstract. The most typical structures that reveal the interaction of Saturn's inner icy moons with energetic electrons are the microsignatures, ie. flux depletion regions that propagate almost along each moon's L-shell and gradually refill, as their longitudinal separation (age) from their origin increases. For the study of the microsignature evolution, it is commonly assumed that they start as 100% depleted flux tubes with a radial extent equal to the diameter of the absorbing moon. This approximation is fully valid only if we neglect the electromagnetic field perturbations that occur in a moon's vicinity due to its magnetospheric interaction. Such perturbations modify the drift properties of energetic electrons and cause deviations from the simple particle absorbing profile, mentioned above. The magnitude of these deviations depends on several parameters, such as the electron energy, the spatial extent and the amplitude of the flow and magnetic field distortions, and the type of interaction (plasma absorbing or mass loading).Using a guiding center code and simple, empirical descriptions for the electromagnetic field perturbations, we investigate how the particle trajectories are deformed and what fundamental effects these modifications have to the properties of the near-moon, energetic electron depletions. Simulations are carried out for both types of moon-magnetosphere interactions, with strong, mass-loading interactions (e.g. Enceladus) yielding the most interesting and complex results. All test particles used are equatorially mirroring, but part of the results could be generalized for all pitch angles.

A re-examination on the Mass Budget of the Saturn's Ring Atmosphere and Ionosphere at Equinox

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Abstract. For a long time, the Saturnian ring system has been suggested to be immersed in a neutral atmosphere. The related source mechanisms are the constant bombardment of the icy particles by interplanetary meteoroid (BIM) and irradiation by solar UV photons (ISP). Both effects release neutral molecules either in the form of impact water vapor (from BIM) or gas emission in the form of H2O, O2 and H2 (from ISP). The existence of an oxygen exosphere and ionosphere in Saturn's main ring region has been confirmed by the SOI observations of the Cassini spacecraft. In addition, Cassini RPWS found that a large amount of the Enceladus-originated water-group plasma would be deposited on the outer edge of the A ring. These icy materials could be recycled to neutral oxygen molecules via grain-surface chemistry. In this work, we have examined the mass budget of the ring oxygen atmosphere of Saturn taking into account such an "exogenic" source. The maximum O2 source rate from recycling of Enceladus-originated plasma is probably comparable to the one from photolytic decomposition of ices. In this case, the neutral O2 source rate would be independent of the solar insolation angle. Therefore, even at Saturn's equinox, the extended oxygen atmosphere still could be an important supplier of oxygen ions in the Sautrnian magnetosphere. We have performed several studies for different recycling source rates from Enceladus. These predictions need further Cassini MIMI and CAPS observations to be verified in future.

Dynamics of the nanometer-size dusts originated from the Jovian and Saturnian systems, Cassini dust detector results

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Abstract. We present the observation of fast nanometer-size dusts, or so-called stream particles, from planetary magnetospheres by the Cosmic Dust Analyzer (CDA) on Cassini spacecraft. Due to the small scale of the nanometer size, stream particles are more sensitive to the electromagnetic force than to gravity. These tiny charged dusts can aquire energy from the magnetospheric electric field and are able to escape the planetary magnetosphere with velocity greater than 100km/s. In the interplanetary space, the dynamics of the tiny dusts is dominated by the interplanetary magnetic field (IMF). In compression regions of the solar wind, stream particles are accelerated strongly by the induced electric field and form the dust bursts as observed by in-situ dust detectors on Ulysses, Galileo and Cassini spacecrafts. With higher sensitivity and a mass spectrometer, CDA on Cassini provide us a more comprehensive picture of stream particles from two planetary systems. First, CDA observations suggest a continuous dust ejection from Jovian and Saturnian systems. Second, the main chemical composition is found out to be NaCl for Jovian-origin particles (Postberg et al., 2006), and silicate material for Saturnian-origin paritlces (Kempf et al., 2005). Third, by understanding the interaction of stream particles and solar wind, the data could provide important insight to their formation environments and gives us an unique opportunity to study the dust-moon-magnetosphere system of Jupiter and Saturn.

Invited Talk

Planet-Star Plasma Interactions and Possible Radio Emission

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Abstract. Planet–Star plasma interactions can be described as the interaction of a plasma flow with an obstacle, each being possibly magnetized. Examples of 4 possible situations are found in our solar system, with intense radio emissions produced in 3 cases out of 4, when either the flow or the obstacle is strongly magnetized. Scaling laws are derived that relate the emitted radio power to the power dissipated in the various corresponding flow-obstacle interactions. They are generalized as a "radio–magnetic" scaling law between the output radio power and the magnetic energy flux convected onto the obstacle. Extrapolating it to the case of exoplanets, we find that hot Jupiters may produce very intense radio emissions due to planetary magnetospheric interaction with a strong stellar wind, reconnection between planetary and stellar magnetic fields, or unipolar interaction between the planet and a magnetic star (or strongly magnetized regions of the stellar surface). Emitted radio power is expected in the hecto–decameter range with intensity 10^3 to 10^6 times that of Jupiter (unless some "saturation" mechanism occurs). Corresponding flux densities should be detectable at tens of parsecs range with modern radio arrays. We briefly discuss ongoing and future observational searches as well as the interests of direct radio detection.

Latest Perspective for the Jovian Magnetospheric Orbiter

Kasaba, Y.[1], M. Fujimoto[2], T. Takashima[2], S. Sasaki[3], and International JMO Science Forum

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(3) *NAOJ*

Abstract. The space plasma research group in Japan has a unified view for the future space missions in next two decades. The small radiation belt mission ERG, the multi-spacecraft mission SCOPE, the BepiColombo mission to Mercury, and the small EUV telescope mission Exceed are the running and proposing core missions.

The Jovian mission, under the study with international collaboration, is set as the next biggest mile stone. Small studies have done from the beginnings of 2000s. In 2006, the team was gradually evolved expanded to a formal 'Future Jovian exploration Working Team', and found a connection to the European studies, 'Laplace', which was proposed to the ESA next generation program, New Cosmic Vision, as the collaboration next to the successful BepiColombo scheme. In 2008, it was linked to the ESA and NASA unified single project, the Europa Jupiter System Mission (EJSM), to be launched in 2020. In this context, while the level of the study is lower than NASA and ESA, JAXA also have the plan to provide JMO (Jovian Magnetospheric Orbiter) and TAE (Trojan Asteroid Explorer) to the mission.

'The JMO Science Forum' has tried to define the science requirement for the JMO, under the coordination with the JAXA mission study team formed in April 2008. We expect that the spacecraft is a spinner, which is the best platform for plasma in-situ measurements, and will perform high-quality in-situ plasma observations in, from the space plasma physics point of view, the most attractive corner of the solar system. In synergy with JEO and JGO, which will have plasma instruments onboard as well, there will be made possible three-point measurements in the Jovian magnetosphere prior to the final orbit insertion of the two orbiters. Combination with the plasma imaging capabilities provided by the JMO will also provide key information. After the final orbit insertions, JMO will provide large-scale view of the plasma environment variations that the orbiters will observe locally.

Earth Posters

Magnetosonic Mach number dependence of the efficiency of reconnection between the interplanetary and terrestrial magnetic fields

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Abstract. We present a statistical investigation into the magnetosonic Mach number dependence of the efficiency of reconnection at the Earth's dayside magnetopause. We use the transpolar voltage, V_{PC}, derived from radar observations of the ionospheric electric field, as a proxy for the dayside reconnection voltage. Our results show that the IMF clock angle dependence of V_{PC} is closely approximated by the function $f(\theta) = \sin^2(\theta/2)$, which we use in the derivation of a solar wind transfer function $E^* = E_{SW} f(\theta)$, where E_{SW} is the solar wind electric field. We find that V_{PC} is strongly related to E^*, increasing almost linearly with small E^*, but saturating as E^* becomes high. We also find that E^* is strongly dependent on the magnetosonic Mach number, M_{MS}, decreasing to near-zero values as M_{MS} approaches 12, due principally to decreasing values of the IMF strength. V_{PC}, on the other hand, is only weakly related to M_{MS} and for lower, more usual, values of E^* actually shows a modest increase with increasing M_{MS}. This result has implications for the solar wind-magnetosphere interaction at the outer planets where the Mach number is typically much higher than it is at 1 AU. Example SuperDARN convection maps from two high Mach number intervals are also presented, illustrating the existence of fairly typical reconnection driven flows. We thus find no evidence for a significant reduction in the magnetopause reconnection rate associated with high magnetosonic Mach numbers.

Jupiter Posters

A model to simulate the current systems of the Jovian magnetosphere.

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Abstract. In the Jovian magnetosphere, the corotation enforcing current system plays a major role and controls the main oval auroral emissions. This current system is composed of: 1) radially outward currents in the equatorial plane, where the closed field lines of Jupiter are deformed by the subcorotating plasma; 2) Pedersen currents in the ionosphere, which are pointing to the equator; 3) field aligned (Birkeland) currents closing the system. In this study, we present a consistent MHD model specially designed to perform three dimensional global simulations of the Jovian magnetosphere and to reproduce the corotation enforcing current system. This model will allow us to improve our understanding of the current systems in the Jovian magnetosphere.

Solar wind-driven flows in Jupiter's magnetosphere

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Abstract. The New Horizons flyby of Jupiter in the spring of 2007 provided a unique set of observations in Jupiter's magnetotail from 150 RJ to 2500 RJ. The particle data showed large plasmoids, lacking a signature of the planet's 10-hour rotation period beyond 200 RJ, filling the magnetotail. These observations were contrary to the expectations for an "open" magnetosphere and precipitated a new debate regarding the fundamental nature of Jupiter's magnetosphere. We present a review of relevant data and theories from Pioneer to New Horizons. Based on the available evidence, we argue for a "quasi-closed" magnetosphere with solar wind-driven flows due primarily to viscous processes at the magnetopause boundary. In particular, we show that a "quasi-closed" magnetosphere is consistent with observations of: 1) flux tubes substantially depleted of energetic particles in regions outside of the plasmasheet, 2) anti-sunward flow in the dawnside ionosphere, and 3) a long magnetotail extending 4 AU downstream. In addition we emphasize that the magnetosphere exists in either a compressed or an extended state where the magnetopause boundary is determined by a pressure balance between the solar wind dynamic pressure and the magnetospheric high-beta plasma.

Modeling dynamics in Jupiter's outer magnetosphere and its interaction with the solar wind

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Abstract. We have begun to develop a spatial model of the cushion region in Jupiter's outer magnetosphere. Using the Khurana magnetic field model at Jupiter, we have mapped out regions of high and low fluxes of energetic particles along the trajectories of Pioneer, Voyager, Ulysses, and New Horizons spacecraft. We find the fluxtubes with low particle flux map to a region within the magnetosphere (i.e. on closed field lines) at the flanks of the magnetosphere. We have also used the Khurana field model to map the dark polar region of the aurora to the cushion region. By examining possible regions of reconnection at the magnetopause, we will be able to better understand flux tube motion at the outer magnetopause and the extent of the solar wind influence at Jupiter. We begin this study by mapping out the Khurana magnetic field model at the magnetopause and the draping of the IMF at this boundary with the intent of testing for regions of possible reconnection by considering the relative field orientations. This work will allows us to better characterize the interaction between Jupiter's magnetosphere and the solar wind.

Low energy (< 7.5 keV/Q) plasma observations in the 150 - 2550 RJ region of Jupiter's magnetotail

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Abstract. The New Horizons (NH) spacecraft entered the Jovian magnetosphere on DOY 56, 2007, crossing the dayside magnetopause at ∼67 RJ. After closest approach at 32 RJ on the dusk-side, NH proceeded on a trajectory nearly directly down Jupiter's magnetotail, including the previously unexplored ∼150 to 2550 RJ tail region. The Solar Wind Around Pluto (SWAP) plasma instrument onboard NH was able to observe ions in this region over an energy per charge (E/Q) range of 0.035 to 7.5 keV/Q. As Jupiter's magnetosphere is known to be populated by a significant amount of heavy ions, mostly sulfur and oxygen in various charge states, we looked for a mass dependant signal in the SWAP science and calibration data with the goal of revealing the composition of the plasma measured by SWAP. As described by McComas et al. [2007], we used flight calibration data to compare the instrument response for 1 keV H+ and 1 keV N+ and found that, at least at these energies, we may be able to distinguish between light and heavy ions. Thus, we have rebuilt a flight-like engineering model of SWAP and are currently in the process of characterizing its response to ions of different mass over the entire E/Q range of the instrument. Once finished, we will apply these results to the Jovian magnetotail data with the goal of determining the composition and indentifying the potential source (Io torus, Jupiter's ionosphere, magnetosheath/solar wind) of the plasma measured by SWAP throughout the entire Jupiter encounter.

A study on the solar wind effect on non-Io decametric Jupiter radio emissions

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Abstract. Auroral Jupiter decametric radio emission not controlled by Io (non-Io DAM) is known to have a solar wind modulation effect. In this work, solar wind data from Ulysses (November 2003- March 2004) flyby, and Nançay decametric array radio data are used to study the effects of interplanetary solar wind structures on Jupiter non-Io DAM emissions. Plasma and magnetic field data are used to identify solar wind structures. Solar wind data are propagated to Jupiter and correlated with the occurrence of non-Io DAM emissions. The effect of interplanetary strucuctures, such as shocks, on non-Io DAM emissions is evaluated using a superposed epoch analysis. Correlations between solar wind pressure and radio emission power are also investigated.

Detection of Magnetically Organized Auroral Features by Segmentation Technique

Guio, P.[1] **and N. Achilleos**[1]

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Abstract. We extend our previous work on the use of the VoiSe image segmentation algorithm for auroral analysis (*Guio and Achilleos, MNRAS, submitted*) by constructing segmentation maps of jovian images which have been transformed to a system of magnetic latitude and longitude. For this transformation we use an eccentric dipole representation corresponding to the coefficients of the VIP4 model (*Connerney et al 1998, JGR*). We comment on the efficiency of this approach for enabling the discrimination of arc-like features that lie approximately along contours of constant magnetic latitude. We also draw comparisons with other techniques based on data-filtering.

The Composition of energetic particles in Jupiter's magnetotail

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Abstract. The New Horizons spacecraft offered a unique opportunity to explore the distant Jovian magnetotail to over 2565 RJ. Previous observations of ion abundances were available only out to 150 RJ. During the 100+ day exploration of the magnetotail, instruments on New Horizons observed a number of energetic particle bursts, similar to particle bursts observed by Galileo much closer to Jupiter. We examine the composition of these dynamic structures and compare the ion abundances with those found in more quiescent regions. We show that the composition of these energetic bursts is Iogenic and suggest it is within these bursts that Jupiter releases the bulk of its energetic material. We report on the ion composition ratios as a function of distance down the Jovian magnetotail, finding an increasing intrusion of interplanetary He into the tail with distance from the planet. It is not well understood how solar wind ions enter the tail. These observations show that the radial gradients in particle flux observed by Galileo in the magnetotail close to Jupiter extend deep into the magnetotail. We observed large electron intensities at the noon magnetopause crossing and continuous strong 10-h modulations in electron intensity to nearly 500 RJ toward the tail. Our current hypothesis is that Jupiter enforces a periodicity to hundreds of RJ, but this suggests the new question of how this is carried out. At distances greater than 500 RJ we observed long-duration periods of strong electron anisotropy beaming down the magnetotail. Intermittent observations of 10-h electron modulation continue into distant regions of the magnetotail and we suggest these are a signature of occasional field line connection to the magnetosphere.

Modeling the Jovian radio arcs: Particle energy and field line geometry

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Abstract. The Jovian radio arcs are decameter emissions related to the Io-Jupiter interaction. Their arc shape in the time frequency plane is known to be due to geometrical visibility effect on sources spread along an "active" magnetic field line. The state of the art in their modelization will be presented, including some recent results which permit to deduce from their shape the position of the active field line relative to the Io field line and the emitting particle energy. This modeling is permitted by a numerical code, which was also used to model the Cassini observation of Saturn. The interest on such a modelization of the future observations of JUNO will be discussed.

Energetic Particle Evidence for Magnetic Filaments in Jupiter's Magnetotail

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Abstract. We will show that energetic ions with Iogenic composition are recurrently injected at 150±30 R_J (R_J = 71,492 km) anti-sunward of Jupiter and funneled down the magnetotail. The particle events show velocity dispersion and were observed during the first half of 2007 by the PEPSSI (Pluto Energetic Particle Spectrometer Science Investigation) instrument on New Horizons (NH). Our survey to 2562 R_J down the magnetotail characterizes the behavior of ∼few-keV – 1 MeV particles and their environment, yielding an estimate of the injection site location. A case study of one of the most interesting events, beginning on day-of-year 118, 28 April 2007, contributes to the determination that the ∼400 R_J-wide >9000 R_J-long magnetotail is actually composed of narrow ∼1 R_J-diameter filaments stretching down the tail. Reconciling this with the large (∼500 R_J) plasmoid interpretation supported by the NH/SWAP (Solar Wind Around Pluto) observations is an opportunity to greatly expand our understanding of the Jovian magnetotail and its particle dynamics. We will present our results and discuss the many intriguing open questions.

Polarization analysis of Jupiter's decametric and hectometric radio emissions from Cassini RPWS data

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Abstract. Although Jupiter's decametric (DAM) and hectometric (HOM) radio emissions were extensively observed from ground stations and spacecraft, they still are not clearly understood, due to their apparent complex phenomenology and limited observing conditions. Since the reachable lowest frequency at ground stations is limited by terrestrial ionospheric conditions, only the higher frequency part above about 15 MHz can be usefully studied from Earth. On the other hand, the observable frequency range from spacecraft is depending on actual capabilities of onboard receivers. Up to now, only the Planetary Radio Astronomy instrument aboard Voyager was designed for fully recording Jupiter's DAM and HOM spectrum ($\sim$0 - 41 MHz), but with incomplete polarization analysis capability. In particular, the apparent sense of circular polarization in single emission was found to change at $\sim$15 MHz. This complicated behavior is due to responses of the antennas, no longer short with respect to the wavelength, as theoretically studied by Ortega-Molina and Daigne (1984). Observations by Cassini around Jupiter's flyby provides the opportunity to reexamine this problem. We present a statistical analysis of Jupiter's HOM polarization by using data from Cassini Radio and Plasma Wave Science (RPWS) instrument, obtained over several months around Jupiter's flyby. Taking into account previous Voyager's results, we also show that the short antenna approximation, considered to work only up to $\sim$2 MHz when using 10 meter wire antennas, can provide useful (but qualitative) polarization results on DAM emission, up to 16 MHz. We anticipate that more representative antenna models (by using refined analytical approximations or numerical wire grid modeling (Macher, PhD thesis, 2008)) might be successfully used for extracting accurate Jupiter's polarization from RPWS measurements.

Polarization measurements of Jovian radio emissions at high- and low-magnetic latitudes observed by Ulysses spacecraft

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Abstract. In early 2004, the Unified Radio And Plasma wave (URAP) experiment onboard Ulysses measured the Stokes parameters of Jovian kilometric radiations at northern high-latitudes during the "distant encounter" flyby. Ulysses observed from more than +80 deg to less than +10 deg of Jovicentric latitude for several months. The observation indicated that quasi-periodic (QP) bursts and narrowband kilometric emissions (nKOM) have LH polarization (V +1). Therefore, we conclude that these emissions are LO mode waves. This is consistent with several previous observations at low-latitudes (0 deg) and mid-latitudes (-40 deg) (e.g., Daigne and Leblanc, 1986; MacDowall et al., 1993).

On the other hand, it was shown that broadband kilometric radiations (bKOM) have RH polarization (V -1) at high-latitudes. This result does not agree with our previous study based on the combination of observed location of bKOM and ray tracing, which showed these emissions as LO mode waves (Kimura et al., 2008). We confirmed by additional ray tracing analyses that a solution can allow LO mode waves to be observed with RH polarization at high-latitudes.

We are now analyzing polarization data observed at low latitudes during Ulysses' first flyby to Jupiter for comparison of polarizations at low latitude with those at high latitudes. Resultant polarization characteristics will constrain generation process and global propagation process of Jovian radio components.

Strong Solar Control of Infrared Aurora on Jupiter: Correlation Since the Last Solar Maximum

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Abstract. Polar aurorae in Jupiter's atmosphere radiate throughout the electromagnetic spectrum from X-ray through mid-infrared (mid-IR, $\sim 5-20$ μm wavelength). Voyager IRIS data and ground-based spectroscopic measurements of Jupiter's northern mid-IR aurora, acquired since 1982, reveal a correlation between auroral brightness and solar activity that has not been observed in Jovian aurora at other wavelengths. Over nearly three solar cycles, Jupiter auroral ethane emission brightness and solar 10.7 cm radio flux and sunspot number are positively correlated with high confidence. Ethane line emission intensity varies over tenfold between low and high solar activity periods. Detailed measurements have been made using the GSFC HIPWAC spectrometer at the NASA IRTF since the last solar maximum, following the mid-IR emission through the declining phase toward solar minimum. An even more convincing correlation with solar activity is evident in these data. Current analyses of these results will be described, including planned measurements on polar ethane line emission scheduled through the rise of the next solar maximum beginning in 2009, with a steep gradient to a maximum in 2012. This work is relevant to the Juno mission and to the development of the Europa Jupiter System Mission.

Results of observations at the Infrared Telescope Facility (IRTF) operated by the University of Hawaii under Cooperative Agreement no. NCC 5-538 with the National Aeronautics and Space Administration, Science Mission Directorate, Planetary Astronomy Program. This work was supported by the NASA Planetary Astronomy Program.

A Test of North-South Conjugacy in Mid-Infrared Auroral Emission from Jupiter

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Abstract. We investigate whether the mid-infrared component ($\sim 5 - 20$ μm) of Jupiter's multiwavelength auroral emissions system demonstrates conjugate variability between the north and south polar regions, using groundbased observations acquired over the past three decades. Northern and southern ultraviolet auroral power have been demonstrated to vary together, indicating that total power delivered to each polar region by deposition of energetic primary particles is controlled by similar or even identical magnetospheric processes. At least some mid-IR auroral emission features, however, are correlated strongly with solar activity (see Kostiuk *et al.*, this meeting), while the ultraviolet auroral intensity has not been shown to correlate with solar activity, a decoupling which suggests that mid-IR aurora responds to distinct magnetospheric phenomena. Conjugate north-south variability in the mid-IR thus is not assured and a test of conjugacy provides an initial avenue to probe for differences between mid-IR aurora and other auroral emission processes at Jupiter.

Results of observations at the Infrared Telescope Facility (IRTF) operated by the University of Hawaii under Cooperative Agreement no. NCC 5-538 with the National Aeronautics and Space Administration, Science Mission Directorate, Planetary Astronomy Program. This work was supported by the NASA Planetary Astronomy Program.

Spectro-polarimetry measurements of Jupiter's infrared aurora

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Abstract. Linear polarization of the terrestrial auroral oxygen red line (630 nm) was recently reported, providing the possibility of a new observational probe of planetary ionospheres. At Earth the polarization rate depends on the energy and pitch angle of the incident precipitation. Due to the very large lifetime of the O1D state (110 s) the remaining polarization rate can also give information on the collisional processes that occur between 200 and 400 km in the thermosphere. Can such a polarization study be applied to Jupiter's aurora? Emissions from the H3+ molecular ion dominate Jupiter's aurora in the infrared. H_3^+ is created after a chemical reaction which scrambles collisional information, such that remaining polarization may be due to a static anisotropy created by an electric field. Measuring this polarization may therefore provide a measure of the ionospheric electric field. In order to first test if Jupiter's infrared aurora exhibits observable polarization, we made spectro-polarimetry measurements of near infrared H_3^+ emissions in Jupiter's southern aurora using UIST/IRPOL on the UK Infrared Telescope. Results are presented.

Ground-based observations of Jupiter's infrared aurora

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Abstract. Jupiter's infrared aurora is dominated by emissions from the H_3^+ molecular ion; emission rates are around 10^{12} to 10^{13} W planetwide. Observations of these emissions using ground-based telescopes have provided insight into the physical conditions of the auroral ionosphere and the ionosphere's connection to the magnetosphere. We discuss results from high-resolution spectroscopic observations in the 3 – 4 micron wavelength region and discuss future directions for infrared studies.

Variation characteristics of Jupiter's synchrotron radiation at 610MHz

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Abstract. Jupiter's synchrotron radiation (JSR) is generated by the relativistic electrons trapped in Jupiter's inner radiation belt (JRB). Variation of JSR is, therefore, an important probe to investigate generation and dissipation processes of the relativistic electrons. Regular and systematic JSR observations have been made by several groups and revealed the existence of short-term variations at a time scale of several days to weeks inferring some global electro-magnetic activities in the JRB. Now it's the time to investigate details of variation characteristics and their causalities.

A series of interferometer observations for JSR tells us information of spatial distribution and its variation of pitch angle and/or radial distribution of relativistic electrons around Jupiter ($\sim$ 3Rj). Campaign observations for JSR using the Giant Metrewave Radio Telescope (GMRT) in India, which is the largest radio interferometer in the meter wave length, had been made from May to June, 2007 and also May to June, 2008. We made the interferometer observations mainly at 610MHz once a few days when some specific Jupiter's magnetic longitudes faced to the earth. In the observation periods, the solar EUV flux showed gradual increase and decrease at the amount of about 20% in 2007, while showed about 10% variations in 2008. Since EUV flux variation is considered to be a possible causality of JSR variations (Miyoshi et al., GRL, 1999), it is expected that the campaigns were good opportunities to examine the effect of the solar EUV flux on JSR.

As the results, short-term variations at the amount of nearly 20% with the time scale of several days were identified, which showed little correlation with solar EUV flux and implied existence of some internal process in the JRB. It is also suggested that both increase and decrease of flux variations were caused by plural physical processes, such as partial inward diffusion in longitude and/or radial distance for the flux increase, and wave-particle interaction, satellite absorption and some unknown loss process in the innermost JRB for the flux decrease.

Acknowledgement: We thank Dr. C. H. Ishwara-Chandra and all the staff of the GMRT who have made these observations possible. GMRT is run by the National Centre for Radio Astrophysics of the Tata Institute of Fundamental Research.

Observations of jovian polar auroral filaments

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Abstract. In this paper we report a phenomenon hitherto unobserved in Jupiter's ultraviolet polar auroras, specifically thin (∼0.6° wide), long-lived quasi-sun-aligned polar auroral filaments (PAFs) of brightness ∼100 kR spanning the highly variable region poleward of the main oval. This observation, made using Hubble Space Telecope images, is significant since no coherent structures have previously been observed in Jupiter's very high latitude auroral region. PAFs have been observed in 4 sets of observations over 6 days in 2007, and their occurrence appears to be independent of impinging solar wind conditions. The feature comprises two components: the section toward noon remains fixed in orientation toward the sun, while the anti-sunward section rotates. We estimate overall rotation rates of ∼0 - 45% of corotation, values which may indicate the rotation rate of Jupiter's polar ionosphere and tail lobes.

Variability of Jupiter Synchrotron Emission on Time-scales of days to weeks: First Observations with the VLA

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Abstract. We present the first evidence of short-term variations of Jupiter's radiation-belt emission obtained with interferometric measurements. Over a two-month period of observational time in 2002, we have observed the Jovian synchrotron emission with the Very Large Array (VLA). The images constructed at the wavelength of 6 cm demonstrate significant changes in the spatial structure of the brightness distribution. We report that the peak brightness distribution near the magnetic equator evolved differently during the 10-hour rotation of the planet and over the campaign of observations.

Our detailed analysis of the equatorial brightness will show that, for a series of CMLs, the radiation peak near 1.4 Rj was shifting back and forth from one side of the planet to the other on a time-scale of days. We will demonstrate that the change in the location of the emission peak is the result of fluctuations in the peak brightness distribution by 10% up to 40%. We will discuss how the source of variability can be linked to the angular sectors covering the Jupiter SIII longitudes where the field strength along the equatorial magnetic surface is maximum or minimum.

Finally, we will discuss the possible mechanism taking place in the innermost region of Jupiter's magnetosphere and responsible for the variability of Jupiter synchrotron emission on short time-scales.

CHARACTERISTICS OF JOVIAN MAGNETOSPHERE-IONOSPHERE CURRENT SYSTEM INDUCED BY DIURNAL VARIATION OF IONOSPHERIC CONDUCTANCE

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Abstract. We investigate the effects of diurnal variation of ionospheric conductance caused by solar EUV on the system using a newly developed numerical model of the Jovian magnetosphere-ionosphere coupling system. The ionospheric conductance is determined by ion chemical processes with hydrogen and hydrocarbon ions produced by solar EUV and auroral electrons, which are important in the lower ionosphere because this region contributes larger to the conductance. The model solves the torque equations of the magnetospheric plasma due to radial currents flowing at the magnetospheric equator, which enables us to update the electric field projected onto the ionosphere and the field-aligned currents (FACs) depending upon the ionospheric conductance. As a result, the ion density and conductance shows diurnal variation. Because of the positive feedback of the ionospheric conductance on FAC, the calculated FAC shows diurnal variation with the maximum on dayside and the minimum just before sunrise. The power transferred from the planetary rotation is mainly consumed in the upper atmosphere around noon, while it is consumed by plasma acceleration other local time. Our simulations also show that the magnetospheric plasma density and mass flux affect to the time variation of peak FAC flux. FAC density increases by 40% associated with an enhancement of the solar EUV flux by a factor of 2.4. Dependence of FAC variation on the auroral electron spectrum does not simply correspond with the relation between the electron flux and conductance but also affected by the system inertia. Furthermore, both the theoretical analysis and numerical simulations reveal that the amount of FAC is directly related to the planetary angular velocity on the dayside and its square on the nightside. We would like to discuss the effect of additional radial current on the system in this presentation.

Short-term variations in Jupiter's synchrotron radiation: Comparison between observations and a radial diffusion model

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Abstract. Observations of Jupiter's synchrotron radiation (JSR) were made at 325 and 785 MHz by the Iitate planetary radio telescope (IPRT) and at 2.3 GHz by the 34-m radio telescope at NICT in 2007 and it is found that the flux density of JSR shows the short-term increases and subsequent decreases with a time scale of several days. Comparisons between the variations in JSR and the solar UV/EUV indices show positive correlations, but the variations in JSR were preceded by those of the solar indices by several days (Tsuchiya et al. 2009).

A numerical simulation on a radial diffusion model has been made in order to examine the time variation in JSR. The model takes account of only equatorially mirroring electrons and includes fundamental physical processes in the radiation belt such as the radial diffusion, energy degradation by the synchrotron radiation, and some loss processes (sweeping by satellites and rings, coulomb interaction with thermal electrons, and so on). Two diffusion models are considered: a normal diffusion model in which the radial diffusion coefficient is adopted from Goertz et al. (1979) and a fast diffusion model where the diffusion coefficient is ten times greater than the normal value. This value is still in the range of a theoretical estimate of Brice and McDonogh (1973). We first tried to find equilibrium solutions which were consistent with an empirical radiation belt model (Devine and Garrett 1983). The factors in each loss rate were adjusted to bring the numerical results into correspondence with the empirical model at four electron energies of 1, 5, 10, and 20 MeV for both the normal and fast diffusion models.

By using the equilibrium distribution as an initial condition, the time variation in JSR was investigated. We examined a hypothesis that temporal changes in the radial diffusion rate associated with the solar UV/EUV heating in Jupiter' thermosphere could be an origin of the short-term variation. It is found that the both models reproduced the increase in JSR but the normal model did not account for the fast decrease seen in the observation. In the case of the fast model, we found a suitable solution which accounted for not only the increase in JSR but the decrease and the time delay between the variations in JSR and the solar UV/EUV. This suggests that the radial diffusion dominates the variability in Jupiter's radiation belt and the diffusion rate is faster than it has previously been thought.

Jupiter's equatorial magnetic field: a 2-D model and its implications for the open/closed boundary in the polar cap

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Abstract. Measurements of the Jovian magnetic field are available at a range of radial distances and at nearly all local times. Previous studies have quantitatively described how the field magnitude and magnetic pressure fall off with radial distance, but little has been done to model changes with local time. Changes with local time are especially relevant for nightside modeling of B_θ, the north-south component of the magnetic field, which is known to be larger pre-midnight than post-midnight. In this work we present a two-dimensional surface fit for the equatorial magnetic field magnitude and for the radial, north-south, and azimuthal components. This fit accounts for changes in both radial distance and local time. The equatorial distribution of B_θ can then be used to map fieldlines from the equatorial region to the ionosphere by using appropriate assumptions about the internal field and the bendback angle. We will estimate the ionospheric field by the VIP4 model for the internal Jovian field. The ionospheric mapping will establish possible locations of the boundary of open/closed flux in Jupiter's polar cap, which could have important consequences for models of dynamics and our understanding of the open or closed nature of the Jovian magnetosphere.

Voyager 1 out-bound view of the Io plasma torus

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Abstract. We have investigated the Voyager 1 out-bound UVS observations of the Io plasma torus. Our intent was to find an upper limit for the width of the ribbon feature in the torus, which was found to be 0.2 R_J, in agreement with earlier estimates. Furthermore we wanted to get an average distance of the torus from Jupiter, from the Voyager 1 out-bound viewpoint to get a better understanding of the torus asymmetry. We found that the averaged position of the approaching ansa is 5.74 ± 0.10 R_J and of the receeding ansa 5.83 ± 0.15 R_J.

Io Posters

Generation of Parallel Electric Fields in the Jupiter-Io Torus Wake Region

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Abstract. Infrared and ultraviolet images have established that auroral emissions at Jupiter caused by the electromagnetic interaction with Io not only produce a bright spot, but an emission trail that extends in longitude from Io's magnetic footprint. Electron acceleration that produces the bright spot is believed to be dominated by Alfvén waves whereas we argue that the trail or wake aurora results from quasi-static parallel electric fields associated with large-scale, field-aligned currents between the Io torus and Jupiter's ionosphere. These currents ultimately transfer angular momentum from Jupiter to the Io torus. We examine the generation and the impact of the quasi-static parallel electric fields in the Io trail aurora. A critical component to our analysis is a current-voltage relation that accounts for the low-density plasma along the magnetic flux tubes that connect the Io torus and Jupiter. This low density region, ~ 2 R_J from Jupiter's center, can significantly limit the field-aligned current, essentially acting as a "high-latitude current choke". Once parallel electric fields are introduced, the governing equations that couple Jupiter's ionosphere to the Io torus become nonlinear and, while the large-scale behavior is similar to that expected with no parallel electric field, there are substantial deviations on smaller scales. The solutions, bound by properties of the Io torus and Jupiter's ionosphere, indicate that the parallel potentials are on the order of 1 kV when constrained by peak energy fluxes of 1 milliWatt per meter squared. The parallel potentials that we predict are significantly lower than earlier reports.

A Search for Changes in Io's Sodium Cloud Caused by Jupiter Eclipse

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Abstract. We report preliminary results of a study of true temporal variations in Io's sodium cloud before and after eclipse by Jupiter. The eclipse geometry is important because there is a hypothesis that the atmosphere partially condenses when the satellite enters the Jupiter's shadow, preventing sodium from being released to the cloud in the hours immediately after the reappearance. The challenge lies in disentangling true variations in sodium content from the changing strength of resonant scattering due Io's changing Doppler shift in the solar sodium absorption lines. In 2007 we undertook four observing runs at Telescopio Nazionale Galileo (TNG) at La Palma Canary Island with the high resolution spectrograph SARG in order to observe this phenomenon. We observed two times with Io entering into Jupiter's shadow and two times with Io coming out from it, in the region around Na, the most easily detectable element in Io's atmosphere. The particular configuration chosen for the observations allowed us to observe Io far enough from Jupiter and to disentangle line-of-sight effects looking perpendicularly at the sodium cloud. Here we present preliminary results, which took advantage of a very careful reduction strategy. We remove the dependence from gamma factor, which is the fraction of solar light available for resonant scattering, in order to remove the dependence on the radial velocity of Io with respect to the Sun. Then we convert the observed photon intensity which depends on Io's orbital position, to column abundance, to test whether it is constant along Io's trajectory. We will present column abundance and spatial profile differences before and after the eclipse, as well as velocity profiles. This work has been supported by NSF's Planetary Astronomy Program, INAF/TNG and the Dipartimento di Astronomia and Cisas of Università degli Studi di Padova, through a contract by the Italian Space Agency ASI.

Polarization Characteristics of Io-related Jupiter 18 MHz Radio Emissions

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Abstract. Jupiter decametric radio emissions at 18 MHz were recorded with a crossed dipole polarimeter during 2000 – 2003 at the University of Florida Radio Observatory (UFRO). These data were recorded at a rate of two samples per second and the axial ratios (i.e. the percentage of circular polarization) were calculated for several Io-related radio emission events. Using this good time resolution data, we explore how the axial ratio evolves with time in each event and how Io-related emissions from the same source compare. We present a summary of axial ratio values for all Io-related radio sources.

Acceleration region above Io's trailing tail aurora

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Abstract. The satellite Io related decameter radio wave (Io-DAM) is radiated from Jupiter. The radiation mechanism of Io-DAM is thought to be the cyclotron maser instability and emission beam is assumed to be confined into hollow cone. Io-DAM generally appears as repeating bursts and they are classified into L-bursts (a few minutes) and S-bursts (tens of milliseconds) by their duration time.

DAM is often argued with auroral kilometric radiation (AKR) from viewpoint of the comparative planetary science. It is well known that broadband AKR is generated in an acceleration region. Therefore it is likely that L-bursts may be radiated from such a quasi-static acceleration region which will be related to Io's trailing tail aurora.

Io-DAM from the northern hemisphere is thought to be radiated from source regions on the field line passing through Io's revolution orbit where footprint magnitude of magnetic field is relatively strong (Genova and Calvert 1988). Purpose of this study is evaluation of validity of the thinking of Genova and Calvert 1988 by the way of numerical calculation. To derive electron velocity distribution at Io-DAM's source region, electrostatic potential profile along the field line is needed.

To calculate electrostatic potential profiles along magnetic field lines associated with Io's trailing tail aurora, we used modified Static Vlasov code (SV code was originally developed by Ergun et al. 2000). Along each field line, we allocated 64 grid points at regular intervals from the northern ionosphere of Jupiter to the Io plasma torus (centrifugal equator). Potential difference between the boundaries was fixed to be 30kV.

Using the VIP4 magnetic field model, we investigated altitudes of the acceleration regions (large potential jumps) on the field lines which pass through Io's revolution orbit with longitudinal intervals of 30 degrees. Parameters at the both boundaries were assumed to be uniform in longitude. Results show that large potential jumps are formed at the same grid point. This indicates altitudes of the acceleration regions are nearly same in longitude. And it implies that if one observes Io-DAM at a specific frequency, there will be positive correlation between intensity of emission from source region on the field line and magnitude of magnetic field at its footprint because the larger ratio of magnitude of magnetic field at the acceleration region and that at the frequency is, the larger pitch angle of accelerated electron is.

Shell versus ring maser-cyclotron instability in the Io-Jupiter flux tube.

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Abstract. In the Earth auroral zone, the Auroral Kilometric Radiations (AKR) is produced by the *shell/horseshoe* instability in cavities devoid of cold plasma. Their propagation angle is purely perpendicular. The relativistic dispersion function in a hot plasma allows direct generation of fast X-mode waves. The waves are reflected along the cavity, untill they can escape into space, with a different propagation angle. They are also partially converted into other wave modes (Z, O) accross the cavity boudaries.

In the case of the Io-Jupiter S-bursts, recent studies indicate that the waves have been directly generated with oblique propagation, resulting from a cyclotron-maser *loss-cone/ring* instability. With a purely hot plasma, they should be less unstable than X-mode waves associated to the shell instability. But in the simulations, the X-mode waves features do not not correspond to what is observed with S-bursts. A possible explanation is that cavities such as those seen on Earth do not exist on the Io-Jupiter flux tube regions of emission. Therefore, there is a cold plasma and perpendicular X-mode waves cannot be emitted. Instead, the shell instability produces Z-mode waves that cannot propagate outside the plasma region. This should be why, seen from outside the emission region plasma, the perpendicular waves triggered by the shell instability do not overcome the oblique waves in intensity. If Juno crosses the S-burst emission regions, we predict that it will measure a very high level of Z-mode perpendicular waves.

The View of the Io Plasma Torus From Cassini and New Horizons

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Abstract. The flybys of Jupiter by the *Cassini* spacecraft in 2000–2001 and the *New Horizons* spacecraft in 2007 provide a unique opportunity to fundamentally advance our understanding of the Io plasma torus and the Jovian magnetosphere. Here, we present the preliminary results from our program to analyze and model the UV observations of Io's corona, extended neutral clouds, and plasma torus made by the Ultraviolet Imaging Spectrograph (UVIS) aboard *Cassini* and the Alice ultraviolet imaging spectrograph aboard *New Horizons*. Additionally, we recapitulate our previous work demonstrating the importance of hot ($\sim$50 eV) electrons as the source of up to 50% of the energy budget of the torus and the driver of azimuthal variations in torus composition.

Plasma Temperature Anisotropies at Io

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Abstract. The volcanic moon Io is the source of much of the plasma in the Jovian magnetosphere. Neutrals originally from Io's volcanoes are ionized in the vicinity of Io and are picked up in the Jovian plasma. We are building a hybrid (kinetic ions and fluid electrons) simulation code to study the interaction of Jovian plasma with Io. In our initial study we have used a two dimensional version of the code to study the kinetic properties of the Jovian plasma near Io. In these calculations we investigate the level of the growth of temperature anisotropy of the Jovian plasma in the immediate neighborhood of Io which may trigger waves via anisotropy driven instabilities. In particularly we investigate the location of thresholds for ion cyclotron and mirror instabilities.

Saturn Rotation Rate Posters

Jupiter's Radio Rotation Period: 50 Years of Ticking

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Abstract. We present an updated measurement of the radio rotation period of Jupiter. Our previous measurement used 35 years of fixed-frequency data at 18, 20, and 22 MHz from the University of Florida Radio Observatory (Higgins et al., JGR, 102, 1997). Data from the University of Chile was also included to supplement the Florida measurements. We add 15 years more data to give a complete 50-year data set from 1957 – 2007. Occurrence probability graphs shown as a function of Jupiter central meridian longitude are calculated, and a 12-year cross correlation method is employed to reduce source variability from orbital effects. The additional data not only provide an updated rotation period but also reduce uncertainties in the measurement. We also discuss whether a drift is possible in Jupiter's magnetic field.

The phase and polarization of planetary-period magnetic field oscillations in Saturn's magnetosphere

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Abstract. We have studied magnetic field oscillations at near to the planetary period observed by the Cassini spacecraft on a sequence of near-equatorial periapsis passes spanning from SOI to the beginning of 2008. Using the revised phase model for the SKR planetary period oscillations proposed by Kurth et al. (2008), we have extended the magnetic phase model of planetary period oscillations of Andrews et al. (2008). This revised phase model forms the 'clock' as we study other planetary period oscillations at Saturn, namely oscillations observed in the polar regions, in the UV auroral oval and in the tail plasma sheet. A physical picture is presented that links together observed planetary-period modulations in the middle and outer magnetospheric field, plasma, radio emissions and the periodic tilting of Saturn's plasma sheet recently reported by Carbary et al. (2008).

Thermospheric vortices as a driver of Saturn's magnetosphere

Smith, C. G. A.

Abstract. Thermospheric vortices are discussed as a possible driver of the periodic signals observed in Saturn's magnetosphere. For example, a persistent anticylonic vortex in the northern hemisphere, rotating in local time close to the planetary rotation period, could drive an interhemispheric current system that produces the observed magnetic field perturbations. Such a vortex could be driven by a zonally asymmetric heat source rotating in local time, most likely related to a persistent and stably rotating asymmetry in a lower layer of the atmosphere. This asymmetry could then drive the thermosphere either by gravity wave dissipation or by Joule heating. Alternatively, the thermospheric vortex could be self-sustaining. An anticyclonic vortex in Saturn's thermosphere will drive upwards field-aligned currents at its core. If these currents are carried by downwards accelerated electrons, the associated heating could provide the energy to sustain the vortex.

Circulation, momentum transfer and the rotating magnetic signatures in the Saturnian magnetosphere

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Abstract. Magnetic signatures seen throughout the Cassini orbital are interpreted in the frame of a 3-regime rotating magnetospheric circulation system with single (less dense) inflow and (denser) outflow sectors (m = 1). At invariant latitude less than 70-72 deg, an omnipresent compressional signature indicate an m = 1 interchange motion (and thus a partial rotating ring current) superposed on the background ring current signature. The dominant field perturbations are transverse, the "cam" signal. Rotating field aligned currents at 70-72 deg invariant latitude mark the outer boundary of the cam. These currents are the source of the SKR. Peak SKR is when the cam field aligned currents and the currents associated with the solar wind stress at higher invariant latitude add together. The cam signal indicates intra-hemispheric momentum transfer, presumably from ionosphere to ionosphere. Its synchronization with the compression field points to it being a pseudo-Coriolis effect. The implication is that rotation has been imposed from the southern ionosphere and thus atmosphere during the Cassini epoch up to now. Above 70-72 deg invariant latitude, a highly swept back field pattern is found in the morning sector at high invariant latitude. In the afternoon the same field lines are much less stressed. Nonetheless, in both morning and afternoon the field normally shows a residual pulsing. The field signature indicates a slowed angular velocity in the morning where stress builds up with speed up in once midday is passed as stress is released with field lines ballooning outwards in evening and night sectors. In a steady rotating circulation, field lines carrying denser plasma blow open once per cycle as they move through the night side. This is the mechanism for losing plasma with a substorm-like change in the tail field once per cycle. Magnetic evidence is that inflow is much faster than the outflow. Equilibrium means the system is near marginal stability as the denser tubes enter the tail sector, a fact consistent with extreme substorm events occurring at a preferred SKR phase (i.e. during outflow tail passage)(Jackman, private comm). The final element of the model are regions at high invariant latitude where signals are very sinusoidal, resembling those of a rocking dipole. These are regions of permanently open flux and the magnetic period differs between north-south as elaborated in the Lecacheux-Southwood MOP 2009 paper.

Saturn's rotation period from Cassini/RPWS goniopolarimetric measurements

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Abstract. Radio (SKR), magnetic field, and plasma measurements in Saturn's magnetosphere all reveal a time–variable recurrence period about 10.6 to 10.8 hours, which raises two fundamental questions: (i) what is the cause of the observed variability, and (ii) what is the true rotation rate of Saturn's interior (or of its magnetic field) ? Concerning (i), all variations probably involve some "slippage" (e.g. due to the solar wind) of the measured phenomena with respect to Saturn's magnetic field, unless non–solid (differential) rotation affects the magnetic field itself. Previous work showed that a non–random slippage (whatever its cause) induces an apparent period variation consistent with the observations. Here we attempt to address (ii) thanks to the ability of Cassini/RPWS, in its "goniopolarimetric mode", to measure quasi–continuously 3D SKR source locations and magnetic footprints. We propose a means to relate observed footprints to magnetic longitude, independent of any slippage phenomenon. While the study of short–term motions of radiosource footprints can reveal (sub–)corotational motions, the statistical analysis of their distribution over several years permits to test the existence of an "active" longitude (possibly related to a magnetic anomaly), providing at the same time a measure of the true rotation of Saturn's magnetic field.

Saturn Aurora and SKR Posters

Elliptical polarization of Saturn Kilometric Radiation observed from high latitudes

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Abstract. The high-inclination orbits of the Cassini spacecraft from autumn 2006 until spring 2007 allowed the Cassini/RPWS (Radio and Plasma Wave Science) instrument to observe Saturn Kilometric Radiation (SKR) from latitudes up to 60° for the first time. This has revealed a surprising new property of SKR: Above ∼30° in observational latitude a significant amount of SKR is strongly elliptically polarized, in marked contrast to previous observations from low latitudes which showed only circular polarization. There are transitional latitudes where the elliptical polarization occurs in "patches" in the time–frequency spectrograms next to regions of still completely circularly polarized SKR. From ∼45° – 60° in northern latitude it is found that most of the SKR is elliptically polarized throughout its entire frequency range with an average degree of ∼0.7 in linear polarization. We also observe that the polarization of the SKR goes back to fully circular at very high latitudes (above 70°). We demonstrate the ellipticity of SKR by using the concept of "apparent polarization" in case of 2-antenna measurements, but also show 3-antenna measurements from which the polarization can be unambiguously determined. Possible reasons for the variation of SKR polarization with the observer's latitude will be discussed.

Calculations of Ionospheric Electrical Conductances in the Saturn's Auroral Oval

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Abstract. In the high latitude regions of Saturn, the ionosphere is coupled strongly to the magnetosphere though the exchange of particles and energy. Beside the generation of the well-known atmospheric auroral emissions, the influx of energetic particles from Saturn's magnetosphere upon the high latitude upper atmosphere enhances the ionospheric densities and temperatures, affects the electrodynamical properties of the ionosphere, and contributes to the heating of the thermosphere. It is therefore critical to accurately model the transport and energy degradation of these magnetospheric particles in the upper atmosphere in order to evaluate key quantities of the coupled magnetosphere-ionosphere system. We will present results of our Saturn Thermosphere-Ionosphere Model (STIM) focusing on the auroral oval. The electron and ion production rates induced by electron precipitation are derived from the kinetic component of STIM solving the Boltzmann's equation applied to suprathermal electrons. The upper atmospheric conditions are self-consistently derived from the STIM 3D General Circulation Model which includes ionization by electron precipitation. We will provide an assessment of the ionosphere's electrical conductances in the auroral main oval and compare them with the current values used in the models of the magnetosphere-ionosphere coupling at Saturn, as well as with empirical values derived from Cassini RSS observations.

Characteristics of electron precipitation derived from FUV observations of Saturn's aurora

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Abstract. Images of Saturn's aurora have been obtained with the Advanced Camera for Surveys (ACS) on board the Hubble Space Telescope between January 13, 2007 and February 16, 2008 during the HST-Cassini campaign. The limb of the planet has been observed in the ultraviolet at different latitudes, including in the auroral region. These images have been used to determine the altitude and the vertical distribution of Saturn's aurora above the limb. We find that it is generally located 900-1300 km above the 1-bar level. This result may be combined with the analysis of FUV and EUV auroral spectra which allow the determination of the methane and H_2 columns overlying the aurora, based on differential absorption and self-absorption respectively. The comparison of these different observations suggests that temperatures in the auroral thermosphere increase at a higher pressure level than in the low-latitude regions which were probed during the Voyager occultations. Using an electron transport code, we estimate the characteristic energy of the precipitated electrons derived from these observations to be in the range 1-5 keV using a low latitude model and 5-30 keV in case of the modified model we propose. Additionally, we derive information on the energy spectrum of the precipitated electrons by comparing the simulated emission rates with the profiles observed above the limb.

On the character and distribution of lower-frequency radio emissions at Saturn, and their relationship to substorm-like events

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Abstract. With the arrival of the Cassini spacecraft at Saturn in July 2004, there have been quasi-continuous observations of Saturn Kilometric Radiation (SKR) emissions. Exploration of the nightside magnetosphere has revealed evidence of plasmoid-like magnetic structures and other phenomena indicative of the kronian equivalent of terrestrial substorms. In general, there is a good correlation between the timing of reconnection events and enhancements in the auroral SKR emission. The vast majority of reconnection events occur at SKR phases where the SKR power would be expected to be rising with time. We show three examples in each of which the SKR spectrum extends to lower frequencies. We then conduct a survey of such low frequency extensions during the equatorial orbits of 2005-2006, and place some constraints on visibility of these radio emissions.

Auroral Hiss at Saturn - A Multi-Instrument Cassini Study

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Abstract. Over the last two years, the Cassini spacecraft has undergone a series of high inclination orbits, allowing investigation and measurements of the Saturnian auroral zone. The Radio and Plasma Wave Science (RPWS) Investigation has detected low frequency funnel-shaped whistler mode emissions along the auroral field lines, much like the auroral hiss observed at Earth. The poleward and equatorward flaring of the auroral hiss funnel on the frequency-time spectrogram is the result of whistler mode waves propagating upward into a region of diminishing plasma density. These detections are important in understanding the auroral processes occurring at Saturn. Integration of RPWS data with that from other instruments, including MAG, MIMI, and CAPS, reveals a more complete picture of this emission, demonstrating the field, currents, and particles involved with this emission. Early analysis of this multi-instrument study will be presented.

Characterization of Saturn's Kilometric Radiation (SKR) from measurements inside its source region

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Abstract. The Saturnian Kilometric Radiation (SKR) is an intense, non-thermal free-space propagating radio emission, similar to the Auroral Kilometric Radiation (AKR) at Earth, generated by wave-electron resonance in auroral regions. SKR has been continuously observed, since mid 2003, by the Radio Plasma and Wave Science (RPWS) experiment, onboard Cassini. So-called goniopolarimetric analysis of RPWS data provide the Poynting vector of each time-frequency measurement (intensity and direction of the k-vector) as well as its complete state of polarization. Investigation of many years of distant observations thus provide average SKR properties (spectrum, visibility of the emission, and polarization state). However, previous studies at Earth investigated observations inside AKR sources (Viking, FAST...) and showed drastically different characteristics of the emission inside and outside the emitting region (found in density depleted cavities where part of the AKR is trapped). Here, we investigate the recent (and yet only) crossing of an SKR source region by Cassini, and apply goniopolarimetric analysis to RPWS in situ measurements to derive SKR sources characteristics (polarization state, k-vector, modes of emission, and radiated power).

Does Saturn's UV aurora vary with SKR phase?

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Abstract. It is well known that various magnetospheric phenomena, e.g. the SKR power and magnetic field vector as measured by Cassini, exhibit oscillations near the planetary rotation period, and the location of Saturn's southern UV auroral oval was recently shown by Nichols et al. (2008) to oscillate with a period near that of the SKR. However, rather conspicuously, the emitted UV auroral power has not been shown to vary at the SKR period. In this paper we use bandpass-filtered SKR power to obtain the instantaneous SKR phase at the times when the Hubble Space Telescope was observing Saturn's UV aurora in 2005, 2007 and 2008, and we use this phase to order the UV power detected by HST during auroral 'quiet-time'. Our results suggest that the UV power may indeed be dependent on SKR phase, although the power variation is only by factors of order ∼2, rather than the orders of magnitude observed in the SKR. We also show that the majority of the variation originates from the dawn side, consistent with observations of the source of the SKR.

Source Locations of Saturn Narrowband Radio Emissions

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Abstract. Saturn narrowband radio emissions, mostly detected around 5 and 20 kHz, usually occur periodically for several days after intensifications of Saturn Kilometric Radiation. The 5 kHz and 20 kHz narrowband emissions are similar in many ways to Jovian nKOM and Earth's continuum radiation, respectively. Although they have been studied since their discovery by the Voyagers in the early 1980s, the generation mechanism and source location of Saturn narrowband emissions still remain uncertain. Since Cassini was placed in orbit around Saturn in 2004, the Radio and Plasma Wave Science (RPWS) instrument has detected many episodes of narrowband emissions at various radial distances, latitudes and local times. Evidence has been found that the generation of 20 kHz narrowband emissions is consistent with mode conversion from electrostatic upper hybrid waves on the boundary of the plasma torus. Various direction finding methods show that the source locations of 5 kHz narrowband emissions are in the auroral zone, where Z-mode narrowband emissions at 5 kHz are often observed below the local electron cyclotron frequency. We propose that the L-O mode narrowband emissions are mode converted from these Z-mode waves.

Saturn's Magnetosphere Posters

Force Balance in Saturn's Warped Magnetodisc

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Abstract. In the Cassini era, the north magnetic axis of Saturn's planetary dipole field has been oriented at angles of $>\sim 65$ degrees with respect to the upstream solar wind flow. This deviation from perfect orthogonality is responsible for the formation of a 'bowl-shaped' current sheet in the outer magnetosphere (Arridge et al, JGR, 2008). In order to investigate the force balance in such a structure, we have started by using the formalism of Caudal *(JGR, 1986)* to construct planar disc structures in which centrifugal, pressure and magnetic ('JXB') forces are in equilibrium. We extend this planar model to produce bowl-shaped geometries through the representation of the magnetopause 'shielding field' with an external dipole, displaced from the planet along the axis of azimuthal symmetry of the modelled system. The location and strength of the external dipole relative to the planetary source determines a curl-free field with north-south asymmetry which, when added to the planetary and disc fields, produces a distortion of the planar disc, 'sweeping' it back from the equatorial plane. We examine the effect on the sheet geometry of the external dipole parameters, and make preliminary comparisons with Cassini magnetometer data.

Effects of a Corotating Interaction Region on the structure and dynamics of the Saturnian magnetosphere

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Abstract. In order to understand the response of the Saturnian magnetosphere to solar wind dynamic pressure enhancements, we investigate magnetic field and plasma variations observed in-situ by the Cassini spacecraft. We take advantage of two particular orbits (Rev. 26 and 27 in July and August 2006) with similar radial distance, latitude and local time coverage of the Saturnian magnetotail to examine the large-scale structure and dynamics of the nightside current sheet. The observations obtained during these two orbits differ remarkably and some of them present some similarities with the phases of loading/unloading observed during terrestrial substorms.

During one of this orbit (Rev. 27), several increases of lobe magnetic pressure are observed, followed by a sudden change in the average position of the current sheet and variations in the longitudinal modulations of the magnetic, plasma and radio fluctuations (short-term dephasing). The deformation of the current sheet lasted for several days before it returned to its past position. Correlation with enhancements in Saturn Kilometric Radiation emissions suggests that solar wind disturbances may have triggered the observed reconfiguration of the Saturnian magnetotail by compressing and relaxing the magnetosphere. We test this hypothesis using a solar-wind propagation model and provide a plausible interpretation of the observed event that illustrates the Solar-planetary magnetosphere coupling at Saturn.

CDPP/AMDA, an interoperable web-based service usable for planetary plasma data exploitation and comparative studies: Application to the Saturnian environment and to the MAPSKP data

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Abstract. These last years, CDPP has developed a new service, AMDA (Automated Multi-Dataset Analysis, http://cdpp-amda.cesr.fr/), which is a web-based facility for on line analysis of space physics data (heliosphere, magnetospheres, planetary environments) coming from either its local database or distant ones, such as the CDAweb or the VEX/MAG database in Graz. This tool allows the user to perform on line classical manipulations such as data visualization, parameter computation or data extraction. AMDA also offers innovative functionalities such as event search on the content of the data in either visual or automated way. These functionalities extendable for automated recognition of specific signatures can be used for performing classification of events and for generating time-tables and catalogues.

In the context of Cassini Magnetosphere and Plasma (MAPS) IDS activities, the University of Michigan and CESR have developed a database for downloading and visualizing key parameters of the Cassini MAPS instrument suite. In collaboration with CESR, CDPP has set up an interoperable connection between AMDA and the Cassini MAPSKP (and VEX-MAG) databases. This experiment served as a demonstrator for the Europlanet/IDIS (Integrated and Distributed Information System). This is now an operational service of the IDIS/Plasma Node developed in close cooperation between CDPP and IWF. In addition to the MAPSKP data sets, the local AMDA database also contains normalized radio SKR data from the Cassini RPWS instrument which were derived by LESIA.

In this paper, we will present the service AMDA and illustrate some of its applications for the analysis of the Saturnian magnetosphere and its comparison with other planetary environments. Online demonstration of the service will be done on demand during the conference.

Cassini observations of Saturn's polar cusp

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Abstract. In this poster we describe observations from Saturn's southern polar cusp taken by the Cassini spacecraft in January and February 2007. A total of seven cusp encounters were observed in a total of three orbits of the spacecraft. Two of these cusps contained evidence of significant plasma acceleration, heating and associated diamagnetic effects. Double cusps were seen on two separate orbits through the high-latitude dayside region. We present the evidence for the presence of magnetosheath-like electron distributions inside the magnetosphere and show both energy-latitude ion dispersions and low-energy ion cut-offs. We interpret these dispersions and cut-offs in terms of reconnection between the kronian and interplanetary magnetic fields with the solar wind and use the observations to estimate the location of the reconnection X-line. Finally the observations are compared and contrasted with similar observations in Earth's magnetosphere.

Plasma electrons in Saturn's magnetotail: structure, distribution and energisation

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Abstract. Cassini was the first spacecraft to directly measure Saturn's nightside plasma sheet. For a proper interpretation of dynamical features in Saturn's magnetotail it is important to understand what is typical and atypical about the plasma sheet. In this paper we study the nightside and pre-dawn electron (0.5 eV - 28 keV) plasma sheet using Cassini data from 2006. We present intervals of data from the plasma sheet which exemplify the typical and atypical states of the plasma sheet and present a statistical study of the plasma sheet. We find that Saturn's nightside and pre-dawn electron plasma sheet exists in two states: a quiescent state with a steady electron temperature of 100 eV and where the electron distribution functions are best characterised by Kappa distributions, and a disturbed state where the electrons are hot (1 keV) and often seen in alternating layers between warm and hot populations. Evidence is also presented for bimodal cold/warm (both quiet and disturbed states) and warm/hot distributions (disturbed states). The disturbed states are qualitatively similar to electron distributions from Earth's magnetotail during intervals of reconnection and we argue that these disturbed states also result from periods of tail reconnection. We present statistics of electron number density, temperature, partial electron beta, and pressure, and show that large values of partial beta are necessary but not sufficient to identify the central plasma sheet. Finally the thermodynamic properties of the electron plasma sheet are studied and we show that the electrons behave isothermally. These results are important for modelling and theoretical analyses, and for use in studies which examine dynamics in Saturn's magnetosphere.

Saturn's ionospheric open field line region dependent on the IMF and solar wind dynamic pressure

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Abstract. The open field line region in Saturn's southern polar ionosphere is modelled appropriate to two compression regions observed by the Cassini spacecraft upstream of Saturn in January 2004, and compared with the auroral ovals observed simultaneously in ultraviolet images obtained by the Hubble Space Telescope. The modelling employs the paraboloid model of Saturn's magnetospheric magnetic field, whose parameters are varied according to the observed values of both the solar wind dynamic pressure and the interplanetary magnetic field (IMF) vector. It is shown that the open field area responds strongly to the IMF vector for both expanded and compressed magnetic models, corresponding to low and high dynamic pressure, respectively. It is also shown that the computed open field region agrees with the poleward boundary of the auroras. The results support the hypothesis that the auroral oval at Saturn is associated with the open-closed field line boundary and hence with the solar wind interaction.

An Updated Model of Saturn's Internal Planetary Magnetic Field

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Abstract. By the end of the Cassini prime mission in July, 2008, the fluxgate magnetometer had acquired four years of nearly continuous measurements of Saturn's magnetic field. During this time there were more than seventy periapsis passes at a variety of latitudes, longitudes and local times. Previous models based on Cassini data [Dougherty et al., 2005] show very little change in the planetary magnetic field since the Pioneer/Voyager era. A subsequent axisymmetric model shows little secular variation as well [Burton et al., 2009]. In this analysis we present new models based on all data obtained during the four-year Cassini prime mission. The external currents are estimated as those due to an axisymmetric equatorial ring current and standard inversion methods are used to determine the spherical harmonic coefficients that describe the internal planetary magnetic field. Given the fact that Saturn's rotation rate is poorly understood, the non-axisymmetric terms of the magnetic field are difficult to determine accurately if at all. We examine the values the non-axial magnetic field could assume for a range of likely planetary rotation rates.

Velocities of Radial Transport of Plasma in Saturn's Inner Magnetosphere

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Abstract. The Cassini Plasma Spectrometer (CAPS) and the Cassini Magnetospheric Imaging Instrument (MIMI) frequently observe longitudinally localized injection and drift dispersion of hot plasma in Saturn's magnetosphere. These signatures provide direct evidence for the major convective process in the inner magnetosphere of a rapidly rotating planet, in which the radial transport of plasma is expected to comprise hot, tenuous plasma moving inward and cooler, denser plasma moving outward. Based on the steady state plasma transport model of Pontius et al. [1986] and the ion velocity moments presented by Wilson et al. [2008], we estimate the radial velocity of these injection structures, where we have assumed that plasma is largely confined to a thin equatorial sheet and applied a centrifugal scale height model developed by Hill and Michel [1976]. The large values of radial velocity obtained here might indicate a larger-than-expected ionospheric Pedersen conductivity. These estimated velocities of inward-flowing plasma are then compared with direct measurements by the Ion Mass Spectrometer (IMS). Furthermore, by analyzing the width of the injection structures, the radial velocity of the outflowing plasma can be deduced from the fact that the total potential drop around a given L-shell should be zero.

Neutral Injection Sources and Transport in Saturn's Inner Radiation Belts

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Abstract. Saturn's inner radiation belts are located in several adjacent zones of long term trapping between orbits of moons and rings. Low energy electrons and ions are depleted by interactions with the E-ring and associated neutral gas from Enceladus. There are high intensity belts of high energy protons injected from beta decay of neutrons produced by galactic cosmic ray interactions with the main rings. These cosmic ray albedo neutron decay (CRAND) protons diffuse slowly and thus have very long trapping lifetimes in the belts. Electrons from the same neutron beta decay source would also populate these belts but inward radial diffusion appears to be the dominant source of energetic electrons. These electrons affect lifetimes of neutral gas atoms and molecules through ionization and impact the radiolytic surface chemistry of moon and dust grain surfaces. Another neutral injection source is charge exchange of energetic neutral atoms (ENAs) from the magnetospheric ring current region. The ENAs lose atomic electrons and become trapped from interactions with the neutral gas and dust environment pervading the inner magnetosphere from cryovolcanic activity of Enceladus. This ENA injection source is similar to that populating the low-altitude equatorial belt of keV-MeV protons in the upper atmosphere of Earth. An ENA source from double change exchange was detected by the Cassini MIMI/INCA instrument in the upper atmosphere of Saturn. The neutron and neutral atom sources would be active both outside the main rings in the known radiation belts and also planetward of these rings in the innermost belt (Cooper, DPS 2008) region first to be explored in-situ during the final phase of the Cassini mission. Modeling of the CRAND proton belts outside the rings indicates that proton and ion radial diffusion are driven at very low rates by magnetic impulses. Other work on local time distributions of moon sweeping microsignatures for electrons suggests that convective electric fields are not driving radial diffusion. These source and transport considerations are used to model the radial profiles of proton and ion belts originating from the neutron decay and neutral charge exchange sources. Upper limits for projected peak fluxes of CRAND protons in the innermost belt are very high. Radial profiles of these protons near Enceladus show depletion by interaction with E-ring material. Low energy ion fluxes in the main belts have much lower limits and likely arise from ENA injection.

Variations in the Suprathermal Ion Composition in Saturn's Magnetosphere with Time and Latitude

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Abstract. Using data from the MIMI/CHEMS instrument on Cassini we examine variations in the ion composition in Saturn's magnetosphere, both as a function of time during the 2004 to 2009 period and as a function of latitude, comparing the high latitude passes of 2008 and 2009 with the earlier equatorial passes. CHEMS determines the composition of suprathermal ions in the 3-220 keV/e range.

The relative abundances of different observed species are expected to reflect the relative strengths of various plasma sources, along with possible acceleration biases. The water group W+ is a good tracer for Enceladus, He++ of the solar wind, and the molecular ion H3+ of Saturn's ionosphere. The Enceladus source strength, in particular, might be expected to show long term temporal variations. The most abundant species from the 2004-2007 equatorial passes are W+, H+, and H2+ in a ratio of 1.9:1.0:0.15. The H3+ tracer is present at only 0.1% of H+ in that data set, although we have preliminary indications that it may be more abundant during the later higher latitude passes. Indeed, during brief observations of auroral beams, the H3+ to H+ ratio can reach 10%.

The Structure of Saturn's Current Sheet, Bow Shock, and Magnetopause as a Function of Solar Wind Dynamic Pressure and Season (Axial Tilt)

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Abstract. We present models of Saturn's bow shock, magnetopause and current sheet which have been developed using the results of our global, 3D MHD simulations of the magnetosphere. Our global MHD model self consistently treats the entire magnetosphere and includes magnetospheric plasma sources from a major disk-like source from Enceladus and the rings and a secondary toroidal plasma source from Titan. The model produces solutions which are not constrained to be symmetric therefore the results are quite useful in trying to extend previous models that have been generated using Cassini data. Because we can carefully control the inputs to our MHD model, we do not have to worry about separating variations due to local time, varying upstream conditions, spacecraft motion or changes in the mass loading rate that often make interpreting the data complicated. To generate our surface models, we begin by performing a series of steady states runs of the global model. To date we have more than 15 runs using different upstream dynamic pressures, axial tilts (corresponding to different Saturn seasons), upstream magnetic field orientation and internal mass loading rates. From each of these simulations we extract the surface every hour during a minimum of 100 hours. Because many of the runs show non-steady behavior we fit our analytic model surfaces to each of these simulation surfaces over several periods of the inherent dynamics. For the bow shock we fit a 4-parameter model to the surface where the fast magnetosonic Mach number falls to 90% its upstream value in the MHD simulations. In the case of the magnetopause, we determine the location of the surface using flow streamlines starting in the solar wind and then fit a 9-parameter analytical model that includes terms that represent the location of the cusps. Finally, for the current sheet location we will present a model that is based on that of Arridge (JGR, 2008) but that includes local time asymmetries. In each case, the models are a function of solar wind dynamic pressure as well as the Saturn season (axial tilt).

MHD study of the corotating plasma disk of the saturnian inner Magnetosphere

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Abstract. The dynamics of the saturnian magnetosphere is largely controlled by the planetary spin at a rate of about 10.5 hours. T is believed that Enceladus is the key agent for enabling this control. Enceladus creates neutrals that are ionized and picked up at a rate of a few kilograms per second and spun up to the corotational velocity to form a torus. The gas and plasma density peaks at the Enceladus orbit. In this torus, the majority of the gas particles travel at their keplerian speed of 14km/s, while the bulk of the plasma rotates at 40km/s as a response to the rigid spinning of the saturnian magnetic field. The corotating plasma torus feels a centrifugal force that is balanced by the magnetic tension force. The frozen-in saturnian magnetic field stretches radially to contain the plasma near the spin equator. When this corotating plasma again encounters Enceladus, it can suddenly lose momentum through charge exchange with the plume neutral gas. We investigate the force balance in the torus plasma and this possible effect of charge exchange with the Enceladus neutral plume, using our Saturn-centered MHD model together with recent Cassini observations.

The Saturnian ring current as revealed through plasma, energetic particle and magnetic field measurements made by the Cassini spacecraft.

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Abstract. Saturn's ring current flows eastward in the equatorial region and distorts the planetary field, thus influencing the configuration of the magnetosphere. Here we investigate its origins and physical characteristics have been investigated using combined plasma (CAPS), energetic particle (MIMI) and magnetic field (MAG) measurements.

First, magnetic field data from high-latitude orbits (Rev 35 to 37 and 40 to 42) have been used to determine the thickness of the current layer in the dayside and nightside magnetosphere between radial distances of 9 and 15 RS. The dayside data indicate the presence of a near equatorial current disk with a near constant half-thickness of 1.5 RS. More variable conditions are found on the nightside with minimum and maximum half-thicknesses of 0.4 RS and 2.5 RS respectively. The data also provide confirmatory evidence of northward displacements of the centre of the current layer from Saturn's equatorial plane in the outer regions, on both the dayside and the nightside of the planet.

Second, the combined data have been employed on the inbound and outbound passes of equatorial orbits (Rev 15 to 25, 47, 48 and 52) to address each term of the radial force balance equation, and to determine how each contribution to the current varies with radial distance. Initial results suggest that the azimuthal current density attributed to the plasma pressure gradient reaches its maximum contribution to the total current density in the region 10-15 RS. At smaller radial distances there is preliminary evidence to suggest that the inertial current term may be of importance.

The latest results from these studies will be presented.

RCM Simulations of Plasma Transport in Saturn's Inner Magnetosphere

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Abstract. We will describe recent numerical simulations of plasma transport in Saturn's inner magnetosphere ($2 < L < 12$) using the Rice Convection Model (RCM), incorporating a continuously active distributed plasma source derived from neutral-cloud modeling, peaking in the radial range $5.5 < L < 7.5$. The resulting convection consists of alternating longitudinal sectors ("fingers") of inflow and outflow, with average longitude spacing comparable to the radial width of the source distribution. The initial (linear) growth rate of these convection cells follows earlier analytical predictions, and their further (nonlinear) development confirms the retarding effect of the Coriolis force as elucidated by Vasyliunas (1994) and Pontius (1997). In the further nonlinear development, the inflowing fingers become much narrower in longitude than the outflowing ones, which may explain a previously unexplained feature of the Cassini CAPS plasma observations (Chen and Hill, 2008). In future simulations (probably before the meeting) we plan to incorporate a source of hotter but more tenuous plasma at the outer simulation boundary, in an attempt to simulate the drift-dispersion signatures (Chen and Hill, 2008) that are the most definitive observational signatures of the radial transport process.

Hot flow anomalies at Saturn's bow shock

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Abstract. We present evidence for the occurrence of a hot flow anomaly (HFA) at Saturn's bow shock. A survey of Cassini magnetic field and electron data taken upstream of the dawn flank bow shock is carried out in order to identify kronian HFAs. 17 events are identified that were all associated with heating of the ambient solar wind electrons and satisfy the majority of the conditions for HFA formation. For the event that occurred on 8 November 2004 the calculation of ion moments is possible. These moments reveal an ion temperature increase by a factor of approximately 1000 in the central region of the event that was associated with a significant deflection of the solar wind bulk flow. The spatial extent of the event was approximately 4.6 Saturn radii in the direction normal to the current sheet underlying the event. Pressure calculations imply that the heated central region was expanding at the time of the encounter. We conclude that the 8 November 2004 event was a spacecraft encounter with an HFA at Saturn's bow shock and we propose that the other 16 events identified by the survey were also HFA encounters. These observations suggest that HFAs are a solar system-wide phenomenon.

Possible Generation Mechanisms of Saturn Plasma Waves: Narrowband Emission and Whistler Mode Chorus

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Abstract. Narrowband emissions (NB) at Saturn are observed by the Cassini radio and plasma wave instrument (RPWS) at frequencies near 5 kHz and 20 KHz and harmonics of each frequency. Recently we have observed Z-mode emission associated with NB emission and strong density gradients providing good evidence for the direct generation Z-mode and subsequent mode conversion to O-mode (NB) emission. We report on the results of growth rate calculations of Z-mode emission by the cyclotron maser instability using observed electron phase space distributions. In addition, whistler mode chorus has a source region near the magnetic equator and is seen at frequencies generally less than 3 kHz. We report on recent efforts to better understand the role of non-linear growth mechanisms to predict the drift rate of fine structure observed by the Cassini RPWS high resolution wide band plasma wave receiver.

Kronian CMI growth rates based on Cassini RPWS spectra and ELS particle distributions

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Abstract. The Cassini spacecraft recently made the first in situ measurements of SKR and electron distribution functions in the Kronian auroral zone. The RPWS instrument recorded intense SKR bursts characteristic of cyclotron maser instability driven by unstable electron distributions as measured by the ELS instrument . We combine fitted models of these electron distributions with intensities and polarization of the observed RX and Z-mode radiation to calculate the expected growth rates and compare them with the observed RPWS spectra.

Identifying the Control Parameters for Plasma Dynamics within Saturn's Inner Magnetosphere

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Abstract. Soon after the initial passage of Cassini through Saturn's magnetosphere in 2004, transient events were observed by the magnetospheric instruments onboard the spacecraft. For the period Fall 2005 to Spring 2006, most of these events were characterized by a significant change in the magnetic field strength (MAG data), wave activities (RPWS data), and a drastic change in the densities of the low-energy and hot electron populations (CAPS-ELS and MIMI-LEMMS data). These transient events were interpreted as evidences of plasma circulation within Saturn's magnetosphere via centrifugal interchange instabilities. Using the formalism described in the 1980s for modeling the disk currents of Jupiter and Saturn, we have calculated the ring current's parameters for each equatorial passing of the spacecraft Cassini and obtained a good match with the MAG data inside about 14 Saturnian radii. The L-shell values where transient events occurred were then estimated with confidence. It was found out that one to two of the significant transient events observed during each equatorial orbit are located near the inner edge of the ring current. The analysis of the solar-wind parameters calculated by the Michigan Solar Wind Model shows that transient events can be correlated with synchronized and steep changes in the solar wind speed and density, and interplanetary magnetic field. These facts thus raise the question regarding the processes governing plasma dynamics within Saturn's magnetosphere and their response to solar wind conditions. In this paper, we present the results of our on-going investigation of the origins of transient events and their link to magnetospheric perturbations. We will discuss the possibility that local plasma dynamics driven by solar wind conditions contribute to the circulation of plasma, as well as the generation of plasma waves and radio activity.

Identification of photoelectron energy peaks in Saturn's inner neutral torus

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Abstract. We present observations from the CAPS electron spectrometer of characteristic peaks in the electron energy spectrum that are identified for the first time in the innermost regions of the Saturnian magnetosphere during some orbits of the Cassini spacecraft around Saturn. We show how a narrow electron energy peak at about 20 eV and a possible peak at about 42 eV can be extracted from the background in CAPS observations after the contamination from high-energy particles has been removed from the measurements. We estimate the density of the newly discovered electron population to be a small fraction (0.1) of the uncorrected total electron density measured in the CAPS/ELS energy range, and a much smaller fraction (0.01) when negative spacecraft potential is taken into account. We suggest that this population corresponds to photoelectrons generated by the solar UV photo-ionization of the extended cloud of neutral gas observed in these regions. We use pitch angle information to assess the equatorial source of these photoelectrons and a simple model of chemistry in order to further support our interpretation. In addition to the charge exchange mechanism, photoionization seems to be an efficient process for plasma production in the innermost magnetosphere. Finally, the comparison of the predicted and the measured photoelectron peak energies gives an estimation of the spacecraft potential in this region.

Radial particle pressure profile in the dayside magnetosphere of Saturn: Ring current density during selected near-radial passes of Cassini.

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Abstract. Passes of minimum Local Time change during Cassini's dayside equatorial plane orbits are selected, and combined energetic particle (MIMI), plasma (CAPS) and magnetic field (MAG) measurements are employed to construct a representative particle pressure radial profile and compute a particle pressure gradient and ring current intensity. Plasma (E<keV) and suprathermal (E>keV) pressures are locally compared to each other and to the magnetic field pressure, providing a precise in-situ plasma beta. The total particle pressure radial gradient is further compared to the centrifugal body force in order to determine the relative contribution of each term to the total ring current intensity. A statistical approach, including the analysis of a more extended -yet less representative of the radial direction- data set is also presented for comparison. Initial results indicate that: a) The suprathermal pressure component maximizes in the ring current region near the maximum total pressure (9 to 11 Rs), representing more than half of the total particle pressure; b) The in-situ measured radial pressure gradient, and thus the related contribution to the ring current intensity, appears slightly higher than the corresponding centrifugal body force term, within their variation range (3E-19 N/m vs. 2E-19 N/m); c) The azimuthal current components are also computed for the selected passes by fitting the magnetic field data with a modified axisymmetric model of the ring current. Cases of significant pressure gradient features of local or temporal character are also presented.

Global water group neutral density model in Saturn's inner magnetosphere

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Abstract. Water group neutral particles (H2O, OH, and O) are considered to dominate the dynamics of Saturn's inner magnetosphere since neutral density in Saturn's inner magnetosphere is about ten times greater than plasma density. Therefore it is important to understand the neutral distribution in Saturn's inner magnetosphere. Cassini observations have revealed that icy moon Enceladus ($L \sim 3.94$) is highly active with plume of water from its south polar region (Porco et al., 2006).

We have derived distribution characteristics of water group neutral cloud in Saturn's inner magnetosphere using a Monte-Carlo procedure to account for H2O density observed by Cassini, and OH density observed by the Hubble Space Telescope. We consider sputtering from Enceladus, Tethys ($L \sim 4.89$), Dione ($L \sim 6.26$), Rhea ($L \sim 8.74$), and E ring ($L \geq 3$), and plume from the south pole of Enceladus as release processes of water molecule. We also used plasma parameters such as ion densities and electron temperature, which depend on some chemical reactions, based on Cassini observations. Results show that the distributions form azimuthally asymmetric feature. The asymmetric distributions are caused by short lifetimes of hot electron impact rates which depend on background hot electron density and temperature. These neutrals also peak near Enceladus due to copious H2O source rate of a plume. Parameter survey indicates that the H2O and OH observations can be fit if the source rate of the plume is 4×10^{28} H2O/sec, although this rate is higher than a plume source rate observed by Cassini. The main cause of the discrepancy might be due to neglect of a hotter neutral cloud originated from newly pick- up ions in this simulation. The contribution of the hotter cloud will also be discussed.

Characterisation of current systems in Saturn's magnetosphere: High-latitude Cassini observations

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Abstract. We present observations from the high-latitude phases of the Cassini mission during which the azimuthal field component exhibits the signature of field-aligned currents flowing between the magnetosphere and ionosphere. We will compare the observations of the mainly nightside field-aligned currents from 2008 with those previously observed during the high-latitude orbits in 2006/2007, where the encounters with the field-aligned currents occurred at mainly dayside local times. For the 2008 high-latitude orbits, the same general pattern of field-aligned currents is observed for both the northern and southern hemispheres at midnight and dusk local times, respectively. At highest latitudes, it is found that there are 'lagging' fields (typically spanning both open and closed field lines) which gradually increase in strength, indicative of a downward current. This is then followed by a layer of upward-directed field-aligned current as the 'lagging' field declines either to small values or instead reverses to a 'leading' configuration. 'Lagging' and 'leading' fields are generally indicative of plasma sub- and super-corotation, respectively. Therefore, this upward current can be characterised into two 'states', one where the plasma angular velocity undergoes a transition from sub-corotating to corotating plasma flow, and a second case where the transition is instead to a super-corotating flow regime. Finally, at lowest latitudes, the field then declines from either a strongly or weakly 'leading' field configuration, depending on the behaviour of the signature that precedes it, to either small values or to a strongly 'lagging' field, indicative of a downward current. Given the dusk and midnight local times of these field-aligned currents, they may be symptomatic of dynamics in the nightside magnetosphere. We will present a statistical analysis of these field-aligned current signatures from one years' worth of observations.

The Neutral Cloud Environment in the Saturnian Magnetosphere

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Abstract. From HST observations and the Cassini measurements, we know that the Saturnian system is immersed in a vast neutral gas cloud of water molecules and their dissociative products like OH, O and H. Most of the gas molecules originate from the plumes in the south pole of Enceladus. In addition, the ring system is an important source of oxygen atoms and molecules which can be injected into the distant Saturnian magnetosphere via scattering processes. Titan's exosphere is another major source of neutral gas composed of escaping H2 and H, and probably CH4. These neutral materials will be fed into the thermal plasma disk in the inner Saturnian magnetosphere. In this work, we will examine the structures and compositions of these separate gas clouds and plasma disc using an updated photochemical and plasma chemistry model with the latest plasma measurements from Cassini CAPS. In the model calculations, we have taken into consideration the orbital dispersal of water molecules and their fragments from photodissociation excess energy, charge exchange collisions and (hot) electron-impact reactions. A preliminary model of the thermal ion composition in Saturn's magnetosphere also will be described.

MHD simulation of a Kronian plasmoid event observed by Cassini

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Abstract. One of the few plasmoid events observed so far in Saturn's magnetotail is that of March 4, 2006, as recently reported by *Jackman et al.* [JGR, 2008] and *Hill et al.* [JGR, 2008], and evidenced by a strong southward then northward turning of the magnetic field. We use a global MHD model of the mass-loaded Kronian magnetosphere (BATS-R-US) to simulate this event. The corresponding upstream solar wind conditions have been inferred by means of the solar wind propagation model of *Zieger and Hansen* [JGR, 2008]. We show that this plasmoid event occurred at a time of extremely low solar wind dynamic pressure, while Saturn encountered a rarefaction region between two corotating interaction regions (CIR). First, we demonstrate that at such a low dynamic pressure, Saturn's magnetosphere is found in the state of quasi-periodic or chaotic mass release, when large-scale plasmoids are pinched off along an X-line in the dawn side of the magnetotail in accordance with the Vasyliunas cycle. The magnetic field signatures of plasmoids extracted from the simulation at the location of Cassini are similar and comparable in magnitude with the observed magnetic field variations. However, because of the non-deterministic nature of plasma release in this dynamic pressure regime, the exact timing of such plasmoid events cannot be predicted. On the basis of our simulation, we argue that the March 4, 2006 plasmoid event was triggered by rotationally-driven internal instabilities rather than by magnetospheric compression due to an interplanetary shock. Our interpretation is strongly supported by the propagated upstream solar wind data, which show that this plasmoid was released more than 5 days after the arrival of a CIR. Second, we simulate the response of the Kronian magnetosphere to actual solar wind driving in the course of a full Carrington rotation around March 4, 2006 in order to validate our hypothesis of a predominant internal forcing, at least in this particular case.

Titan Posters

Comparative analysis of Cassini's Titan flybys T25-T33 and T35-T51 according to the measurements of Cassini-MIMI and CAPS

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Abstract. In this study we focused on two groups of targeted Titan flybys of Cassini between DOY 053-180 in 2007 and DOY 243 (2007) -086 (2009). We analyzed the measurements of the MIMI-LEMMS and the CAPS-IMS instruments, and also used the data of the onboard Magnetometer. During these two intervals Titan was located at approximately the same orbital positions; at 13.5 SLT during T25-T33 and 10.7-11.5 SLT during T35-T51. The dominant ionization sources (solar EUV, charge exchange, magnetospheric electron impacts) were similar during the individual groups of flybys so we made a survey of the plasma parameters and compared the measurements to get a more detailed picture of Titan's global plasma environment. Our analysis was focused on the differential intensities of energetic electrons and ions, and we also used the low energy ion measurements of CAPS-IMS. We also investigated the T32 flyby in more detail, during which the magnetosphere was significantly more compressed compared to the other flybys of this group. We analysed the possibility of a solar event reaching Saturn at this time. In April and May 2007 there were several active regions on the Sun, so we used plasma parameters measured by the Venus Express spacecraft (which was approximately along the Sun-Saturn line) to estimate whether the energetic particles of a CME erupted towards Saturn could have been responsible for the compression detected during T32.

The structure of Titan's induced magnetosphere

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Abstract. As a result of the virtual absence of an intrinsic magnetic field, Titan's atmosphere directly interacts with Saturn's rotating magnetosphere. The obstacle to the external plasma flow represented by the moon's collisional ionosphere and the exospheric heavy ions that mass load the external plasma flow leads to the formation of an induced magnetosphere characterized by magnetic field pileup in the sub-flow sector and strong draping in the flanks and downstream sector. We use Cassini Magnetometer and plasma observations obtained over more than 4 years to characterize the spatial extent, orientation and shape of Titan's induced magnetosphere above 950 km altitude. The role of parameters such as Saturn Local Time (SLT), and upstream magnetic field orientation is studied. We also compare the magnitudes of the dynamic, magnetic and plasma pressures at different altitudes.

Titan's extended atmosphere: INCA results

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Abstract. During the Titan flybys, INCA obtained ENA images of the interaction between the atmosphere of Titan and the magnetospheric ion fluxes sweeping over Titan with subcorotational speeds (approximately 145 km/s). The ENA images show highly variable ENA fluxes from Titan due to the structure in the magnetospheric ion population. The ENA fluxes extend out to several 10,000 km altitude from the surface of Titan. We use a parametric neutral atmosphere model consisting of H2 to simulate Hydrogen ENA images in the 20-50 keV energy range and compare to the images obtained by INCA. Several events are analyzed to investigate how the H2 distribution falls off with altitude.

Upper limits on the abundance of carbon-bearing ions near the orbit of Titan

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Abstract. High neutral methane escape rates from Titan ($\sim 3x10^9$ cm^{-2}s^{-1}) have been proposed based on Cassini INMS data [Yelle et al., 2008]. This is much higher than past predictions (e.g. Jeans loss). To investigate this hypothesis, we have examined Cassini CAPS data obtained near Titan's orbit. We have used the CAPS linear electric field (LEF) mass spectra, which provide high resolution measurements of atomic ions and the atomic constituents of molecular ions.

The expected lifetime of neutral methane is long, and escaping molecules would not ionize in Titan's immediate vicinity. Ionospheric methane is observed in Titan's atmosphere. To distinguish between these two sources of magnetospheric methane, we have examined spectra obtained within 0.5 R_S of Titan's orbit, but at distances of over 1 R_S from Titan itself. Between March 2005 and May 2009, 892 TOF spectra were obtained in this region, although only 396 contained non-zero counts due to limitations imposed by spacecraft orientation.

These data show a clear oxygen peak, either from atomic O+ or from fragmentation of oxygen-bearing molecular ions. A weaker nitrogen peak, with approximately 10% the amplitude of the oxygen peak, is also present. However, at the instrument's noise level, no carbon peak is present. This corresponds to an abundance of carbon ions and carbon-bearing molecular ions under 0.8% that of oxygen and oxygen-bearing ions. Estimates of the neutral and ion loss rates, and ion production rates, allow us to convert this upper limit into an upper limit on the escape rate of neutral methane from Titan.

Structure in the Titan torus region

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Abstract. The plasma in the Titan region has been found by *Cassini CAPS* to consist primarily of water group plasma, the ultimate source of which is the inner magnetosphere of Saturn. This holds despite the proximity of Titan and its dense atmosphere which had been expected in the pre-Cassini era to be the prime provider of matter to the region. The wake of Titan is the only volume that appears to be dominated by plasma from Titan. The plasma throughout the space between the boundary of the plasma sheet and the magnetopause is quite variable in density and temperature and may reflect structure in the source regions. We consider various possible sources for the clumps of plasma not directly associated with the presence of Titan in the region:

a) "Fingers" of plasma from the plasma sheet created by centrifugal interchange analogous to phenomena seen outside the Io torus at Jupiter.

b) Reionization of neutral atoms emitted after charge exchange from either the ring atmosphere or the Enceladus torus the spatial distribution of which reflects the azimuthal and radial structure in the source region.

c) Detached blobs, the magnetic fields of which are disconnected from the ambient field by a mechanism analogous to the Finzi-Wolf magnetic [1] "tangles" assumed to transport energy in early-type magnetic stars, or by the flute instability invoked by Goertz [2] in the Titan-Saturn context.

We find that mechanisms a and b are more likely than c to contribute significantly to the spatial structure of the Titan torus plasma.

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Analysis of Titan airglow UV spectra from Cassini Ultraviolet Imaging Spectrograph (UVIS)

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Abstract. We present the analysis of FUV (1150-1750 Å) limb dayglow spectra of Titan's atmosphere obtained on 13 December 2004 at 5 Å resolution by the Ultraviolet Imaging Spectrograph (UVIS) onboard Cassini. The fit to the data show that Titan's airglow consists of four principal emissions: 1) the N2 Lyman-Birge-Hopfield (LBH) band system, which peaks in intensity at 1150 +/- 50 km, 2) N I multiplets peaking at 1050km +/- 50 km, 3) sunlight reflected by N2 between 0 and 300 km and 4) H Ly alpha which grows in intensity with increasing altitude. Comparisons with limb spectra obtained by the Voyager 1 Ultraviolet spectrometer (V1/UVS) show that the vertically integrated brightness are larger for V1/UVS than for UVIS by a factor of 3, consistent with the XUV solar flux ratio at Titan at the time of these observations. The N2 LBH and N I profiles obtained from the regression to the Titan data are compared to models obtained by the Atmospheric Ultraviolet Radiance Integrated Code (AURIC), adapted from Earth's atmosphere to Titan's.

Investigations towards the analysis of complex organic aerosols and related solids as analogues to Titan haze materials

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Abstract. The complex organic materials (tholin) found on the surface and within the haze layer of Titan is attributed to chemistry occurring in its thick N2/CH4 atmosphere. The resulting organic aerosols potentially contain a large mixture of nitrogen-rich organic molecules (i.e. substituted pyrroles, nitriles, pyrimidines, amino acids, etc), as well as polyaromatic hydrocarbons.[1,2] Several groups have been successful in simulating the believed Titan atmospheric aerosols,[1,3] and the laboratory generated tholin materials have been characterized by several analytical methods including UV/Vis, fluorescence, IR, and MS, providing a wealth of information on the nature of these organic aerosols believed to be in Titan's atmosphere.[1,4,5] Because of the complexity of the tholin mixtures, attempts have been made to use chromatography to separate and analyze the tholin mixtures. Both 1- and 2-D GCMS have been used to analyze the volatile and semi-volatile components of tholin mixtures.[2] To study the less volatile species in tholins, a few attempts have been made to utilize liquid chromatography methods, such as HPLC-MS, but these studies have been limited to 1-D HPLC analysis.[6-8] Here we report our preliminary investigations to develop a 2-D liquid chromatography methodology in combination with mass spectrometry that allows us to preselect the volatile compounds and reduce their interference from the organic polymeric components. Additionally, a 2-D approach allows for the incorporation of a chiral column to determine the enantiomeric excess of the small organic molecules present in tholin, such as amino acids.

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Energy Deposit onto Titan's Ionoshere by Magnetospheric Ions

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Abstract. Titan's ionosphere interacts with the magnetospheric plasma flow of Saturn magnetosphere in multiple ways. The ionosphere is a sink to energetic magnetospheric particles such as protons and oxygen ions. The extended neutral corona is a source of newly ionized particles (especially molecular hydrogen ions and methane ions). There is also ion escape taking place directly from the ionosphere. Further, the ionospheric currents deflect the magnetized plasma flow and cause magnetic barrier to form on the ram side.

We have studied the energy deposit of the magnetospheric ions onto Titan's ionosphere using an updated hybrid model for Titan. The benefit of a hybrid model is that the significant ion drift and gyro effects at Titan are part of the magnetic field calculation. The neutral-ion momentum transfer has also been considered.

Titan's induced magnetosphere under non-ideal upstream conditions

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Abstract. A three-dimensional, multi-species hybrid model (kinetic ions, fluid electrons) has been applied to the interaction between Saturn's largest satellite Titan and the plasma in the giant planet's outer magnetosphere. In contrast to the idealized picture deduced from Voyager 1 data, recent observations made by the Cassini magnetometer instrument suggest that the ambient magnetic field is not directed perpendicular to Titan's orbital plane. Therefore, our purpose is to investigate systematically how Titan's induced magnetosphere is affected by a tilt of the upstream magnetic field. In the first part of our study, the structure of Titan's induced magnetosphere is analyzed as a function of the angle between the ambient magnetic field $\vec{B}_0$ and the bulk velocity $\vec{u}_0$ of the corotating plasma flow. Our simulations show that introducing a flow-aligned magnetic field component goes along with an asymmetrization of Titan's magnetotail, in addition to the asymmetry that already arises from the large gyroradii of the ion species involved in the interaction. In the vicinity of Titan, the field lines become strongly twisted, permitting the wakeside magnetic lobe structure to even penetrate into the satellite's geometric plasma shadow. However, despite the increased complexity of Titan's magnetic environment, the overall characteristics of the pick-up tail remain practically the same as in the case of ideal magnetic field orientation ($\vec{B}_0 \perp \vec{u}_0$). In the second part of our study, we investigate in real-time the transition that Titan's plasma interaction undergoes during a change of the ambient magnetic field direction. In contrast to earlier analyses of Titan's plasma environment under non-stationary upstream conditions, the tilt of the ambient magnetic field is again taken into account. While in the case of $\vec{B}_0$ being perpendicular to $\vec{u}_0$, the reconfiguration of Titan's induced magnetosphere is mainly governed by reconnection, our simulations suggest that when a flow-aligned field component is included, convection of the field lines around the obstacle's ionosphere plays the key role for the reconfiguration process.

Satellites with Thin Atmospheres
Posters

Exospheric signatures of alkali abundances in Europa's regolith

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Abstract. We carried out 3D Monte Carlo simulations of the sodium and potassium content of Europa's exospheres and surface induced by the surface bombardment by Jupiter magnetospheric ions and electrons.

We used observations of the exospheric Na/K ratio by Brown (2001) to adjust Na and K surface source rates. We find a ratio of the source rates close to 17, in good agreement with Johnson et al (2002). This in turn led to an average Na/K ratio in the surface that is close to 7. This implies there is a significant enrichment in the surface of potassium compared to sodium, due to preferential escape of sodium. Interestingly, we observe a steep increase in the Na to K ratio in the exosphere densities within 2 Europa's radii. This ratio varies with distance from Europa from the surface value of 7 up to the observed value of 26. Such increase vs altitude is directly related to the energy distributions of the ejected species and gives an observable parameter allowing characterization of the ejection processes by a Europa orbiter.

The variations of the calculated Na/K ratio at the surface will be related with the surface albedo derived from McEwen (1986) in 3 different areas of Europa's surface: a longitude band between 60°W and 90°W (low albedo surface features associated with an area of large mottled terrains next to bright plains), between 270°W and 300°W (high percentage of lineas features and mottled terrains, no bright plain), and an area centered 6°N, 322°W about 500 km by 300 km (hummocky (mottled) terrains observed by Galileo).

Based on the analysis of the variations with altitude of the Na/K exospheric ratio over such areas, significant low altitude exospheric signatures of surface composition inhomogeneities could be easily detectable above 100 km in altitude when the surface ratio in a 20° width region is two times larger than its surrounding value. Such regions could correspond to areas having a high non-ice fraction and/or altered by warm ice/water resurfacing events. Therefore, in situ measurements of the exospheric composition should allow one to retrieve crucial information on the variations of the surface composition.

Neutral H_2O density in the Enceladus plume

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Abstract. The Cassini E3 encounter with Enceladus on March 12 2008 probed the south polar dust plume, where the Ion and Neutral Mass Spectrometer (INMS) measured neutral H_2O molecular densities up to $10^7 cm^{-3}$. A previous model for the water vapor density in the plume assumed a spherical expansion from a source at the south pole. We have constructed an alternative model that assumes a southward flowing Maxwellian velocity distribution at a point-like south pole source. If we set the Mach number (flow speed over thermal speed) to have a value ~ 3, the model produces a plume-like particle distribution over the south pole which resembles the ISS dust images. We are comparing the model predictions with INMS observations of neutral H_2O density along the spacecraft trajectory in order to determine the best fit value of the Mach number and the total source rate. So far we have a good fit value of 2 - 3 for the Mach number and 10^{26} - 10^{27} molecule /sec for the source rate. This work is still in progress.

The Plasma Interaction Near Enceladus

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Abstract. Early Cassini encounters with Enceladus revealed surprising evidence of a significant source of water from geysers located at the moon's southern pole. Based on these early observations, Cassini was subsequently flown closer to the surface of Enceladus (e. g. , the EN2 and EN3 flybys). It has now been widely accepted that the water emanating from this small enigmatic moon is largely responsible for supplying the mass necessary to sustain the Enceladus plasma torus. Here we use our homogenous physical chemistry model (developed to study the water-based chemistry in the Enceladus torus) to investigate the Enceladus interaction. The local source of neutrals due directly to the plumes and a global neutral source are prescribed according to Saur et al. (2008) and Burger et al. (2007) respectively. We consider perturbations to plasma flowing past a non-magnetized conducting sphere (Enceladus) as well as mass-loading effects due to pickup ions. We compare our model results to Cassini data acquired during the 14 July 2005 EN2 and the 13 March 2008 EN3 Enceladus flybys. Our results suggest that charge exchange dominates the local chemistry and is responsible for significant corotation lag for flow lines passing near the densest part of the plumes. In addition, we find that H_3O^+ dominates the water-group composition downstream of the Enceladus plumes.

Electron absorption signatures in the vicinity of Rhea: Evidence for a debris disk

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Abstract. During its November 2005 flyby of Saturn's second-largest moon Rhea, the LEMMS portion of Cassini's Magnetospheric Imaging Instrument, MIMI, detected an unexpected decrease in the fluxes of magnetospheric electrons with energies exceeding approximately 20 keV. This depletion extended to around 8 Rhea radii on either side of the moon. When combined with data from several other Cassini instruments, including those from the Cassini Plasma Spectrometer, CAPS, that also detected the electron depletion, it was proposed that the signature indicated the presence of a disk of electron-absorbing debris orbiting Rhea. A set of brief, deeper electron depletions on either side of the moon may indicate the presence of discrete rings or arcs within the debris disk. A similar signature was detected during a more distant Rhea flyby in August 2007. No successful remote observations of a debris disk or rings have been reported to date. We present further analysis of MIMI and CAPS data from these close flybys, and report on a survey of the numerous crossings of Rhea's L shell that have occurred during the course of Cassini's mission to date. The implications of all these observations for the proposed debris disk scenario are summarized.

The spiky signatures of Saturn's moons: low energy electron features coincident with microsignatures

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Abstract. The Cassini spacecraft regularly crosses the L shells of Saturn's inner moons. These moons reside in a region containing high energy particles trapped in Saturn's radiation belts. Because these particles can strike the moons, depletions, termed microsignatures, are sometimes seen in the energetic particle population that intersects a moon's orbit. Studies of microsignatures in the Cassini Plasma Spectrometer (CAPS) have been carried out, investigating how their characteristics change as a function of longitudinal separation from the moon. These tell us about the absorber as well as the diffusion process by which magnetospheric plasma refills these wakes, hence aiding in characterising the magnetospheric dynamics of Saturn.

Based on the detection of microsignatures by Cassini's Magnetospheric Imaging Instrument (MIMI) we have enhanced and extended the microsignature dataset using the Cassini Plasma Spectrometer's electron spectrometer (CAPS-ELS) in order to investigate fully the microsignatures and any new aspects of the data. As well as the wakes themselves we note the existence of low energy features coincident with the absorption features in the MIMI data. These features tend to present themselves as short period enhancements, or 'spikes', in the low energy plasma density. Although first discovered near the L shell of Enceladus, similar features are seen in the vicinity of other moons' orbits. We present possible links between the spikes and corresponding fluctuations in the magnetometer data, and suggest some causes and implications of their presence.

Iapetus' interior: Constraints from the solar wind interaction

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Abstract. Iapetus is Saturn's third largest and most distant regular satellite. This moon is best known for its unique hemispheric albedo asymmetry and the kilometers-high ridge circling its equator, but observations made during Cassini's 2007 flyby show another of the moon's unusual features. The spacecraft approached Iapetus from downstream and stayed to the side until it had passed upstream, never having entered the moon's geometric wake. The interplanetary magnetic field's (IMF) orientation was such that during the approach, Cassini's trajectory took it towards a region where it would be magnetically connected to the moon. During this time, the Cassini plasma wave spectrometer observed low-frequency waves that were unique to the Iapetus encounter and strongly correlated with the spacecraft's distance from the moon. When Cassini passed into the space where the IMF should have magnetically connected it to the moon, the magnetometer observed a strong perturbation of the magnetic field. When we extrapolate that perturbation towards Iapetus, we find that the IMF rotated to completely avoid intersecting the moon. This is consistent with Iapetus deflecting the solar wind plasma. We analyze the perturbation and find that it can be caused by neither an inert body nor a mass-loading source. Such a perturbation could be caused by either an internal, electrically-conducting ocean or remanent magnetization. Given Iapetus' density of 1100 kg m-3 we consider an interior ocean to be the more geophysically probable possibility.

GANYMEDE UV OBSERVATIONS BY NEW HORIZONS-ALICE AND HST-ACS

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Abstract. The New Horizons (NH) spacecraft observed Ganymede and other Galilean satellites with the Alice instrument during the Jupiter flyby in spring of 2007. Hubble Space Telescope Advanced Camera for Surveys (ACS) far-ultraviolet (FUV) images of Ganymede complement the Alice FUV spectroscopy at this time. OI 130.4 nm and 135.6 nm emissions were detected. Alice observed Ganymede in eclipse twice, viewing the sub-Jupiter and anti-Jupiter hemispheres separately. The ACS Ganymede images show limb brightened emissions from auroral ovals on the leading and trailing sides, consistent with previous Space Telescope Imaging Spectrograph (STIS) imaging. A Ganymede stellar occultation observation to probe the O_2 atmosphere was planned, but a final trajectory correction maneuver was skipped and caused the star to miss the disk and bound atmosphere. We describe our initial analyses of these data, and discuss the potential of FUV stellar occultation measurements with the upcoming Jupiter system flagship missions for better understanding Ganymedes atmosphere and auroral interaction processes.

Modelling the interaction of Io's atmosphere-ionosphere with the Jovian magnetosphere including the moon's auroral emission

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Abstract. Jupiter's moon Io is embedded in a dense plasma environment. Due to Jupiter's fast rotation the corotating plasma particles constantly flow past the moon. This flow of electrons and ions causes a complex plasma interaction and triggers auroral emission in the moon's atmosphere. With three dimensional two-fluid plasma simulations we calculate the plasma interaction of Io and its atmosphere-ionosphere with the Jovian magnetosphere. We compare our results for the plasma environment with Galileo in-situ measurements during two polar flybys at Io. Using model results we also simulate the auroral radiation, which is generated in the moons atmosphere by collisions with magnetospheric electrons. During the Jupiter flyby of the New Horizons spacecraft in February 2007 Io's aurora has been observed by the on board UV spectrograph ALICE and visible camera LORRI and simultaneously by the Hubble Space Telescope. The observations revealed a complex emission pattern, where local volcanic plumes appear in the ultraviolet and visible radiation. By comparison of the observed intensity and morphology with our simulated emission we derive constraints for the distribution and density of Io's atmosphere. Both, a sunlit surface and Io in eclipse are investigated.

Inductive response of Callisto's interior

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Abstract. Magnetometer measurements of the Galileo spacecraft near Callisto showed, in addition to the Jovian background magnetic field, a magnetic contribution originating inside the moons body. It was interpreted to be the signal of an induced field inside a subsurface conducting layer, possibly a liquid ocean. This induction occurs due to variations of the Jovian background magnetic field along Callisto's orbit. In this work we refine previous models of the induction effect. We use a multilayer induction model for the moons interior, that better resembles Callisto's only slightly differentiated structure. The induction mainly occurs due to Jupiter's Dipole tilt that causes a exciting frequency arising from Jupiter's fast rotation. We use models for the Jovian current sheet field and the field caused by currents flowing inside the magnetopause to study the effects of additional exciting frequencies. We investigate if the contributions of those different frequencies to the total signal help narrowing the limits for the conductivity and the extension of the subsurface conducting layer.

The plasma wake of Tethys: Hybrid simulations versus Cassini MAG data

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Abstract. The interaction between Saturn's fifth largest satellite, Tethys, and the corotating plasma of the inner magnetosphere has been studied by applying a three-dimensional hybrid simulation code. Since Tethys possesses neither an intrinsic magnetic field nor a substantial ionosphere, the moon's surface is directly exposed to the impinging plasma. This leads to the formation of an extended density cavity in the downstream region, expanding above and below Tethys along the magnetic field lines. The resulting deficit of magnetospheric plasma pressure is compensated by a compression of the magnetic field lines at the moon's wakeside. By confronting our simulation results with Cassini magnetometer data from the so far only targeted flyby in 2005, we demonstrate that these key features of Tethys' plasma interaction are quantitatively reproducible within the framework of the hybrid model.

CASSINI/RPWS DUST MEASUREMENTS DURING THE ENCELADUS FLYBYS IN 2008

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Abstract. The Cassini spacecraft completed four very close flybys of Enceladus in 2008. They are the E3, E4, E5, and E6 flybys. All flybys are targeted to fly through the water plume near the south pole of Enceladus. At closest approach, the spacecraft was merely several tens of kilometers away from the moon's surface. The RPWS instrumentation thus had good opportunities to measure the parameters of micron-sized particles in the water plume. As the spacecraft approached the water plume, the RPWS dipole antenna started recording intense impulsive noise indicating dust impacts. A Gaussian distribution can be fit to the impact rate. For all four flybys, the peak impact rate is around 600-800 per second, the corresponding peak number density is about 7.2 $\times$ 10^{-2}m^{-3} to 9.6 $\times$ 10^{-2}m^{-3}, and the half thickness of the Gaussian distribution is around 1600 km. The dust particles in the plume are thought to have radii less than 10 micrometers. Due to the limitation of RPWS lower threshold, only dust particles larger than 1 micrometer can be precisely measured. In this presentation, we will describe the dust density distributions as a function of distance away from south pole of Enceladus.

Uranus Posters

Adaptive optics images of H_3^+ emission from Uranus.

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Abstract. In 1985 the Voyager 2 encounter with Uranus revealed UV auroral emissions in the planet's polar regions (Herbert and Sandel, 1994). Since then, few observations have been made of emissions from Uranus. Trafton el al. (1998) used ground based observations of infrared H_2 and H_3^+ emission to measure variability in the infrared intensity across the disk of Uranus, showing that the auroral component contributes <25% of the total emission, and analysis of long term intensity variations in H_3^+ strongly suggested the presence of auroral emission (Melin, 2006). However, analysis of H_3^+ images of Uranus has showed that variability in emission strength across the disk could not be directly correlated to the previously observed UV emission, and might have been an effect of smearing due to the Earth's atmosphere (Melin, 2006), or 'seeing'. We present observations made using the CRIRES instrument on the VLT array in 2008 which are corrected using adaptive optics, removing the effect of seeing from the observations. Wide slit ($\sim$ 2.8 arcsec) emission lime imaging was used to directly observe the planet. Using these observations we can now examine the emission from the entire disk of the planet and show the variability in local position and in time, in an attempt to show the presence of aurorae within the infrared emission.

Exoplanets Posters

Plasma interaction between exoplanets and hoststars: An Io-Jupiter scenario

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Abstract. In the last 14 years over 340 exoplanets have been discovered and most of them are so-called Hot Jupiters. These are planets with a short semi-major axis (< 0.1 AU) and a relative high mass (approx. M_J). For some of these planets the stellar wind is sub-Alfvénic, which means that no fast-shock is present and an Alfvén wing forms. In this case the interaction is similar to the Io-Jupiter interaction where the Alfvén wing produces a footprint in the ionosphere of Jupiter. Aspects of this interaction are discussed by Ip et al. (2004), Preusse et al. (2006) and detected in the chromosphere of HD 179949 by Shkolnik et al. (2005). In the present study the energy flux transported from the Hot Jupiters to the central stars by the Alfvén wing is calculated. The main contribution of the energy flux comes from the integrated Poynting flux. Our calculations are based on a model for the Alfvén wing at Io developed by Neubauer(1980). Furthermore, we discuss how the energy flux depends on the extend of the magnetosphere, the stellar wind velocity, the stellar magnetic field and other parameters. Finally, we will provide the total energy fluxes for several exoplanets, where observational hints for a planet-star connection exist.

Future Missions/Campaigns Posters

Resolving Jupiter's Aurora with the Juno Suite of Magnetospheric Instruments

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Abstract. The Juno mission, a Jupiter polar orbiting program that begins its 1-year mission at Jupiter in 2016, resolves critical questions regarding the processes that drive Jupiter's dramatic aurora and tests the universality of the processes that generate aurora and couple magnetized planets to their space environments. Jupiter's magnetosphere is known to be powered very differently than is Earth's, specifically by strong planetary rotation rather than by the interplanetary environment controlled by the solar wind. And yet, we see hints that some of the fundamental processes that drive Jupiter's aurora are the same as those that drive Earth's aurora. Is the global aurora regulated by a global pattern of electric currents that connects Jupiter's magnetosphere to its polar ionosphere along magnetic field lines? Does particle acceleration occur as a result of the scarcity of field-aligned current carriers, and where does the acceleration occur? Are the dominant acceleration processes the same as those that dominate at Earth or do other processes prevail? How do the auroral processes that generate emissions modify the energy and momentum coupling between the magnetosphere and ionosphere? Juno addresses and answers these and other critical questions by flying a capable suite of in situ particles and fields magnetospheric instruments through Jupiter's low-altitude polar regions, and combining those measurements with UV and IR imaging of the polar auroral displays. Here we review the critical issues and questions regarding Jupiter's aurora that Juno addresses, and show how they are resolve by the Juno mission and instruments.

Jupiter Magnetosphere and Moons Plasma (JuMMP) Investigation for EJSM

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Abstract. We will describe the Jupiter Magnetosphere and Moons Plasma investigation, JuMMP, a proposed plasma instrument suite for the EJSM JGO spacecraft. Development of JuMMP for JGO will be coordinated with that of an instrument package to be proposed in a somewhat modified format for the JEO spacecraft. The instrument targets a 4 pi field of view for the electron and negative ion (JENI) and ion mass spectrometer (JIMS) sensors. An energetic neutral atom sensor (LENA) and an Advanced Mass and Ionic Charge Composition Experiment (AMICCE) will also be described. The JENI and JIMS sensors each have strong individual outer planets heritage from Cassini CAPS (ELS and IMS) and use detailed design knowledge from the Juno (Jupiter polar orbiting mission) plasma electron and ion instrument (JADE). The LENA sensor has strong design heritage from similar instruments on BepiColombo. Plasma measurements in an adverse high penetrating radiation environment represent a significant challenge. However, our Juno experience enables us to define the required approach regarding the radiation environment with confidence, and minimum resource impact. We will describe the scientific drivers and some design issues for the proposed investigation.

Jupiter Radio VLBI Science Using the Lunar Low Frequency Astronomy Study Telescope (LLFAST)

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Abstract. Assuming that the Japanese lunar exploration will be conducted as a continuous series, our LLFAST (Lunar Low Frequency Astronomy Study Telescope) team has been assessing the feasibility of putting a low frequency array on the lunar far-side. We have studied the capabilities of Jupiter radio VLBI (Very Long Baseline Interferometer) observations at 20-25 MHz with an Earth-Moon baseline as a first stage. We considered installing the VLBI receiver and antenna system on either the moon lander or the orbiter. The main objective of this stage is to observe the low frequency radio emissions from Jupiter with high resolution.

The radiation mechanism of Jupiter's decametric radio emissions has not been fully understood. The important parameter of this study is the coherent size of Jupiter's radio source, which can be determined by VLBI observations. We have developed a Jupiter radio e-VLBI system which operates over the Internet. The Jupiter radio e-VLBI observations started at Kashima, Kochi, and Agawa in February 2008. We successfully received Jupiter radio emissions by using this e-VLBI system around 19:50 (UT), May 29, 2008, and around 17:10 (UT), July 7, 2008. The results show a highly coherent source region. Such micro structures in the Jupiter radio source region are also assumed to be a part of the model of a Jupiter radio searchlight beam [Imai et al., MOP2007]. This new model shows that the beam structure of Jupiter radio emissions, which is thought to be like a hollow-cone, has a narrow beam like a searchlight, which can be explained by assuming that the three dimensional shape of the radio source expands along the line of the magnetic field. This model predicts the size of the coherent source region along the line of the magnetic field is about 1 km for each individual source frequency component.

The Earth-Moon baseline length for the VLBI has a resolution of about 20 km for 20-25 MHz sources at Jupiter and will be able to open the window of new science for the micro structures and beaming of Jupiter's radio source. A description of this VLBI system will be presented. Since a global e-VLBI network for the Earth stations will be needed to enable the Earth-Moon baseline VLBI, international collaboration is essential.

THE EUROPA JUPITER SYSTEM MISSION

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Abstract. The Europa Jupiter System Mission (EJSM) will be an international mission that will achieve Decadal Survey and Cosmic Vision goals. NASA and ESA have concluded a joint study of a mission to Europa, Ganymede and the Jupiter system with orbiters developed by NASA and ESA; contributions by JAXA are also possible. The baseline EJSM architecture consists of two primary elements operating in the Jovian system: the NASA-led Jupiter Europa Orbiter (JEO), and the ESA-led Jupiter Ganymede Orbiter (JGO). The JEO mission has been selected by NASA as the next Flagship mission to the out solar system. JEO and JGO would execute an intricately choreographed exploration of the Jupiter System before settling into orbit around Europa and Ganymede, respectively. JEO and JGO would carry eleven and ten complementary instruments, respectively, to monitor dynamic phenomena (such as Io's volcanoes and Jupiter's atmosphere), map the Jovian magnetosphere and its interactions with the Galilean satellites, and characterize water oceans beneath the ice shells of Europa and Ganymede.

The EJSM fully addresses high priority science objectives identified by the National Research Council's (NRC's) Decadal Survey and ESA's Cosmic Vision for exploration of the outer solar system. The Decadal Survey recommended a Europa Orbiter as the highest priority outer planet flagship mission and also identified Ganymede as a highly desirable mission target. EJSM would uniquely address several of the central themes of ESA's Cosmic Vision Programme, through its in-depth exploration of the Jupiter system and its evolution from origin to habitability.

The EJSM will investigate the potential habitability of the active ocean-bearing moons Europa and Ganymede, detailing the geophysical, compositional, geological and external processes that affect these icy worlds. EJSM would also explore Io and Callisto, Jupiter's atmosphere, and the Jovian magnetosphere. By exploring the Jupiter system and unraveling its history, the formation and evolution of gas giant planets and their satellites will be better understood. Most important, EJSM will shed new light on the potential for the emergence of life in the celestial neighborhood and beyond.

The EXtreme Ultraviolet spectrosCope for ExosphEric Dynamics (EXCEED): Science objectives

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Abstract. An earth-orbiting extreme ultraviolet spectroscopic mission, EXtreme ultraviolet spectrosCope for ExosphEric Dynamics explore (EXCEED) that will be launched in 2012 is now under development. The EXCEED mission will carry out observations of Extreme Ultraviolet (EUV) emissions from tenuous plasmas around the planets. It is essential for planetary EUV spectroscopy to avoid the Earth's atmospheric absorption, therefore it should be mandatory to observe above the Earth's atmosphere. In the presentation, we will introduce the general mission overview, the instrument, and the scientific targets.

One of the major objectives in the EXCEED mission is to measure plasma escape rates from the terrestrial planets. The amount of terrestrial atmosphere escaping to space still remains as one of the unresolved problems (Shizgal and Arkos, 1996). There were in-situ observations by orbiters, but our knowledge has still been limited. They measured physical parameters such as velocity and temperature along the orbits, but global aspects such as total amount of outward-flow plasma are difficult to deduce. EXCEED carries out imaging observations of the planetary plasmas. The observation will enhance our knowledge on characteristics of outward-flowing plasmas, e.g., composition, rate, and dependence on solar activity.

The Io plasma torus in the inner magnetosphere of Jupiter is other target of the EXCEED mission. The Io plasma torus is the main source of plasmas for the Jovian magnetosphere, and it characterizes shape and dynamics of the rapidly rotating magnetosphere. Major ion species, sulfur and oxygen ions, have a lot of EUV emission lines from 65 nm to 145 nm, and they radiates the energies outward (Delamere and Bagenal, 2003; Steffle et al., 2004). The EUV imaging enables us to know spatial distribution of the ions, and to deduce electron temperature in the inner Jovian magnetosphere.

The target mass of the EXCEED is 350 kg. The satellite will be inserted into 800 km x 1200 km orbit with the orbital inclination of 31 degrese. The mission life is designed as 1-2 years. The nominal pointing accuracy of the satellite is around 1'. A target finding camera identifies the planet, and feeds the offset back to an attitude control system so that we can drop the target image into the slit. The instrument employs a middle-size off-axis telescope with the diameter of 20 cm and a spectrograph covering a wavelength range of 65 to 145 nm.

First Author Index