Dawn-Dusk Asymmetries in the Coupled Solar Wind-Magnetosphere-Ionosphere System

A proposal in response to ISSI's 2012 Call of International Teams

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Abstract

In recent years, increasing availability of remote-sensed and in-situ measurements of the Earth's ionosphere, magnetosphere and magnetosheath have allowed ever larger statistical studies to be carried out. These studies have revealed persistent, significant dawn-dusk asymmetries throughout the solar wind-magnetosphere-ionosphere system. As yet there is no consensus regarding the source of these asymmetries, nor the physical mechanisms by which they are produced and maintained.

Dawn-dusk asymmetries have been observed in the Earth's magnetotail current systems and particle fluxes, in the ring current, and in polar cap patches and the global convection pattern in the ionosphere. Various authors have related these asymmetries to differences in solar illumination, ionospheric conductivity and processes internal to the magnetosphere. Significant dawn-dusk asymmetries have also been observed in the terrestrial magnetosheath, and there is evidence that plasma entry mechanisms to the magnetotail, for example, operate differently in the pre- and post-

midnight sectors.

The goal of this team is to examine all of these asymmetries and investigate their causes, with the ultimate aim of providing a theoretical and conceptual framework into which they can be placed. Achieving this will require an investigation of the coupled solar wind-magnetosphere-ionosphere system where ground and space-based measurements of the magnetosheath, magnetosphere and ionosphere are interpreted in terms of the macrophysics of the system as a whole as well as locally operating microphysical processes. As such we aim to bring together elements of the theory and observational communities, specialising in the relevant aspects of magnetospheric and ionospheric physics, to determine those physical processes that are responsible for the observed asymmetries in the system and assess their relative importance.

Research Domains: Space Science (Solar-Terrestrial Sciences, Space Plasma Physics, Magnetopsheric Physics, Ionospheric Physics)

Scientific Rationale

In recent years, there has been significant progress in identifying persistent dawn-dusk asymmetries in the magnetosheath, the magnetosphere and the ionosphere. These asymmetries have usually been explained without considering the coupled nature of the solar wind-magnetosphere-ionosphere system. The goal of this proposed International Team is to address this gap in our understanding and provide a consistent framework through which asymmetries in the entire system may be understood.

It has been established by a number of previous studies that dawn-dusk asymmetries exist in the magnetosheath. Experimental studies based on statistical evaluation of single spacecraft datasets revealed asymmetry in plasma density and flow velocity (e.g. Longmore et al., 2005; Paularena et al., 2001; See also Figure 1, below). Fewer and less conclusive results exist on the asymmetric spatial distribution of low frequency waves and oscillations (e.g. Genot et al., 2009; Shevyrev and Zastenker, 2005). Most importantly, the above publications are mostly of experimental and statistical nature and no comprehensive explanation of the observed asymmetries is presented.

It is commonly proposed that the asymmetries in magnetosheath plasma and waves are related to the local properties of the bow shock upstream of the observation point. The IMF is in general not aligned with the Sun-Earth line and this inclination introduces a natural asymmetry to the bow shock and to the magnetosheath. Typically, the quasi-perpendicular shock is located on the dusk side magnetosheath, so plasma heating and compression at the shock is different on the dusk and dawn flanks. Furthermore, asymmetries at the magnetopause, such as differences in magnetopause reconnection geometry or field line draping, may also influence magnetosheath asymmetries. References to the above mechanisms are scattered throughout the literature, but no systematic and conclusive results have been published on this topic.

The current understanding of the structure, dynamics and origin of magnetosheath asymmetries is thus limited at best. Within the ISSI team we plan to approach the problem by sophisticated analysis of data from recent multi-spacecraft missions (Cluster, THEMIS, Double Star), which often provide simultaneous measurements on opposite sides of the magnetosheath and by comparing the in-situ experimental data with numerical models. The magnetosheath provides upstream boundary conditions and plasma sources for processes in the cusp, tail and inner magnetosphere.

Within the team we will combine expertise on these processes and investigate how and if the magnetosheath asymmetry induces asymmetries in the magnetospheric regions further downstream and vice versa.

Any asymmetry in magnetosheath velocity introduces a different flow shear across the magnetopause in different locations. This difference can alter the reconnection rate (e.g. Cassak & Otto, 2011) and hence the rate and locations at which plasma and energy can enter the magnetosphere at the dayside. As well as through reconnection between the magnetosheath and magnetospheric magnetic fields under southward IMF, plasma entry has been posited to occur at the magnetopause through the action of kinetic Alfvén waves (e.g. Johnson & Cheng, 1997) and through reconnection in rolled-up Kelvin-Helmholtz vortices (e.g. Nykyri & Otto., 2001; Hasegawa et al., 2003). These mechanisms are thought to dominate under northward IMF and produce, in the magnetotail, a plasma sheet that is characterised by two component proton distributions. A cold component presumably with its source in the magnetosheath and a hot component with properties more typical of the southward IMF plasma sheet have been observed (Wing et al., 2005; Nishino et al., 2007). This two component plasma sheet is generally more often observed close to the flanks of the magnetotail (Wing et al., 2005) although it too displays significant dawn-dusk asymmetry. The cold component ions are more energetic at dawn than dusk (Wing et al., 2005; Nishino et al., 2011). This suggests increased energy transport across the post-midnight magnetopuase relative to the pre-midnight magnetopause, which has been predicted by theory (Johnson and Cheng 1997). Although the post-midnight cold component is more energetic than the pre-midnight cold component, Cluster observations (Walsh et al., in preparation; see also Figure 2, below) have shown that the cold component of the plasma sheet is more likely to be observed pre-midnight than post-midnight. The growth rate of the KH instability has been shown to be roughly symmetric at the dawn magnetopause and dusk magnetopause, at least in some cases (Nishino et al., 2011), and similar numbers of rolled up vortices have been observed in both the pre- and post-midnight sectors (Hasegawa et al., 2006; Taylor et al., submitted). This suggests alternative mechanisms, for example dual lobe reconnection (e.g. Øieroset et al., 2008) may be responsible for the presence and increased strength of the cold component in the pre-midnight sector. The relative importance of dual lobe reconnection and transport via Kelvin-Helmholtz vortices and kinetic Alfvén waves in the production of the asymmetric northward IMF plasma sheet is unknown.

Processes internal to the magnetosphere can also introduce dawn-dusk asymmetries in the magnetotail. Ion beams observed in the plasma sheet boundary layer tend to be more energetic duskward of the noon-midnight meridian than dawnward (Grigorenko et al., 2009). A dawn-dusk asymmetry has also been observed in energetic electron fluxes by Geotail (Imada et al., 2008) and Cluster (Åsnes et al., 2008): Higher energetic electron (i.e. $E > 40$ keV) fluxes are observed in the post-midnight sector than the pre-midnight sector. All of these observations have been explained in terms of acceleration by the cross-tail electric field, although little work has been done in linking any asymmetries in the source populations for these energetic electrons with the observed asymmetries in the electrons themselves. As well as the asymmetries in particle populations, there are other dawn-dusk asymmetries in the magnetotail that have yet to be explained, for example the apparent duskward offset of the magnetotail reconnection site (e.g. Imber et al., 2011).

One goal of this team is to assess the asymmetries present in the magnetotail and determine to what extent they are controlled by asymmetries in plasma transport into the magnetotail (either directly from the magnetosheath, via dual lobe reconnection, or southward IMF reconnection at the dayside magnetopause) and to what extent they controlled by processes occurring within the magnetotail itself. We will compare results from increasingly available large-scale statistical surveys of in-situ data, novel ENA images of the plasma sheet from missions such as TWINS and IBEX (e.g. Keesee et al., 2011) and global- and local-scale simulations.

Solar wind-magnetosphere interaction leads to a large-scale circulation of magnetospheric plasma and magnetic flux that extends all the way down to the ionosphere. The reconnection hypothesis of Dungey (1961) explains the dependence of the basic convection pattern on the orientation of the interplanetary magnetic field (IMF) carried by the solar wind. For southward IMF, reconnection occurs on the dayside magnetopause with closed magnetospheric field lines. Once interconnected, open magnetic flux tubes are carried by the solar wind over the poles downstream, penetrating deeper and deeper into the magnetotail, where they eventually reconnect again to form closed field lines that are convected sunward past the Earth. In the high-latitude ionosphere the result is the familiar two-cell pattern, with anti-sunward flow over the polar caps returning to the dayside via the dawn and dusk flanks.

The characteristic twin-cell flow often exhibits dawn-dusk asymmetries that are oppositely directed in the Northern and Southern Hemispheres. The sense of the asymmetry depends on the IMF B_Y component. This effect can be understood (e.g., Cowley and Lockwood, 1992) in terms of the tension exerted on newly reconnected field lines in the presence of an IMF B_Y which leads to asymmetrical additions of open magnetic flux tubes to the tail lobes.

However, even during periods with little or no external influence in the form of a IMF B_Y component, a persistent dawn-dusk asymmetry can be seen. Figure 3 below shows ionospheric convection patterns derived from measurements from the Cluster Electron Drift Instrument mapped down to the polar cap ionosphere. The left and right panels illustrate the skewed convection patterns due to the above B_Y influenced tension, whereas the middle panel shows the convection pattern for a purely southward IMF. The convection patterns appear to be rotated clockwise, and for purely southward IMF, the flow channels will bring plasma from dayside noon to the pre-midnight sector on the nightside. This skewed transport of plasma across the polar caps has also been observed in-situ in the polar ionosphere using optical and radar observations of polar cap patches (Moen et al, 2007).

This lack of symmetry is poorly understood, but some studies (e.g., Atkinson and Hutchison, 1978; Tanaka, 2001) have attributed this effect to non-uniformities in ionospheric conductivity. If this hypothesis holds, it illustrates that plasma circulation in the magnetosphere is not simply the result of processes at the magnetospheric boundaries or the magnetotail, but that it is modified and partly controlled by ionospheric effects.

In order to understand asymmetries in the magnetosphere, we will therefore need to understand asymmetries in the magnetosheath and ionosphere, and the processes linking them. This ISSI International Team plans to do just that.

Expected Output

The goal of this team is to consider all of these observed asymmetries and attempt to synthesise a conceptual framework that can explain them. we will investigate the sources of asymmetry in the magnetosheath and how these influence the magnetosphere; we will consider the relative importance of transport, local processes and coupling to the ionosphere in producing the asymmetric magnetotail; we will determine to what extent the asymmetries in the ionosphere are magnetospheric in origin or come from other sources.

As such, the primary output from the team will be an overview paper published in a peer reviewed journal examining the asymmetries in the magnetosheath, magnetosphere and ionosphere. This overview paper will place them all within one conceptual framework which we will identify during our meetings. We will also undertake new research into the topics identified above to inform the writing of the overview paper and intend to publish the results of that research in peer-reviewed journals.

Furthermore, several of the team members have proposed a special session at the 2012 AGU Fall Meeting focussing on dawn-dusk asymmetries in planetary magnetospheres.

Added Value From ISSI

It is only through bringing together scientists who have studied the different asymmetries described above that an overarching framework into which asymmetries in the magnetosheath, magnetosphere and ionosphere can be constructed. The necessary range of expertise cannot be found in individual institutions, or indeed in individual countries, so the hosting of this International Team by ISSI will be necessary for us to solve this problem.

Schedule

We anticipate that we will require 3 meetings.

The first meeting in late 2012 / early 2013 will last five days, during which we will assess the current state of research into dawn-dusk asymmetries and identify specific gaps in our understanding that will need to be filled with new research. This assessment will also inform the structure of the overview article.

The second meeting (late summer / autumn 2013) will last 5 days and will focus on completing the research identified during the first meeting and beginning to write any papers based on it. We will also finalise the structure and content of, and define individual responsibilities vis-à-vis, the overview paper, the bulk of which will be written between the second and third meetings.

The third meeting (spring/summer 2014) will last for 3 days and will focus on editing the manuscript for the overview article and addressing any referee comments for those new research papers that have not yet been accepted for publication.

Funding

Individual team members will arrange funding for travel to ISSI. We request funding to cover facilities, accommodation and subsistence for 8 team members for 13 days. We also request travel support for one of the team coordinators. An estimate of costs is given below.

Travel for one team coordinator: €800
Subsistence for 8 team members for 13 days: 8 x 13 x €60 = €6 240
Hotel for 8 team members for 13 days: 8 x 13 x €100 = €10 400
Total: €17 440

Annex A: Figures

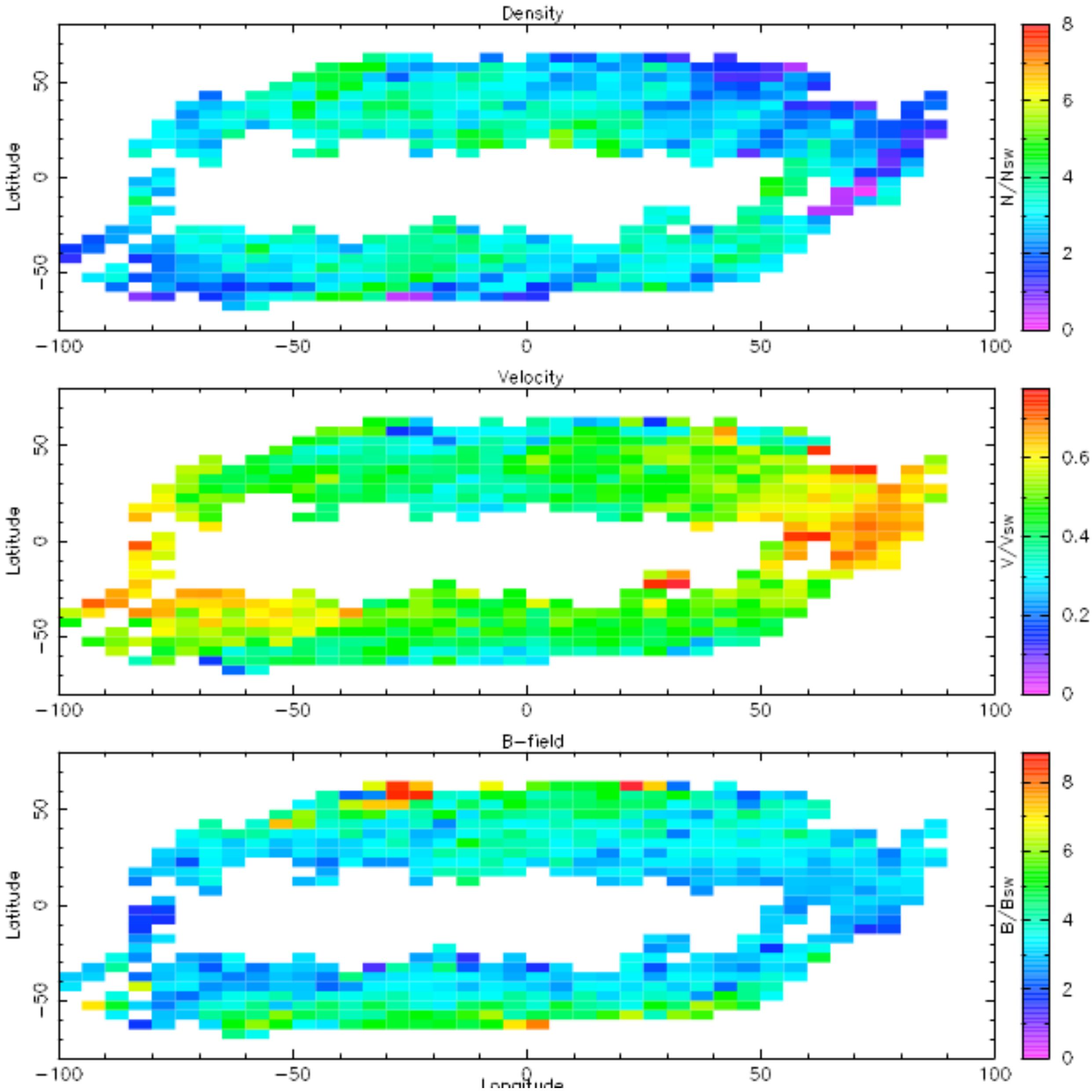

Figure 1. Observed asymmetries in the magnetosheath density, velocity and magnetic field, respectively (Longmore et al., 2005, Figure 5). There is a marked dawn-dusk asymmetry in magnetosheath velocity that is reversed in the Northern and Southern Hemispheres. The exact source of this asymmetry is not known, nor is it's effect on the magnetosphere.

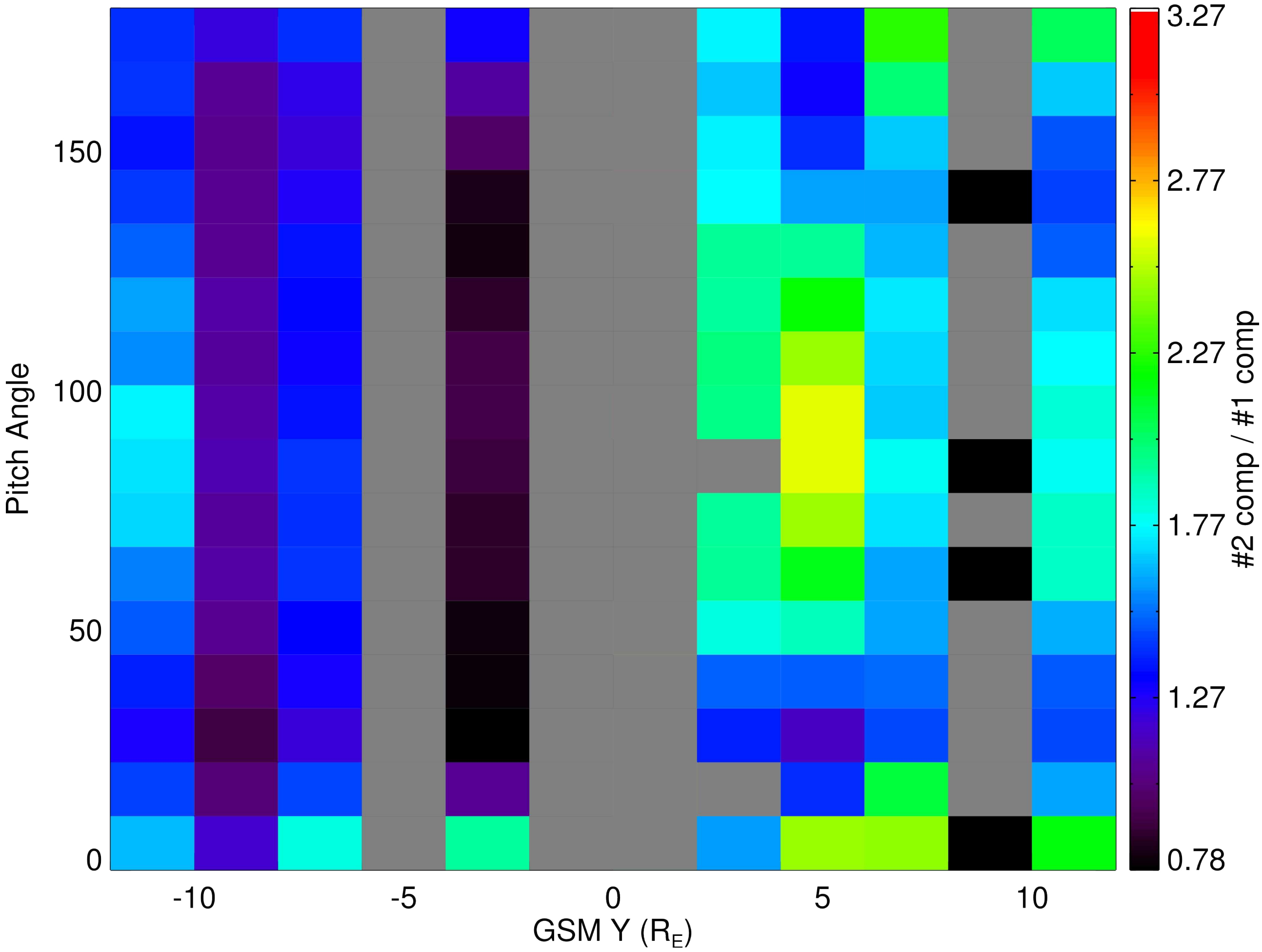

Figure 2. Colours represent the occurrence of two component proton distributions relative to occurrence of one component proton distributions in the terrestrial magnetotail, during intervals of steady Northward IMF, as a function of GSM Y and pitch angle (Walsh et al. In preparation). A second, cold component is much more likely to be measured in the premidnight sector than the postmidnight sector. Grey colours represent pitch angle / Y bins where data coverage is insufficient to obtain a representative sample.

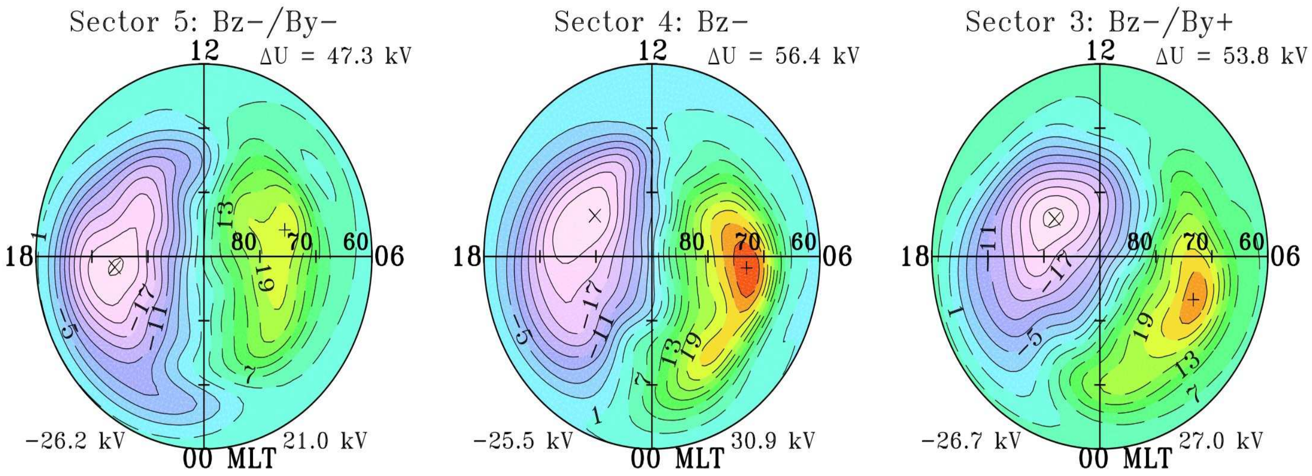

Figure 3. Left panel: Ionospheric convection patterns for southward IMF orientation with a negative B_Y component. Middle panel, ditto for purely southward IMF. Right panel: Ditto for a positive B_Y component. Note the lack of dawn-dusk symmetry and apparent clockwise rotation of the pattern. Background colour shows the value of the potential. Lines are drawn at fixed values of the electric potential, with a 3 kV spacing.

Annex B: References

A. Åsnes et al., J. Geophys. Res., 113, A03202, 2008

G. Atkinson & D. Hutchinson, J. Geophys. Res. 83, 725-729, 2001

P. Cassak and A. Otto, Phys. Plasmas, 18, 7, 074501-074501-4, 2011

S.W.H. Cowley & M. Lockwood, Ann. Geophys., 10, 103-115, 1992

J. Dungey, Phys. Rev. Lett., 6, 47, 1961

V. Genot et al., Advances in Geosciences, Volume 14 : Solar Terrestrial (2007), pp.263-283, 2009

E. Grigorenko et al., J. Geophys. Res., 114, A03203, 2009

S.E. Haaland et al., Ann. Geophys., 25, 239-253, 2007

H. Hasegawa et al., Nature, 430, 755-758, 2004

H. Hasegawa et al., J. Geophys. Res., 111, A09203, 2006

S. Imada et al., J. Geophys. Res., 113, A11201, 2008

S. Imber et al., J. Geophys. Res., 116, A02201, 2011

J. Johnson and C.Z. Cheng, 1997, Geophys. Res.Lett., 24,1423-1426, 1997

A. M. Keesee et al., Geophys. Res. Lett., 38, L03104, 2011

M. Longmore et al., Ann. Geophys., 23, 3351–3364, 2005

J. Moen et al., Geohphys. Res. Lett., 34, L14113, 2007

M. Nishino et al., Ann. Geophys., 25, 769-777, 2007

M. Nishino et al., Planet. Space Sci., 59, 7, 502-509, 2011

K. Nykyri and A, Otto, Geophys. Res. Lett., 28, 3565-3568, 2001

M. Øieroset et al., Geophys. Res. Lett., 35, L17S11, 2008

K. Paularena et al., J. Geophys. Res., 106, 25377-25394, 2001

N.N. Shevyrev and G.N. Zastenker., Planet. Space Sci., 53, 95–102, 2005

T. Tanaka, J. Geophys. Res., 106, 24505-24516, 2001

S. Wing et al., J. Geophys. Res., 110, A08205, 2005

Annex C: CVs

Team member CVs follow on the subsequent pages.