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Solar wind-Magnetosphere-Ionosphere Coupling and Aurora at Jupiter and Saturn

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Abstract

Solar wind-magnetosphere-ionosphere coupling is accomplished through the existence of large-scale field-aligned currents which are generated in a source region and end in a sink region, and which transfer momentum (and energy) between the regions. Therefore, to move beyond a theoretical picture of how this works at Jupiter and Saturn we require in-situ measurements of these regions primarily in the form of magnetic field measurements, but importantly combined with in-situ plasma, plasma wave data, and remote auroral observations. Since the arrival of Cassini at Saturn in 2004 we have had many opportunities to sample the high-latitude magnetosphere and aurora and have learned a great deal about how this giant magnetosphere works. We also await the "proximal" orbit phase of Cassini where we will obtain information on the high-latitude magnetosphere very close to Saturn. In the case of Jupiter, we eagerly anticipate the first high-latitude observations from the Juno mission, due to arrive in the Jupiter system in 2016. The simultaneous observations from Cassini at Saturn in the final phase of the mission until 2017, and Juno at Jupiter during 2016/17, will be a first in planetary science, and we expect to learn a great deal about both planetary magnetospheres individually and by comparison. Here then, we will give an overview of what we have learned so far from Cassini at Saturn, and how it might apply to Juno at Jupiter.

A principal "source" of the field-aligned currents is the planetary neutral atmosphere, that at Saturn imposes both sub-corotation (and is axi-symmetric to a first approximation), as well as an m=1 rotating twin-vortex perturbation of comparable magnitude. The Cassini data have revealed that there are two separate systems in the Northern and Southern hemispheres rotating with slowly-changing separate periods.

These have been systematically studied, principally in the pre-equinox (2008) Cassini data on the nightside. The sub-corotation system of field-aligned currents consists of seasonally-dependent distributed downward currents over the whole polar region extending to slightly equatorward of the polar cap/open-closed boundary with enhanced Pedersen conductivity across the boundary, followed by a narrow (auroral) layer of upward-directed field-aligned currents on the equatorward side as the conductivity decreases. The profiles are therefore similar in principle to previous theoretical predictions, but demonstrate that the conductivity profile is as important as the angular velocity in determining the field-aligned current profile.

In addition at Saturn, planetary-period oscillation (PPO) currents flow principally in the closed field region, approximately from the polar cap/open-closed boundary inwards to ~10 R_s in the equatorial plane (with smaller currents mapping inside that to at least ~6 R_S); they are associated with cross-field currents in the magnetosphere that sweep wave-like through the sub-corotating magnetosphere, causing radial displacements of the plasma (the "cam" effect). In 2008 the field-aligned currents in the South were dominated by the southern PPO phase, while those in the North were approximately equally modulated by the North and South PPO systems, showing presence of inter-hemispheric PPO current flow.

We see a strong and obvious solar-wind effect at Saturn associated with strong compressions of

magnetosphere, whose effects are interpreted as being due to the excitation of strong, tail reconnection that strongly modulates the field-aligned currents and the auroras. The system is “trickle charged” with open flux usually over intervals of days due to system size, weak interplanetary magnetic field, and Corotating Interaction Region (CIR) morphology. It therefore seems that solar wind dynamic pressure (rather than IMF direction) plays the major role in the solar wind modifying Saturn’s magnetosphere and aurora. However, there is also evidence in dayside auroras for IMF-modulated reconnection effects in post-noon sector.

Looking to Jupiter, the evidence appears strong that the main auroral oval at Jupiter is related to corotation breakdown and associated magnetosphere-ionosphere coupling currents, although the precise details of how this works will be revealed by Juno in 2016. For example, it is not obvious whether there are solar wind compression-related effects at Jupiter similar to Saturn. Following a CIR compression at Jupiter it is clear that the aurora brightens, but it is not clear which components (main auroral oval or polar aurora) are affected. A simple application of corotation breakdown models would suggest that the field-aligned currents associated with the main auroral oval should weaken under compression (i.e. dimmer aurora), and brighten under rarefaction conditions. By comparison with Saturn, we might expect that the polar aurora (possibly related to the solar wind interaction) should be brightest under compression conditions. We need to be able to measure and distinguish between field-aligned current systems associated with magnetosphere-ionosphere (corotation) and solar wind-magnetosphere coupling, and investigate how they vary over a solar rotation. This is what Juno will measure in 2016!

We will discuss the topics discussed above, with a view to taking a forward look to the exciting new data from the Cassini proximal orbits at Saturn, and the first high-latitude data from the Juno mission at Jupiter.