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Rotational Saturn Magnetospheric Dynamics

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Abstract

The coupling of Saturnian atmosphere, ionosphere and magnetosphere is rendered special by the alignment of planetary magnetic and rotation axes. Illumination of the magnetic polar caps varies only with season and this is the root of the separate northern and southern periodicities observed in both radio emissions and in the polar B field. The relatively narrow band nature of the northern and southern periodicities and the magnetic polarization indicate the periodicities are imposed independently from northern and southern polar regions, i.e. open field line regions. However, it is also argued that the power that sustains each signal only partially comes from the polar cap itself but globally through the circulation system that transports ionized material from the inner magnetosphere ultimately to interplanetary space. There are separate north and south "cam" source currents flowing along the field lines at invariant latitude ~70°. The location of the currents marks the region where the dipole field no longer dominates in equatorial regions and the field is distended by solar and centrifugal effects.

Introduction

Most aspects of the 10.7 hr periodic magnetic oscillations that permeate the Saturn magnetosphere can be explained by special aspects of the plasma circulation system. when the planetary field is symmetric about the rotation axis. We start from the co-rotating circulation system proposed on the basis of electron density and magnetic data by Gurnett et al. (2007) whose ionospheric flow pattern is sketched in the Figure. We assume that magnetic flux in the polar cap is constant on the scale of 10.7 hr. In other words, solar wind reconnection is not important.

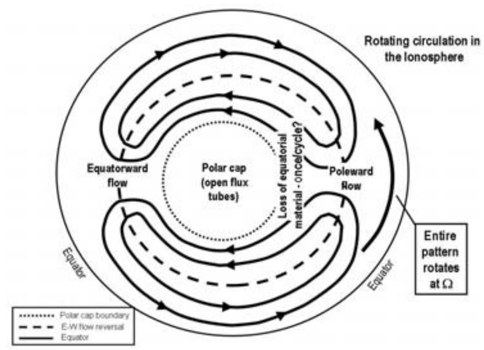

Figure 1. Rotating circulation like that suggested by Gurnett et al. (2007) projected into the ionosphere. In a purely internally driven system, loss must occur in the vicinity of the polar cap boundary. However because of the presence of the solar wind loss through the formation of plasmoids will only occur as the poleward moving sector moves through the night sector and so at high invariant latitudes just below the polar cap the system becomes strongly local time dependent.

In such circumstances, the polar cap ionospheres play an important part in the loss process in imparting angular momentum to eject plasma finally down-tail and in to interplanetary space. This helps resolve the final mystery of the Saturn radio and magnetic oscillations, namely the presence of separate northern and southern rotation periods as well as suggesting the origin of the slow variation in the period over season.

Rotating Circulation

Gurnett et al., (2007) assume that there is a rotating twin vortex pattern (i.e. $m = 1$ symmetry) and we agree with this on magnetic shells within invariant latitudes of 69-71°. The system self sustains as material releases energy during transport. There are two linked sources of energy or heat to drive the circulation of the ionised material, the internal energy of the ionised material and that the rotation of the system is imposed by ion-neutral coupling in the ionospheres at the field line feet. However such a system cannot be maintained in a magnetosphere embedded in the solar wind. Material has to be lost somewhere in the high latitude parts of the outbound sector and this then has to be down-tail.

The sketch in Figure 1 ignores the effect of the pressure provided by the solar wind on the dayside on the geometry of the system. In regions where the equatorial field is no longer dominated by the planetary dipole, we would expect a local time (LT) structure to be superimposed at high latitudes in the region of loss. The invariant latitude where this takes place in the Saturn system is near the shells at invariant latitude 69-71°. We propose that this corresponds to the major feature in the flow marked with the dashed line. Here the azimuthal flow in the assumed rotating system reverses and makes a natural major shear in the flow. This marks the end of the Gurnett system and is also the source of the cam magnetic currents identified by Southwood and Kivelson (2007). Beyond the dashed line the flow becomes LT dependent as the loss is strongly LT dependent. It follows that the flow shown becomes a perturbation on a LT dependent flow where flux tubes expand out and collapse back from the tail similar to the process proposed for Jupiter by Kivelson and Southwood (2005). Magnetic flux is conserved in the flow and prima facie one would expect that the polar caps do not take part in the flow as is shown in the Figure. However this is wrong. The mix of the rotating perturbation imposed on the LT dependent flow makes drawing a steady state sketch not possible. However each time the denser outbound sector of the inner region flow comes in the tail sector, the outermost flux tubes will break and release a plasmoid and nearly less dense flux tubes will rotate at high speed to rejoin the in bound flow half a cycle ahead. The process of loss and return imposes a regular perturbation on the flow in each polar cap and in the ionosphere this imposes a rocking motion on each polar cap as a whole. There is no a priori reason for the two polar caps to rotate at the same rate and so the rocking will be at slightly different rates. As field lines approach breaking point Alfven wave transmission along the field ceases to be possible with the consequence that the final spin up of the lost material is accomplished by stress transmitted separately from northern and southern ionospheres. The last two facts provide the core of an explanation of the imposition of separate northern and southern periodicities on the system with both detected in the field in the dipole region and only one beyond invariant latitude 69-71°.

References

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