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Three dimensional aspects of magnetospheric circulation at Jupiter and Saturn

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Abstract

Cowley et al. [2004] described flow in the giant planet magnetospheres by a Vasyliunas cycle transporting heavy material ionised in the inner magnetosphere outwards to eventual loss, mainly down-tail and a Dungey cycle whereby solar wind enters by day and the solar magnetic field connects to the magnetic flux in the polar cap through reonnection. We look at the latter Dungey cycle for the fast rotating magnetospheres of Jupiter and Saturn, emphasising particularly three-dimensional aspects.

1. Introduction

Cowley et al. [2004] described giant planet magnetospheric circulation with two cycles: the Vasyliunas cycle which carries heavy material from the inner magnetosphere outwards to eventual loss, mainly down-tail and a Dungey cycle where solar wind enters by day and reconnection connects the magnetic flux in the polar cap to the solar field. The recent discovery by the Cassini RPWS team [Gurnett et al. 2010] of a high latitude boundary they identify as the plasmapause is in our view the boundary between the Dungey and Vasyliunas regimes. The material originating in the Vasyliunas cycle starts near the magnetic equator and there is little reason for it to migrate off the equator as centrifugal effects keep it there. In the Dungey system is predominantly confined to the polar regions and the outermost closed flux tubes, solar wind material is likely to enter at high latitude far off the field line equator. Moreover, the lighter nature of the solar wind material that has entered means it can gain a much larger fraction of corotation speed. In this regime, the three dimensional structure of the circulation is important. The antisolar segment of the Dungey circulation is on open flux tubes and, in a fast rotator, the open tubes are swept towards the afternoon side of the magnetosphere and sunward flow on closed tubes is in the morning sector.

Dayside blockage and consequences

Using both theoretical estimations and a simulation parametrised for the jovian magnetosphere but with an aligned rotation and field symmetry axis like Saturn, we note that the morning side return path of the Dungey cycle is blocked in the equatorial plane by the combined effect of the slower moving heavy material of the Vasyliunas cycle and the subsolar magnetopause compression. As a result the lighter material in the outer regions coming from the Dungey tail reconnection region in the early morning region is both squeezed off the equator and moves outward. This results in

reconnection preferentially before noon and preferentially off the equator. The open tubes resulting from dayside reconnection can then move over/under the noon blockage and are accelerated down the afternoon side of the magnetosphere. Cassini data from high inclination orbits at high invariant latitude shows a reversal of magnetospheric-ionospheric stress near midday where there should also be distinct changes in auroral morphology.

Results

We present a scenario for the Dungey cycle with a strong dawn-dusk asymmetry and where most solar wind material entering near noon on an open tube is likely to leave the system by streaming down tail when that tube rotates into the evening/night sector. For Jupiter, we provide a natural explanation of the cushion region seen on the morning side. More controversially, we propose that for Saturn the entire Dungey system is pulsed at the 10.7h rate seen in magnetic field and radio emissions. Our scenario where much of the particle motion is off the equator goes some way to explain the maintenance of a slight difference in northern and southern rotation periods in the magnetic field pulsations and in the periodic planetary radio emission. Moreover it also explains the most intense radio emissions coming from the morning sector as well as the reported periodic injection of energetic particles from the early morning sector.

References

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