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Identifying the mechanical source of Saturn's periodic signals

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Abstract

Saturn emits kilometric wavelength radiofrequency signals (SKR) whose amplitude is modulated at roughly the planetary rotation period, yet decades after the discovery of the modulation we do not understand how rotational modulation of electromagnetic signals is imposed on a planet with a highly axisymmetric magnetic field. The magnetosphere and the upper atmosphere/ionosphere are possible drivers of the rotation-linked modulations. It may seem easy to determine the source of a rotational asymmetry, but the ionosphere and the magnetosphere are so tightly coupled by field-aligned currents that it is hard to establish whether the periodic phenomena are driven from one end of a flux tube or the other. We show that spatial gradients of oscillating signals can, in principle, enable us to distinguish the signatures of mechanical sources in the magnetosphere from the signatures of such sources in the ionosphere. Data are sparse but appear adequate to tell us whether the ionosphere or the magnetosphere drives the periodic behaviour.

1. Introduction

In a magnetosphere, momentum transport over large distances is typically achieved electromagnetically; the flux of electromagnetic momentum relates to the gradient of the Maxwell stress tensor and the sign of the inertial contribution near the equator indicates whether the ionospheric plasma is the driver of the perturbations or the load. By measuring gradients of relevant magnetic properties as a function of latitude, L-shell, local time and rotation phase, one should be able to establish whether the mechanical momentum source lies at the ionospheric or magnetospheric end of magnetospheric flux tubes. Initial analysis of Cassini MAG data suggests that it will be possible to identify the direction of electromagnetic momentum transport. Comparisons to the MHD simulations of *X. Jia et al.* [1] should add insight to the analysis. Establishing the momentum source will greatly constrain models of the imposition of rotational periodicity.

2. Background

Although several models have been proposed to account for electromagnetic periodicity, they can be separated into two groups defined by the locus of the mechanical source of momentum. Some models place the source in the equatorial magnetosphere. Others place the source in the ionosphere. Which group is consistent with observations can be established by determining whether the equatorial magnetosphere is a source or sink of mechanical energy. The idea is to relate the time variation of mechanical momentum to electromagnetic momentum using an appropriate low frequency approximation [2]:

$$< d/dt\, P_{\mathrm{mech,i}} > = < \int_{Vol} d^3x \sum_j \partial_j \cdot [dB_i dB_j - \tfrac{1}{2}\delta_{ij}(dB)^2] > / \mu_o \qquad (1)$$

where $P_{mech,i}$ is the *i*th component of the total momentum of particles in a volume element, *V*, near the equator, $d\mathbf{B}$ is the magnetic perturbation at the SKR period, and the pointed brackets indicate an average over rotation phase at fixed radial distance. If the right side of the equation is negative, the source of momentum is equatorial. If it is positive, the source is ionospheric.

3. Data

Magnetometer data are more extensive than plasma data. Thus it is possible to determine the sign of the left side of equation (1) by using measured variations of the perturbation magnetic field. Derivatives of the fluctuating field can be extracted from the data by putting together measurements made over much of the Cassini mission. Figure 1 shows orbital plots from inclined orbits from 2005 to 2012. In most local time sectors, sufficient data are available to evaluate the right hand side of equation (1).

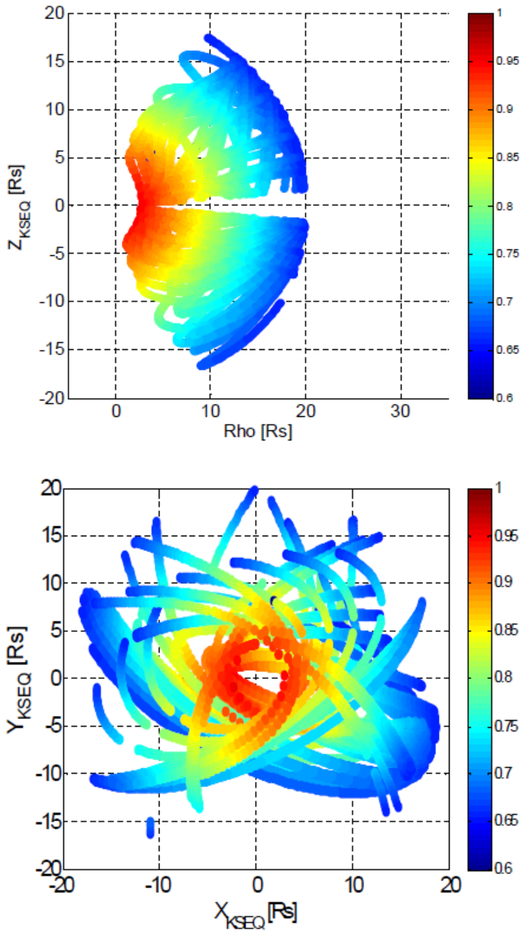

Figure 1: Inclined passes from 2005 to 2012 in the KSEQ coordinate system. Below: equatorial plane projection; Above: Z vs. cylindrical radial distance in R_S. Color represents spacecraft speed in R_s/hour.

Figure 2 provides an example of the way in which the ϕ component of the magnetic perturbation varies with latitude. Here the azimuthal field perturbation is seen to vary nearly monotonically with latitude at fixed SKR phase. Work continues on establishing the variation of the other components of the fluctuating field in order to extract evidence of the origin of the mechanical momentum that drives the fluctuating signals of Saturn's magnetosphere.

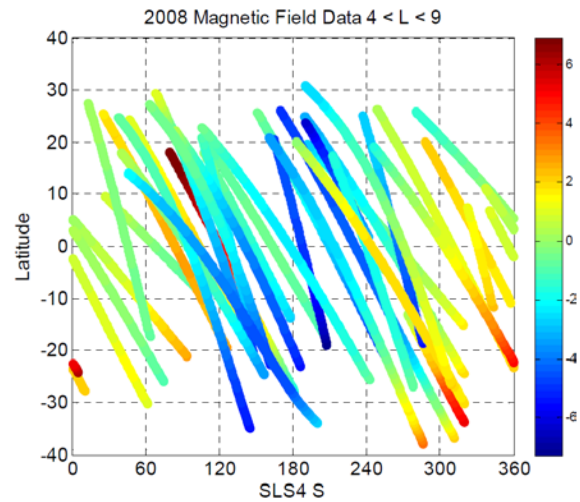

Figure 2: On a plot of latitude vs. SKR phase, denoted SLS4 [3], left: dB_ϕ (color bar) extracted from data in 2008 between L of 4 and 9.

6. Summary and Conclusions

In most local time sectors, Cassini MAG data are now sufficiently complete that it will be possible to obtain approximate values of the gradients of the perturbation field. This makes it possible to establish the sign of the mechanical momentum flow. The sign alone can exclude from further consideration either models that place the driver in the equatorial magnetosphere or models that place the driver in the ionosphere.

References

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