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An inner magnetospheric vortex as the source of periodicities in Saturn's magnetosphere

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Abstract

Many different field and plasma parameters collected from Saturn's magnetosphere show the presence of rotational periodicities even though Saturn's magnetic field is highly axisymmetric. Most of the observed periodicities are in sync with the period observed in Saturn's intense radio waves called Saturn's Kilometric Radiation (SKR). Recently, it was shown that the SKR emitted from the northern and the southern hemispheres have slightly different modulation periods creating a puzzling but persistent dual clock in the Saturn system.

In this work, we show that the modulations of SKR emissions and many field and plasma parameters are the manifestations of a massive ($M > 10^8$ kg) slow-moving ($V < 1.5$ km/s) two-cell plasma convection system operating in the inner magnetosphere of Saturn that was first proposed by Gurnett et al. [1]. We show that during the southern summer the longer-period southern SKR emissions are exclusively excited by sources in the plasma outflow region of the convection system which lags corotation to conserve angular momentum. The two key components of Saturn's summer clock are the unequal conductivities of the northern and the southern hemispheres from differences in solar insolation and a plasma convection cycle that provides persistent memory to the magnetosphere. We illustrate, how, various field and plasma parameters synchronize themselves to Saturn's summer clock.

1. Introduction

Strong radio waves are generated on field lines connected to the auroral regions of the magnetized planets. The radio waves are beamed in narrow hallow cones directed along the field lines, so that their intensity at a receiver is modulated by the rotation of the planet if the magnetic dipole axis is tilted relative to the rotational axis of the planet providing a clock signal that can be used to measure the rotation period of the planet. Saturn's spin and dipole axes are aligned to better than 0.5° [2], yet Saturn's SKR wave intensities and many field and plasma parameters display rotational modulations. It has also been shown that the SKR period varies at the level of 1% over a time scale of years [3], [4]. An even more perplexing observation is that the northern and the southern hemispheres modulate SKR radiation at slightly different rotational periods [4]. These observations cast doubt on the idea that the SKR wave intensities are modulated by the internal rotational period of Saturn but also raise the question of what processes excite the dual clock in Saturn's magnetosphere.

2. Model

We show that Saturn's SKR clock from the hemisphere experiencing the summer (henceforth called the summer clock) is synchronized to a two-cell plasma convection system operating in the inner magnetosphere of Saturn. Figure 1 shows the theorized rotating two-cell plasma convection system in which the magnetic flux tubes recently loaded in Enceladus's gas torus move outward under the action of centrifugal force. On their way to the inflow region, the flux tubes lose plasma to the middle magnetosphere through processes such as diffusion and small-scale magnetic flux interchange. Thus, the inflowing flux tubes would have much lower plasma density. In the outflow region, the plasma loses angular velocity as it conserves angular momentum while moving outward. Magnetic field applies Lorentz force (J×B) on the plasma to enforce corotation by generating radial currents which are drawn out of the ionosphere in the region lagging corotation and returned to the ionosphere along field lines that map along the outer edge of the convection system. The field-aligned currents transfer angular momentum from the ionosphere to the magnetosphere. If the ionospheric conductivity is finite, perfect enforcement of corotation is never achieved. Using the same argument, it can be seen that in the inflow region, the plasma while conserving angular momentum would gain azimuthal speed. However, as the mass inflow rate is much smaller than the outflow rate, the expected currents strengths are lower in the inflow rate. The associated radial and field-aligned electrical current system which provides the magnetosphere-ionosphere (MI) coupling currents generate zero magnetic field perturbations near the equator. However, when differences in the ionospheric conductivity are considered, it is seen that the low conductivity of the northern ionosphere impairs its MI coupling capacity and the electrical current system is modified significantly. During southern summer, the southern ionosphere not only supplies the bulk of the magnetic torque (through radial currents) to the magnetosphere to facilitate MI coupling, the southern ionosphere also tries to synchronize the speed of the northern ionosphere to its own to avoid large scale twists on the closed field lines threading the two hemispheres. The inter-hemispheric (IH) current system required to accomplish the equalization of magnetic torques in the northern and southern halves of the magnetodisk (where most of the magnetospheric plasma resides) is similar to the current system proposed by Southwood and Kivelson [5] to explain the magnetic field observations in the inner magnetosphere (with minor differences in how the currents flow across the ionosphere). We show that the associated field-aligned current system creates energetic electron precipitations in the ionosphere generating the SKR emissions. Finally, we will discuss how the energetic particles synchronize themselves to the rotating plasma vortex and modify the magnetic field in the magnetosphere.

3. Figures

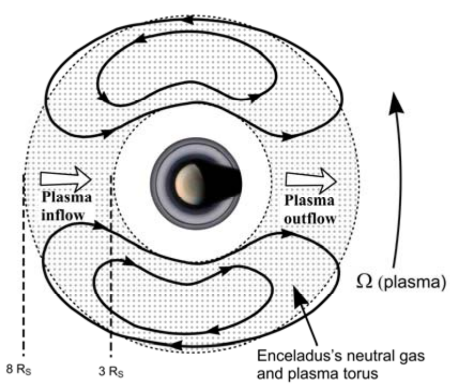

Figure 1: An equatorial view of the rotating two-cell plasma convection system thought to be operating in Saturn's inner magnetosphere. The low density inflowing magnetic flux tubes pick up additional plasma from Enceladus's neutral gas torus as they move toward the outflow region. The difference in the centrifugal force experienced by the flux tubes in the inflow and the outflow regions drives the convection system in the inner magnetosphere.

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