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Growth of the Kelvin-Helmholtz instability at Saturn's magnetospheric boundary: Charged particle acceleration and potential auroral implications

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Abstract

The growth of the Kelvin-Helmholtz (K-H) instability at Saturn's magnetospheric boundary is introduced, and we review the proposed relationship with planetary auroral emissions. We present Cassini observations of a plasma vortex in Saturn's dayside outer magnetosphere. The spacecraft crossed the magnetopause three times, before being immersed in the low-latitude boundary layer. During the transition between the boundary layer and the magnetosphere proper the spacecraft observed deflected boundary layer plasma, a twisted magnetic field topology, and high-energy (>20 keV) directional electron fluxes. These observations are consistent with an encounter with a vortex on the inner edge of the boundary layer – an interface that is expected to be susceptible to the growth of the K-H instability due to its low magnetic shear. A simple model of the current system resulting from the formation of the vortex is proposed, and the possible acceleration mechanisms responsible for the high-energy electrons are discussed.

1. Introduction

The growth of the Kelvin-Helmholtz (K-H) instability at the boundary of a planetary magnetosphere has long been considered to be an important aspect of the solar wind-magnetosphere interaction. The instability operates at a fluid interface and can manifest itself in the form of waves that propagate along the interface itself, which may then evolve into vortices as the instability enters its non-linear phase. In a space plasma environment, conditions are favourable for the growth of the K-H instability where there is a large velocity shear between plasma flows, combined with local magnetic fields that are approximately perpendicular to the relative flow direction, reducing the stabilizing effect of the magnetic tension force [1].

Compared to its terrestrial counterpart, Saturn's magnetosphere is far larger and possesses significant internal plasma sources, with the dominant motion of magnetospheric plasma being in the sense of corotation with the planet. The plasma flow pattern illustrated in Figure 1 suggests that the dawn flank boundaries are susceptible to the growth of the K-H instability, whereas the dusk flank boundaries are expected to be generally stable on the dayside. Likely K-H waves on Saturn's dawn flank magnetopause have been recently reported [2].

Large-scale vortices form in some simulations of Saturn's magnetosphere, and are associated with intense field-aligned currents [3]. Galopeau et al. [4] proposed that the growth of the K-H instability at the magnetopause could explain why the most intense source regions of Saturn Kilometric Radiation (SKR) – Saturn's auroral radio emissions – are on the morning side at high latitudes. In this scenario, the typically K-H unstable morning magnetopause produces magnetohydrodynamic waves capable of accelerating electrons along magnetic field lines towards the planet.

2. Summary of Observations

On 13 December 2004 the Cassini spacecraft was moving towards Saturn during the inbound pass of its third planetary orbit. After crossing the magnetopause three times the spacecraft was immersed in the low-latitude boundary layer (a region of mixed magnetosheath and magnetospheric plasma adjacent to, and planetward of, the magnetopause). When Cassini crossed the inner edge of the boundary layer the spacecraft instruments observed significant variations in the thermal electron environment, deflected flows, a twisted magnetic field topology, and an increase in the flux of field-aligned electrons at energies above 20 keV. These data are consistent with a spacecraft encounter with a K-H vortex in Saturn's outer magnetosphere.

3. Figures

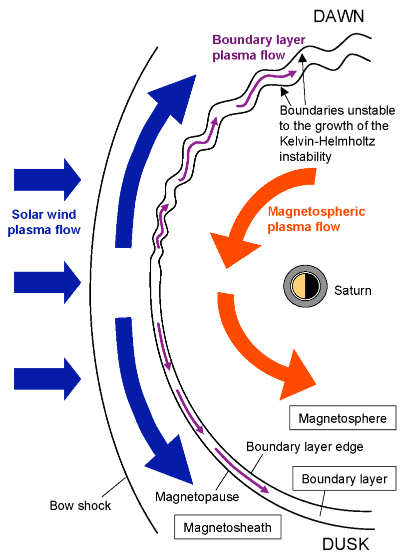

Figure 1. Schematic illustrating the structure of Saturn's magnetospheric boundary.

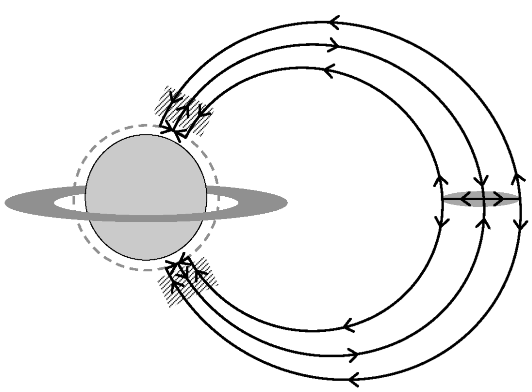

Figure 2: Schematic illustrating the vortex-induced current system.

4. Discussion

The observation of accelerated electrons during the vortex encounter is particularly interesting. These beams were principally field-aligned, and unidirectional (anti-parallel to the magnetic field, northward). We construct a simple model of the electric current system induced by the formation of the vortex (Figure 2). This current system closes in Saturn's ionosphere, providing a coupling between the magnetosphere and the ionosphere. We discuss the potential mechanisms responsible for the high-energy electrons. We conclude that both vortex-induced magnetic reconnection and anti-planetward acceleration associated with auroral processes are plausible explanations. The present status of our work on understanding the importance of the K-H instability for the transport of solar wind energy into Saturn's magnetosphere, and the implications for other planetary magnetospheres, are outlined.

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