Evidence of magnetic reconnection from wave measurements at Saturn's magnetopause: Cassini RPWS observations

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Evidence of magnetic reconnection from wave measurements at Saturn's magnetopause: Cassini RPWS observations

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Abstract

Magnetic reconnection is a universal mechanism that is responsible for major energy conversion in planetary magnetospheres. Recent theoretical estimations suggest that reconnection is infrequent at Saturn's magnetopause and that it is not a major driver of the dynamics of the kronian magnetosphere. This scenario need however to be confirmed by in situ observations at the magnetopause current sheet. Evidence of reconnection in the form of accelerated plasma jets is difficult at Saturn's magnetopause due to limitations in the field of view of particle detectors. Here we show evidence of reconnection for one magnetopause event by using measurements of low frequency waves (lower-hybrid, whistlers, plasma/upper hybrid). We discuss how wave measurements can be used as evidence of reconnection in planetary magnetospheres.

1. Introduction

Magnetic reconnection is responsible for major energy conversion and particle heating/acceleration in astrophysical plasmas [1]. Reconnection is the major driver of the Earth's magnetosphere dynamics as substantiated by many observations at the magnetopause [2] and in the magnetotail [3]. In other magnetospheres e.g. Saturn's, on the other hand, processes such as rotationally-driven transport also contribute to the magnetospheric dynamics [4]. Understanding the relative importance of reconnection and other processes for magnetospheric dynamics is an important open question. Recent theoretical estimations [5,6] suggest that reconnection is infrequent at Saturn's magnetopause and that Dungey's cycle is much less important at Saturn's than at Earth. These predictions need however to be confirmed by in situ observations of reconnection both at the magnetopause and in the tail. As for Saturn's magnetopause, evidence of reconnection is limited mostly due to the fact that particle detectors cannot very often resolve accelerated plasma jets in the magnetopause current layer. Magnetic field observations [7] are useful but they do not provide any evidence of plasma energization. Furthermore, the expected value of the component of the magnetic field normal to the magnetopause (a few % of total field for fast reconnection) is comparable to the measurement error of the magnetometer for typical magnetopause magnetic field strengths (~ a few nT). Observations of heated/accelerated electrons within the magnetopause can provide more information [8] however resolving the pitch-angle distributions expected from the theory is also limited by field-of-view issues. In this paper we show one case where observations of low frequency waves (lower-hybrid, whistlers, plasma/upper hybrid) within the magnetopause are consistent with ongoing reconnection. We also suggest how wave measurements can be used to statistically provide evidence of reconnection, when particle data are not available.

1.1 Purpose of the study

The goal of this paper is to show how low frequency waves (lower-hybrid, whistlers, plasma/upper hybrid) can be used to provide evidence of reconnection at Saturn's magnetopause. We show wave observations for one magnetopause event where evidence of reconnection was provided by using electron data [8] and show that wave and electron measurements are consistent with each other.

2. Method and instruments

We use observations from several instruments onboard Cassini: fluxgate magnetometer (MAG), electron spectrometer (ELS) and electric and magnetic antennas (RPWS). As for the waves, we use the on-board computed spectrograms of electric and magnetic power in two frequency bands from both the low-frequency receiver LFR (1-26 Hz) and the medium frequency receiver MFR (24-180 Hz). These frequencies cover the frequency range relevant for reconnection (up to the local plasma/upper hybrid frequency). The evidence of reconnection from waves is based on earlier studied done at the earth's magnetopause (e.g. [9]). Whistler-waves are used to identify the magnetic separatrix on magnetospheric side of the magnetopause, i.e. the first open field line. Lower-hybrid waves are used to identify the electron, ion edge, that is, the boundary of first transmitted magnetosheath electrons, ions on magnetospheric side. Plasma waves indicated the presence of accelerated magnetosheath electrons in between the ion and electron edge.

3. Observations & results

Figures 1 shows a summary of the observations for the magnetopause crossing for the event 2005-09-21 earlier reported by [8]. The time interval refers to the magnetospheric side of the magnetopause.

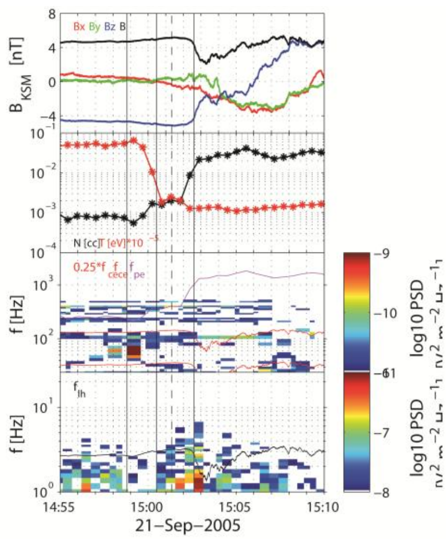

Figure 1: Crossing of a reconnecting magnetopause by Cassini spacecraft on 2005-09-21. The magnetosphere is on the left (lower density). The three vertical lines (from left to right) indicate the magnetic separatrix, the electron edge and the ion edge. The lines overplotted over the electric field spectrograms represent the local lower-hybrid (f_{lh}), the electron gyro (f_{ce}) and the plasma (f_{pe}) frequencies.

The magnetic separatrix on the magnetospheric side corresponds to the region of strong whistler waves that are found in between $0.25f_{ce}$ and f_{ce} (panel c). These waves are produced due to the escaping of hot magnetopsheric electrons along freshly reconnected field lines and are associated to the formation of a density cavity (panel b) [9]. At this time, magnetosheath plasma had not yet the time to arrive on the magnetospheric side. As the spacecraft moves towards the center of current sheet (panel a), transmitted magnetosheath electrons are first observed (electron edge). This corresponds to a boundary in the lower hybrid (panel d) waves associated to a density gradient (panel b). The ion edge marks the arrival of the slower magnetosheth ions and is associated to another boundary in lower-hybrid waves and a larger density gradient. Emissions at the local plasma frequency are observed in between the electron and the ion edge (panel c) and are associated to electron beams accelerated by reconnection [9]. Finally, the main rotation of the magnetic field (current sheet) is observed after the ion edge when density is approximately constant.

4. Summary and Conclusions

In this paper we showed evidence of reconnection from low-frequency wave measurements at Saturn's magnetopause. Whistler waves mark the location of the magnetic separatrix i.e. the first open field line. Boundaries in the lower hybrid waves are observed at two density gradients that correspond to the electron, ion edges respectively. These are the boundary of the first transmitted magnetosheath electrons, ions respectively. Emission at the local plasma/upper hybrid frequency corresponds to electron beams accelerated by reconnection. Wave measurements are consistent with earlier observations of electron distribution functions across the magnetopause. Wave measurements (at least spectra) are continuously transmitted during the boundary crossing and the time resolution (8-16 s) is sufficient to resolve the expected boundaries. Furthermore, wave measurements are independent for field-of-view issues of particle detectors so that measurements are available through the magnetopause crossing. We suggest that low-frequency wave measurements are an important tool to provide evidence of reconnection at planetary magnetopause such Saturns's, which can complement/substitute particle measurements.

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