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Magnetospheric energetic ions as pressure and plasma β regulator in the Saturnian magnetosheath

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Abstract

In situ measurements by Cassini reveal the presence of heavy energetic ions of magnetospheric origin in the Saturnian magnetosheath, in the form of localized “islands”. The statistical study shows that this particle population shifts the sheath from its typical solar wind composition and adds to its energy content and its variability, affecting also the tail-ward and upstream energy loss rate from the system.

1. Introduction

A typical planetary magnetosheath is expected to have a solar wind ion composition, with its plasma content being essentially shocked solar wind. In the case of Saturn, however, in situ measurements by Cassini have shown that energetic (> 10 keV), water product ions (W+) can escape from the outer magnetosphere into the magnetosheath, altering its typical plasma composition [1]. In addition, the heavy energetic ions add a significant pressure component that increases the total particle pressure and the plasma β in the sheath. In this work we have selected orbit segments of Cassini, during which the spacecraft was moving continuously for more than 24 hours in the magnetosheath. The selection returned a total of 916 hours (~38 days) of magnetosheath sampling between July 2004 and July 2011. Most of data were obtained near the rotational equatorial plane, with the dawn-to-noon local time sector being much better covered.

2. Results

A typical magnetosheath pass (days 53-54 of 2006) is presented in Figure 1. The spacecraft crosses the bow shock entering the magnetosheath near noon of day 52 and enters the magnetosphere at the end of day 53, after spending ~36 hours in the magnetosheath.

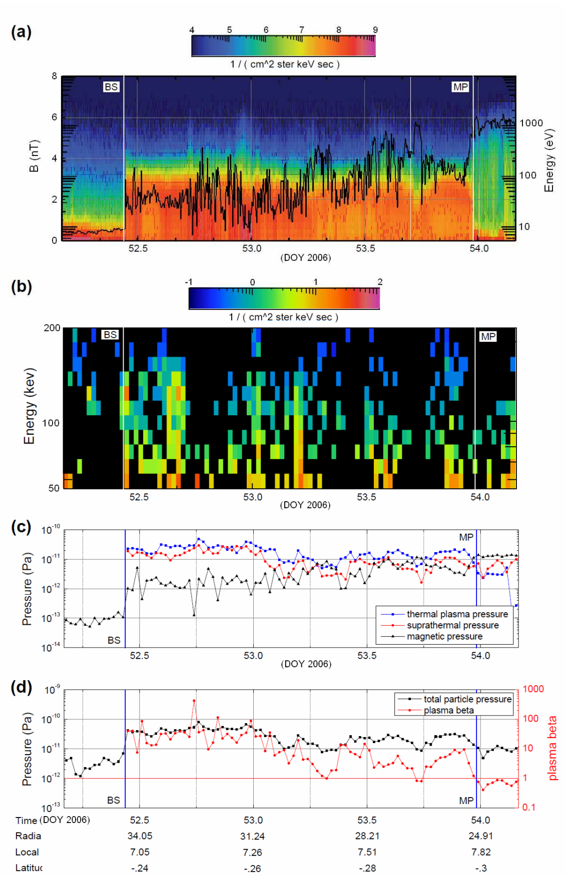

Figure 1: Cassini recordings during a magnetosheath pass. (a) Thermal electron energy spectrogram with the magnitude of the magnetic field over-plotted (black line). (b) Energetic W+ energy spectrogram. (c) Thermal plasma (blue), energetic ion (red) and magnetic (black) pressures, along the pass. The bow shock (BS) and magnetopause (MP) crossings are indicated with blue vertical lines. (d) The total particle pressure (in black) and the total plasma β (red line and axis), along the same pass. The red horizontal line corresponds to β=1.

Both the bow shock and the magnetopause crossings are clearly observed in panel (a) where the electron plasma energy spectrogram is shown with the magnetic field magnitude superimposed. Panel (c) is a comparison of magnetic, thermal and suprathermal pressure along the same pass, as measured in situ by Cassini. Thermal and suprathermal pressures (not available upstream from the bow shock for this particular pass) appear comparable to each other and well over the magnetic pressure. Panel (d) shows the total particle pressure together with the plasma beta (red line and abscissa), revealing that the sheath was, at least during this pass, in a high plasma beta state ($1<\beta<100$).

The analysis of all available magnetosheath measurements allowed also a statistical approach to the energetic particle composition of the Saturnian magnetosphere and in particular to the degree of magnetospheric W+ "contamination" of the magnetosheath plasma. Figure 2 summarizes the statistics of the W+ presence in the Saturnian magnetosheath. Panel (a) shows the pressure contribution of W+ ions for energies over 50 keV. Two distinct maxima appear to form, one peak below 0.05 (<5% W+ contribution to total pressure for E>50 keV) and one broader maximum beyond ~0.75 (>75% W+ contribution). The first peak corresponds to typical magnetosheath conditions where no (or very little) W+ ion contribution is expected. The second maximum region is the statistical signature of the W+ "islands" that populate the magnetosheath. This bimodal behavior is better illustrated in pane (b), where we see that for almost 85% of the times the magnetosheath is (as far as energetic particles are concerned) either in its theoretically expected state with zero or very little evidence of magnetospheric ions, or in a W+ ion rich state of magnetospheric plasma composition, embedded in the sheath, with intermediate regimes rarely appearing. The picture is quite different for the thermal plasma (energies up to few keV). The available ion composition data showed that only in 1.6% of the measurements the W+ contribution to the total ion number density is larger than 5%, indicating a typical planetary sheath composition.

3. Summary and Conclusions

In situ measurements by the particle sensors of Cassini have shown that energetic (> 10 keV) magnetospheric ions escape into the Saturnian magnetosheath, primarily due to their large gyroradii. Those heavy, energized W+ ions that populate the sheath not only change its particle composition, but also add an important pressure component, increasing significantly the plasma pressure and plasma β parameter in the magnetosheath. The energy content of the Saturnian magnetosheath deviate strongly from that assumed for a typical planetary sheath composed of shocked solar wind. Among the implications of this magnetospheric "contamination" are: (a) An increase in the total pressure variability in the sheath, caused by the additional W+ pressure component (typical for the energetic particle population), and (b) A change in the tail energy flow and the upstream energy loss, as energetic ions seem to account for an important part of the magnetosheath energy content.

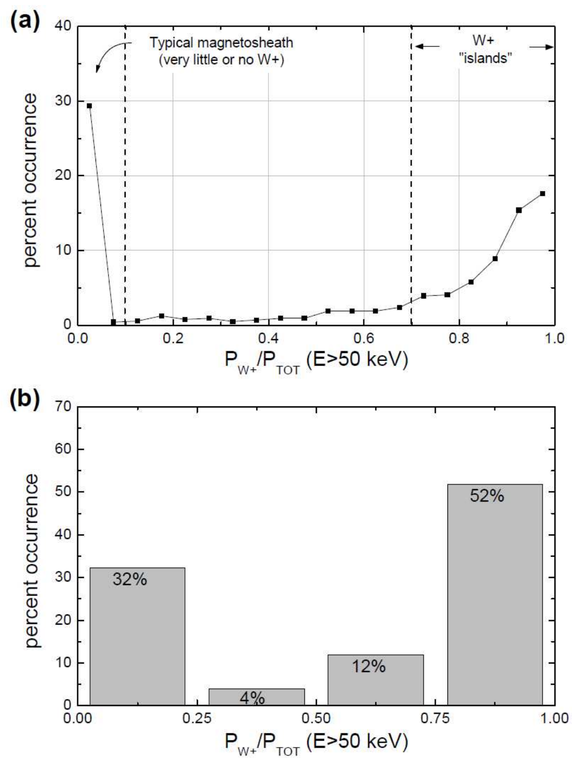

Figure 2: Statistic of the energetic ion population in the Saturnian magnetosheath. **(a)** Distribution of the W+ presssure contribution for energies over 50 keV. Two different states can be identified, typical magnetosheath conditions and W+ "islands". **(b)** The same data binned in 0.25 ratio intervals.

References

[1] Sergis, N.: Energetic particle configuration in the magnetosphere of Saturn: Advances and open questions, American Geophysical Union, Fall Meeting 2011, 5–9 December 2001, San Francisco, CA, USA.