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Energetic Ions and Magnetic Fields Upstream From the Saturnian Bow Shock: Dawn-Dusk Comparison and Search for Periodicity

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Abstract

Energetic particle events associated with IMF field fluctuations were first seen by Voyager in pre-noon upstream of Saturn [1]. The extensive spatial coverage of both the dawn and dusk upstream regions provided by the Cassini orbiter since July 2004, offered the possibility to detect, identify, list and statistically study a large number of upstream particle events. Using the energetic particle and plasma sensors of Cassini, namely the Magnetospheric Imaging Instrument (MIMI) and the Cassini Plasma Spectrometer (CAPS), measurements of H^+, O^+ and electrons are made in a broad energy range (few eV to MeV), together with plasma wave activity measurements, observed by the Radio and Plasma Wave Science experiment (RPWS) at a few kHz, indicative of low energy (tens of eV) electrons travelling up from the planetary bow shock. Magnetic field measurements (Cassini/MAG) are also utilised to reveal low frequency waves associated with the upstream flux enhancements. Statistical analysis shows that particle events are only observed when the projected interplanetary magnetic field (IMF) vector connects the spacecraft to the bow shock, while all particle fluxes appear markedly anisotropic [2,3,4]. It is possible that such events may appear in a periodic fashion upstream, but more measurements are required to confirm such a result. The unambiguous presence of upstream water-product ions (MIMI/CHEMS compositional measurements), and the energy spectrum of the observed population is a very strong indication of the magnetospheric origin of the upstream particles (magnetospheric leakage).

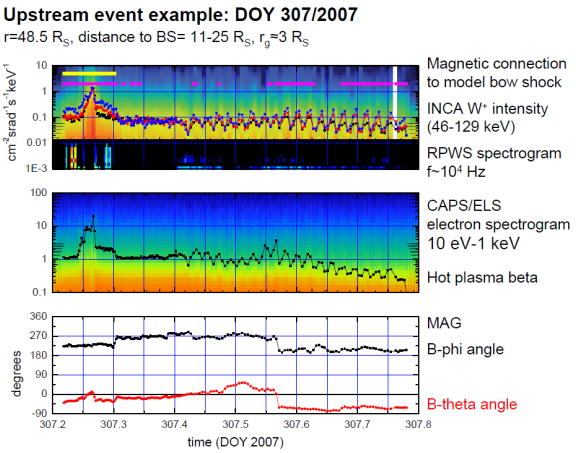

Figure 1: Example of a particle event observed upstream from the Kronian bow shock. Top panel shows the energetic (>46 keV) W+ ion intensity measured by MIMI/INCA (energy spectrogram and line plot of 3 energy channels), together with a frequency spectrogram from RPWS, indicating the simultaneous plasma wave activity. Horizontal color bars indicate intervals of magnetic connection to the average (magenta) or to the adjusted (yellow) model bow shock. In the middle panel, thermal (10 eV-1 keV) electron plasma measurements are shown (CAPS/ELS), together with a line plot of the hot (>keV) component of the plasma beta. In the bottom panel the phi and theta angles of the in-situ measured magnetic field vector are shown as a function of time.

In Figure 1 we present a representative example of an upstream particle event detection, as recorded by various Cassini sensors. The abrupt enhancement in the energetic W+ ion flux, obvious in the top panel, is associated with a clear change in the IMF configuration, seen in both phi and theta angles (bottom panel). Possible particle sources to explain the presence of an energetic W+ population (dominated by O+ and O++ ions) upstream from the Kronian bow shock are the solar wind (through Fermi acceleration processes occurring during its interaction with the planetary bow shock), leakage from the magnetosphere of Saturn of already energized ions, and potentially neutrals escaping upstream that are then photo-ionized in the vicinity of the planet and accelerated by the solar wind electric field (pick-up ions). The comprehensive observational set provided by Cassini, allows for the first time the experimental testing of the predictions that each of these competing models makes.

Summary and Conclusions

(1) Energetic H+ and W+ ions are observed upstream from the Kronian bow shock, as far away as ~10 to 70 R_S from the bow shock). These events are seen in MIMI/INCA, CAPS/ELS, RPWS and (sometimes) in MIMI/CHEMS. (2) There is very strong correlation between magnetic connection of the spacecraft to the IMF and W+ event detection. In almost all of the cases, the onset of the event was associated with a change in the IMF direction that connected Cassini to the planetary bow shock. (3) The energy extent is >700 keV for W+ ions and their distribution is well fitted by a kappa function with kT of few tens of keV, while partial (hot) plasma β is ~1-20 (73% of the cases β>1, 32% β>10). (4) Continuous connection to the bow shock was never long enough to allow the detection of a 10.8 hr periodicity. However, the search for a preferred longitude of particle escape is currently being carried out, as a 3D model of the BS is now used and the points of connection are (approximately) determined. (5) All of Cassini's traversals within the solar wind are analyzed and a statistical approach has now become feasible. We have accumulated ~33 hr of W+ events that allow reliable compositional statistical analysis to be performed.

References

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