OBSERVATIONS OF SHORT LARGE AMPLITUDE MAGNETIC STRUCTURES AT THE KRONIAN BOW SHOCK

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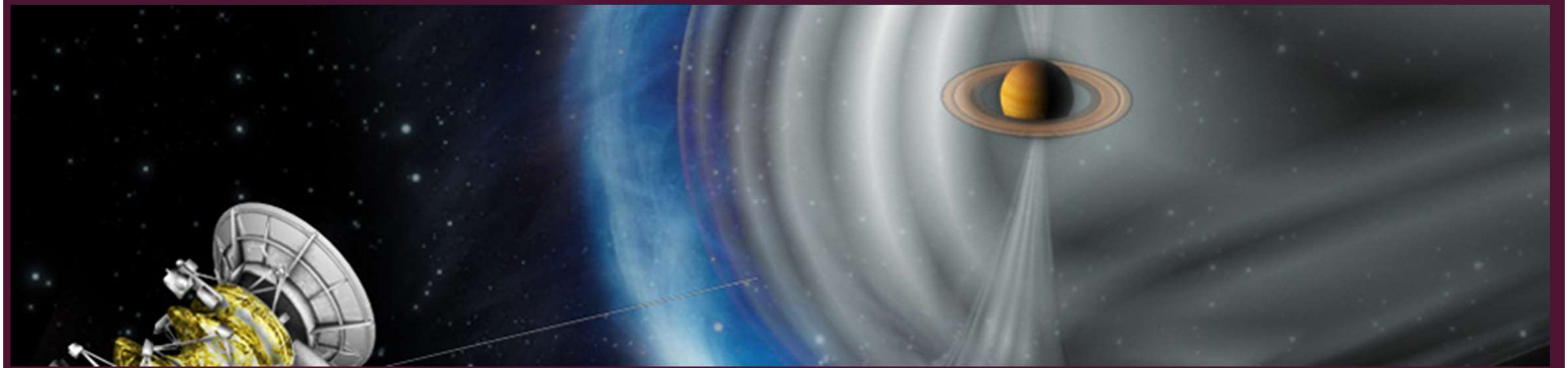

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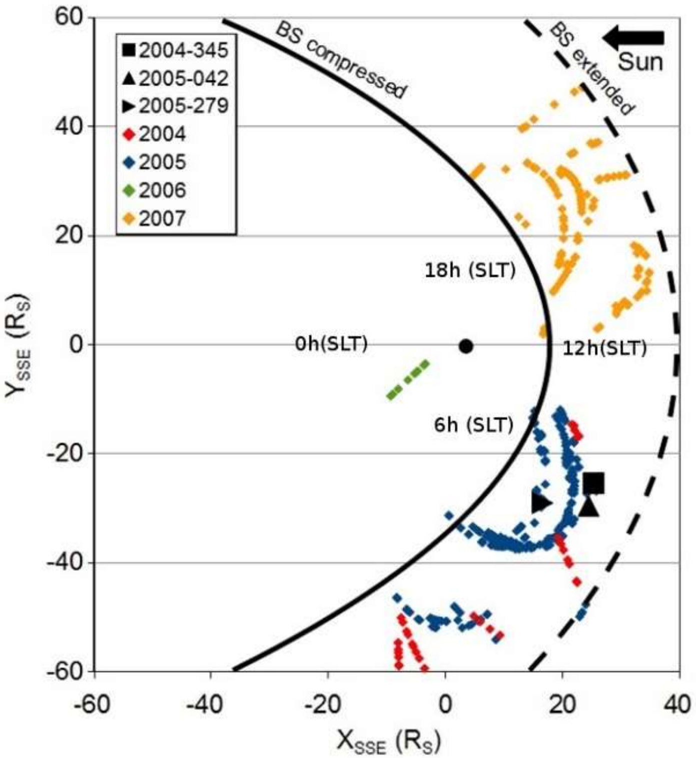
BUDAPEST, HUNGARY

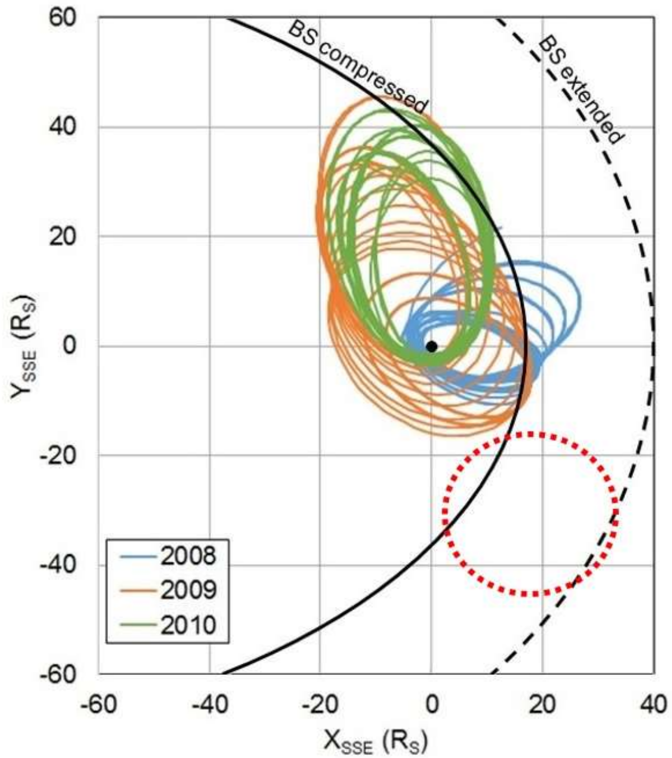
ABSTRACT

- We present observations of Short Large Amplitude Magnetic Structures (SLAMS) upstream of the quasi-parallel bow shock of Saturn. Cassini surveyed the quasi-parallel bow shock regime during 2004 and 2005, and from this time period we chose four events for a detailed study. For our analysis we used the measurements of the Cassini Plasma Spectrometer (CAPS) and the Magnetometer (MAG).
- Locally the SLAMS act as a fast mode shock wave, and we observed possible ion beam reflection, multiple beams, deceleration and plasma heating of the solar wind protons. These features are in agreement with the near Earth observations. We also detected whistler precursor waves multiple times, which was also documented in studies of the Earth's foreshock region. Since the frequency of the upstream ULF waves detected at Saturn is lower than it is at Earth, it also has an effect on the spatial extension of the SLAM structures, which arise from these waves. With only one spacecraft's measurements it is not possible to study the SLAMS with the same efficiency as with the four-point measurements of the CLUSTER probes, but the basic observational features and the description of their evolutional characteristics are summarized.

OBSERVATION SITES

Location of bow shock crossings (inbound and outbound) between 2004 and 2007 (left) in SSE (Saturn Centered Solar Ecliptic) coordinates, from the positive Z direction. The trajectories in the right side plot are shown between January 1st, 2008-December 31st, 2010, in the same parameter space and coordinate system. The co-rotation direction in the figures is counter-clockwise, and the red circle on the right side plot illustrates the absence of measurements in the quasi-parallel bow shock regime.

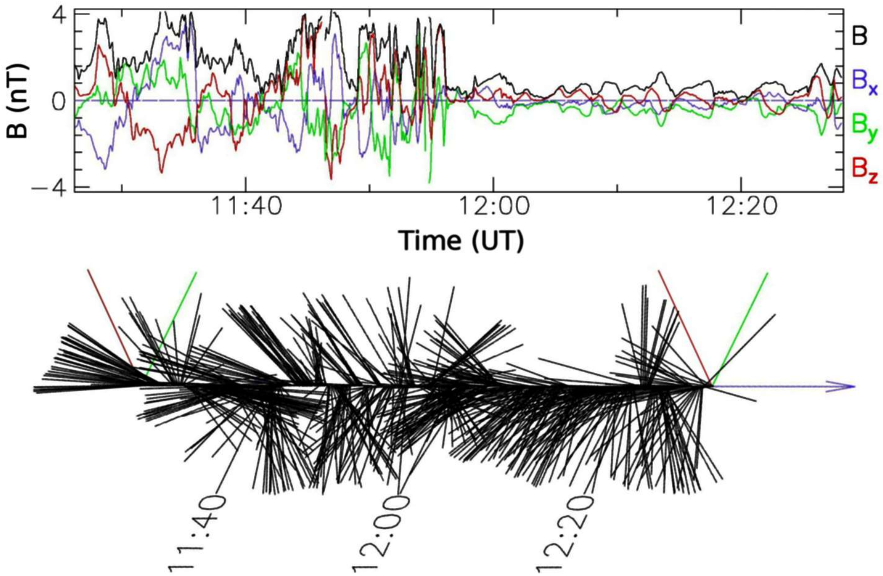




SHOCK GEOMETRY

For the classification of shock geometry we conducted a co-planarity analysis, however we encountered difficulties for the cases discussed here. We can observe that there was a bow shock outbound crossing at 11:53 time, however, the magnetic field vector fluctuates in such a large extent, in particular in direction, that simply there is no rationality to select a time interval around the shock to perform the coplanarity analysis. We can obtain any shock normal vector and ϑ_{Bn} angle, depending on what interval we select.

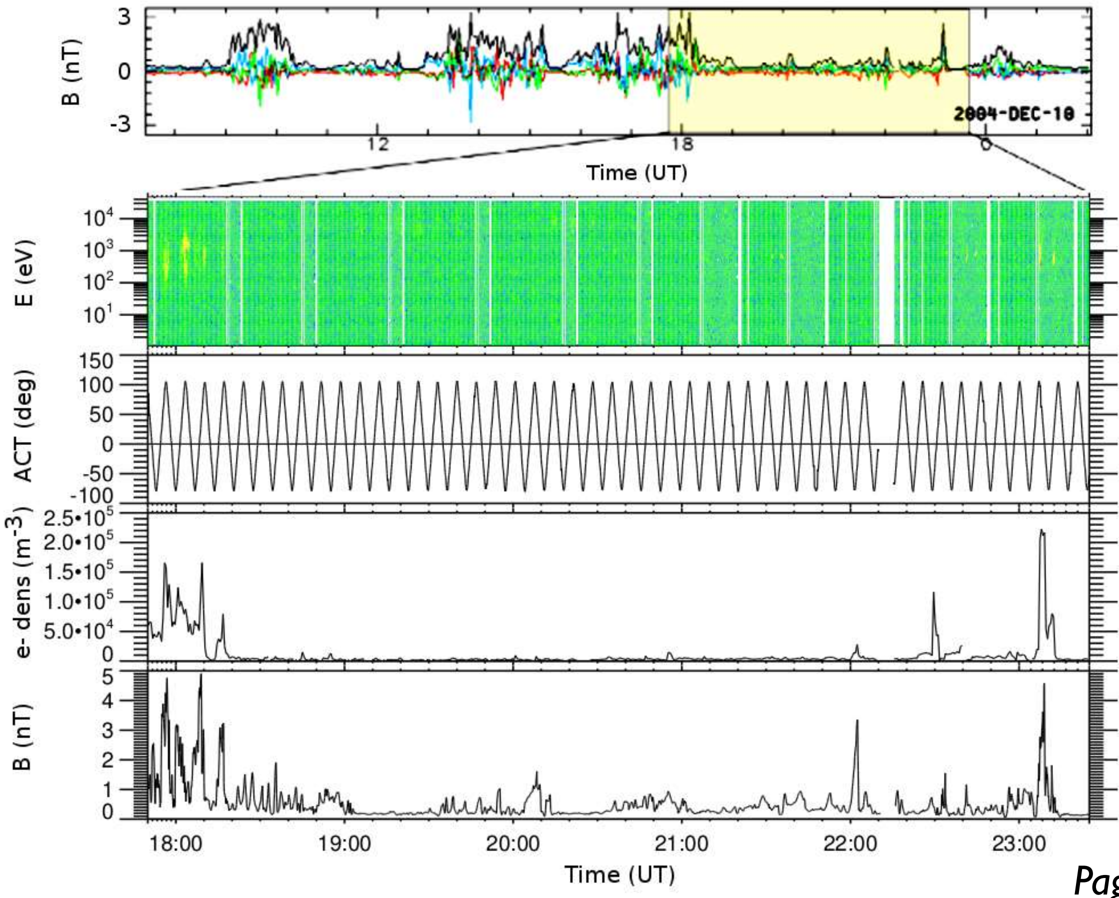
However later we show the results of minimum variance analysis, performed only for upstream ULF waves and whistler waves.



The top panel shows the magnetic field data in KSO (Kronocentric Solar Orbital) co-ordinates for DOY 281, 2005. The bottom plot illustrates the field unit vectors shifted in time in KSO.

EVENT 1.

Magnetic field data in RTN (def; X-red, Y-green, Z-blue, total-black) measured between DOY345T08:30-DOY346T02:00 UTC (top panel), CAPS-IMS Singles data (Anode 5, fourth panel) detected in the time interval of 18:55-23:20 UTC on DOY345, CAPS Actuator angle (middle panel), electron density (second panel from bottom), magnetic field magnitude (bottom panel).



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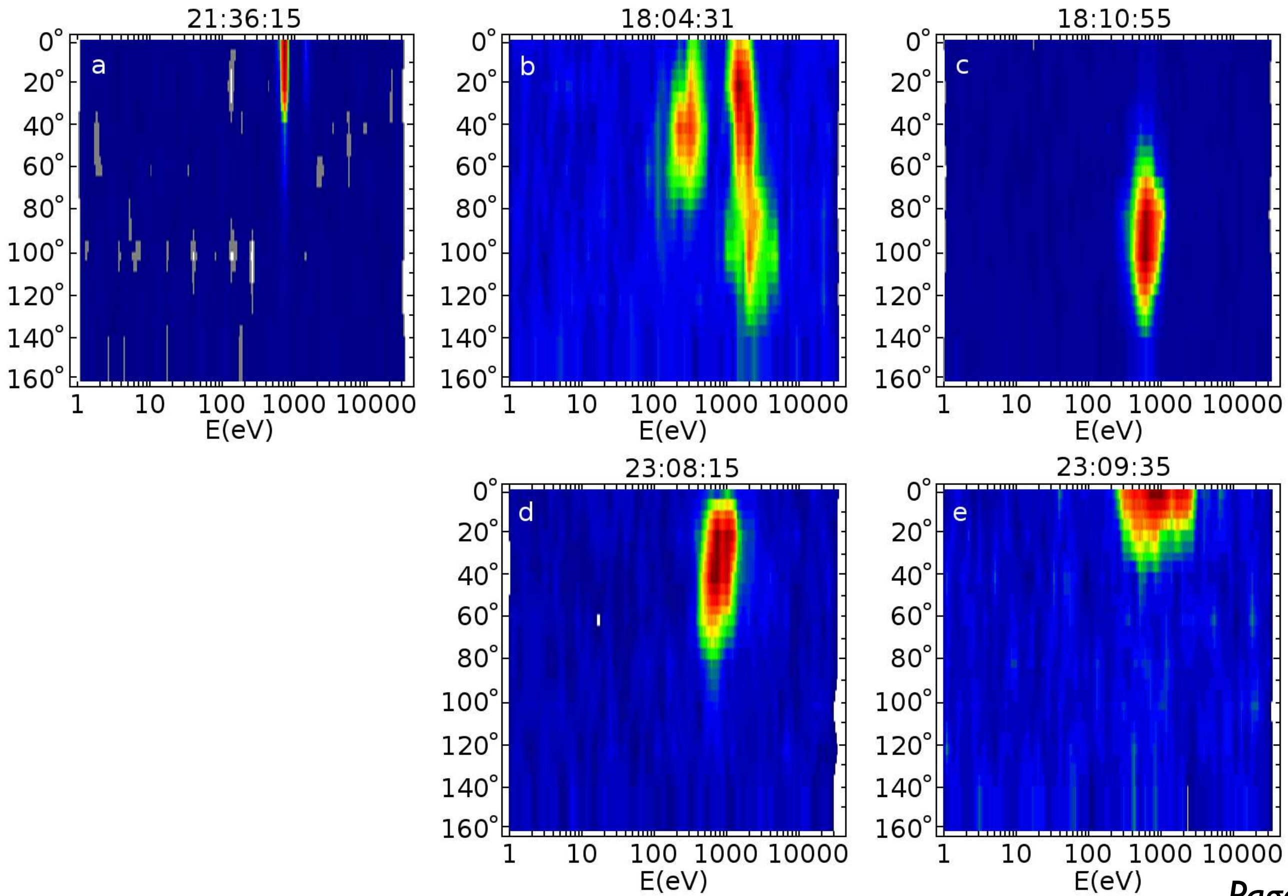
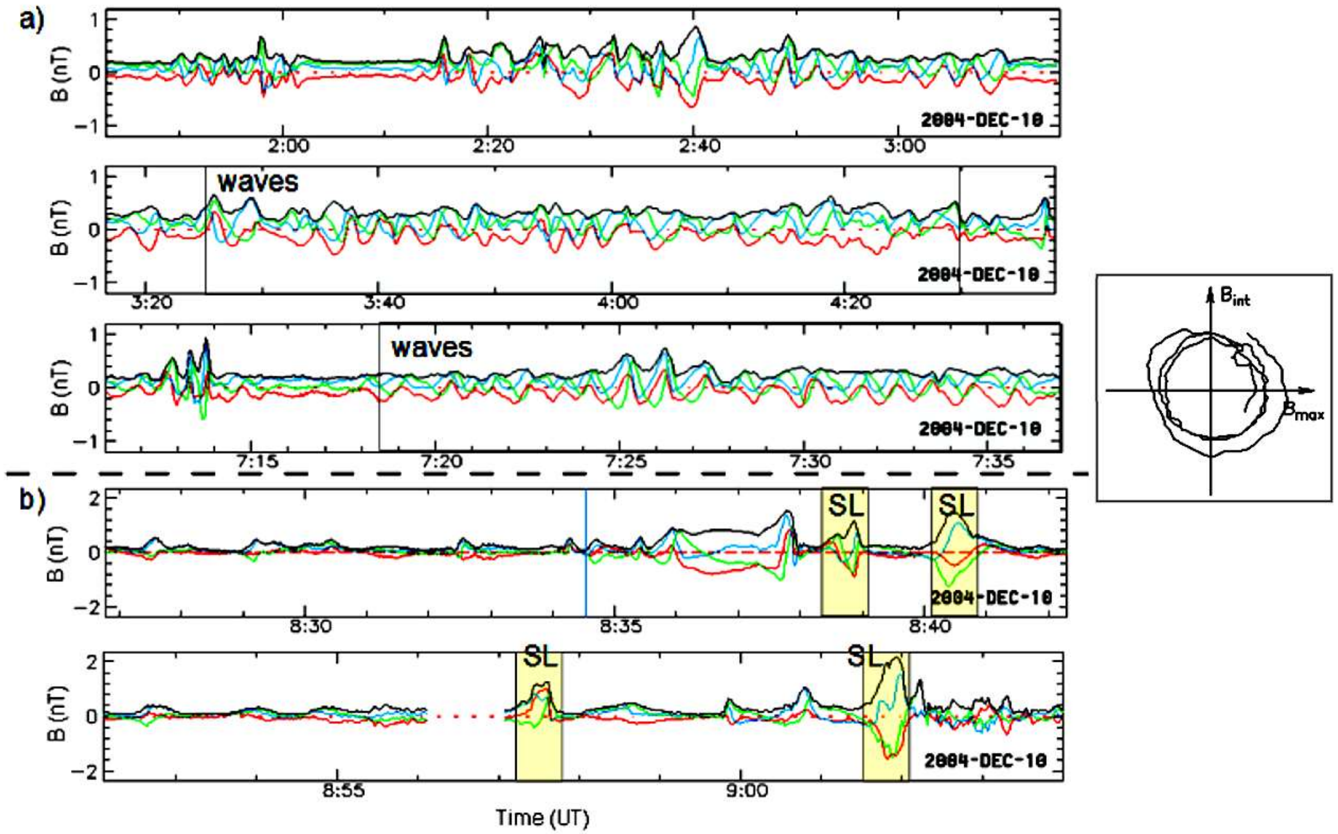
EVENT 1.

CAPS-IMS spectra for DOY 345. The direction of the unperturbed solar wind is marked with SW in the black rectangle, and is in the upper left corner. The other four plot pairs show the ion count rates vs. energy measured in the 8 IMS anodes.



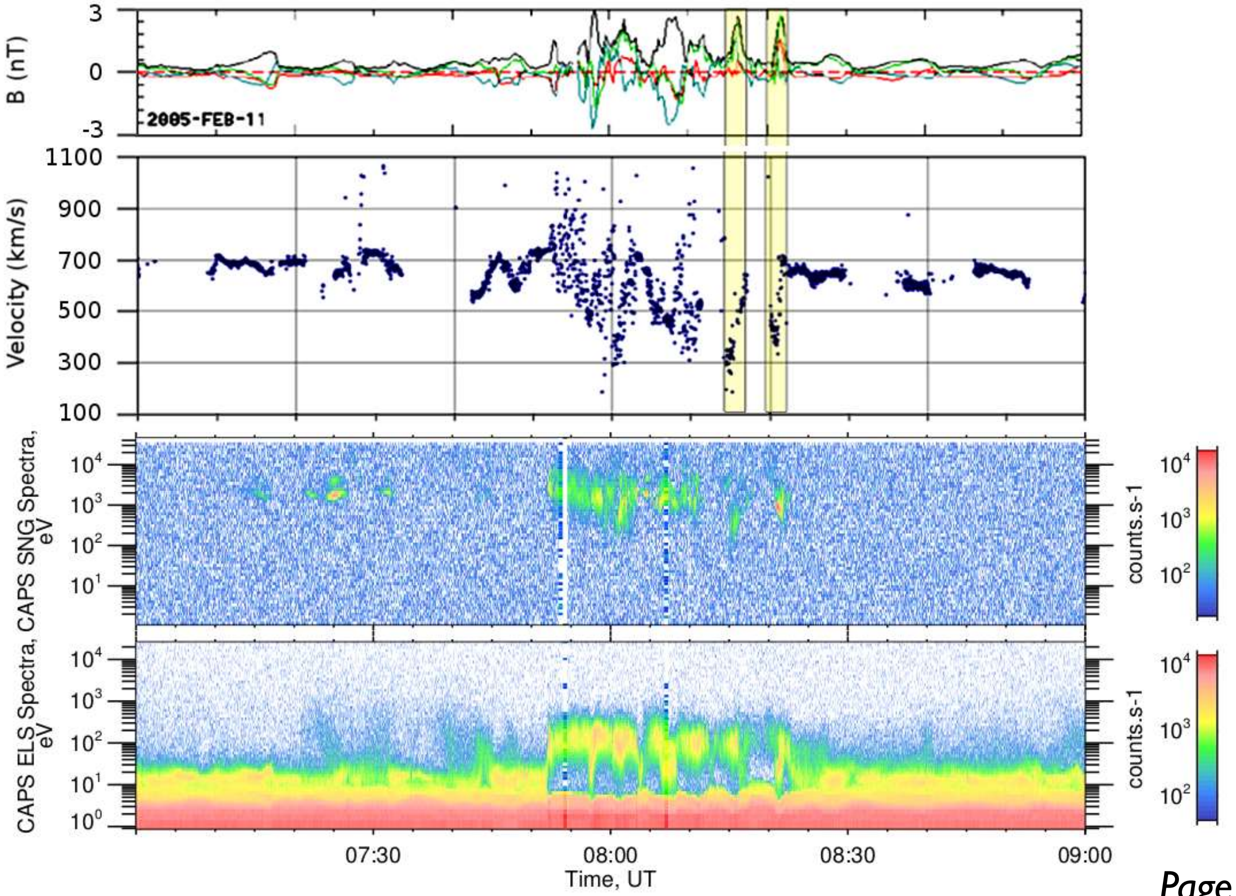
EVENT 1.

Magnetic field structure during a quasi-parallel bow shock crossing on DOY 345, 2004. The upper section a) is plotted in lower time resolution between ~1:00 and ~07:37, the bottom panel data is in higher time resolution for the time interval of 08:27-09:04 UTC. The hodogram insert corresponds to the interval between 07:30-07:33 UTC.



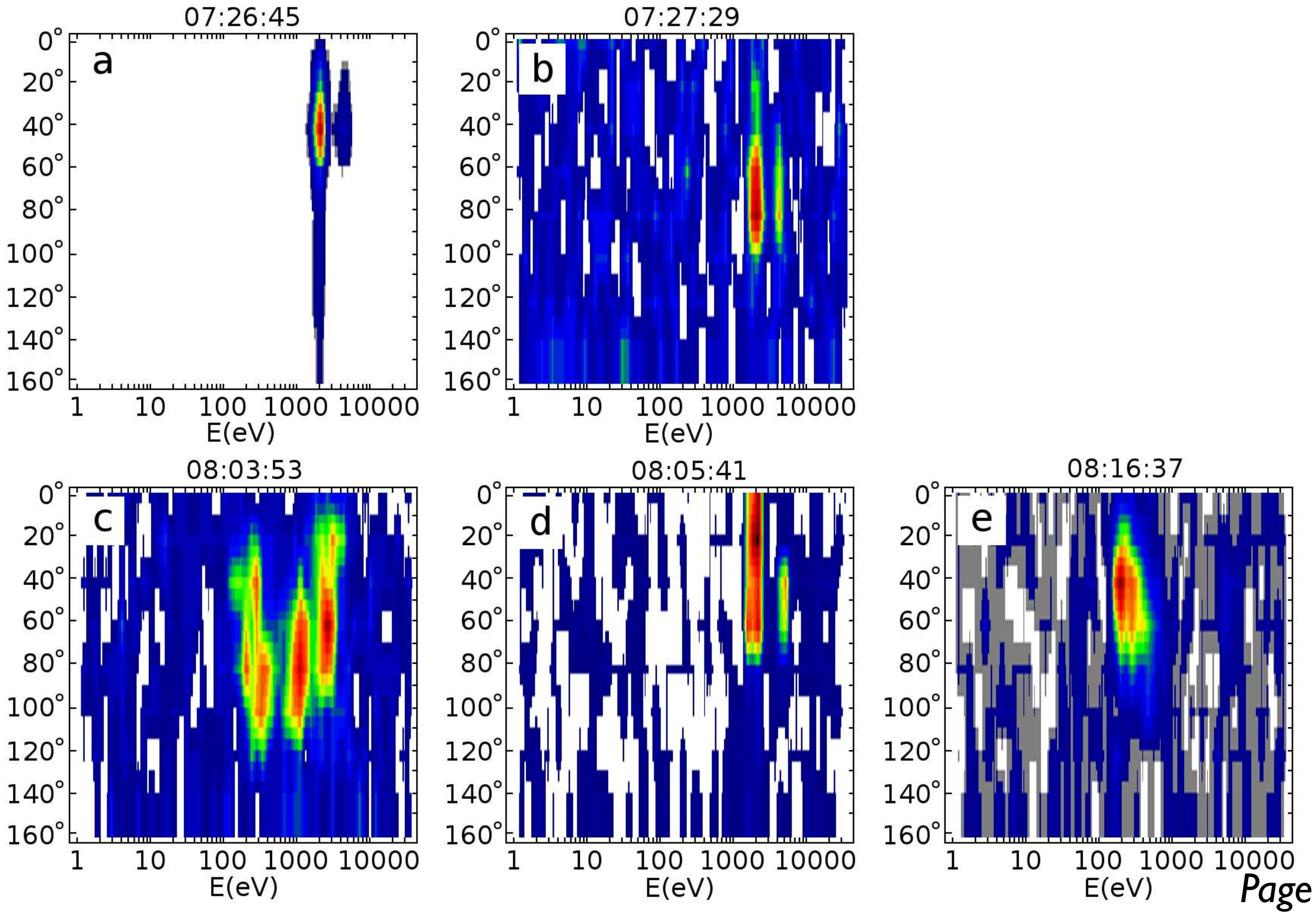
EVENT 2.

Magnetic field data in RTN (top panel) and plasma speed derived from CAPS-IMS measurements (second from top), CAPS-IMS ion spectrum (second from bottom), and CAPS-ELS electron spectrum (bottom), the latter two measured in Anode 5, on February 11, 2005.



EVENT 2.

Particle events on DOY 042. The direction of the unperturbed solar wind is marked with SW in the black rectangle, and is in the upper left corner. The other four plot pairs show the ion count rates vs. plasma speed in their upper panel, and the same count rates measured in the 8 IMS anodes vs. energy channels.



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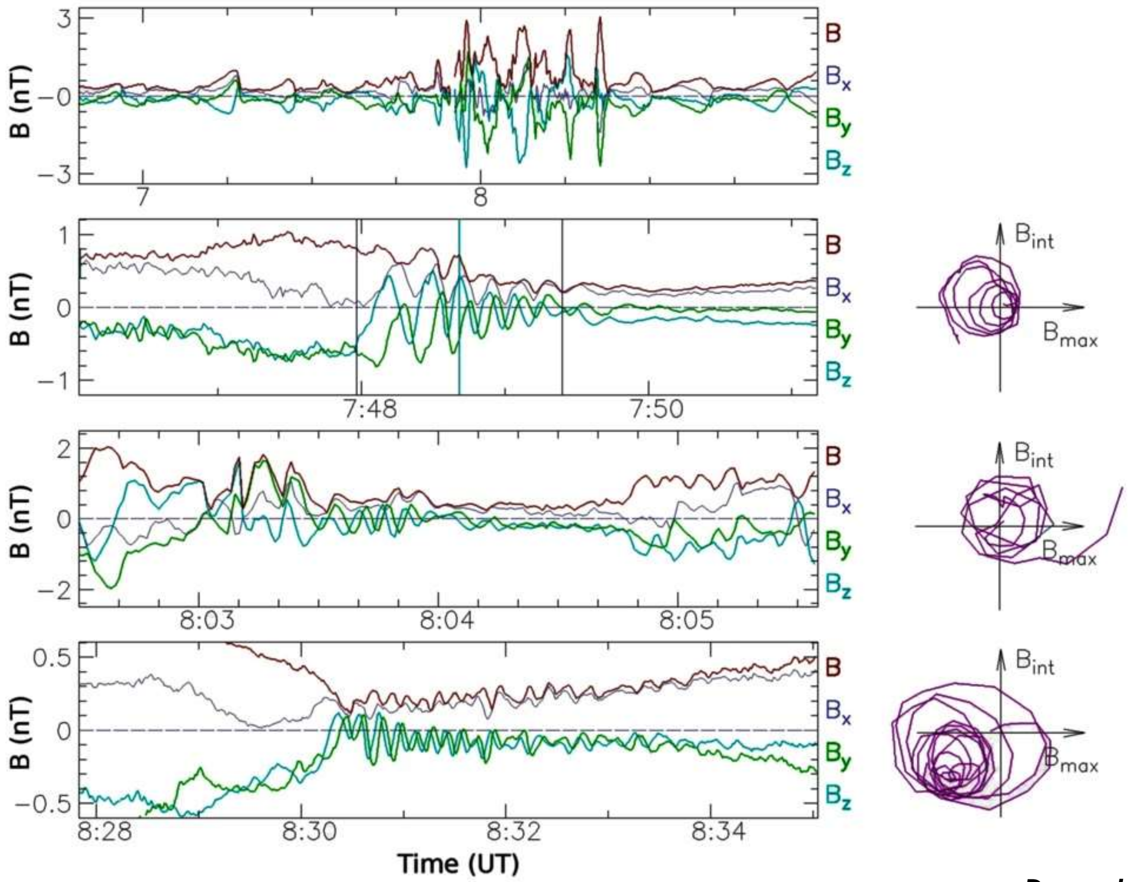
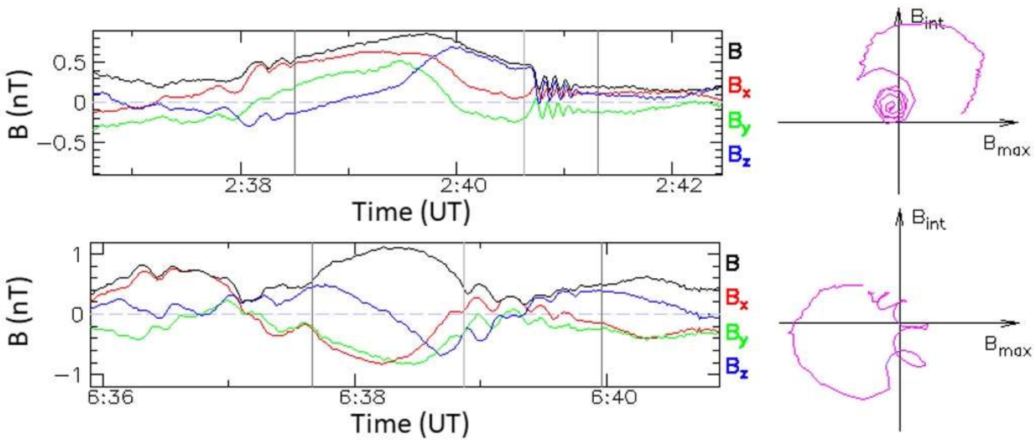
EVENT 2.

Magnetic field structure during a quasi-parallel bow shock crossing on DOY 042, 2005. The upper 3 panels shows the magnetic field data between ~7:45 and ~8:28 UT, with two whistler waves (yellow filled regions). The bottom two panels show evolved SLAM structures and another whistler detected at ~08:31 UT. The hodograms (in the (B_{int}, B_{max}) plane where B_{int} is the intermediate and B_{max} is the maximum variance direction component) on the right side inserts correspond to the detected whistlers.



WHISTLER WAVE OBSERVATIONS

In both cases circularly polarized waves and arising whistlers can be seen, as the polarization and the amplitude suddenly changes. We cannot transform the measurements into the plasma frame of reference, but the changes in polarization are clearly visible on the hodograms shown in the inserts on the right. The magnetic field data used here is in KSO. The results of the minimum variance analysis are summarized in the table.



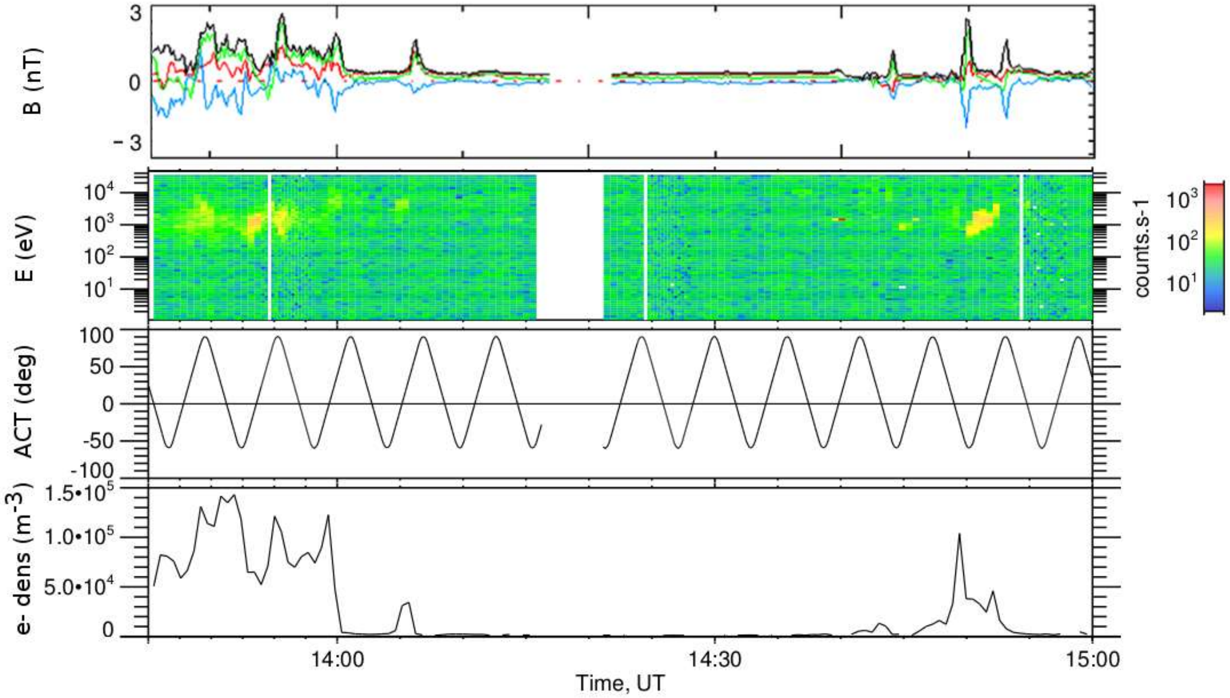
Two cases of whistler waves detected on DOY345/2004 (top) and DOY281/2005 (bottom) with the corresponding hodograms shown in the inserts on the right.

Year	DOY	Start time	Stop time	Max/min eigenvalue ratio	Max/int eigenvalue ratio	Number of 1 s vectors	Angle between wave and field vector
2005	42	7:47:58	7:49:24	11.8	9.0	87	47°±6.64°
2005	42	8:03:25	8:04:13	4.6	2.7	49	32°±16.73°
2005	42	8:30:31	8:32:39	2.9	2.2	129	31°±15.39°

The results of the minimum variance analysis for the selected time intervals.

EVENT 3.

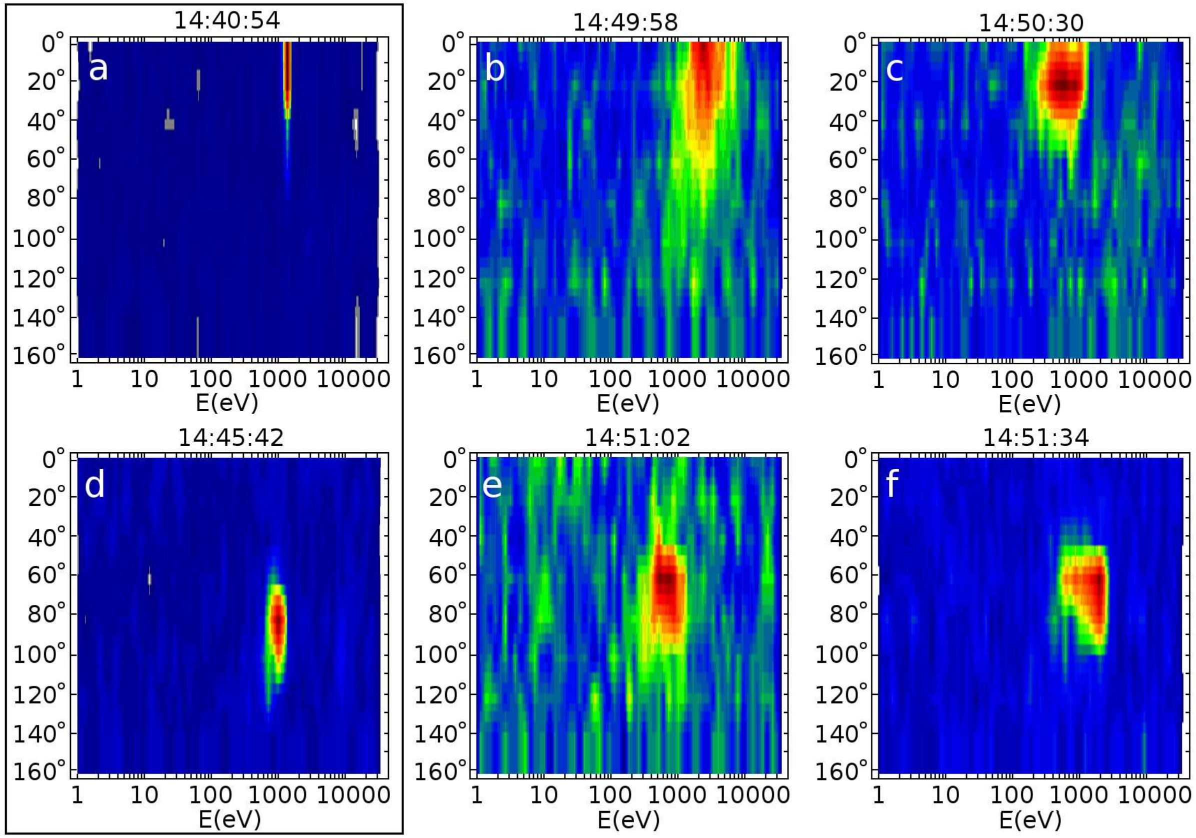
The third series of events occurred on October 6, 2005 (DOY 279) along Cassini's inbound trajectory, with four distinct solitary magnetic field enhancements (at ~14:06, 14:44, 14:50, 14:53), as shown in Figure 10.
Cassini crossed the bow shock (outbound) at ~14:00 at a distance from Saturn of approximately 39 RS.



Cassini Magnetometer (upper panel) and CAPS-ELS electron density data (bottom panel) for DOY 279, 2005 between ~13:50 and ~15:00 UTC. The red arrows mark the SLAM structures.

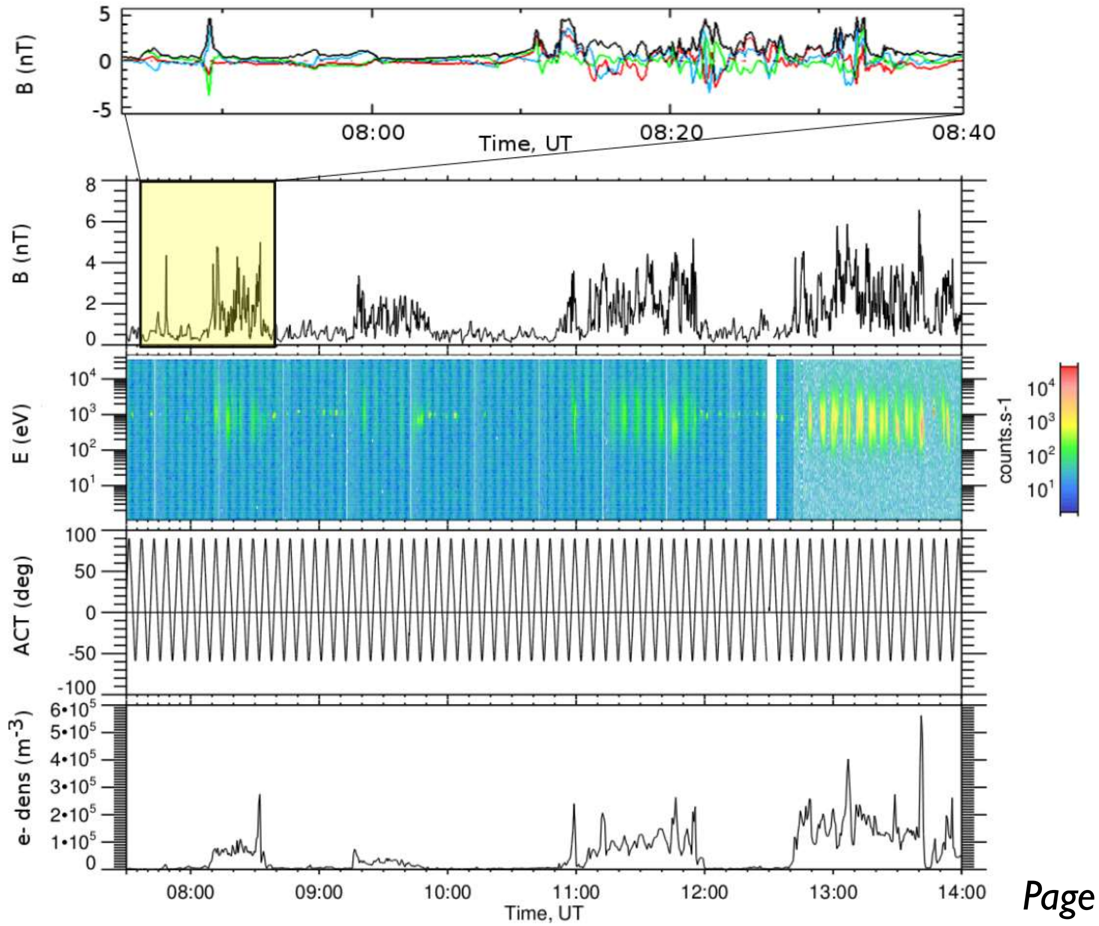
EVENT 3.

CAPS-IMS spectra for DOY 279. The framed spectra (a and d) correspond to the solar wind interaction with one of the magnetic structures, and a) is used as a reference for the undisturbed solar wind plasma distribution. Panels b), c), e) and f) were measured at and in between the two higher amplitude SLAM structures following 14:48 UTC.



EVENT 4.

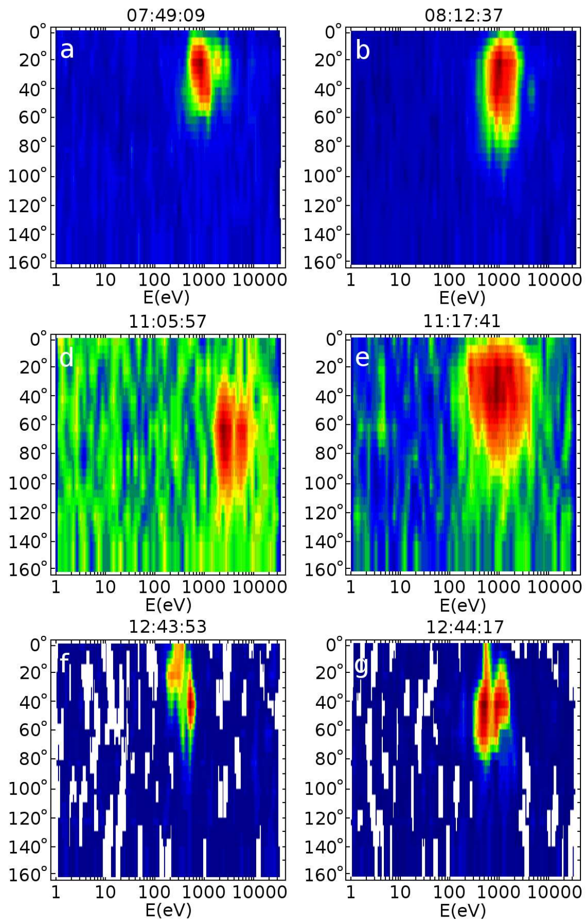
Magnetic field in RTN (top insert of a shorter time interval than the main figure section), magnetic field magnitude (second from top), CAPS-IMS Singles spectrum of Anode 5 (middle panel), Actuator angle in degrees (second from bottom) and electron density measured on October 8, 2005 along Cassini's inbound trajectory.



EVENT 4.

The same upstream region as Event 3, but further inbound, at a distance of 31 RS from Saturn.

The corresponding ion spectra shows beam deflection and plasma beam deceleration and plasma thermalization near the SLAM structures. Directional scattering is also observed. The solar wind velocity varied between ~390-420 km/s. Panel a) and b) shows the variation of solar wind protons as the spacecraft approaches the SLAMS. Panel e) was measured in the magnetosheath.



CAPS-IMS ion spectra measured during the series of quasi-parallel bow shock crossings on DOY281, 2005.

DISCUSSION

- The size of SLAMS scales with the ion gyroradii, which depends on the magnitude of the upstream magnetic field. It also determines the frequency of the ULF waves, from which SLAMS may arise. The foreshock ULF wave frequency increases for larger B, and it also depends on the IMF cone angle (decreasing for increasing angle value).
- From the one-point measurements of Cassini's plasma instruments it is neither possible to tell the exact location of the BS relative to the SLAMS, nor to observe their spatial structure. However, we found that the general characteristics of these structures and the particle populations measured in their direct vicinity match the features of the magnetic structures found at the Earth. We observed multiple proton populations with directional scattering, which implies particle acceleration and beam deflection.
- Due to the upstream conditions at Saturn (weak interplanetary magnetic field, lower solar wind density), its environment is very favorable to study the fine structure of the bow shock transitions, including the dynamic processes at the shock.

CONCLUSIONS

- The formation of SLAMS is possible upstream of Saturn through the same mechanism, like at the Earth. ULF wave formation can be observed near the bow shock, and in several instances the whistler precursor waves were also present.
- Although with Cassini it is not possible to analyze the spatial distribution of the observed magnetic structures, we can assume that their principal propagation mechanisms and steepening are similar to those observed in the terrestrial upstream regime.
- During most of the events the (locally) quasi-perpendicular behavior of the SLAMS fronts were verified as plasma heating, deceleration, and beam deflection at the structures were all observed. These features are common with the events previously observed in the terrestrial upstream region of the quasi-parallel regime. We can conclude that the SLAMS at Saturn exhibit the general signs of the structures detected at Earth.

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