Three Dimensional, Mass Resolved Ion Distributions Obtained from the TIMAS Instruments on POLAR

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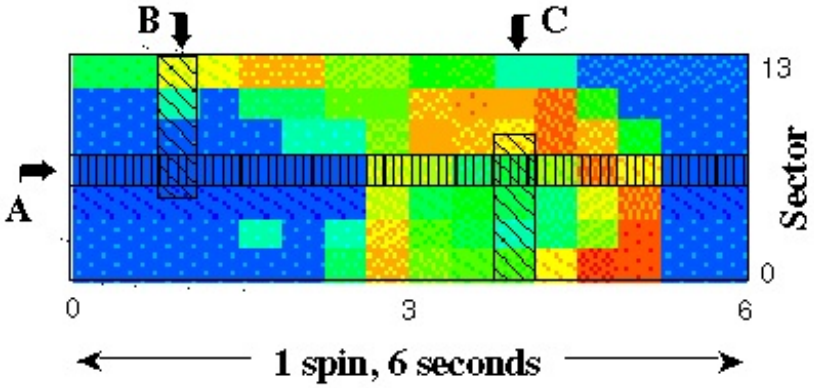
Each side of TIMAS is made up of a fan of detector sectors each of which behaves like a separate narrow angle ion mass spectrometer (e.g. EICS/DE-1). The central sector is about perpendicular to the spin axis and makes a full pitch angle scan in one spin of POLAR. The end sectors, 0 and 13, point close to the spin axis and so view pitch angles near 90*. When the fan of sectors intercepts the field line a high resolution, ~11*, pitch angle snapshot (PAD) is made. Adjacent detector sectors are summed to make the 3D distribution (MRDF) data products. Their resolution is ~22*. The diagram below displays MRDF data for one energy with detector sector vertically and spin sector (alias time) horizontally (Part of Fig. 6). The shaded strips indicate the relationship of the data used to make the velocity space distribution plots inFigs. 8and 13.

A: This strip is perpendicular to the spin axis and is used to make the plots in Fig. 8. (Figs. 7 and 9 are similar).



B and C: Pitch angle snapshots were taken at these points in the spin. B is looking in the geomagnetic field direction (upward / head) and C in the anti-field direction (downward / tail). These snapshots were used to make Fig. 13a.

On March 18, 1996 when POLAR was near perigee at 1.8Re and passing through the dayside southern cusp TIMAS observed H+ and O+ conics which increased and faded in intensity between 8:37:30 and 8:38:09. At the same time EFI detected a marked intensification of wave power. This intensification triggered the EFI burst mode.
TIMAS acquires full 3D ion distributions every spin (6 seconds), see Figs 6,7, 8,9, and snapshots of the pitch angle distribution about every 3 seconds, see Figs 13 and 14. This exccelent time resolution permitted the development of the conics to be tracked through this rather brief, 40 second, event and together with the high resolution wave data from EFI provided the opportunity to compare the ion heating with the available wave energy. The ion temperatures were measured every 3 seconds from the pitch angle snapshots and the temperature history of the ion conics is shown in Fig. 10. The E-field fluctuations were perpendicular to B as can be seen in Fig. 12. The spectral energy densities at the ions' gyrofrequencies (9Hz for O+ and 140Hz for H+) were used to estimate the ion heating rate via the electromagnetic ion cyclotron resonance mechanism described by Chang et al. (GRL, p636, 1986). It appears that the observed wave energy is sufficient to account for the conics' development.

- Figure 1 -POLAR orbit and footprint on March 18, 1996
- Figure 2 -Mass Spectra plot for March 18
- Figure 3 -Survey plots of energy spectra for H+, O+, He+, He++
- Figure 4 -Energy Spectra for H+ and O+
- Figure 5 -EFI/POLAR low frequency dynamic power spectrum
- Figure 6 -Three dimensional O+ distribution at the peak of the conic event
- Figure 7 -Velocity space distributions of H+ and O+ for one spin

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Chang et al. (GRL, p636, 1986) derived the perpendicular heating rate of ions via electromagnetic ion cyclotron resonance with left-hand polarized waves

$$W^* = q^2 * E / (2 m)$$

where W* is the ion heating rate, E is the spectral energy density at the ion gyrofrequency (fci) and * is the fraction which is left-hand polarized.

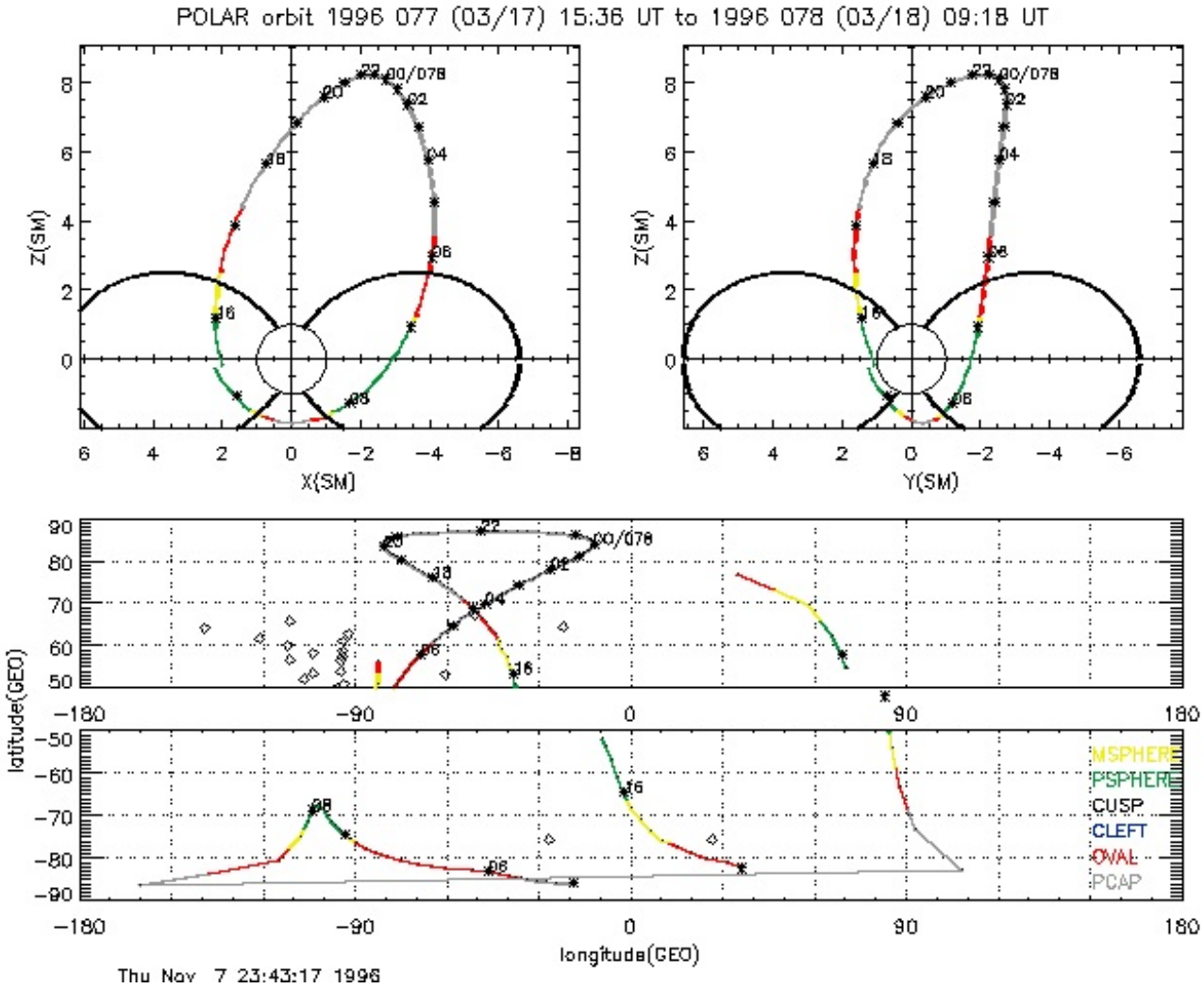
Assuming that the waves were fully left-hand polarized, *=1, the table gives the expected ion heating rates for the observed spectral energy densities for each ion.
(fcH * 140, fcO * 9).

	O+		H+	
Time Interval	**E**	**W***	**E**	**W***
8:37:45-51	100	460	4.0	300
8:37:51-57	50	230	1.0	74
8:37-8:39	11	51	1.1	81

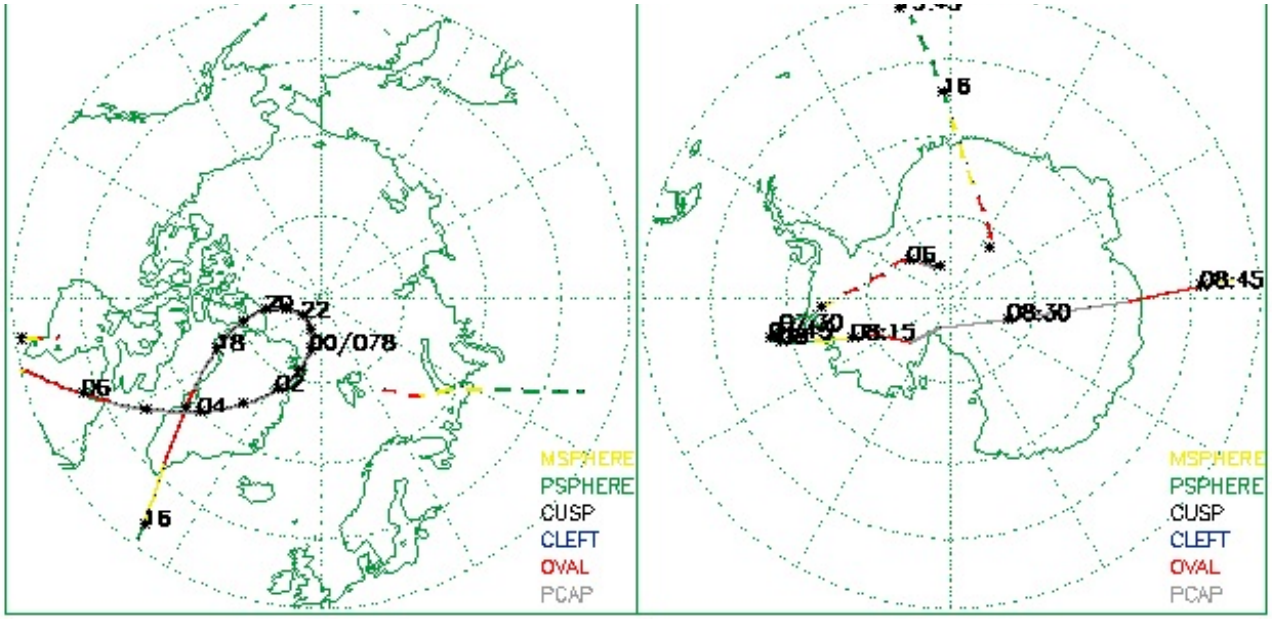
Figures

Figure 1

a.



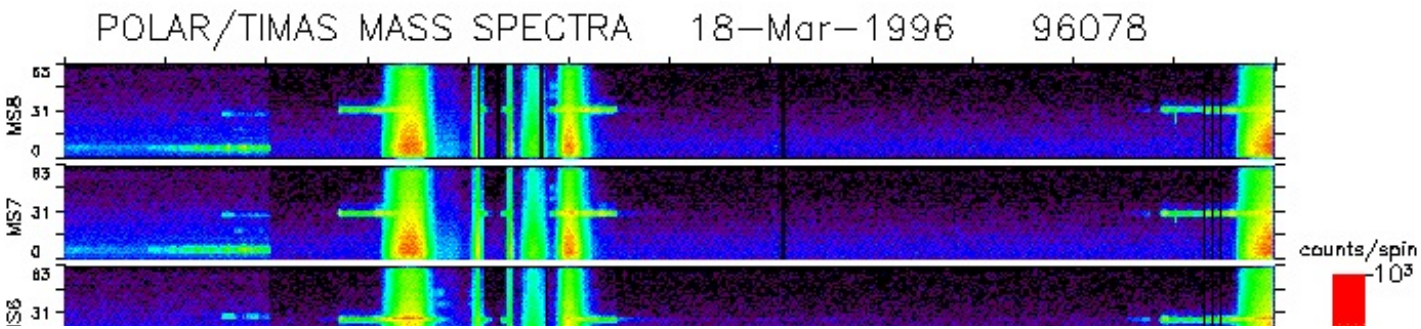
2.



Fri Nov 8 09:31:52 1996

Figure 1; POLAR orbit and footprint on March 18, 1996. Ion conics and intense wave activity were observed at 8:37:45 when POLAR was near perigee and passing through the southern cusp.

Figure 2



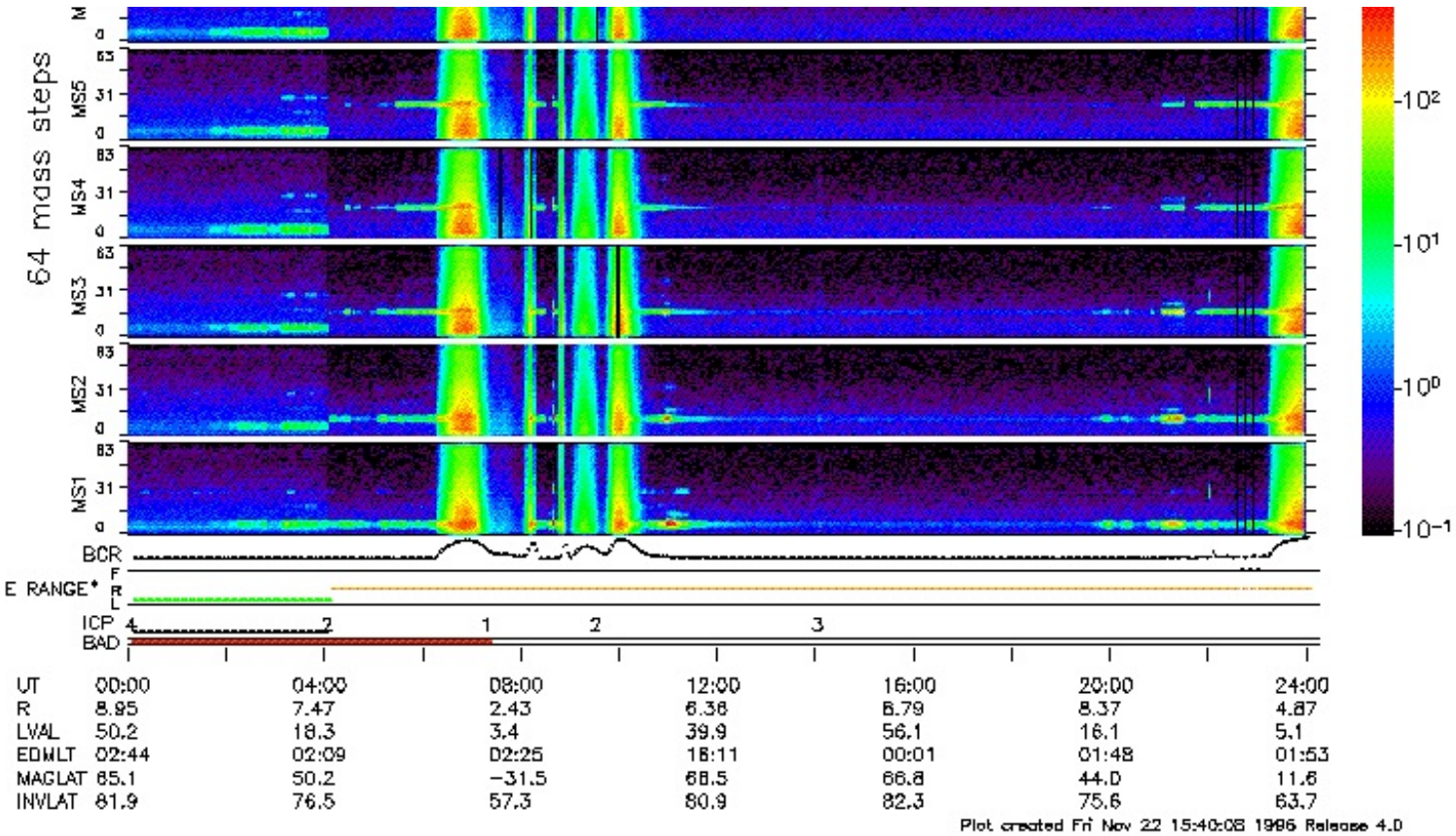
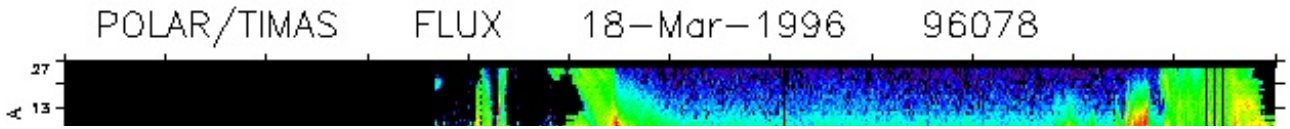


Figure 2; One day survey plot of mass spectra for 8 energies in the range 25eV to 32keV, lowest at bottom. The locations of the mass peaks vary with energy. Background from the radiation belts shows as vertical bands. The ion conic heating event occurred close to perigee at 8:37:45 indicated by the pointer.

Figure 3



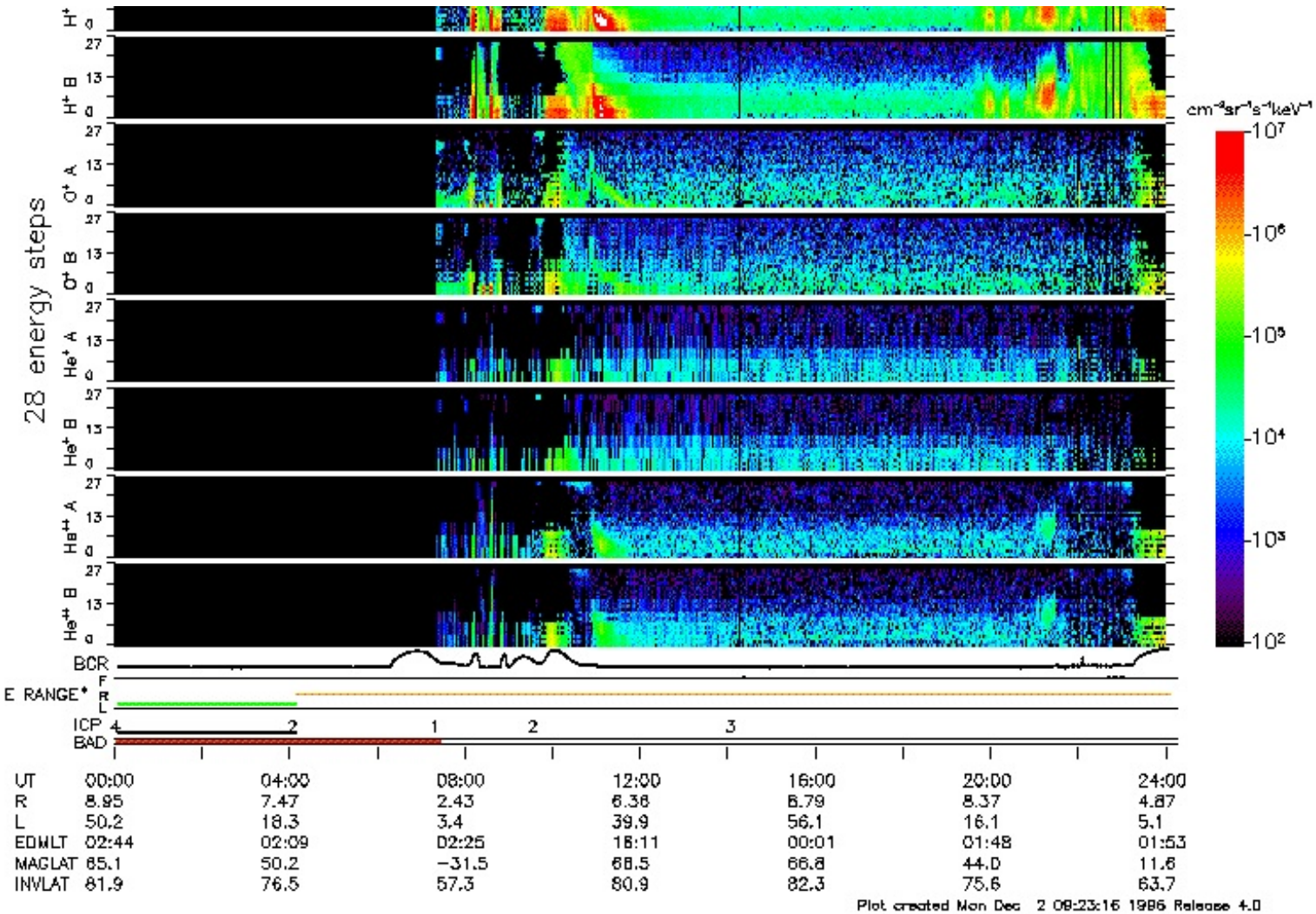


Figure 3; One day survey plot of energy spectra for H+, O+, He+ and He++ for each side (A and B) of TIMAS. Background has been subtracted. The ion conic heating event occurred close to perigee at 8:37:45 indicated by the pointer. This plot was constructed from three dimensional distribution function data products, mainly MRDF, averaged over 192 seconds (32 spins).

Figure 4

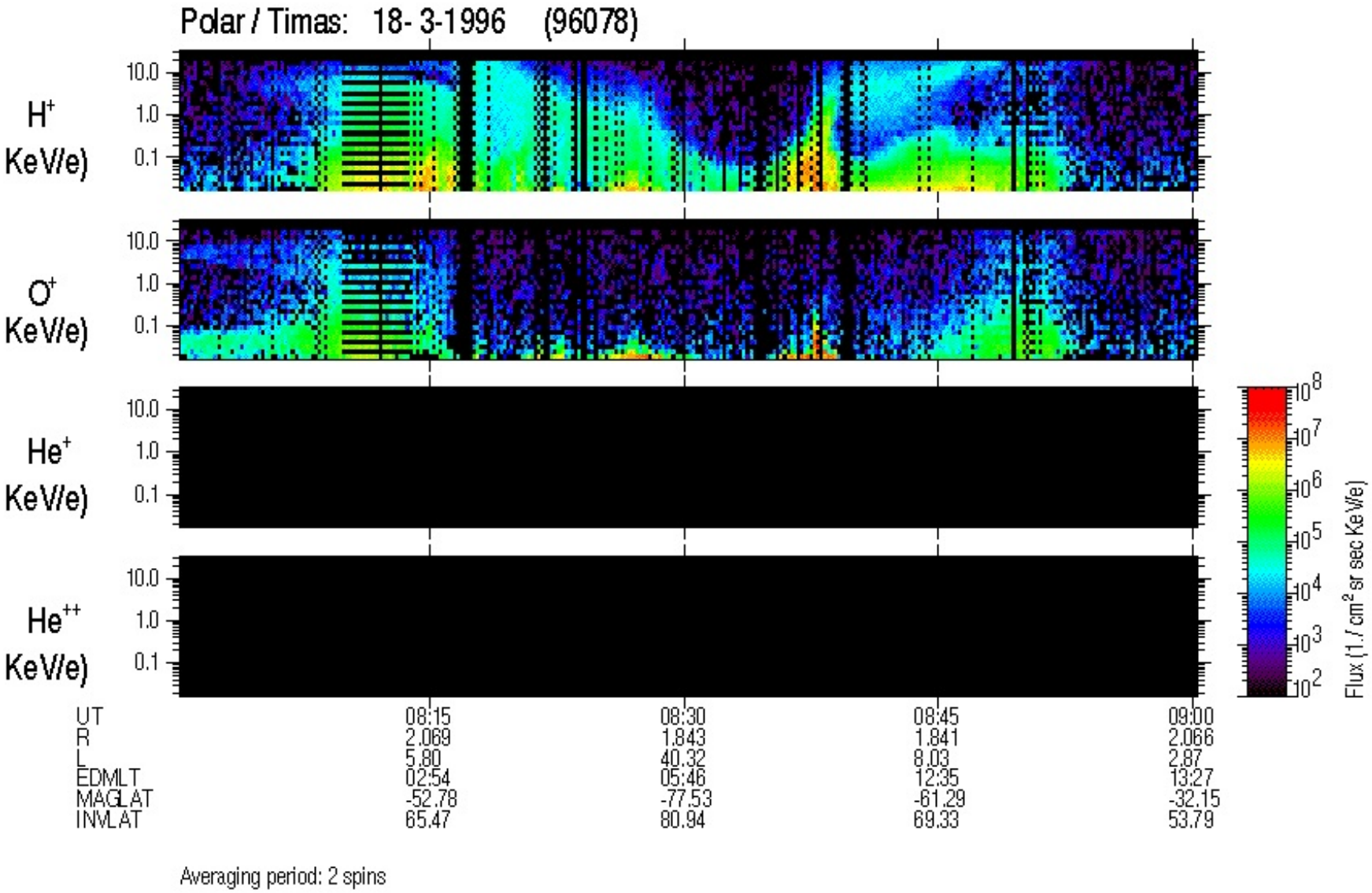


Figure 4; Energy spectra for H+ and O+ for one hour around the time of the conic heating event. This plot was constructed from three dimensional distribution function data products (MRDF) averaged over 12 seconds (2 spins). Black stripes or checkerboard correspond to spins when these data products were not available. The ion conic heating event occurred in both H+ and O+ around 8:37:45, indicated by the pointer.

Figure 5

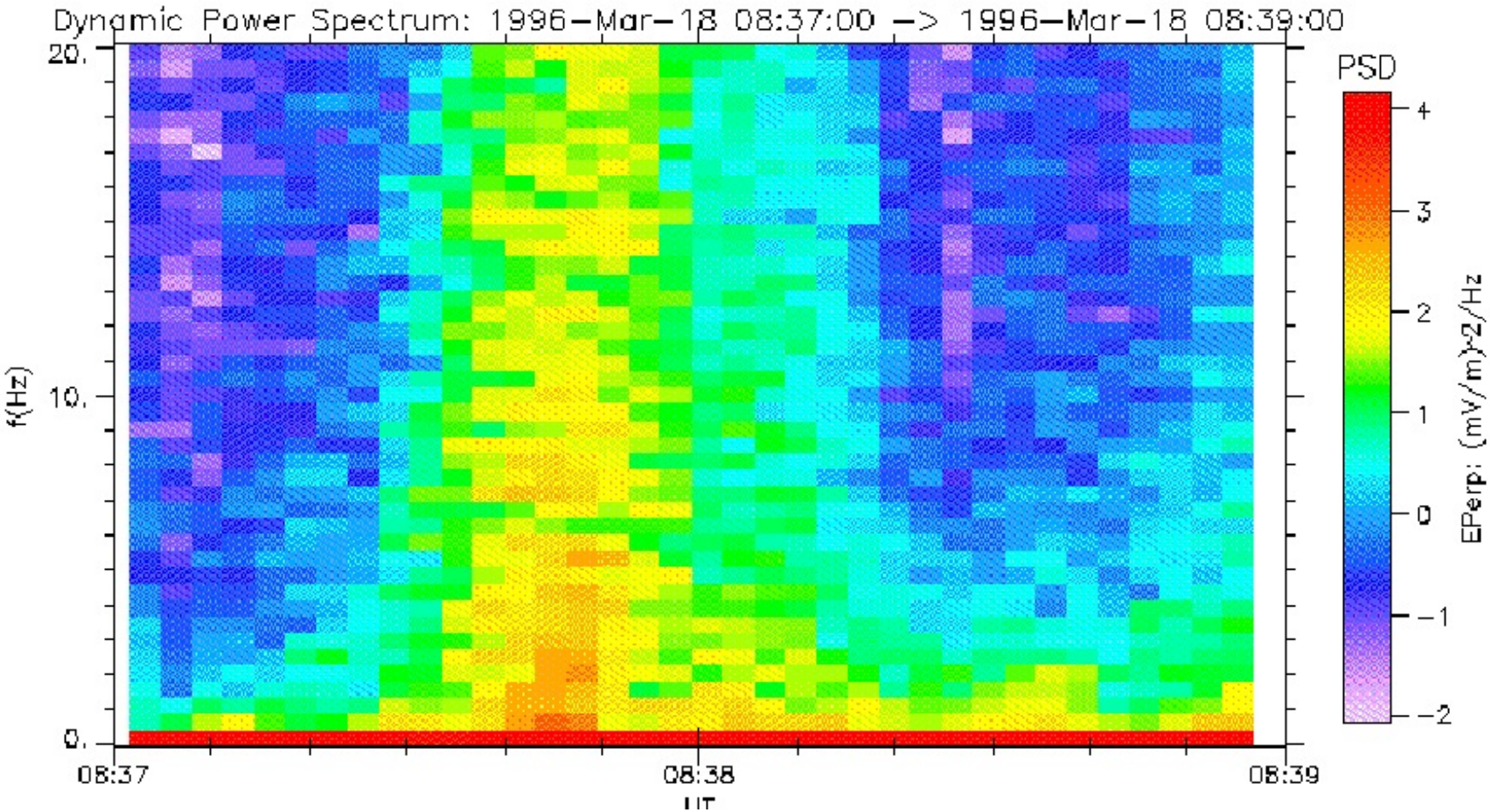
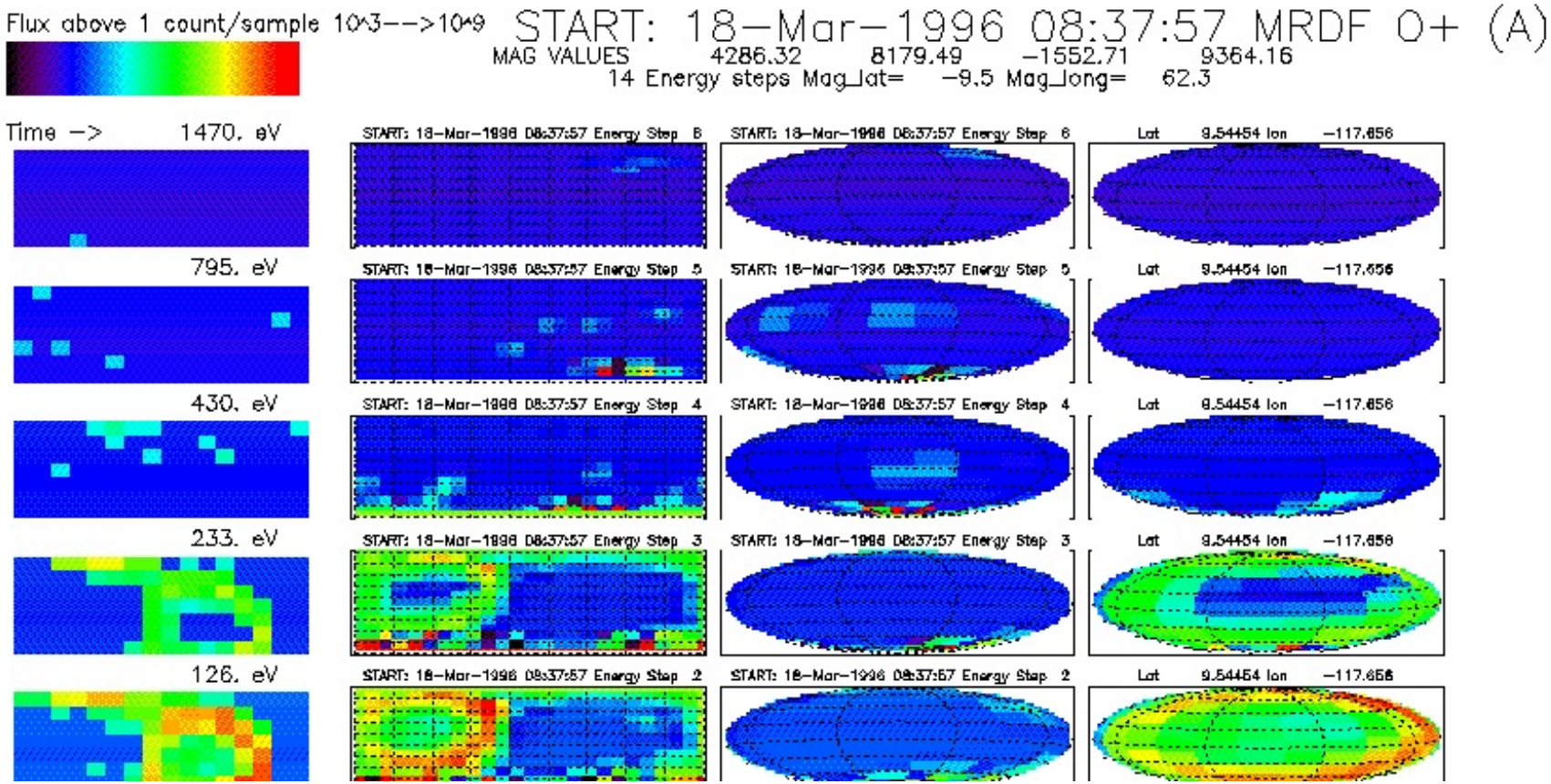


Figure 5; EFI/POLAR low frequency dynamic power spectrum for 8:36 to 8:38. A marked intensification of wave power occurred at the time of the ion conic heating event. The intensification spans the O+ gyrofrequency of about 9Hz. The power spectrum during the intensification is shown in Fig 11 at a higher time resolution and for a wider frequency range.

Figure 6



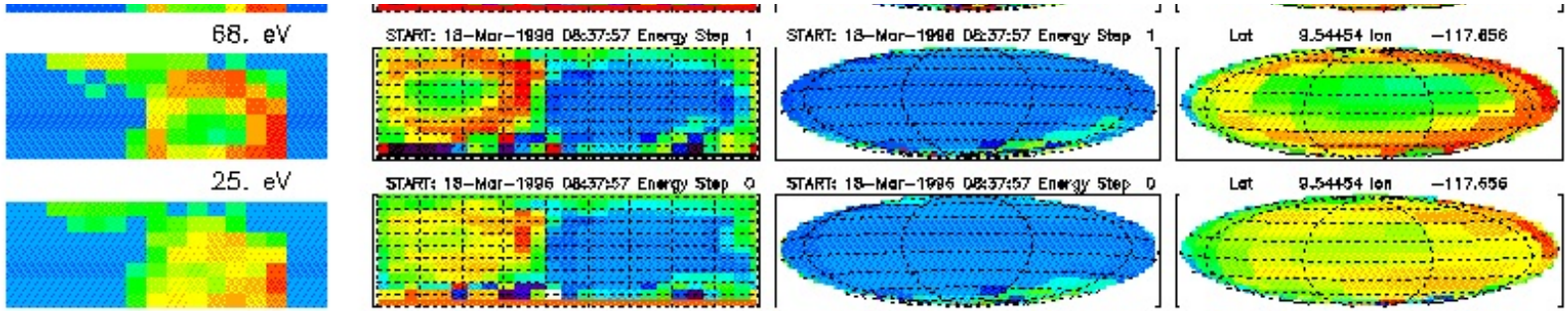
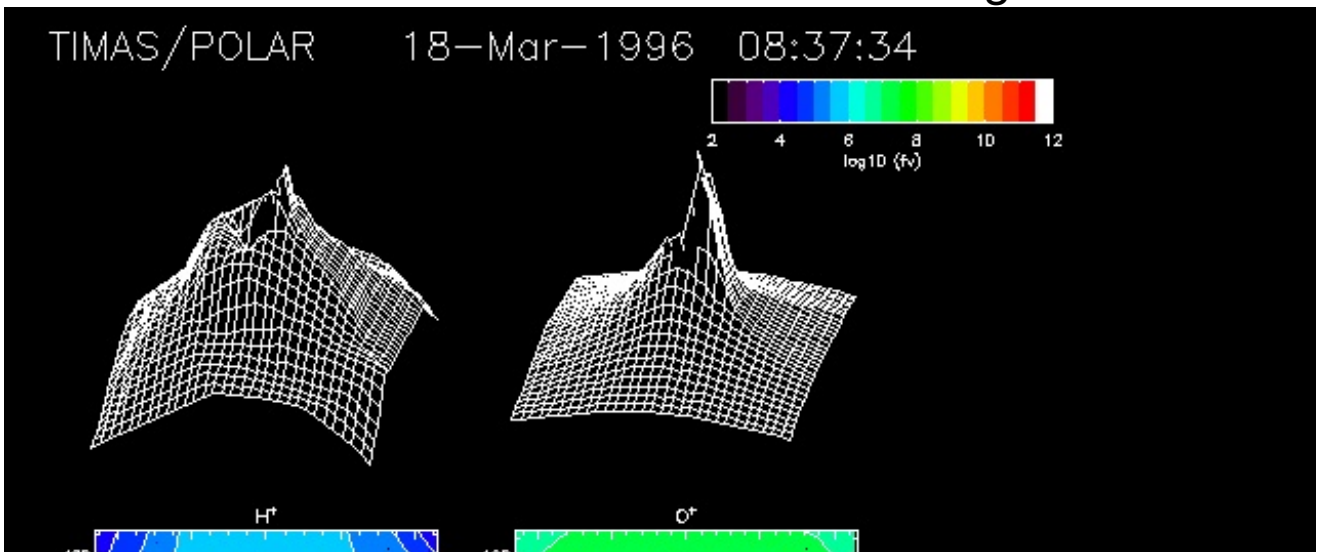


Figure 6; Three dimensional O+ distribution at the peak of the conic event. Rows are different energies in the range 25eV to 1.5keV. Left hand column is MRDF data with detector sector vertically and spin sector (alias time) horizontally. The center detector sector scans close to the field line and was used to construct the contour plots in Fig. 8. The end sectors are aligned close to the spin axis and always view pitch angles near 90°. The conic shows as a bright circle at the lower energies. In the second column the data has been mapped with spin axis vertically and spin phase horizontally. In the two right hand columns the data has been mapped onto a sphere which in the third column is viewed looking in the +B direction (at downward moving ions) and in the fourth column is viewed in the -B direction (at upward moving ions). The dotted ellipses represent 30° and 60° pitch angles. The upward moving conic shows at the lower energies between pitch angles of 60° and 90°.

Figure 7



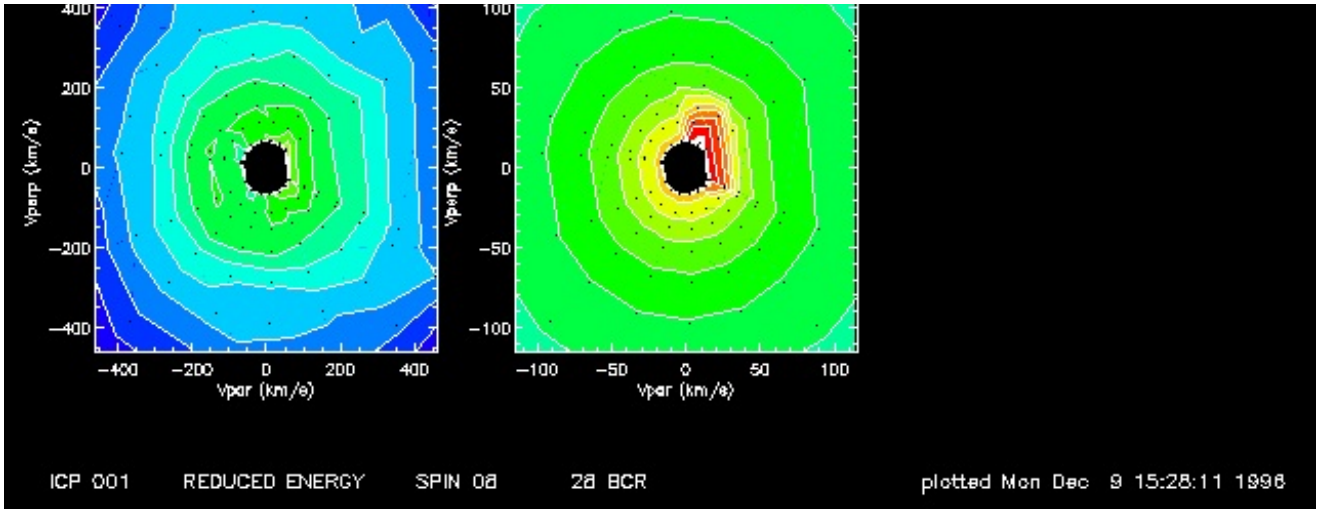
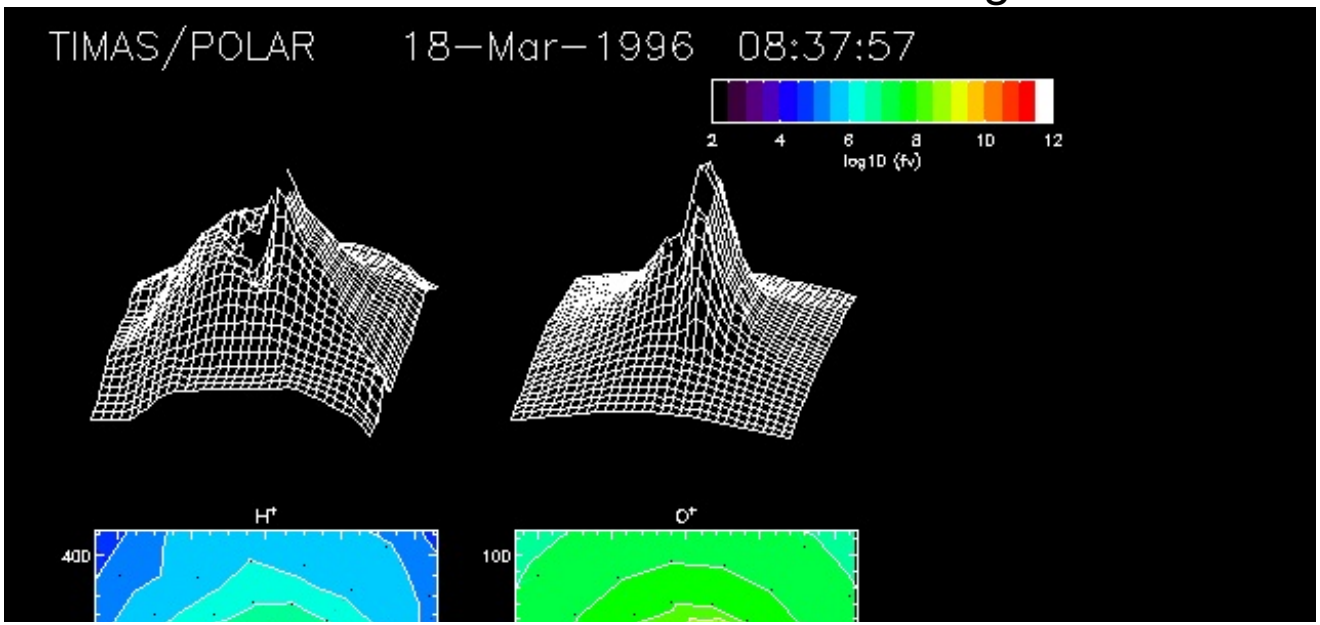


Figure 7; Velocity space distributions of H+ and O+ for one spin, 6 seconds, starting at 8:37:34. At this time the conic is just beginning to develop in H+ and is already quite well developed in O+. This plot was constructed using MRDF data from the center detector sector only and represents a slice through the full 3D distribution obtained by TIMAS. The velocity range has been reduced to a quarter of the full range of TIMAS in order to emphasize the conic. The O+ distribution protrudes through a surface equivalent to one count / sample while the H+ distribution includes an isotropic component which at these velocities is rather higher than one count / sample.

Figure 8



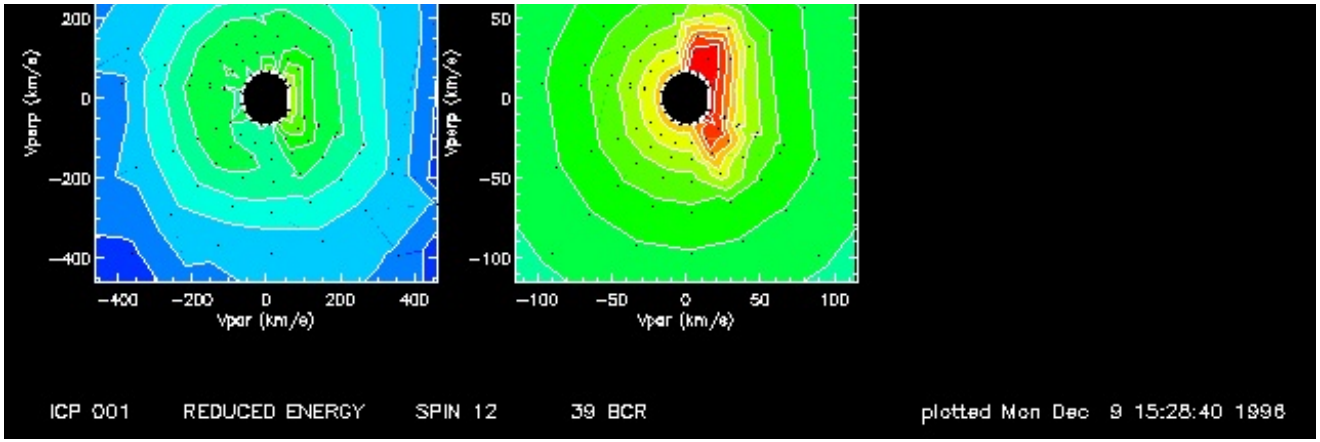


Figure 8; Similar to Fig 7, but for 8:37:57 when both H+ and O+ conics are fully developed.

Figure 9

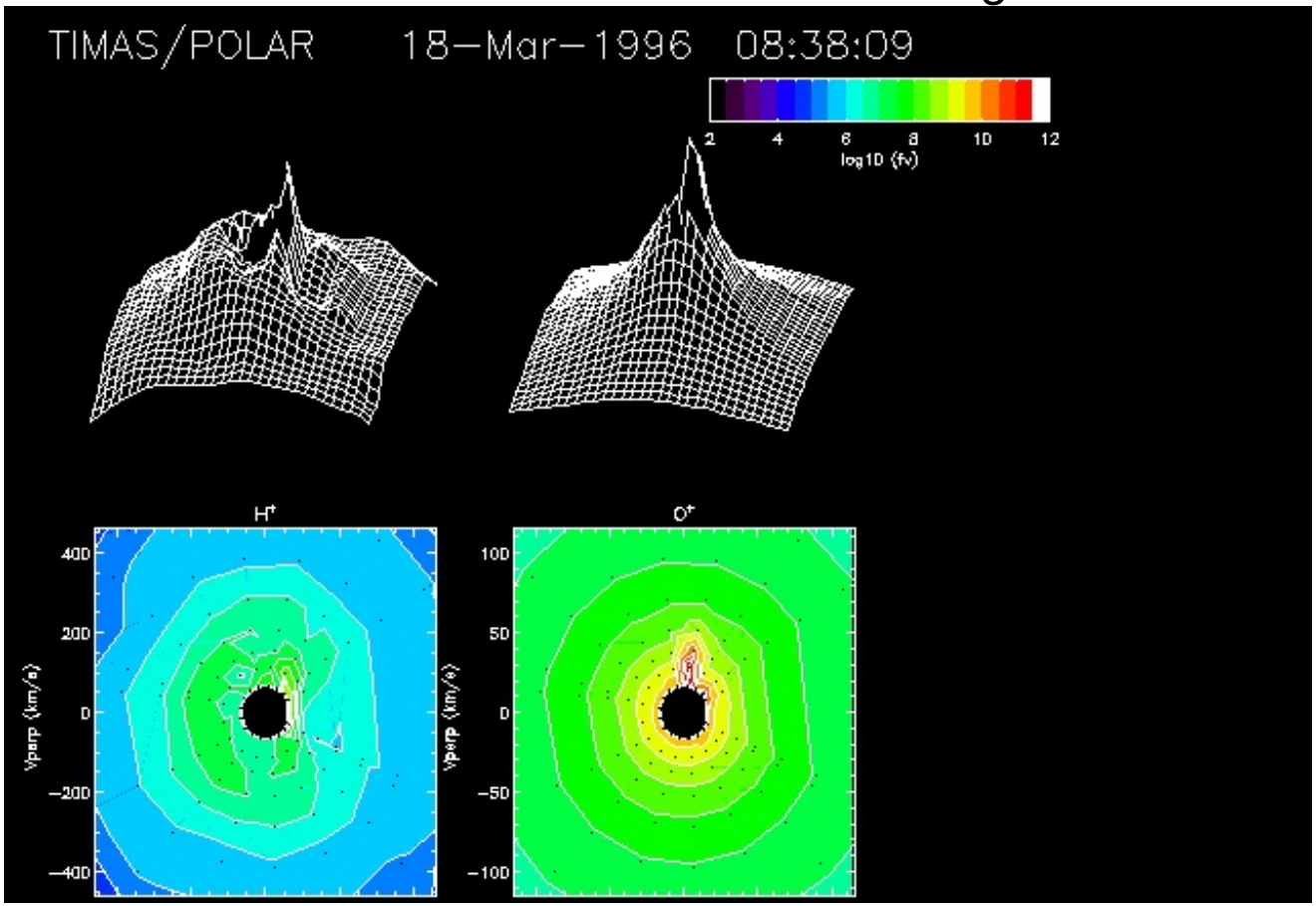


Figure 9; Similar to Fig 7, but for 8:38:09. By this time both H+ and O+ conics are decaying.

Figure 10

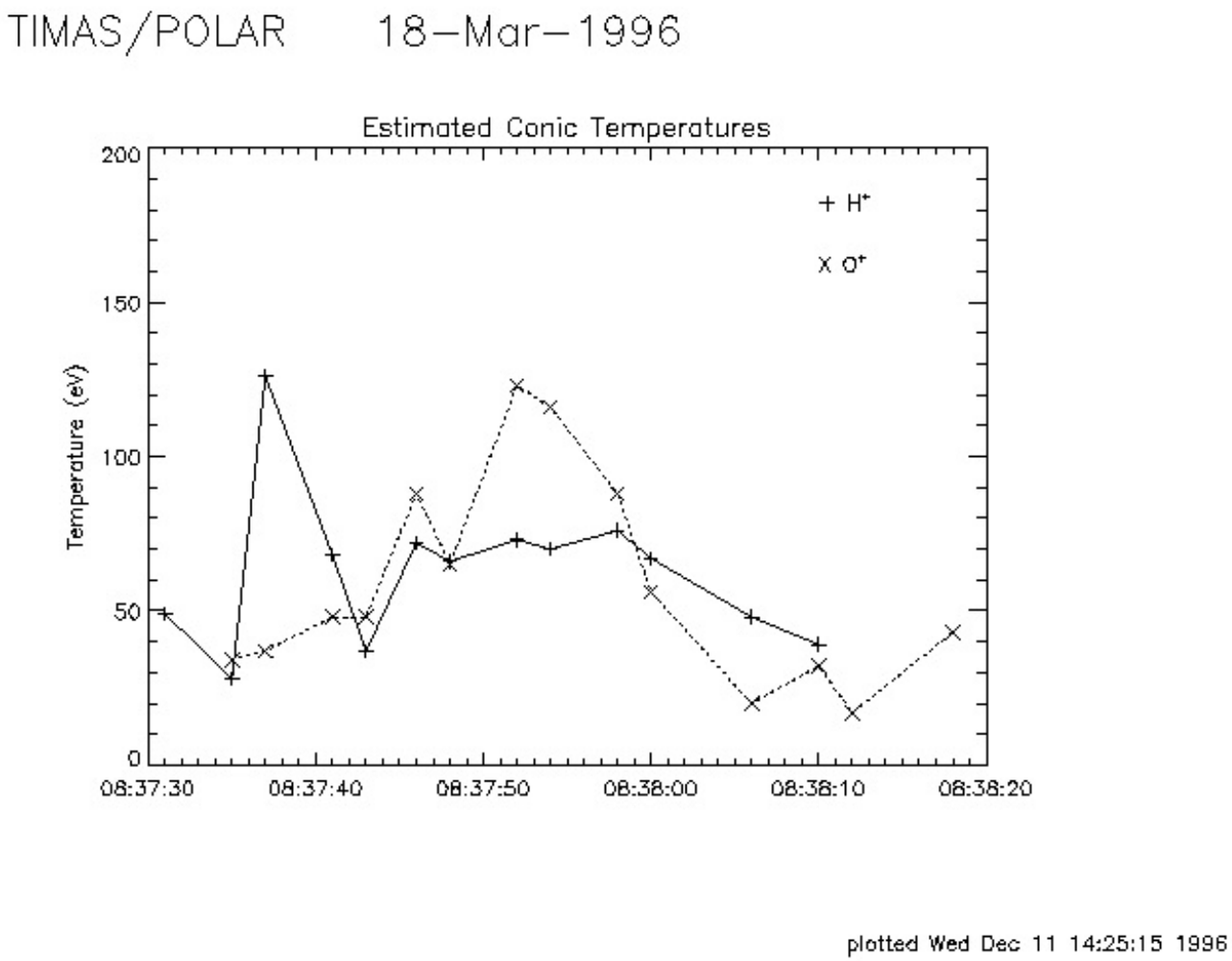
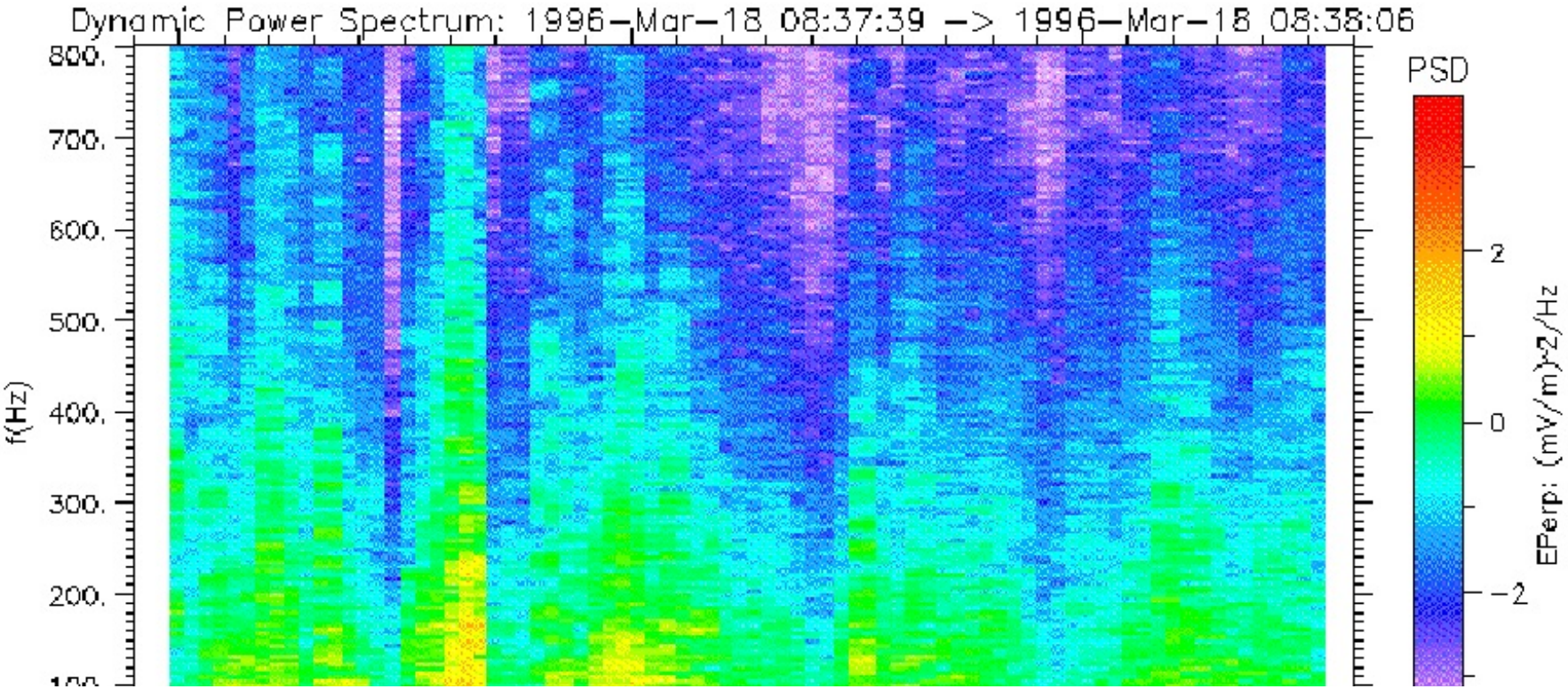


Figure 10; Time history of the temperatures of the H+ and O+ conics. Temperatures were estimated from the pitch angle snapshots (PADs) by visually identifying the appropriate pitch angle and velocity range and then automatically (IDL) interpolating the density / velocity profile and determining the temperature from the slope. (See Figs. 13 and 14) The upper markers indicate the approximate times of the contour plots in Figs. 7, 8 and 9. The lower marker indicates the time of the EFI/POLAR dynamic power spectrum in Fig. 11.

Figure 11



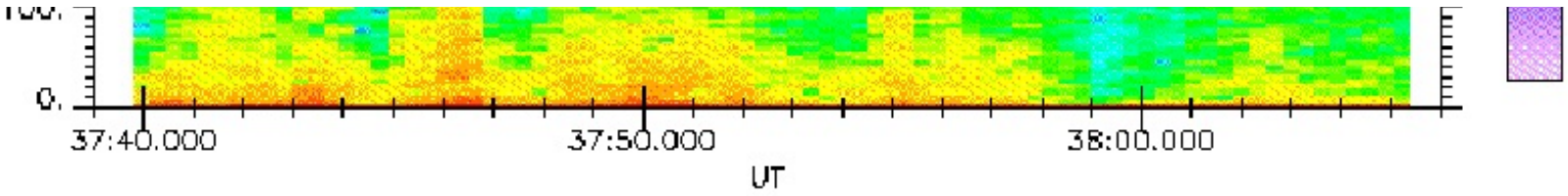
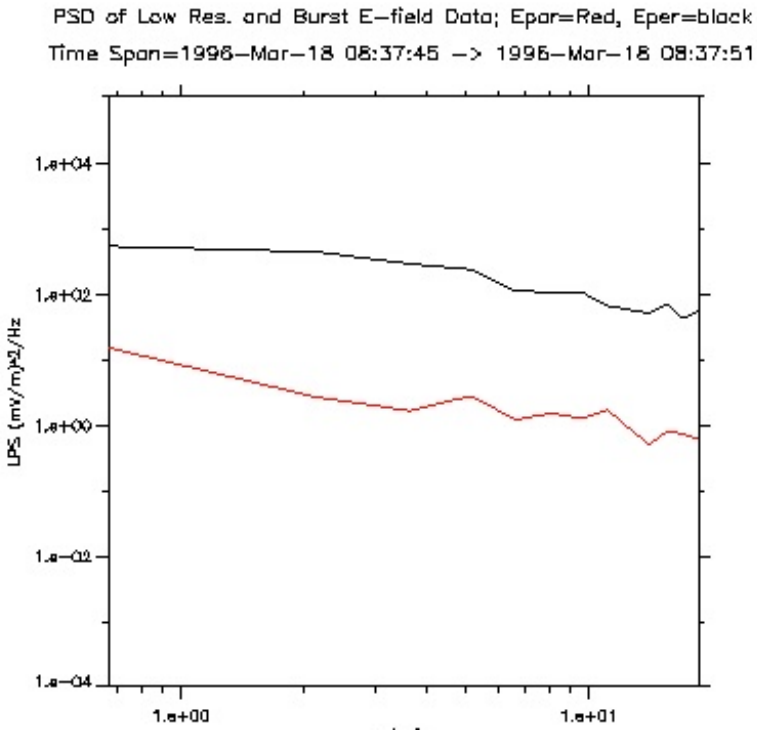
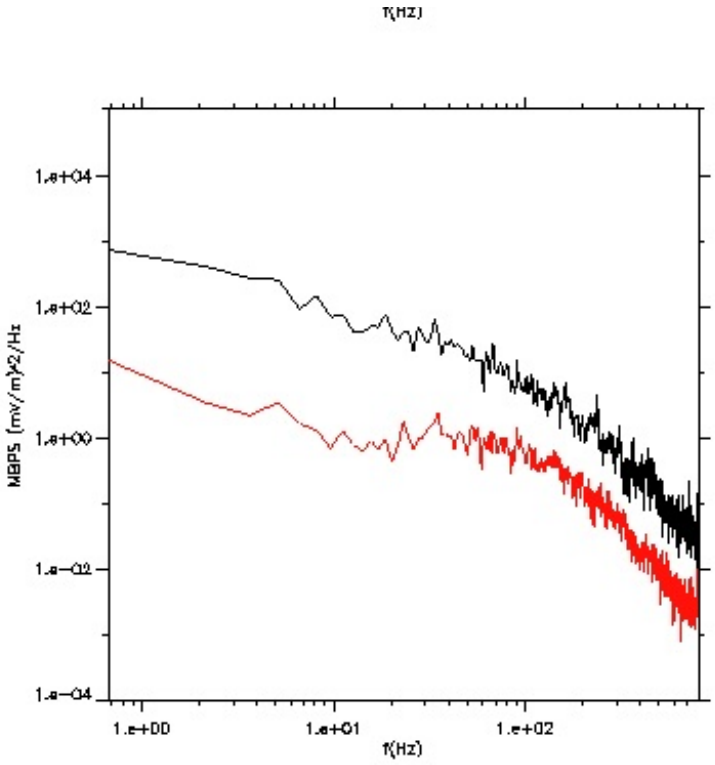


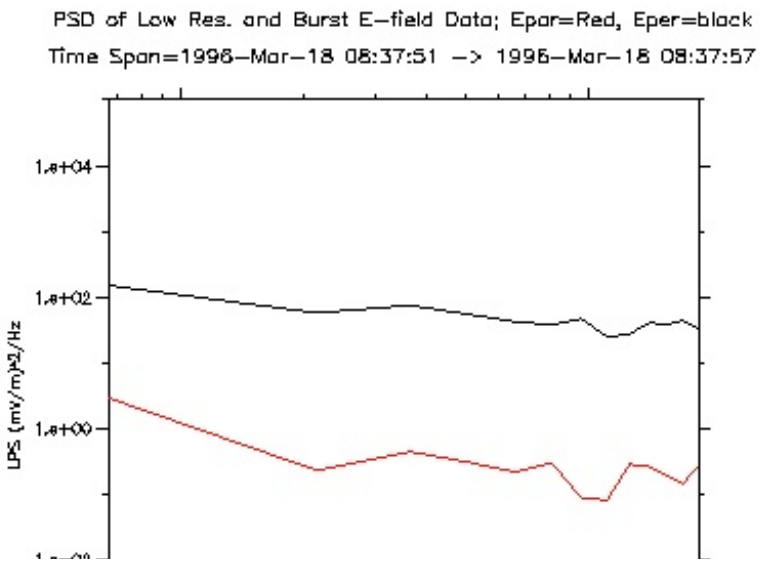
Figure 11; EFI/POLAR low frequency dynamic power spectrum for 8:37:40 to 8:38:06 during the marked intensification of wave power which occurred at the time of the ion conic heating event. The intensification spans the O+ gyrofrequency of about 9Hz and reaches the H+ gyrofrequency of about 140Hz. The power spectrum was very much weaker both before and after this event, Fig 5.

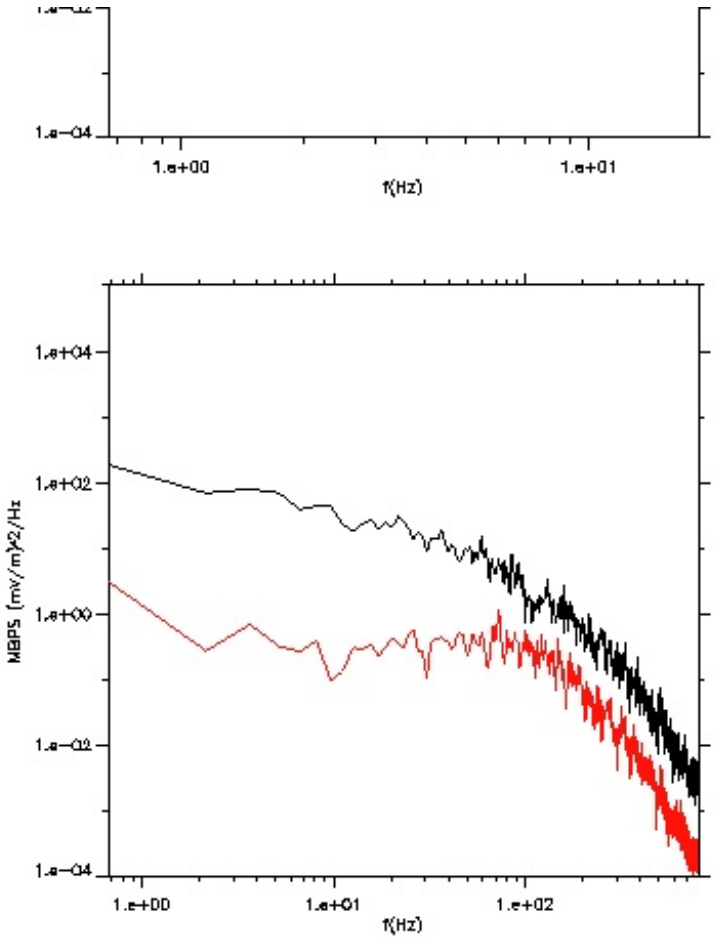
Figure 12





a.



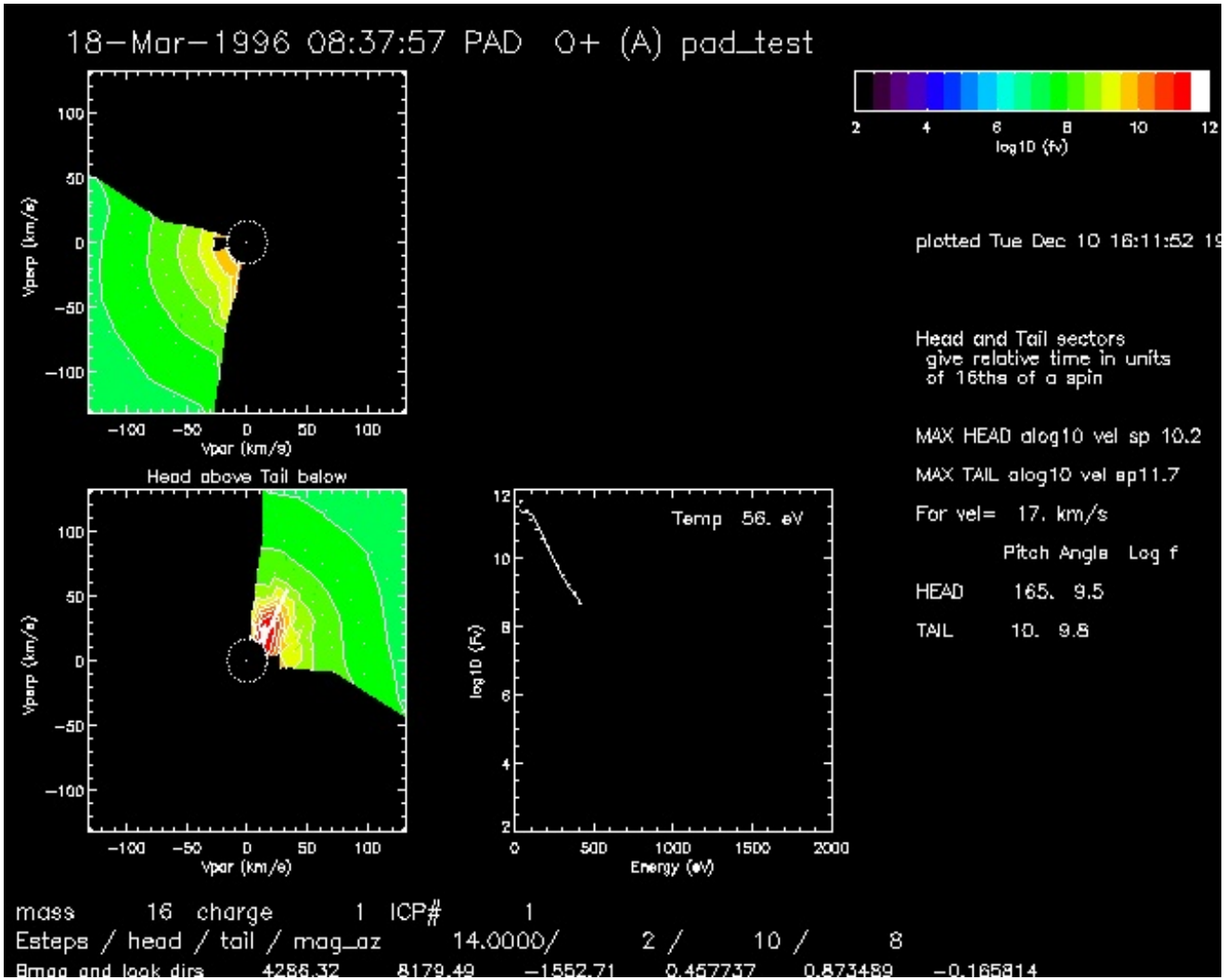


2.

Figure 12; EFI/POLAR power spectral density for one spin, 8:37:45 to 8:37:51. The upper plot covers the frequency range 0.6 to 18Hz and the lower plot extends the range to 800Hz.

Figure 13

a.



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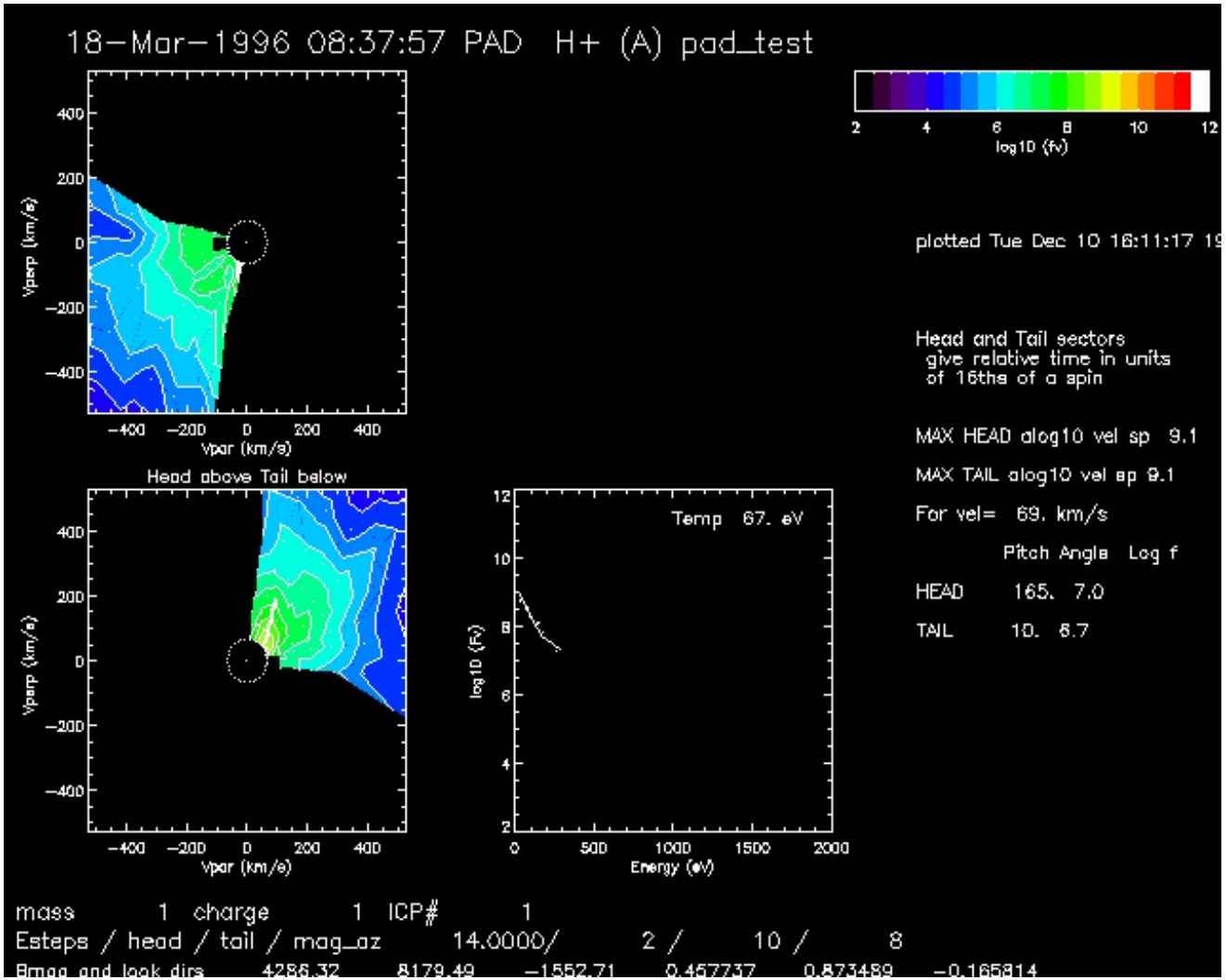

Figure 13; Pitch angle snapshots and temperature measurement. O+ in Fig 13a and of H+ in Fig 13b. On the left are partial velocity space distributions constructed from pitch angle snapshots taken near the peak of the conic heating event, during the spin which started at 8:37:57 (the same time as in Fig 8). The upward looking (head) and downward looking (tail) snapshots each contribute a different segment of the distribution. Temperatures were estimated from the downward looking snapshots by visually identifying the appropriate pitch angle and velocity range and then automatically (IDL) interpolating the density / velocity profile and determining the temperature from the slope. The position of the chosen profile is marked on the contour plot and the profile (solid line) and fitted distribution (dotted line) are plotted at the right.

Figure 14

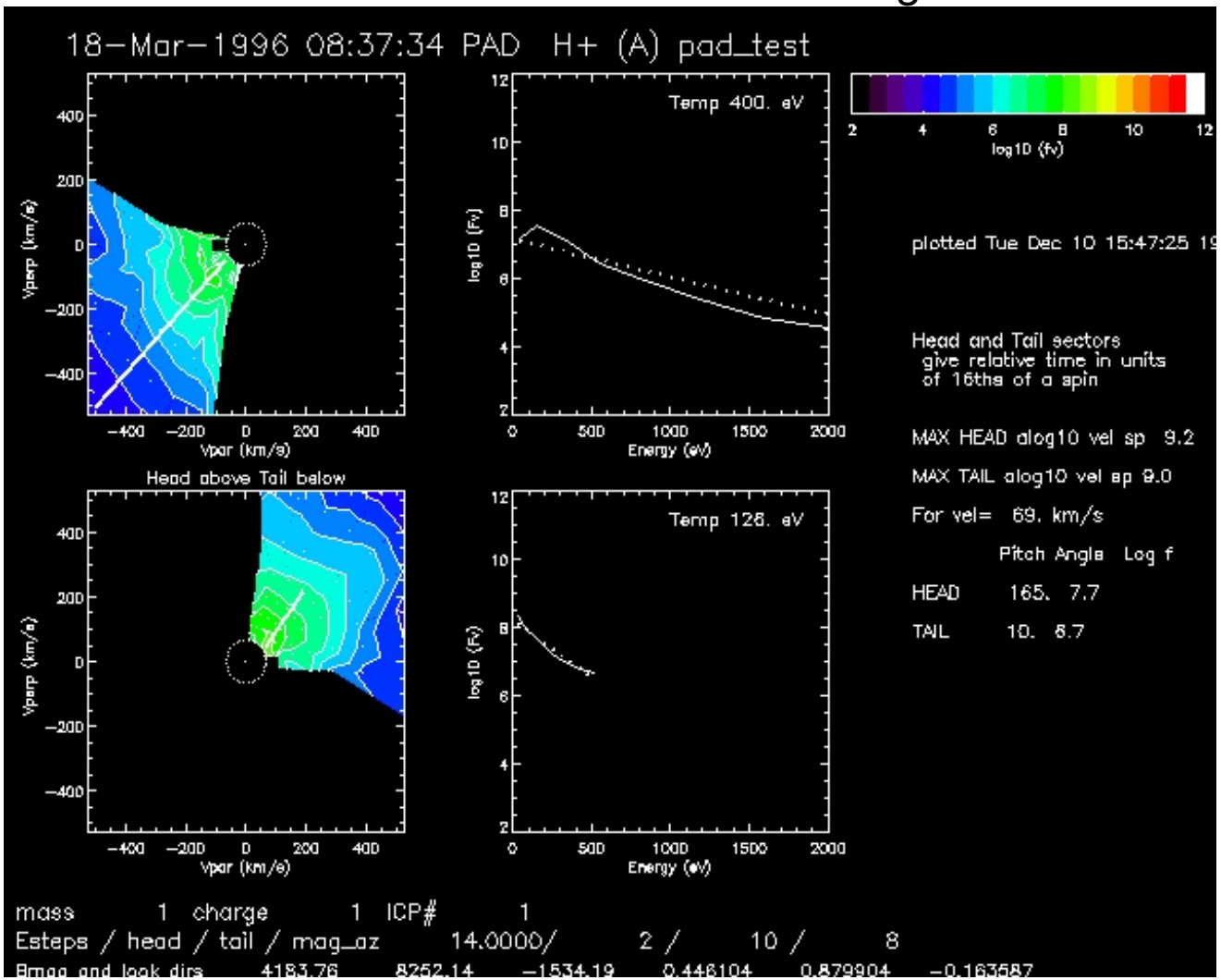

Figure 14; Similar to Fig 13b. An attempted temperature measurement of a weak H+ conic with an isotropic component also present. This data was acquired towards the beginning of the event during the spin starting at 8:37:34, Fig 7. At this time the H+ conic was too weak to be distinguished clearly from the isotropic component and the density / velocity profile used to estimate temperature was contaminated by the isotropic component resulting in an overestimate of the conic's temperature.