

Charge neutrality and ion conic distributions at the equatorward electron edge of the mid-altitude cusp

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Abstract. We have investigated the physical processes occurring in order to maintain charge neutrality at the equatorward edge of the cusp by examining data from 200 POLAR cusp crossings. The significant differences in magnetosheath ion and electron velocities could potentially create a region at the equatorward edge of the cusp where only solar wind electrons have access. Although our calculations suggest that POLAR should encounter this region at least 5 minutes before the first solar wind ions are observed, we have only identified six cusp crossings where a clear separate electron edge is seen. We then used state-of-the-art plasma instruments on POLAR to examine in detail features at the separate electron and ion edges. We find evidence that in the electron only region, electrons have been retarded by an electric potential above the spacecraft, and discuss the validity of examining electron spectra for evidence of retarding potentials. We also find that ionospheric ion conic distributions are frequently seen in these regions. We establish that H^+ and He^+ conics undergo two distinct acceleration processes. An initial acceleration in the 'electron only' region is followed by further acceleration later when the first mirrored solar wind ions return to POLAR from low altitudes. O^+ ions do not appear to be energised by the same process as the H^+ and He^+ ions. The conic distributions which we observe are not a steady feature but disappear and reappear on time scales of 1.5sec or less. Low frequency electromagnetic waves are observed at similar times to the ion conic distributions, and also exhibit a pulsed nature. However, there does not appear to be a detailed correlation between wave and particle observations.

Introduction

In the open magnetosphere model [Dungey, 1961], solar wind plasma enters the magnetosphere through reconnection. For southward interplanetary magnetic field (IMF), the combination of low latitude reconnection, large scale poleward convection, and finite and distinctly different velocities of solar wind plasma constituents give rise to the velocity filter effect [Rosenbauer, 1975]. The significant differences in ion and electron velocities could potentially create a region at the equatorward edge of the cusp where only solar wind electrons have access, as has been observed in the low latitude boundary layer [Gosling *et al.*, 1990]. A survey of 200 POLAR cusp crossings reveals only six events where a separate electron only region is observed. This region is not generally observed for several possible reasons, including unclear cusp boundaries, non steady convection and electrostatic forces constraining magnetosheath electrons to follow the motion of the much heavier ions.

When electrons and ions travel along field lines away from a reconnection site towards the earth, the electrons' ability to travel ahead of the ions due to faster electron velocities, may be restricted due to the plasma's general need to maintain charge neutrality [e.g. Reiff *et al.*, 1977; Burch, 1985]. Any variations from neutrality can only take place at frequencies higher than the electron plasma frequency ($\sim 10\text{kHz}$), or on length scales smaller than the Debye length ($\sim 10\text{m}$). Spacecraft are therefore unlikely to directly observe the mechanisms for maintaining charge neutrality in the plasma, but may measure the secondary effects of these mechanisms. The role of the background plasma in maintaining charge neutrality must not be overlooked, but it is generally at such low energies as to be undetectable by spacecraft instruments.

In this paper we use state-of-the-art plasma instruments on POLAR to examine in detail two cusp crossings where a clear 'solar wind electron only' region is present. Particle data reveals evidence of parallel retardation of electrons and both perpendicular and parallel acceleration of ions in this region. The presence of perpendicularly accelerated ions at the equatorward edge of the low

altitude cusp has been reported by various authors [e.g. *Andre et al.*, 1988; *Dubouloz et al.*, 1998]. Recently, higher altitude cusp crossings by POLAR [*Huddleston et al.*, 2000] have observed toroidal distributions. Whilst our survey reveals ion conic distributions are common at high latitudes in the noon sector at POLAR's high altitude, our detailed analysis of the two events in this paper reveals distinct regions of perpendicular ion acceleration related to the 'electron only' region at the equatorward edge of the cusp.

The most frequently cited method of transverse ion acceleration is due to wave-particle interactions and the presence of various waves at the equatorward edge of the cusp have also been reported [e.g. *Klumppar*, 1986; *Andre et al.*, 1998]. We find that the heating of H^+ and O^+ conics at POLAR's altitude are not correlated. H^+ conics appear shortly after the first solar wind electrons appear at POLAR, in the region before the first solar wind ions arrive. These H^+ conics then undergo a second energisation process shortly after the first mirrored solar wind ions arrive back at POLAR from low altitudes. In contrast, O^+ conics are only seen in one of the events presented, are present before the first solar wind electrons arrive, and do not undergo any energisation until the first solar wind ions arrive from above POLAR.

The two events that we present here show similar features in both the particle and wave data and we therefore choose not to show the full data sets for each event. Instead, we concentrate on electron data and parallel electric fields in the first event, and then focus on perpendicularly accelerated ions and wave activity in the second event. Although our observations come from two special noon sector events where clear separate electron and ion equatorward edges are observed, we believe the processes that we examine are typical in the high altitude cusp during periods of southward IMF.

Results – 4th May 1997

On the 4th May 1997, from 08:50 to 11:00 UT, POLAR flew polewards through the northern hemisphere polar cusp at 7.5 – 8.6 R_e altitude, with a magnetic local time range of 12:14 to 14:30. Proton and electron spectrograms from the TIMAS [*Shelley et al.*, 1995] and HYDRA [*Scudder et al.*, 1995] instruments are shown in plate 1. Before 08:50, high and low energy

trapped magnetospheric protons are seen, along with similar electron populations. The transition from closed to open field lines for electrons, occurs at 08:50.30, followed by the appearance of an enhanced flux of low energy protons with upper energies of 300 eV. After a brief initial encounter at 08:54:00, a higher energy population of protons appears at 08:55:00, at an energy of 2 to 8 keV which is at the top end of the solar wind thermal distribution. The low energy population continues to be visible until 09:00.00 by which time solar wind ions at the peak of the distribution are being detected.

Panels 1 to 4 in plate 2 show high resolution (8 samples/sec) residual magnetic field data (with the T96 model magnetic field subtracted [Tsyganenko, 1996]) from the MFE instrument [Russell *et al.*, 1995] at the equatorward edge of the cusp from 08:49 to 09:04. Panels 5 to 8 show TIMAS H⁺ and O⁺ energy and pitch angle spectrograms. The banding in H⁺ pitch angle spectra is an artifact of ground data processing which does not correctly normalise pitch angle spectra in intervals with data from only one of two sets of interleaved energy bins. The TIMAS instrument acquires data in two interleaved sets of energy bins on alternate spins, and due to limited telemetry bandwidth is sometimes unable to transmit both distributions. A slight enhancement in wave activity begins at 08:53:40 as indicated by the spiky nature of the separate components of the magnetic field data, although no overall change in B_T is observed. These waves begin after the appearance of the low energy H⁺ population already noted in the TIMAS data. Pitch angle data (panel 6) show this to be a transversely accelerated ion population. A second enhancement in wave activity begins in the MFE data around 09:00. Unlike the first enhancement, this is accompanied by a depression in the total magnetic field. At the same time, the lowest energy H⁺ ions are no longer visible in the TIMAS data, but a broad band of H⁺ flux is observed with energies from 60 eV to 8 keV. Panels 7 and 8 in plate 2 reveal little evidence of any O⁺.

Plate 3 plots field aligned HYDRA electron phase space density distributions for five intervals. Each distribution is averaged over 55sec. The electron distributions have been shifted by the spacecraft potential as calculated by the EFI electric field instrument on POLAR [Harvey *et al.*, 1995], and the black line is the one count level. The dotted and dashed black lines are model spectra of the core and halo components of the solar wind electron distribution [Fairfield and

Scudder, 1985], based on densities of 10 cm^{-3} and 0.3 cm^{-3} and temperatures of $1 \times 10^5 \text{ K}$ and $8 \times 10^5 \text{ K}$.

The first spectrum starting at 08:49:12, whilst POLAR is still on closed magnetospheric field lines, shows low ($< 50 \text{ eV}$) and high ($> 1000 \text{ eV}$) energy electron populations, whilst the final distribution in the cusp proper, during a period of enhanced flux at 09:10:08, shows a fairly typical maxwellian distribution over the energy range from 10-1000 eV. The second, third and fourth spectra correspond to the following three regions: when POLAR is in the region where solar wind electrons are present but before solar wind ions; when POLAR encounters the first high energy solar wind ions, and when POLAR first encounters the main cusp.

Results - 21st April 1996

On the 21st April 1996, POLAR encountered the cusp travelling outbound through the earth's dayside magnetosphere, towards increasing latitudes. Proton and electron spectrograms from the TIMAS and HYDRA instruments are shown in plate 4. Before 01:30, high and low energy trapped magnetospheric protons are seen, along with similar electron populations. The transition from closed to open field lines for electrons, occurs at 01:30.30, followed by the first appearance of an enhanced flux of low energy protons whose upper energy gradually increases from below 100 eV to 300 eV at 01:32.00. At 01:32.30, a higher energy population of protons appears at an energy of 2 to 10 keV. The low energy population continues to be visible until 01:35.30. The high energy part then displays a typical latitudinal dispersion which is interpreted as the velocity filter effect.

Panels 1 to 4 in plate 5 show high resolution residual magnetic field data from the MFE instrument at the equatorward edge of the cusp as in plate 2. Panels 5 to 8 show TIMAS H^+ and O^+ energy and pitch angle spectrograms. An enhancement in wave activity is seen from 01:31 to 01:33 in the separate components of the magnetic field data, although no overall change in B_T is observed. These waves correspond to the appearance of the low energy H^+ population already noted in the TIMAS data. Pitch angle data again show this to be a transversely accelerated ion population.

A second enhancement in wave activity begins in the MFE data at 01:35:10. Unlike the first enhancement, this is accompanied by a large depression in the total magnetic field. At the same time, the lowest energy H^+ ions are no longer visible in the TIMAS data, but a broad band of H^+ flux is observed with energies from 60 eV to 10 keV. Data (not shown) from the low frequency waveform receiver (LFWR) instrument [Gurnett *et al.*, 1995] shows similar enhancements in electric and magnetic waves at this time. Wavelet analysis of the LFWR time series data shows these enhancements to be of an irregularly pulsed nature at discrete frequencies similar to an event reported by Huddleston *et al.*, [2000], rather than broadband low frequency waves.

A transversely accelerated O^+ population can be observed from 01:28 to 01:35, decreasing in flux and increasing in energy during this period. A He^+ conic distribution (not shown) is also observed, at the same time as the H^+ conic is observed. Lund *et al.*, 1998 have suggested that He^+ can be preferentially accelerated in association with electromagnetic ion cyclotron waves, which may explain the high ratio of He^+ to O^+ observed by the TIMAS instrument. The presence of an O^+ population during this event but not during the 4th May 1997 event, may be due to the lower observation altitude (over 2 Re lower than the first event) or reduced O^+ ionospheric outflow, although the Dst index for both days is similar (Dst = -18 for 4th May 1997 and Dst = -26 for 21st April 1996 event).

The temporal evolution of the ions from 01:28:56 to 01:35:47 is shown in plate 6. Four TIMAS proton, energy against pitch angle plots are presented. Data is averaged over two spins (12 seconds), with 0° pitch angle corresponding to particles travelling field aligned, towards the earth. At 01:28:56 a low energy population spread over all pitch angles is observed, indicating magnetospheric protons trapped on closed field lines. In the second panel, at 01:31:00, a low energy population peaked between 90° and 120° is observed. This corresponds to the low energy enhanced flux population observed in plate 4. There is also evidence of an ion beam travelling anti-parallel to the magnetic field at energies of 0.2 to 1 keV. At 01:32:42, in the third panel, a high energy down coming proton population starts to appear, and the low energy conic distribution has increased in energy. Finally in the fourth panel at 01:35.35, down coming protons are seen over a broad energy range, along with higher energy particles travelling upwards.

These are the down coming protons observed in the third panel which have travelled down to a mirror point and are now returning up the field lines past the spacecraft. The low energy conic distribution has now increased in energy, with a low energy cut off now observable around 30eV. It has reduced flux and pitch angles extending to 180° . After this time it is impossible to distinguish between the upcoming ionospheric H^+ and the mirrored solar wind H^+ populations.

A more detailed plot of the magnetic field data from 01:31:45 to 01:32:15 before the solar wind ions arrive at POLAR is shown in figure 1, revealing its irregularly pulsed nature. Plate 7 shows highest resolution (1.5sec) HYDRA ion velocity distributions within this interval, from 01:31:57 to 01:32:06. HYDRA ion and electron measurements are interleaved, which explains the gap between each ion distribution. Plate 7 shows that the conic distributions are not a steady feature. This is typical of the whole period where conics are observed. The conic distribution in plate 7 may be associated with the increase in amplitude of the B_y component of the magnetic field from between 01:32:04 and 01:32:06 seen in figure 1, but a more thorough examination of the data from 01:31 to 01:33 reveals no clear correlation between the two data sets.

Discussion

A survey of over 200 cusp crossings from April 1996 to October 1998 when POLAR is encountering the cusp close to the noon - midnight meridian reveals only six events where a clear electron edge is observed ahead of magnetosheath ions, even though 37 of the crossings are during periods of steady solar wind conditions. The width of the electron edge for these six events extends up to 0.5° invariant latitude. For these events, the magnetic field investigation on the WIND spacecraft [Lepping *et al*, 1995] reports generally southward IMF conditions, except for 29th October 1998 where there was a northward IMF, ion spectrograms reveal a reversed (in latitude) energy dispersion interpreted as a signature of reconnection poleward of the cusp, and the electron edge is measured at the poleward edge of the cusp. Statistical analysis of solar wind and geomagnetic data for these events reveals no parameter which can organise the presence or lack of a separate electron edge.

Ignoring charge neutrality constraints, we can use nominal figures for electron and ion field aligned velocities and magnetospheric convection to estimate the size of the region at the equatorward edge of the cusp to which only electrons should have access. The high energy tail of magnetosheath ion and electron distributions extends to ~ 10 keV and ~ 1 keV, corresponding to field-aligned velocities of ~ 1400 kms^{-1} and ~ 19000 kms^{-1} respectively. The method of analysing down going and mirrored low energy ion cut-offs to obtain a reconnection site location [Onsager *et al.*, 1990], gives a field aligned distance of $\sim 10 R_e$ from POLAR to the reconnection site on the magnetopause for the 21st April cusp crossing. The first magnetosheath ions will arrive at POLAR ~ 43 sec behind the first electrons due to their relative speeds, and assuming a poleward convection speed of ~ 10 -50 kms^{-1} [Lockwood *et al.*, 1994] this leads to a spatial separation of ~ 430 -2150 km or ~ 0.07 -0.3 R_e at POLAR's altitude. On April 21st 1996, POLAR encounters the cusp travelling in the noon - midnight meridian, with a poleward velocity of ~ 1.5 kms^{-1} , so for periods of steady convection POLAR should encounter magnetosheath electrons 5 to 24 minutes before magnetosheath ions. POLAR actually encounters the magnetosheath electrons 2 minutes before the ions which compares reasonably with the simplified calculations.

We now discuss some general questions concerning charge neutrality at the equatorward edge of the cusp, in conjunction with the observations presented in this paper. We then examine the origin of ion conic distributions seen in this region, and address the question of the role, if any, of perpendicular ion heating in maintaining charge neutrality in this region.

Electron edges and charge neutrality

There are several possible physical explanations why POLAR does not encounter an electron edge as wide as our simple calculation suggests. They include slower magnetospheric convection speeds than used in our calculations, or a convection direction at an angle to the noon - midnight meridian (influenced by a B_y component of the IMF), and previously unexplored aspects of charge neutrality now accessible with the POLAR high time resolution plasma and field data.

Burch [1985] showed that suprathermal electron and ion density measurements made by DE-1 in the cusp were the same within experimental errors, and suggested an ambipolar electric field at

the magnetopause regulated electron entry. Other researchers [e.g. *Wing et al.*, 1996] have suggested that a potential drop is maintained between the magnetopause and the earth. Electric fields will have a far greater impact on electrons than ions due to the much larger ion mass, yet the very fact that solar wind electrons have been observed ahead of solar wind ions proves that the electrons are not simply held back and forced to follow the ion motion. During POLAR's pass of the equatorward edge of the cusp on 4th May 1997, the EFI instrument can not rule out the presence of a parallel electric field, although it does see an upper limit of $E_{\text{par}} = 4\text{mV/m}$ (*Nelson Maynard*, private communication). However, large electric field spikes are often seen at the equatorward edge of the cusp [*Maynard et al.*, 1985], and these may be due to the plasma seeking to re-establish charge neutrality. The presence of an upward travelling ion beam in the second panel of plate 6 does suggest that a parallel electric field may be present at the equatorward edge of the cusp, and an E_{par} of only 4mV/m would be able to accelerate particles to energies of 4 keV over a distance of only 4000 km.

By fitting retarding Maxwellian distributions to low altitude DMSP cusp and low latitude boundary layer (LLBL) electron spectra, *Wing et al.*, [1996] suggested that a 250 V potential retarded electrons equatorward of the main cusp. The large difference between the second electron spectrum in plate 3 compared to the spectra at later times, suggests that a retarding potential may well be acting on these initial solar wind electrons.

We choose not to fit Maxwellian distributions to the second electron spectrum in plate 3 in order to calculate potentials, due to the inherent uncertainty of this method. When an electron distribution passes through a retarding potential, the low energy part of that distribution is lost. If the original distribution is compared with the final distribution, the retarding potential can be calculated. If only the final distribution is available, a potential can still be estimated by comparing this distribution to a typical source distribution obtained from a statistical average of spacecraft observations. This however leads to large uncertainties due to the variability of the source distribution as illustrated by the differences in the final two spectra in plate 3, both of which are from the cusp proper, where very low retarding potentials are believed to operate [e.g. *Lemaire and Scherer*, 1978].

For now we note the similarity of the second spectrum in plate 3 with that of the model halo distribution, and suggest that the bulk of the lower energy core electron distribution has been prevented from reaching POLAR's altitude ahead of the solar wind ions, as postulated by *Wing et al.* [1996].

The abrupt change in peak energy of the solar wind ion distribution seen in both events when the bulk of the distribution finally arrives at POLAR is a frequent observation in POLAR cusp crossings. *Fuselier et al.*, [1999] have suggested that this may be due to the magnetosheath source distribution exhibiting a break at 1.3 keV/e since it is made of two separate components. We suggest that acceleration due to ambipolar diffusion as the ions and electrons travel away from the magnetopause reconnection site may also contribute to the initial narrow high energy solar wind ion distribution.

Perpendicularly Accelerated Ions

Plate 8 plots the distribution of low energy (<200 eV) H^+ conics observed by POLAR over a period from April 1996 to March 1998. The conics were identified by an algorithm which searched through TIMAS H^+ data looking for peaks in 90° to 150° pitch angle at energies less than 200 eV. It is clear from plate 8 that H^+ conics are a common high altitude feature in the noon sector, at latitudes equatorward of the average cusp location as determined by *Zhou et al.*, [1999]. It should also be noted that these ions are heated locally over a range of altitudes, as shown by the 2 events in this paper, which both display conics peaked close to 90° at altitudes of $5.4 R_e$ and $7.6 R_e$ respectively.

Whilst H^+ and O^+ conics are frequently seen at the edge of the cusp by POLAR, these 2 unusual events allow us to examine in more detail the separate regions in which they exist or are energised. The initial appearance of H^+ conics is related to the arrival of the first solar wind electrons at POLAR. The second energisation occurring at the edge of the cusp proper, appears either to be related to the upcoming mirrored solar wind ions, or to the sudden increases in density as the bulk of the solar wind ion distribution arrives at POLAR. When O^+ ions are present, they appear to be transversely heated on closed field lines at lower latitudes.

The presence of conic distributions together with low frequency waves raises the unresolved question of which feature is causing the other. The electromagnetic structures may be driven by the downcoming solar wind electrons [Cattell *et al.*, 1998], or may be due to features in the solar wind flow [e.g. Huddleston *et al.*, 2000], which could explain the H⁺ and He⁺ energisation, but this would not explain the O⁺ conics present on closed field lines at lower latitudes. It may be that the same mechanism accelerates all three ion species but is inhibited at the higher H⁺ and He⁺ cyclotron frequencies until the arrival of a population of solar wind electrons. Close examination of the O⁺ conic distributions show that these distributions are peaked above 90° suggesting that they are accelerated in a region below that of the H⁺ acceleration.

Comparisons between wave and particle data do not show a clear correlation, although this may be limited by the temporal resolution of the particle instruments. If POLAR is not in the source region where particles are being energised by wave-particle interactions, then a correlation would not necessarily be expected. However, as noted above, H⁺ conics are seen peaked at 90° over a range of as much as 3 R_e altitude, implying an extended heating region which POLAR is likely to encounter frequently as it crosses the cusp.

The presence of ion conics at the equatorward edge of the cusp may also play a role in maintaining charge neutrality as the solar wind electrons and ions occupy separate regions due to their different velocities and the convection electric field. Electrostatic potential structures are able to transversely accelerate ions [e.g. Borovsky and Joyce, 1986], although theory suggests that heavy ions would be preferentially accelerated, in disagreement with observations presented here. The presence of heavy ions in the ‘electron only’ region at this altitude may however be regulated by other processes occurring at low altitudes. The initial appearance of H⁺ and He⁺ conics within the ‘electron only’ region and their lack of quantitative correlation with observed electromagnetic waves, does suggest that these perpendicularly heated ions have a role to play in maintaining charge neutrality in this region.

Summary

We have identified six POLAR cusp crossings out of 200 examined, featuring a separate electron region at the edge of the cusp. Our calculations suggest these events should be more commonly observed.

Electron spectra within this region appear to show these electrons to be part of the solar wind halo distribution, suggesting that the core electron distribution has been prevented access by a parallel electric field. We have discussed the validity of identifying retarding electric fields from electron spectra.

We have shown that H^+ conics are common at POLAR's altitude, in the noon sector, at the equatorward edge of the cusp. More specifically, H^+ and He^+ conics undergo two energisation processes – one during the electron only region at the equatorward edge of the cusp, and the second when solar wind ions are present and the fastest of these ions have had enough time to mirror at low altitudes and return to POLAR.

High time resolution MFE data shows that whilst there is generally an increase in wave power during these times, there is no clear correlation between wave power increases and the intermittent appearance of these conics.

O^+ conics are sometimes also observed, at low fluxes. These appear to have been initially energised at lower latitudes on closed field lines and are not correlated with the appearance of H^+ and He^+ conics.

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Figure 1. MFE residual magnetic field data with the T96 model magnetic field removed, for April 21 1996. Panel 1 is total magnetic field, and panels 2 to 4 are x, y, and z components respectively in solar magnetic co-ordinates.

Plate 1. TIMAS proton and HYDRA electron energy spectrograms on May 4 1997, integrated over all pitch angles.

Plate 2. May 4 1997 TIMAS particle and MFE residual magnetic field data with the T96 model magnetic field removed. Panel 1 is total magnetic field, and panels 2 to 4 are x, y, and z components respectively in solar magnetic co-ordinates. Panels 5 and 7 are H⁺ and O⁺ energy spectrograms integrated over all pitch angles. Panels 6 and 8 are H⁺ and O⁺ pitch angle spectrograms, where 0° pitch angle is parallel to the magnetic field.

Plate 3. HYDRA field aligned electron spectra on May 4 1997 at a) 08:49:12, b) 08:51:44, c) 08:57:01, d) 09:01:09, e) 09:10:08. The black line is the one count level. Dotted and dashed black lines are modelled core and halo distributions respectively.

Plate 4. TIMAS proton and HYDRA electron energy spectrograms on April 21 1996, integrated over all pitch angles.

Plate 5. April 21 1996 TIMAS particle and MFE residual magnetic field data with the T96 model magnetic field removed. Panel 1 is total magnetic field, and panels 2 to 4 are x, y, and z components respectively in solar magnetic co-ordinates. Panels 5 and 7 are H⁺ and O⁺ energy spectrograms integrated over all pitch angles. Panels 6 and 8 are H⁺ and O⁺ pitch angle spectrograms, where 0° pitch angle is parallel to the magnetic field.

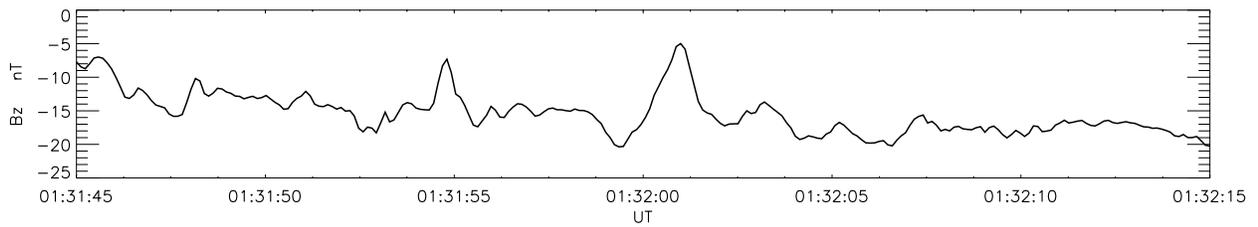
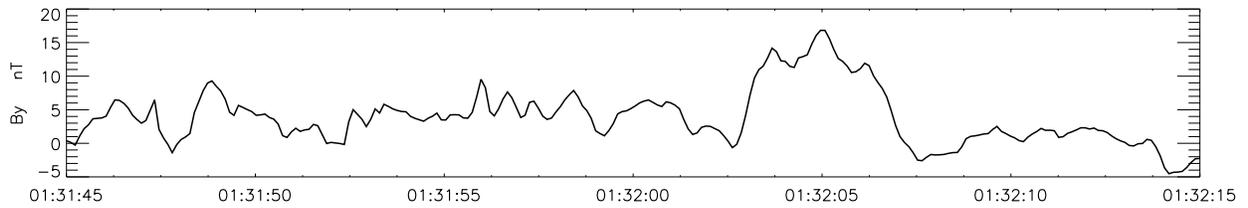
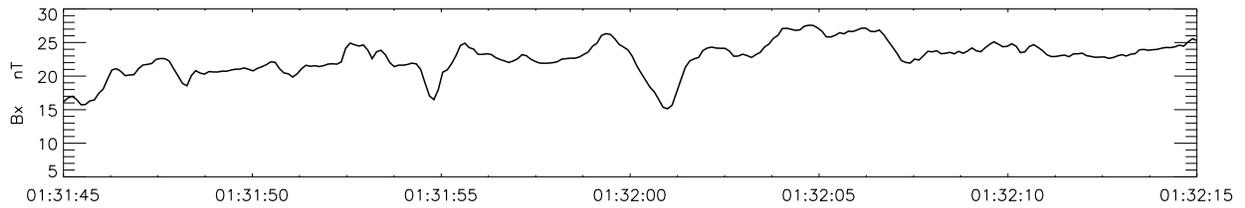
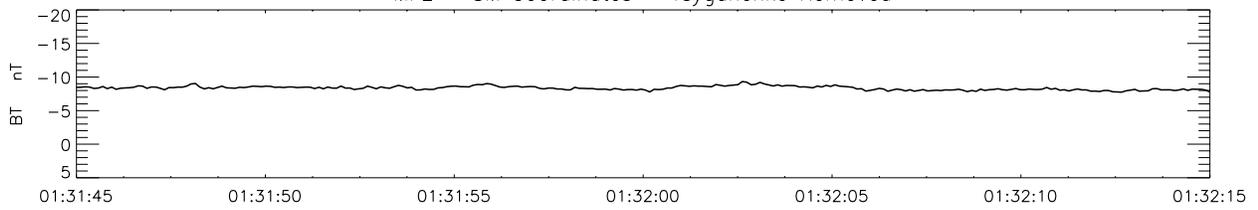
Plate 6. TIMAS energy versus pitch angle plots averaged over 2 spins (12 sec) on April 21 1996; at a) 01:28:56, b) 01:31:00, c) 01:32:42, d) 01:35:35.

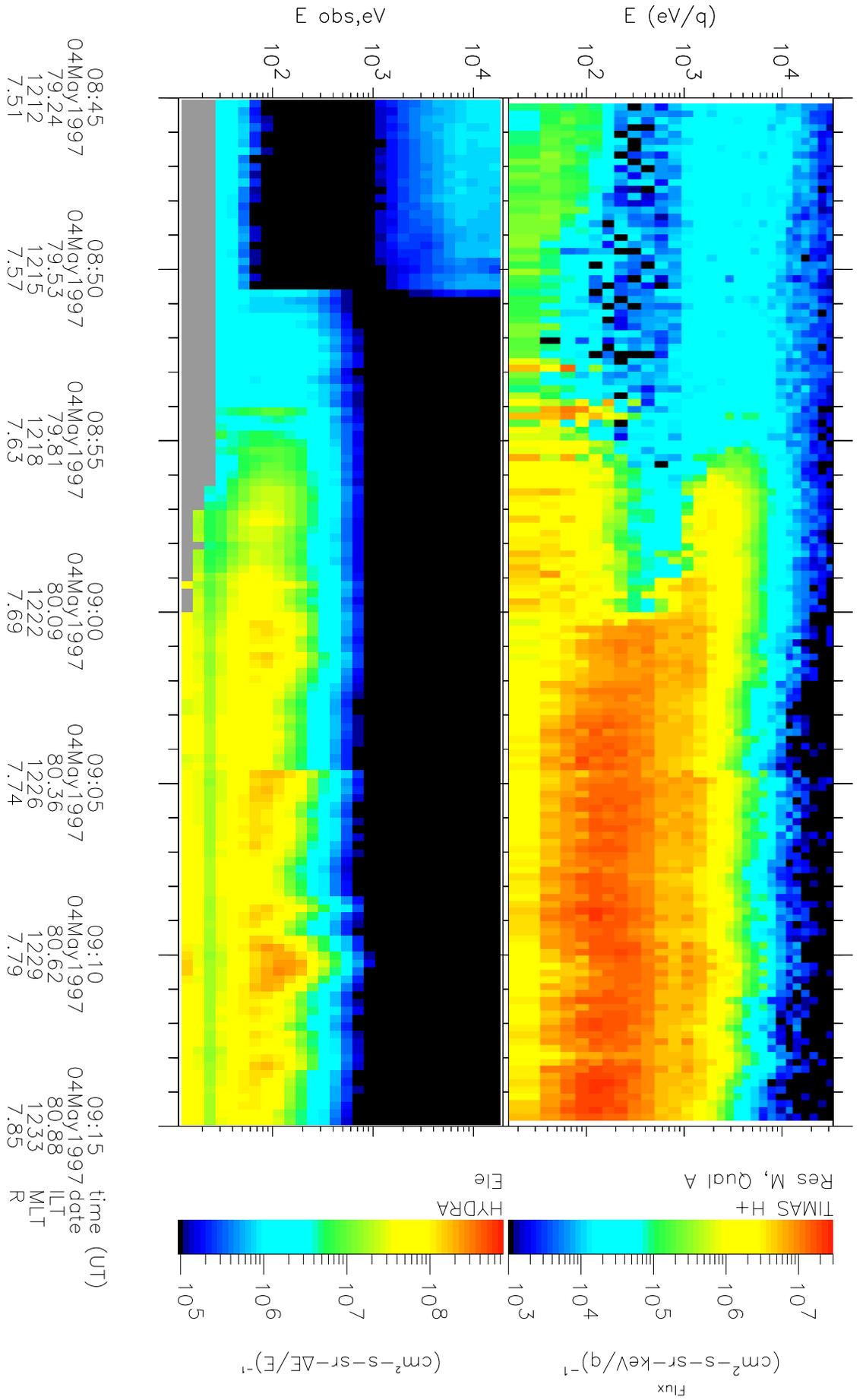
Plate 7. HYDRA ion velocity distribution plots at 1.5 sec resolution, for April 21 1996, at a) 01:31:57, b) 01:31:59, c) 01:32:02, d) 01:32:04, e) 01:32:06. Measurements are reflected in the V_{perp} axis to form a 360° distribution.

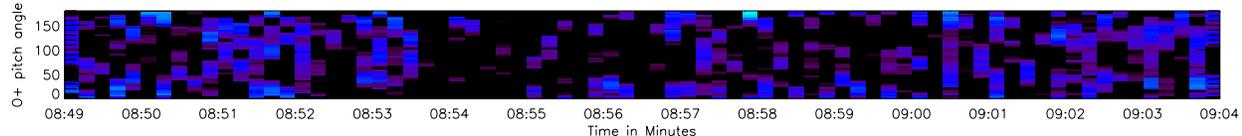
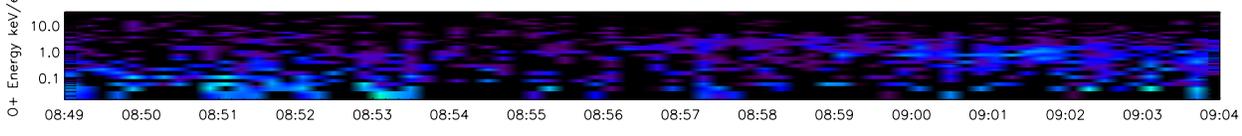
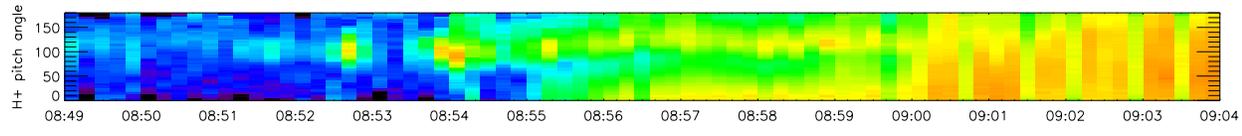
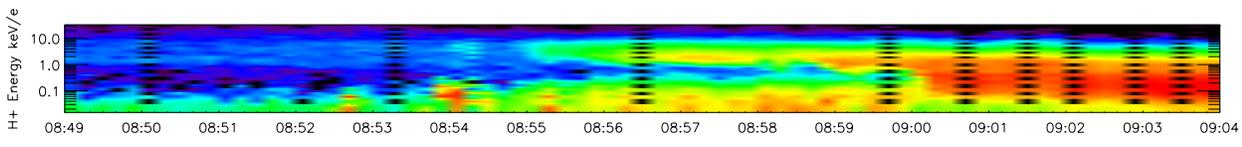
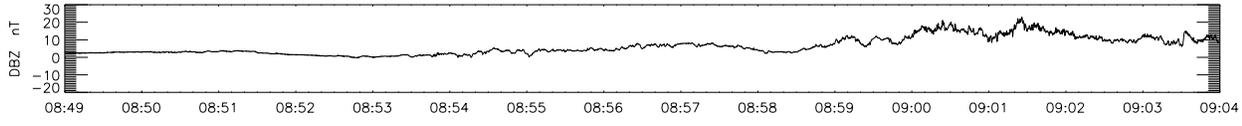
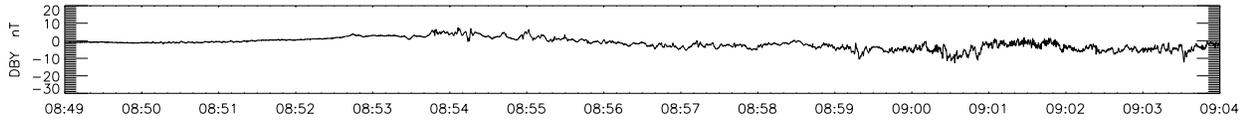
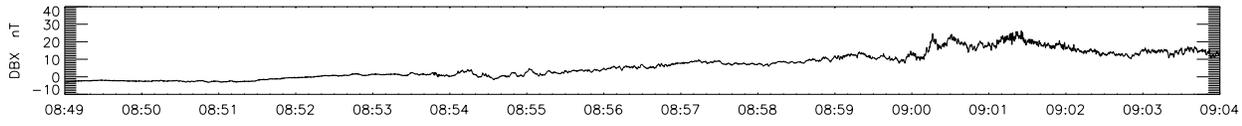
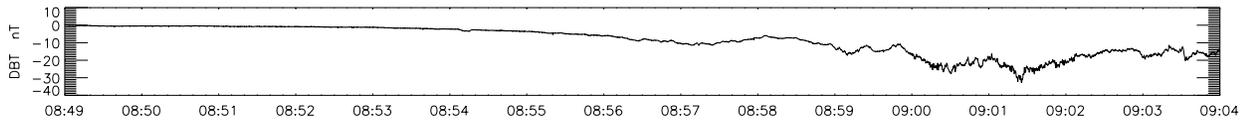
Plate 8. Polar contour plot of the high latitude, northern hemisphere, showing where conic distributions are observed for 2 years of POLAR orbits.

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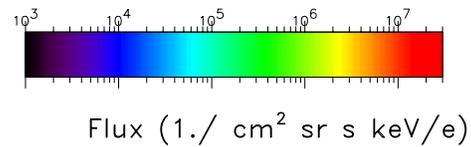
MFE - SM Coordinates - Tsyganenko Removed



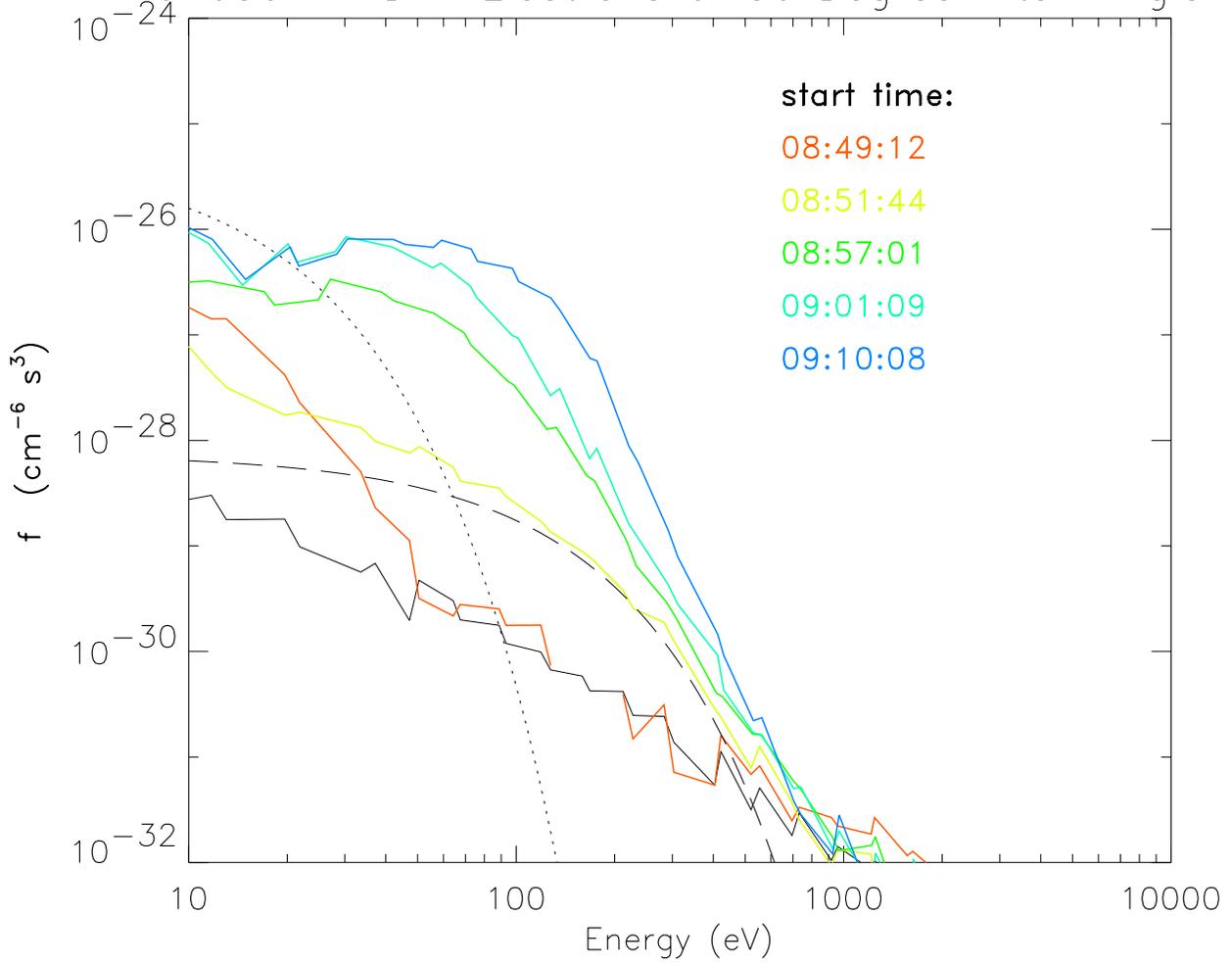


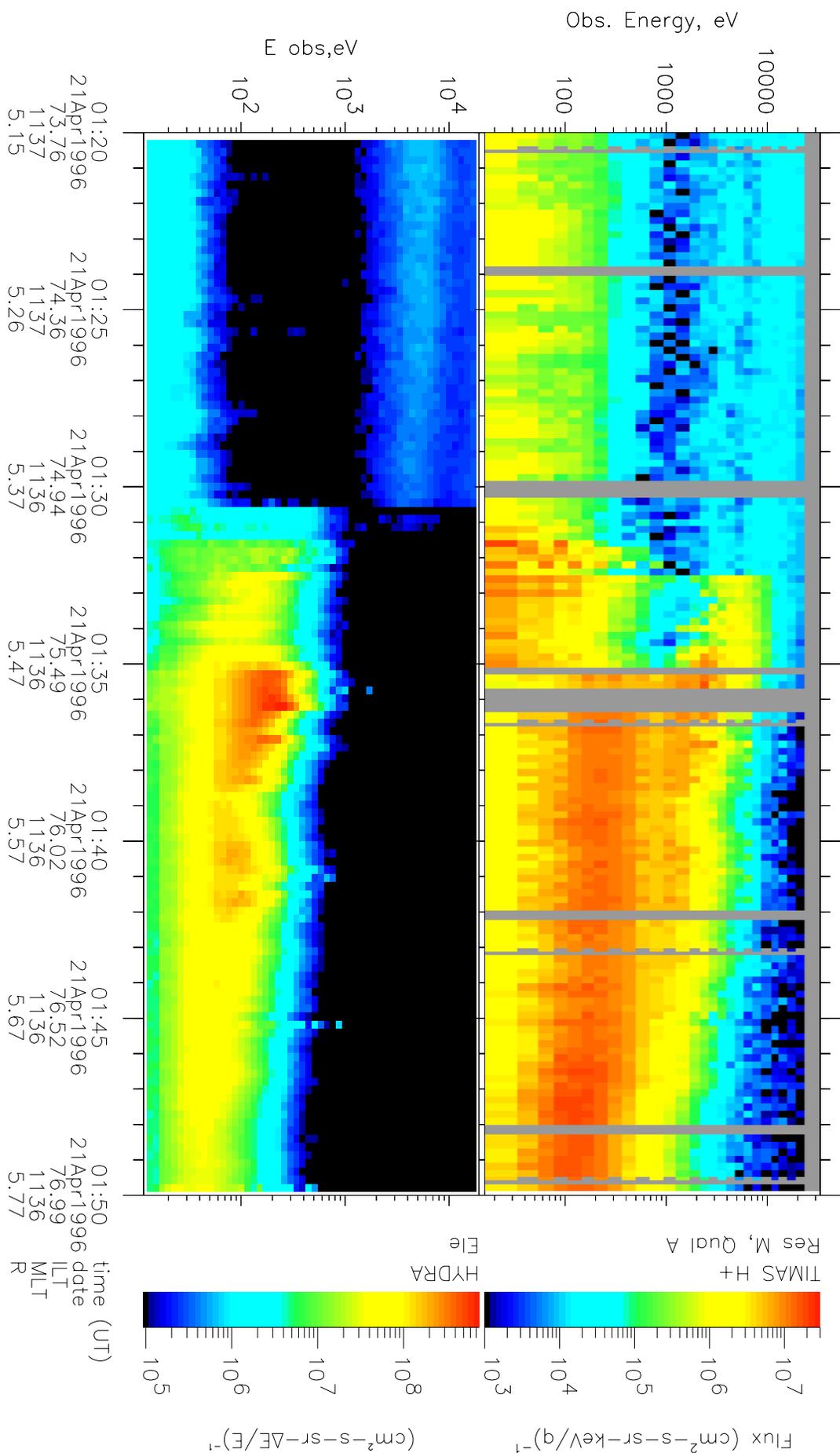


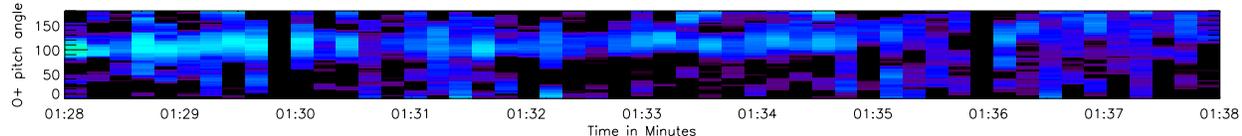
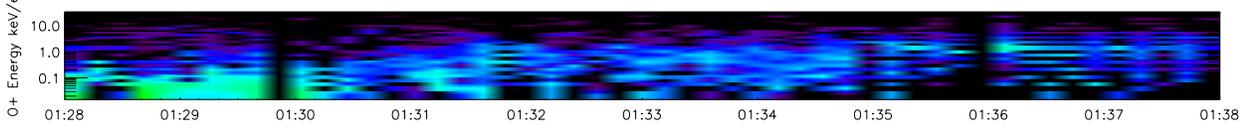
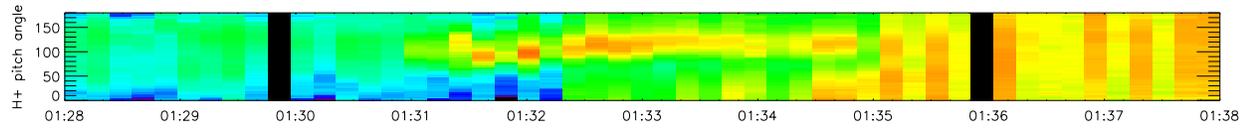
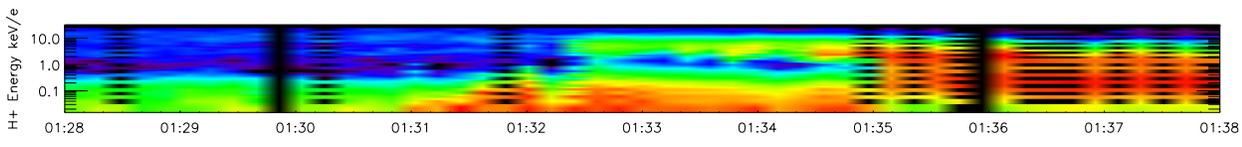
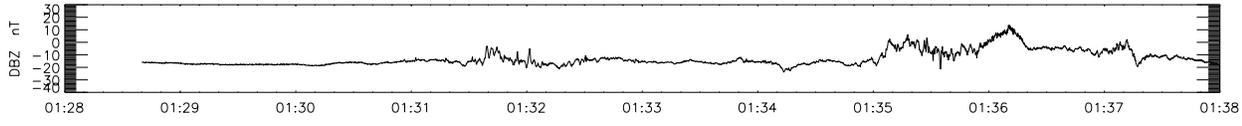
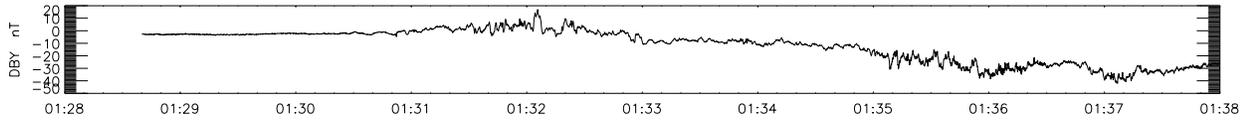
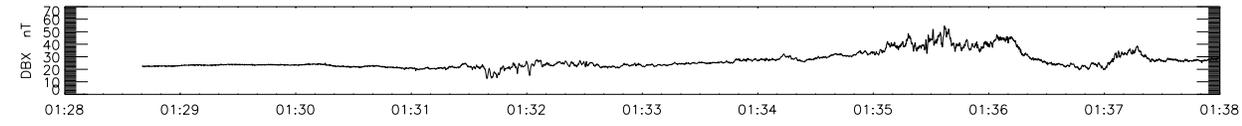
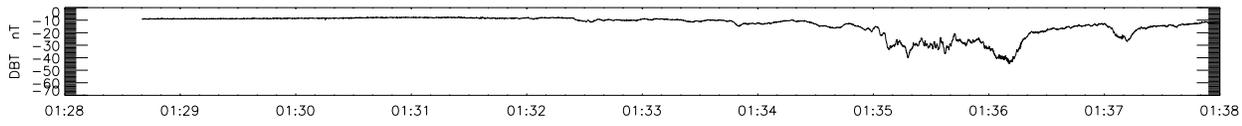
970504 – start time: 08:49
Polar MFE and TIMAS Data



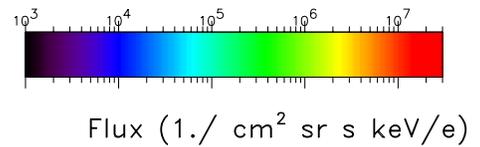
970504 HYDRA Electrons 0-30 Degree Pitch Angle



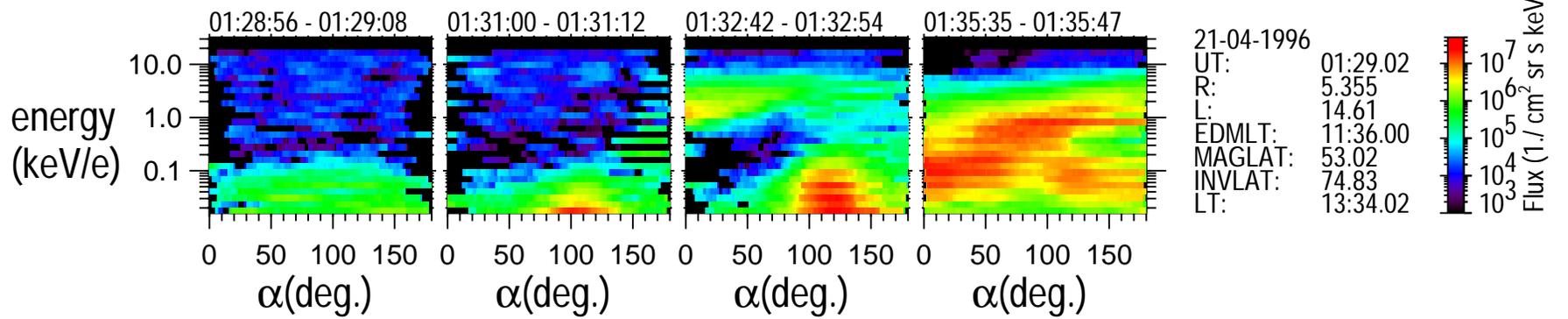


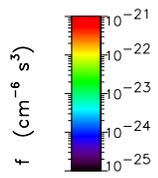
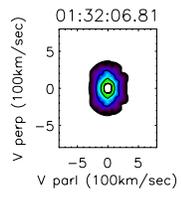
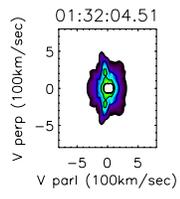
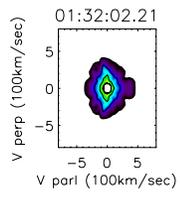
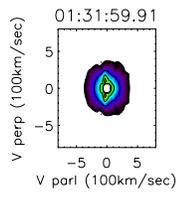
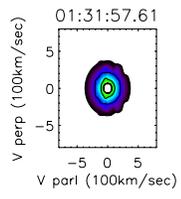


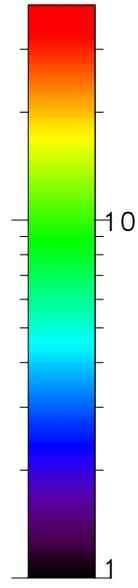
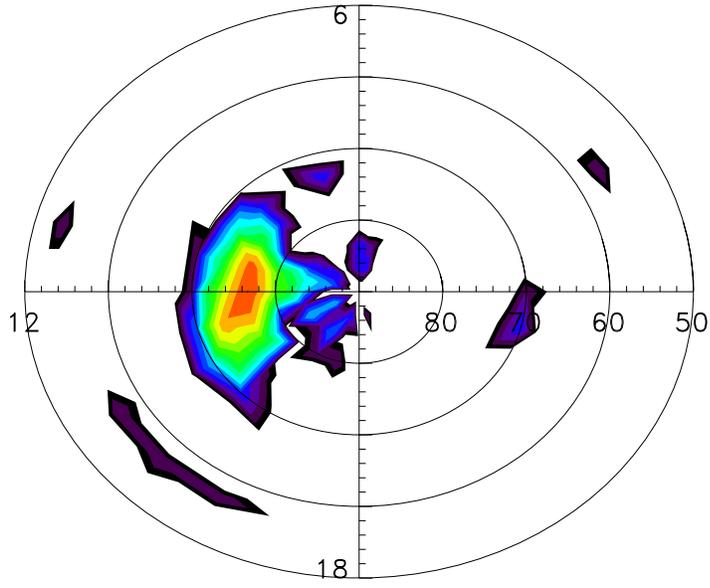
960421 – start time: 01:28
Polar MFE and TIMAS Data



POLAR/TIMAS data: H⁺







No. of Cusp Crossings When Conic Observed