INITIAL TIMAS OBSERVATIONS OF ION CONIC HEATING IN THE CUSP

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ABSTRACT

The Toroidal Imaging Mass-Angle Spectrograph is a first order double focusing (angle and energy) imaging spectrometer that simultaneously measures all mass per charge components from 1 to >32 AMU/e over a nearly 360° by 10° instantaneous field-of-view. The energy-per-charge range from 15 eV/e to 33 keV/e is covered in 28 noncontiguous steps spaced approximately logarithmically. Nearly full 3-D velocity distributions for four mass constituents are obtained every half spin (3 seconds). Data are compressed onboard into data products with various angle, mass and energy resolutions. Initial observations of ion heating by electromagnetic waves in the dayside southern cusp region are examined.

TIMAS SCIENCE OBJECTIVES

The science objectives of the Toroidal Imaging Mass-Angle Spectrograph (TIMAS) are to investigate the transfer of solar wind mass, energy and momentum to the magnetosphere, the interaction between the magnetosphere and the ionosphere, the processes that distribute plasma and energy through the magnetosphere, and the interactions as plasmas of different origins and histories mix. In order to meet these objectives the TIMAS instrument measures virtually the full three-dimensional velocity distribution functions of four magnetospheric ion species with one-half spin period, 3 second, time resolution.

SUMMARY OF TIMAS CHARACTERISTICS

The TIMAS (Shelley et al. 1995) is a novel 3-D ion mass spectrograph which has been optimized for the POLAR missThe TIMAS (Shelley et al. 1995) is a novel 3-D ion mass spectrograph which has been optimized for theion. It simultaneously performs 3-D distribution function measurements of four programmable magnetospheric ion constituents twice per satellite spin. It is a first order double focusing (angle and energy), imaging spectrograph that simultaneously measures all mass per charge components from 1 AMU/e to greater than 32 AMU/e over a nearly 360° by 10° instantaneous field-of-view. Mass per charge is dispersed radially on an annular microchannel plate detector and the azimuthal position on the detector is a map of the instantaneous 360° field of view. The energy per charge range from 15 eV/e to 33 keV/e is covered in 28 non-contiguous steps spaced approximately logarithmically with adjacent steps separated by about 30%. Each energy step is sampled for approximately 20 ms; 14 step (odd or even) energy sweeps are completed 16 times per spin. The extremely large data volume produced by these measurements must be highly compressed to fit within the limited telemetry allocation. This compression is carried out by: data prioritization, distribution function integration to reduce velocity space resolution, and lossless data compression. Versatile control of data acquisition and onboard data compression permit optimal operation in all regions of the magnetosphere surveyed by the POLAR spacecraft. This data processing task is supported by two SA3300 microprocessors. Voltages of up to 5 kV for the tandem toroidal electrostatic analyzers and preacceleration sections are supplied from fixed high voltage supplies using optically controlled series-shunt regulators.

TIMAS Viewing Geometry

The TIMAS ion optics provide a ring-shaped image on the annular microchannel plate (MCP) detector with the mass spectrum dispersed radially and with incident direction dispersed in azimuth across 28 wedge shaped detector sectors. The TIMAS is mounted with its axis of symmetry in the spin plane of POLAR. With the rotation of the spacecraft, the TIMAS wide, almost flat, conical field of view sweeps out very nearly a full solid angle image in a half spin period. The major part (93%) of the full solid angle is sampled twice per spin. Only 2%, within 12° of each spin axis direction, is never sampled due to the conical shape of the field of view.

TIMAS On Board Data Products

The extremely large data volume produced by TIMAS is accumulated onboard into a series of science data products. Because of the limited telemetry available, not all data products can be transmitted to the ground during each spin. On average 3082 bytes per spin can be transmitted. The instrument has the capability to vary the parameters of the data products and the order in which they are processed. For all data products, except mass spectra, data from each detector half and each M/Q are treated separately. The various data products are designed to emphasize different aspects of the ion plasma including its 3-D directional distribution, high angular resolution pitch angle distribution and mass spectra.

INITIAL RESULTS: ION CONIC HEATING

On March 18, 1996 POLAR was near perigee at 1.8Re geocentric and passed through the dayside southern cusp at a magnetic local time of about 11:00 moving towards the high latitude polar cap. While passing through the cusp TIMAS observed H^+ and O^+ conics which increased and faded in intensity between 8:37:30 and 8:38:09 UT. The conics reached their greatest intensity at about 8:37:50 UT. At the same time the Electric Field Instrument (EFI) Harvey et al. (1995) detected a marked intensification of wave power which lasted from 8:37:35 to 8:38:00. This intensification triggered the EFI burst mode. At this time TIMAS data products include 3-D velocity distributions for each ion from each side of the instrument every spin (6 seconds) and snapshots of the pitch angle distribution about every 3 seconds. It is expected that the ion conics are energized by the waves (André et al. 1990) and the excellent time resolution of TIMAS permits 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 provides the opportunity to compare the ion heating with the available wave energy.

Each side of TIMAS is made up of a fan of 14 detector sectors each of which behaves like a separate narrow angle ion mass spectrometer. The plane of the fan is nearly parallel to the spin axis and the spin axis is oriented approximately perpendicular to **B**, so as POLAR spins each fan of detector segments scans across almost the full solid angle. The center segment usually makes a nearly complete pitch angle scan. The end sectors point close to the spin axis and so only view pitch angles near 90°. Velocity space densities of the ions generated from data acquired by the center detector segment are displayed as contour plots in Figure 1 which shows H^+ on the left and O^+ on the right. The plot shows data from one full spin, 6 seconds. Contours are on a logarithmic scale at half decade intervals . The O^+ distribution protrudes through a smooth surface which is equivalent to the one count/sample sensitivity threshold of TIMAS while the H^+ distribution includes an isotropic component which at these velocities is rather higher than one count/sample.

At two points during each spin each fan of 14 detector sectors intercepts the field line and when this happens a high resolution, ~11°, pitch angle snapshot (PAD) is made. Since data are collected for all pitch angles simultaneously the possibility of time aliassing is avoided. The two sides of the instrument together can make snap shots looking both up and down **B** twice per spin, *i.e.* about every three seconds. Each pitch angle snapshot gives one quadrant of the ion velocity distribution from which the temperature of the conic can be determined. Temperatures were estimated by visually identifying the appropriate pitch angle and velocity range, interpolating the density/velocity profile and determining the temperature from its slope. The accuracy is dependent on the count rates and in the case of the H^+, on how clearly the conic can be distinguished from the nearly isotropic population. The uncertainties are estimated to be about 20% for the most intense conics and increase away from the center of the event. Thus during the early part of the event it was not possible to make meaningful estimates of H^+ temperature. Figure 2 shows the H^+ and O^+ conic temperatures estimated by this technique.

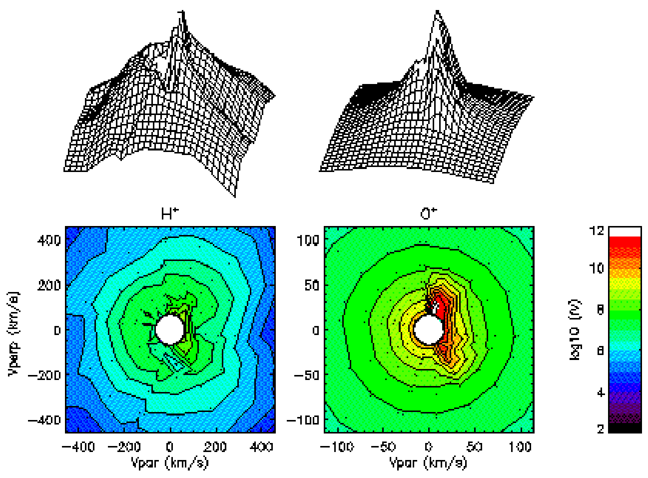

Fig. 1. Velocity space distributions of H^+ and O^+ for one spin, 6 seconds, starting at 8:37:57 when both H^+ and O^+ conics are fully developed. This plot was constructed using data from the center detector sector of one side of the instrument and represents a slice through the full 3-D distribution 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 which is equivalent to one count/sample while the H^+ distribution includes an isotropic component which at these velocities is rather higher than one count/sample.

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

$$W(perp)= q^2 k E / (2 m) \quad (1)$$

where W(perp) is the ion heating rate, E is the spectral energy density at the ion gyrofrequency (f_{ci}) and k is the fraction which is left-hand polarized.

The EFI data showed E-field fluctuations which were perpendicular to **B**. Their spectral energy densities at the ions' gyrofrequencies (9 Hz for O^+ and 140 Hz for H^+) were 100 and 4 $(mV/m)^2$ Hz^{-1} respectively. Assuming that the waves were fully left-hand polarized, k=1, the expected ion heating rates for these observed spectral energy densities are 460 and 300 eV/s for O^+ and H^+ respectively. If only a moderate fraction of the waves are left-hand polarized then it appears that the observed wave energy is sufficient to heat the conics to their observed temperatures of up to 100 eV within a few seconds.

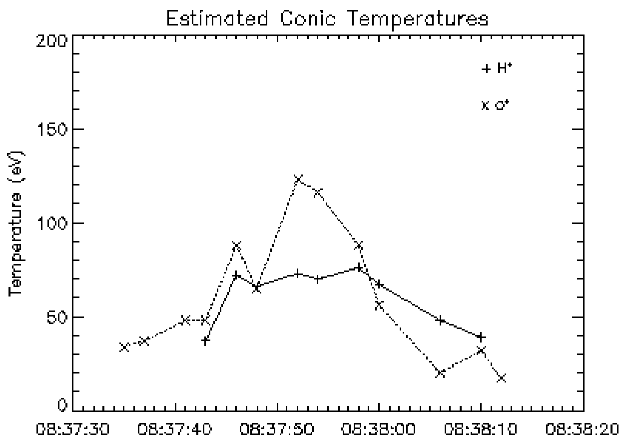

Fig. 2. Time history of the temperatures of the H^+ and O^+ conics. Temperatures were estimated from the pitch angle snapshots (PADs) by visually identifying the appropriate pitch angle and velocity range, interpolating the density / velocity profile and determining the temperature from the slope.

ACKNOWLEDGMENTS

We would like to thank V. Angelopoulos of the University of California at Berkeley for providing the EFI wave data. The research at Lockheed Martin was performed under NASA contract NAS5-30302.

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