Introduction

Ion heating has been correlated with several magnetospheric phenomena, including magnetic reconnection, instabilities, and convection of plasma through different regions of the magnetosphere. Thus, it is important to be able to measure ion temperatures throughout the magnetosphere to better understand the physics of these phenomena. Effective ion temperatures based on the charge-exchange cross section-corrected energetic neutral atom (ENA) flux versus energy spectrum can be calculated from TWINS data. Effective ion temperatures calculated from the Medium Energy Neutral Atom (MENA) imager on the IMAGER spacecraft using this technique were shown to have excellent (within ~30%) agreement with in-situ measurements from MPA instruments on LANL geosynchronous spacecraft and GEOTAIL. In order to achieve adequate statistics for reliable ion temperature calculations, we can use either data with significant ENA flux rates, such as during geomagnetic storms, or superpositions of multiple data sets. We present ion temperature images from one small storm and a superposition of data for fast solar wind conditions.

Calculation of Effective Ion Temperatures

The high-energy portion of the neutral atom energy spectrum, \( F(E) \), generated via charge exchange collisions for a Maxwellian ion distribution of temperature \( T_i \) is given by

\[
F(E) = C \frac{\nu_e}{(2\pi m T_i)^{3/2}} \exp\left(-\frac{E}{k T_i}\right)
\]

where \( C \) accounts for the geometrical viewing properties of the instrument and the volume of the hottest region along the line of sight at \( x \). \( F(E) \) is the ion temperature, \( n(x) \) is the neutral density, \( \nu_e \) is the ion density, \( \nu_e \) is the change exchange cross section between neutrals and ions of energy \( E \), and the integral over \( \nu_e \) accounts for reduction of neutral flux due to additional collisions or ionization along the path from point \( x \) to the instrument located at \( a \). Outside of the plasmasphere, the magnetosphere is optically thin to neutral atom emission so

\[
\frac{F(E)dE}{\sigma dE} = C \frac{\nu_e}{(2\pi m T_i)^{3/2}} \exp\left(-\frac{E}{k T_i}\right)
\]

We use equation (2) to determine the peak ion temperature along the line-of-sight from fits to the ENA energy spectra.

“Skymap” Views and Equatorial Projections

We present two versions of ion temperature images: skymap views and equatorial projections. Creation of a skymap view involves applying the ion temperature calculation directly to the ENA differential number flux versus energy obtained from TWINS and plotting those temperatures in the same geometry used to plot the flux. To create an equatorial projection, a line-of-sight-vector is calculated for each pixel in the ENA differential number flux array. The Geocentric Solar Magnetic Field (GSM) equatorial plane is divided into \( 1 R_s \times 1 R_s \) bins, and the flux for each pixel is placed in the bin with which the associated line-of-sight intersects. The ion temperature calculation is then applied to each bin in the GSM equatorial plane to create the ion temperature image.

Calculated Ion Temperature

Storm Time:

June 2008

Quiet Time:

Superposition

By projecting data to the GSM equatorial plane, we can average together many datasets to get an idea of the average characteristics of the quiet time magnetosphere. This figure includes data from both TWINS satellites from Jan and Feb of 2009 divided into sets with a maximum of 20 sweeps. Only data taken where the satellite has a GSM z component of at least 4 R_s are included to make sure we have a good view from the top of the orbit. This figure includes data during periods of fast solar wind (>400km/s), determined by data from OMNIWeb. For each pixel in a dataset, the intersection of the line of sight (LOS) with the GSM xy plane is calculated. The flux in each of 6 energy bins (4000, 6000, 9000, 13000, 20000, 32500) eV is placed into the 1 R_s x 1 R_s bin that corresponds to the calculated intersection, divided by the square of the magnitude of the LOS vector to account for the effects of the satellite location. Once this has been done for all of the data sets, each energy bin in each spatial bin is divided by the number of times that bin was populated to get an average flux.

Then we apply our ion temperature calculation to the flux versus energy spectrum in each spatial bin to get an effective ion temperature in that bin. Those temperatures are then plotted, and an approximate magnetosphere boundary is used to remove data outside the magnetosphere. The Sun is to the right and dusk is up.

This preliminary plot will be improved by:

• Creating a more realistic magnetopause model boundary for each dataset to remove data outside the magnetosphere.
• Creating an “adaptive grid” that includes larger pixels towards the magnetotail based on the viewing geometry as well as the thickness of the plasma sheet.
• Extending the plot to include data further dawnal.

Discussion and Future Work

The 15 June 2008 event provides the best storm-time data currently available for comparison of the two vantage points. In general, the ion temperatures in the two equatorial projections are in good agreement. The region of increased ion temperatures in the TWINS-2 projection are due to the orbital location of the satellite causing many lines of sight to pass within 1.2 R_E of the Earth. Thus, these pixels include a region which is not optically thin to ENA emission; violating an assumption of the ion temperature calculation technique. Such lines of sight should be ignored and will be removed in future analysis. Because the MPA data from the LANL geosynchronous spacecraft has not been available since the beginning of 2008 [M. Thomsen, private communication], this technique is the only available method for obtaining ion temperatures over broad regions and times in the inner magnetosphere.

Because the sun has been particularly quiet during the TWINS mission, there have been very few storms to study. However, a lot of quiet time data is available. The best way to study this data is through superposition and averaging of the data. Because each dataset has a different geometry due to orbital location, the data are projected to a grid in the equatorial plane and then averaged, as shown in the above figure. We will incorporate additional data from a Themis mission and create superposed averages sorted by solar wind parameters such as \( v_\perp \) and \( v_\parallel \). We are also creating similar equatorial plots of averaged data over the time period using in situ measurements from GEOTAIL, Cluster, and THEMIS for comparison (see paper JPB00016). We will compare the results to models such as the BATSRUS magnetospheric model and to previous in situ and modeling studies of ion temperatures in the plasma sheet [eg. Spence and Kivelson, 1993; Gould et al., 2009].