Determining the Mass Composition of the Plasmasphere using Ground-Based Techniques and IMAGE RPI: A Statistical Study

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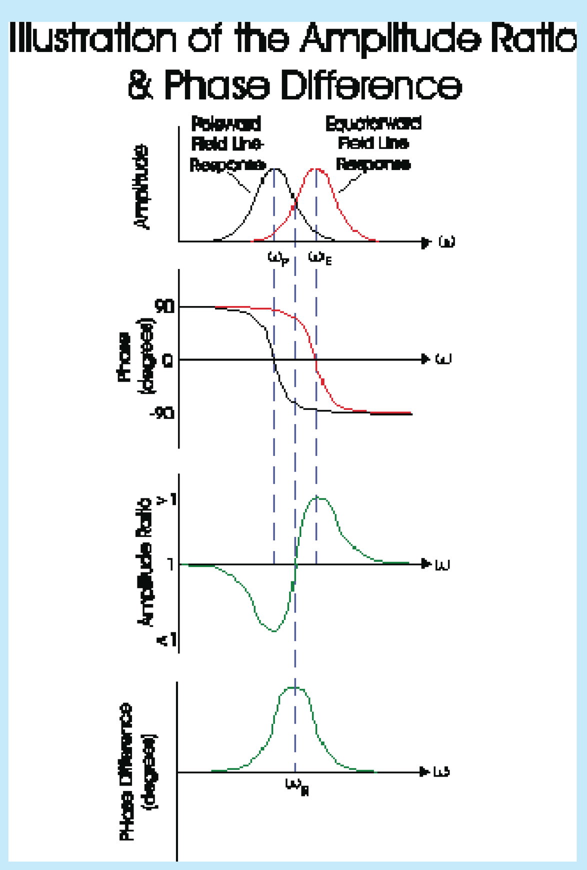
Abstract

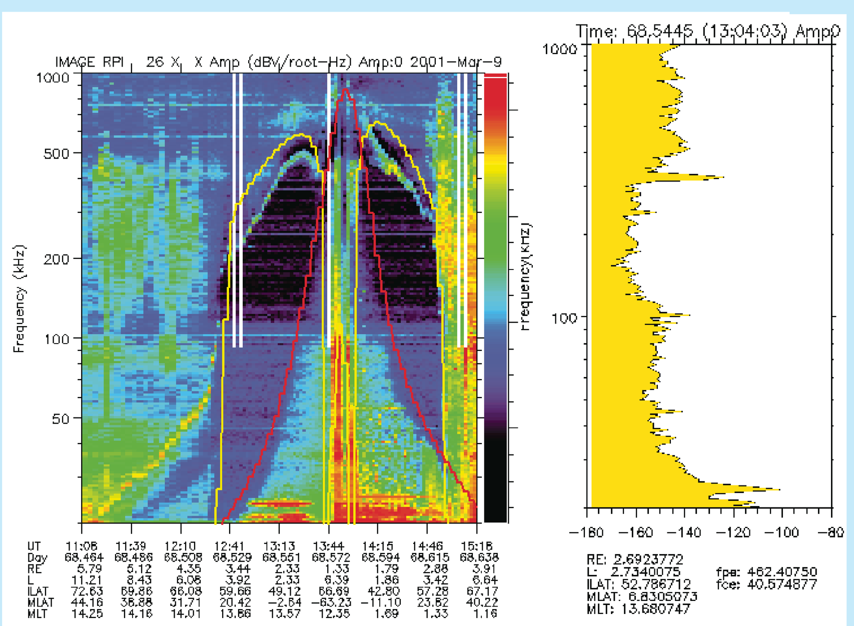
The average plasma mass density profile of the inner magnetosphere from 1.74<*L*<3.12 has been determined by compiling over 5200 hours of equatorial mass density computations using data from the MEASURE chain of ground-based magnetometers. The average ion mass as a function of *L*-shell is also computed by comparison with the equatorial electron density profile from IMAGE RPI. The average ion mass is used to constrain the overall concentration of heavy ions for different levels of geomagnetic activity. In particular, we find that during disturbed times, the concentration of heavy ions increases with increasing *L*-shell. At *L*=3, for the most disturbed times, we find a maximum O^+ concentration of approximately 30 percent, and a minimum of ~13 percent if we assume a purely He^+ and O^+ plasma.

Introduction

It is possible to infer the plasma mass density along magnetic field lines from toroidal mode eigenfrequencies. In the last several years, methods have been developed for measuring these frequencies using pairs of closely spaced ground magnetometers. Two of these methods are the cross-phase method [*Waters et al.*, 1991], and the power ratio method [*Baransky et al.,*1985]. The cross-phase method uses the fact that the H-component phase difference between a pair of stations maximizes at the resonant frequency of the field line whose footpoint lies halfway between them. The field line resonance condition using the power ratio technique is that the ratio of the H-component power is equal to unity with a negative slope at the resonant frequency of the field line whose footpoint lies halfway between the pair. Figure one illustrates the ideas behind the cross-phase and power ratio techniques. For this study, we infer the equatorial mass density assuming a r^{-3} radial dependence of density along the field line and using the results of *Shulz* [1996], who provided a relationship between resonant frequencies and plasma mass density.

The Radio Plasma Imager(RPI) on board the IMAGE spacecraft can be used to determine the local plasma electron density from measurements of the upper hybrid frequency, assuming a magnetic field from a model such as the Tsyganenko '96 model. Figure 2 (from *Fung et al.* [2001]) shows a typical RPI spectrogram as well as the "plasma line" from which the upper hybrid frequency, and hence the plasma frequency and electron density are computed.





Figures 1 and 2. Figure 1 illustrates the cross-phase and power ratio methods for determining field line resonant frequencies, and hence, plasma mass density along magnetic field lines. Figure 2 is an example of a RPI plasmagram from which the local electron frequency and electron number density are determined.

Methodology

We performed the cross-phase and power ratio techniques on all available data from 2000-2001 from the MEASURE array of ground-based magnetometers, which extends from *L=1.68* to *L=3.18* along the east coast of North America. For stations below L=2.5, we used the automated method of *Berube et al.* [2003]. We used data from five different pairs for the study, and have mass density estimates at *L* = 1.74, 2.3, 2.79, 2.89, and 3.12. A one hour FFT was used to compute the cross-phase and power ratio for each hour where a clear resonance was present. Frequencies were only selected if they met both the power ratio and cross-phase criteria. In total, a database containing over 5200 hours of density estimates from five pairs of magnetometers was created, and the average profile of mass density as a function of *L-shell* determined.

The overall profile of electron density has been determined by *Fung et al.* [2001] by constructing a database of all RPI electron density measurements from May 2000 - June 2001. We are only interested in measurements taken when IMAGE is in the equatorial region.

Besides computing the overall profile in mass density and electron density for 1.74 < L < 3.12, we determine the profile for highly disturbed times and moderately disturbed times by binning for various ranges of Dst.

Results

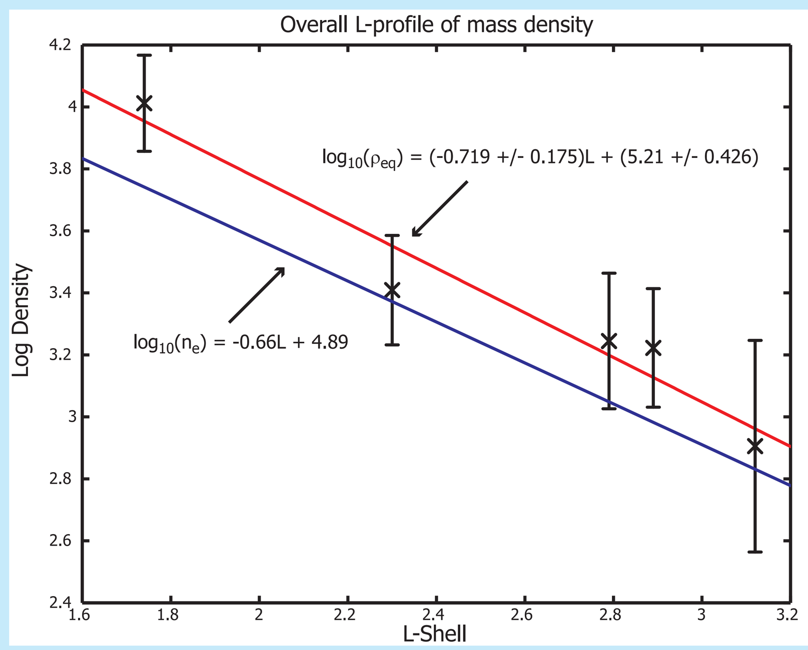


Figure 3. Overall L-profile of equatorial mass density (red line) and RPI electron density (blue line).

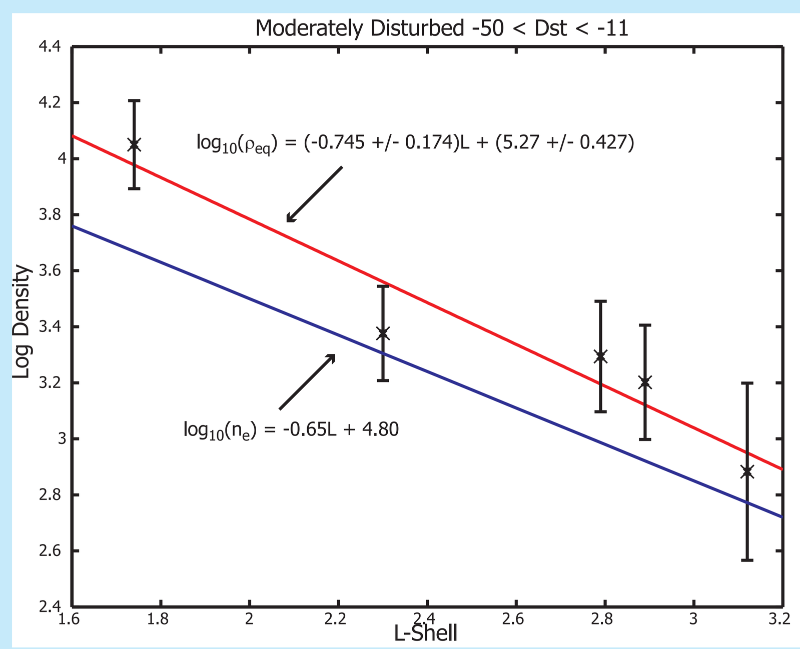


Figure 4. Profile of equatorial mass density (red line) and RPI electron density (blue line) for moderate Dst (-50 < Dst < -11).

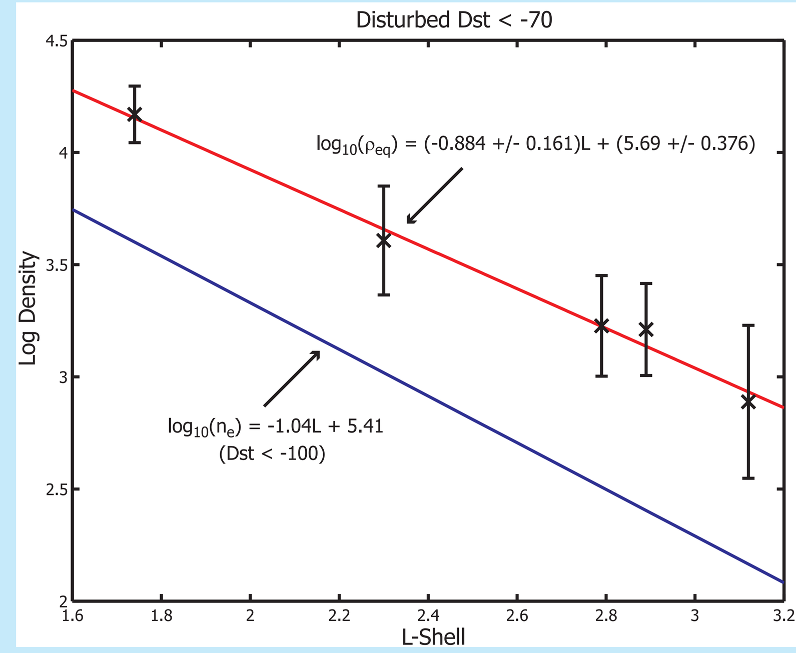


Figure 5. Profile of equatorial mass density (red line) and RPI electron density (blue line) for disturbed times (Dst < -70).

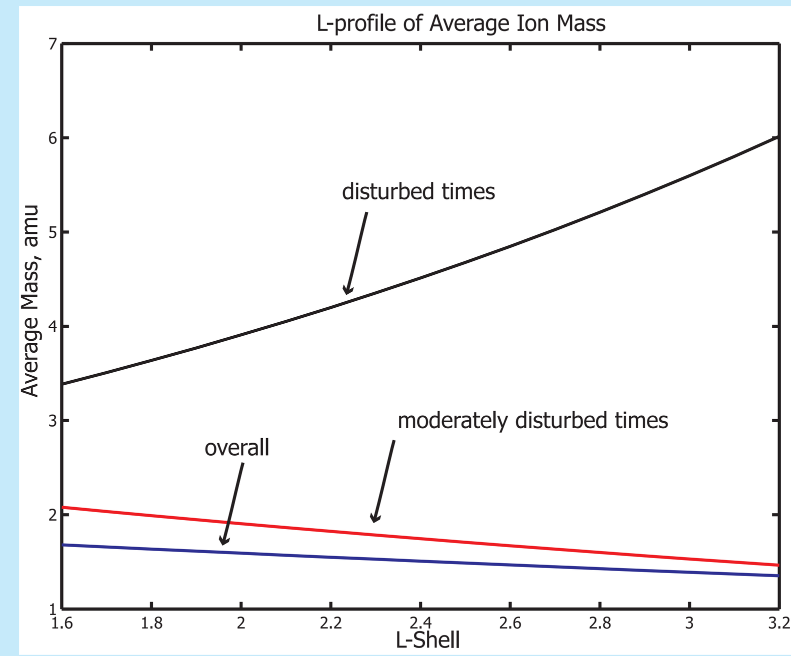


Figure 6. Average Ion Mass (ρ_{eq}/n_e) for the overall, moderately disturbed, and very disturbed bins. During very disturbed times, the average ion mass increases with increasing *L-shell*.

Discussion and Future Work

Figure 3 shows the overall mass density and electron density profiles. If we assume a plasma made up only of protons and O^+, we can constrain the concentration of heavy ions within the plasmasphere. The blue line in figure 6 shows the average mass for the overall profiles. From the overall average mass profile, we estimate the average maximum concentration of O^+ to be ~3.9% at L=2 and ~2.7% at L=3. Figure 5 shows the same mass density and electron number density profiles for the most disturbed times (Dst < -70, for MEASURE; Dst < -100 for IMAGE). The results in figure 5 correspond to the black line in figure 6. We find that the average ion mass, and hence the heavy ion concentration, increases with increasing L-shell for the most disturbed times. We estimate that the average maximum concentration of O^+ is ~19.4% at L=2 and ~31% at L=3. If we assume a purely He+ and O+ plasma then the minimum O+ concentration is ~13% We conclude that heavy ions clearly play an increasing role with increasing geomagnetic activity.

Future work on this topic will include adding more data to the mass density database from more pairs of stations at different latitudes and longitudes in order to improve the determination of average ion mass. Also, if the He^+ abundance in the plasmasphere is known from another technique such as inversion of IMAGE EUV data, then we would be able to constrain the heavy ion concentration even further.

References
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