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ON THE CONSEQUENCES OF BI-MAXWELLIAN
PLASMA DISTRIBUTIONS FOR PARALLEL ELECTRIC FIELDS

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Plasma observations near the earth's magnetic equator in the outer plasmasphere indicate the presence of core plasma distributions which are often highly anisotropic. The core ion distributions are often 'pancake' like, that is, with enhanced fluxes at 90° pitch angle. These distributions can be modeled with reasonable success as bi-Maxwellian distributions, with perpendicular temperatures as much as an order of magnitude greater than the parallel temperatures. (2)

The anisotropy of the electron distributions will, in general, differ from that found in the ions. In equilibrium, this immediately leads to a requirement for a parallel electric field to maintain charge neutrality. (1) The purpose of the work described here is to investigate the nature of the electric field which is implied by the equatorial measurements of the equatorial plasma measurements near the plasmopause, and the consequences of this electric field for the evolution of the plasma distribution along the field line. The variations in density and perpendicular temperature predicted by kinetic theory will be compared to observations.

Trapped ion (and electron) distributions have been reported for a number of years from the outer plasmasphere, particularly near geosynchronous orbit. Such pitch angle distributions are also typically termed 'pancake' distributions. Data from the electrostatic analyzers on SCATHA showed such trapped distributions, and it was found that the ion (and electron) observations obtained near the magnetic equator, from L ~5.5 to 7, could be described as bi-Maxwellians (2). Ion temperatures of 0.6-0.8 eV were found in the parallel direction, and ~25 eV in the perpendicular direction. (4)

The polar orbiting Dynamics Explorer 1 (DE-1) satellite with provided orbital coverage of the outer plasmasphere which included orbit segments of nearly constant "L", particularly near apogee, at L = 4.5. DE-1 measurements by the Retarding Ion Mass Spectrometer showed that the equatorially trapped plasma was primarily hydrogen ions, and provided latitudinal profiles which clearly showed the trapped nature of these ion distributions. (3)

The DE-1 ion measurements can also be fitted with bi-Maxwellian distributions. Such modeling requires careful consideration of the detector response, with integration in energy and angle. The fitting process uses a model detector response, with the ability to specify an arbitrary ambient distribution function. Fitting data obtained on 5 January 1984, obtained at L = 4.6, 1600 MLT, during a reasonably typical equator crossing, gave the fit parameters: $n = 18$ /cm³, $T_{para} = 2$ eV, $T_{perp} = 33$ eV, assuming a spacecraft

potential of +3 V. The density and perpendicular temperature are considered fairly accurate, but there are some indications that the parallel temperature seems to be a bit high.

Our objective is to use the measurements of the equatorial particle distributions to obtain the parallel electric field structure and the evolution of the plasma distribution function along the field line. Appropriate use of kinetic theory allows us to use the measured (and inferred) particle distributions to obtain the electric field, and hence the variation in plasma density along the magnetic field line. The approach, here, is to utilize the adiabatic invariants, and assume the plasma distributions are in equilibrium.

Swann set the basis for this work by showing how, in a collisionless plasma, the distribution function remains invariant for motion along a magnetic field line. (5) A useful formalism for studying the problem, is to make use of the invariance of the total energy, and the first adiabatic invariant, μ . (6) If quasi-neutrality is invoked, it is possible to obtain an expression for the electric field. These integrals are relatively straightforward for bi-Maxwellian distributions.

The results of such analysis are that the distribution function remains the shape of a bi-Maxwellian, even in the presence of a parallel electric field. The parallel temperature remains constant, while the perpendicular temperature drops. The reduced perpendicular temperature is:

$$kT_{\perp\lambda} = \frac{kT_{\perp 0}}{kT_{\perp 0}/kT_{\parallel} + B_0/B_{\lambda}(1 - kT_{\perp 0}/kT_{\parallel})} \quad [1]$$

The new perpendicular temperature is a simple scalar function of the equatorial temperatures, and the change in magnetic field strength. Note that T_{\perp} will approach T_{\parallel} as latitude increases.

The density can be obtained, as well, as a function of the magnetic latitude, and the parallel electric field established by the charge neutrality requirement of the plasma.

$$n_{\lambda} = n_0 (kT_{\perp\lambda}/kT_{\perp 0}) \exp(-q\phi/kT_{\parallel}) \quad [2]$$

The familiar Boltzmann factor appears, along with the temperature ratio, determined in equation 1.

The potential can be obtained by setting the electron and ion densities equal to one another. This requires a specification of the electron and ion distribution. The electric field implied by the SCATHA data described above, and the DE-1 data shown here was evaluated, and found to be ~ 0.1 $\mu\text{V}/\text{m}$. The effect on the plasma density is to retard the drop in ion density implied by the local mirroring of the trapped ions.

The variation in temperature and density with latitude can be compared with measurements from DE-1. Figure 1 shows how the ion plasma parameters vary with latitude, and compares them to the model. The data analysis showed a drop from ~ 30 eV perpendicular temperature to ~ 10 eV in less than 10° travel away from the equator. The parallel temperature remained constant at ~ 2 eV.

The fitted temperatures and density are overlaid with the curves determined solely by the equatorial measurements. The $T_{\text{perp}}/T_{\text{parallel}}$ ratio of 18 is the value generated by the model; a ratio of 40 appears to more closely match the variation in ion temperature. Note that this aspect of the model does not depend on the electron characteristics (and by implication, the electric field), or on the effects of an isotropic background - only on the temperature ratio at the equator. This comparison of model and data suggests that the parallel ion temperature is closer to ~ 0.8 eV, close to the value found with SCATHA, and a much more typical value for the isotropic plasma of the outer plasmasphere.

The density decrease expected in the absence of an electric field is overlaid on the ion density estimate. It describes the variation in density of the trapped plasma reasonably well - the effects of the electric field are fairly modest close to the equator. The simple kinetic model for the variation in a bi-Maxwellian ion distribution gives a remarkably good agreement with the latitudinal profiles of temperature and density, for this case where there is a maximum in density at the magnetic equator.

The plasma distributions found in the outer plasmasphere can often be described as bi-Maxwellian distributions, at least for the core of the distribution. Specification of the full distribution function at the equator allowed us to develop a kinetic model for the variation in the ion temperature and density with latitude. Comparison of the model with DE data shows that for an isotropic electron background, there will be a local maximum in density at the equator, which is reasonably well described by the model. The potential drop in the equatorial region is only 1-2 V, since the parallel ion temperature is relatively low. Still, such potentials may be adequate to explain the apparent repulsion of low-energy field-aligned ion beams from the equatorial region.

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