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A POST-VOYAGER VIEW OF THE JOVIAN MAGNETOSPHERE—THE LOW ENERGY PLASMA INSIDE OF 50 R_J

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SUMMARY

This paper gives a brief account of the major results from the MIT plasma experiment, PLS, which were obtained during the flybys of Jupiter by Voyager 1 and Voyager 2 in March and July of 1979. About half of the results discussed in this paper have been published during the past year; about half are reports of work in progress which will be reported in a forthcoming issue of Journal of Geophysical Research dedicated to Voyager results. A complete bibliography is appended.

We discuss here only data obtained on the inbound trajectories of Voyager 1 and Voyager 2 from ~50 R_J from Jupiter to closest approach. The basic data are ion flux densities as a function of energy per unit charge; a complete spectrum over the range 10-5950 volts with resolution 29% in E/q is obtained every 96 seconds and a high resolution spectrum, 3.9%, every 192 seconds. In situ electron measurements over the same energy range were also made during the encounter periods. Figure 1 shows an E/q spectrum taken inside the orbit of Io (5.9 R_J) at a distance of ~5.3 R_J. The well resolved peaks in this spectrum are the result of a cold supersonic plasma which corotates rigidly with the magnetic field of Jupiter. That is the field forces all of the heavy ions injected into the magnetosphere by Io to move with a common velocity. In this special circumstance the experiment separates ions according to mass per charge rather than kinetic energy per charge, E/q. Between about 4.8 and 9 R_J the ion spectra can be fit to multi-Maxwellian distribution functions to obtain radial profiles of ion temperature and density, figure 2 and figure 3. The total positive charge density can also be found as a function of distance and compared with various measurements of electron density.

The in situ density and temperature measurements made along the spacecraft trajectory have been used with a theoretical expression for the distribution of ions and electrons along a magnetic field line to obtain two dimensional models of the Io plasma torus. That is contour maps showing the local density of electrons and various ionic species in a meridional plane have been constructed as shown in figures 4 and 5. The distribution of mass in the torus obtained in this way has been combined with the magnetic field model of Acuna and Ness [1] to obtain the profile of Alfven velocity in the torus, figure 6.

Beyond 10 R_J many ion spectra show resolved peaks in E/q. These have been analyzed to obtain the volume mass density, a.m.u./cc as a function of distance. The mass density as a function of radius is shown in figure 7. Local maxima indicate plasma

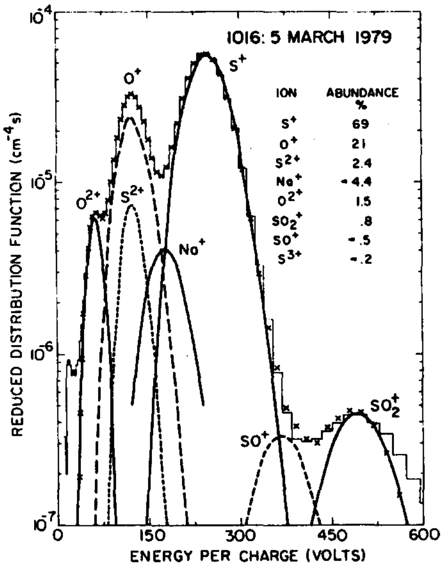


Figure 1: Composition of the plasma in the cold region of the Io torus. The ordinate gives the reduced one-dimensional distribution function measured in the "look direction" of the C-sensor. The abscissa shows the energy per charge, E/q, of the ions. The histogram shows the actual data. The points shown by the x symbols are the results of a simultaneous least squares fit to the data with a sum of convected isotropic Maxwellian distributions. The sum is over the indicated values of A/Z^x. Individual Maxwellian distributions are shown for the various species.

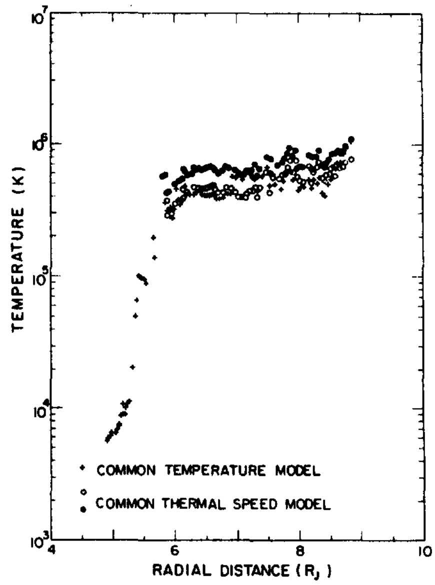
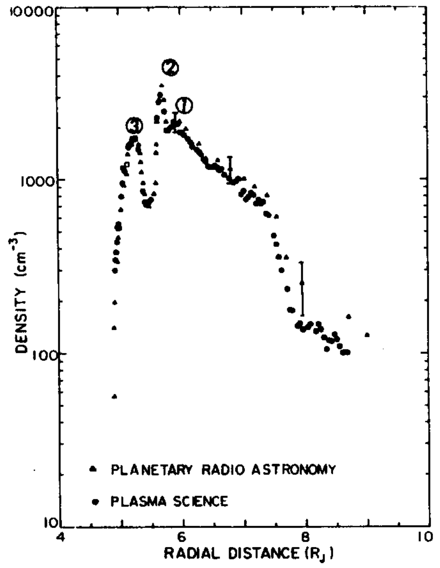


Figure 2: The temperature of the ions determined from fits to the energy per charge spectra under the assumptions that the ions are corotating with Jupiter's magnetic field and have mass to charge (A/Z^x) ratios of 8, 10-2/3, 16, 32 and 64. Inward of 5.7 R_J the spectral peaks are well resolved and the ions are isothermal. When the spectral peaks overlap, the spectra have been fitted assuming the ions have a) common temperature; b) common thermal speed. For the common thermal speed model the average temperature is shown for the $A/Z^x = 16$ peak corresponding entirely to S^{2+} (o) or O^+ (•).

sheet crossings which may or may not coincide with the position of the current sheet as determined from magnetometer data. The E/q spectra have also been used to determine the component of plasma velocity along the axis of the plasma sensor. This component of the plasma velocity has been compared as a function of distance from Jupiter with that expected under the assumption that the plasma moves at the full corotation velocity, i.e., $\overline{\Omega}_J \times \overline{r}$. The results, figure 8, indicate that the velocity starts to depart from the value predicted on the basis of strict corotation at about 7.5 R_J and reaches a limiting value of 200 km/sec at about 20 R_J.

If one uses the velocity profile obtained in this way as a parameter almost all of the spectra can be analyzed to give the number of positive charges per unit volume, i.e., $\Sigma_i n_i Z_i^*$/cc. Provided all positive ions (and electrons) are measured by the instrument the positive charge density should equal the in situ measurements of electron number density obtained by completely independent methods. The excellent agreement obtained between the two data sets is shown in figure 9.



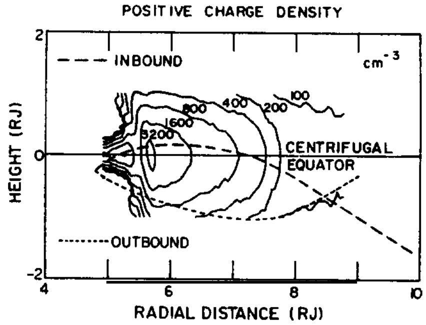
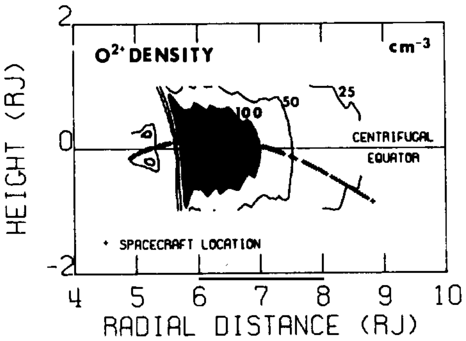


Figure 4: A contour map of local electron density required to balance the total charge of the positive ions. If possible azimuthal variations are neglected, the plot represents a cross-section through the torus in a meridional plane.

Figure 3: The electron density required to balance the total charge of the ions obtained from fits to the energy per charge spectra of the Plasma Science Experiment on Voyager 1.

Δ electron density determined by the Planetary Radio Astronomy Experiment on Voyager 1 (Warwick et al., 1979).
● equivalent electron density determined from the PLS positive ion measurements.



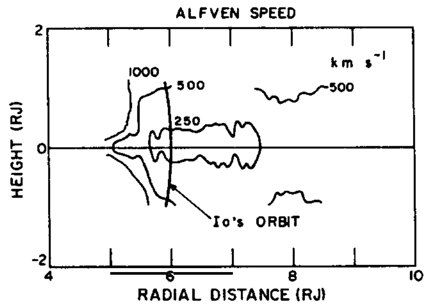


Figure 5: A contour map of the density of O^{2+} ions. The O^{2+} density and temperature at each spacecraft location were determined from the energy per charge spectrum under the assumption that the ions are isothermal. The two density peaks off, but symmetrical about, the centrifugal equator illustrate how minor species ions of low mass to charge ratio can be pulled away from the centrifugal equator by the field-aligned ambipolar electric field set up by the heavier dominant ions.

Figure 6: The local mass density combined with a magnetic field model (in this case the dipole part of the 04 model of Acuna and Ness, 1976) resulting in a contour map of local Alfven speed. As the dipolar magnetic field rotates with Jupiter, the 10^{0} tilt of the magnetic equatorial plane from Io's orbital plane produces a variation in the position of Io relative to the dense center of the torus. This means that Alfven waves generated near Io will take considerably different times to travel along the magnetic field to Jupiter depending on the varying longitude of Io.

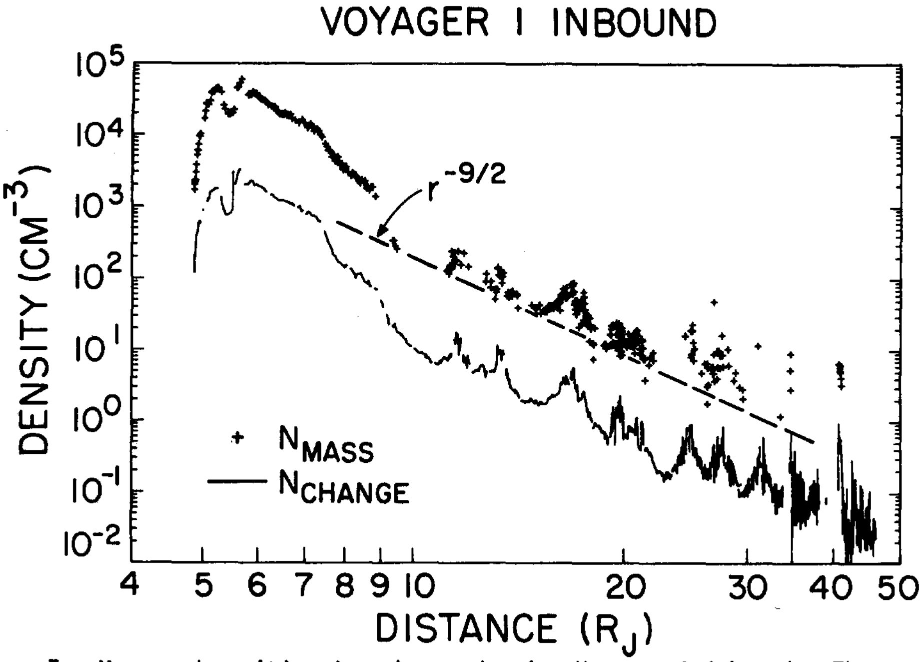


Figure 7: Mass and positive ion charge density Voyager 1 inbound. The crosses represent a.m.u./cc while the solid line gives the positive charge density per cc, i.e. $\sum_i n_i Z_i^x$.

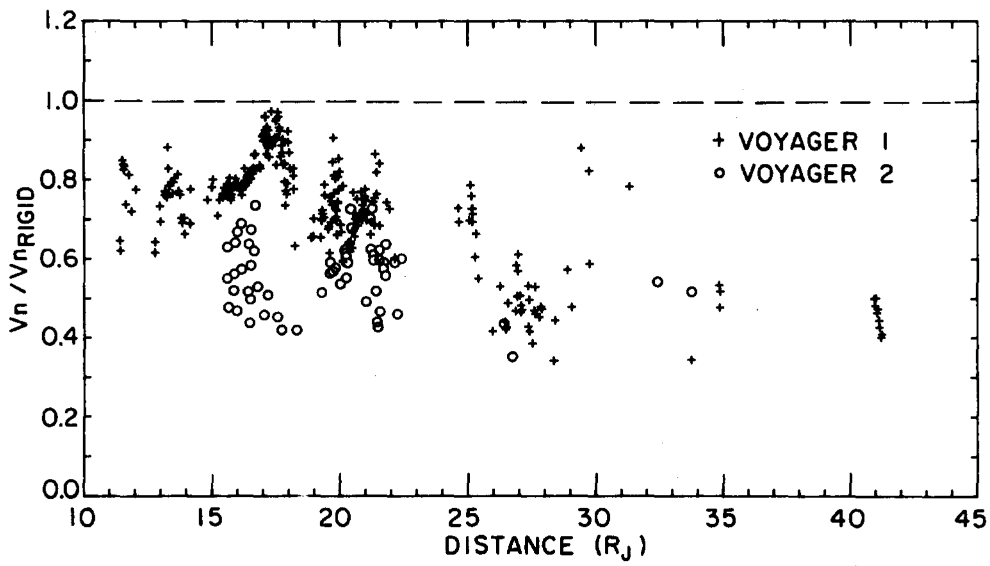


Figure 8: Departure of the plasma bulk velocity from corotation as a function of distance. V_n is the component of velocity parallel to the normal to the sensor and V_n rigid is the value expected on the basis of rigid corotation.

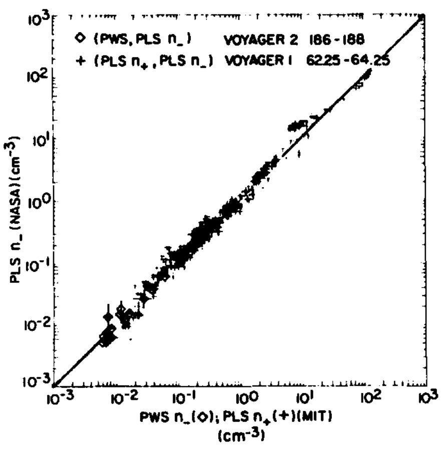


Figure 9: Scatter plot showing the comparison of PLS measurements of electron density (ordinate) with determinations of electron density measured by the PWS (plasma wave experiment) using the cut-off in broad-band continuum emission by Gurnett et al. (1981) (abscissa). The PLS n_-, PWS n_- comparison is shown by the symbol ◇ and the PLS n_-, PLS n_+ comparison by the symbol +. The slope one line is included for reference.

Results concerning the positive ions presented in this paper represent work of the Massachusetts Institute of Technology analysis group, principally by J. W. Belcher, J. D. Sullivan, R. L. McNutt, and Fran Bagenal with contributions from A. J. Lazarus, S. Olbert, C. C. Goodrich, and J. M. Jessen. The analysis of the electron component has been carried out by J. D. Scudder and E. C. Sittler of the Goddard Space Flight Center. Contributions to the theoretical interpretation have been made by V. M. Vasyliunas and C. K. Goertz of the Max-Planck Institut für Aeronomie and by G. L. Siscoe and J. D. Richardson of the University of California at Los Angeles.

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The following papers have been submitted to the Special Voyager Issue of the JGR which is scheduled for publication around April 1981.

13. J. W. Belcher, C. K. Goertz, J. D. Sullivan, and M. H. Acũna: Plasma Observations of the Alfven Wave Generated by Io.

14. F. Bagenal and J. D. Sullivan: Direct Plasma Measurements in the Io Torus and Inner Magentosphere of Jupiter.

15. R. L. McNutt and J. W. Belcher: Postive Ion Observations in the Middle Magnetosphere of Jupiter.

16. J. D. Scudder, E. C. Sittler, and H. S. Bridge: A Survey of the Plasma Electron Environment of Jupiter: A View From Jupiter.