netopause crossing ($r = 97\ R_J$ and SJP = 35°). Thereafter, until a radial distance of $r \approx 52\ R_J$ there was a regular periodic variation of all rates, with a period of 10.0 ± 0.5 hours. This period is identified with the planet's system III rotational period of 9.9249 hours. The well-defined minima are consistent with decimetric radio astronomical determinations of a dipolar tilt of 10° with pole at system III longitude $\lambda_{III} = 224°$ (Fig. 1). A more refined study is in progress. The regular pattern was disrupted by an apparent temporal variation between 0445 and 1030 U.T. on 1 December, during which all counting rates dropped to their magnetosheath values. Thereafter, the periodic pattern, with some significant differences in detail, resumed.

Beginning at about 0800 U.T. on 3 December ($r = 19\ R_J$), all counting rates began a strong upward climb of several orders of magnitude and reached their greatest values at 0210 U.T. on 4 December. The periapsis of the hyperbolic encounter trajectory occurred at 0315 U.T., about an hour later (Fig. 1) ($r = 2.82\ R_J$). The rates then declined to a strong minimum at 1545 U.T. ($r = 13.4\ R_J$) (Fig. 2b). Then the periodic pattern of variation of counting rates (see Fig. 1) resumed with broader minima and flatter maxima than on the inbound leg of the trajectory and with the previously observed 10-hour periodicity. This pattern was still being observed through 8 December ($r = 65\ R_J$ and SJP = 102°).

Preliminary iso-counting rate contours in a magnetic meridian plane are given in Figs. 3 and 4. Approximate expressions for the counting rates of detectors A and C as a function of radial distance r and magnetic latitude θ are of the form

$$R = k\exp[-(r/a) - (\theta/b)^2] \quad (1)$$

For detector A, $k = 2.0 \times 10^7$ and $a = 1.62\ R_J$ for $6 \leq r \leq 20\ R_J$; b declines from 20° at 7 R_J to 10° at 20 R_J. The unidirectional intensity in particles per square centimeter per second per steradian for electrons of energy $E_e > 8$ Mev is found by multiplying the rate of detector A by 100.

For detector C, $k = 1.0 \times 10^7$ and $a = 1.52\ R_J$ for $3 \leq r \leq 20\ R_J$; b declines from 16° at 3 R_J to 10° at 20 R_J. The omnidirectional intensity in particles per square centimeter per second for electrons with $E_e > 21$ Mev is found by multiplying the rate of detector C by 21.

On the basis of data from both inbound and outbound legs of the trajectory, it appears that energetic electrons in the outer magnetosphere of Jupiter are confined to a thin disklike region in the vicinity of the magnetic equatorial plane with approximate rotational symmetry about the magnetic axis. As the planet rotates the disk wobbles up and down across the spacecraft (Fig. 1) with a 10-hour period. This "magnetodisk" is interpreted as a region having a greatly distended magnetic field, a physical situation most clearly foreseen by Piddington (*2*). There is an analogous region in the earth's magnetosphere but only on its night side (*3*). The enormously greater centripetal force required of the magnetic field at Jupiter to confine thermal plasma is presumably responsible for wrapping the quasi-trapping region entirely around the planet as envisioned by Piddington.

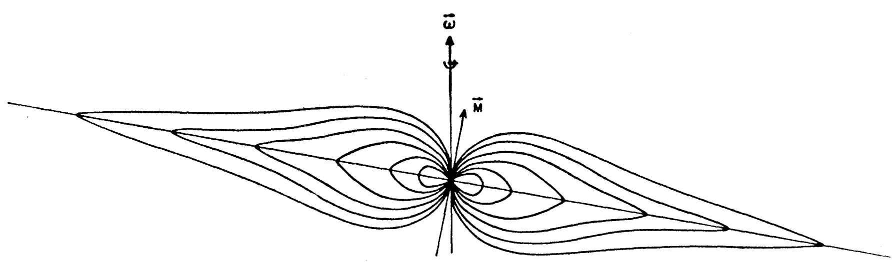

Fig. 5. Disk model of Jupiter's magnetosphere. Schematic diagram showing the hard trapping region within about 20 R_J and the magnetodisk region of quasi-trapping extending outward to approximately 100 R_J. Data on inbound and outbound legs of the trajectory at local times differing by 5 hours suggest approximate rotational symmetry about the magnetic axis M. A variation of this model is one (suggested by Axford) in which the outer part of the disk is envisioned as moving up and down parallel to itself rather than wobbling as a rigid disk as the planet rotates.

The more familiar hard trapping region extends out to approximately 20 R_J. Energetic electrons are confined rather closely to the equatorial plane as given by Eq. 1 and the associated values of k, a, and b. Figure 5 is a schematic representation of the foregoing.

A distinct dip in the counting rates of the lower energy detectors was observed as the spacecraft crossed the magnetic shell through the orbit of Europa on the inbound leg of the trajectory. There are much less well defined and highly tentative signatures at the crossings of the orbits of Ganymede and Io on the inbound leg and of Io, Europa, and Ganymede on the outbound leg (*4*).

There was no apparent degradation of the University of Iowa experiment throughout the encounter.

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5. Supported by NASA contracts NAS2-5603 and NAS2-6553 with the Ames Research Center and by ONR contracts N00014-68-A-0196-0003 and N00014-68-A-0196-0009. We are especially indebted to R. F. Randall, R. B. Brechwald, D. E. Cramer, and H. D. Owens at the University of Iowa for development of the apparatus and the associated data analysis programs, and to C. F. Hall, R. E. Fimmel, A. J. Wilhelmi, and A. Natwick at the Ames Research Center.

21 December 1973

Energetic Particle Population in the Jovian Magnetosphere: A Preliminary Note

This is a preliminary account of the Jovian encounter as viewed by the Pioneer 10 particle detector systems of Goddard Space Flight Center and the University of New Hampshire. The systems were designed to measure the charge, energy, and angular distribution of galactic and solar cosmic rays as well as the energetic particles in the Jovian magnetosphere. In the outer Jovian magnetosphere, the two cosmic ray detector systems provided excellent data on high energy protons and electrons, as well as measuring energetic helium nuclei. A third detector system, especially designed for high intensity fluxes, measured protons with energy from 0.5 to 21 Mev and electrons with energy from 0.1 to 1 Mev. The Jovian magnetosphere over its entire extent contains large numbers of electrons and protons with energies up to a few million electron volts. Conditions in the distant regions are rather disturbed, with rapid changes in flux and angular distribution. The configuration of this region is not understood; trapping lifetimes may be small and particles seem to be commonly leaking away from the boundary. The more energetic particles (> 10 Mev) are largely found within 20 Jupiter radii (R_J). All these particles appear to be confined to a rather narrow region about the magnetic equator, and there may be substantial azimuthal effects. Very little can be inferred about the latitudinal dependence of the fluxes inside 10 R_J.

The first detection of energetic particles near Jupiter came very early when Pioneer 10 was at a distance of $\sim$ 200 R_J from the planet. These were of the form of temporary electron increases with energies extending above 1 Mev. While such upstream effects are not uncommon in front of the earth's magnetosphere, their characteristic energies are much smaller—generally in the range 10 to 100 kev.

Pioneer 10 entered Jupiter's magnetosphere some 6 days later at a distance of approximately 100 R_J. Time histories for fluxes of 0.4- to 2.0-Mev protons and 0.4- to 1-Mev electrons are shown in Fig. 1. In Jupiter's magnetosphere, unlike our own, the boundary for energetic particles is not well defined. The low energy protons are seen well before the bow shock and extend farther out than the electrons. Flux ratios of electrons to protons for the energy range 0.4 to 1 Mev are of the order of 10/1 in the outer region and are generally decreasing as periapsis is approached.

Since Jupiter's magnetic axis is tilted with respect to its axis of rotation, the magnetic latitude of the spacecraft should vary with the rotation period of the planet ($\sim$ 10 hours). The points where the expected magnetic latitude was a minimum (that is, when the spacecraft was closest to or on the magnetic equator) are shown in Figs. 1 to 3 as solid vertical bars. Generally, on the inbound pass, the predicted magnetic latitude varied between about +2° and −20° (depending on the assumed value for this dipole tilt). There are no obvious 10-hour periodicities in the particle fluxes in the distant outer region ($\sim$ 80 to 100 R_J). Inside 80 R_J, first the 1-Mev protons and then the electrons show increased fluxes near the magnetic equator. As we move inward these particles are apparently becoming more and more confined near the magnetic equator, consistent with a thin disk model for Jupiter's magnetosphere as defined by energetic protons and electrons. Inside $\sim$ 40 R_J this lati-

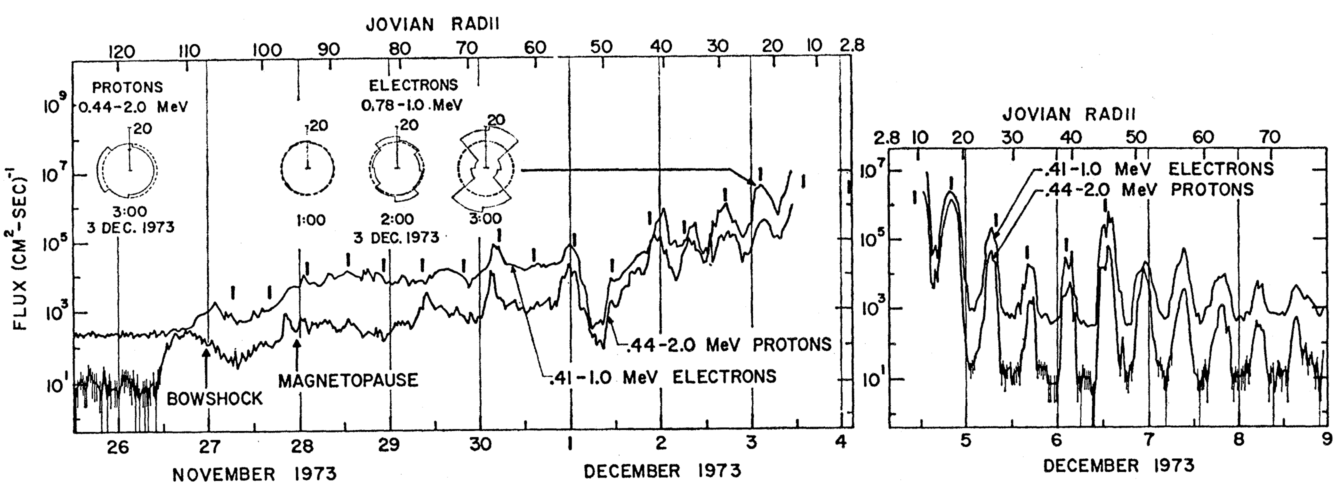

Fig. 1. Fluxes are shown for protons (0.44 to 2.0 Mev) and electrons (0.41 to 1.0 Mev) for the period 25 November through 8 December 1973. Periods of count rate saturation have been removed from all data. Times of predicted minimum latitude or equatorial crossing are shown with broad vertical bars. Error bars are shown only where they are appreciable. The inserts in the top left show angular distributions in the data on 3 December, shown as a polar plot (eight sectors) with the radial amplitude plotted as percentage of total count rate. Tick marks are shown at 10 percent and 20 percent amplitude.

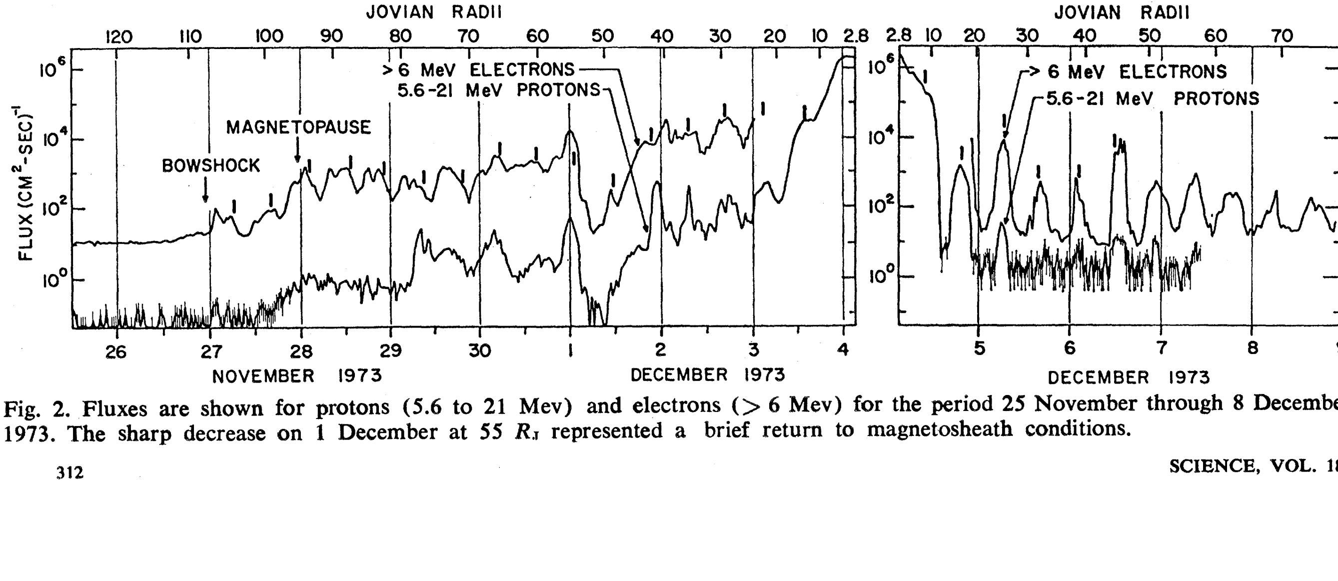

Fig. 2. Fluxes are shown for protons (5.6 to 21 Mev) and electrons (> 6 Mev) for the period 25 November through 8 December 1973. The sharp decrease on 1 December at 55 R_J represented a brief return to magnetosheath conditions.

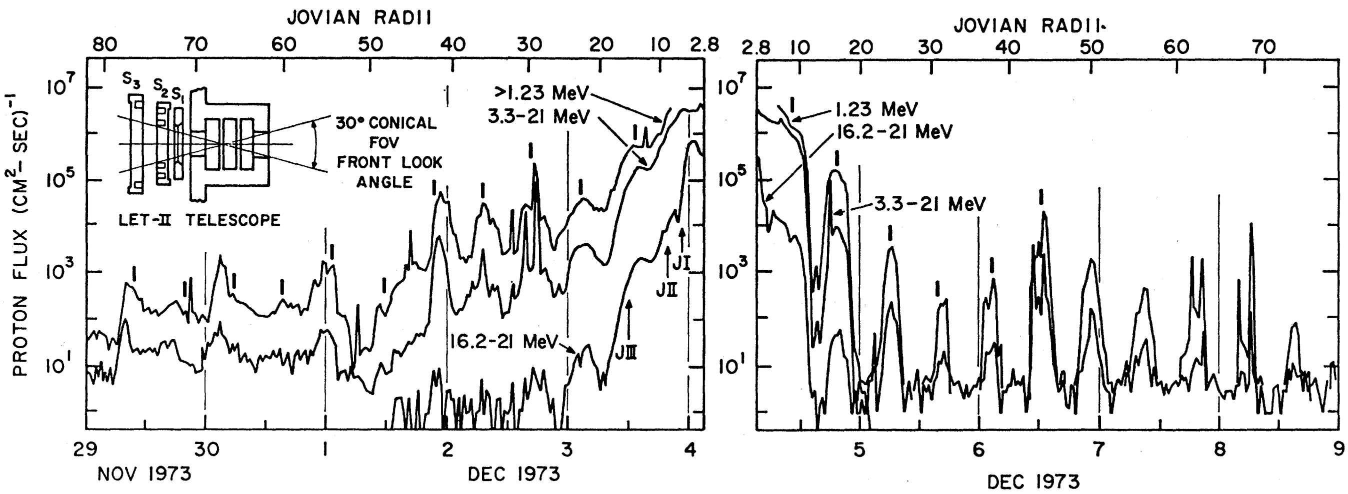

Fig. 3. Proton fluxes for three different energy intervals (> 1.23 Mev, 3.3 to 21 Mev, and 16.2 to 21 Mev) are shown for the period 29 November through 8 December 1973. The crossing of L shells corresponding to JI (Io), JII (Europa), and JIII (Ganymede) are noted. (Insert, upper left) Cross section of the LET-II telescope composed of S_1, a diode 50 μm thick; S_2, a diode 2.5 mm thick with an integral, annular anticoincidence ring; and S_3, a 2.5-mm-thick rear anticoincidence detector. The 30° conical field of view and geometry factor of .015 cm² ster are set by a brass collimator. The telescope was heavily shielded with lead and aluminum in all other directions.

tude confinement is even more pronounced. These low energy counting rates were in saturation for ~ 12 to 15 R_J either side of periapsis. On the outbound pass, the 10-hour periodicity is much more striking with peak-to-valley ratios as much as four or five decades. Outbound, the predicted magnetic latitude varied generally between 0° and 22°. The inbound trajectory enters the magnetosphere at an angle of ~ 35° to the Jupiter-Sun line, whereas the outbound trajectory leaves at close to 90°. This implies that, in the region of the magnetosphere traversed on the outbound pass, both protons and electrons are much more concentrated in low latitude regions. This behavior persists out to at least 80 R_J and is strikingly different from that on the inbound pass. The strong differences in behavior on the inbound and outbound legs suggests that there may be significant azimuthal variations in the structure of the Jovian magnetosphere.

The experiment accumulates angular information for 12 different particle-energy combinations every 96 seconds. The inserts in Fig. 1 show four polar plots of particle angular distributions. From 90 to 60 R_J irregular and changing proton distributions are often seen. Inside 60 R_J, one typically saw a substantial anisotropy (such as that shown in Fig. 1) which is probably produced by corotation or particle gradients or both. Over most of the magnetosphere it was surprising how often the electron fluxes were found to be isotropic. There are transient periods of anisotropy, however, and a good example is outlined in the three polar plots for electrons in Fig. 1. This "dumbbell distribution" is observed in the earth's tail region for lower energies and is associated with particles flowing along the field line, and mirroring very far away. Two hours later, the distribution was once again isotropic. This event occurred during a period of rising fluxes. Either these electrons had a very short lifetime or they were restricted to a very narrow region of field lines.

Figure 2 shows proton and electron time histories at higher energies (> 6 Mev). These particles do not extend as far out in the magnetosphere as the lower energy particles in Fig. 1. However, a 10-hour periodicity is seen much earlier in the high energy electrons, indicating that the outer disk structure is more pronounced for these particles. There is a consistent phase difference between the latitude minima and the minima in the flux of high energy electrons in the region from 70 to 100 R_J. This may indicate distortion of the outer disk structure. The electron/proton ratio at these energies is substantially higher (~ 10^3 in the outer regions) indicating that the proton spectrum is much steeper than the electron spectrum. Inside 80 R_J these protons sometimes show large increases uncorrelated with the electrons, and so this ratio decreases at times to less than a factor of 10. The higher energy particles show even larger peak-to-valley ratios than the lower energy particles in Fig. 1. They are, therefore, even more strongly confined to the equatorial regions.

Three proton energy intervals from the high intensity monitor are shown in Fig. 3. There may be some saturation effects within 5 R_J so this portion should be treated with caution. Note that inside 17 R_J the proton flux > 16 Mev increases very strongly and the energy spectra appear to become increasingly harder. The times when the shells of the innermost Galilean satellites were crossed are also indicated in Fig. 3. Local decreases are seen at both crossings of Io's (JI) shell and on the outbound crossing of Europa's (JII) shell. These times do not coincide with the 10-hour minima and are therefore probably caused by the sweeping effect of the satellites. Helium nuclei with energy in the range 3.3 to 21 Mev per nucleon are clearly identified by multiparameter analysis between 25 and 80 R_J. These show marked increases during proton peaks such as the 40 R_J peak. The helium/proton ratio at this time is $\sim 3 \times 10^{-3}$.

This experiment is mounted outside the spacecraft and several electronic malfunctions in logic and switching circuits were induced during the several-hour period of closest approach. While annealing effects have restored most of these, they provide another indication of the severity of the inner Jovian radiation region.

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