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JOVIAN PROTONS AND ELECTRONS: PIONEER 11

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In this paper we present a preliminary account of the Pioneer 11 passage through the Jovian magnetosphere as viewed by the particle detector systems of the Goddard Space Flight Center and the University of New Hampshire. The detector systems and their operation have been previously described.[1,2,3] In this brief note, we will restrict our comments almost entirely to the region well within the Jovian magnetosphere using data from the LET-II telescope. This detector system measures the proton flux from 0.2 to 21.2 MeV in seven energy intervals and electrons from 0.1 to 2 MeV in four intervals. It is well shielded, has a small geometric factor (.015 cm^2-ster) and has an extended dynamic range allowing flux measurements to $\sim 3 \times 10^7/cm^2$-sec. Representative electron and proton rates (up to $\sim$2 MeV) are sampled over eight angular sectors to study particle anisotropies.

In a previous Pioneer 10 paper[2] we had described the Jovian magnetosphere in terms of certain characteristic regions: the region outside the magnetosphere where large fluxes of MeV electrons and protons are observed to be coming from the magnetosphere; the outer Jovian magnetosphere extending from bow shock crossings to $\sim 50\ R_j$, a region of quasi-trapping and diffusion; a transition region between ~ 50 and $\sim 25\ R_j$ - e.g., between the outer diffusion zone and the region where the magnetic field rigidly rotates with the planet; and the region inside $\sim 25\ R_j$ which is the really stable trapping region. This is a tentative morphology and is similar to that advanced by the other Pioneer 10 particle experimenters.[4,5,6,7,8] The topology of this magnetosphere which emerges from the results of the particle, magnetic field,[9] and plasma[10] measurements is very complicated. One has a rapidly-rotating, giant magnetosphere which is easily deformed; where the physics is often dominated by a hot plasma inferred but not directly measured by Pioneer; where the offset and tilted magnetic field results in a complicated, floppy motion of the magnetic field and the particles within it; and where Pioneer 10 results showed quite a different character for this magnetosphere inbound on the sun side, as opposed to the outbound trajectory near the dawn meridian where the electrons and protons were much more concentrated near the equator.

On Pioneer 10, increases of low-energy Jovian electrons (0.2-8 MeV) were observed more than 1 AU away from Jupiter.[11,12] On Pioneer 11 these increases were first observed in January, 1974, when the spacecraft was $\sim$2 AU from the planet. These electron increases persisted over $\gtrsim$5-day periods and tended to recur at 27-day intervals. Furthermore, during the first half of 1974, many of these electron increases were readily detected at 1 AU by a more sensitive detector on IMP-VII. Due to space limitations, these observations will be published elsewhere. They further confirm that the quiet-time electron increases previously observed at 1 AU are, indeed, of Jovian origin. They suggest a rather stable interplanetary magnetic field configuration exists over this period with Jupiter and the Earth periodically being close to the same magnetic field lines.

Figure 1 gives an overview of the Pioneer 11 encounter with the Jovian magnetosphere for low-energy protons and electrons. Seen more clearly with our higher-energy detectors, electrons are commonly observed outside the magnetosphere. However, it is evident from this figure that large fluxes of low-energy protons also exist, observed well outside the magnetosphere. On Pioneer 10, low-energy protons were first observed only within a few Jupiter radii of the magnetopause. Here they are present for days in advance of crossing into the magnetosphere. This is not unexpected, since the outer Jovian magnetosphere is filled with unstably trapped protons and electrons. The continual presence of low-energy solar protons masks the detection of Jovian protons at large distances from the planet.

It is helpful at this point to discuss the relative trajectories of Pioneer 10 and 11. An introductory paper[13] describes the Pioneer encounter trajectories as viewed in Jovian local time. Pioneer 10 was on a prograde trajectory, approached Jupiter from a direction approximately 30° west of the sun, circled the planet in a counterclockwise direction, and exited towards the dawn meridian. Pioneer 11 approached Jupiter from the dawn side, circled the planet clockwise, and exited at high latitudes towards the direction of the Sun. In a simplified view, the inbound trajectory of Pioneer 11 near Jupiter was through the same region of the magnetosphere that Pioneer 10 traversed outbound. Indeed, the clear ~10-hour periodicities and large peak-to-valley ratios seen on Pioneer 11 between 50 R_j and 20 R_j inbound is quite similar to that measured outbound on Pioneer 10. Similarly, the data from Pioneer 10 inbound and Pioneer 11 outbound are qualitatively similar in terms of spectra, angular distributions, and time variations, although the measured fluxes here are consistently much less than those found on Pioneer 10 at lower latitudes. Pioneer 11 measurements in the inner, high-flux region produced verification of the Pioneer 10 results, as well as important new information, and will be discussed in detail later in this paper.

It is apparent from Figure 1 that the low-energy proton spectra changed little between the magnetopause and ~ 10 R_j. A detailed spectral analysis using data from both the LET-II and LET-I telescopes. (100 KeV to 21.2 MeV) shows the same general hardening of the spectrum as seen on Pioneer 10, as one moves from the magnetopause into the central trapping retion. However, the spectra measured on Pioneer 11 are always described by a single power law with index varying slowly from ~ 4 to ~ 3 as we penetrate the magnetosphere. This is in contrast to the inbound Pioneer 10 results closer to the magnetic equator, where the spectra inside ~ 40 R_j could not be described by a simple power law.

In order to understand the effects measured in the inner core region of the magnetosphere, the "wiggle diagrams" shown in Figure 2 are most useful.[14,15] Note that in this inner region of the magnetosphere, the Pioneer 10 and 11 measurements are directly comparable only at two points, both near L = 12. From ~ 2000 on December 2 to ~ 0130 on December 3, Pioneer 11 was on L shells ~ 12 R_j while moving from 13° to 44° south magnetic latitude. Then while remaining at essentially constant magnetic latitude, Pioneer 11 traversed L shells down to L = 3.4 at ~ 0445 when it passed through -40° magnetic latitude on its way to the equator one hour later.

It is of interest to examine in detail the low-energy nucleon component as shown in Figure 3. On Pioneer 11 the 14.8-21.2 MeV protons were found only inside 15 R_j, while on Pioneer 10 substantial fluxes were first seen at $\sim 40\ R_j$ and a monotonic increase was found inside $\sim 26\ R_j$. This is quite consistent, however, in view of the point made earlier that Pioneer 11 approached Jupiter from the dawn side, and Pioneer 10 found these higher-energy protons only inside $\sim 20\ R_j$ on the dawn side. The Pioneer 11 outbound fluxes go to zero beyond 20 R_j, but the spacecraft was at very high latitudes. Pioneer 10 and 11 data comparisons for both proton energy intervals at ∿1930 and ∿2200 (P11) show good agreement.

Decreases of a factor of ∿3.6 in the 14.8-21.2 MeV protons, were noted both times when crossing the orbit of Io, quite similar to the effects noted on Pioneer 10. Much larger Io effects were seen in the 1.2-2.1 MeV interval. Small but significant decreases are noted very close to the times of crossing of Amalthea's orbit, as predicted by the O_3 model of Jupiter's magnetic field.[16] In contrast to Pioneer 10, no substantial effects were seen on Pioneer 11 while crossing L shells appropriate to Europa.

A major feature is noted in the Pioneer 11 data at $L \sim 1.9$, $\lambda_m \sim 6°N(D_2)$ where a large, sharp peak in the proton flux occurs. The solid curve shown in Figure 3 for the 14.8 to 21.2 MeV protons reflects the actual count rates measured while the dashed curve reflects our best estimate of the true fluxes. Saturation of the involved anticoincidence rates were limiting further increase in the 14.8-21.2 MeV logical rates. Qualitatively, there are very large fluxes in the nucleonic component at the location at or near the magnetic equator and the peak fluxes including low-energy alpha particles could be up to a factor of 3 higher than those estimated ($\sim 4 \times 10^6\ p/cm^2 sec$).

For similar reasons, the large peak shown in the 1.2-2.1 MeV protons is highly suspected to contain many events which should have been logically rejected.

One of the most interesting results from Pioneer 10 was the discovery that Io was able to almost completely remove the lower-energy (1.2-2.1 MeV) protons.[2] Inbound, more than 99% of the protons in this energy interval were removed in the L region which Io occupies. This factor of ∿100 drop compares with a factor of ∿60 noted with Pioneer 10 data; but Pioneer 11 was at magnetic latitudes above 40° and the larger effect there is in agreement with predictions.[17,18]

Figure 4 shows the count rate data for 1.2 to 2.1 MeV protons for Pioneer 10 and 11 vs. L for the D_2 model.[9] Angular distributions measured on the spacecraft at the same times are shown at the indicated L locations. The magnetic latitude (D_2) is also indicated periodically, as well as the predicted regions occupied by Europa and Io. The fit of the data for the removal of particles at Io is fair, but lacks to the extent that on both Pioneer 10 and 11 count rates were dropping appreciably at times substantially after the innermost L shell predicted to be swept by Io. The fit to the D_2 model at Io appears to be much better than for the O_3 model[16] inbound at Io, however, No substantial removal of protons while passing through Europa's orbit is apparent from the Pioneer 11 data.

The Pioneer 10 angular distributions have already been discussed, but the Pioneer 11 angular distributions, together with calculations (O_3) from Pioneer 11 magnetic field data,[19] lead to considerably more insight into these magnetospheric phenomena. Outside L ∿ 10 R_j, the

O_3 model calculations[19] show that the loss cone was less than 5° and increased rapidly up to ∿30° as one came across Io's location, decreasing to very small values again as Pioneer 11 moved in and towards the equator. A similar and inverse effect occurred outbound. It seems quite clear that as the count rate levels off before reaching Io, we are observing the progressive loss of protons into the atmosphere due to the growing loss cone. The effect is even more pronounced at the count rate minimum inside Io. As Pioneer 11 moved inward further the loss cone rapidly shrunk, the fluxes rapidly increased, and the angular distribution moved towards a more isotropic distribution. An analagous effect was seen moving outbound. The Pioneer 11 data confirms our previous result that Io permits only ∿1% of the MeV protons to diffuse by its orbit. It also indicates that radial diffusion is the dominant acceleration process in this region for the low-energy nucleons.

In summary, the Pioneer 11 encounter with Jupiter produced most interesting comparisons, contrasts and new phenomena which will lead to a much better understanding of the Jovian magnetosphere. It is clear that Pioneer 11 was exposed to a much lower total radiation dose than Pioneer 10, largely as a result of the retrograde trajectory which approached and exited the inner region of the magnetosphere at high latitudes. Pioneer 11 has shown that a Jovian-orbiting satellite in a highly-inclined orbit could have a reasonable lifetime before radiation damage effects become a problem. This is most important because it could ultimately allow orbits through the magnetotail region where controlling phenomena probably occur.

Acknowledgements.

We are most appreciative of the magnetic field data for Pioneer 10 and 11 from the helium vector magnetometer by E.J. Smith and co-investigators and from the Pioneer 11 high field, flux gate magnetometer by M. Acuna and N. Ness.

Figure Captions

Figure 1 - Fluxes are shown for protons (0.5 to 2.1 MeV and 1.2 to 2.1 MeV) and electrons (0.1 to 2 MeV for the period November 24 to December 8, 1974). The locations of crossing of the bow shock (B) and magnetopause (M) are noted.[20] The relatively high background in this electron measurement from the LET-II telescope amounts to ∿2 counts/sec due to gamma rays from the radioisotope power supply.

Figure 2 - Projection of the trajectories of Pioneer 10 and 11 on a magnetic meridian plane of Jupiter based on the D2 model.[9] Note that the region sampled by Pioneer 10 was within ∿20° of the magnetic equator while Pioneer 11 was at much higher latitudes, usually above 40°. Beyond L ∿ 10 R_j, distortions are important, so the L = 20 trace is really an idealization.

Figure 3 - Flux profiles of 1.2-2.1 MeV and 14.8 to 21.2 MeV protons measured in the inner, core region of the Jovian magnetosphere by Pioneer 11. The locations of crossing of Amalthea's orbit from predictions of the O_3 model[16] are shown.

Figure 4 - Count rate data for the 1.2 to 2.1 MeV protons are shown for both Pioneer 10 and Pioneer 11 versus L calculated from the D_2 model of Jupiter's magnetic field.[9] The predicted regions of L to be swept by Io and Europa are shown. Angular distributions shown are summed in the experiment data system in eight 45° sectors of spin. The detector has a full field-of-view of 30°. The projection of the magnetic field vector on the sector plane is shown.

References

1. J.H. Trainor, B.J. Teegarden, D.E. Stilwell, F.B. McDonald, E.C. Roelof and W.R. Webber, Science 183, 311 (1974).

2. J.H. Trainor, F.B. McDonald, B.J. Teegarden, W.R. Webber and E.C. Roelof, J. Geophys. Res. 79, 3600 (1974).

3. D.E. Stilwell, R.M. Joyce, J.H. Trainor, H.P. White, Jr., G. Streeter, and J. Bernstein, IEEE Trans. Nucl. Sci. 22, No. 1 (1975).

4. J.A. Simpson, D.C. Hamilton, R.B. McKibben, A. Mogro-Campero, K.R. Pyle and A.J. Tuzzolino, J. Geophys. Res. 79, 3522 (1974).

5. R.B. McKibben and J.A. Simpson, J. Geophys. Res. 79, 3545 (1974).

6. J.A. Van Allen, D.N. Baker, B.A. Randall and D.D. Sentman, J. Geophys. Res. 79, 3559 (1974).

7. T.G. Northrop, C.K. Goertz and M.F. Thomsen, J. Geophys. Res. 79, 3579 (1974).

8. R.W. Fillius and C.E. McIlwain, J. Geophys. Res. 79, 3589 (1974).

9. E.J. Smith, L. Davis, Jr., D.E. Jones, P.J. Coleman, Jr., D.S. Colburn, P. Dyal, C.P. Sonnett and A.M.A. Frandsen, J. Geophys. Res. 79, 3501 (1974).

10. J.H. Wolfe, J.D. Mikalov, H.R. Collard, D.D. McKibben, L.A. Frank and D.S. Intriligator, J. Geophys. Res. 79, 3489 (1974).

11. B.J. Teegarden, F.B. McDonald, J.H. Trainor, W.R. Webber and E.C. Roelof, J. Geophys. Res. 79, 3615 (1974).

12. D.L. Chenette, T.F. Conlon and J.A. Simpson, J. Geophys. Res. 79, 3551 (1974).

13. C.F. Hall, to be published in Science, March, 1975.

14. G.D. Mead, J. Geophys. Res. 79, 3487 (1974).

15. G.D. Mead and R.E. Sweeney, Goddard Space Flight Center Document No. X-922-74-339, November 1974.

16. M. Acuna and N. Ness, to be published in Science, March, 1975.

17. G.D. Mead and W.N. Hess, J. Geophys. Res. 78, 2793 (1973).

18. W.N. Hess, T.J. Birmingham and G.D. Mead, J. Geophys. Res. 79, 2877 (1974).

References - continued:

19. M. Acuna and N. Ness, private communication, February 1975.

20. J.H. Wolfe, private communication, December (1974).

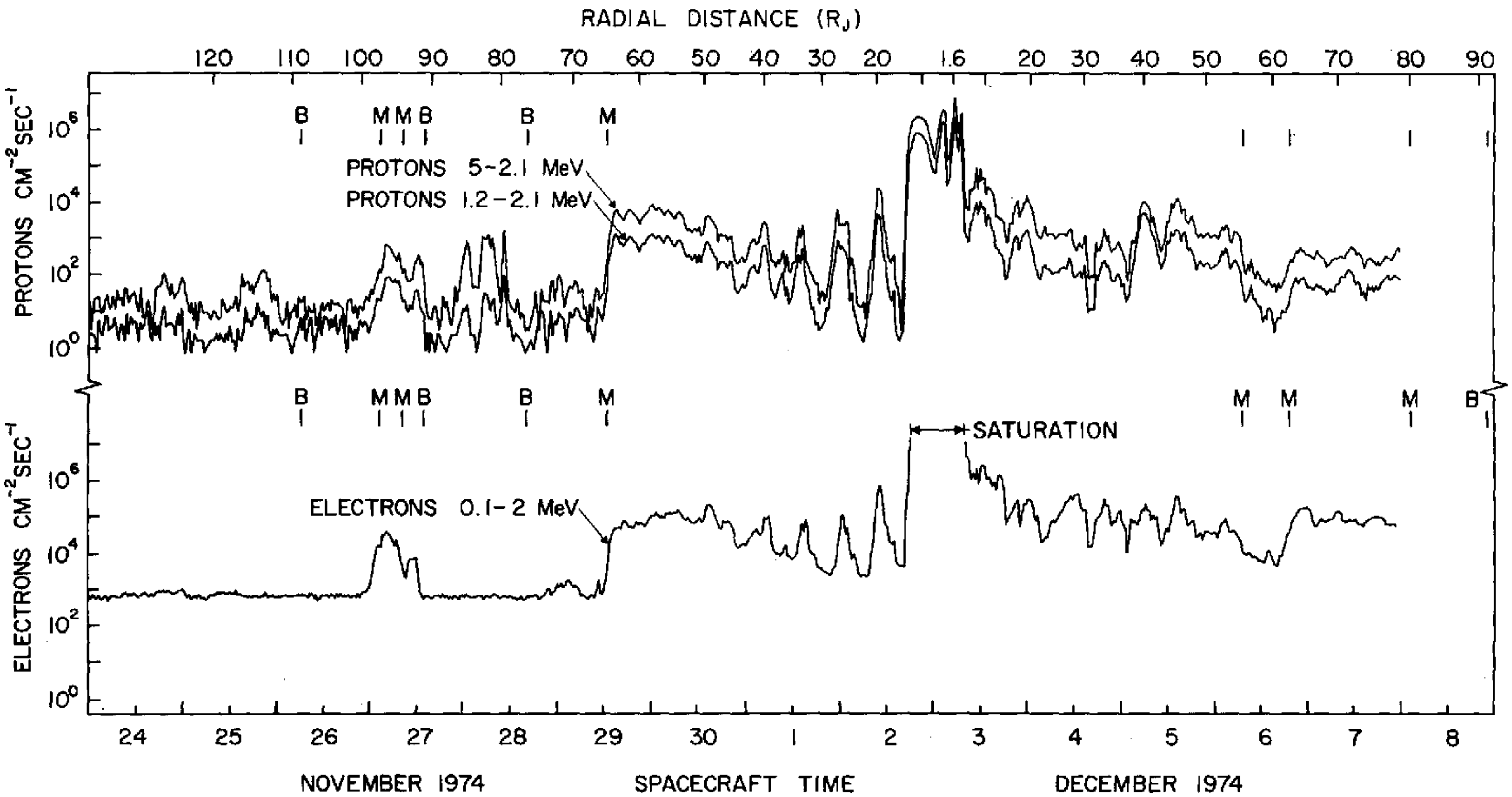
RADIAL DISTANCE (R_J)
120 110 100 90 80 70 60 50 40 30 20 1.6 20 30 40 50 60 70 80 90
B M M B B M
PROTONS 5-2.1 MeV
PROTONS 1.2-2.1 MeV
PROTONS $CM^{-2}SEC^{-1}$
10^6 10^4 10^2 10^0
B M M B B M M M M B
SATURATION
ELECTRONS 0.1-2 MeV
ELECTRONS $CM^{-2}SEC^{-1}$
10^6 10^4 10^2 10^0
24 25 26 27 28 29 30 1 2 3 4 5 6 7 8
NOVEMBER 1974
SPACECRAFT TIME
DECEMBER 1974

FIGURE 1

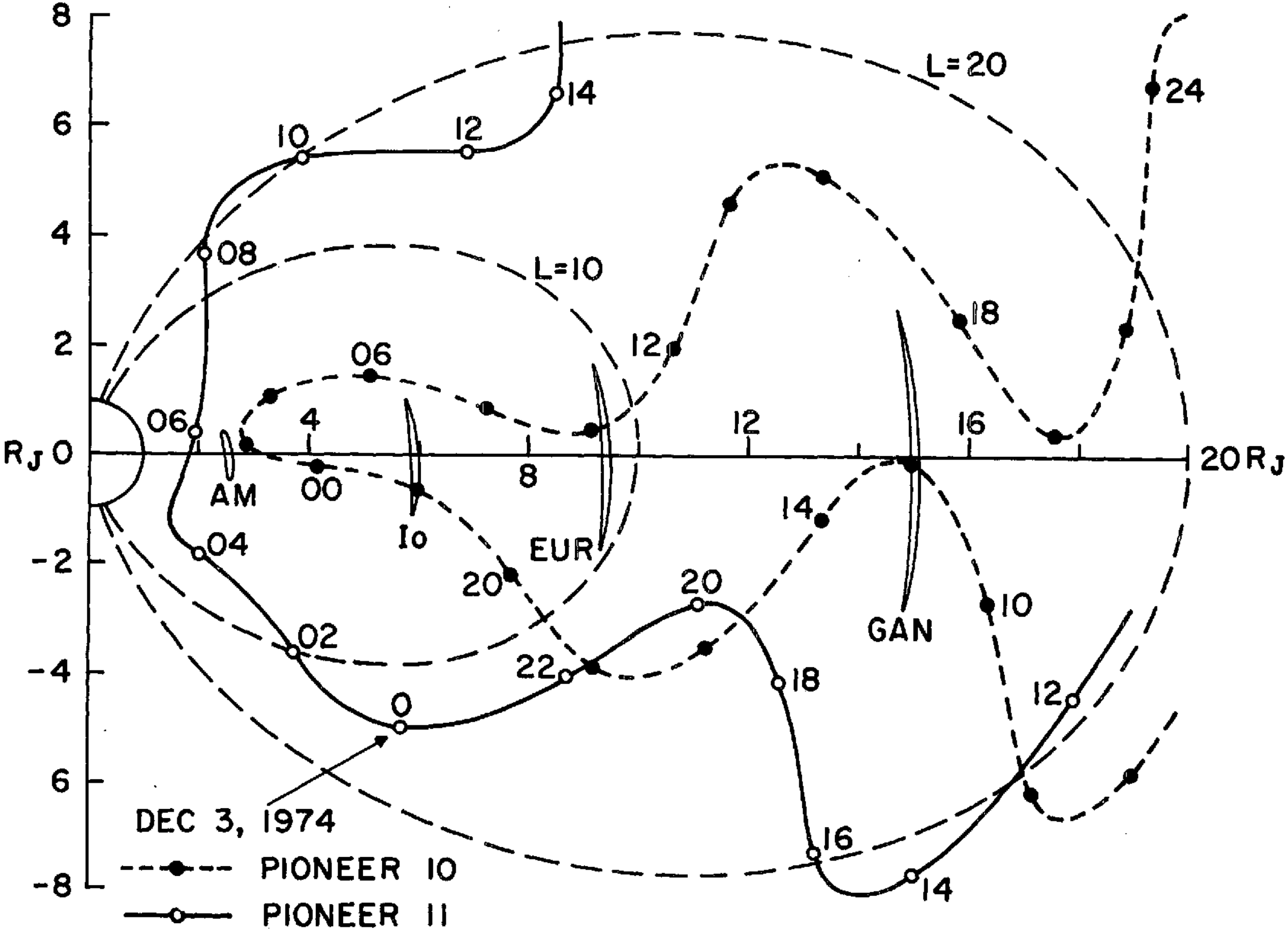
L=20
L=10
14
12
10
08
06
04
02
0
22
20
18
16
14
12
24
18
12
06
00
20
14
10
4
8
12
16
20 RJ
RJ 0
AM
Io
EUR
GAN
8
6
4
2
-2
-4
6
-8
DEC 3, 1974
PIONEER 10
PIONEER 11

FIGURE 2

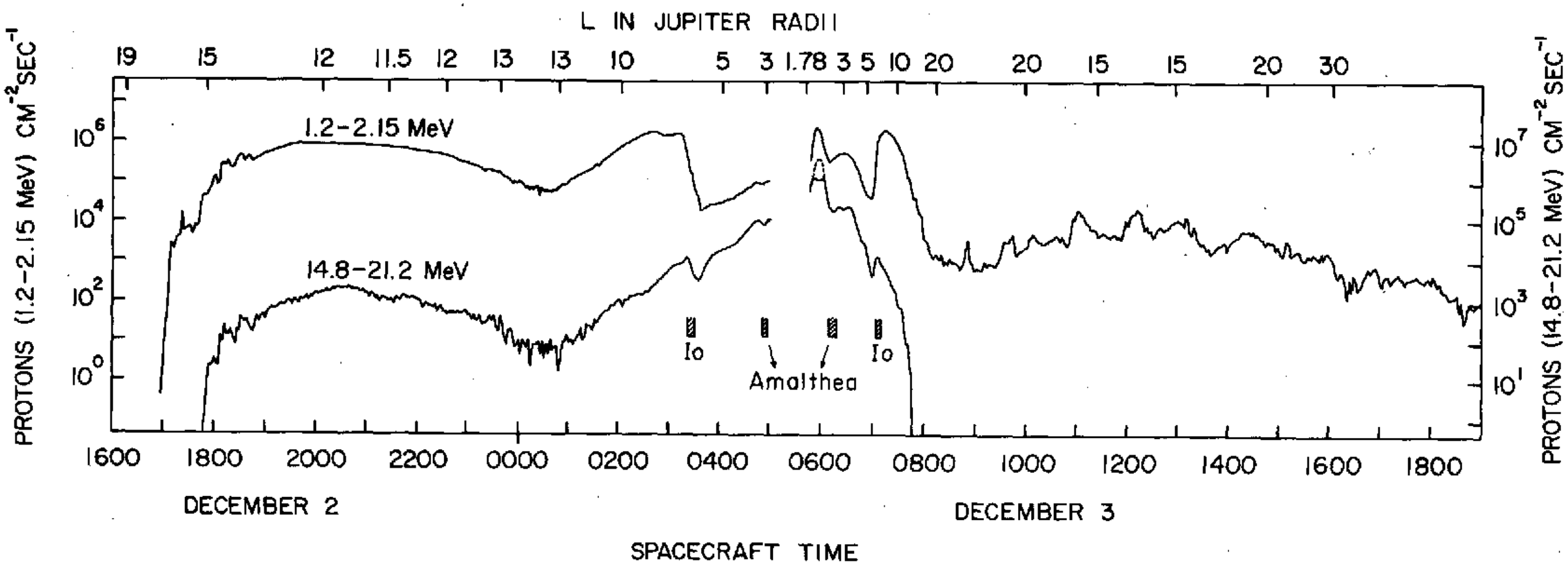
L IN JUPITER RADII
19
15
12
11.5
12
13
13
10
5
3
1.78
3
5
10
20
20
15
15
20
30
1.2-2.15 MeV
14.8-21.2 MeV
Io
Amalthea
Io
PROTONS (1.2-2.15 MeV) CM^{-2}SEC^{-1}
PROTONS (14.8-21.2 MeV) CM^{-2}SEC^{-1}
10^6
10^4
10^2
10^0
10^7
10^5
10^3
10^1
1600
1800
2000
2200
0000
0200
0400
0600
0800
1000
1200
1400
1600
1800
DECEMBER 2
DECEMBER 3
SPACECRAFT TIME

FIGURE 3

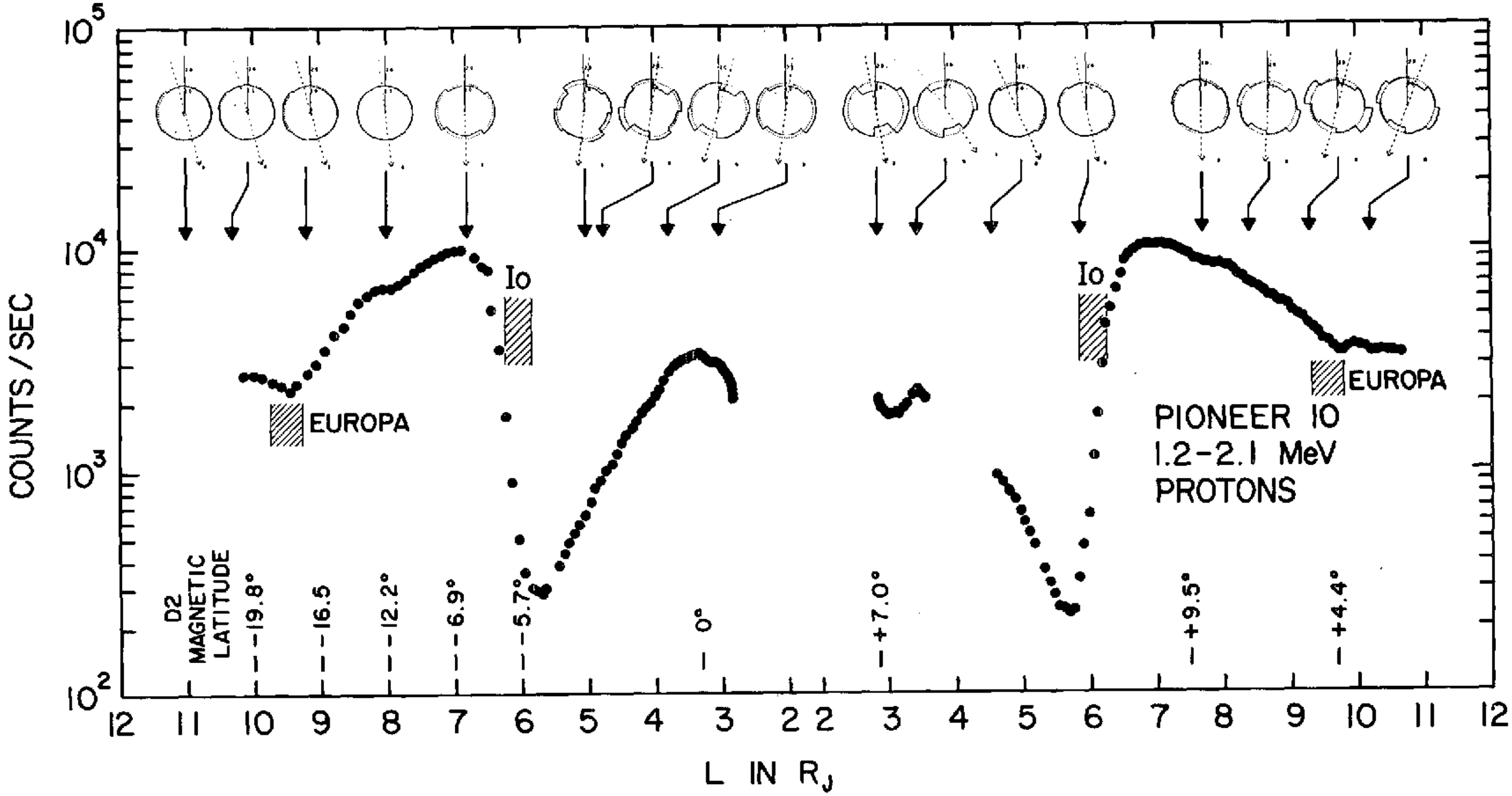
COUNTS / SEC
L IN R_J
D2 MAGNETIC LATITUDE
Io
EUROPA
PIONEER 10
1.2-2.1 MeV
PROTONS

FIGURE 4a

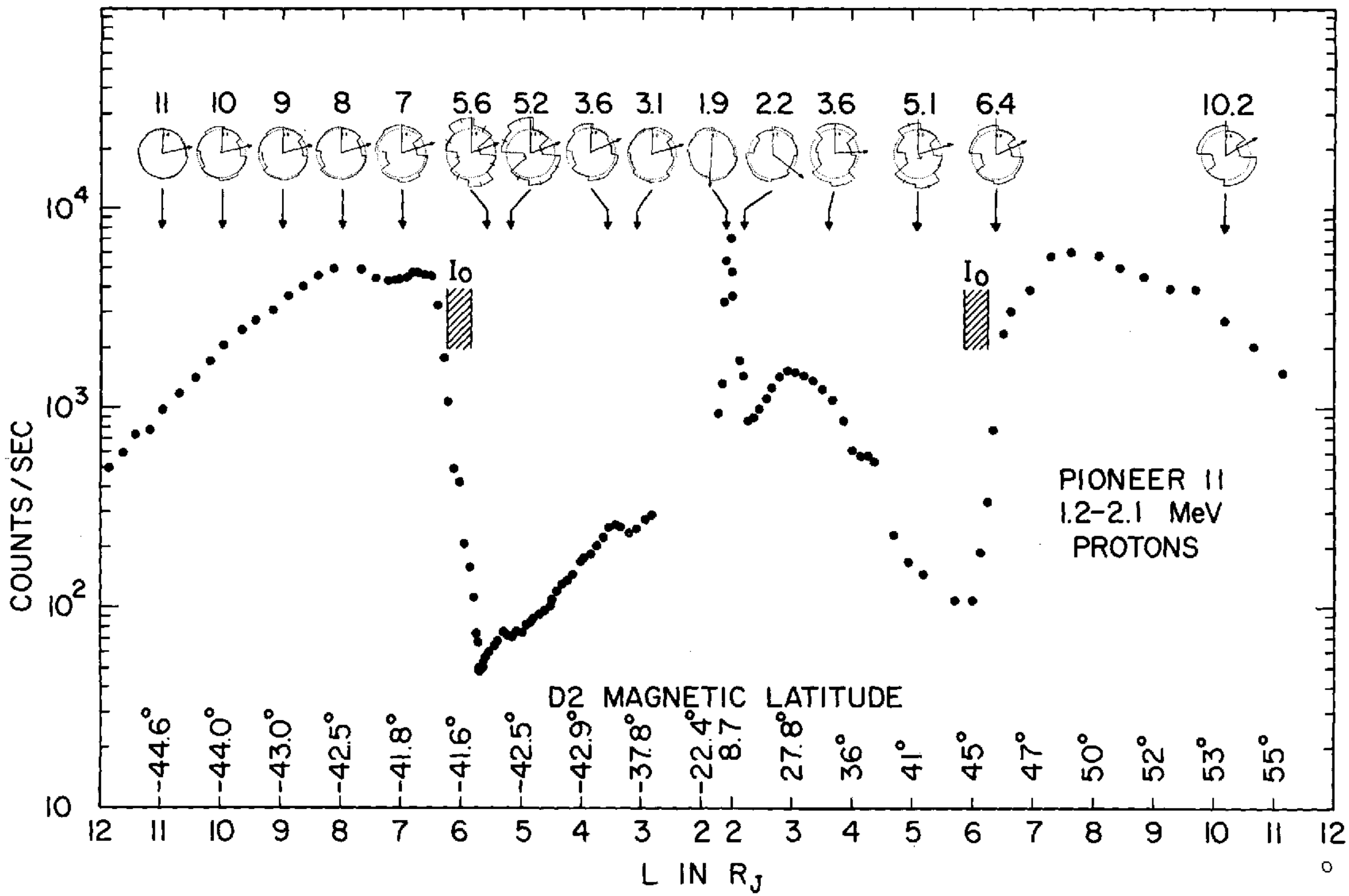
11 10 9 8 7 5.6 5.2 3.6 3.1 1.9 2.2 3.6 5.1 6.4 10.2
10^4
10^3
10^2
10
COUNTS/SEC
Io
Io
PIONEER 11
1.2-2.1 MeV
PROTONS
D2 MAGNETIC LATITUDE
-44.6° -44.0° -43.0° -42.5° -41.8° -41.6° -42.5° -42.9° -37.8° -22.4° 8.7 27.8° 36° 41° 45° 47° 50° 52° 53° 55°
12 11 10 9 8 7 6 5 4 3 2 2 3 4 5 6 7 8 9 10 11 12
L IN R_J

FIGURE 4b