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Asymmetric Access of Energetic Solar Protons to the Earth's North and South Polar Caps

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Asymmetric Access of Energetic Solar Protons to the Earth's North and South Polar Caps

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ABSTRACT

During the energetic solar particle event that began on January 24, 1969, the ratio N/S of the intensity of protons $E_p > 0.3$ MeV over the earth's north (N) polar cap ($\Lambda > 80°$) to that over its south (S) polar cap ($-\Lambda > 80°$) varied from a value greater than 20 to about 1, as observed with satellite Injun 5 in a low altitude polar orbit. The interplanetary intensity of protons was measured simultaneously with similar detectors on Explorer 33 and Explorer 35 in two nearly-orthogonal planes and in eight different directions on the unit sphere (some overlap). High values of the N/S ratio early in the event corresponded to an extraordinarily strong anisotropy of intensity in interplanetary space with the anisotropy vector pointing dominantly southward. The N/S ratio dropped toward 1 as the interplanetary beam relaxed toward isotropy. Similar, though less well determined, findings applied to protons $E_p > 3.4$ MeV and alpha particles $E_\alpha > 1.18$ MeV. The directions of interplanetary field lines that connect with the respective polar caps are uniquely identified by intensity considerations. The interplanetary magnetic vector was measured on Explorer 35 also. Early in

the event, the earth was in a solar positive ($\vec{B}$ outward from the sun) magnetic sector ($\varphi_{SE} \approx 140°$), with a dominantly southward direction ($\theta_{SE} \approx -40°$ to $-70°$). The anisotropy vector was approximately parallel to the magnetic vector and in the same sense. The composite evidence favors the direct access of energetic particles to the earth's polar caps via magnetic field lines interconnected between the terrestrial field and the interplanetary medium; it strongly contradicts models that contemplate diffusion across the magnetospheric tail as an important feature of particle access.

I. INTRODUCTION

A north-south asymmetry in the access of solar protons to the earth's polar caps has been reported previously during several solar proton events [Krimigis and Van Allen, 1967; Reid and Sauer, 1967; Evans and Stone, 1969]. It was suggested by Van Allen in the foregoing reference: "At the earth, the intensity over the north polar cap is probably due to particles moving dominantly southward in interplanetary space and dominantly northward over the south polar cap. Hence, the geomagnetic field itself is a crude directional analyzer." A related suggestion made independently by Reid and Sauer emphasized the more basic relationship of a potential north-south asymmetry to the <u>sense</u> of the interplanetary magnetic field vector. [See Figure 5 of Reid and Sauer, 1967.]

The present report is concerned with observations by three different spacecraft during the solar particle event that began on January 24, 1969. The results are much clearer than earlier ones by virtue of the extraordinarily strong anisotropy of interplanetary particle intensity early in this event and the comprehensiveness of the observations.

II. EXPERIMENTAL DETAILS

The polar cap results presented herein were obtained from solid state proton, electron and alpha particle telescopes [Randall, 1969] on the University of Iowa satellite Injun 5. The satellite was launched on August 8, 1968, into a nearly polar orbit (inclination 80.7°) with initial perigee altitude of 644 km and apogee altitude of 2526 km. It was magnetically aligned during the period of interest and the detector axis was perpendicular (within 10°) to the local geomagnetic field line. The detector channel of principal interest herein has an energy range $0.304 \leq E_p \leq 9.2$ MeV and a geometric factor of 0.0202 cm^2 ster.

The interplanetary proton intensity was measured by two similar solid state detectors: one on Explorer 33 ($0.31 \leq E_p \leq 10$ MeV; geometric factor 0.079 cm^2 ster) [Armstrong and Krimigis, 1968]; the other on Explorer 35 ($0.32 \leq E_p \leq 6.3$ MeV; geometric factor 0.082 cm^2 ster) [Van Allen and Ness, 1969]. The detector collimators are cones of half-angle 30°. The output of each detector was accumulated over four separate angular sectors, each of which covers 90° of satellite rotation. The spin axis of Explorer 35 was directed toward the south ecliptic pole and that of Explorer 33 was near the ecliptic plane at an angle of 63° to the satellite-sun line. Table 1 gives the coordinates of the two spin axes and the solar ecliptic longitude and latitude of the center of each sector. Thus the two spacecraft measured the proton intensity over eight different angular portions of the unit sphere, with some overlap near the ecliptic. Both were effectively in interplanetary space during January 24 and 25, the two days of special interest (Table 2).

III. OBSERVATIONS

On the basis of continuous monitoring of the soft X radiation from the sun by both Explorers 33 and 35, it appears that there was only one solar flare that could have emitted the energetic particles observed on January 24 ff. X-ray emission showed a significant enhancement beginning at 0700 UT on January 24. The maximum intensity F(2-12 A°) of 50 milli-erg $(cm^2 \ sec)^{-1}$ occurred at 0739 UT; the decay phase continued for several hours. According to Solar-Geophysical Data No. 299--Part II (July 1969) [U. S. Department of Commerce] the corresponding optical and radio flare was of importance 2B and occurred at N20 W09 on the solar disc.

Solar electrons $E_e > 45$ keV were first detected near the earth at 0750, and solar protons $E_p > 0.3$ MeV, at 1014.

Figure 1 shows the time history of the spin averaged solar proton intensity observed by Explorer 33 and Explorer 35 during the event. The auxiliary diagram shows the positions of Explorer 33 and Explorer 35 projected onto the ecliptic plane. Further details are tabulated in Table 2. Injun 5 data points representing polar cap averages are shown for comparison. These averages were taken over the polar plateau when clearly defined;

otherwise they were taken for invariant latitudes $|\Lambda| \geqslant 80°$.
The Injun 5 counting rates were then normalized on an absolute basis to those of Explorer 33 and Explorer 35 by multiplying the former by 4, the inverse ratio of geometric factors. Of special interest is the strong north polar cap to south polar cap intensity ratio (N/S) on January 24. At later times the normalized Injun 5 polar cap intensities track the spin averaged interplanetary intensities reasonably closely.

In order to compare the anisotropy of the interplanetary solar protons to the north-south polar cap asymmetry, the counting rates of sectors II and IV of the Explorer 33 detector and the Injun 5 polar cap averages (normalized as before) are plotted in Figure 2. This comparison shows that the northern polar cap intensity is accurately similar to the southward directed interplanetary intensity, and that the southern polar cap intensity is accurately similar to the northward directed interplanetary intensity. Note that the north-south anisotropy of the interplanetary intensity nearly disappears prior to the polar cap observations on January 25.

A corresponding comparison of the counting rates of sectors I and III of Explorer 35 with the Injun 5 rates over the respective polar caps is shown in Figure 3. Although this comparison is broadly similar to that of Figure 2, the tracking of the Injun 5 data points is less intimate, a fact that appears to be adequately accounted for when the full three-dimensional anisotropy vector is determined (see below). Table 3 tabulates detailed counting rates at times of Injun 5 polar passes.

A graphical summary of the foregoing observational material is presented in a different and perhaps clearer way in Figure 4. The upper panel shows the time dependence of the interplanetary anisotropy in the ecliptic plane (Explorer 35) as measured by the ratio of the sum of the counting rates of sectors III and IV to the sum of the counting rates of sectors I and II. This grouping of sectors appeared to be the simplest appropriate one since the rates in III and IV were usually similar to each other as were the rates in I and II. The ratio of hourly averages (III + IV) / (I + II) reached the extraordinarily high value of 33 early in the event. The central panel of Figure 4 shows the time dependence of counting rate ratios III/I and IV/II in a plane nearly-orthogonal to the ecliptic (Explorer 33). The most significant feature appears to be the prominent peak late on January 24 of the ratio of southward (IV) to northward (II) directed intensities. The maximum value of this ratio is 27. The bottom panel shows the N/S polar cap intensity ratio as a function of time. This ratio is not, of course, obtained by simultaneous observations over the respective polar caps but has been derived by interpolation from Table 3. The maximum value is 22.

The similarity of the time dependences and absolute values of IV/II in the central panel to those of N/S in the bottom panel is taken to be of central significance.

A further analysis of the interplanetary anisotropy was made as follows. A function of the form $A_o[1 + C \cos(\beta - \delta)]$ was fitted to the four sectored counting rates of Explorer 33 and Explorer 35 (taken separately) to determine the direction δ of maximum particle intensity in the equatorial planes of the respective spacecraft. The roll angle β is measured from an instrumentally arbitrary zero. The δ's were then transformed into solar ecliptic coordinates--φ_{SE} for Explorer 35 and θ_{SE} for Explorer 33. These two angles specify the approximate direction of the "anisotropy vector" for particles in interplanetary space. The resulting values of φ_{SE} and θ_{SE} as computed from one-hour sector averages are given in the upper two panels (dashed lines) of Figure 5. Values of the corresponding amplitude parameter C are given in the bottom panel. Data at times before 1014 UT of January 24 are irrelevant to the present study.

The time dependence of the direction of the interplanetary magnetic field vector $\vec{B}$ was measured throughout the period of interest by the GSFC magnetometer on Explorer 35 [Behannon, 1968]. Values of φ_{SE} and θ_{SE} for $\vec{B}$ are shown in the upper two panels of Figure 5 (solid lines). These values were determined from hourly averages of three orthogonal components of $\vec{B}$. From mid-day of January 24 through January 25 the earth was in a positive magnetic sector ($\vec{B}$ outward from the sun) and the interplanetary field was strongly southward. The direction of the magnetic vector is determined to considerably better accuracy than is the direction of the anisotropy vector, especially when C drops toward low values. With proper allowance for this fact, it is seen from Figure 5 that the anisotropy vector has substantially the same direction and sense as $\vec{B}$ from onset of the event at 1014 UT on January 24 to 2400 UT on January 25. Interesting departures from this condition occur later in the event but are not immediately relevant to the present study.

Figures 4 and 5 are regarded as summarizing the main features of the observational material.

Additional insight into the access of solar particles is gained by examination of the detailed polar pass data of Injun 5 [Blake et al., 1968; Evans and Stone, 1969; Flindt, 1970]. Figures 6, 7, 8, and 9 give the detailed observations for several pairs of north/south polar passes for protons $0.30 \leq E_p \leq 9.2$ MeV, protons $3.44 \leq E_p \leq 74$ MeV, and alpha particles $1.18 \leq E_\alpha \leq 8.4$ MeV. The counting rate data are plotted against invariant latitude Λ. Note that the magnetic local times are approximately the same for both north and south polar passes of each pair. The northern polar region shows a substantially uniform intensity for $|\Lambda| \geqslant 65°$ in 20 out of 21 passes observed during the course of the event. In contrast, the intensity profiles in the southern polar region on January 24 show a prominent and more or less flat minimum for $|\Lambda| \geqslant 80°$ although the intensity in the region of expected quasi-trapping, $65° < |\Lambda| < 75°$ [Taylor, 1967; Blake et al., 1968; Gall et al., 1968; Paulikas et al., 1968; Smart et al., 1969; Roederer, 1970] is nearly the same over both the north and south polar caps. In fact, the latitude range of equality of particle intensity over the two polar caps provides a clear observational definition of the quasi-trapping region in cases of an anisotropic interplanetary beam. The existence of a quasi-trapping region is dependent on the non-dipolar character of the outer geomagnetic field and more particularly on its lack of axial symmetry. Thus the boundaries of the region are a function of magnetic local time [Stone, 1964; Taylor, 1967].

It is emphasized that the south "polar cap" data in Figures 1, 2, 3, and 4 and Table 3 are for $|\Lambda| \geqslant 80°$. The polar asymmetry of January 24 is also seen for protons $E_p \geq 3.44$ MeV and for alpha particles $E_\alpha \geq 1.18$ MeV. The north-south ratios varied from 1 to 7 for the higher energy protons and from 1 to 15 for the alpha particles. The anisotropy of interplanetary alpha particles, as observed by Explorer 35, follows the same pattern as is seen for the lower energy protons. (The angular distribution of the higher energy protons in interplanetary space was not measured by either Explorer 33 or Explorer 35.) These facts lend further support to the above analysis.

The orbit of Injun 5 was such that its altitudes over the two polar caps were similar during the two-day period January 24-25. For $|\Lambda| \geqslant 80°$ and for all observed passes during these two days, altitudes ranged from 1360 to 1950 km over the north polar cap and from 1250 to 1750 km over the south polar cap; the corresponding ranges of scalar magnetic fields were 0.33 to 0.27 gauss and 0.34 to 0.31 gauss, respectively. It appears that no significant N/S asymmetry can be attributed to an "altitude effect".

It may be noted that a unique and valuable feature of the present observations is that the angular distribution of particles in interplanetary space was measured in two nearly-orthogonal planes. No interplanetary spacecraft other than Explorer 33 has, to our knowledge, measured angular distributions in a plane perpendicular to the ecliptic.

IV. DISCUSSION AND CONCLUSIONS

The sense of the interplanetary magnetic field on January 24 and 25 is such that particles moving outward from the sun with pitch angles $\leqslant 4^\circ$ will reach Injun 5 over the north polar cap whereas those moving inward toward the sun with pitch angles $\geqslant 176^\circ$ will reach it over the south polar cap, provided that there is direct interconnection between magnetic field lines originating in the earth and those in the contiguous interplanetary medium.

The observational data for $|\Lambda| \geqslant 80^\circ$ correspond accurately to these expectations throughout the event. The suggested magnetic topology is shown in a schematic way in Figure 10 [cf. Reid and Sauer, 1967].

It further appears that the quasi-trapping region $65^\circ \leq |\Lambda| \leq 75^\circ$ at local times of about 5 hr and 17 hr is characterized by whichever of the two interplanetary intensities (i.e., parallel or antiparallel to $\vec{B}$) is the greater. When the interplanetary intensity approaches isotropy [data of Figures 1, 2, 3, and 4 and Table 3 for January 25], it is expected that the N/S ratio will approach unity and that the quasi-trapping region will merge indistinguishably into the direct access (and direct escape) region as observed with a detector whose collimator is filled and whose axis is oriented at a local pitch angle of ≈ 90°. The pitch angle distributions in the direct access and quasi-trapping regions will be different by virtue of loss of particles into the earth's atmosphere [Blake et al., 1968].

The work of Evans and Stone [1969] on the solar proton event of November 2-4, 1967, is the most relevant to the present study of any previously published. In that event the south polar cap received the greater intensity, as was in fact appropriate to our direct interconnection hypothesis if the outward flowing particle intensity (in the negative interplanetary magnetic sector that prevailed at the time) was as much as ten times as great as the inward flowing intensity. The authors quote Sullivan and Simpson (private communication) as reporting that the interplanetary intensity was "essentially isotropic". We have examined our Explorer 35 data for the same period and find that the ratio of outward to inward flowing intensities was in fact about two or three as measured in the ecliptic plane. Unfortunately Explorer 33 data were not available at that time. But in light of the present investigation it seems reasonable to think that the interplanetary anisotropy might have been substantially greater if the full anisotropy vector had been determined. Further, we suggest that the "20-hour delay" of access of particles to the northern polar cap as reported by Evans and Stone might better be attributed to the duration of substantial anisotropy rather than to a diffusive access delay. The characteristic relaxation time to isotropy in interplanetary space (for protons, $E_p \approx 1$ MeV) is in fact of this magnitude in many events that we have observed.

The hypothesis of diffusive access of energetic solar particles into a closed or very long (~ 1 A.U.) magnetotail [Michel, 1965; Michel and Dessler, 1965] seems to be in complete conflict with the present body of observations on at least two grounds.

(a) Prolonged diffusion would almost certainly destroy the strong north-south polar cap asymmetry by yielding an averaged and more-or-less equal intensity over both polar caps.

(b) Our observed access time of protons $E_p \approx 0.35$ MeV from interplanetary space to the polar caps is ≤ 1 hr, over an order of magnitude less than delay times anticipated by the diffusive access hypothesis.

Michel and Dessler [1970] have recently modified their diffusive access hypothesis to respond to the massive body of contrary observational evidence that has been developed since their original suggestions in 1965. The modified hypothesis may permit the preservation of a north-south polar asymmetry as a more-or-less ad hoc feature but still predicts delay times for protons of the order of 10 hours.

Moreover, Van Allen [1970] has reported that solar electrons $E_e \approx 45$ keV enter the magnetotail from interplanetary space with a delay of less than 100 seconds, that the effective length of the magnetotail is therefore less than 900 R_E (earth radii), and that the magnetic topology of the tail is an open one.

For 0.35 MeV solar protons, an access delay of 1 hr corresponds to a magnetotail length (downstream distance of interconnection to the interplanetary field) of 2200 R_E if the full rectilinear kinetic velocity of the particles is assumed, or of about 100 R_E if the solar wind convective velocity is assumed. A number of well documented cases of access delays of 0.2 to 2 hrs for protons have been reported by Kane et al. [1968] ($E_p \approx 15$ MeV) and Montgomery and Singer [1969] ($E_p = 0.7$ to 40 MeV). In a study that will be reported later, we find however that delays of the same order of magnitude occur between two spacecraft both of which are in interplanetary space at separations of the order ot 50 to 100 R_E [Van Allen, private communication]. Hence, it seems probable that the effective magnetotail length (downstream distance to interconnection) is of the order of only a few hundred earth radii or less--as is appropriate to a convective and/or co-rotational delay of the interplanetary intensity structure, rather than to a diffusive delay. Also a diffusive delay in the magnetotail would almost certainly destroy the detailed intensity-time profile, contrary to observation.

Thus, we conclude that the earth's polar cap magnetic field and the interplanetary magnetic field were directly interconnected during the January 24, 1969 event and that this interconnection probably occurred no further than a few hundred earth radii on the anti-solar side of the earth.

The three-hour indices of geomagnetic activity K_p had the following values on January 24: 1-, 0+, 1-, 1-, 3, 4-, 4-, and 4-; and on January 25: 4, 3+, 4+, 4, 5-, 4+, 4+, and 4.

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Table 1

Angular Data on January 24, 1969

(a) Orientation of Spin Axes

	Celestial R.A.	Celestial Decl.	Solar Ecliptic φ_{SE}	Solar Ecliptic θ_{SE}
Explorer 33	240°	-16°	297°	+ 5°
Explorer 35	90°	-67°	--	-90°

(b) Orientation of Centers of Sectors in Solar Ecliptic Coordinates

	Explorer 33				Explorer 35			
	I	II	III	IV	I	II	III	IV
φ_{SE}	206°	242°	26°	62°	185°	95°	5°	275°
θ_{SE}	+7°	-81°	-7°	+81°	0°	0°	0°	0°

Table 2

Geocentric Solar Ecliptic Coordinates of Spacecraft
(Earth Radii)

Date 1969	UT	Explorer 33 X_{SE}	Explorer 33 Y_{SE}	Explorer 33 Z_{SE}	Explorer 35 X_{SE}	Explorer 35 Y_{SE}	Explorer 35 Z_{SE}
January 24	0000	- 7.91	+33.89	+25.98	+17.56	+59.54	+1.39
	1200	-17.22	+31.68	+26.49	+11.62	+61.12	+1.99
January 25	0000	-26.04	+28.63	+26.15	+ 5.55	+62.06	+2.57
	1200	-34.19	+24.92	+25.06	- 0.58	+62.35	+3.12
January 26	0000	-41.59	+20.75	+23.36	- 6.73	+62.00	+3.63
	1200	-48.22	+16.27	+21.18	-12.85	+61.04	+4.10
January 27	0000	-54.12	+11.62	+18.63	-18.88	+59.48	+4.52
	1200	-59.32	+ 6.91	+15.81	-24.79	+57.37	+4.89
January 28	0000	-63.90	+ 2.19	+12.78	-30.54	+54.78	+5.19
	1200	-67.90	- 2.47	+ 9.63	-36.04	+51.83	+5.41
January 29	0000	-71.39	- 7.05	+ 6.38	-41.05	+48.62	+5.52
	1200	-74.42	-11.52	+ 3.09	-45.40	+44.95	+5.55

Table 3

Interplanetary and Polar Cap Intensities
Counts/Sec

	Time**	Explorer 33† Sectors				Explorer 35† Sectors				Injun 5*	
	(UT)	I	II	III	IV	I	II	III	IV	North	South
Jan 24	1412	95	16	45	212	10	12	73	74	76	---
	1506	137	16	44	213	13	7	163	190	---	16
	1615	127	11	51	275	33	35	121	88	273	---
	1707	94	28	94	235	52	55	199	136	---	12
	1815	104	53	130	278	---	---	---	---	220	---
	1912	213	79	146	402	66	103	243	183	---	39
	2012	140	129	247	324	110	169	366	235	269	---
Jan 25	1345	30	30	30	31	31	32	59	48	37	---
	1742	27	28	32	32	31	33	43	28	32	---
	1856	22	28	34	31	16	23	37	24	---	32
	1954	8	16	20	12	6	7	11	9	16	---

* Counting rate multiplied by 4.0

† Interpolated from 0.5 hour averages

** Mean time of polar cap pass

FIGURE CAPTIONS

Figure 1. Simultaneous observations of directional intensities of solar protons with Explorer 33, Explorer 35, and Injun 5. The two solid curves join half-hourly averaged counting rates (also averaged over spin) from Explorer 33 and Explorer 35, respectively. On each of these plots are superimposed north and south polar cap averaged counting rates from Injun 5 (normalized on an absolute basis by multiplying the raw rates by 4.0, the inverse ratio of geometric factors). The auxiliary diagram shows the positions of Explorer 33 and Explorer 35 at one day intervals as projected onto the ecliptic plane ($X_{SE} - Y_{SE}$ plane). The Z_{SE} coordinate of Explorer 33 is shown at several points along the counting rate curve (cf. Table 2). The average bow shock and magnetopause traces after Behannon [1968] are shown for reference.

Figure 2. Graphical comparison of the normalized, north polar cap averaged counting rates and south polar cap averaged counting rates from Injun 5 with the half-hourly averaged counting rates from Explorer 33's sector IV (southward

directed intensity) and sector II (northward directed intensity). The arrows in the auxiliary diagram indicate the mean directions of the collimator axis in the four sectors.

Figure 3. Graphical comparison similar to Figure 2 except for rates from Explorer 35's sector III (outward intensity from the sun in the ecliptic plane) and sector I (inward intensity toward the sun in the ecliptic plane).

Figure 4. Summary plots of interplanetary counting rate ratios for several different angular sectors as shown in auxiliary diagrams (upper two panels) and the N/S polar cap counting rate ratios from Injun 5 (bottom panel). Points in the upper two panels are calculated directly from simultaneous data in Table 3; those in the bottom panel, by interpolation between non-simultaneous north and south polar pass data in Table 3.

Figure 5. Solid lines in the upper two panels show hourly-averaged directions of the interplanetary magnetic vector $\vec{B}$ as measured by the GSFC magnetometer on Explorer 35. The dashed lines give the corresponding directions of the three-dimensional particle "anisotropy" vector, φ_{SE} from Explorer 35 in the top panel and θ_{SE} from Explorer 33 in the center panel. The quantity C in the bottom panel is the amplitude parameter of the

anisotropy in two different planes (see text). The solar proton event under study began at 1014 UT on January 24. The letters P designate times of periselene passage of Explorer 35 in its orbit about the moon. At these times the values of φ_{SE} for the anisotropy vector are significantly modified by lunar shadowing. No correction for this effect has been made [Van Allen and Ness, 1969]. Geocentric solar ecliptic coordinates are used throughout, φ_{SE} being the longitude measured in the ecliptic plane from the earth-sun vector and θ_{SE} being the latitude, positive to the north and negative to the south of the ecliptic plane. A vector outward from the sun tangent to the nominal archimedean spiral has $\varphi_{SE} = 135°$, $\theta_{SE} = 0°$.

Figure 6. Injun 5 raw counting rate data from a pair of adjacent polar passes for two different proton energies. The satellite was continuously oriented with the axis of its conical collimator orthogonal to the local geomagnetic vector. The abscissa is the absolute value of the nominal, dipolar invariant latitude Λ. Magnetic local time (MLT) is shown for both north and south polar passes. Two heavy, dashed curves in the upper panel show the approximate counting rate vs Λ

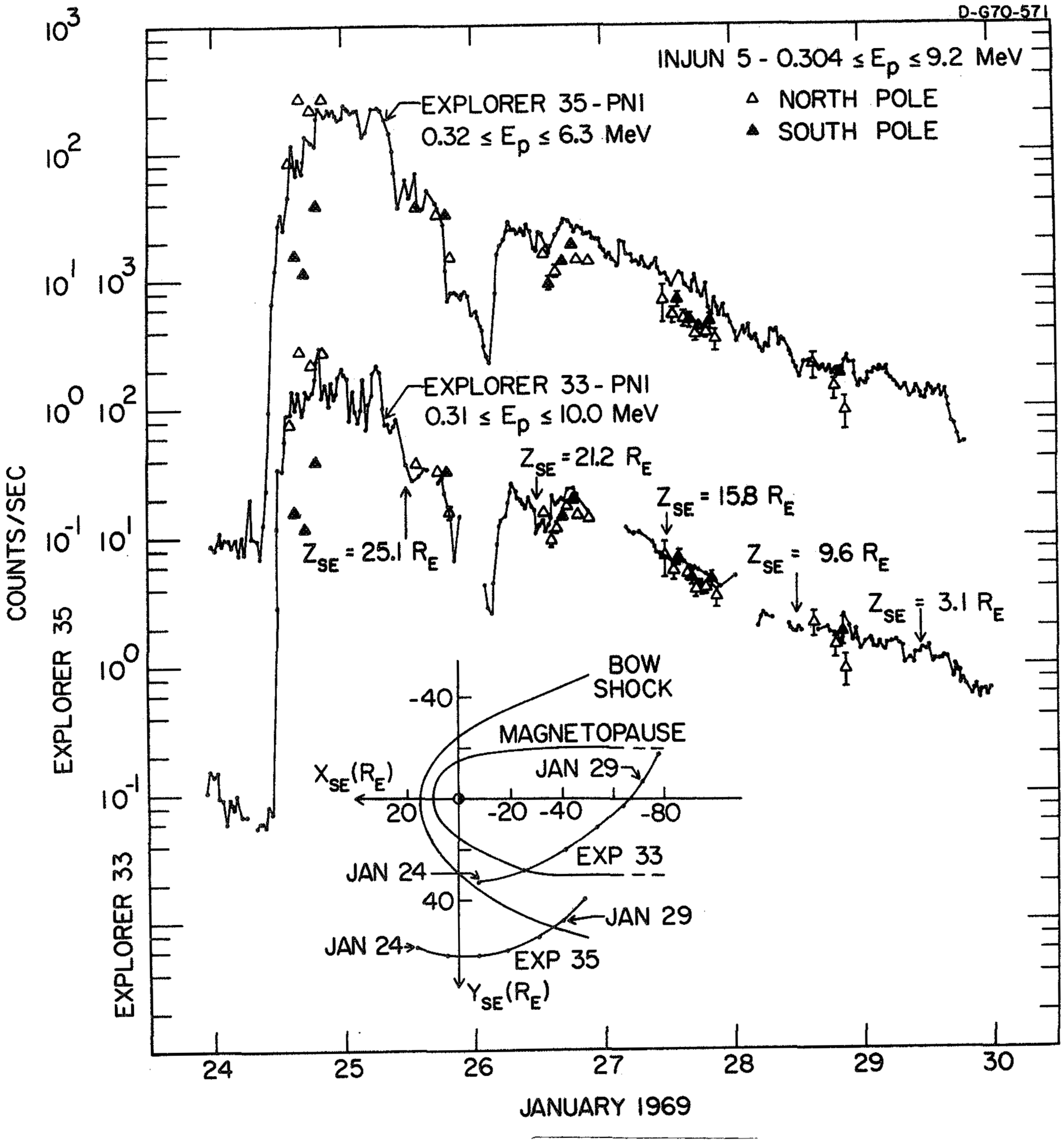
dependence that is observed at the high latitude boundaries of the outer radiation zone when no solar particles are present.

Figure 7. Similar to Figure 6.

Figure 8. Similar to Figure 6.

Figure 9. Similar to Figure 6, except for alpha particles.

Figure 10. A schematic diagram of the proposed magnetic topology in the noon-midnight meridian. The central features of this diagram (not to scale) are (a) the direct interconnection of polar cap magnetic lines of force to magnetic lines of force in the interplanetary medium and (b) the relationship of this topology to the N/S asymmetry of polar cap particle intensities when the interplanetary beam is anisotropic as shown.



D-G70-571
INJUN 5 - 0.304 ≤ E_p ≤ 9.2 MeV
△ NORTH POLE
▲ SOUTH POLE
EXPLORER 35 - PN1
0.32 ≤ E_p ≤ 6.3 MeV
EXPLORER 33 - PN1
0.31 ≤ E_p ≤ 10.0 MeV
Z_{SE} = 25.1 R_E
Z_{SE} = 21.2 R_E
Z_{SE} = 15.8 R_E
Z_{SE} = 9.6 R_E
Z_{SE} = 3.1 R_E
BOW SHOCK
MAGNETOPAUSE
$X_{SE}(R_E)$
$Y_{SE}(R_E)$
JAN 29
JAN 24
EXP 33
EXP 35
-40
40
20
-20
-40
-80
10^3
10^2
10^1
10^0
10^{-1}
COUNTS/SEC
EXPLORER 35
EXPLORER 33
24
25
26
27
28
29
30
JANUARY 1969

Figure 1

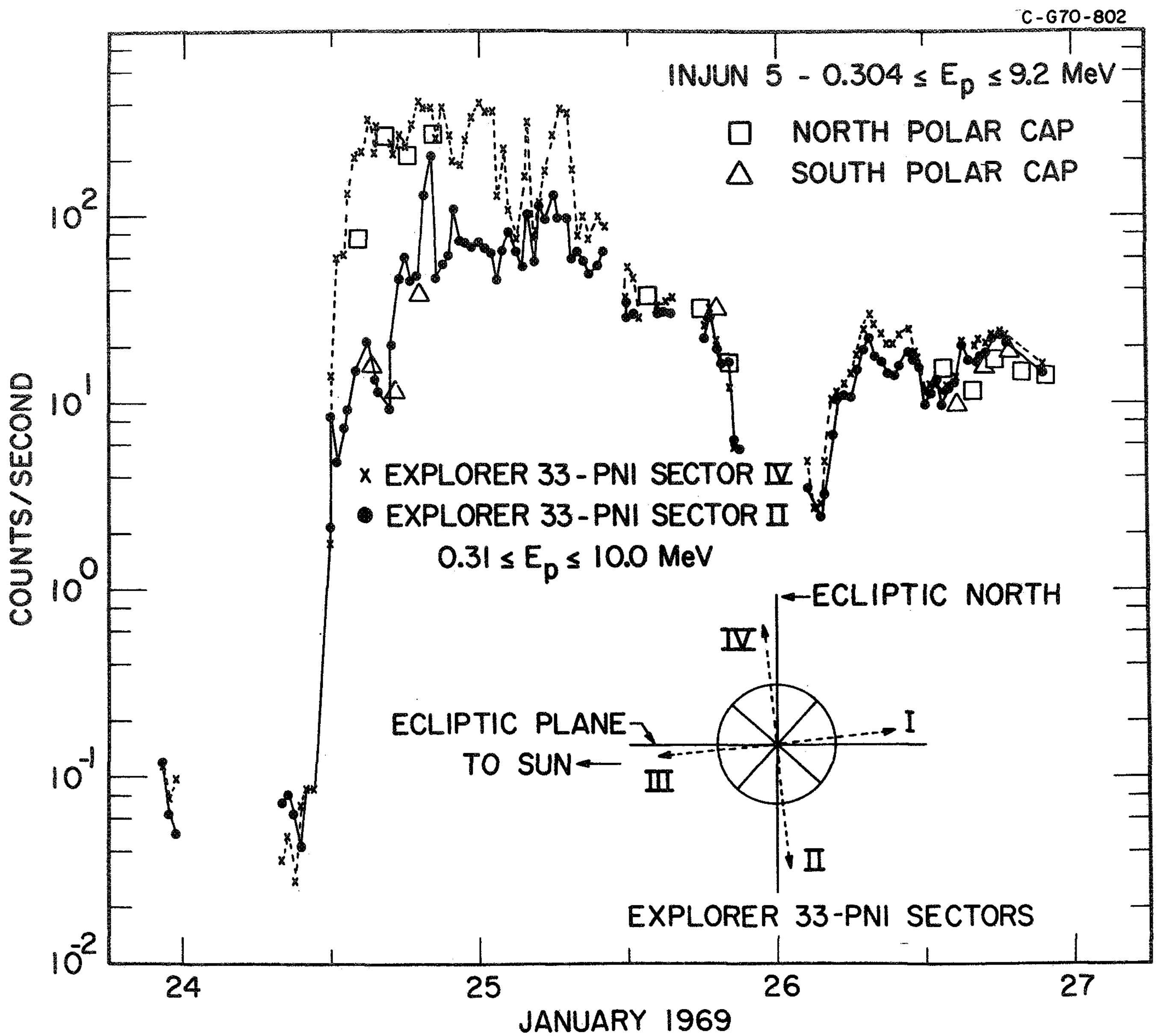

C-G70-802
INJUN 5 - 0.304 ≤ E_p ≤ 9.2 MeV
NORTH POLAR CAP
SOUTH POLAR CAP
x EXPLORER 33-PNI SECTOR IV
● EXPLORER 33-PNI SECTOR II
0.31 ≤ E_p ≤ 10.0 MeV
ECLIPTIC NORTH
ECLIPTIC PLANE
TO SUN
I
II
III
IV
EXPLORER 33-PNI SECTORS
COUNTS/SECOND
10^2
10^1
10^0
10^-1
10^-2
24
25
26
27
JANUARY 1969

Figure 2

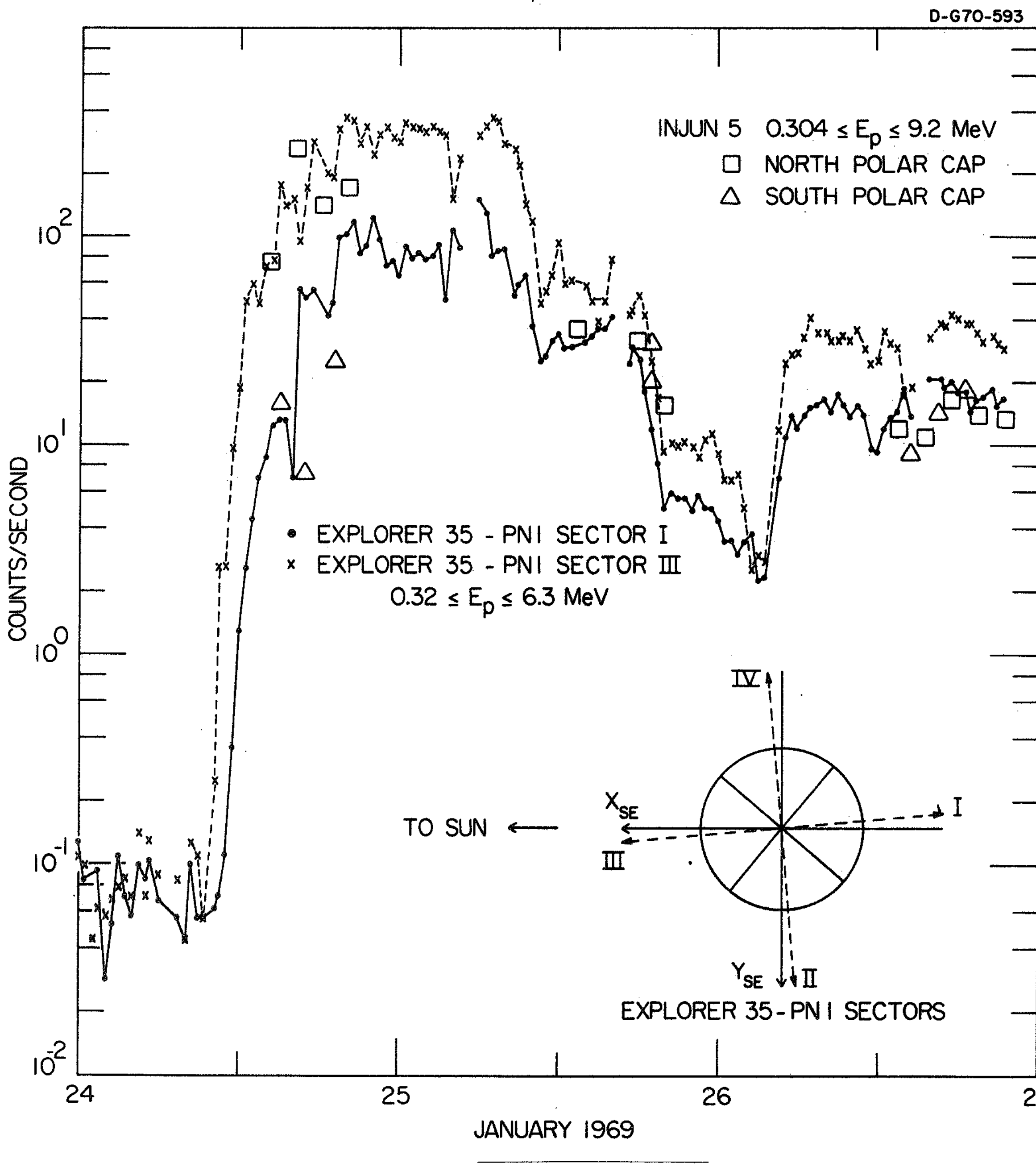
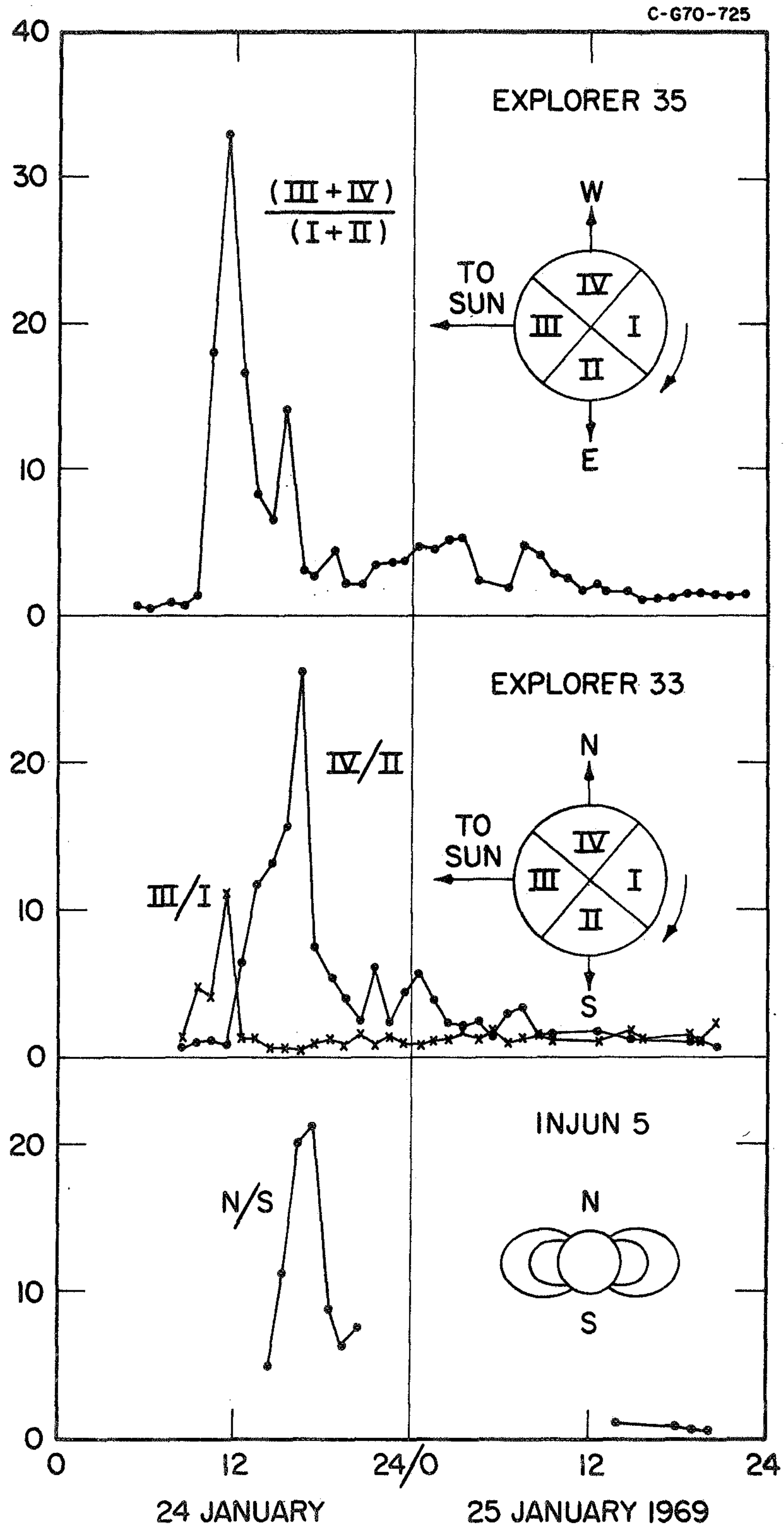

D-G70-593
INJUN 5 0.304 ≤ Ep ≤ 9.2 MeV
NORTH POLAR CAP
SOUTH POLAR CAP
EXPLORER 35 - PNI SECTOR I
EXPLORER 35 - PNI SECTOR III
0.32 ≤ Ep ≤ 6.3 MeV
COUNTS/SECOND
TO SUN
XSE
YSE
I
II
III
IV
EXPLORER 35-PNI SECTORS
JANUARY 1969
24
25
26
27
10^2
10^1
10^0
10^-1
10^-2

Figure 3



C-G70-725
EXPLORER 35
(III + IV) / (I + II)
W
TO SUN
IV
III
I
II
E
EXPLORER 33
IV/II
III/I
N
TO SUN
IV
III
I
II
S
INJUN 5
N/S
N
S
40
30
20
10
0
20
10
0
20
10
0
0
12
24/0
12
24
24 JANUARY
25 JANUARY 1969

Figure 4

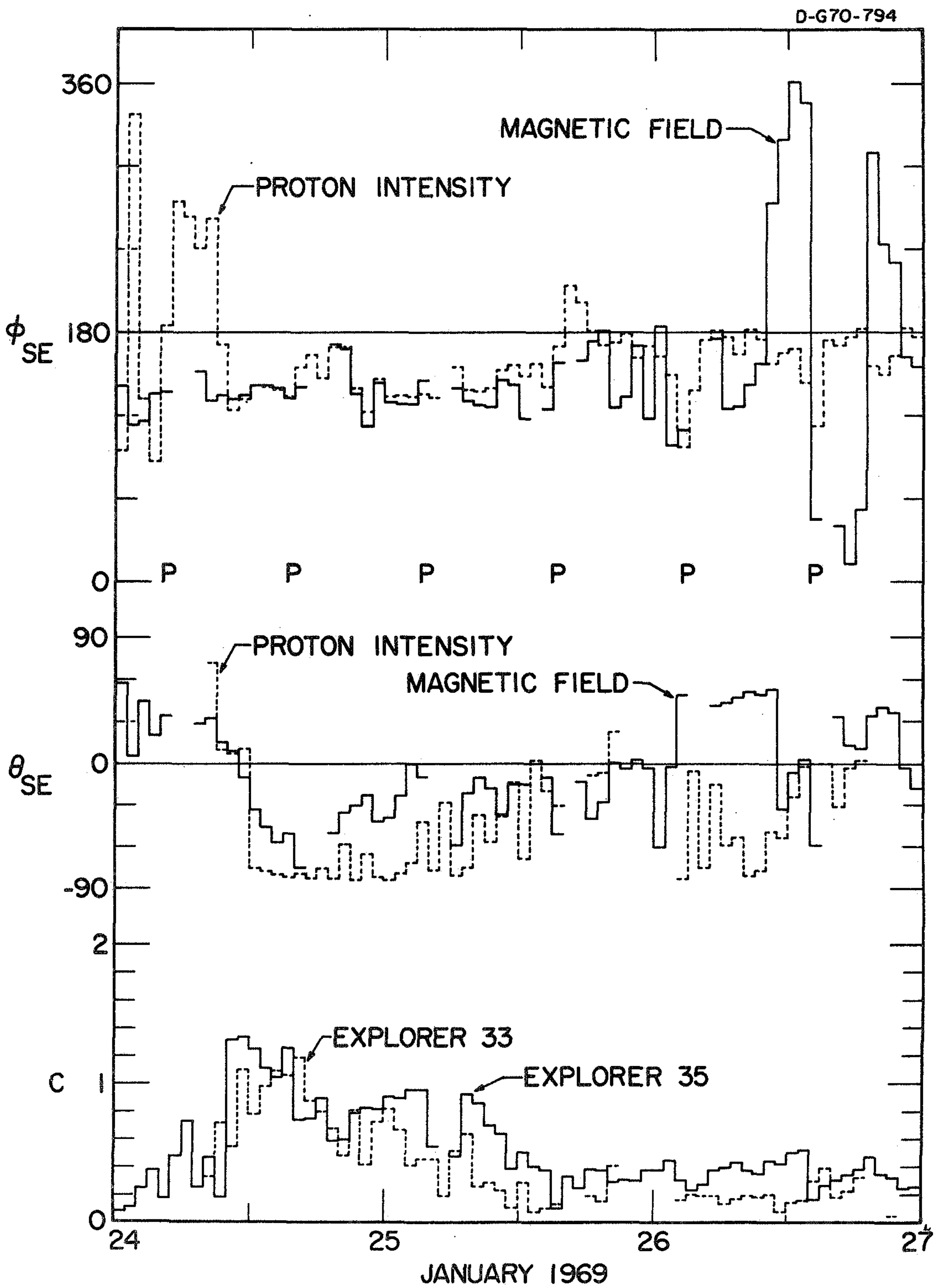
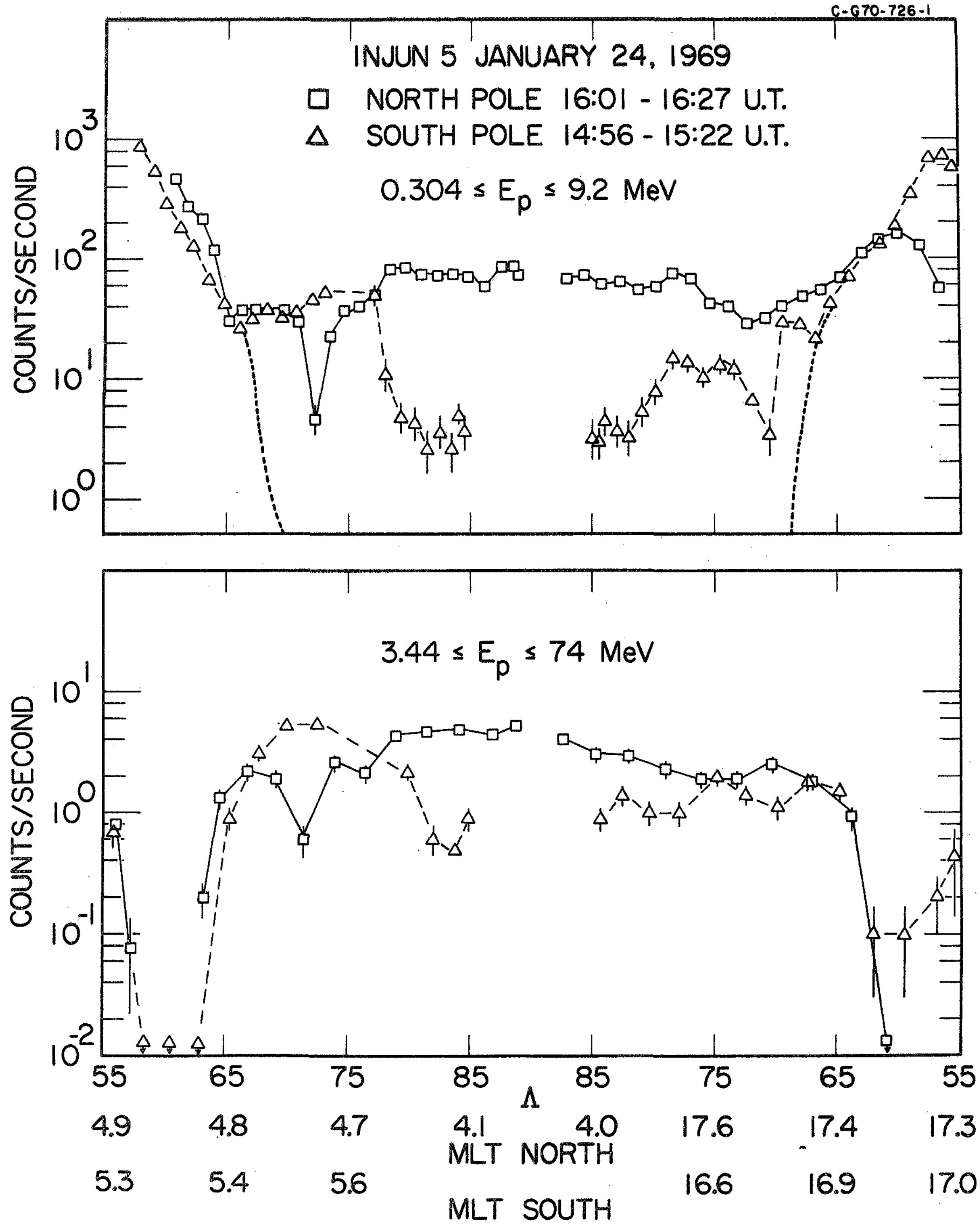
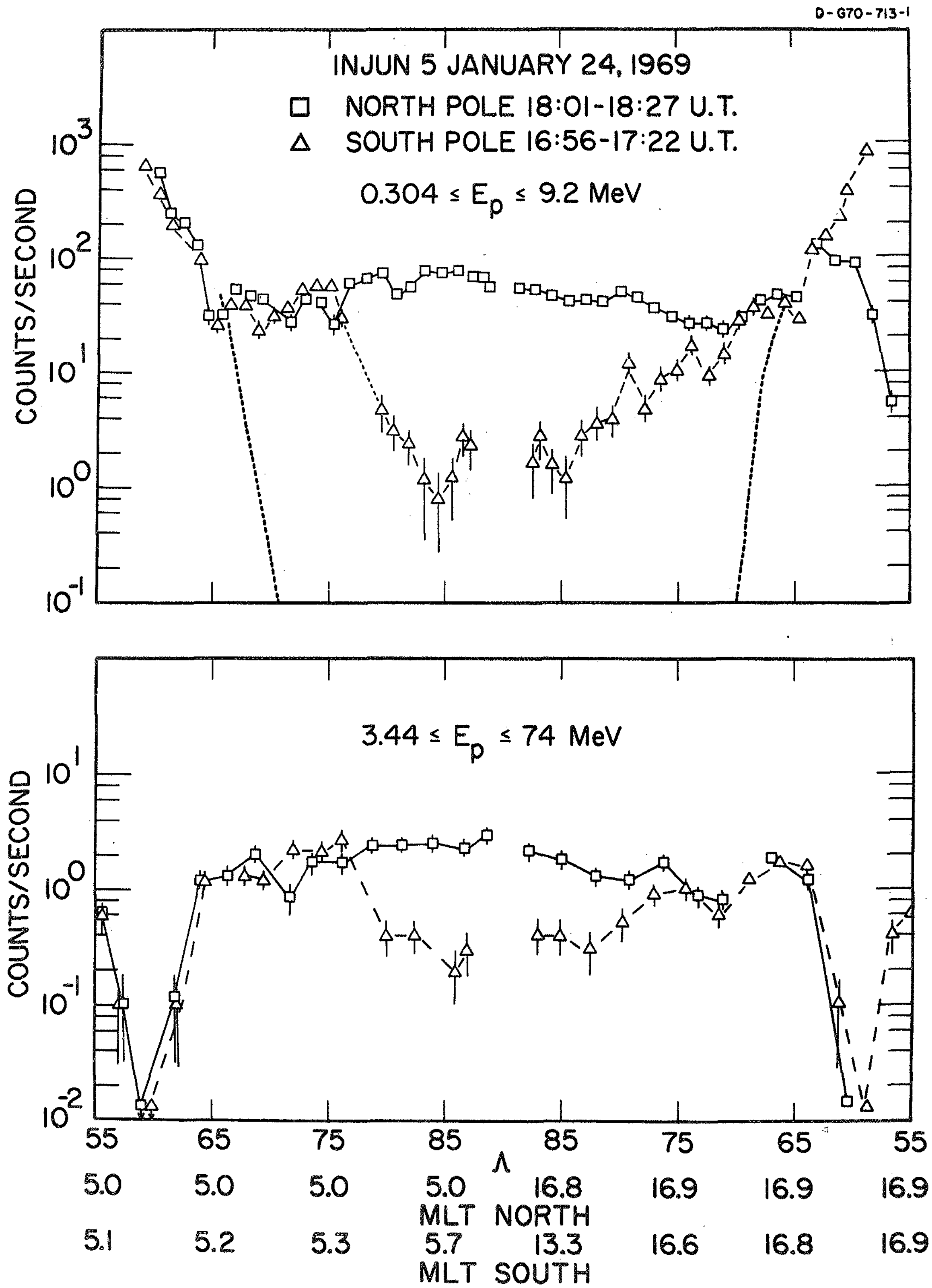

D-G70-794
360
MAGNETIC FIELD
PROTON INTENSITY
ϕ_{SE} 180
P P P P P P
0
90
PROTON INTENSITY
MAGNETIC FIELD
θ_{SE} 0
-90
2
EXPLORER 33
C 1
EXPLORER 35
0
24
25
26
27
JANUARY 1969

Figure 5



C-G70-726-1
INJUN 5 JANUARY 24, 1969
□ NORTH POLE 16:01 - 16:27 U.T.
△ SOUTH POLE 14:56 - 15:22 U.T.
0.304 ≤ Ep ≤ 9.2 MeV
COUNTS/SECOND
10^3
10^2
10^1
10^0
3.44 ≤ Ep ≤ 74 MeV
COUNTS/SECOND
10^1
10^0
10^-1
10^-2
55
65
75
85
85
75
65
55
Λ
4.9
4.8
4.7
4.1
4.0
17.6
17.4
17.3
MLT NORTH
5.3
5.4
5.6
16.6
16.9
17.0
MLT SOUTH

Figure 6



D-G70-713-1
INJUN 5 JANUARY 24, 1969
NORTH POLE 18:01-18:27 U.T.
SOUTH POLE 16:56-17:22 U.T.
0.304 ≤ E_p ≤ 9.2 MeV
COUNTS/SECOND
10^3
10^2
10^1
10^0
10^-1
3.44 ≤ E_p ≤ 74 MeV
COUNTS/SECOND
10^1
10^0
10^-1
10^-2
55 65 75 85 85 75 65 55
Λ
5.0 5.0 5.0 5.0 16.8 16.9 16.9 16.9
MLT NORTH
5.1 5.2 5.3 5.7 13.3 16.6 16.8 16.9
MLT SOUTH

Figure 7

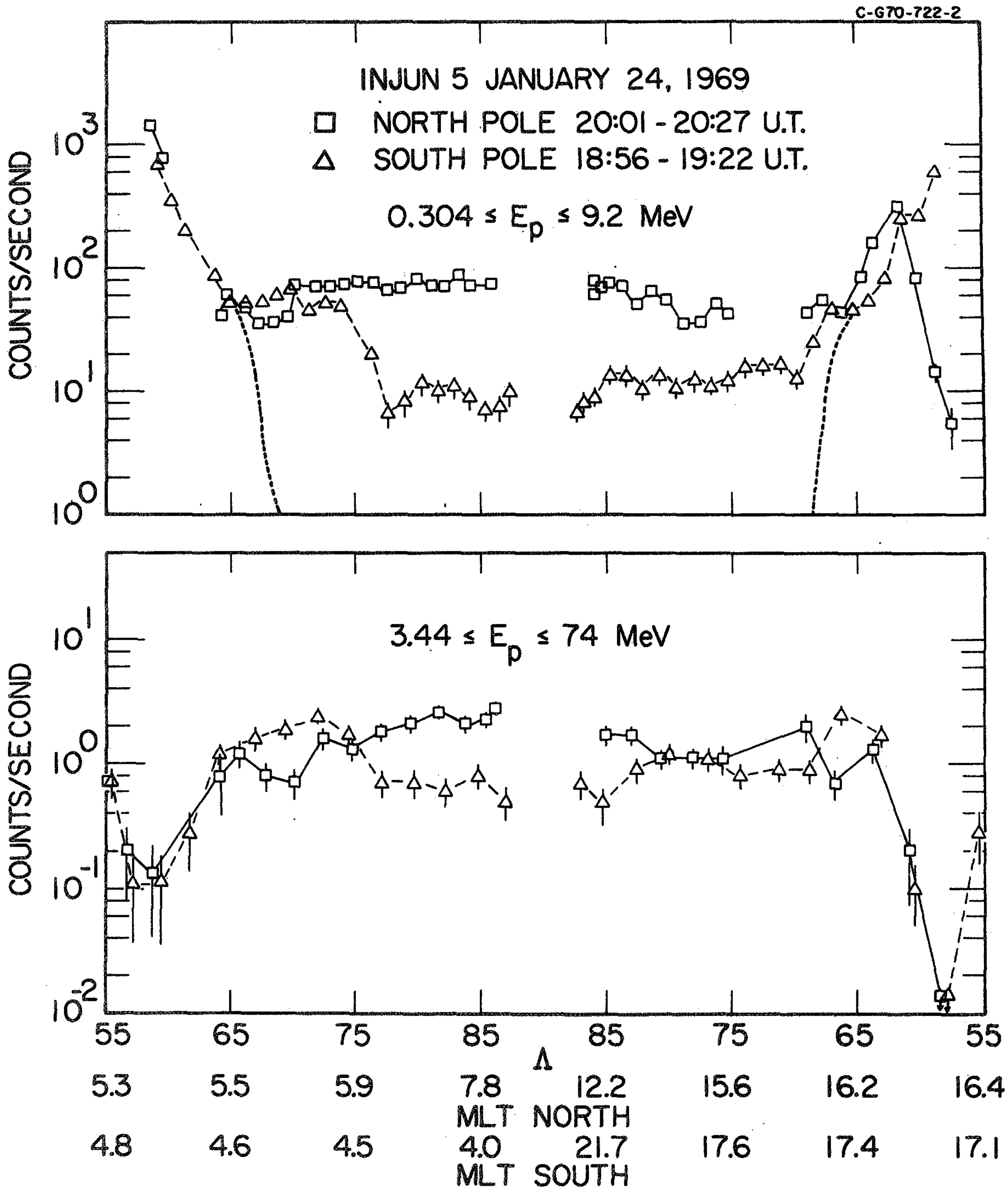
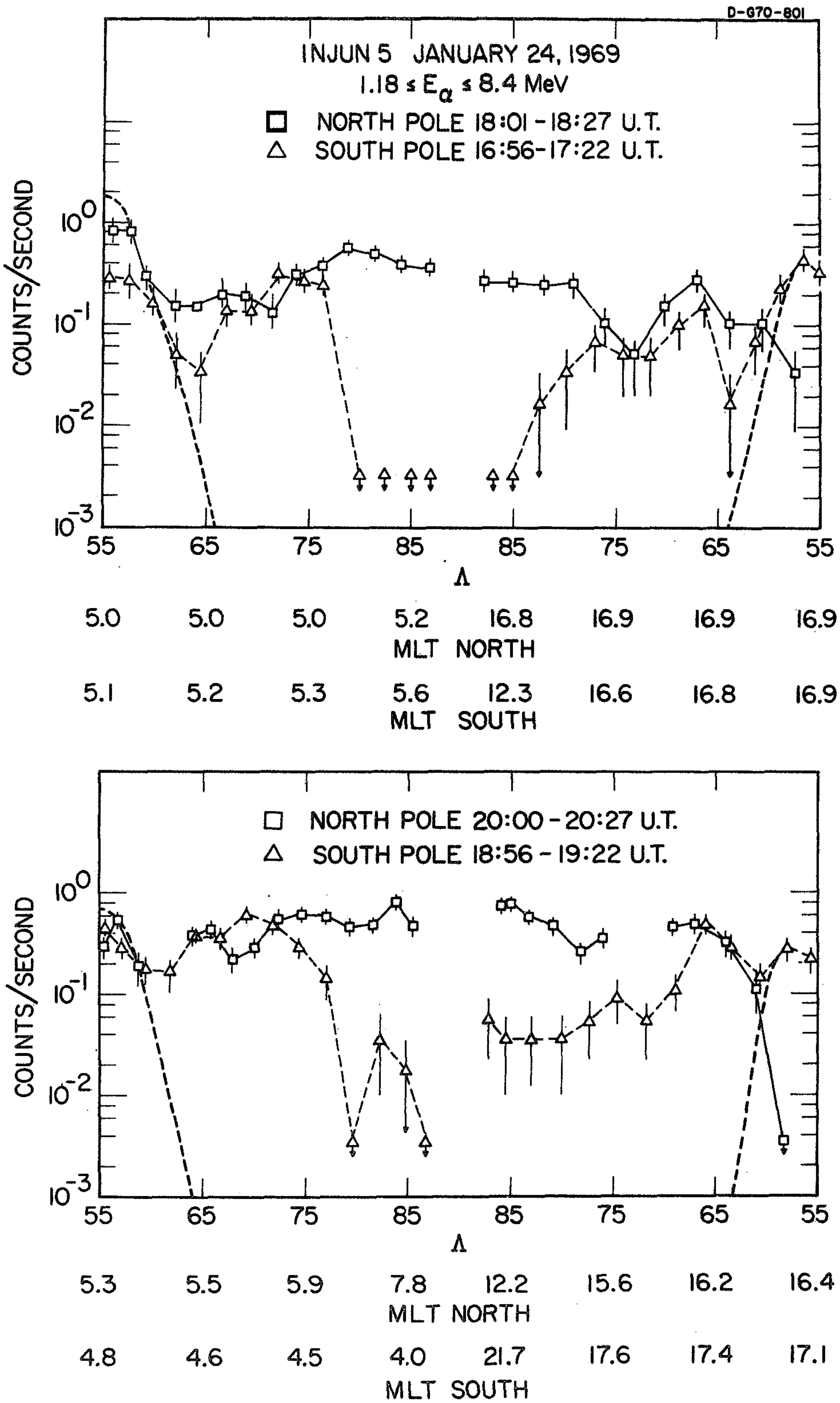

C-G70-722-2
INJUN 5 JANUARY 24, 1969
NORTH POLE 20:01 - 20:27 U.T.
SOUTH POLE 18:56 - 19:22 U.T.
0.304 ≤ E_p ≤ 9.2 MeV
3.44 ≤ E_p ≤ 74 MeV
COUNTS/SECOND
10^3
10^2
10^1
10^0
10^{-1}
10^{-2}
55 65 75 85 85 75 65 55
Λ
5.3 5.5 5.9 7.8 12.2 15.6 16.2 16.4
MLT NORTH
4.8 4.6 4.5 4.0 21.7 17.6 17.4 17.1
MLT SOUTH

Figure 8



D-G70-801
INJUN 5 JANUARY 24, 1969
1.18 ≤ E_α ≤ 8.4 MeV
NORTH POLE 18:01 - 18:27 U.T.
SOUTH POLE 16:56-17:22 U.T.
COUNTS/SECOND
10^0
10^{-1}
10^{-2}
10^{-3}
55 65 75 85 85 75 65 55
Λ
5.0 5.0 5.0 5.2 16.8 16.9 16.9 16.9
MLT NORTH
5.1 5.2 5.3 5.6 12.3 16.6 16.8 16.9
MLT SOUTH
NORTH POLE 20:00 - 20:27 U.T.
SOUTH POLE 18:56 - 19:22 U.T.
COUNTS/SECOND
10^0
10^{-1}
10^{-2}
10^{-3}
55 65 75 85 85 75 65 55
Λ
5.3 5.5 5.9 7.8 12.2 15.6 16.2 16.4
MLT NORTH
4.8 4.6 4.5 4.0 21.7 17.6 17.4 17.1
MLT SOUTH

Figure 9

C-G70-724

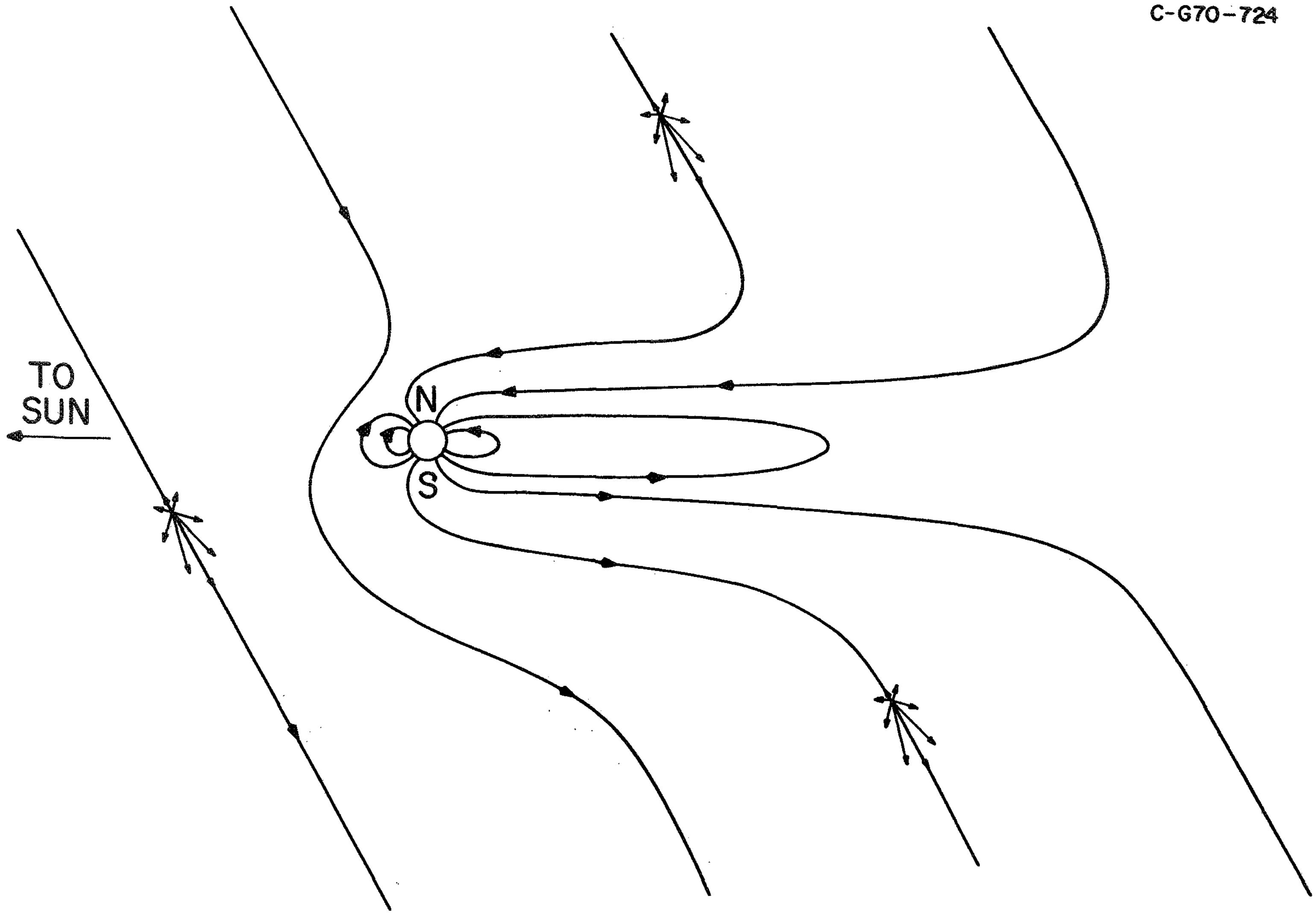


Figure 10