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Iowa City, Iowa

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FURTHER COMMENTS CONCERNING LOW-ENERGY CHARGED PARTICLE DISTRIBUTIONS WITHIN THE EARTH'S MAGNETOSPHERE AND ITS ENVIRONS*

by

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I. Introduction

The following discussion summarizes recent observational evidences concerning the nature and origin of the vast population of low-energy protons ($0.5 \lesssim E \lesssim 50$ keV) within the earth's outer zone and within the magnetotail and is a necessarily abridged epitome of the oral presentation. For adequate summaries of the various recent observations of the distributions of low-energy electron and proton intensities within the magnetosphere and its environs, the reader is referred to the following literature: the 'storm-time' ring current protons [Frank, 1967a]; the relationship between the plasmapause and plasma sheet at the magnetic equator [Schield and Frank, 1969]; atomic hydrogen densities, 1.5 to 4 R_E (R_E, earth radii) altitudes [Swisher and Frank, 1968]; the existençe of two distinct proton distributions in the earth's magnetic tail [Kanbach and Frank, 1969]; asymmetric injection of ring-current protons into the outer radiation zone during the early development phase of a magnetic storm [Frank, 1969a]; existence of significant proton ($5 \lesssim E \lesssim 50$ keV) intensities in the interplanetary medium and of solar origin [Frank, 1969b]; high resolution studies of trapped and precipitated proton and electron intensities at low altitudes over the auroral zone and polar regions [Frank, Münch and

Ackerson, 1969]; and comprehensive L-value versus time diagrams of low-energy proton intensities at the magnetic equator in the outer radiation zone [Frank and Owens, 1969]. Our present attention, however, is drawn to the proton ($0.5 \lesssim E \lesssim 50$ keV) distribution within the distant magnetosphere since this proton population provides the largest single charged-particle energy reservoir in the magnetospheric system and by the fact that its presence and behavior is generally not understood.

II. Overall Morphology of the Extraterrestrial 'Ring Current'

Our brief survey of the character of the proton ($0.5 \lesssim E \lesssim 50$ keV) distributions within the magnetosphere begins with several comments concerning these proton intensities within the outer radiation zone and the earthward edge of the plasma sheet. Omnidirectional, differential intensities of protons averaged over the energy range $16 \leq E \leq 25$ keV as functions of the magnetic-shell parameter L and time at the magnetic equator are summarized for the period 10 June through 23 July 1966 in Figure 1 [Frank and Owens, 1969]. Two salient features of these proton distributions in the local evening-midnight quadrant of the magnetosphere are of immediate interest: (1) the persistent presence of a 'quiet-time ring current' centered at $L \simeq 6.5$ (position of peak proton, $5 \lesssim E \lesssim 50$ keV, energy densities) [cf Swisher and Frank, 1968; Frank, 1967a] and (2) the penetration of these proton intensities deep into the outer radiation zone during the two moderate magnetic storms on 23 June and 9 July. These enhanced proton ($5 \lesssim E \lesssim 50$ keV) distributions are largely responsible for the world-wide decreases of magnetic field intensities [Frank, 1967a] and are known as the storm-time 'extraterrestrial ring-current'. No clear association among various parameters of the solar wind, such as ion temperatures and velocities and interplanetary magnetic field intensities and direction, and the great enhancement of the extra-terrestrial ring current responsible for the main-phase geomagnetic storm has yet been found [cf Snyder, Neugebauer and Rao, 1963; Fairfield and Cahill, 1966; Wilcox, Schatten and Ness, 1967; Burlaga and Ogilvie, 1969; Verzariu, Strong and Sugiura, 1969]. The differential energy spectrums of proton intensities at various positions within the storm-time ring current should provide several clues as to the mechanism responsible for their origin. Such a series of proton spectrums for 9 July is provided in Figure 2. These spectrums for L = 4.0, 6.0 and 7.1 are not remarkably dissimilar; the proton density increases and the average energy increases by a factor ~ 2 as L decreases from 7.1 to 4.0. If the motion of the protons inward proceeded with conservation of the first adiabatic invariant μ in a dipole field the expected increase in the average proton energy is ~ 6. However, the observational fact that this increase is not realized in this series of observations is not surprising due to the high β ($\beta \gtrsim 1$) of the plasma [cf Frank, 1967a] and associated inflation of the geomagnetic field. The proton spectrums within the 'quiet-time' ring current possess similar spectrums when compared to the above storm-time distributions, but feature lower number densities [cf Frank, 1967b] and significant intensities are restricted to larger radial distances, $\gtrsim 5.5\ R_E$. No clear indication of a region of 'local acceleration', where acceleration of solar wind or magnetosheath ions with kinetic energies ~ several hundred eV to energies typical of the dominant 'ring current' proton distributions is evident in this series of observations. Even during the earliest development phase of a geomagnetic main-phase storm hours before a decisive decrease is evident in the $D_{ST}(H)$ values but during which these proton intensities have penetrated deep into the evening sector of the outer radiation zone, these proton spectrums are again characterized by average energies ~ 5 to 20 keV and broad width [Frank, 1969a]. Direct observations of this asymmetric injection of protons into the outer radiation zone are summarized for four 'snapshots' of proton ($31 \leq E \leq 49$ keV) intensities as functions of shell parameter L in Figure 3: quiescent or pre-storm (snapshot 1); early development phase (3); main phase (4); and recovery phase (2). The proton spectrums of snapshot 3 during the early development phase in the evening sector of the outer radiation zone (●, local evening; O, local noon) displayed no evidences of a proton energy spectrum with lower average energy and/or narrower width relative to the quiescent or storm-time proton spectrums which perhaps would indicate concurrent acceleration by, for example, a wave-particle interaction or a geoelectric potential system. The above overall homogeneity of these proton spectrums with regard to average energy and similar broad widths and the general character of the temporal behavior of the proton distributions over such a large region of the magnetosphere and broad range of geomagnetic activity suggest that bulk transport throughout these regions is an important contributor to the morphology of this proton distribution. A decisive evaluation of the relative importance of transport and acceleration awaits simultaneous measurements of magnetic and electric fields.

III. Comments on the Proton Distributions in the Earth's Magnetic Tail

A discussion of the proton ($0.5 \lesssim E \lesssim 5$ keV) distributions within the magnetosphere is incomplete without at least several comments concerning the character of the continuation of this near-earth plasma into the earth's magnetic tail, the so-called 'plasma sheet'. The existence of the earth's magnetic tail and its neutral sheet [Ness, 1965; Ness, Behannon, Scearce and Cantarano, 1967] is important to a host of magnetospheric models for the acceleration and transport of low-energy charged particles, including the auroral corpuscular radiation, based upon the dynamical behavior of this region [cf Dungey, 1968; Speiser, 1965, 1967; Taylor and Hones, 1965; Piddington, 1968; Dessler, 1968; Schield, 1969]. A typical series of observations of the average energy and number densities for proton (25 eV $\leq E \leq$ 47 keV) intensities within the magnetic tail as functions of geocentric radial distance are summarized in Figure 4 [Kanbach and Frank, 1969]. Proton number densities and average energies range from $< 10^{-3}$ to 0.4 protons$(cm)^{-3}$ and $\sim$ 200 eV to 10 keV, respectively. No obvious order such as a clear increase in average proton energy with increasing (decreasing) radial distance, which would be indicative of an acceleration by geoelectric potential fields, for example, is evident in the large fluctuations of these parameters although the average energy and number densities do generally appear to increase with decreasing distance from the neutral sheet (Z_{sm}, top of Figure 4). This ordering arises from the apparent existence of two proton distributions within the magnetotail characterized by the two directional, differential spectrums of proton intensities shown in Figure 5. The energy spectrum with average proton energy ~ several hundred eV is similar to typical proton spectrums observed within the magnetosheath (see Figure 6) but is usually characterized by a lesser number density by factors ~ 10^{-2} to 10^{-3}. In fact these proton intensities within the magnetic tail are similar in intensities to the magnetosheath proton intensities directed normal to the downstream magnetopause surface; this feature strongly suggests that these proton intensities have access to the magnetic tail. The second proton energy spectrum displayed in Figure 5 has an average energy ~ 5 keV and is typical of the proton spectrums within the plasma sheet. This second proton population is present, with a large range of number densities and hence energy densities, over a large region of the earth's magnetic tail to geocentric radial distances of a least 35 R_E (see Figure 4, also Kanbach and Frank [1969]). Generally the angular distributions of these proton intensities are closely isotropic [Frank, 1969c]. However, detailed studies of these angular distributions in the vicinity of the neutral sheet are currently being undertaken and the results of this search for a possible current system will soon be reported. We note at this point that the average electron energies within this proton distribution (plasma sheet, near-earth plasma sheet, quiescent and storm-time ring currents) range from ~ 0.5 to several keV [Frank, 1967b, c; Bame, 1968; Schield and Frank, 1969] while the corresponding proton average energies are ~ 3 to 30 keV, factors ~ 5-10 larger than the average electron kinetic energy (and energy densities). Any magnetospheric mechanism or model will necessarily be required to account for this feature of the largest charged-particle energy reservoir within the earth's magnetosphere. This relatively high average proton energy, the general homogeneity of the proton spectrums with regard to average energy and broad width from the center of the storm-time extraterrestrial ring current at ~ 4 R_E to the distant plasma sheet at $\gtrsim 35$ R_E, the presence of magnetosheath proton intensities of the character described herein within the magnetotail, and the overall temporal behavior of the extraterrestrial ring current perhaps suggest to us that the interplanetary medium should again be examined as a direct source for these proton ($0.5 \lesssim E \lesssim 50$ keV) intensities which possibly gain the magnetosphere via the magnetopause downstream from the earth and are subsequently convected within the magnetosphere by geoelectric potentials and/or fluctuating magnetic fields driven by the solar wind.

IV. Interplanetary Medium: 'Invisible Source' for Extraterrestrial Ring-Current Protons?

A recent observational survey of the interplanetary medium in the vicinity of the earth has revealed the existence of substantial enhancements of interplanetary proton ($5 \lesssim E \lesssim 50$ keV) intensities, presumably of solar origin, during the development phases of two moderate geomagnetic storms [Frank, 1969b]. Salient features of these two increases of proton intensities were (1) a broad differential energy spectrum of intensities over the energy range $5 \lesssim E \lesssim 50$ keV with peak intensities ~ 10 protons$(cm^2\text{-sec-sr-eV})^{-1}$ at ~ 20 keV (see Figure 7), (2) peak number densities $\sim 10^{-2}$ protons$(cm)^{-3}$, (3) peak energy densities ~ 300 eV$(cm)^{-3}$, (4) an anisotropy in the angular distributions in the ecliptic plane favoring intensities arriving from near-solar directions by factors ~ 2 or 3 (see Figure 8), and (5) duration of these events ~ 1 day. A coarse assessment of the relative importance of these proton ($5 \lesssim E \lesssim 50$ keV) distributions to the dynamical character of the interplanetary medium can be gained by noting that the above peak energy densities exceed the 'quiet-sun' ion and electron thermal energy densities by a factor ~ 10 and are comparable to or exceed these thermal energy densities during solar disturbances. The observations of these increases of interplanetary proton intensities during the development phases of two moderate magnetic storms and the hourly $D_{ST}(H)$ values are summarized in Figure 9. Note that these increases commence hours before a clear decrease in the ground-based magnetometer records is evident and terminate approximately with the occurrence of the maximum main-phase decrease. There is a remarkable agreement in chronological sequence among the observational facts that (1) the interplanetary proton ($5 \lesssim E \lesssim 50$ keV) intensities increase hours before the storm and (2) the early development phase of a magnetic storm is characterized by a highly asymmetric injection of protons ($5 \lesssim E \lesssim 50$ keV) into the evening sector of the outer radiation zone again hours before a decisive decrease is evident in the $D_{ST}(H)$ values [cf Frank, 1969a; Cahill, 1968]. This timely arrival of proton ($5 \lesssim E \lesssim 50$ keV) intensities at the earth just prior to the onset of two small geomagnetic storms and the similarities of the proton differential spectrums within the extraterrestrial ring current (see Figure 2) with those in the interplanetary medium provide ample motivation to examine the possibility that the mechanism responsible for supplying a major fraction of the energy within the extraterrestrial ring current is not local acceleration of lower energy protons (~ several hundreds of eV) but largely convection of interplanetary protons ($5 \lesssim E \lesssim 50$ keV) to positions deep within the magnetosphere with large enhancements of interplanetary intensities and that, for example, the great variety of magnetic storms (i.e., slow and fast growth phases, multiple storms, etc. [Akasofu, 1966]) reflect the temporal variations of solar proton ($5 \lesssim E \lesssim 50$ keV) intensities arriving at the earth [Frank, 1969b]. It has been shown by Frank [1969b] that it is necessary to convect into the terrestrial magnetosphere only approximately two per cent of the interplanetary protons ($5 \lesssim E \lesssim 50$ keV) incident on the sunlit magnetopause in order to account for the observed $D_{ST}(H)$ decreases during these two magnetic storms; in other words, it is energetically plausible. A similar result ensues if this calculation is repeated for energy fluxes incident upon the magnetopause at the magnetic tail. The energy fluxes directed perpendicular to the magnetopause at ~ 10 to 20 R_E downstream from the earth are $\sim 10^{-3}$ erg(cm^2-sec)$^{-1}$ for magnetosheath protons [Frank, 1969b] and $\sim 4 \times 10^{-2}$ erg(cm^2-sec)$^{-1}$ for the above peak interplanetary proton ($5 \lesssim E \lesssim 50$ keV) intensities. As discussed above, magnetosheath protons are observed to gain access to the magnetotail; there is no apparent reason to believe that these more energetic interplanetary protons do not enjoy the same privilege. The reader is reminded at this point that observations of these proton intensities are difficult in the interplanetary medium near the earth and that these intensities are beyond the capabilities of most instruments designed to measure the properties of the solar wind ions (cf Frank, 1969b; Frank, 1967c); it is not surprising that this constituent of the interplanetary medium has heretofore been undetected. These are two further series of observational evidences which are directly pertinent to the above suggestion and which are recalled here from previously published literature. First, a similar, and apparently singular, observation of the arrival of relatively high energy densities of solar protons ($E \gtrsim 140$ keV) of $\sim 10^{-9}$ erg(cm)$^{-3}$, or 600 eV(cm)$^{-3}$, on 30 September 1961 [Hoffman, Davis and Williamson, 1962] was followed several hours later by the growth of a well-developed main-phase geomagnetic storm. Second, Akasofu [1964] has conducted an extensive correlative study of ground-based observations of magnetic storms and solar activity and has concluded that the source for storm-time ring current particles was a blast wave of as yet undetected, or 'invisible', corpuscular radiation from the sun; these 'invisible' particles were assumed to be neutral hydrogen atoms. Several criticisms of the above suggestion are directed toward the plausibility of relatively large proportions of solar neutral hydrogen arriving at the earth [cf Brandt and Hunten, 1966]. Our present interpretation allows us to adopt Akasofu's analyses and conclusions as substantially correct but with the assertion the 'invisible' corpuscular radiations are the heretofore unobserved solar proton ($5 \lesssim E \lesssim 50$ keV) intensities, not solar neutral hydrogen. Throughout the preceding discussions, a strong observational connection among the proton distributions of the plasma sheet and the quiescent and storm-time ring currents has been established. Accordingly it should be expected that these proton distributions share a common origin. At present only upper limits for interplanetary proton ($5 \lesssim E \lesssim 50$ keV) intensities during periods of relative magnetic quiescence are available. These upper limits for proton ($5 \lesssim E \lesssim 50$ keV) energy densities are ~ 50 eV$(cm)^{-3}$; this corresponds to an energy flux on the sunlit magnetopause, for example, of ~ 10^{18} ergs$(sec)^{-1}$. A rough estimate of the energy input required to maintain these 'quiet-time' magnetospheric proton distributions may be acquired by assuming that the dominant loss mechanism is precipitation into the earth's atmosphere at auroral latitudes. Preliminary estimates [Frank, Münch and Ackerson, 1969] of proton ($5 \lesssim E \lesssim 50$ keV) energy losses to the earth's upper atmosphere are less than the quiescent energy precipitation due to auroral electrons ($E \gtrsim$ several keV) by factors ~ 10-100. The corresponding rate of energy input into the atmosphere due to electron precipitation is ~ 2×10^{17} ergs$(sec)^{-1}$ [Craven, 1969] and by adopting an intermediate ratio ~ 30 as noted above the corresponding estimate for proton ($5 \lesssim E \lesssim 50$ keV) energy losses into the atmosphere is ~ 6×10^{15} ergs$(sec)^{-1}$. If this estimate for the power input is reasonable for maintaining the protons within the plasma sheet and extraterrestrial ring current during quiescent conditions, then again it is necessary to transport into the magnetosphere only ~ 1 percent of the observed upper limit for proton ($5 \lesssim E \lesssim 50$ keV) intensities in the interplanetary medium. Clearly there is a need for further measurements of interplanetary and magnetosheath proton intensities over the energy range extending from several keV to tens of keV to further evaluate the interplanetary medium and the magnetosheath as sources for the vast populations of magnetospheric protons with these energies. As a final note, it is stressed that these interplanetary proton ($5 \lesssim E \lesssim 50$ keV) intensities recently observed are suggested as a dominant contributor to the proton distributions with similar energies in the plasma sheet and the extraterrestrial ring current, but that the energy required to provide the transport of these protons within the magnetosphere and to provide auroral electron precipitation, energetic charged particle diffusion, etc., must be derived from the primal energy source, the solar wind ions.

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Figure Captions

Figure 1. Contours of constant omnidirectional intensities of protons ($16 \leq E \leq 25$ keV) as functions of magnetic shell parameter L and time at the magnetic equator for the period 10 June through 23 July 1966. The contour intensity increments are 1, 3, 5 and 7 x 10^n. Units are omnidirectional differential flux, protons$(cm^2$-sec-eV$)^{-1}$, averaged over the instrument energy bandpass [Frank and Owens, 1969].

Figure 2. Several examples of proton differential energy spectrums at L = 4.0, 6.0 and 7.1 during the main phase of the magnetic storm in early July 1966. The proton (200 eV $\leq$ E $\leq$ 50 keV) number density at L = 4.0 (λ_m = 27°) was 8(± 2)$(cm)^{-3}$ [Frank, 1967a].

Figure 3. Proton ($31 \leq E \leq 49$ keV) directional intensities as functions of L during several phases of two geomagnetic storms on 9 July and 8 September 1966. Hourly values of $D_{ST}(H)$, several useful coordinates for these observations, and the OGO-3 trajectory through the outer radiation zone as functions of local time and shell parameter L have also been included in this graphic summary [Frank, 1969a].

Figure 4. A typical series of observations of the proton ($25\ eV \leq E \leq 47\ keV$) energy densities and number densities as functions of geocentric radial distance in the earth's magnetic tail. Values for the calculated height of the satellite above the neutral sheet, Z_{SM}, and for the corresponding earth-centered solar magnetospheric longitudes φ_{SM} are included at the top of the graph [Kanbach and Frank, 1969].

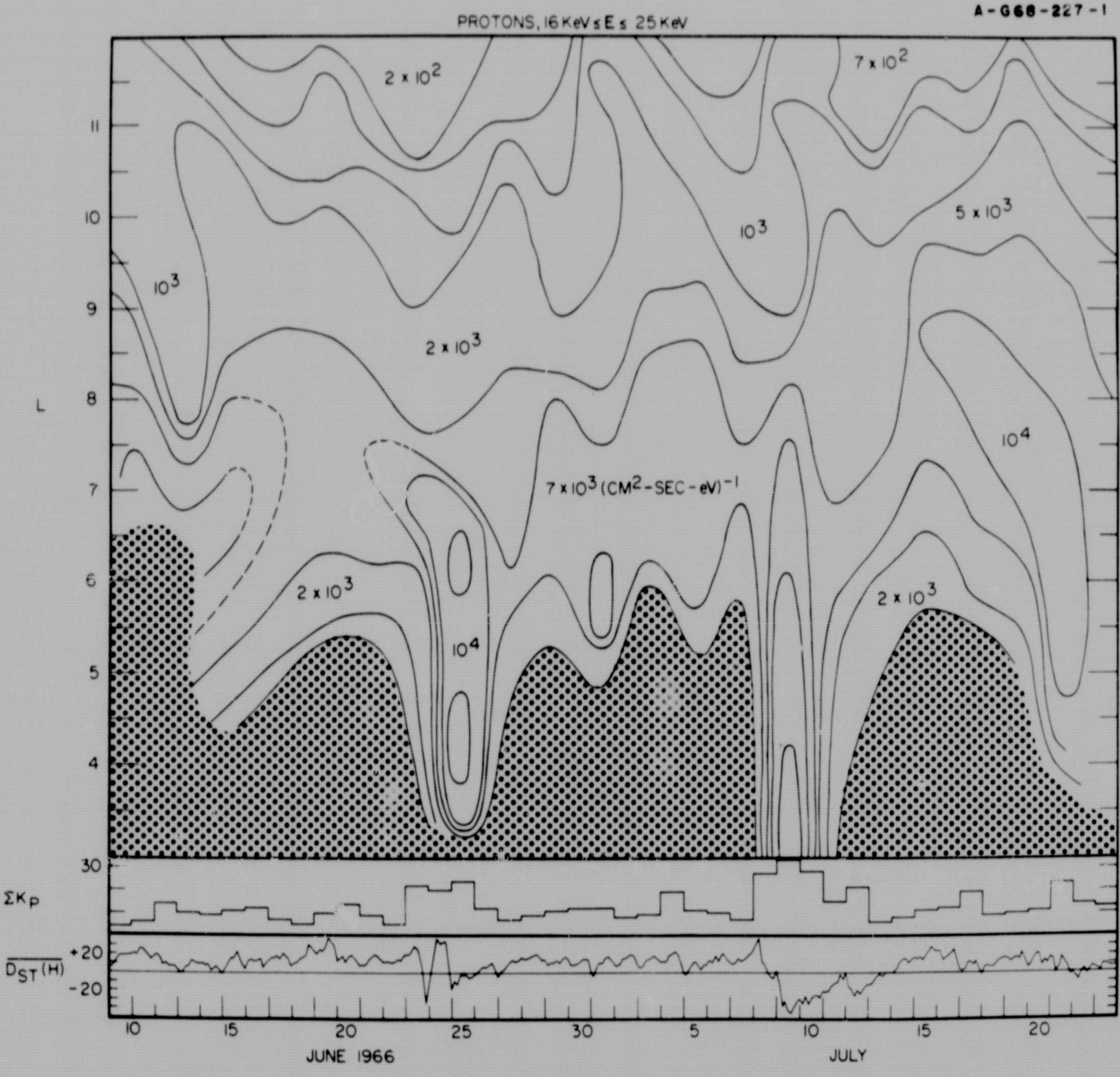
Figure 5. Two characteristic spectrums of directional, differential proton intensities observed in the earth's magnetic tail [Kanbach and Frank, 1969].

Figure 6. Comparison of differential spectrums of proton intensities for a typical magnetosheath observation in the direction of bulk flow (O) with the low-energy proton spectrum observed in the magnetotail (●, see also Figure 5) [Kanbach and Frank, 1969].

Figure 7. Differential energy spectrum of interplanetary proton intensities averaged over the angular distributions during 17:00-17:30 U.T. on 11 August 1967 [Frank, 1969b].

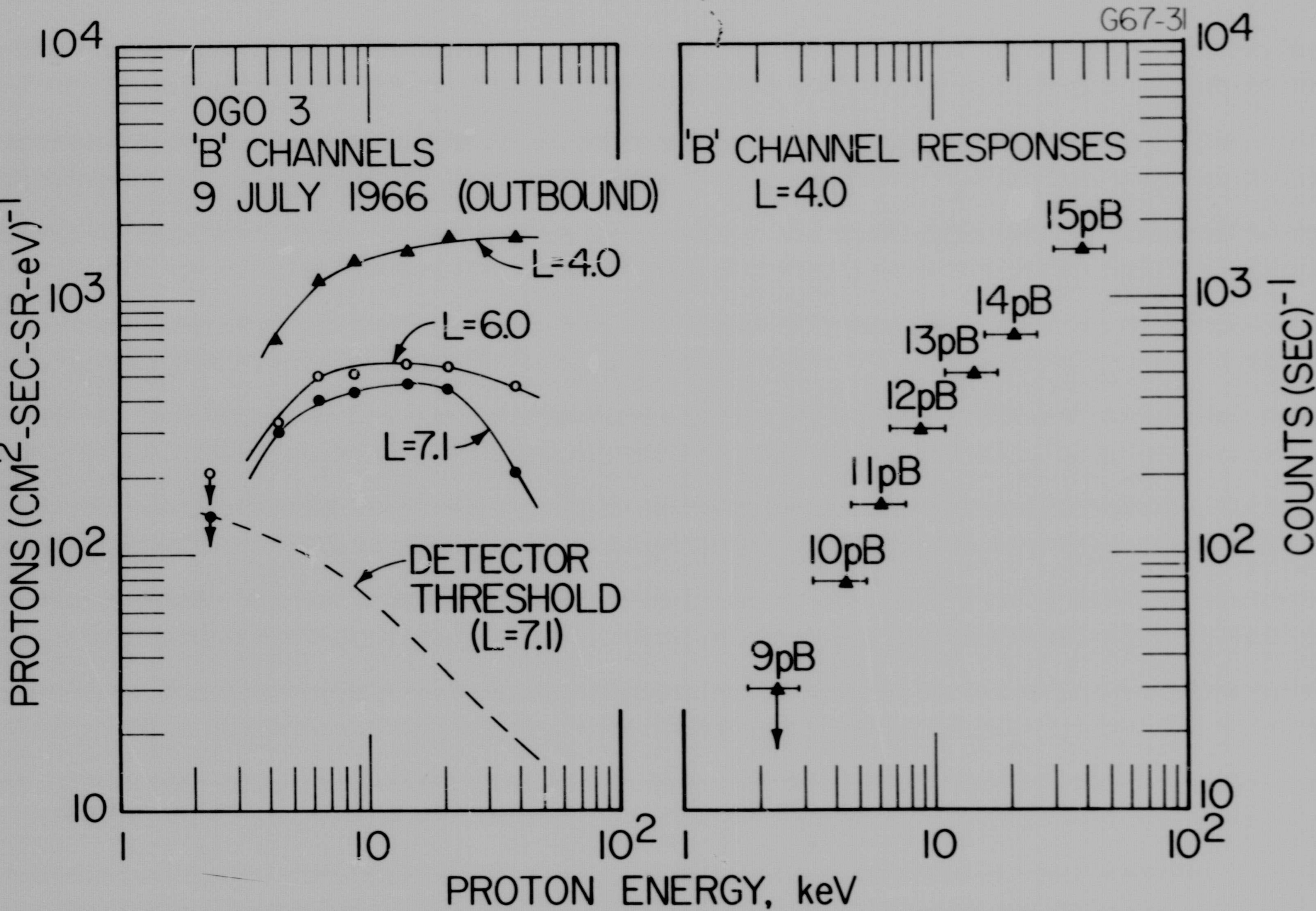
Figure 8. Angular distribution of interplanetary proton ($11 \leq E \leq 29$ keV) intensities during the event on 11 August (φ_{SE}, satellite-centered solar ecliptic longitude) (see also Figure 7) [Frank, 1969b].

Figure 9. Hourly average responses of the LEPEDEA instrumentation due to interplanetary proton ($11 \leq E \leq 18$ keV) intensities arriving at the satellite from directions within a 270° angular sector centered on the anti-solar direction (II, bottom) and within the quadrant centered on the solar direction (I, middle) and hourly $D_{ST}(H)$ values (top) as functions of time for the period 25 July through 13 August 1967 [Frank, 1967b].



A-G68-227-1
PROTONS, 16 KeV ≤ E ≤ 25 KeV
2 x 10^2
7 x 10^2
10^3
10^3
5 x 10^3
2 x 10^3
10^4
7 x 10^3 (CM^2-SEC-eV)^-1
2 x 10^3
10^4
2 x 10^3
L
11
10
9
8
7
6
5
4
30
ΣKp
$\overline{D_{ST}(H)}$
+20
-20
10
15
20
25
30
5
10
15
20
JUNE 1966
JULY

Figure 1



G67-31
OGO 3
'B' CHANNELS
9 JULY 1966 (OUTBOUND)
L=4.0
L=6.0
L=7.1
DETECTOR THRESHOLD (L=7.1)
PROTONS (CM2-SEC-SR-eV)-1
'B' CHANNEL RESPONSES
L=4.0
15pB
14pB
13pB
12pB
11pB
10pB
9pB
COUNTS (SEC)-1
PROTON ENERGY, keV

Figure 2

25

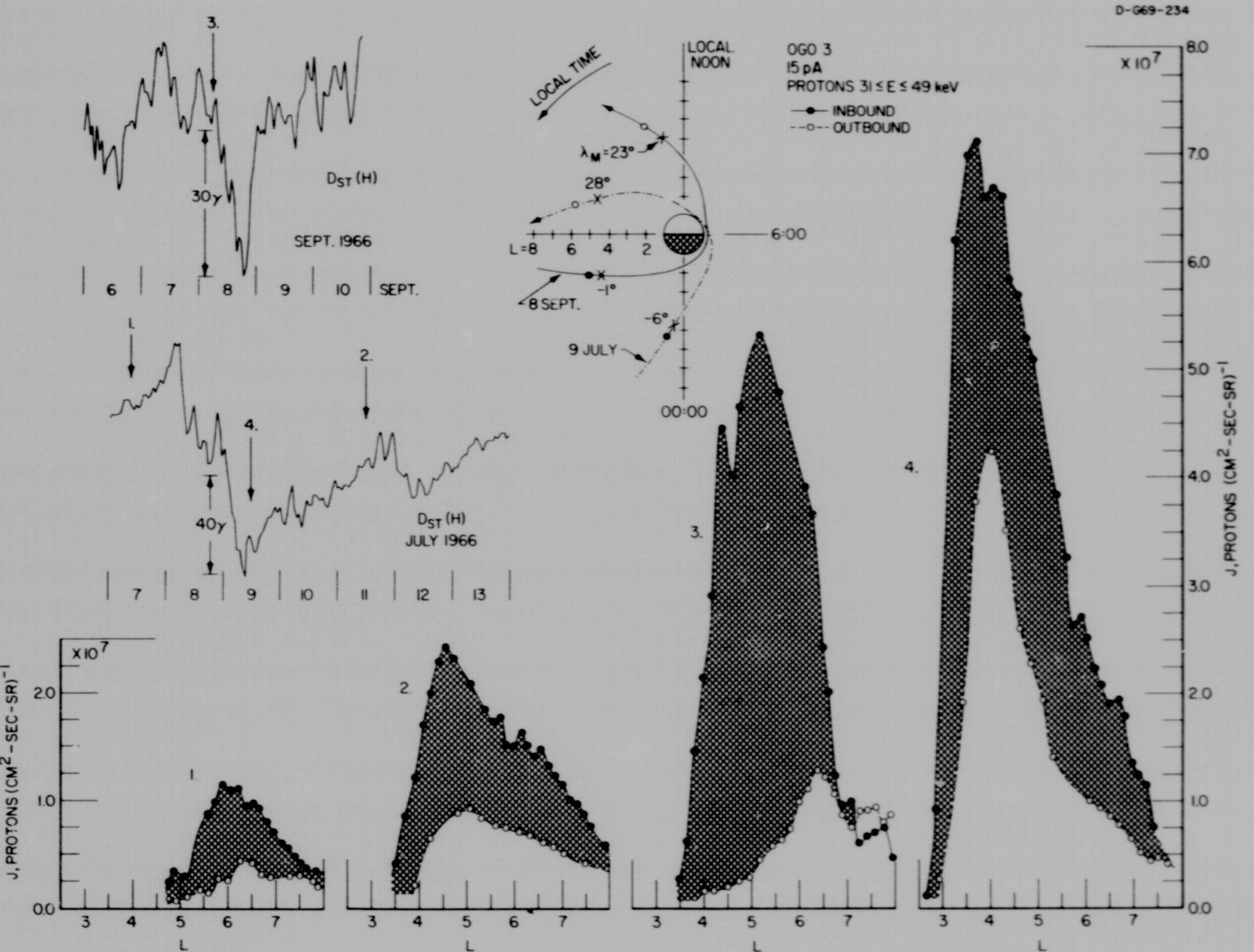

D-G69-234
OGO 3
15 pA
PROTONS 31 ≤ E ≤ 49 keV
INBOUND
OUTBOUND
LOCAL NOON
LOCAL TIME
6:00
00:00
L=8 6 4 2
λM=23°
28°
-1°
-6°
8 SEPT.
9 JULY
DST (H)
SEPT. 1966
30γ
6 7 8 9 10 SEPT.
DST (H)
JULY 1966
40γ
7 8 9 10 11 12 13
X 10^7
J, PROTONS (CM²-SEC-SR)^-1
L

Figure 3

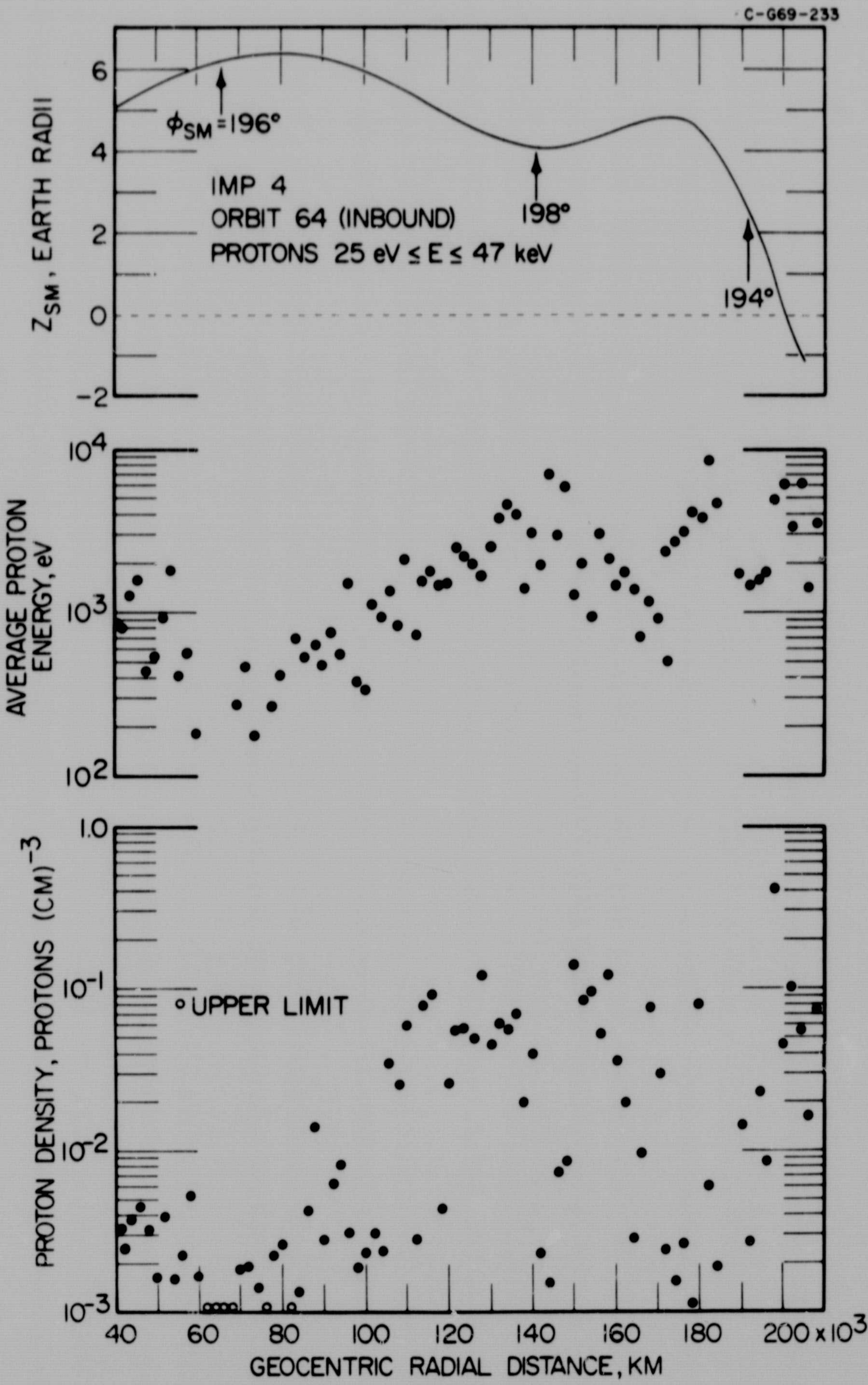
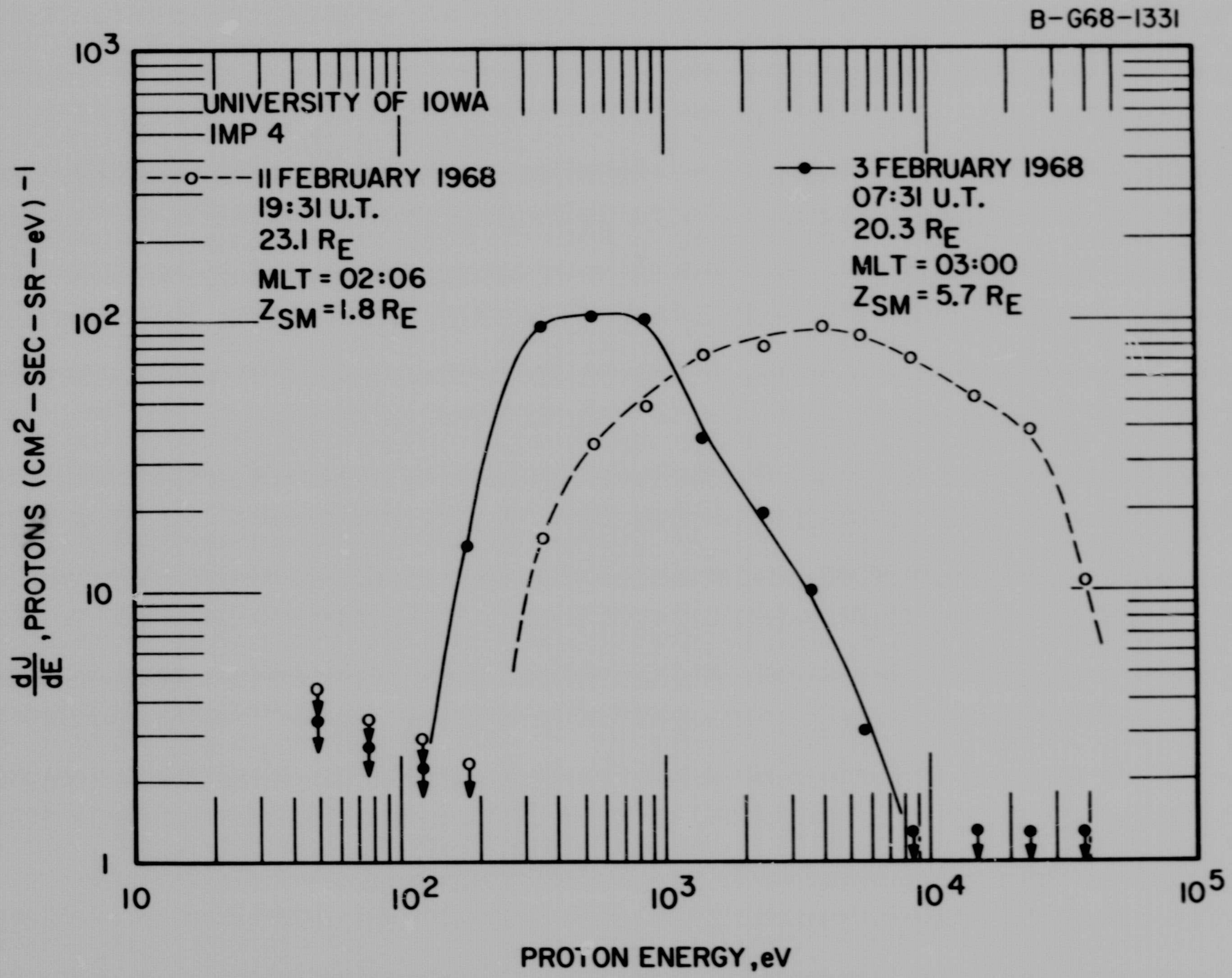

C-G69-233
Z_{SM}, EARTH RADII
ϕ_{SM} =196°
198°
194°
IMP 4
ORBIT 64 (INBOUND)
PROTONS 25 eV ≤ E ≤ 47 keV
AVERAGE PROTON ENERGY, eV
PROTON DENSITY, PROTONS (CM)$^{-3}$
○ UPPER LIMIT
GEOCENTRIC RADIAL DISTANCE, KM

Figure 4



B-G68-1331
UNIVERSITY OF IOWA
IMP 4
11 FEBRUARY 1968
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23.1 RE
MLT = 02:06
ZSM = 1.8 RE
3 FEBRUARY 1968
07:31 U.T.
20.3 RE
MLT = 03:00
ZSM = 5.7 RE
dJ/dE, PROTONS (CM2 - SEC - SR - eV)-1
PROTON ENERGY, eV

Figure 5

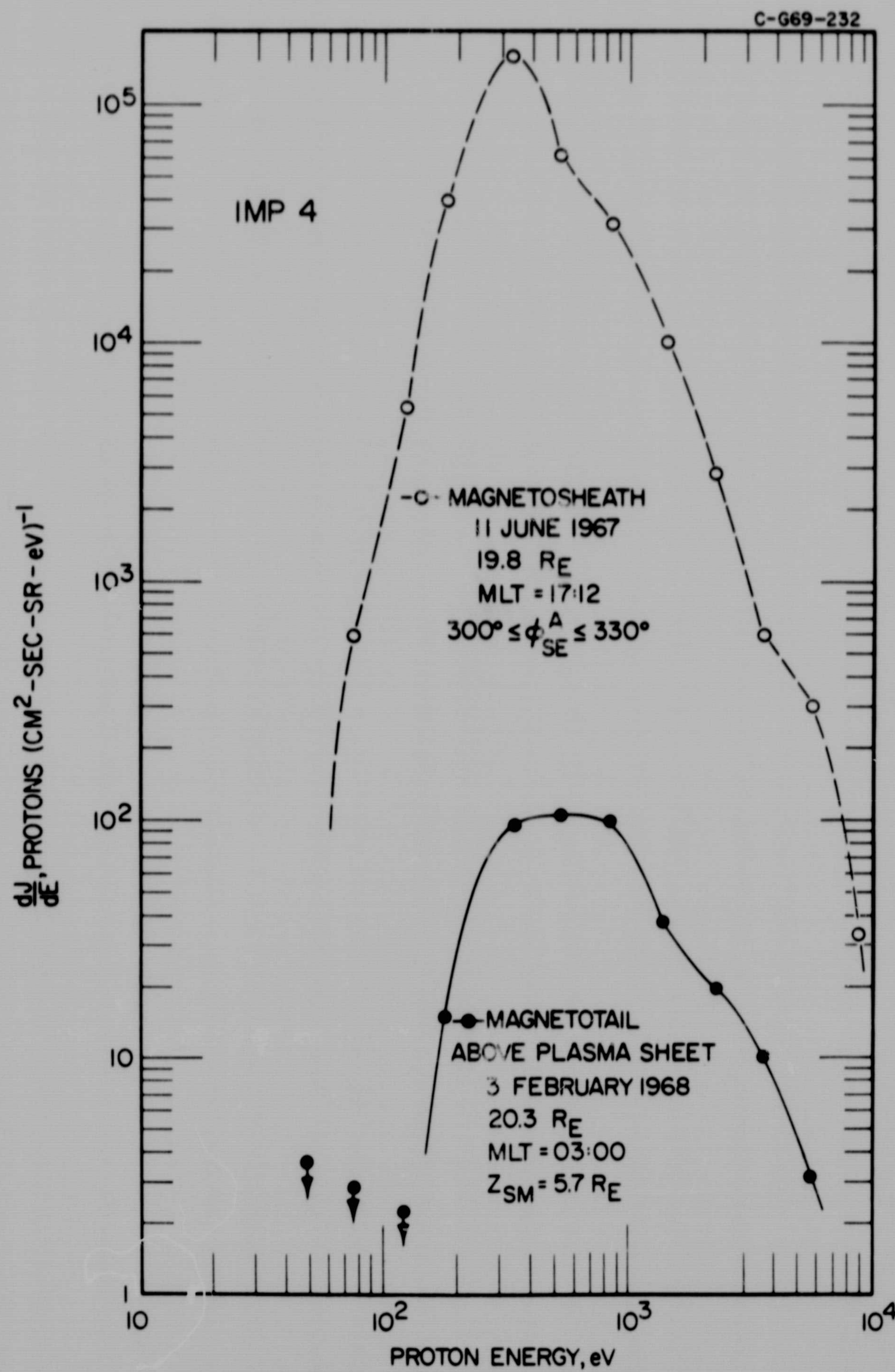

C-G69-232
IMP 4
-o- MAGNETOSHEATH
11 JUNE 1967
19.8 R_E
MLT = 17:12
300° ≤ φ_SE^A ≤ 330°
-●- MAGNETOTAIL
ABOVE PLASMA SHEET
3 FEBRUARY 1968
20.3 R_E
MLT = 03:00
Z_SM = 5.7 R_E
dJ/dE, PROTONS (CM²-SEC-SR-eV)⁻¹
PROTON ENERGY, eV
10
10²
10³
10⁴
1
10⁵

Figure 6

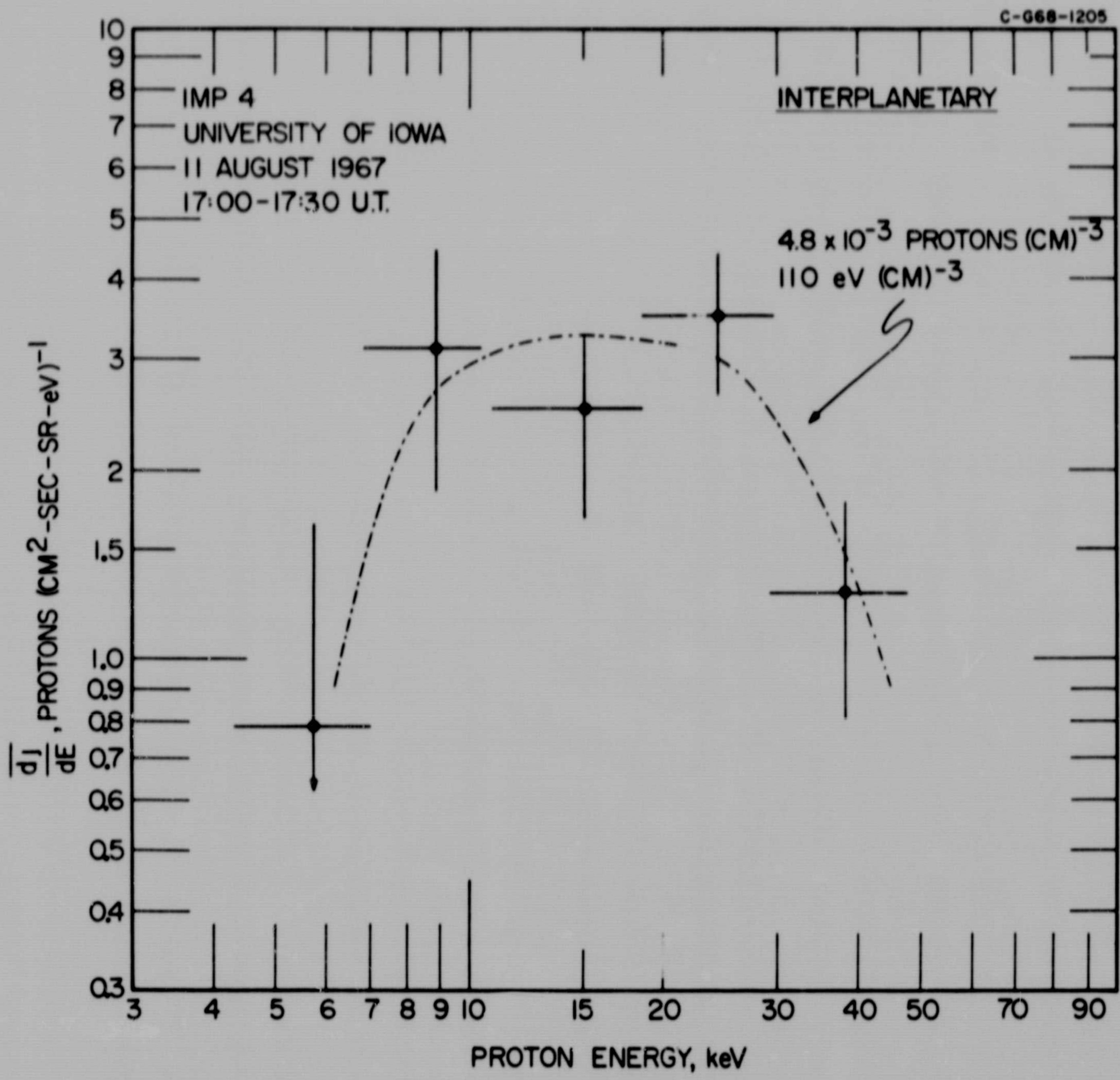

C-G68-1205
IMP 4
UNIVERSITY OF IOWA
11 AUGUST 1967
17:00-17:30 U.T.
INTERPLANETARY
4.8 x 10^-3 PROTONS (CM)^-3
110 eV (CM)^-3
dI/dE, PROTONS (CM^2-SEC-SR-eV)^-1
PROTON ENERGY, keV
10
9
8
7
6
5
4
3
2
1.5
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
3
4
5
6
7
8
9
10
15
20
30
40
50
70
90

Figure 7

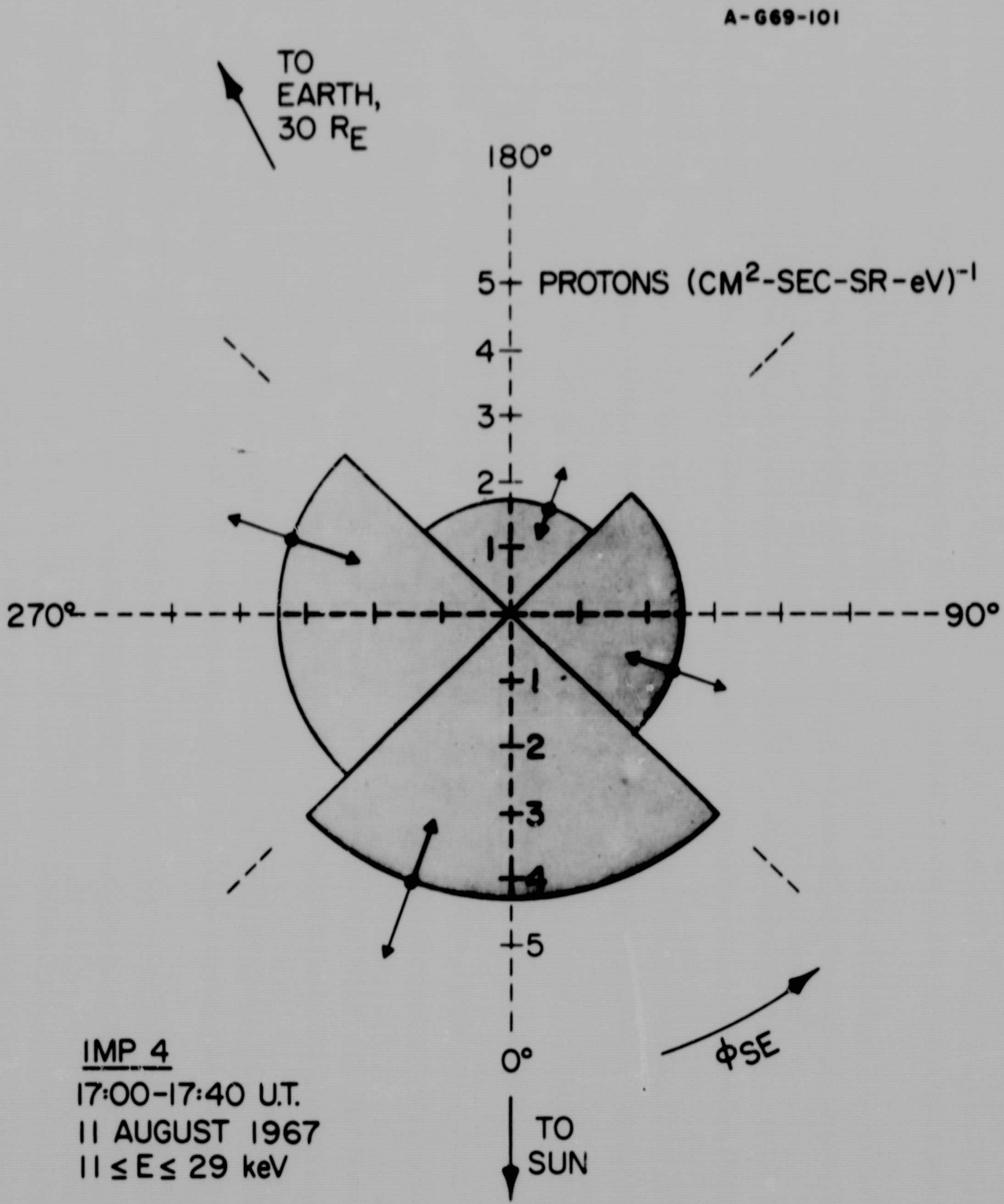
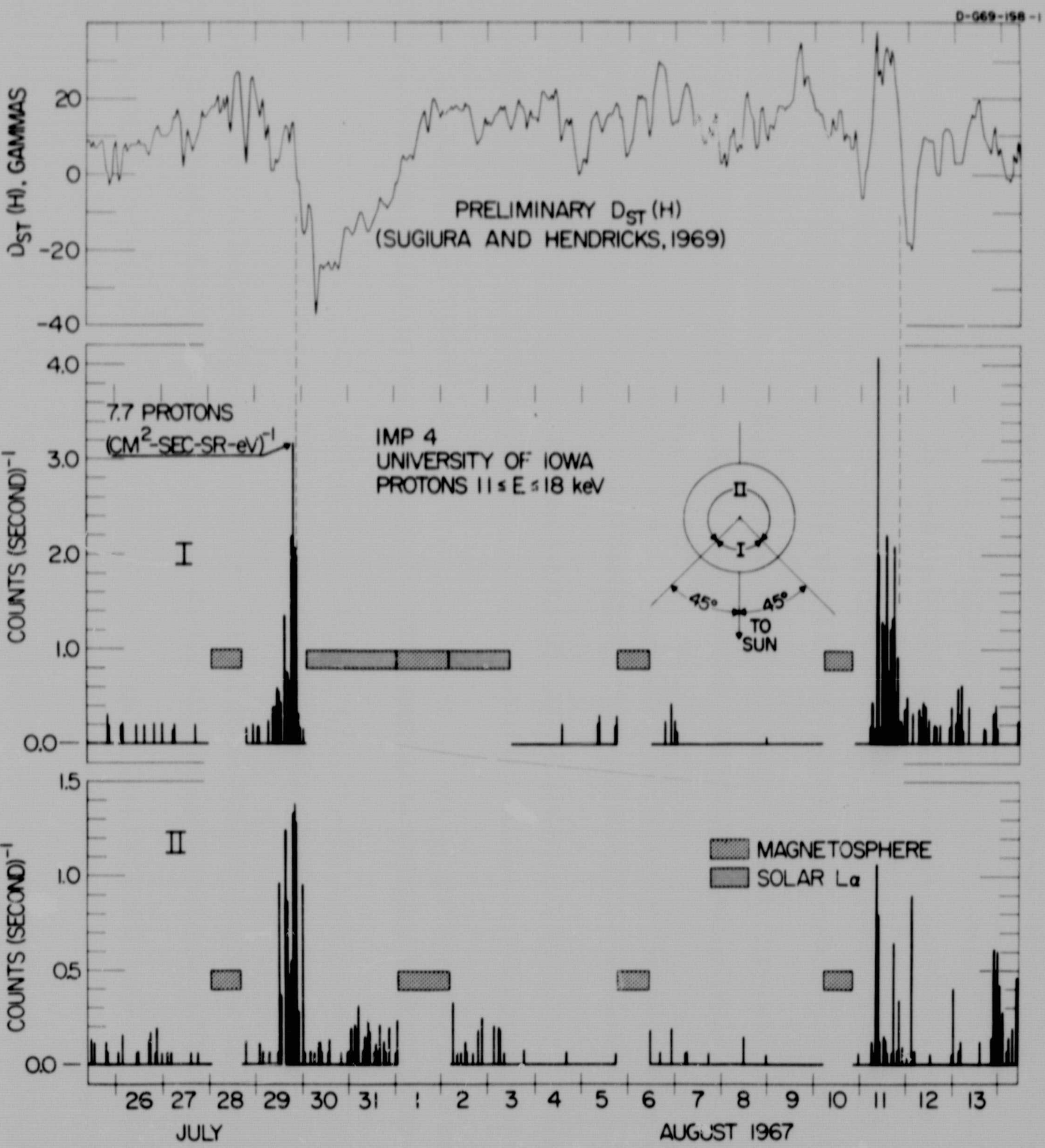

A-G69-101
TO
EARTH,
30 R_E
180°
5 PROTONS $(CM^2\text{-}SEC\text{-}SR\text{-}eV)^{-1}$
4
3
2
1
270°
90°
1
2
3
4
5
0°
ΦSE
IMP 4
17:00-17:40 U.T.
11 AUGUST 1967
$11 \leq E \leq 29$ keV
TO
SUN

Figure 8



D-G69-158-1
D_{ST} (H), GAMMAS
20
0
-20
-40
PRELIMINARY D_{ST} (H)
(SUGIURA AND HENDRICKS, 1969)
4.0
3.0
2.0
1.0
0.0
7.7 PROTONS
$(CM^2\text{-SEC-SR-eV})^{-1}$
IMP 4
UNIVERSITY OF IOWA
PROTONS 11 ≤ E ≤ 18 keV
COUNTS (SECOND)$^{-1}$
I
II
45°
45°
TO
SUN
1.5
1.0
0.5
0.0
MAGNETOSPHERE
SOLAR Lα
26 27 28 29 30 31 1 2 3 4 5 6 7 8 9 10 11 12 13
JULY
AUGUST 1967

Figure 9