CHARGE-EXCHANGE LIFETIMES FOR LOW-ENERGY PROTONS IN THE OUTER RADIATION ZONE AND IMPLICATIONS CONCERNING THE DENSITY OF ATOMIC HYDROGEN IN THE TERRESTRIAL EXOSPHERE*

by

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Abstract

The directional, differential intensities of protons over the energy range ~ 200 eV to 50 keV injected into the outer radiation zone (i.e., the extraterrestrial ring current) coincident with the initial phase of the geomagnetic storm during early July 1966 were monitored with a sensitive array of electrostatic analyzers borne on the earth-satellite OGO 3. Proton intensities are greatly enhanced throughout the outer radiation zone for L-values $\gtrsim 3$ during the main phase of this moderate magnetic storm, and the injection mechanism ceases to be effective after the storm main phase for L-values $\lesssim 5.5$. Proton ($30 \leq E \leq 50$ keV) intensities are shown to exponentially decay with lifetimes ranging from 15 to 105 hours in substantial agreement with calculated lifetimes invoking measured charge-exchange cross-sections for protons incident upon atomic hydrogen and a model of the atomic hydrogen density in the earth's exosphere. The atomic hydrogen density model for the terrestrial exosphere providing the best fit to the observed proton lifetimes over geocentric radial distances 2.5 to 4.8 earth radii (corresponding to observed densities ~ 200 to 30 hydrogen atoms $(cm)^{-3}$) allows only atoms in ballistic orbits in the exosphere as opposed to a model geocorona which includes an additional atomic hydrogen population in captive elliptical orbits.

I. Introduction

Recently direct observations of the low-energy protons which dominate the extraterrestrial ring current during geomagnetic storms have shown that these protons are convected or locally accelerated deep within the outer radiation zone coincident with the initial phase of the storm and subsequently decay in intensities exponentially with increasing time for a specified mirror point altitude during the recovery phase of the magnetic storm [Frank, 1967c]. The source mechanism for these large enhancements of low-energy (~ tens of keV) proton intensities within the outer radiation zone has not yet been delineated; however, an initial comparison of the decay of the proton intensities during the storm recovery phase with an early calculation of proton charge-exchange lifetimes [Liemohn, 1961] for a model of the telluric hydrogen corona [Johnson and Fish, 1960] solidly indicated that charge-exchange processes were predominantly responsible for the decay of the storm-time extraterrestrial ring current [Frank, 1967c]. Our present purpose is directed toward extending this preliminary survey of proton lifetimes during the recovery phase of a moderate geomagnetic storm and to infer the exospheric atomic hydrogen densities from these observations over geocentric radial distances ~ 2.5 to 5 R_E (R_E, earth radius). Current knowledge of the densities, constitution and temperature of the terrestrial exosphere is incomplete and largely inferred from rocket observations of scattered and absorbed solar Lyman-α emissions [cf. Kupperian, Byram, Chubb and Friedman, 1958, 1959; Purcell and Tousey, 1960; Morton and Purcell, 1962]; air drag experiments conducted with balloon satellites have provided density determinations up to altitudes of 3500 km [Fea, 1966]. Our calculations of the atomic hydrogen densities as derived from *in situ* observations of charge-exchange lifetimes for protons over a large range of mirror-point altitudes require only that atomic hydrogen, not helium or oxygen, is the principal neutral exospheric constituent over the altitude range 8,000 to 25,000 km. This assumption is firmly in accord with realistic model exospheres [Johnson, 1961; Opik and Singer, 1959, 1960, 1961; Chamberlain, 1963] with which we compare our results herein.

II. Observations

First measurements of the low-energy proton distributions in the outer radiation zone which are the dominant contributors to the extra-terrestrial ring current during magnetic storms were obtained with a set of electrostatic analyzers employing continuous channel electron multipliers and cylindrical curved plates biased with a series of programmed, monitored voltages borne on the earth-satellite OGO 3 (launch, 7 June 1966; apogee 128,500 km and perigee 6,700 km geocentric radial distances; inclination, 31°; period, 48.6 hours) [Frank, 1967c]. Detailed descriptions of the instrumentation, orbital characteristics and observations have been previously given by Frank [1965, 1967a, b, c]; however, we recall here for the convenience of the reader two salient factors which facilitate our present investigation, (1) the ample energy resolution and sensitivity of the analyzer array for the determination of the directional, differential energy spectra of protons over the energy range ~ 200 eV to 50,000 eV and (2) the fortuitous combination of a nearly two-day orbital period and operational spacecraft attitude control system for providing a series of measurements of proton intensities at closely identical magnetic latitudes and pitch angles on a specified L-shell over a span of three or four consecutive traverses of the spacecraft through the outer radiation zone. The gross temporal and spatial character of the low-energy proton distributions in the outer radiation zone during the moderate geomagnetic storm of early July 1966 is exhibited in Figures 1 and 2 [Frank, 1967c]. Hourly $D_{ST}(H)$ values derived from the observations of ground-based magnetic observatories for the period 6-14 July 1966 are summarized in Figure 1 accompanied by four perigee crossings (P) of the spacecraft which designate, within a few hours, those periods during which 'snapshots' of the proton and electron populations are obtained during the inbound and outbound segments of the satellite orbit. The series of observations of proton ($31 \leq E \leq 49$ keV) directional intensities as functions of L for the four inbound passes through the outer radiation zone are presented in Figure 2 and correspond to the pre-storm, main phase, recovery phase and post-storm eras of the magnetic storm. These intensity measurements were obtained at magnetic latitudes $\lambda_m \lesssim 20°$, equatorial pitch angles $30° \lesssim \alpha_o \lesssim 90°$ [Frank, 1967c] and within 40° of the midnight meridional plane over the range of L-values shown in Figure 2. A second set of electrostatic analyzers with the axes of their fields of view directed perpendicularly to those of the above analyzer set obtained a similar, simultaneous series of measurements at different equatorial pitch angles. Several features of the observations summarized in Figure 2 are of immediate pertinence to our present discussion: (1) the intensity profiles of 7 and 13 July which are typical of the quiescent extraterrestrial ring current centered at L ~ 6, (2) the large enhancements of intensities over L-values ~ 3 to 5.5 during the main phase on 9 July and (3) the depletion of proton intensities, more severely with decreasing L-value, with the recovery phase 'snapshot' of 11 July. The impulsive injection of protons onto L-shells ~ 3 to 5.5 during the initial phase of the magnetic storm and evidences that no significant additional enhancements of intensities occur after storm main phase as indicated by the location of the quiescent extraterrestrial ring current allow an almost ideal situation for measuring low-energy proton lifetimes (and hence the effectiveness of the loss mechanism) over these L-values by monitoring the decay in intensities at a specified L-value and equatorial pitch angle. We are limiting our present study of low-energy proton lifetimes to electrostatic analyzer bandpasses corresponding to the energy range $30 \lesssim E \lesssim 50$ keV since the decay of these proton intensities may be followed over a longer duration than lower energy proton intensities due to the nature of the spectrum and of the instrumentation [cf. Frank, 1967c]. No loss of generality is inflicted by this restriction, however, as the principal loss mechanism for protons ~ 5 to 200 keV delineated here is charge-exchange with neutral constituents of the terrestrial exosphere and charge-exchange lifetimes may be easily extended over this broader energy range with laboratory measurements of charge-exchange cross-sections [Fite, Stebbings, Hummer and Brachmann, 1960; Bates and McCarroll, 1962].

Normalized proton ($31 \leq E \leq 49$ keV) intensities at specified L-values and mirror point latitudes λ_m^* as functions of time(hours) measured from the termination of the initial phase of the early-July magnetic storm (t = 0 at 10:00 U.T., 9 July, cf. Figure 1) are summarized in Figure 3. The strong dependence of the rate of exponential decay of intensities upon the parameter L is readily apparent with cursory examination of these intensity versus time profiles. For example, a comparison of the slopes for L = 3.5, 3.7 and 4.0 with proton mirror latitudes $\lambda_m^* = 23°$, 20° and 19°, respectively, shows a severely decreasing proton lifetime with decreasing L-value (or with decreasing mirror point altitude). At L = 3.5, $\lambda_m^* = 23°$ the mirror point altitude h_m^* is 12,500 km and the observed lifetime τ is 16 hours and are to be compared with mirror point altitude 16,500 km and observed lifetime 37 hours for L = 4.0, $\lambda_m^* = 19°$. A second series of similar observations have been included in Figure 4 for proton ($30 \leq E \leq 48$ keV) intensities observed with the second proton electrostatic analyzer during this magnetic storm but at differing mirror point latitudes on a specified L-shell. These observed proton lifetimes have been summarized in Table I with corresponding values of shell parameter L, mirror point latitude λ_m^*, mirror point altitude h_m^* and calculated charge-exchange lifetimes τ_{ce}

Table I

Observed Proton Lifetimes and Calculated
Proton Charge-Exchange Lifetimes in the Outer Radiation Zone

L, R_E	Mirror Latitude, λ_m^*	Mirror Altitude†, h_m^*, km	Proton Energy	Observed Lifetime, τ, hours	Calculated Charge-Exchange Lifetimes*, τ_{ce}, hours
3.5	23°	12,500	31 - 49 keV	16(±2)	17
3.7	20°	14,480	31 - 49 keV	24(±4)	19
3.7	38°	8,291	30 - 48 keV	18(±6)	8
4.0	19°	16,450	31 - 49 keV	37(±3)	35
4.5	14°	20,600	31 - 49 keV	51(±10)	64
5.0	12°	24,170	31 - 49 keV	79(±8)	91
5.0	31°	17,090	30 - 48 keV	44(±8)	41
5.5	28°	20,980	30 - 48 keV	105(±10)	76

*After Liemohn [1961]
†Dipole interpretation of L-λ_m coordinate system

according to Liemohm [1961]. For protons with $\lambda_m^* \neq 0$ the approximation for calculated lifetimes

$$\tau_{ce} \simeq \tau_o \cos^6 \lambda_m^*$$

where τ_o is the charge-exchange lifetime for a proton mirroring at the equator has been invoked [Liemohn, 1961] and is based upon the approximate (radial distance)$^{-3}$ dependence of the Johnson and Fish [1960] atomic hydrogen density model over the radial distance range 2 to 6 R_E and the approximation that a geomagnetically trapped charged particle spends the largest part of its latitudinal bounce period near its mirror latitude. The validity of the second approximation may be evaluated by consideration, for example, of a charged particle mirroring at $\lambda_m^* = 30°$ at L = 3.5: the percentage of time the particle is spiralling between $\lambda_m^* = 28°$ to 30°, corresponding to an excursion of 660 km (0.1 R_E) in mirror altitude, is conservatively estimated to be 68% [Hamlin, Karplus, Vik and Watson, 1961]. The agreement of the observed lifetimes with calculated charge-exchange lifetimes over a large segment of the outer radiation zone as demonstrated in Table I firmly establishes charge-exchange as the principal loss mechanism in this region for ring-current protons with energies ~ tens of keV. Our major source of error in the determination of observed lifetimes arises from the uncertainty in the determination of the L-value for the observations summarized in Figures 3 and 4. A geomagnetic field model derived from surface measurements of the geomagnetic field [Jensen and Cain, 1961] has been invoked to assign values of the magnetic shell parameter L and mirror latitude λ_m^* to each intensity measurement. However, the energy densities of the storm-time extraterrestrial ring curent are sufficient to significantly deform the geomagnetic field within the outer radiation zone [cf. Cahill, 1966; Frank 1967c] and are reflected in inaccuracies in the assignment of these magnetic coordinates; these probable errors in proton lifetimes at given L and λ_m^* have been estimated with the aid of realistic models of the storm-time distant geomagnetic field [Hoffman and Bracken, 1967; Akasofu, 1963, 1966] and are also included in Table I.

Beyond L $\simeq$ 5.5 it is not possible to determine in the above manner the low-energy proton lifetimes since the quiet-time extraterrestrial ring current is positioned on these higher L-shells and is maintained by an almost continual source mechanism. The persistent presence of this source mechanism is demonstrated by the observations of proton ($31 \leq E \leq 49$ keV and $30 \leq E \leq 48$ keV) directional intensities at L = 6 and 8, respectively, as functions of storm time summarized in Figure 5. Evidences of the storm-time ring current and its subsequent dispersal (cf. Figures 1 and 2) are almost completely masked by the presence of the quiescent extraterrestrial ring current at these higher L-values.

III. Discussion

The excellent agreement between the observed low-energy proton lifetimes and calculated charge-exchange lifetimes as indicated by the summary of results provided in Table I almost assures that the predominant loss mechanism for outer-zone protons within the energy range $\sim$ 5 to 200 keV is charge-exchange with the neutral constituents of the terrestrial exosphere. Further confidence in this conclusion may be gained from considerations of the effectiveness of other possible loss mechanisms such as Coulomb scattering, ionization and wave-particle interactions. The Coulomb scattering 'lifetimes', or the times required for 90% of a low-energy proton distribution initially mirroring near the magnetic equator to be scattered into the loss cone by small-angle Coulomb scattering (including energy loss), have been previously estimated [Wentworth, MacDonald and Singer, 1959] by assuming, in the absence of definitive observations, a distribution of ions in the upper atmosphere. These positive ion densities have subsequently been surveyed [Taylor, Brinton and Smith, 1965] and do not differ from the above assumed densities over geocentric radial distances 2.0 to 5.0 R_E so greatly as to invalidate the estimate of Coulomb scattering 'lifetimes' offered by Wentworth et al. [1959] for our present purposes. For example, the assumed proton densities at geocentric radial distances 2.0

and 5.0 R_E were 2.5×10^3 $(cm)^{-3}$ and 3.5×10^1 $(cm)^{-3}$, respectively, whereas the observed densities are typically $\sim 3 \times 10^3$ $(cm)^{-3}$ and 10^1 to 10^2 $(cm)^{-3}$ at these radial distances. The calculated Coulomb scattering 'lifetimes' at L = 2.0, 4.0, and 5.0 are then $\sim 1.5 \times 10^2$, 2×10^3 and 8×10^3 hours, respectively. Comparison of these estimated values with the observed low-energy proton lifetimes of $\sim$ 80 hours for protons ($30 \lesssim E \lesssim 50$ keV) at L = 5.0 and $\lambda_m^* = 12°$, for example, (see Table I) demonstrates that Coulomb scattering is not a competitive loss mechanism. Similarly the relative ineffectiveness of ionization may be evaluated by comparison of the measured ionization cross-sections for protons incident upon hydrogen atoms ($p + H \longrightarrow 2p + e$) of 1.5×10^{-16} and 5×10^{-17} cm^2 at 40 keV and 7 keV, respectively, with the corresponding experimental values for the cross-sections for charge-exchange in this collision ($p + H \longrightarrow H + p$) of 3.0×10^{-16} and 1.2×10^{-15} cm^2 at the above energies, respectively [Fite, Stebbings, Hummer and Brackmann, 1960]. Hence, since the loss of incident proton kinetic energy is only of the order of the ionization potential of atomic hydrogen per ionizing collision, loss of proton kinetic energy by ionization of atomic hydrogen over the above energy range is a relatively unimportant loss mechanism within the outer radiation zone at altitudes $\gtrsim$ 1000 km. Finally our rejection of the possibility that the loss mechanism for low-energy, outer-zone protons is attributable to a wave-particle interaction is principally based upon the improbability that such mechanisms will furnish the evident correlation of proton lifetimes with altitude, independent of shell parameter L (see Table I). In consideration of the foregoing comments, it is unlikely that any other mechanism can compete with the charge-exchange process as the loss mechanism for low-energy protons ~ 5 to 200 keV in the outer radiation zone over $L \simeq 2.5$ to 5.5. This energy range is limited by the possibility that Coulomb scattering may become important at lower and high proton energies [Wentworth, et al., 1959; Liemohn, 1961].

The measured charge-exchange lifetimes for low-energy protons in the outer radiation zone as reported here can be converted to equivalent atomic hydrogen densities in the terrestrial exosphere. This calculation is undertaken with the assumption that the principal neutral exospheric constituent over the altitude range 8,000 to 25,000 km is atomic hydrogen; this assumption is firmly in accord with the predicted mean molecular weight-vs-altitude profiles of realistic model exospheres [cf. Johnson 1961; Opik and Singer, 1961; Chamberlain, 1963; Kockarts, 1966; Donahue, 1966]. These results, for a period near solar minimum, are summarized in Figure 6 which displays atomic hydrogen densities corresponding to the proton lifetimes tabulated in Table I as functions of geocentric radial distance in units of earth radii ($1\ R_E = 6{,}378$ km) and includes estimates of the probable errors in densities and radial distances attributable to (1) a dipole interpretation of the L - λ_m^* coordinate system, (2) the 'breathing', or deformation, of the distant geomagnetic field due to the storm-time extraterrestrial ring current, (3) the approximation that these low-energy protons spend most of their latitudinal 'bounce' period near the mirror points and (4) the range of mirror point altitudes corresponding to the finite range of local pitch angles within the fields of view of the electrostatic analyzers. For comparison with our present results we have included the profiles for the predicted atomic hydrogen densities from the model calculations of Johnson [1961] for a temperature of 1000°K in Figure 6, the upper curve corresponds to a model atmosphere populated with atomic hydrogen atoms with ballistic and captive elliptical orbits with perigee altitudes $\gtrsim$ 500 to 1000 km and the lower density profile includes only the atomic hydrogen population with captive or escaping ballistic orbits. A more realistic temperature at the base of the exosphere near solar minimum is probably ~ 800°K [cf. Keating and Prior, 1967; Fea, 1966] which would be reflected in lower densities predicted by the above model exosphere and, by invoking a linear interpolation of Johnson's [1961] results, position the density profile for ballistic orbits only in good agreement with our present results (see Figure 6). The calculated density profile for atomic hydrogen with both ballistic and captive elliptical orbits differs, even with this lower temperature, significantly when compared with our present results. For example, at a radial distance of 5 R_E, the calculated density with captive elliptical orbits at ~ 800° K is greater than the observed densities by a factor of ~ 3 and strongly indicates that atomic hydrogen lifetimes at these radial distances are insufficiently long to maintain a relatively large population of hydrogen atoms in collisionless gravitational orbits. Chamberlain [1963] has included satellite orbits only with perigee geocentric radial distances of $\leq 2.5\ R_E$ in his model of the terrestrial exosphere with a corresponding decrease of the differences in calculated atomic hydrogen densities at a specified altitude for models which include or exclude these captive orbits; our results do not possess sufficient resolution to exclude the possibility of a significant atomic hydrogen population in satellite orbits with perigees below 2.5 R_E.

Finally, we have calculated the charge-exchange lifetimes for low-energy protons mirroring at the magnetic equator as functions of magnetic shell parameter L and proton energy utilizing our present observations of proton lifetimes and the measured charge-exchange cross-sections for protons incident upon atomic hydrogen [Fite, et al., 1960; Allison, 1958] and have summarized these lifetimes in Figure 7. Charge-exchange lifetimes for mirror latitudes λ_m^* at a specified L-value but not at the magnetic equator can be adequately approximated with the $\cos^6 \lambda_m^*$ dependence invoked by Liemohn [1961] as discussed in the previous section. Our observations of proton lifetimes within the outer radiation zone have been shown to be consistent with a dominant loss mechanism of charge-exchange with atomic hydrogen for L-values 2.5 to 5.5 over a proton energy range $\sim$ 5 to 200 keV. The lifetimes summarized in Figure 7 provide a direct determination of the magnitude of the loss mechanism for low-energy protons within the outer radiation zone during the epoch near solar minimum.

Acknowledgements

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Figure Captions

Figure 1. Hourly $D_{ST}(H)$ values for the period covering the geomagnetic storm during early July 1966 (after Frank [1967c]).

Figure 2. Directional intensities of protons ($31 \leq E \leq 49$ keV) as functions of L at low magnetic latitudes during the pre-storm, main phase, recovery phase and post-storm eras of the early-July geomagnetic storm (after Frank [1967c]).

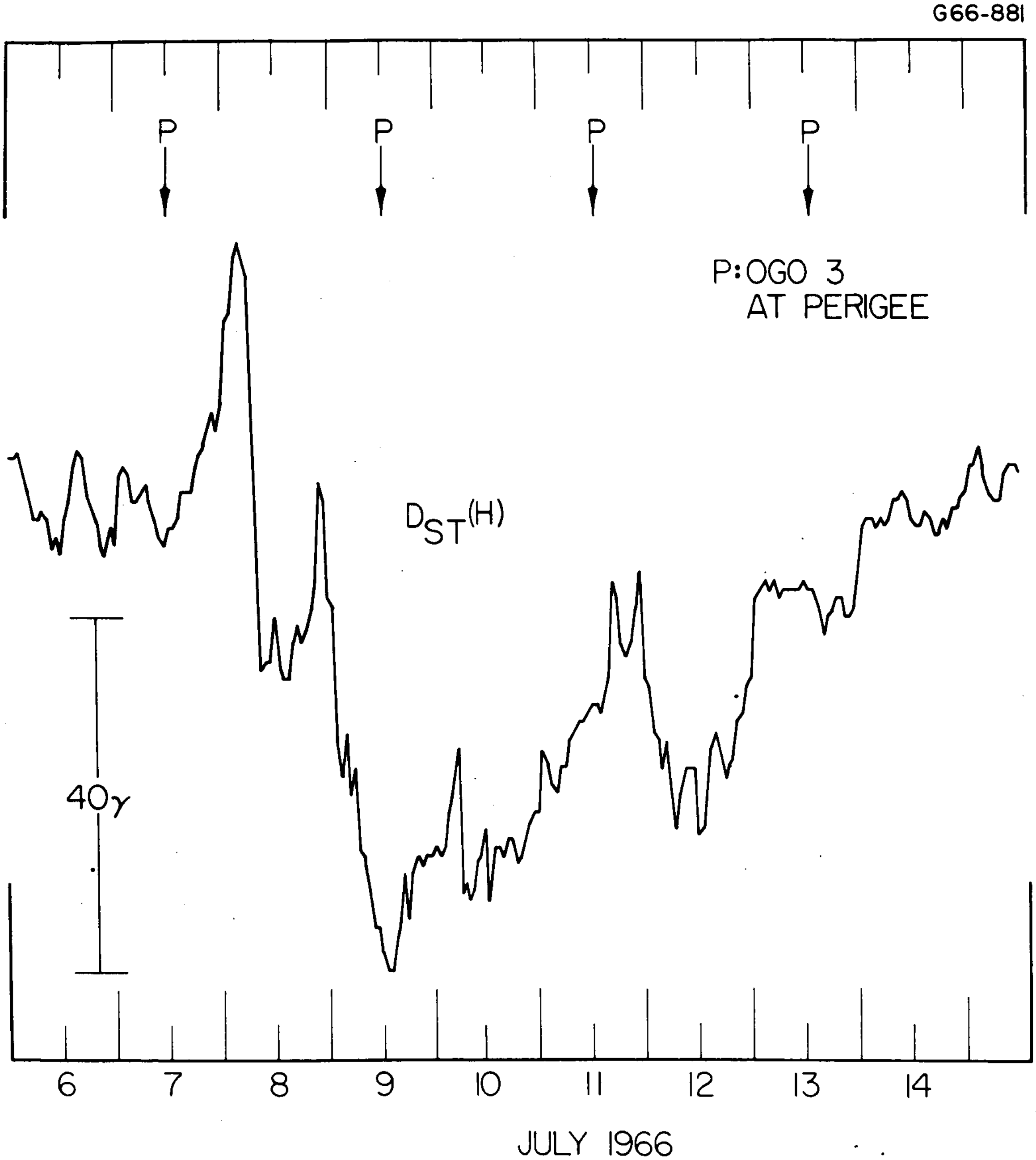
Figure 3. Normalized directional intensities of protons ($31 \leq E \leq 49$ keV) as functions of storm-time measured from the termination of the initial phase of the early-July magnetic storm for selected mirror latitudes λ_m^* and magnetic shell parameters L.

Figure 4. Continuation of Figure 3 for proton ($30 \leq E \leq 48$ keV) intensities at selected values of L and λ_m^*.

Figure 5. Directional intensities of protons ($30 \leq E \leq 48$ keV and $31 \leq E \leq 49$ keV) as functions of storm-time at L = 6 and 8 near the magnetic equator.

Figure 6. The atomic hydrogen densities as functions of geocentric radial distance calculated from the observed proton lifetimes summarized in Table I. The smooth curves are the theoretical density profiles given by Johnson [1961] for an exospheric temperative of 1000° K which exclude hydrogen atoms in essentially collisionless trapped orbits (ballistic orbits only, lower curve) and include these orbiting atoms (ballistic plus gravitationally bound orbits, upper curve).

Figure 7. Charge-exchange lifetimes for low-energy protons mirroring at the magnetic equator ($\lambda_m^* = 0°$) as functions of shell parameter L and proton energy. These lifetimes have been computed from the observed proton lifetimes (see Table I) and the laboratory measurements of the charge-exchange cross-sections for protons incident upon atomic hydrogen of Fite et al [1960].



G66-881
P
P
P
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P:OGO 3
AT PERIGEE
DST(H)
40γ
6
7
8
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JULY 1966

Figure 1

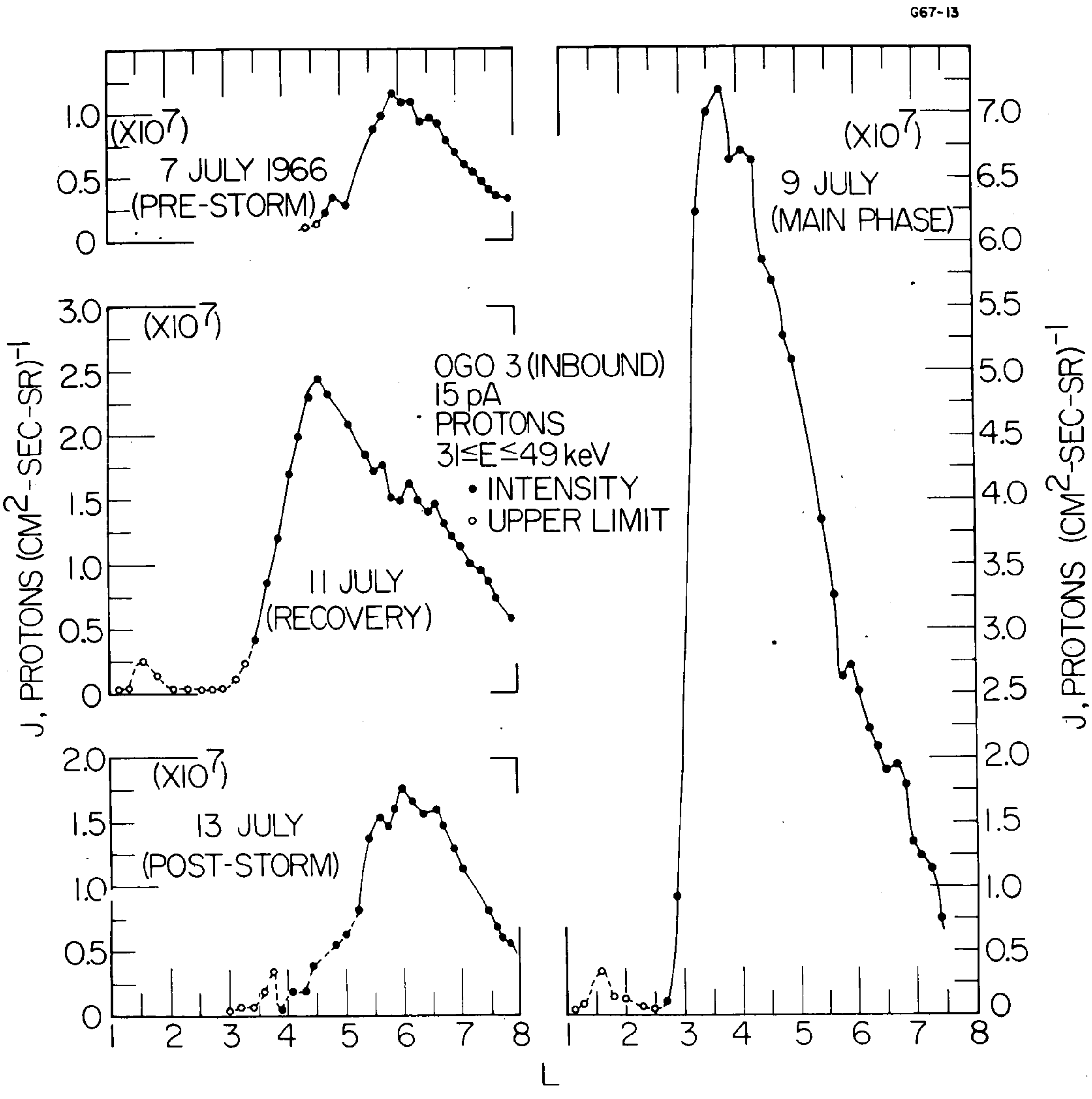
G67-13
(X10⁷)
7 JULY 1966
(PRE-STORM)
(X10⁷)
11 JULY
(RECOVERY)
OGO 3 (INBOUND)
15 pA
PROTONS
31≤E≤49 keV
• INTENSITY
∘ UPPER LIMIT
(X10⁷)
13 JULY
(POST-STORM)
(X10⁷)
9 JULY
(MAIN PHASE)
J, PROTONS (CM²-SEC-SR)⁻¹
L

Figure 2

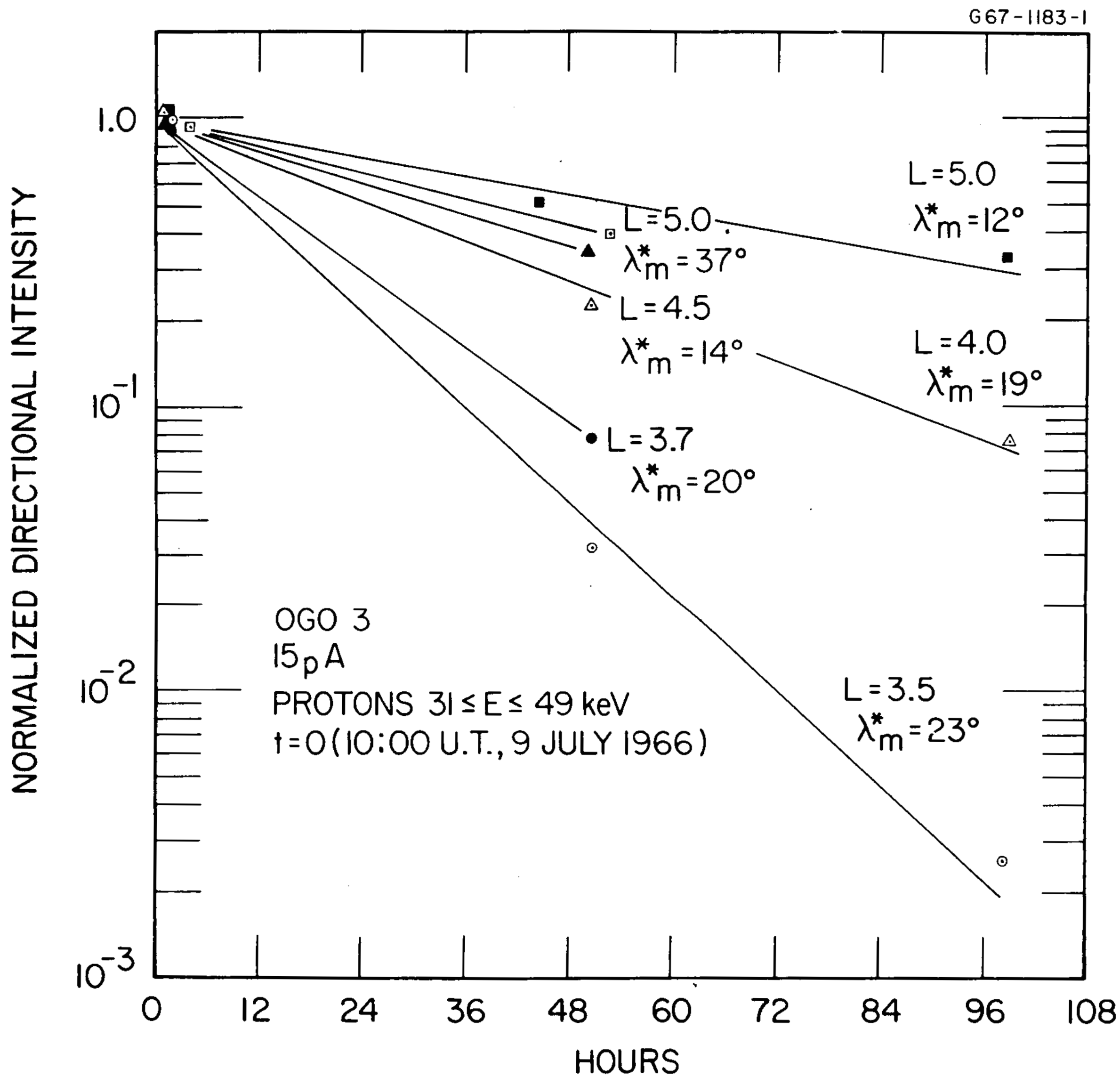
G67-1183-1
NORMALIZED DIRECTIONAL INTENSITY
1.0
10^-1
10^-2
10^-3
0
12
24
36
48
60
72
84
96
108
HOURS
L=5.0
λ*m=12°
L=5.0
λ*m=37°
L=4.5
λ*m=14°
L=4.0
λ*m=19°
L=3.7
λ*m=20°
L=3.5
λ*m=23°
OGO 3
15pA
PROTONS 31 ≤ E ≤ 49 keV
t=0(10:00 U.T., 9 JULY 1966)

Figure 3

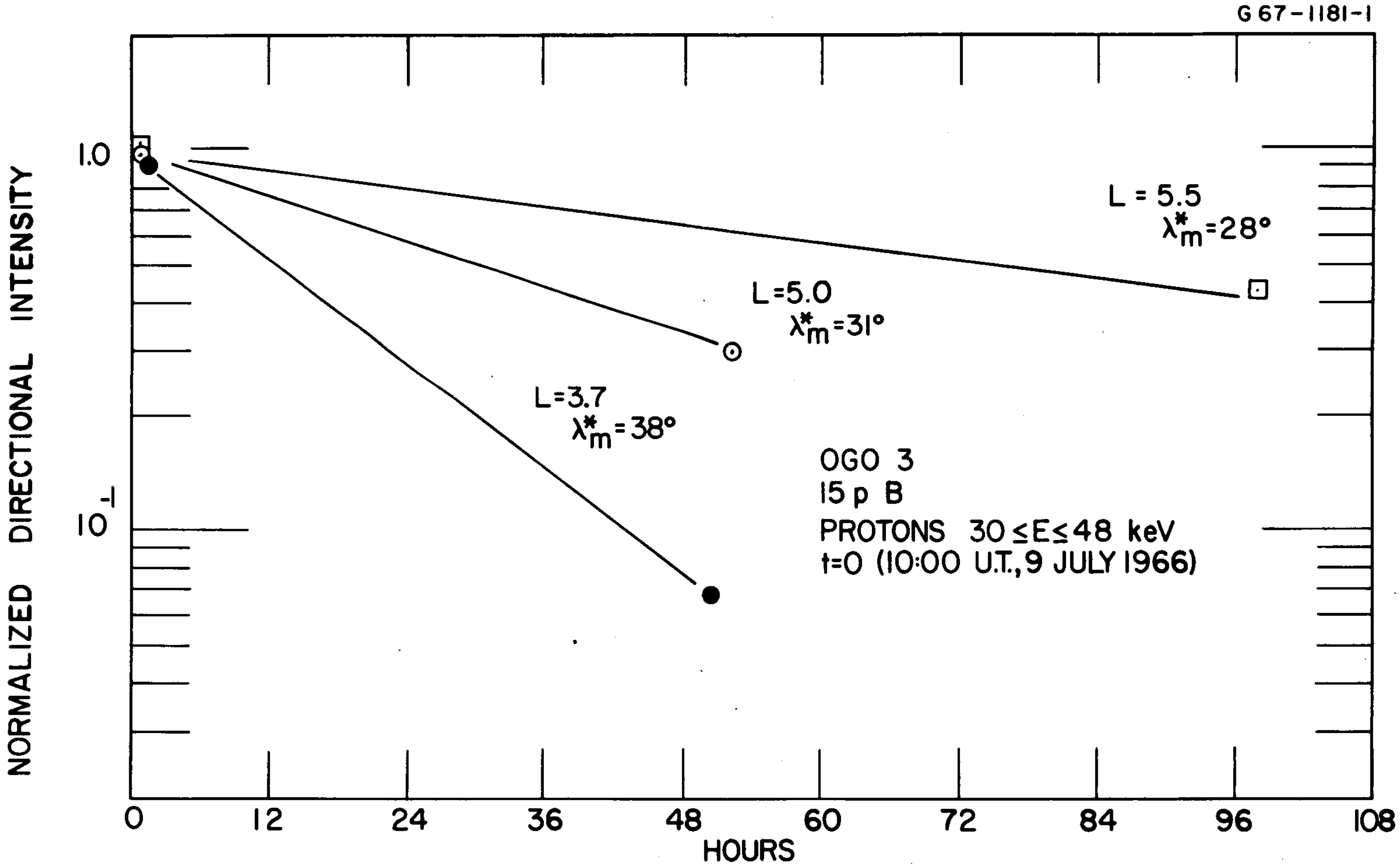
G 67-1181-1
NORMALIZED DIRECTIONAL INTENSITY
1.0
10-1
L = 5.5
λ*m = 28°
L = 5.0
λ*m = 31°
L = 3.7
λ*m = 38°
OGO 3
15 p B
PROTONS 30 ≤ E ≤ 48 keV
t=0 (10:00 U.T., 9 JULY 1966)
0
12
24
36
48
60
72
84
96
108
HOURS

Figure 4

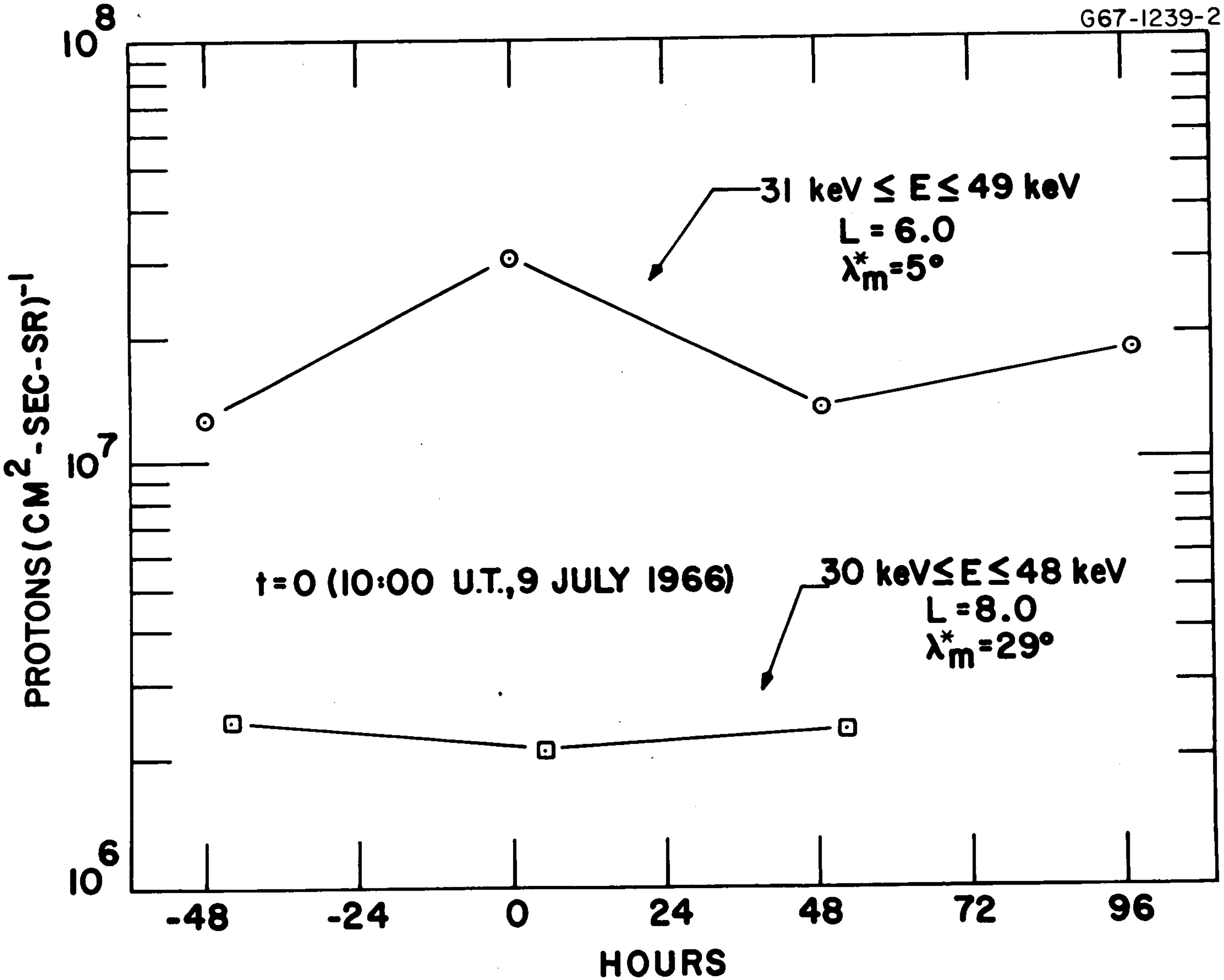
G67-1239-2
31 keV ≤ E ≤ 49 keV
L = 6.0
$\lambda_m^* = 5°$
t = 0 (10:00 U.T., 9 JULY 1966)
30 keV ≤ E ≤ 48 keV
L = 8.0
$\lambda_m^* = 29°$
PROTONS $(CM^2\text{-SEC-SR})^{-1}$
10^8
10^7
10^6
-48
-24
0
24
48
72
96
HOURS

Figure 5

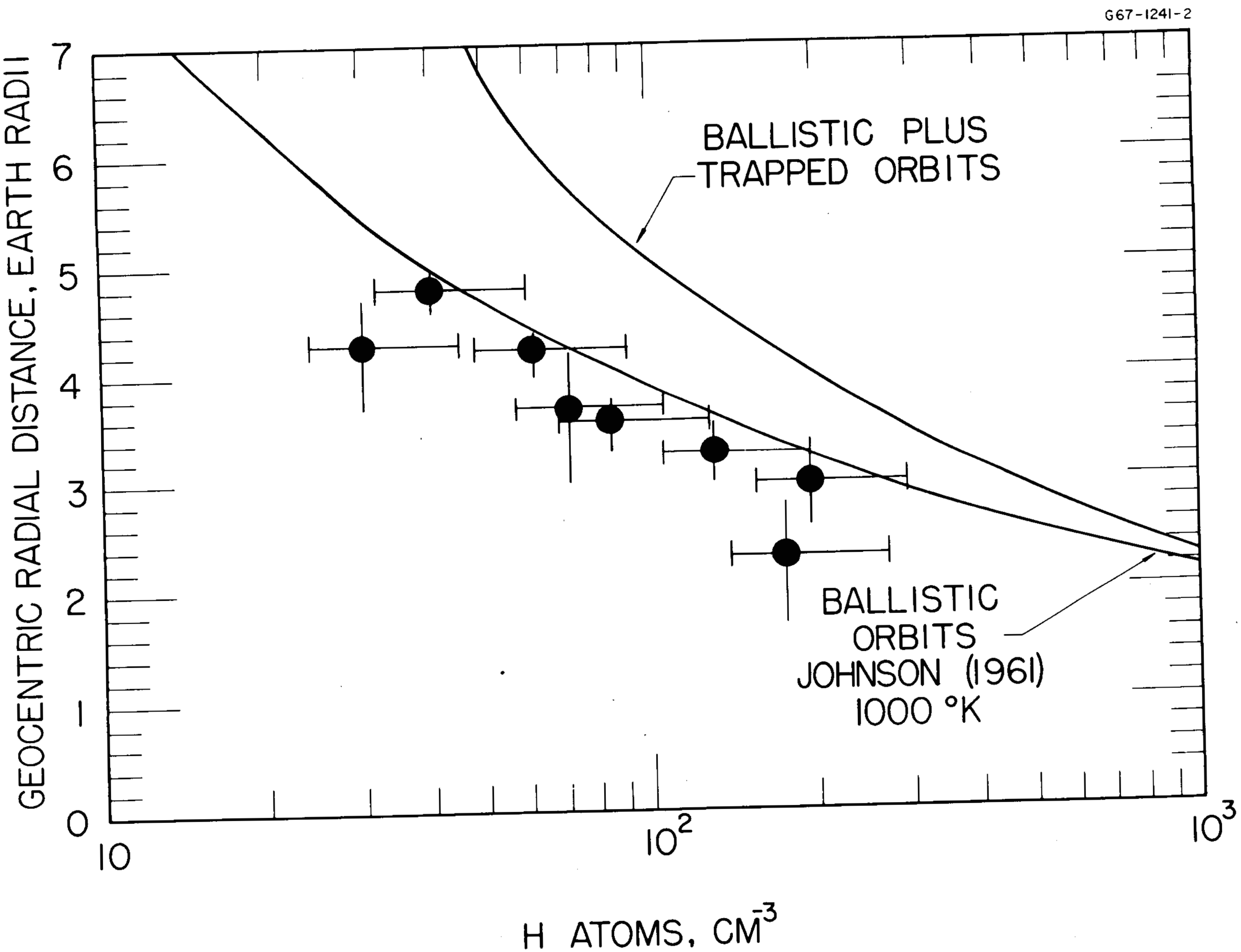
G67-1241-2
BALLISTIC PLUS
TRAPPED ORBITS
BALLISTIC
ORBITS
JOHNSON (1961)
1000 °K
GEOCENTRIC RADIAL DISTANCE, EARTH RADII
7
6
5
4
3
2
1
0
10
10^2
10^3
H ATOMS, CM^{-3}

Figure 6

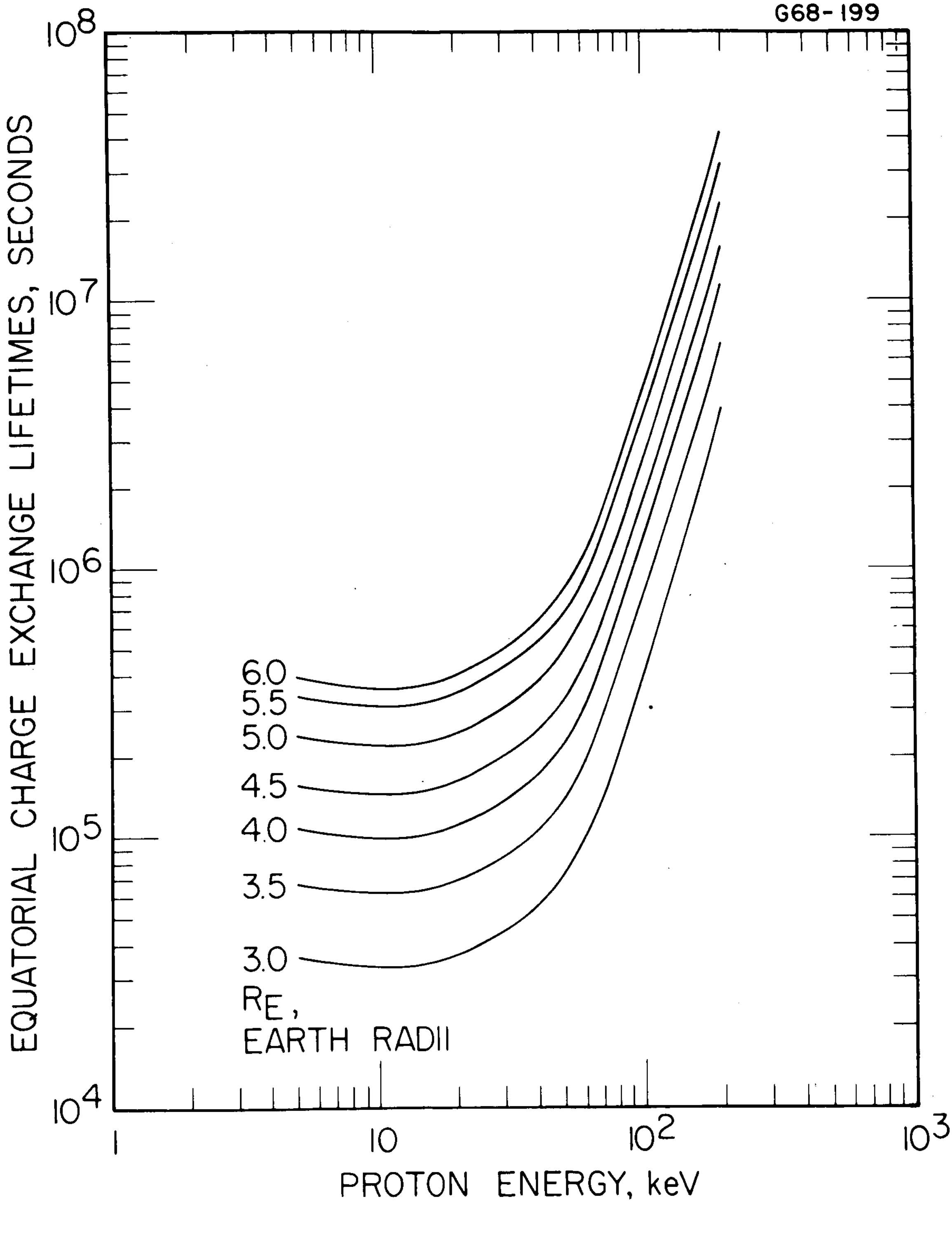
G68-199
EQUATORIAL CHARGE EXCHANGE LIFETIMES, SECONDS
10^8
10^7
10^6
10^5
10^4
6.0
5.5
5.0
4.5
4.0
3.5
3.0
RE,
EARTH RADII
1
10
10^2
10^3
PROTON ENERGY, keV

Figure 7

UNCLASSIFIED

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13. ABSTRACT

The directional, differential intensities of protons over the energy range ~ 200 eV to 50 keV injected into the outer radiation zone (i.e., the extra-terrestrial ring current) coincident with the initial phase of the geomagnetic storm during early July 1966 were monitored with a sensitive array of electrostatic analyzers borne on the earth-satellite OGO 3. Proton intensities are greatly enhanced throughout the outer radiation zone for L-values $\gtrsim 3$ during the main phase of this moderate magnetic storm, and the injection mechanism ceases to be effective after the storm main phase for L-values $\lesssim 5.5$. The proton ($30 \leq E \leq 50$ keV) intensities are shown to exponentially decay with lifetimes ranging from 15 to 105 hours in substantial agreement with calculated lifetimes invoking measured charge-exchange cross-sections for protons incident upon atomic hydrogen and a model of the atomic hydrogen density in the earth's exosphere. The atomic hydrogen density model for the terrestrial exosphere providing the best fit to the observed proton lifetimes over geocentric radial distances 2.5 to 4.8 earth radii (corresponding to observed densities ~ 200 to 30 hydrogen atoms $(cm)^{-3}$) allows only atoms in ballistic orbits in the exosphere as opposed to a model geocorona which includes an additional atomic hydrogen population in captive elliptical orbits.

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