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ORBITAL RADIATION EXPOSURE OF THE ASTRONOMICAL NETHERLANDS SATELLITE (ANS)

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GSFC — GODDARD SPACE FLIGHT CENTER
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ORBITAL RADIATION EXPOSURE OF THE ASTRONOMICAL NETHERLANDS SATELLITE (ANS)

A special report on expected radiation levels of the ANS Satellite.

by

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FOREWORD

Orbital flux calculations were performed for the ANS Satellite at the request of the project office. This data is needed to determine the applicability of COS/MOS circuits for the ANS mission, for use in the flight system (in the on-board computer and the X-ray experiment logic).

Introduction

High inclination circular and elliptical trajectories ($i > 55°$) or low inclination elliptical orbits of large eccentricity traverse the terrestrial radiation belts twice during each revolution. The vehicle thus executes a transverse motion in L-space, passing successively through a region of low L-values ($1.0 \leq L \leq 2.0$) and of high L-values ($2.0 \leq L \leq 6.6$), commonly referred to as the inner zone and the outer zone. The specified ANS trajectory performs in a very similar way.

Although the inclination of the proposed ANS orbit was fixed at 97 degrees proprade, which is identical to 83 degrees retrograde, the trajectories were nevertheless generated for a 83 degree prograde inclination. This was done in order to bypass difficulties usually encountered in the conversion of retrograde positions from geodetic polar to magnetic B-L coordinates and only after previous test runs had established that the results would be about equal if long enough intervals of flight-times were considered, provided the orbit-periods were comparatively small ($t \leq 2.5$ hrs.) and were not an exact divisor of 24 (hours in a day).

Obviously, this happens because the same limited area of space is being sampled by either prograde or retrograde trajectory and when the sampling density is sufficiently increased by extending the time in orbit (the flight duration considered in the calculations), the statistical treatment of the data, the averaging process, produces the almost identical results.

Launch epoch for the ANS mission is given as sometime in 1972, which falls halfway between the last solar maximum and the next solar minimum. This means that conditions prevailing then in the radiation belts would be similar to those of 1966-1967, except for the remnants of the artificial "Starfish" electrons that populated the inner zone from July 1962 to about 1968. Since the electron fluxes are calculated with Vette's AE2 model (Vette et. al, 1966) which describes the environment as it actually existed back in 1964, at which time the artificials were still vastly predominant in the inner zone, it is necessary (a) to entirely remove the artificial component from the inner zone fluxes and (b) to account for solar cycle variations in the outer zone. The first objective was achieved by decaying the fluxes exponentially with experimentally determined decay lifetimes, defined as functions of B, L, and E (energy), up to an epoch, when it is felt, that natural background levels had been reached (Stassinopoulos and Verzariu, 1971). The second by increasing the uncertainty factor attached to the results. The increase is in proportion to the time spent in the outer zone, and the expected variations of the intensities, both taken as a function of the parameter L.

Orbital flux integrations for high energy protons were performed with the current models AP1 (Vette, 1966), AP6 (Lavine and Vette, 1969), AP7 (Lavine and Vette, 1970), while low energy protons were obtained with the AP5 (King, 1967). All are static models, including the AE2, which do not consider temporal variations. For the protons this is a valid representation because experimental measurements have shown that no significant changes with time have occurred. With the exception of the fringe areas of the proton belt, that is, at very low altitudes and at the outer edges of the trapping region, the possible error introduced by the static approximation lies well within the uncertainty factor of 2, attached to the models. Consequently, the proton models may be applied to any epoch without the need for an updating process.

Occasionally discontinuities appear in the proton spectra. These "breaks" occur because the complete proton environment is being described by three (formerly four) independent maps or grids, each valid only over a limited energy range; for certain critical orbital configurations the discontinuities are than produced when moving from one energy range to another. They are caused, in part, by the exponential energy parameter of the model which in many instances had to be extrapolated to make up for lacking data and, in part, to insufficient experimental measurements over some areas of B/L-space; furthermore, the discontinuities reflect the fact that the available data cannot be completely matched at their overlap. In order to overcome such spectral breaks, a continuous weighted mean curve is usually drawn, connecting the adjacent segments; it should be regarded as an approximate spectral distribution. In doing this, the AP1 results (30< E(Mev)< 50) have to be totally ignored sometimes. The ANS orbit belongs to the affected group.

Classification of orbit integrated spectra as hard or soft is relative; it is based on an overall evaluation of near earth space in terms of circular trajectories between equatorial and polar orbits.

Attachment A contains other pertinent background information with regard to units, field models, trajectory generation and conversion, etc.

At this point, we wish to emphasize again that our calculations are only approximations; we strongly recommend that all persons to receive parts of this report be advised about the uncertainty in our data.

Results: Analysis and Discussion

Our calculations for the proposed ANS orbit are summarized in Table 1 for electrons and Table 2 for protons. The superimposed spectral distribution for both types of particles is given graphically in Figure 1.

The spectrum for electrons with energies $E > 1$ Mev may be classified as "hard" for near earth space missions, while the protons rate a "hard" to "very hard" classification for energies $E > 5$ Mev. Figures 2 and 3 are computer plots depicting the characteristic electron and proton spectra of the flightpath, separately.

Table 3 indicates what percent of its total lifetime the satellite spends in "flux-free" regions of space, what percent of its total lifetime in "high intensity" regions, and while in the latter, what percent of its total daily flux it accumulates.

In the context of this study, the term "flux-free" applies to all regions of space where trapped-particle fluxes are less than one electron or proton per square centimeter per second, having energies $E > .5$ Mev and $E > 5.$ Mev respectively; this includes regions outside the radiation belts. Similarly, we define as "high intensity" those regions of space, where the instantaneous, integral, omnidirectional, trapped-particle flux is greater than 10^5 electrons with energies $E > .5$ Mev, and greater than 10^3 protons with energies $E > 5.$ Mev. The values given in Table 3 are statistical averages, obtained over extended intervals of mission time. However, they may vary significantly from one orbit to the next, when individual orbits are considered.

Predictably, the high energy proton population, which occupies a smaller volume of the radiation belt, affords a larger flux-free time than the electrons, especially for orbits with inclination $i > 30°$. It should be noted that at the indicated height, a change in altitude does not alter significantly the flux-free time afforded the satellite, in either the electron or the proton medium.

If the flux-free time is important in mission planning, it is advisable, before decisions are made, to evaluate and compare the radiation hazards or effects due to the predicted electron and proton fluxes, either in regard to the entire mission or in regard to specific mission functions or requirements. For, while the proton intensities are on the average about two orders of magnitude smaller than the electrons, and while they apparently do afford more flux-free time, their greater mass and harder spectra may prove more damaging to the mission than the more numerous electrons with their lesser flux-free time.

In Table 4 the percentage of total lifetime T spent by the vehicle in the inner zone (T^i) and in the outer zone (T°) is given, with the percent duration spent outside the trapped particle radiation belt ($L > 6.6$), denoted by T^e (T-external).

For any mission then:

$$T = T^{i} + T^{o} + T^{e} = 100\%$$

Evidently, at the selected altitude, the high inclination ANS spends almost equal amounts of its entire lifetime in the inner and the outer zone trapping regions (see footnote on Table 4). It extendedly visits regions of space outside the Van Allen belts (about 27% of T). The satellite thus performs a complete sweep through magnetic L-space, which constitutes the transverse motion mentioned in the first paragraphy, executed twice during each revolution (orbit). Part of this information is used to evaluate the possible contribution of the outer zone solar cycle dependence to the uncertainty factor attached to the results.

The following related points are submitted for consideration in connection with the lifetime distribution over distinct regions of space;

a. Lasting solar cycle effects are more severely experienced in the <u>outer zone</u> (significant changes in the trapped electron population from solar minimum to solar maximum).

b. Energetic artificial electrons from high altitude nuclear explosions (Starfish) have displayed a remarkable longevity, <u>but only in the inner zone</u>; there they contaminated the environment for over 5 years, while they rapidly decayed to background levels in the outer zone (within weeks to months). A planned or accidental explosion of another atomic device with the appropriate yield and at the right latitude and altitude may, very likely, produce conditions similar to those experienced with "Starfish", transforming the inner zone again into a radiation hotbed.

c. Transient solar flare effects (high energy solar proton fluxes) may be especially hazardous and damaging in regions external to the trapped particle belts.

Figures 4 and 5 are additional computer plots for the ANS trajectory showing the vehicle encountered instantaneous peak electron (E > .5 Mev) and proton (E > 5 Mev) intensities per orbit for a sequence of about 30 revolutions. On these graphs a periodic pattern emerges that indicates a daily cycle of about 15 orbits which may shift slightly in the plotting. This is due to the relative orbit period, which determines the precession of the trajectory.

It is known that altitude affects the peaks for both types of particles. The tendency at the ANS level is towards greater fluxes for higher altitudes. There is a relatively small variation in the peak-levels of the electrons over a daily cycle (maximum about a factor of 5), contrary to the protons, which experience totally flux-less intervals of time, lasting for several revolutions of the interphase between successive cycles.

Finally, two more computer plots are included, Figures 6 and 7, for protons and electrons respectively, depicting the characteristic averaged instantaneous intensities of the trajectory in terms of constant L-bands of .1 earth radius width; the percent of total life-time spent in each L-interval is shown on the same graph by the contour marked with x's.

ATTACHMENT A

General Background Information

For the specified ANS trajectory, orbit tapes were generated with an integration stepsize of one minute for a sufficiently long flighttime, so as to insure an adequate sampling of the ambient environment; on account of its period, which determines the rate of orbit-precession, the following circular light path of 48-hour duration was produced:

Inclination	Altitude	Period
83° prograde (97° retrograde)	500 km	1.577 hrs.

The orbit was subsequently coverted from geocentric polar into magnetic B/L coordinates with McIlwain's INVAR program of 1965 (Hassit and McIlwain, 1967), and with the field routine ALLMAG (Stassinopoulos and Mead, 1971), utilizing the POGO (8/69) geomagnetic field model (Cain and Sweeney, 1970) calculated for the epoch 1972.0 (B is the field strength at a given point and L is the geocentric distance to the intersect of the field line, passing through that point, with the geomagnetic equator).

Orbital flux integrations were performed with Vette's current models of the environment, the AE2 for electrons, the AP1, AP6, AP7 for high energy protons, and King's AP5 for low energy protons. All are static models which do not consider temporal variations. See text for further details on this matter.

The results, relating to omnidirectional, vehicle encountered, integral, trapped particle fluxes, are presented in graphical and tabular form with the following unit convention:

1. Daily averages: total trajectory integrated flux averaged into particles/cm^2 day,
2. Totals per orbit: non-averaged, single-orbit integrated flux in particles/cm^2 orbit,
3. Peaks per orbit: highest orbit-encountered instantaneous flux in particles/cm^2 sec,

where 1 orbit = 1 revolution.

Please note: We wish to emphasize the fact that the data presented in this report are only approximations. We do not believe the results to be any better than a factor of two (2) for the protons and a factor of five (5) for the electrons. It is advisable to inform all potential users about this uncertainty in the data.

References

1. A. Hassit and C.E. McIlwain, Data Users' Note, NASA NSSDC 67-27, 1967.
2. E.G. Stassinopoulos and G.E. Mead (to be published), 1971.
3. J.C. Cain and R.E. Sweeney, J. Geophys. Res., Vol. 75, No. 22, August 1, 1970.
4. J.I. Vette, Lucero, A.B., Wriglet, J.A. (AE2), NASA SP-3024, Vol. II, 1966.
5. J.H. King (AP5) NASA SP-3024, Vol. IV, 1967.
6. J.I. Vette (AP1) NASA SP-3024, Vol. I, 1966.
7. J.P. Lavine and J.I. Vette (AP6) NASA SP-3024, Vol. IV, 1969.
8. J.P. Lavine and J.I. Vette (AP7) NASA SP-3024, Vol. VI, 1970.
9. E.G. Stassinopoulos and P. Verzariu, J. Geophys. Res., Vol. 75, No. 7, March 1, 1971.

Table 1

ORBITAL FLUX STUDY WITH COMPOSITE ELECTRON ENVIRONMENT* (VETTES AE2) * DATE OF RUN = YEAR 1971. DAY 0291
FLUXES EXPONENTIALLY DECAYED WITH DECAY-FACTOR D1 = VETTE TBLE *** DECAY DATE = YEAR 1967. . MONTH 6. . DAY 0.

AVERAGED FLUXES ON THIS TABLE ARE IN UNITS OF PARTICLES/CM**2/DAY *** NON-AVERAGED FLUXES ARE IN UNITS OF PARTICLES/CM**2/SEC
ALL FLUXES ON THIS TABLE ARE FOR ENERGIES E>.5MEV (EXCEPT WHERE ENERGY IS SPECIFIED. AS IN SPECTRUM)

INCLINAT.= 83 * PERIG.= 500 * APOG.= 500 KM * B&L ORBIT TAPE TD 7410 * PERIOD = 1.577 * VEHICLE = ANS

SPECTRUM IN % DE

ENERGY RANGES (MEV)	AVERAGED TOTAL FLUX (PER DAY)	SPECTRUM (PER CENT)
0-.5	4.840E 09	83.88
.5-1	5.856E 08	10.15
1-2	2.707E 08	4.69
2-3	5.379E 07	0.93
3-4	1.368E 07	0.24
4-5	4.114E 06	0.07
5-6	1.351E 06	0.02
6-7	4.560E 05	0.01
GT.7	2.417E 05	0.00
TOTAL =	5.770E 09	100.00

COMPOSITE ORBIT SPECTRUM

ENERGY GRTR. THAN (MEV)	AVERAGED INTEG. FLUX (PER DAY)
0.0	5.770E 09
0.25	1.899E 09
0.50	9.299E 08
0.75	5.471E 08
1.00	3.443E 08
1.25	2.269E 08
1.50	1.531E 08
1.75	1.050E 08
2.00	7.363E 07
2.25	5.163E 07
2.50	3.685E 07
2.75	2.686E 07
3.00	1.984E 07
3.25	1.467E 07
3.50	1.094E 07
3.75	8.215E 06
4.00	6.163E 06
4.25	4.695E 06
4.50	3.566E 06
4.75	2.664E 06
5.00	2.049E 06
5.25	1.562E 06
5.50	1.185E 06
5.75	9.111E 05
6.00	6.977E 05
6.25	5.386E 05
6.50	4.124E 05
6.75	3.080E 05
7.00	2.417E 05

EXPOSURE INDEX

INTENSITY RANGES (EL/CM**2/SEC)	DURATION OF EXPOSURE (HRS)	TOTAL NO. OF ACCUMULATED PARTICLES (E>.5)
ZERO FLUX	35.3	6.394E 03
1.E0-1.E2	1.83	1.489E 05
1.E2-1.E3	1.70	2.653E 06
1.E3-1.E4	2.33	3.523E 07
1.E4-1.E5	5.43	7.994E 08
1.E5-1.E6	1.47	1.022E 09
1.E6-1.E7	0.0	0.0
1.E7-1.E8	0.0	0.0
1.E8-INFIN	0.0	0.0
TOTAL =	48.017	1.860E 09

Table 2

AVERAGED FLUXES ON THIS TABLE ARE IN UNITS OF PARTICLES/CM**2/DAY *** NON-AVERAGED FLUXES ARE IN UNITS OF PARTICLES/CM**2/SEC
ALL FLUXES ON THIS TABLE ARE FOR ENERGIES E>5 MEV (EXCEPT WHERE ENERGY IS SPECIFIED, AS IN SPECTRUM)

ORBITAL FLUX STUDY FOR COMPOSITE PROTON ENVIRONMENT * GRIDS AP1,AP7,AP6,AP5 * DATE OF RUN = YEAR 1971, DAY 0285
INCLINAT.= 83 * PERIG.= 500 * APOG.= 500 KM * B&L ORBIT TAPE TD 7410 * PERIOD = 1.577 * VEHICLE =,ANS

HIGH ENERGY

SPECTRUM IN % DE

ENERGY RANGES (MEV)	AVERAGED TOTAL FLUX (PER DAY)	SPECTRUM (PER CENT)
3-5	1.311E 07	54.465
5-15	7.282E 06	30.243
15-30	1.362E 06	5.657
30-50	2.425E 05	1.007
50-100	9.644E 05	4.006
>100	1.113E 06	4.622
TOTAL =	2.408E 07	100.00

COMPOSITE ORBIT SPECTRUM

ENERGY GRTR.THAN (MEV)	AVERAGED INTEG.FLUX (PER DAY)
1	NOT VALID
3	2.408E 07
5	1.096E 07
7	7.307E 06
9	5.657E 06
11	4.719E 06
13	4.111E 06
15	3.682E 06
18	3.227E 06
21	2.905E 06
24	2.663E 06
27	2.474E 06
30	2.320E 06
35	2.265E 06
40	2.093E 06
45	1.954E 06
50	2.077E 06
60	1.818E 06
70	1.599E 06
80	1.413E 06
90	1.252E 06
100	1.113E 06

EXPOSURE INDEX

INTENSITY RANGES (PT/CM**2/SEC)	DURATION OF EXPOSURE (HRS)	TOTAL NO. OF ACCUMULATED PARTICLES (E>5)
0.E0-1.E0	42.967	7.139E 04
1.E0-1.E1	0.767	8.700E 03
1.E1-1.E2	0.817	1.227E 05
1.E2-1.E3	1.417	1.927E 06
1.E3-1.E4	2.050	1.980E 07
1.E4-1.E5	0.0	0.0
1.E5-OVER	0.0	0.0
TOTAL =	48.000	2.193E 07

Table 3

ANS

Circular

Inclination 83°

Altitude 500 km

Approx. Decay Epoch: 1967.6

	Electrons (E > .5 Mev)	Protons (E > 5. Mev)
1. Fraction of total lifetime spent in flux-free regions* of space:	73.54%	89.58%
2. Fraction of total lifetime spent in high-intensity regions* of Van Allen Belts:	3.06%	4.27%
3. Fraction of total daily flux accumulated during (2):	54.95%	90.29%

*See text for definition

Table 4

ANS

Circular

Inclination 83°

Altitude 500 km

Percent of total lifetime spent inside and outside the Trapped Particle Radiation Belt

1.	Inner Zone (T^i)*	47.5%
2.	Outer Zone (T^o)	35.9%
3.	External (T^e)	16.6%
		100.0%

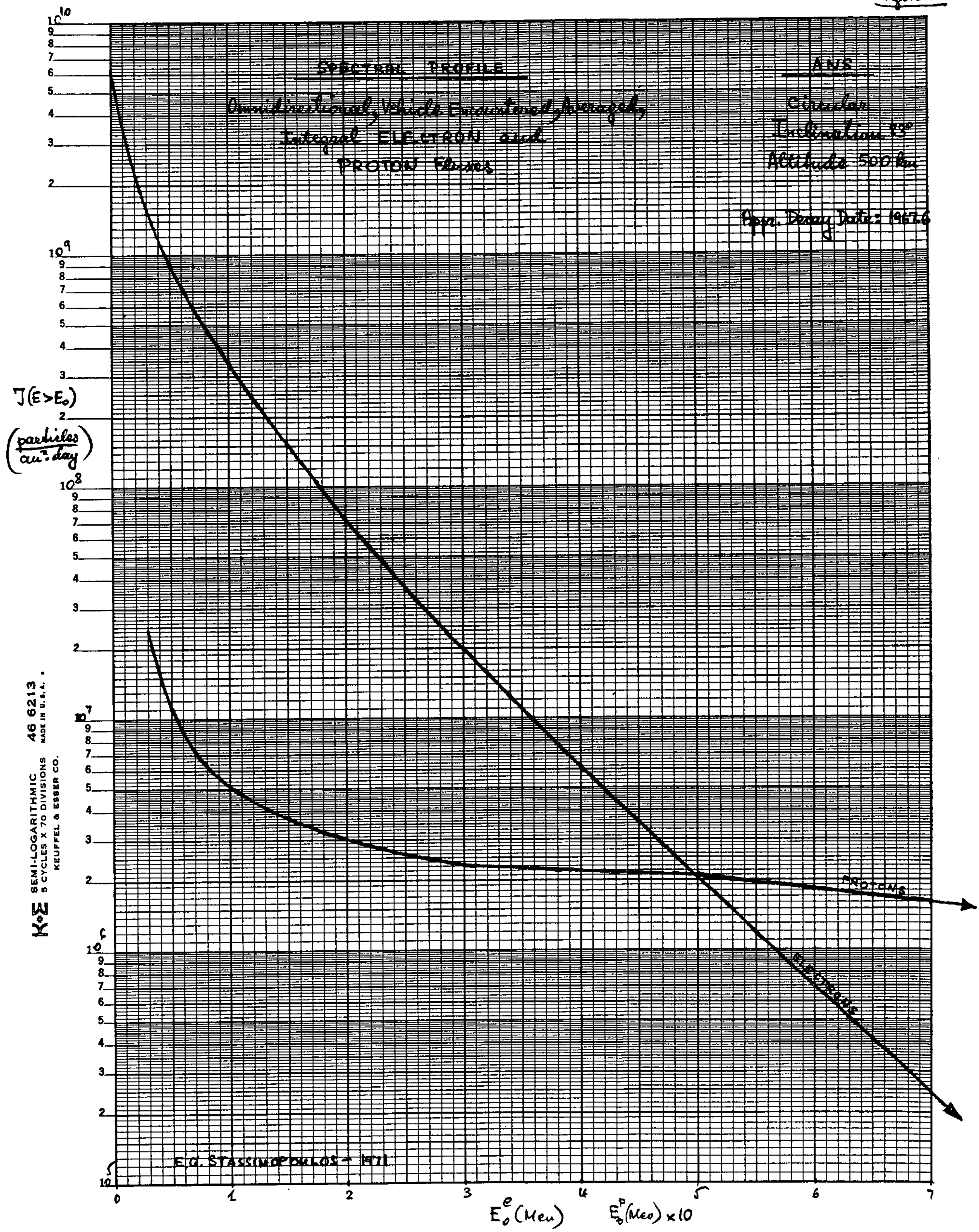
*This time may be subdivided into two parts:

37.5% in the L-interval $1.1 \leq L < 2.0$

10.0% in the L-interval $1.0 \leq L < 1.1$

where the T^i $(1.0 \leq L<.1)$ lies outside the actual trapping region.

Figure 1



SPECTRAL PROFILE
Omnidirectional, Vehicle Encountered, Averaged, Integral ELECTRON and PROTON Fluxes
ANS
Circular
Inclination 83°
Altitude 500 km
Appr. Decay Date: 1967.6
J(E>E₀)
(particles / cm² · day)
PROTONS
ELECTRONS
E.G. STASSINOPOULOS - 1971
E_o^e (Mev)
E_o^p (Mev) × 10
SEMI-LOGARITHMIC 46 6213
5 CYCLES X 70 DIVISIONS MADE IN U.S.A.
KEUFFEL & ESSER CO.

FOLDOUT FRAME 1

FOLDOUT FRAME 2

Figure 2

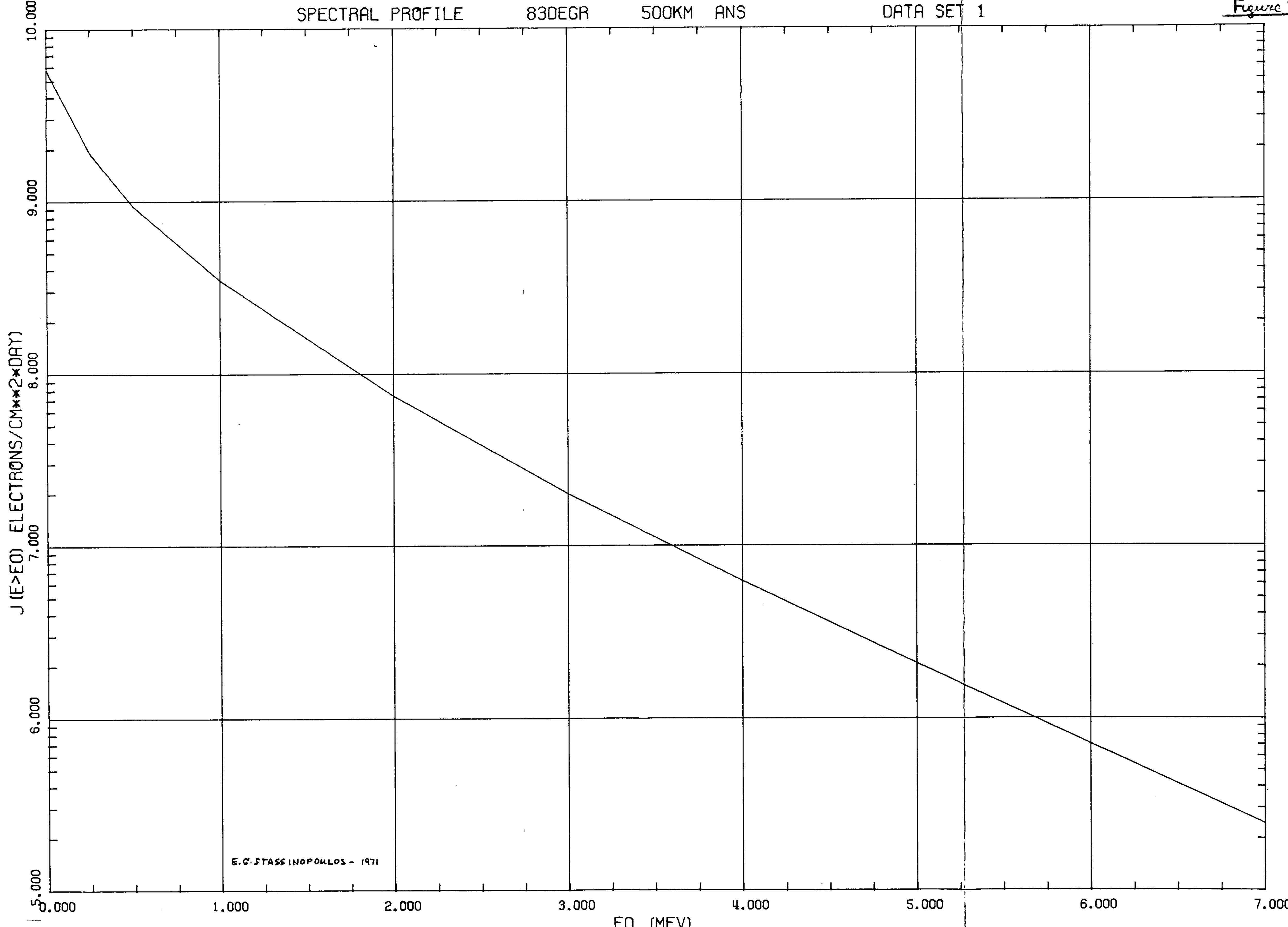
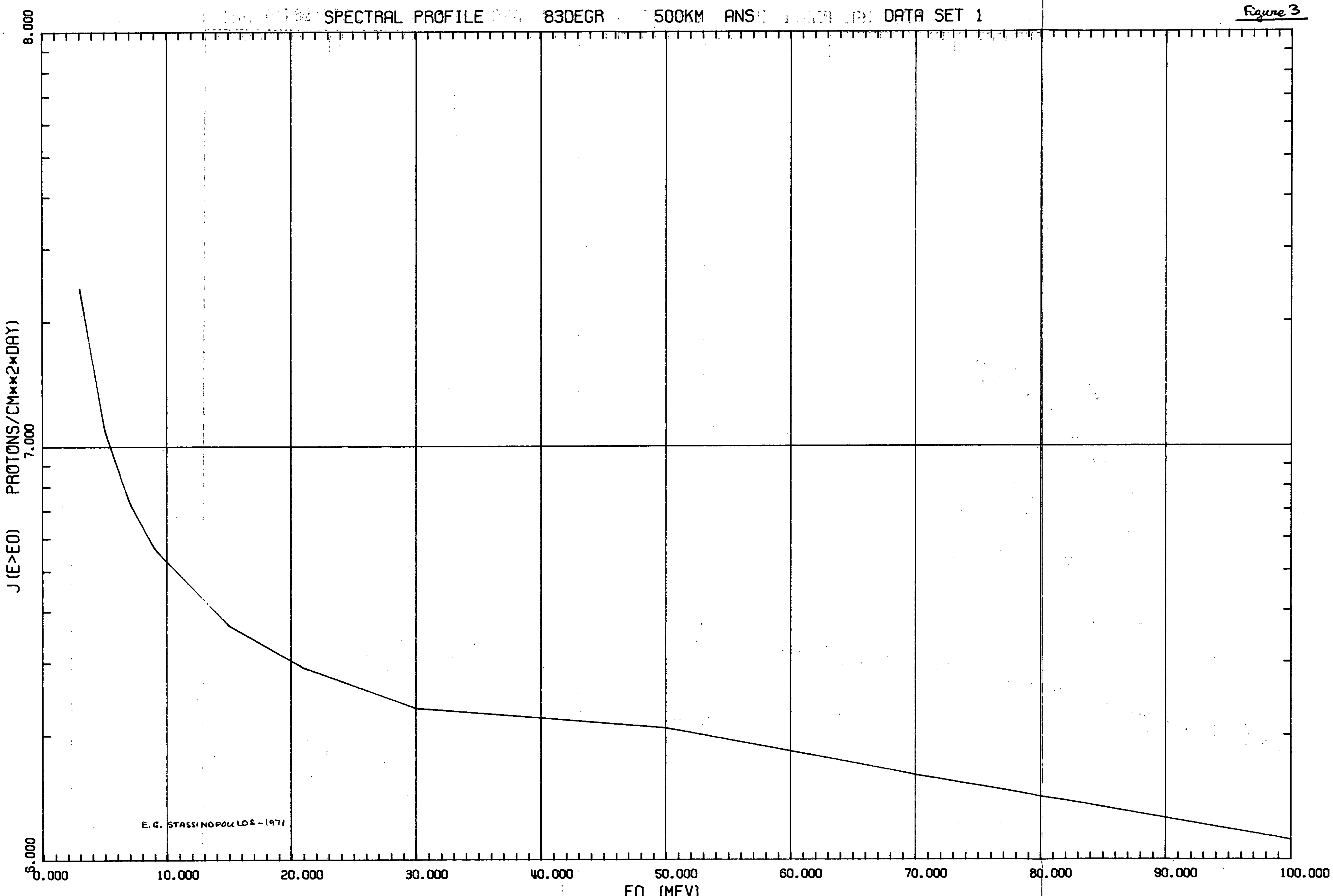


Figure 3

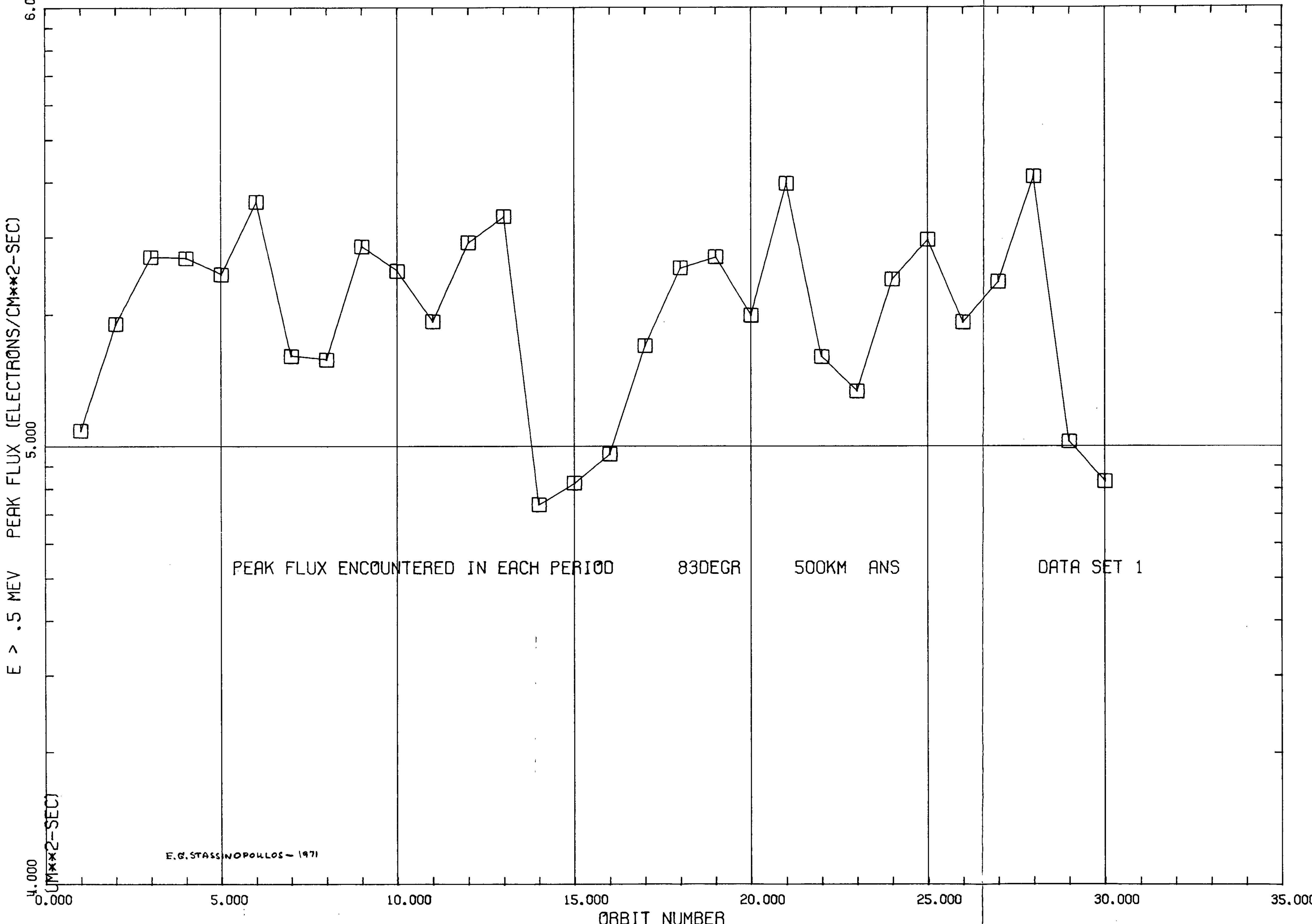


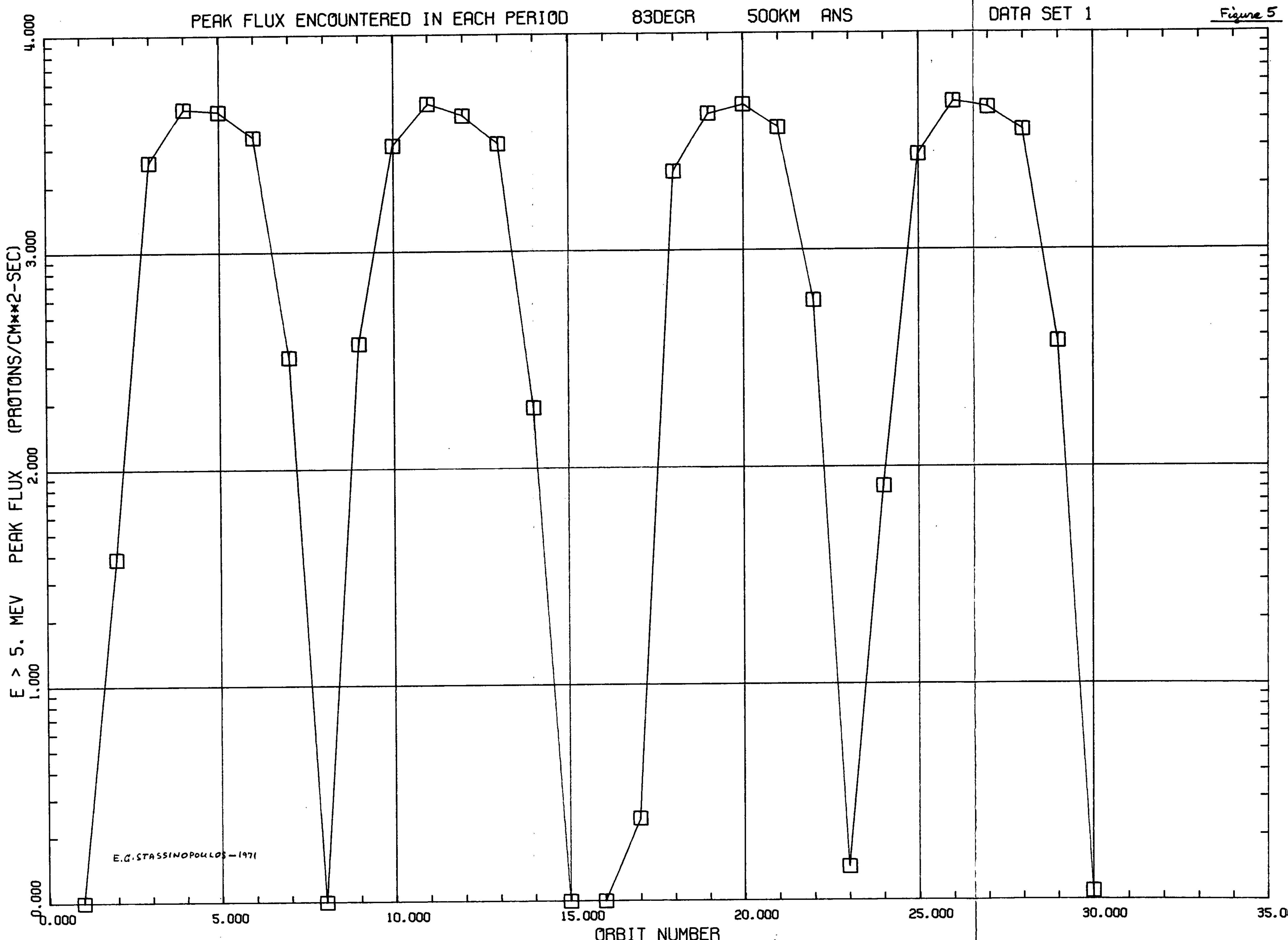
SPECTRAL PROFILE 83DEGR 500KM ANS DATA SET 1
J (E>EO) PROTONS/CM**2*DAY)
8.000
7.000
6.000
0.000
10.000
20.000
30.000
40.000
50.000
60.000
70.000
80.000
90.000
100.000
EO (MEV)
E.G. STASSINOPOULOS - 1971

FOLDOUT FRAME 1

FOLDOUT FRAME 2

Figure 4




PEAK FLUX ENCOUNTERED IN EACH PERIOD
83DEGR
500KM ANS
DATA SET 1
Figure 5
E > 5. MEV PEAK FLUX (PROTONS/CM**2-SEC)
ORBIT NUMBER
0.000
1.000
2.000
3.000
4.000
5.000
10.000
15.000
20.000
25.000
30.000
35.000
E.G. STASSINOPOULOS - 1971

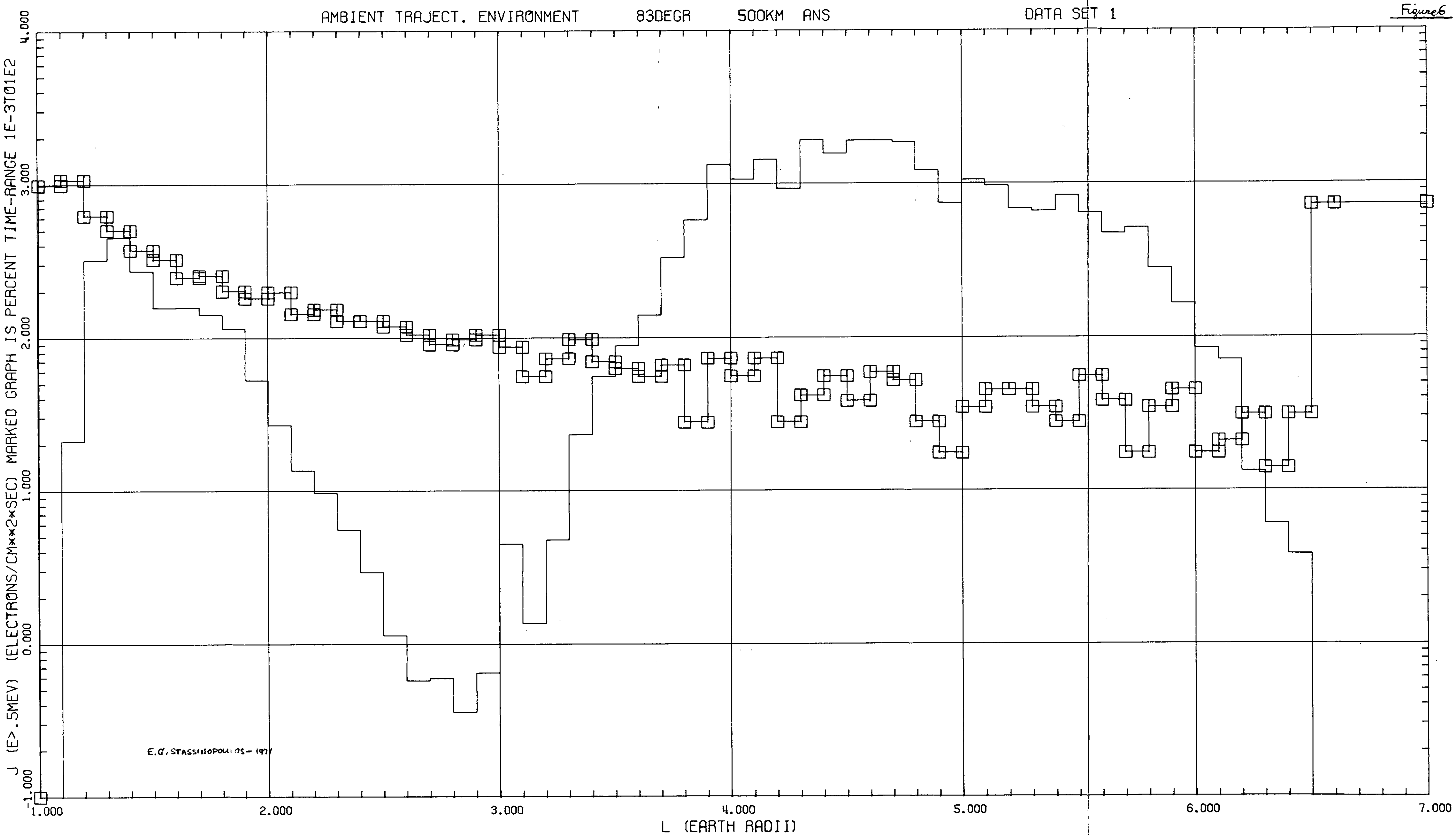
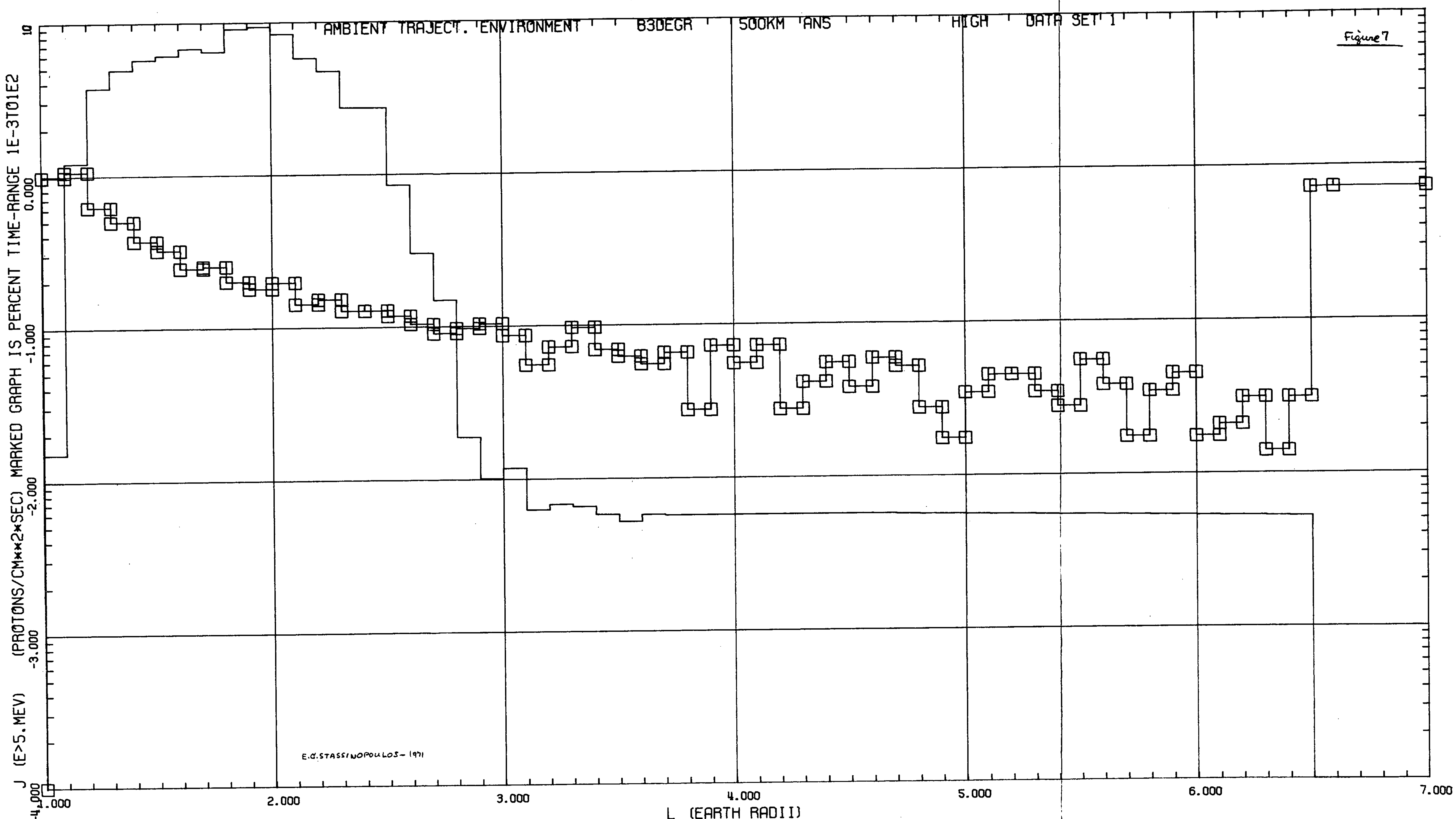


Figure 6
AMBIENT TRAJECT. ENVIRONMENT 83DEGR 500KM ANS
DATA SET 1
J (E>.5MEV) (ELECTRONS/CM**2*SEC) MARKED GRAPH IS PERCENT TIME-RANGE 1E-3TO1E2
4.000
3.000
2.000
1.000
0.000
-1.000
1.000
2.000
3.000
4.000
5.000
6.000
7.000
L (EARTH RADII)
E.G. STASSINOPOULOS - 1971


AMBIENT TRAJECT. ENVIRONMENT
83DEGR
500KM ANS
HIGH
DATA SET 1
Figure 7
J (E>5.MEV) (PROTONS/CM**2*SEC) MARKED GRAPH IS PERCENT TIME-RANGE 1E-3TO1E2
10
0.000
-1.000
-2.000
-3.000
-4.000
1.000
2.000
3.000
4.000
5.000
6.000
7.000
L (EARTH RADII)
E.G.STASSINOPOULOS-1971