BACKGROUND RADIATION IN SOME RECENT HIGH-RESOLUTION MEASUREMENTS IN GAMMA-RAY ASTRONOMY

by

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ABSTRACT

The existence of a background gamma-radiation at balloon heights is very inconvenient for the development of gamma-ray astronomy. Gamma-ray spectra measured during four recent balloon flights in Brazil with a large Ge(Li) high energy resolution gamma-ray spectrometer were analysed to study the local low-energy gamma-ray background. The results of this analysis show that the local background contains contributions from gamma-rays produced in the earth's atmosphere, and also from gamma-ray induced in the detector and in its surrouding materials. The contribution of induced gamma-rays depends on the intensity of protons and neutrons at balloon heights. Comparison of our results with previous results obtained by other authors at different latitudes shows a weaker background at 12 GV cut-off magnetic rigidity.

1. INTRODUCTION

Theoretical nuclear gamma-ray line astronomy has had a rapid development in the recent years (Lingenfelter and Ramaty; Ramaty and Lingenfelter, 1977). The weak intensities of these gamma-ray lines have required the construction of complex detection systems with increasingly better spectral resolution. Improved scintillation detectors (Chupp; Forrest; Higbie; Suri; Tsai and Dunphy, 1973; Ling; Gruber, 1977) and high energy resolution systems using germanium semiconductor detectors (Womack and Overbeck, 1970; Albernhe; Frabel; Vedrenne; Boclet; Claisse; Durouchoux; Olivier; Pagnier; Rocchia and Costa, 1978) have been flown on board of balloons, rockets and satellites.

Experimental nuclear gamma-ray line astronomy is, however, still in its infancy and suffering from several limitations. The basic ones are concerned with the flux sensitivity of the gamma-ray telescopes and the complexity of the gamma-ray background (discrete and continuum) found at balloon and satellite heights. Although the former seems to be overcome by a careful designing of higher sensitivity detection systems, the latter, however, demands a good knowledge of the physics of the sources which contribute to the local background.

In the case of experiments with high energy resolution telescopes, using NaI(Tl) and Ge(Li) detectors, external (to the detection system) neutrally charged and internal nuclear radiation are responsible for the instrument background. The external sources are usually identified as diffuse cosmic and atmospheric gamma-rays, atmospheric neutrons, locally produced neutrons and gamma-rays, and the bremsstrahlung radiation from primary and secondary electrons, including splash and reentrant albedo. The interval sources have their origin in the intrinsic radioactivity of the detector itself and the activation of the detector material by charged particles.

The contribution of some of the sources cited above is also very dependent on the magnetic cutoff rigidity of the region where the experiment is performed. The nature and variety of the background sources make the analysis of low energy gamma-ray spectrum very lengthy and difficult, for every nuclear line gamma-ray astronomy experiment done with NaI(Tl) and Ge(Li) detectors.

This paper reports on the background found during balloon flights of a high energy resolution Ge(Li) spectrometer at 12 GV, to search nuclear gamma-ray lines stemming from the galactic center.

2. INSTRUMENTATION

The gamma-ray spectrometer consists of a 140 cm^3 Ge(Li) crystal surrounded by an anticoincidence NaI(Tl) scintillator active shield as shown in Fig. 1. Thermal control for Ge(Li) crystal is provided by a dewar containing 25 liters of liquid nitrogen, giving a lifetime of about 8 days. The inner pressure of the dewar is maintened by a valve, set at 300 g cm^{-2} above the external pressure. The energy resolution of the Ge(Li) detector, measured in the laboratory at 1.33 MeV (Co^{60}), is 3.0 KeV (FWHM) and 3.4 KeV mounted in the balloon gondola. The spectrometer has a 3σ sensitivity of 0.9 x 10^{-3} photons $cm^{-2}s^{-1}$ at 0.480 MeV for three hours of observation.

The gondola consists of a duraluminium cubic frame, 150 cm on a side, as shown in Fig. 2, where the spectrometer, cryogenic system, electronics, stabilization, telemetry and telecomand are housed. The entire system weights 400 Kg. A complete description of the Ge(Li) spectrometer and whole balloon payload is given by (Albernhe; Frabel; Vedrenne; Boclet; Claisse; Durochoux, Olivier; Pagnier; Rocchia and Costa, 1978).

3. BALLOON FLIGHTS

A total of four balloon flights were attempted from Guaratinguetã (22^o.50 S, 45^o. 12 W, 12 GV), during December 1976 and February 1977, with the Ge(Li) spectrometer on board of 350 000 m^3 stratospheric balloons. These flights provided accumulated data for 8.5 hours of observation in the direction of the galactic center and

4.67 hours of "background" observation. During each flight an on board calibration source of yttrium (0.898 MeV - 1.836 MeV) continuously checked on the gain stability of the electronics.

Figure 3 shows the growth curve of the total count rate in the Ge(Li) detector, for the energy range of 0.1 - 2.3 MeV, during the flights of February 1977. For all flights the data were transmitted via a 444 MHz FM/FM telemetry using 8 IRIG standard channels.

4. RESULTS

Figures 4-5 show the gamma-ray energy loss spectrum measured, for a total time of 6193s, during the February 14, 1977 flight, when the balloon floated between 2.5 and 1.7 g/cm^2. The data is corrected only for the detector dead time. In addition to some few atmospheric lines, several peaks can be identified in the spectrum. The majority of these peaks can be explained in terms of cosmic ray and neutron induced nuclear transition in the detector, or in the anticoincidence crystal and the gondola. The strongest peaks, at 898 KeV and 1836 KeV, are due to the Y^{88} on board calibration source which had also some impurities of Co^{60}. The peak at 511 KeV corresponds to the positron electron annihilation line.

Table I shows the most prominent gamma ray lines, over a 3σ background excess, calculated for an accumulated observation time of 48805 s, during the balloon flights (Albernhe; Boclet; Costa; Durouchoux; Borgne; Rocchia and Vedrenne, 1978) of February 14-17, 1977.

The neutron induced peaks at 139 KeV and 198 KeV are also reported in all low energy gamma ray spectra measured with Ge(Li) spectrometer at balloon (Womack and Overbeck, 1970; Jacobson; Bishop; Culp; Jung; Mahoney and Willet, 1975; Leventhal; Maccallum and Watts, 1977) and satellite (Nakano; Imhof; Reaga and Johnson, 1973) heights. A comparison of the intensities of these lines measured by our detector, with the results of (Leventhal; Maccallum and Watts, 1977) measured at 4.5 GV, indicated a lower neutron induced bacground for experiments performed at lower latitudes.

Besides the lines given at Table I, other neutron induced peaks at 54 KeV - Ge^{72} (n,γ) Ge^{73m}, 67 KeV - Ge^{72} (n,γ) Ge^{72m} are also identified in the gamma ray spectrum shown in Figures 4 - 5. Other induced peaks are expected to be found as a result of a finer analysis of the data.

The spectrum of Figures 4 - 5 shows also a great contribution from the continuum radiation. The major sources for the continuum are the atmospheric bremsstrahlungradiation, due to secundary cosmic rays, and the cosmic gamma rays diffuse radiation. Another source, which could have enhanced the continuum background, is the bremsstrahlung photons, produced by electrons precipitating into the atmosphere of the South Atlantic Magnetic Anomaly (SAMA). This precipitation depends on the level of the geomagnetic activity. Among several related observations (Martin; Rai; Costa; Palmeira and Trivedi, 1977; Martin; Rai; Palmeira; Trivedi; Abdu and Costa, 1975) found evidence of enhancement of the continuum gamma radiation, associated with magnetic disturbances, during balloon measurements, in the SAMA region. Another evidence of the importance of the bremsstrahlung produced by precipitation electrons are the results reported by (Imhof; Nakano; Johnson and Reagan, 1973; Imhof; Nakano and Reagan, 1976). Their Ge(Li) spectrometer detected bremsstrahlung of precipitating electrons even when the satellite was far away from the radiation belts. The effect of the bramsstrahlung of precipitating electrons on the background of our measurement will be the subject of a separate publication.

5. CONCLUSIONS

It seems that our high energy resolution Ge(Li) spectrometer does not have enough sensitivity to resolve the gamma ray lines expected from the galactic center. Only upper limits could be given from our measurements (Albernhe; Boclet; Costa, Durouchoux; Borgne, Rocchia and Vedrenne, 1978), although the lower intensity of the atmospheric, and the proton and neutron induced background at 12 GV magnetic cutoff rigidity. A more quantitative study of the background is in progress. It includes and extensive study of the background sources for the 0.511 MeV positron-electron annilation line as did (Ling; Mahoney; Willet and Jacobson, 1977), and the effect of the bremsstrahlung produced by precipitating electrons in the atmosphere of the South Atlantic Magnetic Anomaly.

In a general way, the number of proton and neutron induced gamma ray lines in Ge(Li) and NaI(Tl) crystals, and in the detector surrounding, and also the existence of atmospheric gamma rays and cosmic gamma rays diffuse radiation are all of great inconvenience for the development of nuclear gamma ray astronomy. A precise estimation of the extraterrestrial gamma rays weak flux demands great care from the experimenter to account for the instrument background. Very high sensitivity telescops are necessary to resolve the astrophysically important gamma ray lines from the background found at balloon and satellite heights.

ACKNOWLEDGEMENTS

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TABLE I

GAMMA-RAY LINES

Photon Energy (MeV)	σ	Flux counts $cm^{-2}s^{-1}$	Tentative Identification
0.139	14.7	6.83×10^{-3}	$Ge^{74}(n,\gamma)\ Ge^{75m}$
0.175	7.1	1.7×10^{-3}	$Ge^{70}(n,\gamma)\ Ge^{71m}$
0.198	26.5	1.15×10^{-3}	$Ge^{70}(n,\gamma)\ Ge^{71m}$
0.511	46.5	3.47×10^{-2}	$e^{+} + e^{-}$
0.603	11.		$Ge^{74}(n,n')\ Ge^{74m}$
0.691	7.1		$Ge^{72}(n,n')\ Ge^{72}$
0.757	3.		
0.845	6.7		$Al^{27}(n,n')\ Al^{27} + Fe^{56}(p,p')\ Fe^{56}$
0.898	70.		Y^{88}(in flight source calibration)
1.170	12.5		Co^{60}(in flight source calibration)
1.330	11.6		Co^{60}(in flight source calibration)
1.460	4.8		K^{40} on the gondola
1.540	6.3		
1.836	54.		Y^{88}(in flight source calibration)

REFERENCES

ALBERNHE, F., E. BOCLET, J.M. da COSTA, Ph. DUROUCHOUX, J.F. Le BORGNE R. ROCCHIA and G. VEDRENNE. Search for Gamma-Ray Lines in the Direction of the Galactic Center, presented at the Symposium on X-Ray Astronomy, COSPAR, Innsbruck, Austria, 1978.

ALBERNHE, F., M. FRABEL, G. VEDRENNE, D. BOCLET, J. CLAISSE, Ph. DUROUCHOUX, E. OLIVIER, P. PAGNIER, R. ROCCHIA and J.M. da COSTA. Recent Measurements with a Balloon-Borne GE(Li) Spectrometer in Gamma-Ray Astronomy, submitted to Nucl. Inst. Meth., 1978.

ALBERNHE, F. and G. VEDRENNE. Measurement in the Atmosphere of a Gamma-Ray Line at 6129 KeV. *J. Geophys. Res.*, 81, 2433, 1976.

CHUPP, E.L., D.J. FORREST, P.R. HIGBIE, A.N. SURI, C.TSAI and P.P. DUNPHY. Solar Gamma-Ray Lines observed during Solar Activity of August 2 to August 11, 1972. *Nature*, 241, 333, 1973.

IMHOF, W.L., G.H. NAKANO, R.G., JOHNSON and J.B. REAGAN. In Gamma-Ray Astrophysics, NASA SP-339, p. 77, 1973.

IMHOF, W.L., G.H. NAKANO and J.B. REAGAN. High Resolution Measurements of Atmospheric Gamma-Rays from a Satellite. *J. Geophys. Res.*, 19, 2835, 1976.

JACOBSON, A.S., R.J. BISHOP, G.W. CULP, L. JUNG, W.A. MAHONEY, and J.B. WILLET. A Balloon-Borne Ge(Li) Spectrometer for Gamma-Ray Astronomy, Nucl. Inst. Meth. 127, 115, 1975.

JOHNSON, W.N. and R.C. HAYMES. Detection of Gamma-Ray Spectral Line from the Galactic Center. *Astrophys. J.*, 184, 103, 1973.

LEVENTHAL, M., C.J. MACCALLUM, and A.C. WATTS. Possible Gamma-Ray Line from the Crab Nebula. *Nature*, 266, 696, 1977.

LING, J.C., W.A. MAHONEY, J.B. WILLET and A.S. JACOBSON. Measurements of 0.511 - MeV Gamma-Rays with a Balloon-Borne Ge(Li) Spectrometer. *J. Geophys. Res.*, 82, 1463, 1977.

LINGENFELTER, R.E. and RAMATY, R. Gamma-Ray Lines from Interestellar Grains. *Astrophys. J.*, 211, L19, 1977.

LING, J.C. and D.E. GRUBER. Spectra and Angular Distributions of Atmospheric Gamma-Rays from 0.3 to 10 MeV at $\lambda = 40^{o}$. *J. Geophys.* 82, 1211, 1977.

MARTIN, I.M., D.B. RAI, J.M. da COSTA., R.A.R. PALMEIRA and N.B. TRIVEDI. Enhanced Electron Precipitation in Brazilian Magnetic Anomaly in Association with Sudden Commencement. *Nature*, 240, 100, 84, 1977.

MARTIN, I.M., D.B. RAI, R.A.R. PALMEIRA, B.B. TRIVEDI, M.A. ABDU and J.M. da COSTA. Enhanced Low-Energy Gamma-Rays at balloon altitude in the Brazilian Magnetic Anomaly. *Nature*, 252, 5478, 25, 1974.

NAKANO, G.H., W.L. IMHOF, J.B. REAGA and R.G. JOHNSON. In Gamma-Ray Astrophysics, NASA SP-339, P. 71, 1973.

NAKANO, G.H., W.L. IMHOF and J.B. REAGAN. Cooled Germanium Spectrometers for X and Gamma-Ray Astronomy, Space Sci. Inst. 2, 219, 1976.

RAMATY, R. and R.E. LINGENFELTER, ^{26}Al: A Galatic Source of Gamma-Ray Line Emission. *Astrophys. J.*, 213, L5, 1977.

WOMACK, E.A. and J.W. OVERBECK. High Resolution Search for Solar Gamma-Ray Lines. *J. Geophys. Res.*, 75, 1311, 1970.

FIGURE CAPTIONS

Figure 1 - View of the spectrometer

Figure 2 - The gondola

Figure 3 - Total count rates in the Ge(Li) detector, versus pressure.

Figure 4 - Gamma rays energy loss spectum, for a total time of 61935 s, during the February 14, 1977 flight.

Figure 5 - Fine plot of the gamma ray energy loss spectrum measured during the February 14, 1977 flight. The extraterrestrial gamma-ray lines whose upper limits are given by Albernhe et al.[11], are also indicated in parentheses.

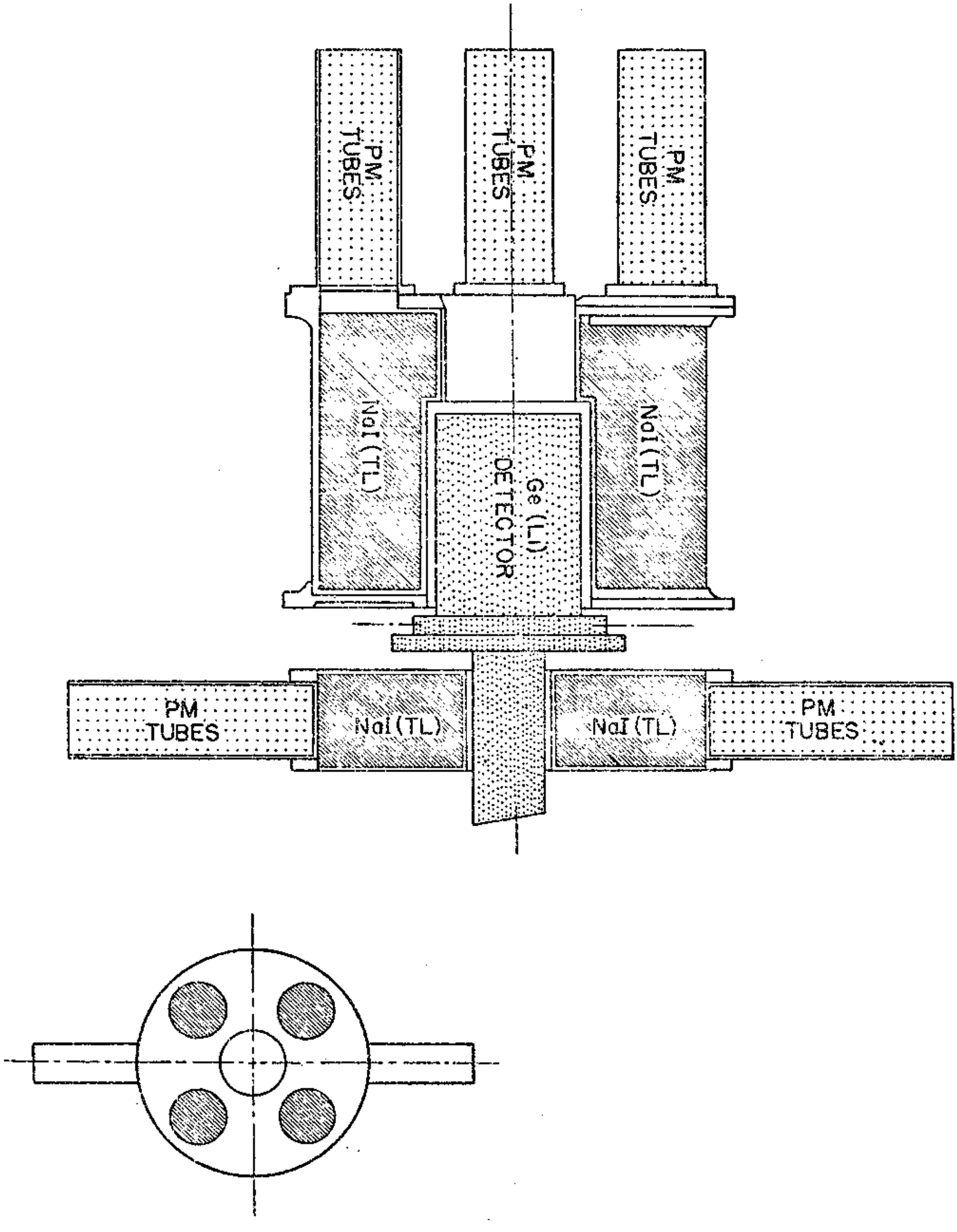
PM TUBES
PM TUBES
PM TUBES
NaI(TL)
Ge (Li) DETECTOR
NaI(TL)
PM TUBES
NaI(TL)
NaI(TL)
PM TUBES

Fig. 1

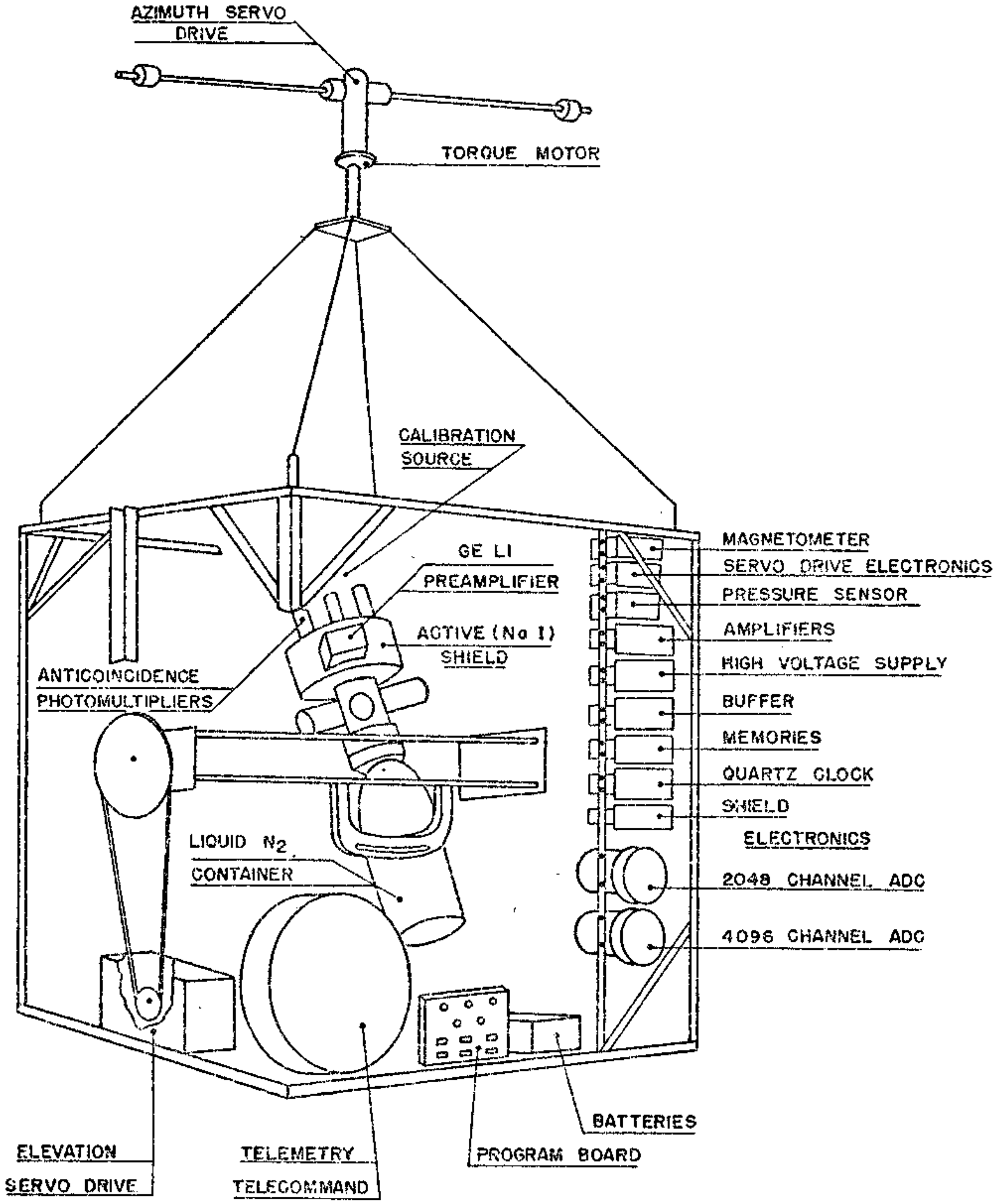
AZIMUTH SERVO DRIVE
TORQUE MOTOR
CALIBRATION SOURCE
GE LI
PREAMPLIFIER
ACTIVE (Na I) SHIELD
ANTICOINCIDENCE PHOTOMULTIPLIERS
LIQUID N_2 CONTAINER
MAGNETOMETER
SERVO DRIVE ELECTRONICS
PRESSURE SENSOR
AMPLIFIERS
HIGH VOLTAGE SUPPLY
BUFFER
MEMORIES
QUARTZ CLOCK
SHIELD ELECTRONICS
2048 CHANNEL ADC
4096 CHANNEL ADC
BATTERIES
ELEVATION SERVO DRIVE
TELEMETRY TELECOMMAND
PROGRAM BOARD

Fig. 2

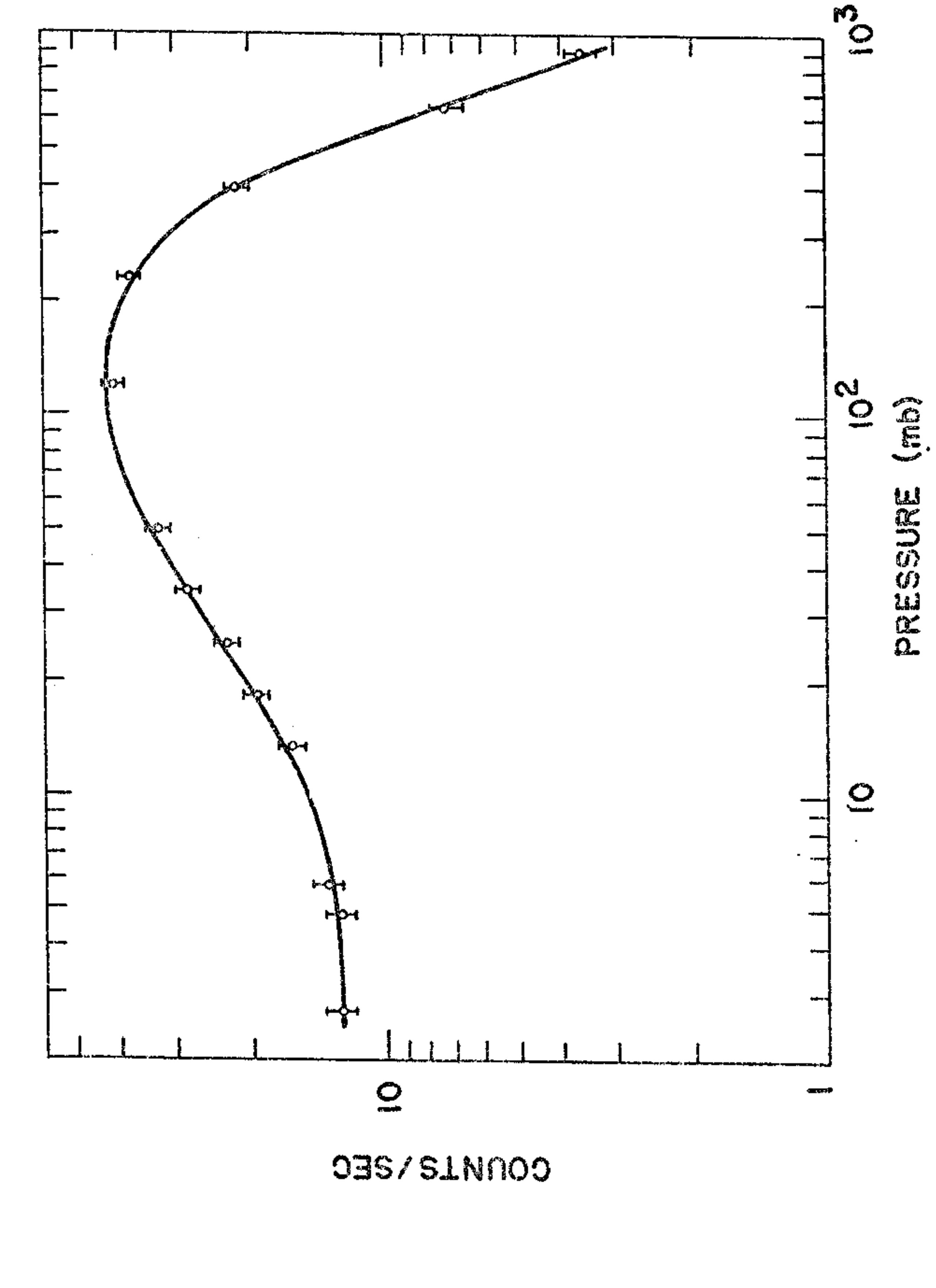

Fig. 3

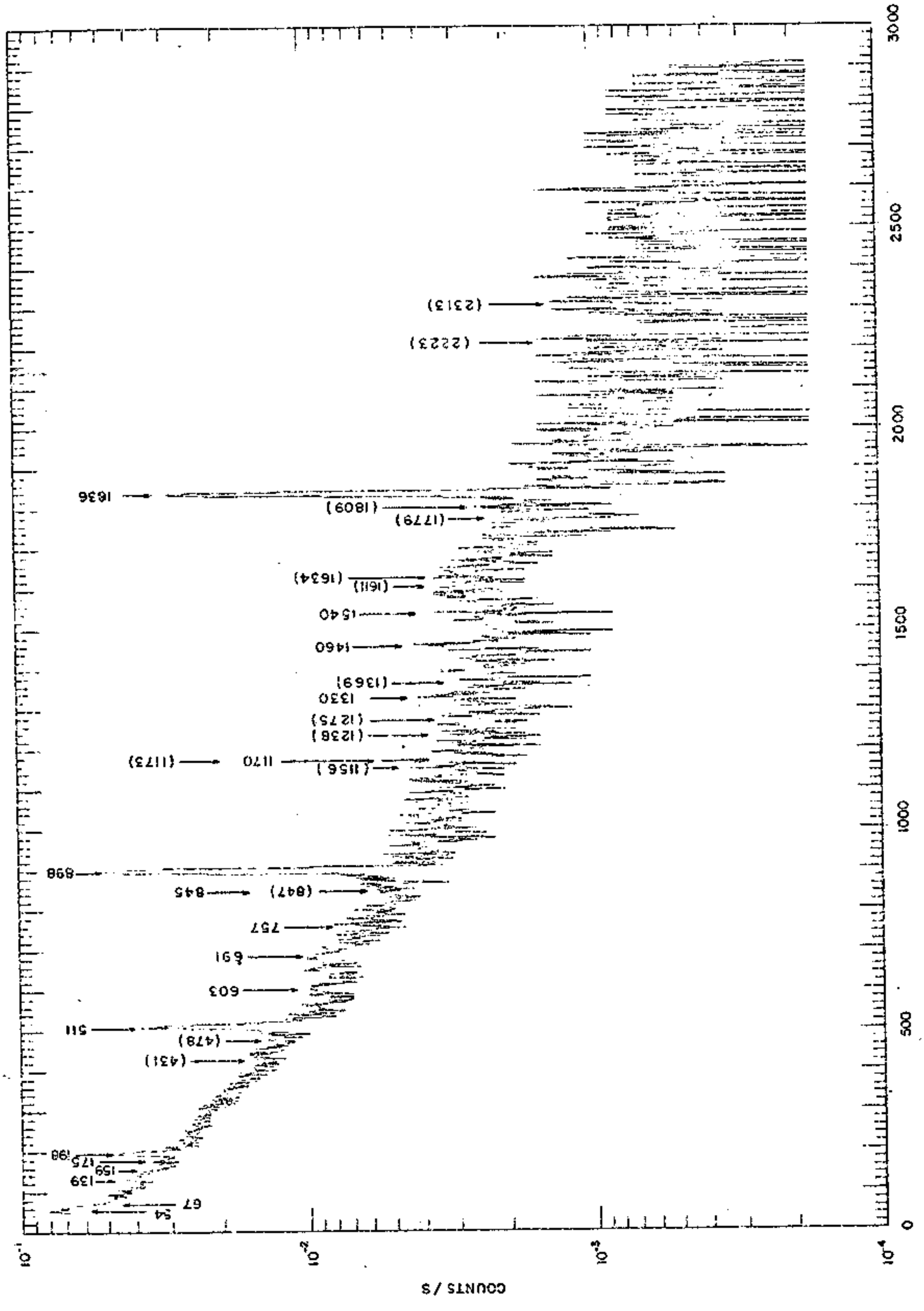
ENERGY (KeV)
COUNTS / S
0
500
1000
1500
2000
2500
3000
10^{-1}
10^{-2}
10^{-3}
10^{-4}
54
67
139
159
175
198
(431)
(478)
511
603
691
757
845
(847)
898
(1156)
1170
(1173)
(1238)
(1275)
1330
(1369)
1460
1540
(1611)
(1634)
(1779)
(1809)
1836
(2223)
(2313)

Fig. 5

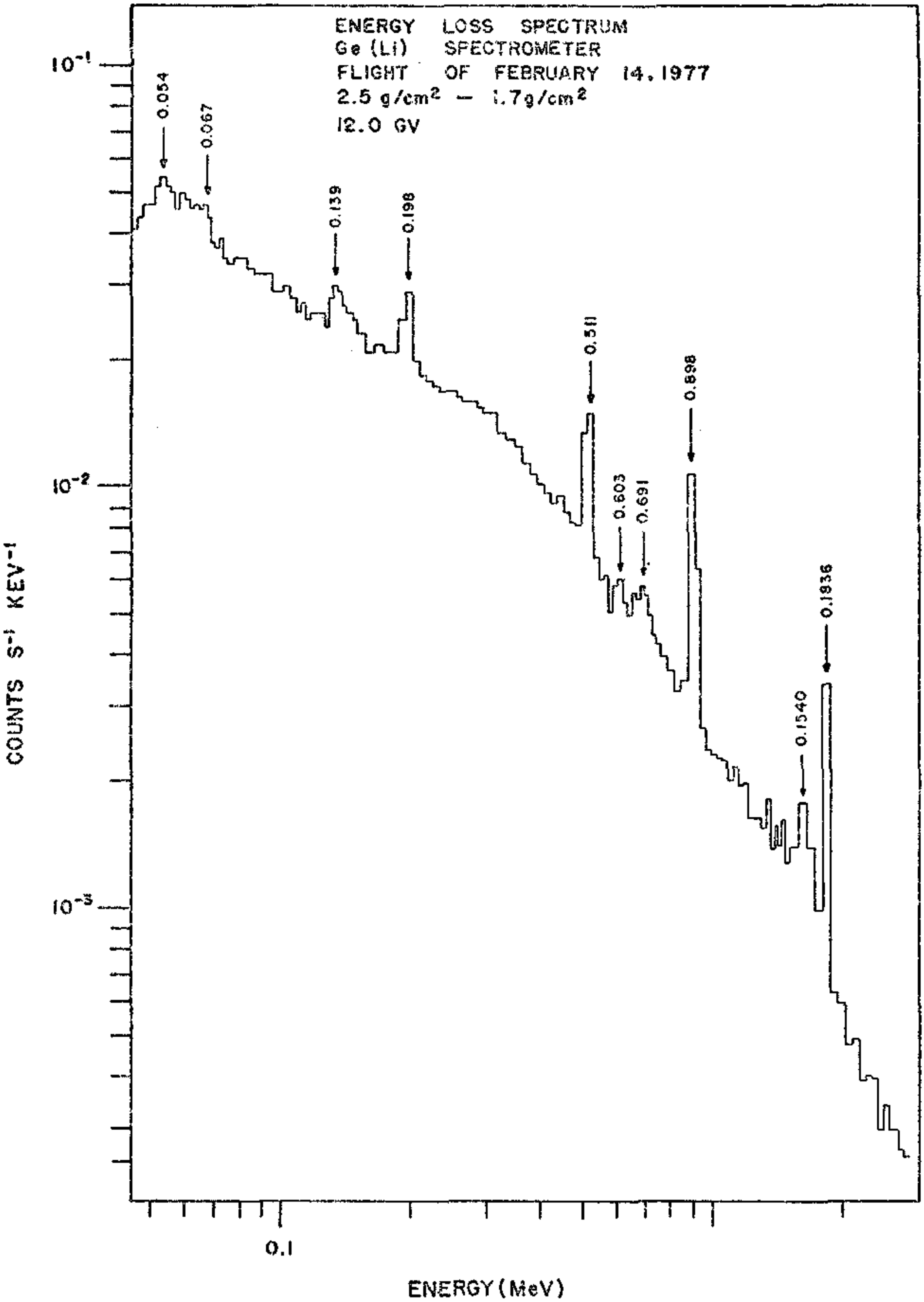
ENERGY LOSS SPECTRUM
Ge (Li) SPECTROMETER
FLIGHT OF FEBRUARY 14, 1977
2.5 g/cm² — 1.7g/cm²
12.0 GV
0.054
0.067
0.139
0.198
0.511
0.603
0.691
0.898
0.1540
0.1936
10⁻¹
10⁻²
10⁻³
COUNTS S⁻¹ KEV⁻¹
0.1
ENERGY (MeV)

Fig. 4