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16. Summary/Notes

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GAMMA-RAY LINES OBSERVED IN BALLOON FLIGHTS AT HIGH RIGIDITY

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ABSTRACT

Gamma-ray lines at 0.511 Mev and 1.632 Mev have been observed at high rigidity (12.5 GV) during stratospheric balloon flights carried out, up to 4 g/cm^2, from São José dos Campos, Brasil. The flux of these lines are compared with the results obtained at other rigidity regions. The intensity variation of the most prominent of these lines, the annihilation line at 0.511 Mev, is found to be compatible, at various atmospheric depths, with theoretical predictions. This study leads to the estimation of an upper-limit for the flux of the extra-terrestrial 0.511 Mev gamma-ray line.

1. INTRODUCTION

The first and most prominent gamma-ray line measured so far is at 0.511 Mev, and results from electron-positron annihilation. Positrons are produced in the atmospheric environment either by the decay of pions, generated in high energy interactions, or by the β^+ decay following nuclear interactions. The slowing down or stopping of these positrons, through an ionization process, leads to their annihilation. The range of these positrons before their annihilation depends on the size and the density of the medium.

As the local production of gamma-ray lines (inside the detector or the gondola) can contribute considerably to the observed line intensity, the study of atmospheric production of these lines becomes more complex. However, our observations with omnidirectional detectors from stratospheric balloon flights, when compared with the theoretical production rates at different atmospheric depths, and with results obtained by other investigators, can indicate the contribution of each component. This study of atmospheric production of gamma-ray lines can also be used in the estimation of the contribution of the extra-terrestrial line to the total intensity observed.

2. INSTRUMENTATION

Three stratospheric balloons were flown from São José dos Campos, Brasil (table 1), with omnidirectional detectors. The omnidirectional detector consists of a NaI (Tl) crystal coupled to a photomultiplier tube. The pulse heights delivered by the detector, during the flights, are analised by an encoder with 128 energy channels. The encoded signals and other scientific parameters (pressure, temperature, etc...) are transmitted to the ground via FM/FM telemetry. All the data are recorded on magnetic tapes for subsequent analysis. The details of the experiments are described by Martin (1974) and Bui-Van and Martin (1977).

The NaI (Tl) crystals used are more efficient compared to the Ge (Li) detector (70% at 0.511 Mev vs. 26%), although they are inferior in energy resolution (0.5% v.s 14%) (Ling et. al. 1977; Jacobson et. al. 1975). Because of this low resolution, the NaI (Tl) crystals require precautions in their use and the energy calibration must be done more carefully for line identification. This calibration was done before and after each flight with radioactive sources (Table 2), which give a standard error of about 13 KeV in each channel. For the 0.511 Mev line, the calibration with ^{24}Na was made by the photon-pair detection technique which eliminates the contribution due to Compton scattering. A gaussian curve fitting method was used for the 1.6 Mev line, as no standard source provides this line for calibration.

3. RESULTS

The spectrum of the atmospheric gamma-ray flux consists of a continuum, which can be represented by a power-law (Reedy, 1973), on which the lines are superimposed (Figure 1). Fitting a curve to this continuum, over a wide range of energies allows one to obtain the gamma-ray line distribution. This distribution, at 0.5 Mev, is compared with the calibration curve (solid line. Figure 2), and with the gaussian curve at 1.6 Mev (solid line, Figure 3). The vertical bars in these figures represent the statistical fluctuations and errors due to curve fitting. The horizontal bars give the energy calibration standard deviations. The inensities of these lines are calculated by integrating the predicted distributions.

The variation of the calculated intensity of 0.5 Mev line at various atmospheric depths is plotted in Figure 4, where the vertical bars signify the same as mentioned above. The solid curve in this figure represents the theoretical calculations based on the source function concept, according to Ling (1977). In Figure 5, the results obtained at the top of the atmosphere (5 g/cm^2) are compared with the results of other investigators for different cut-off rigidities.

4. DISCUSSION

In Figures 2 and 3, the observed distributions of each line, at the top of the atmosphere, appear to be broader than expected. This broadening, which affects the calculated intensity of the line by about 20%, may be due to errors in detemining the continuum. These uncertainties were taken into account in estimating the error mentioned earlier. By taking these into consideration, the line intensities were calculated at different atmospheric depths for the two flights of December 20, 1974 and February 24, 1978 (Table 1). For the earlier flight, the balloon reached ceiling during the transit of galactic center region (around Sco X-1) and, for the later flight, about 3 hours before its transit, Variations of line intensities with atmospheric depth can be described by a semi-empirical model given by Ling (1977). The source function in this model is given by:

$$S\ (x) = S_o\ .\ (1 + b.x + c.x^2).\ e^{-x/p}$$

where x is the atmospheric depth in g/cm^2 and the constants S_o, b, c, and p are obtained by fitting the data to the function. These theoretical values for the 0.5 Mev line are plotted as solid line in Figure 4. Intensities observed during the second flight, which are supposed to be due mainly to the atmospheric component, are close to those theoretical values. This fact indicates that, on one side, the local production of gamma-ray lines is negligible when compared to the atmospheric production and that, on the other, the production at other depths cannot have a very important contribution to the total intensity, because the scattering effect smears out the line. Data from the first flight show that, at the top of the atmosphere, the intensity is slightly higher than that of the second flight, which may be due to the presence of the galactic center region. This intensity,

$$(2.682 \pm 0.456)\ .\ 10^{-2} \quad \text{photons}.(cm^2.s.)^{-1}$$

is found to be compatible with the results obtained by Vedrenne (1978) with a directional Ge(Li) detector, shielded against charged particles, during the observation of the galactic center region (Figure 5). Even though the omnidirectional detector, in the present experiment, was used without charged particle anticoincidence, the compatibility of both results indicates that the charged particle effects are negligible at the balloon altitudes. For the same rigidity these effects seem to be considerable in the satellite observations of Cosmos 461 (Mazets et al., 1975).

The slight difference observed in the 0.5 Mev line intensities for the two balloon flights mentioned above, can only give an upper limit for its emission from the galactic center region. This upper limit of $(0.475 \pm 1.23).\ 10^{-2}$ photons . $(cm^2\ .s.)^{-1}$ is of the same order of 1.8×10^{-3} photons.$(cm^2.s.)^{-1}$ given by Haymes (1975).

Similar analysis could be carried out for the 1.6 Mev line, but its low intensity and short exposure time, during the balloon ascent, do not allow us to give reliable results compared to the statistical fluctuations, except at the top of the atmosphere (5 g/cm^2) where the intensity,

$$(1.427 \pm 0.562).10^{-2}\ \text{photons}.(cm^2\ .s.)^{-1}$$

is found to be higher than the 7.2×10^{-3} photons.$(cm^2.s.)^{-1}$ predicted by Ling (1974) at 3.5 g/cm^2 and 6.6 GV of rigidity.

5. CONCLUSIONS

The present results, obtained with omnidirectional detectors, seem not to be affected by the presence of charged particles. However, the lack of shielding may enhance the continuum spectrum because of multiple Compton scattering in the crystal. The anti-Compton shielding techniques can reduce this effect and help in extracting the lines more accurately. The intensity of the lines depends upon the energy distribution and, by increasing the energy definition of the encoder, the error in its determination can be reduced. By increasing the exposure time at ceiling, these facts will be taken into consideration in constructing our future detectors.

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TABLE 1

FLIGHT DATE	LAUNCH TIME (UT)	CEILING REACHED (UT)	CEILING ENDED (UT)	FLOAT ALTITUDE (g/cm^2)	DETECTORS USED	OBJECTIVE
October 7,73	0710	0840	0920	3.5	4"x4" with charged particles shield (0.9 to 17 Mev)	Observation of the atmospheric gamma-ray component
December 20,74	0410	0600	1220	4.0	4"x4" without charged particles shield (0.3 to 5.0 Mev)	Observation of galactic center region
February 24,78	2327	0115	0230	4.0.	3"x $\frac{1}{4}$" without charged particles shield (0.1 to 2.0 Mev)	Observation of the atmospheric gamma-ray component

TABLE 2

RADIOACTIVE NUCLIDE	PHOTON ENERGIES (Mev)
^{137}Cs	0.032 0.662
^{24}Na	0.511 1.28
^{60}Co	1.17 1.33

FIGURE CAPTIONS

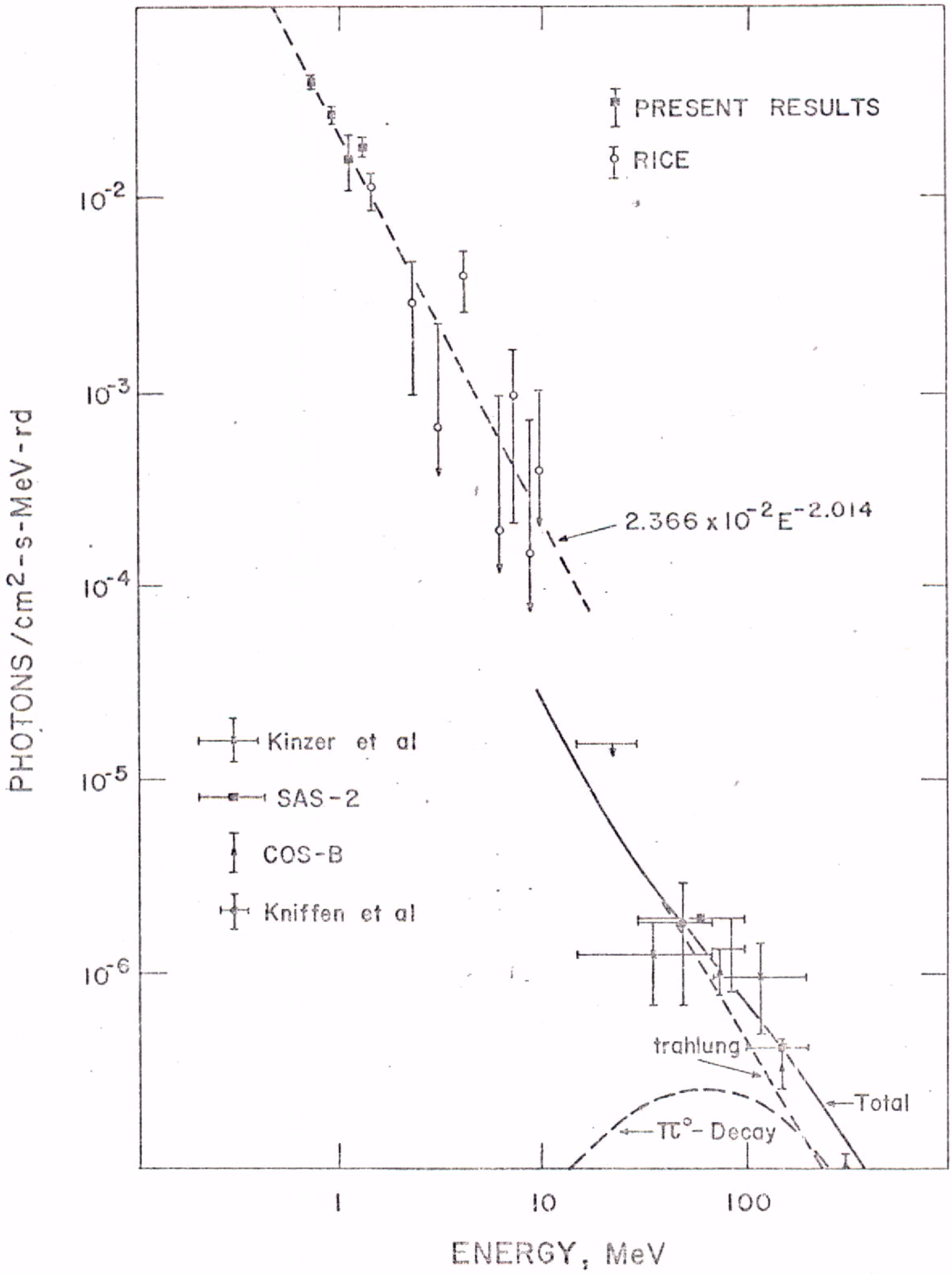
Figure 1 - Atmospheric gamma-ray spectrum measured near the top of the atmosphere at high rigidity cut-offs.

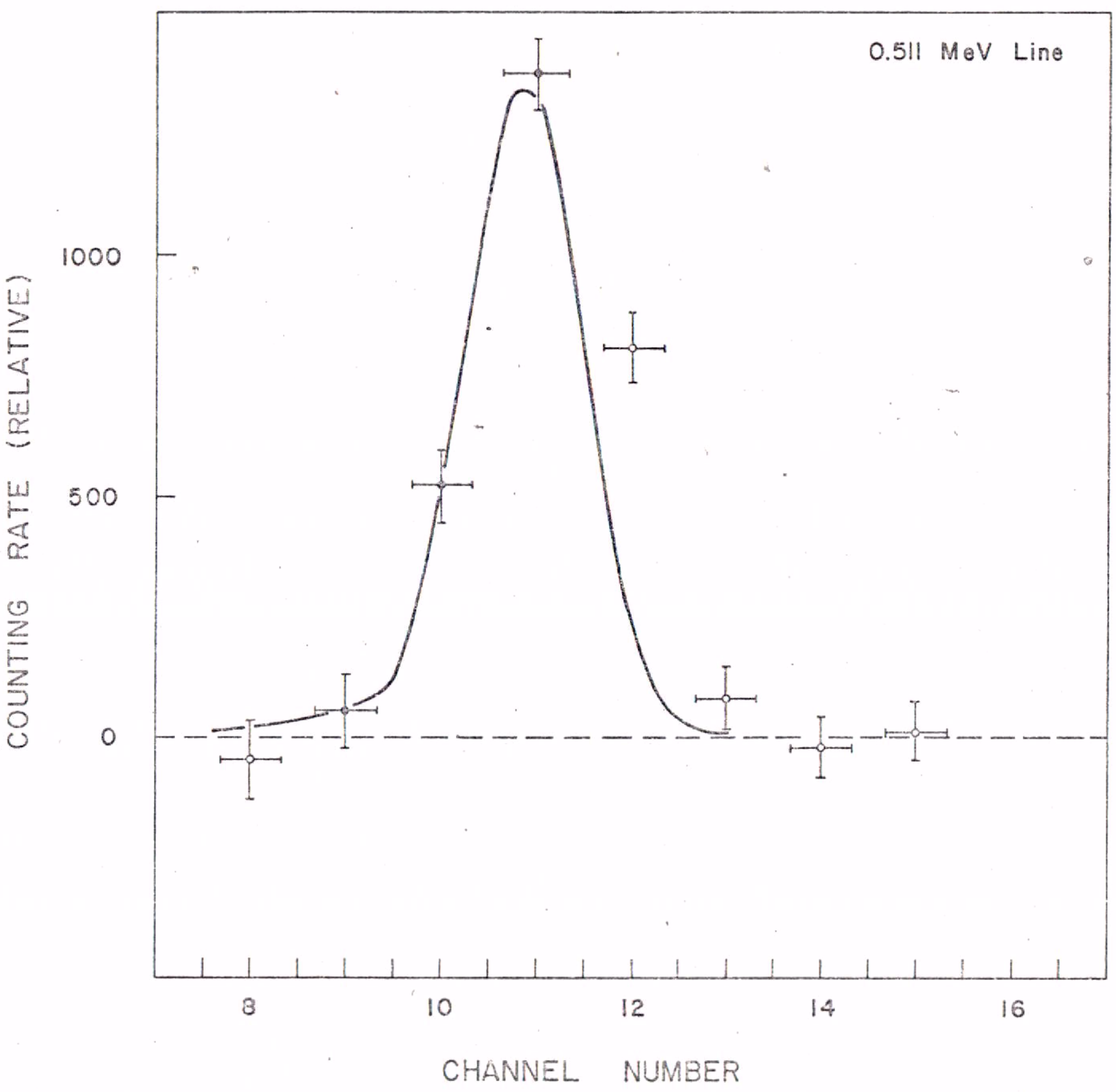
Figure 2 - Comparison of the 0.5 Mev line distribution observed near the top of the atmosphere with the calibration curve.

Figure 3 - Comparison of the 1.6 Mev line distribution observed near the top of the atmosphere with the gaussian curve fit.

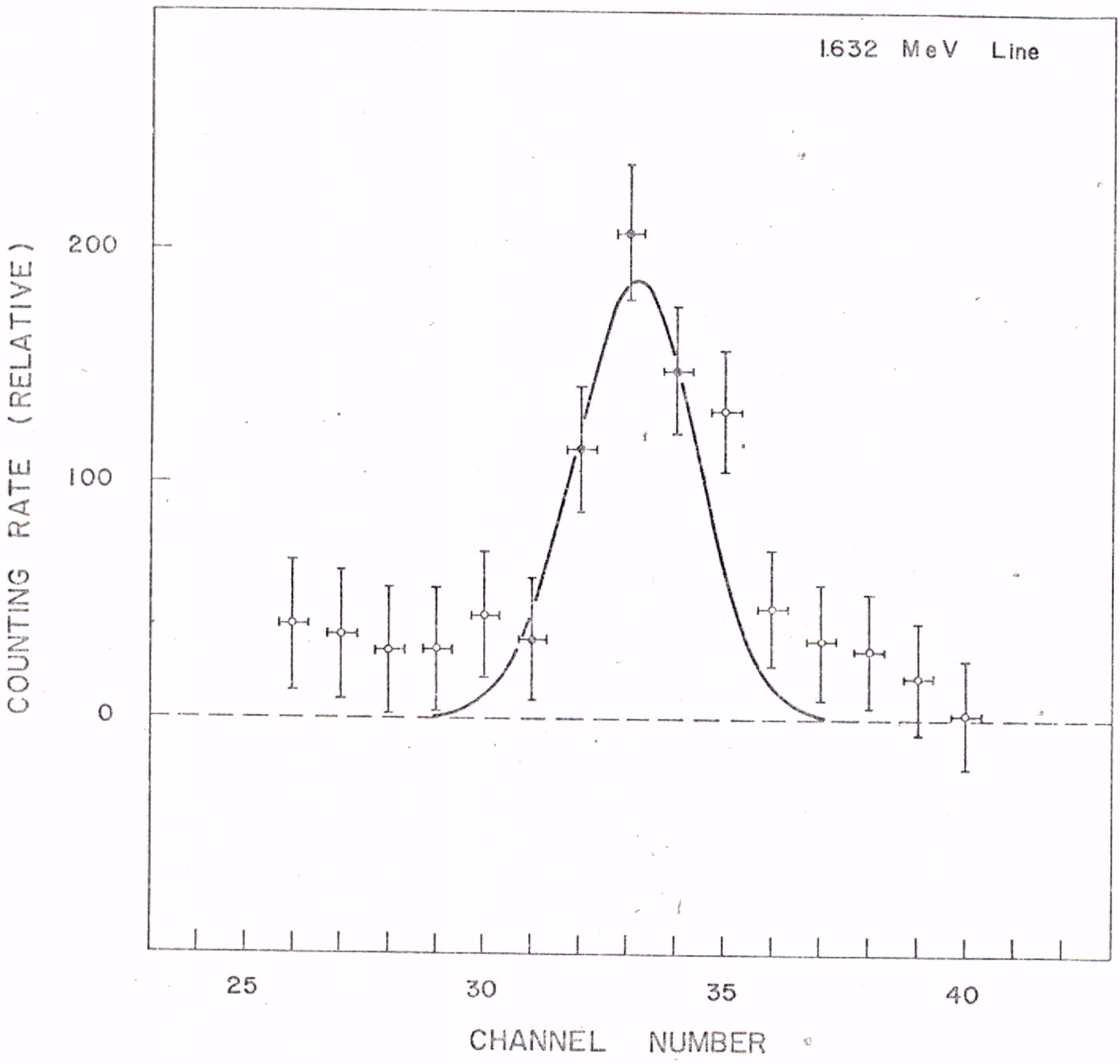
Figure 4 - Comparison of the 0.5 Mev line intensity observed at various atmospheric depths with that predicted by the semi-empirical model.

Figure 5 - Comparison of the 0.5 Mev line intensity observed by various investigators at different rigidity regions.

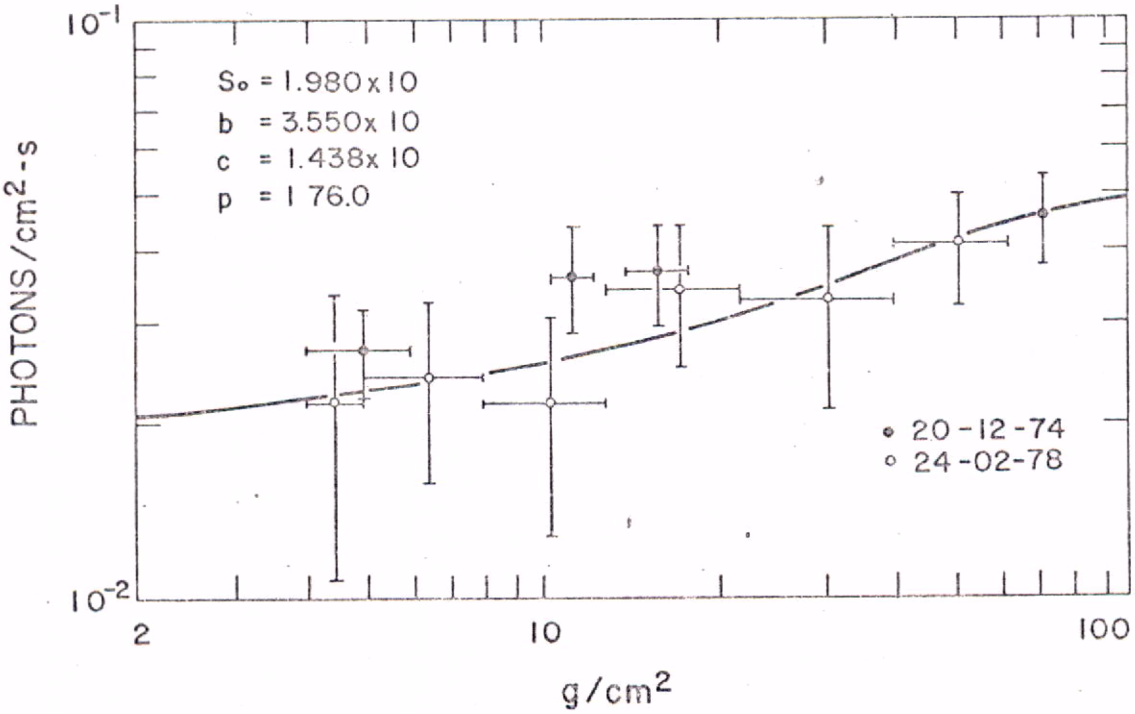

PRESENT RESULTS
RICE
$2.366 \times 10^{-2} E^{-2.014}$
Kinzer et al
SAS-2
COS-B
Kniffen et al
trahlung
Total
π°- Decay
PHOTONS/cm²-s-MeV-rd
ENERGY, MeV
10^-2
10^-3
10^-4
10^-5
10^-6
1
10
100



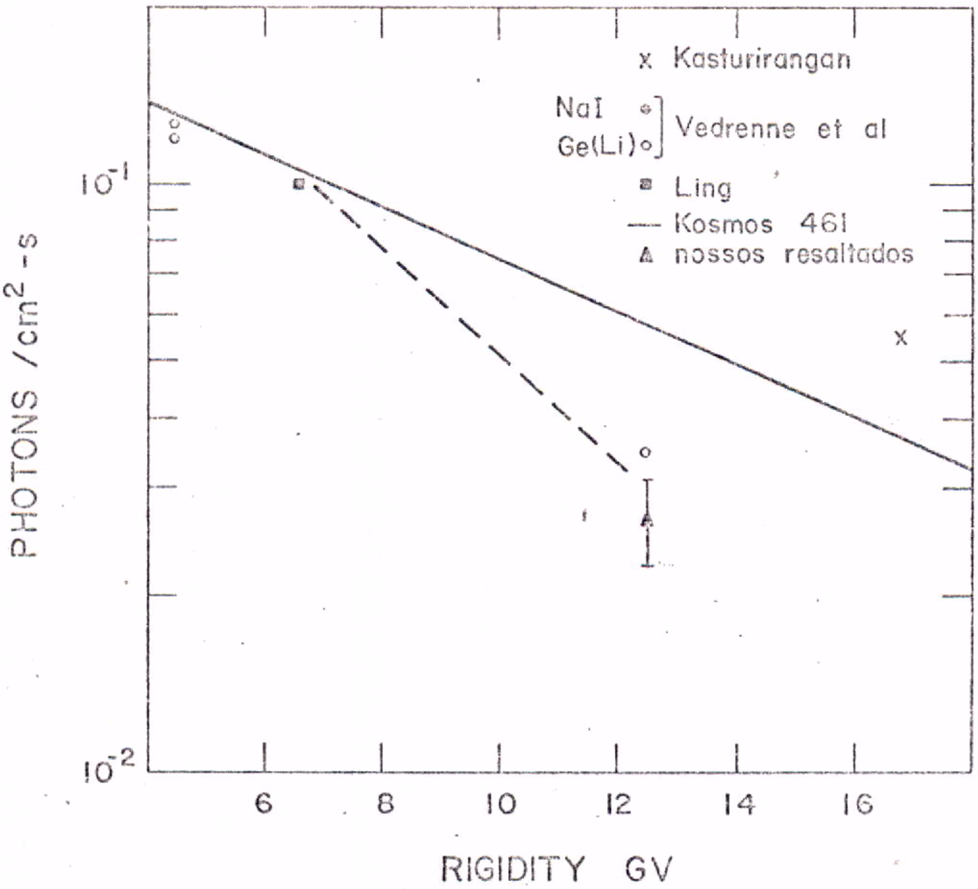
0.511 MeV Line
COUNTING RATE (RELATIVE)
1000
500
0
8
10
12
14
16
CHANNEL NUMBER



1.632 MeV Line
COUNTING RATE (RELATIVE)
200
100
0
25
30
35
40
CHANNEL NUMBER



10-1
So = 1.980x10
b = 3.550x10
c = 1.438x10
p = 176.0
PHOTONS/cm2-s
• 20-12-74
○ 24-02-78
10-2
2
10
100
g/cm2


x Kasturirangan
NaI
Ge(Li)
Vedrenne et al
Ling
Kosmos 461
nossos resaltados
10^{-1}
10^{-2}
PHOTONS /cm^2 -s
6
8
10
12
14
16
RIGIDITY GV