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16.Summary/Notes

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ATMOSPHERIC GAMMA-RAYS AT HIGH RIGIDITY REGION

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ABSTRACT

The differential atmospheric gamma-ray spectra have been obtained between 0.2 and 17 Mev with omnidirectional detectors from stratospheric balloon flights carried up to 4 g/cm^2 from São José dos Campos, Brasil (12,5 GV of rigidity) and compared with high energy spectra obtained by other authors for approximately the same rigidity. The observed flux at different energies and at different atmospheric depths above 100 g/cm^2 is found to be compatible with theoretical predictions. The comparison of observations with theory allows one to predict the contribution of the atmospheric component in the astronomical gamma-ray observations.

1. Introduction

The study of atmospheric gamma-ray component is fundamental in geophysical and astrophysical investigations. Because of the interaction of cosmic-rays with atmospheric nuclei, the gamma-ray production in these interactions can reveal the morphology of the atmosphere. Also, the knowledge of this component can help to extract the extra-terrestrial gamma-ray contribution. Several investigators have done experimental and theoretical work in this respect, mostly in the low rigidity region in the Northern hemisphere. For the Southern hemisphere only a few results are available to date. Therefore, experiments were flown with the aim of getting a gamma-ray spectrum in an energy range as wide as possible and to compare it with that obtained at very high energies. The comparison of observations with the calculated terrestrial gamma-ray production allows one to predict the contribution of the atmospheric component in the astronomical gamma-ray observations.

2. Instrumentation

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 Buivan and Martin (1977). The characteristics of all the flights are summarized in Table 1.

3. Results

The best way to study the gamma-ray production in the atmosphere is to analyzes its flux for different energies at various atmospheric depths. Above 100 g/cm^2 the results obtained are shown in Figures 1 and 2. The variation of the counting rate, observed at various depths, can be described by a semi-empirical model given by Ling (1974).

This model is based on the concept of a source function expressed as:

$$S(E,x) = S_0(E).(1 + b(E).x + c(E).x^2).e^{-x/p(E)} \qquad (1)$$

where E and x are respectively the energy of the photon expressed in Mev and the atmospheric depth in g/cm^2. The parameter p should be closely related to the absorption length of primary cosmic-rays. The parameters S_0, b,c and p are obtained by fitting the data to the function and the flux calculated by (1) is plotted as solid lines in the Figures.

The values of p obtained in these calculations for 12.5GV of rigidity and those obtained by Ling (1974) for 6.6 GV of rigidity are plotted in Figure 3.

Spectra obtained during the flight of December 20, 1974 at two atmospheric depths, 5 g/cm^2 and 72 g/cm^2, are shown in Figure 4.

Finally, in Figure 5 are shown the spectra observed at the ceiling during the flights of October 7, 1973 and December 20, 1974, along with the observations of Kinzer et al. (1974) and Staib et al. (1973) at higher energies.

4. Discussion

In Figures 1 and 2, discrepancies between the observations and theoretical predictions are seen at low pressures (below 10 g/cm^2), indicating that the processes of production of gamma-rays near the top of the atmosphere are to be represented by a more complex source function than the one given by Ling, because the scattering of the gamma-ray albedo generated at lower depths may be more important than the production at the top of atmosphere and, so, influence this function. The production and the transport of the gamma-rays near the top of the atmosphere cannot easily be resolved by using the omnidirectional detector.

The values of p, calculated by using the present observations, are lower and have a steeper slope than those calculated by Ling, for lower rigidity, as shown in Figure 3. This means that the strength of penetration of primary cosmic-rays is higher for 12.5 GV and consequently the rate of production of gamma-rays is more sensitive than for 6.6 GV. This last aspect can also be seen by comparing the spectrum given by Ling at 70 g/cm^2, i.e.:

$2.139 \times 10^{-1} \cdot E^{-1.24}$ photons (cm^2 s Mev sr)$^{-1}$

with the steep spectrum, at same depth, observed during the flight of December 20, 1974 (Figure 4):

$1.196 \times 10^{-2} \cdot E^{-1.54}$ photons (cm^2 s Mev sr)$^{-1}$

The results of observations, from 0.3 Mev to 1 GeV, at a geomagnetic out-off approximately 12.5 GV (Figure 5), show that the spectrum, up to 2 Mev, is compatible with that at very high energies given by Staib et al. (1973). From 2 Mev to 17 Mev we can observe a bulge which may extend for energies higher than about 20 Mev. This bulge, though not very pronounced, is also seen at 6.6 GV (Ling, 1974).

5. Conclusions

Although simple detectors have been used in these investigations the results show the importance of atmospheric gamma-ray production in the Southern hemisphere, where only a few observations have been made to date. However, these results allow us to estimate the contribution of the emission of gamma-rays from the galactic center region. This will be the subject of our next paper. The attempt to explain the atmospheric gamma-ray production, by using the source function concept, is not complete. Only results obtained with the directional detectors can explain the discrepancy between observations and theoretical predictions, by measuring the contribution of the re-entrant and albedo gamma-ray flux. This will be the objective of our future experiments.

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TABLE 1

FLIGHT DATE	LAUNCH TIME (UT)	CEILING REACHED (UT)	CEILING ENDED (UT)	FLOAT ALTITUDE (g/cm^2)	DETECTORS USED	OBJETIVE
October 7,73	0710	0840	0920	3.5	4"x4" with charged particles shield (0.9 to 17 Mev)	Observation of the atmoshperic 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

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Ling J. - Spectral and Angular Distributions of Low Energy Atmospheric Gamma Rays at λ = 40º, Thesis, University of California, San Diego, USA, 1974.

Martin, I.M. - Determination des flux de photons Gamma de basse énergie dans l'atmosphere, Thesis, Paul Sabatier University, Toulouse, France, 1974.

Staib, J., Frye G., and Zych A., - Proc. 13th Int. Cosmic Ray Conference, Denver, 916, 1973.

FIGURE CAPTIONS

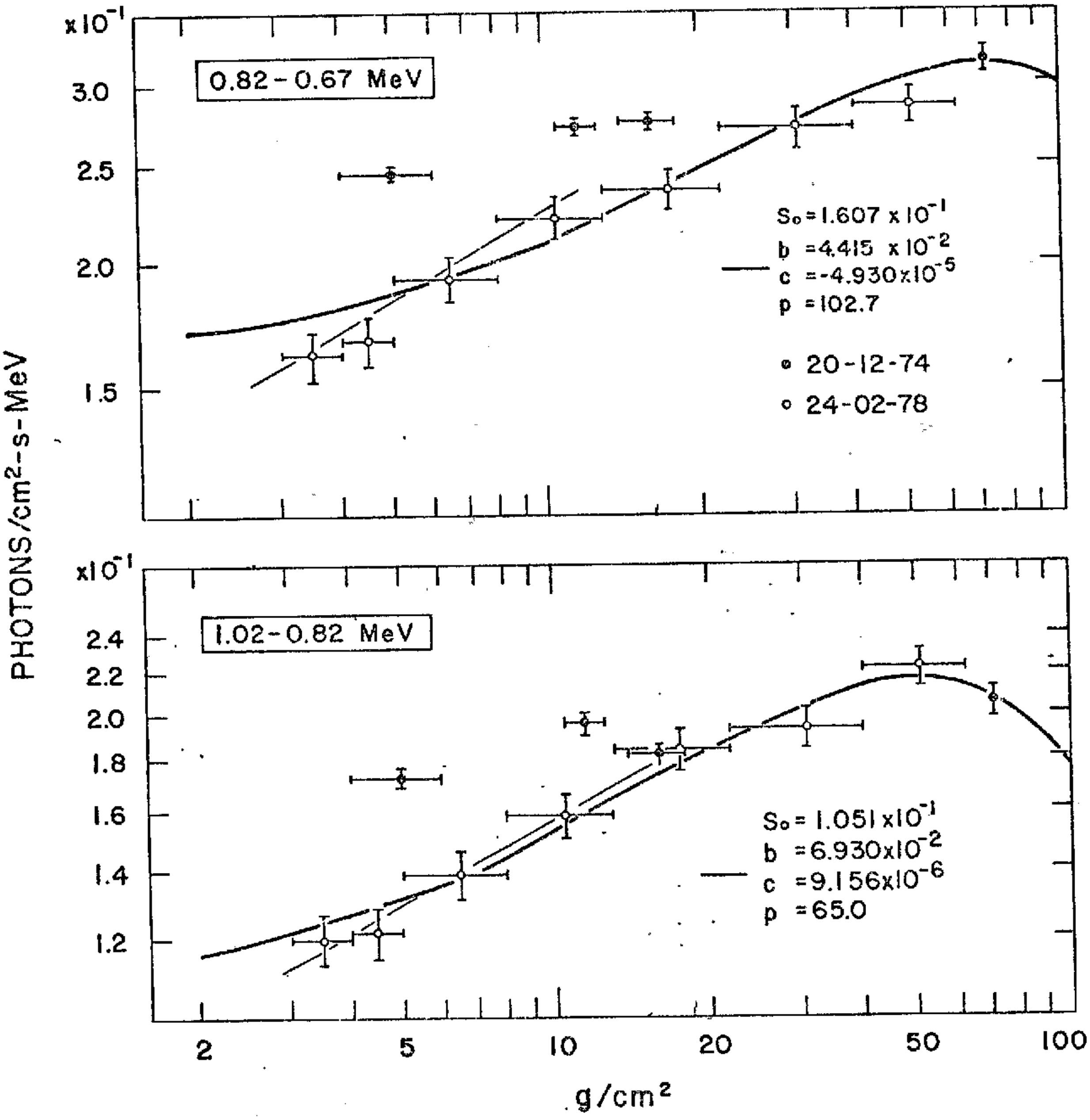
Figure 1 - Variation of the counting rate of gamma-rays at various atmospheric depths, for two energy intervals:
0.67 to 0.82 Mev
0.82 to 1.62 Mev

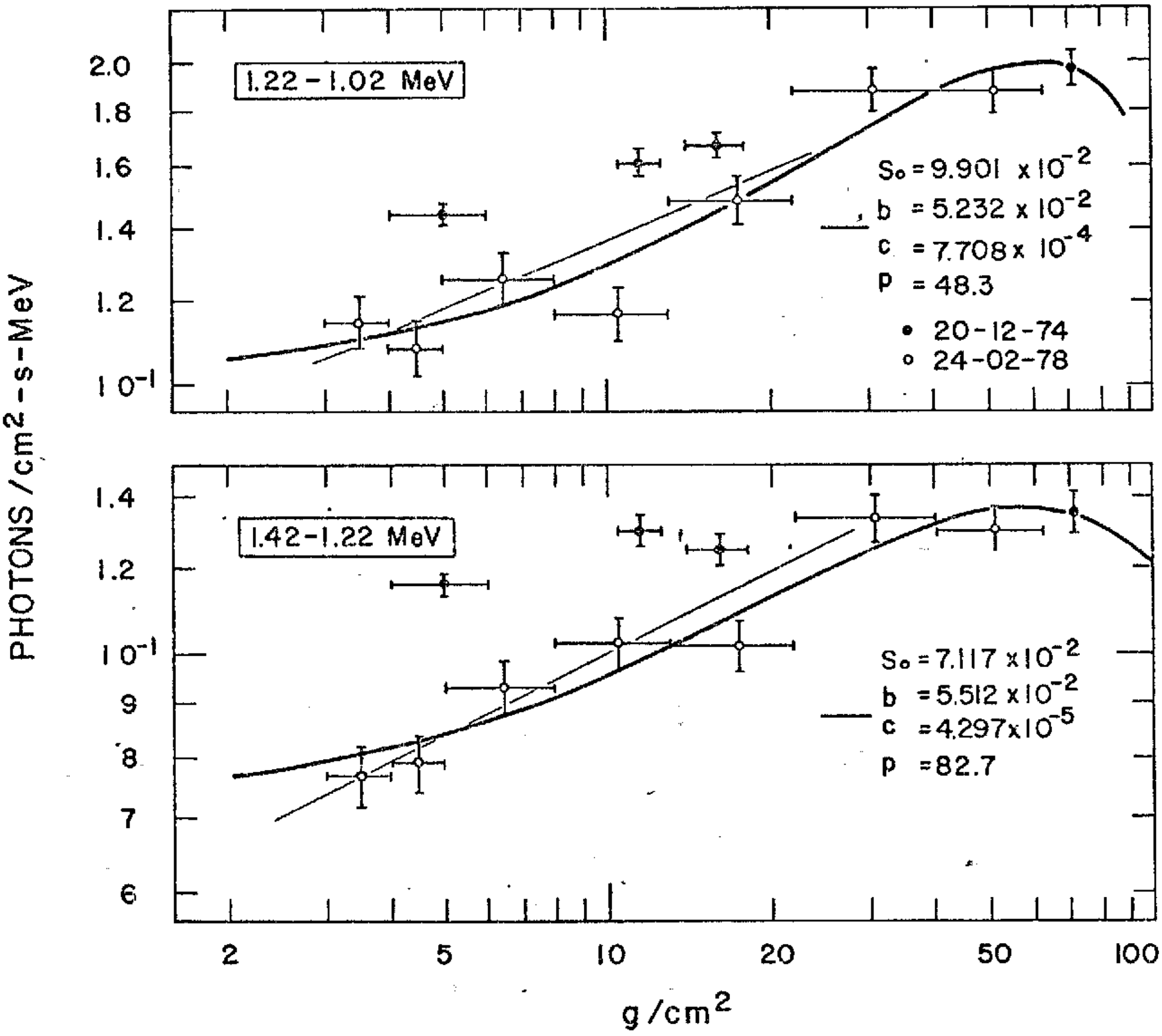
Figure 2 - Variation of the counting rate of gamma-rays at various atmospheric depths, for two energy intervals:
1.02 to 1.22 Mev
1.22 to 1.42 Mev

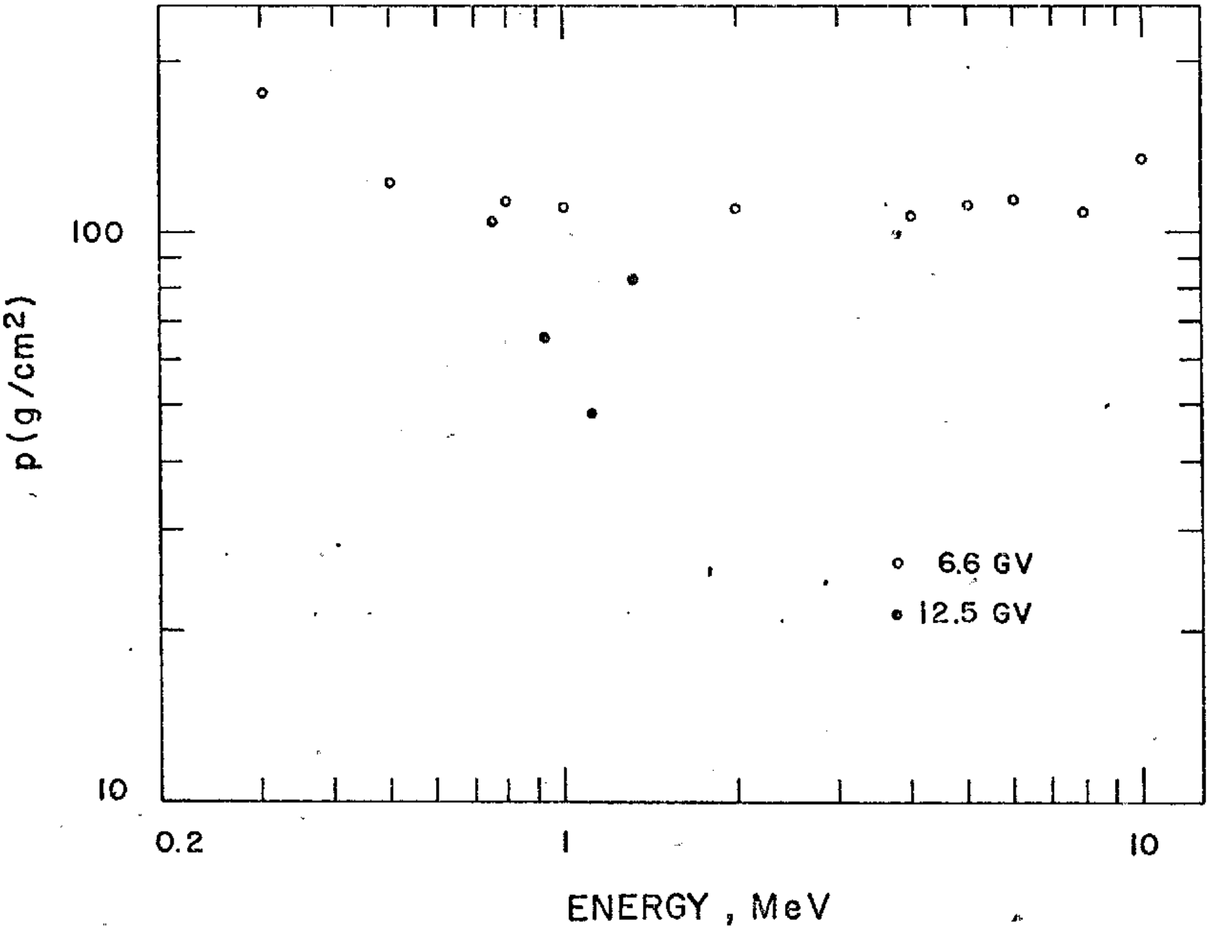
Figure 3 - Variation of the parameter p vs. photon energy for two geomagnetic cut-offs 6.6 and 12.5 GV.

Figure 4 - Differential gamma-ray spectrum observed at two atmospheric depths 5 and 72 g/cm^2.

Figure 5 - Atmospheric gamma-ray spectrum measured near the top of the atmosphere at high rigidity cut-offs.


x10⁻¹
0.82 - 0.67 MeV
3.0
2.5
2.0
1.5
So = 1.607 x 10⁻¹
b = 4.415 x 10⁻²
c = -4.930 x 10⁻⁵
p = 102.7
20-12-74
24-02-78
x10⁻¹
1.02 - 0.82 MeV
2.4
2.2
2.0
1.8
1.6
1.4
1.2
So = 1.051 x 10⁻¹
b = 6.930 x 10⁻²
c = 9.156 x 10⁻⁶
p = 65.0
PHOTONS/cm²-s-MeV
2
5
10
20
50
100
g/cm²


1.22 - 1.02 MeV
2.0
1.8
1.6
1.4
1.2
1 0^{-1}
S₀ = 9.901 x 10^{-2}
b = 5.232 x 10^{-2}
c = 7.708 x 10^{-4}
p = 48.3
● 20-12-74
○ 24-02-78
1.42-1.22 MeV
1.4
1.2
1 0^{-1}
9
8
7
6
S₀ = 7.117 x 10^{-2}
b = 5.512 x 10^{-2}
c = 4.297 x 10^{-5}
p = 82.7
PHOTONS /cm^2 - s - MeV
2
5
10
20
50
100
g /cm^2


100
10
p (g/cm^2)
0.2
1
10
ENERGY , MeV
○ 6.6 GV
● 12.5 GV

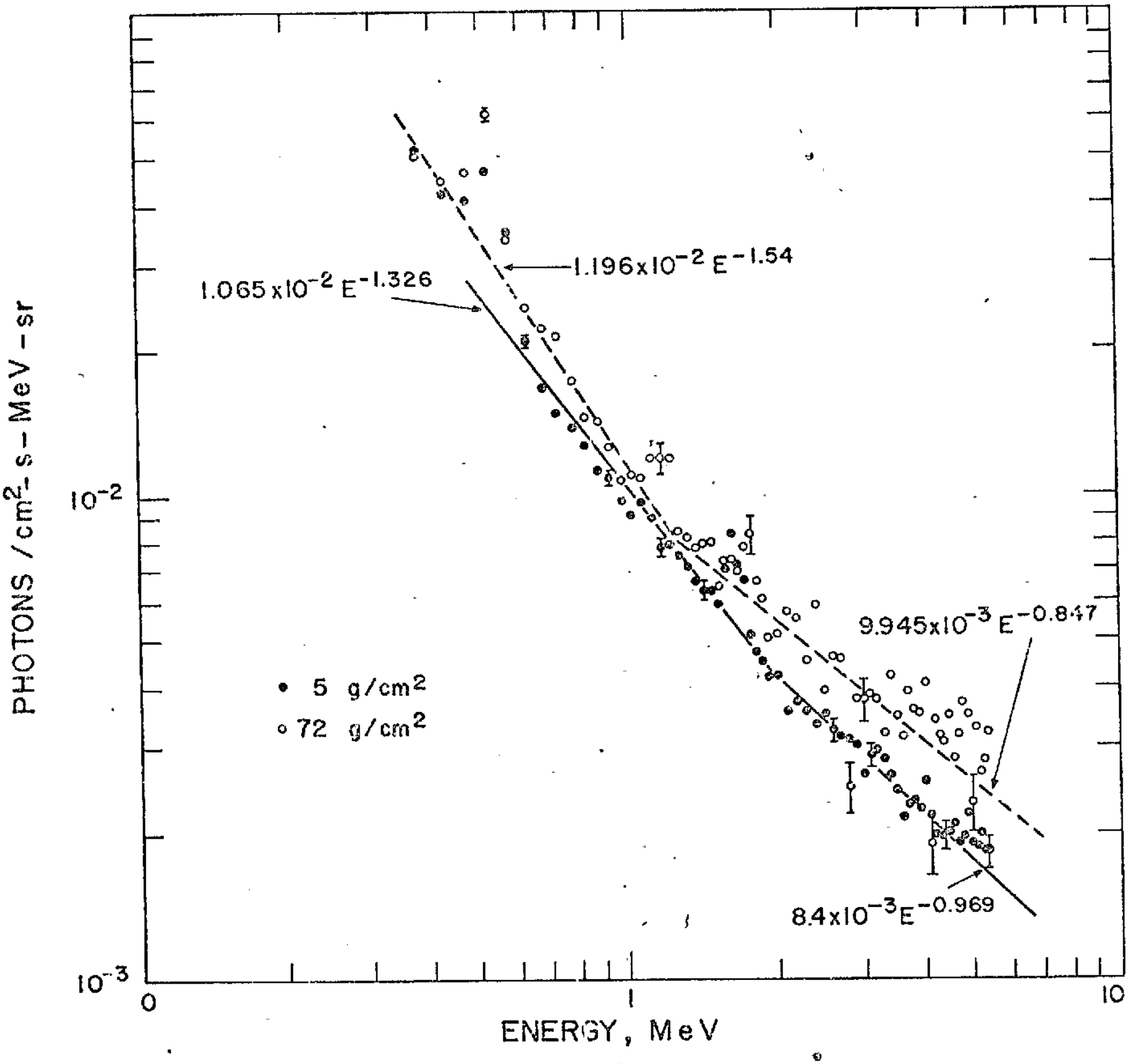
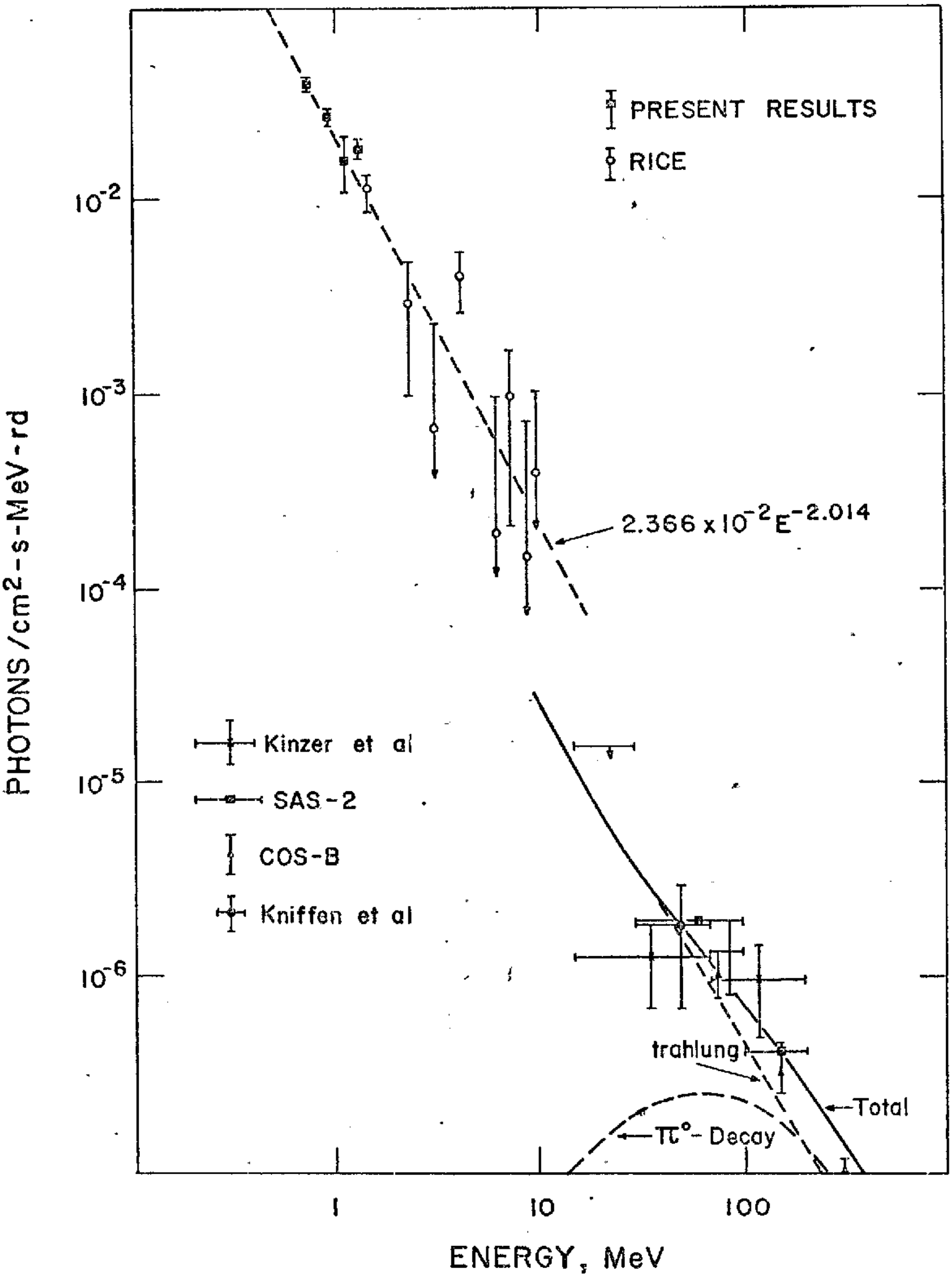

PHOTONS /cm²- s - MeV - sr
10⁻²
10⁻³
0
1
10
ENERGY, MeV
1.196x10⁻² E⁻¹·⁵⁴
1.065x10⁻² E⁻¹·³²⁶
9.945x10⁻³ E⁻⁰·⁸⁴⁷
8.4x10⁻³E⁻⁰·⁹⁶⁹
● 5 g/cm²
○ 72 g/cm²

Fig 6


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
10⁻²
10⁻³
10⁻⁴
10⁻⁵
10⁻⁶
1
10
100
ENERGY, MeV