Revista Brasileira de Física, Vol. 12, Nº 3, 1982

Spectral Observations of Atmospheric γ-Ray Background

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Recebido em 30/9/80; versão revista recebida em 13/4/81

Based on the results of two balloon flights, made at São José dos Campos and at Juazeiro do Norte in Brazil, using omni- directional gamma ray detectors, the different aspects of atmospheric gamma rays equatorial latitudes in the energy interval of 0.3 to 4.5 MeV are investigated. The energy loss spectrum in this energy band is found to consist of a continuum and a photo peak at 0.51 MeV in agreement with previous observations. A discussion of the spectral nature of this background and the observed lower intensities of both the continuum and the 0.51 MeV line with reference to observations at other latitudes is presented.

Diferentes aspectos de raios gama atmosféricos a latitudes equatoriais no intervalo de energia de 0,3 a 4,5 MeV são investigados com base em resultados de dois vôos de balão, realizados em São José dos Campos e em Juazeiro do Norte, Brasil, usando detetores de raios gama omnidirecionais. Verificamos que o espectro de perda de energia nessa banda consiste de um contínuo e de um foto-pico em 0,51 MeV, de acordo com observações previas. Uma discussão da natureza espectral desse fundo e das intensidades mais baixas tanto do contínuo quanto da

* On leave of absence from Physical Research taboratory, Ahmedabad, India. To be submitted to "Revista Brasileira de Física" for publication.

linha a 0,51 MeV em relação a observações a outras latitudes, é também feita.

1. INTRODUCTION

Investigations of different aspects of atmospheric gamma rays at high and mid-latitudes have been made by many workers[1-7]. The spectral results, in the 0.3 to 10 MeV y-ray energy, showed in general a featureless continuum except for the well established 0.51 MeV line, attributed to positron-electron annihilation. The background continuum spectrum closely follows a power law function and is attributed to compton degraded photons originating from Π^0 meson decay and small contributions from neutron capture and inelastic scatter on N^{14} and O^{16} species. The few experiments conducted at equatorial latitudes[8-10] have shown clearly reduction in this background intensity.

In view of the importance of lower y-ray background fluxes for y-ray astronomy studies, it is desired to conduct these measurements at equatorial latitudes and a better understanding of the nature of background. In this paper we report the results of our observations conterning the characteristic features of atmosphere y-rays in experiments conducted at equatorial latitudes in Brazil with our particular detector configuration employed for observations of discrete y-ray sources.

2. TELESCOPES AND FLIGHT DETAILS

The telescopes, flown for observations of discrete gamma ray sources, had 10x10 cm cylindrical crystals of NaI (Tl) as basic detectors with RCA 8045 photomultipliers. The telescope consisted of two detector assemblies,. mounted vertically with a separation distance of 1.8 meters. An absorber, consisting of aluminum and paraffin, was placed midway between the detectors. No other material surrounded the detector assembly except for aluminum supports within 50 cm. The y-ray events, from each detector assembly, was pulse height analysed separately into 128 energy channels. The 128 channel analyser permit charge--to-time height conversion and each analyser covered an equivalent of 0.3 to 5.0 MeV y-ray energy approximately. Pressure monitors (Rosemount barometers) have been employed to obtain pressure data to an accuracy better than 0.5 mbar. The encoded signals and house keeping information (pressure, temperature, etc.) were telemetered to ground via FM-FM telemetry. The electronics and batteries of approximately 25 kg in weight were placed on an annular platform near the absorbers. On ground the data were recorded on rnagnetic tapes for subsequent analysis.

Extensive prefligh calibrations have been conducted to evaluate the response of the detectors and electronics. The response of each detector was determined with gamma ray sources Cs^{137}, Na^{24}, Co^{60} and Am-Be. The detectors had a typical resolution of ≤ 14 percent at 0.51 MeV. Identical payloads SOURCE II and SOURCE III y-ray telescopes were flown on Raven 75,000 and 13,000 cubic meter balloons at São José dos Campos (23^{o} 12'S, 45^{o}W) and at Juazeiro do Norte (7^{o}3'S, 39^{o}12'W), respectively. The balloon carrying SOURCE II telescope was launched on March 31, 1979 at 04:30 UT, reached ceiling at 06:08 UT andfloated for 6 hours at 4.2 mbar altitude. SOURCE III telescope launched on Nov.22, 1979 at 09:08 UT, had a float at 3.50 mbar from 11:30 UT till 12:25 UT. The performance of the on board electronics and response of the detectors were satisfactory in both the flights.

3. RESULTS

We have utilised the data collected by the top detector assembly of each telescope for the studies of atmospheric y-ray background. The two flights showed the characteristic decrease in the initial phase after launch, due to the continuous reduction in the terrestrial radio activity at the payload. As the balloon ascended further, the counting rates increased from about 800 g cm^{-2} depth to reach a maximum at Pfotzer region (-120 g cm^{-2}) and then onwards decreased till the float ceiling altitudes. In Figure 1 are shown the total counting rates for the two flights in the respective y-ray energy regions plottedagainst the pressure. The counting rates forming 5 minute time bins are corrected for dead time losses. We obtained the time information from the tape speed for **SOURCE III**, because of malfunction in the ground timer system during the flight. This and more likely the ground powerline noise during the time, perhaps account for the lower count rates observed from 200 g cm^{-2} till 40 g cm^{-2} of atmospheric depth. The flattening of the growth curve for altitudes above ~10 *g cm*$^{-2}$ is expected due to diffuse y-ray cosmic background. The count rates, binned into dífferent energy bands, also showed similar growth curves and essentially proved stability of the detector and electronic systems in both these flights.

The raw counting rates, in the various energy channels, have been utilized to derive the energy loss spectrum of the background events at different times of the flight. To facilitate easy intercomparison later, we have converted the count rates into counts s^{-1} cm^{-2}

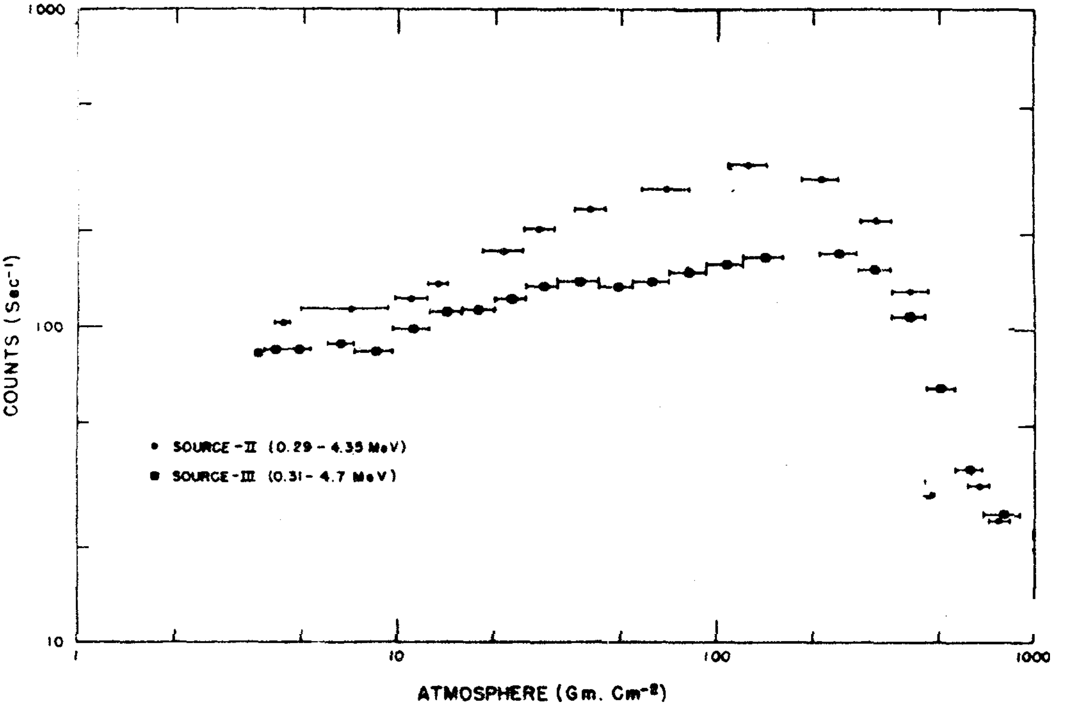

Fig.1 - Atmospheric growth curves of total counting rates in the energy range 0.3 to 4.5 MeV for SOURCE II and SOURCE III flights respectively.

MeV^{-1}, taking into consideration energy interval of each channel and the omnidirectional geometrical factor of the detector system.

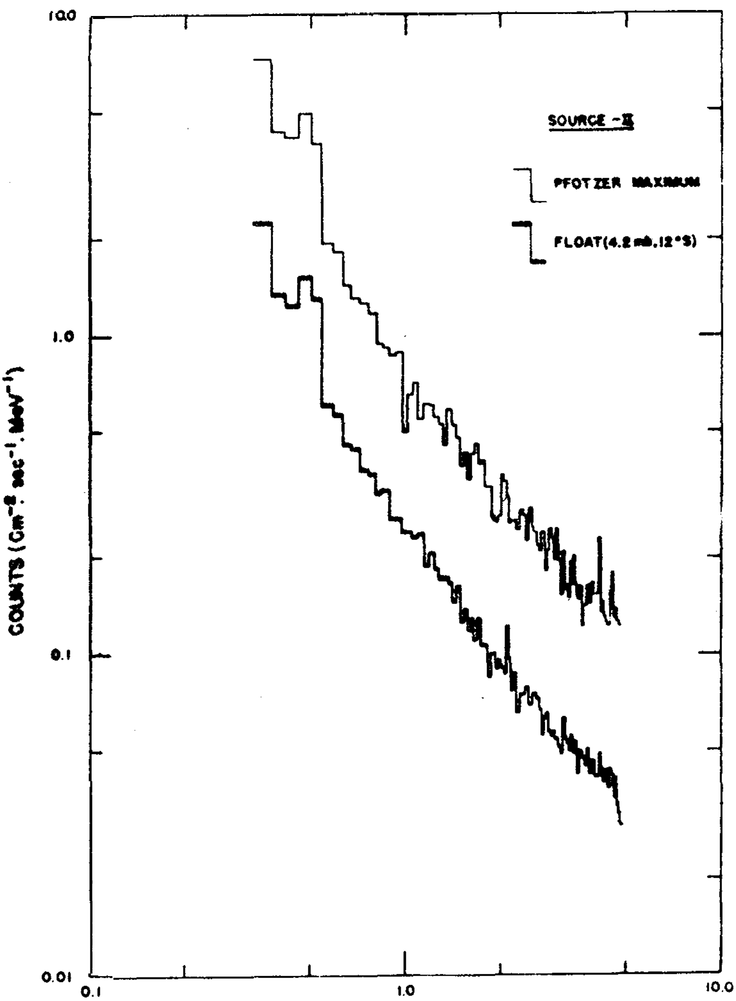

Fig. 2a - The gamma ray spectra observed at the ceiling and at the Pfotzer maximum for SOURCE II flight.

In Figures 2a and 2b are shown different spectra of the two flights. In Figure 2a the plot shows spectra at Pfotzer maximum and at the ceiling of 4.3 g cm^{-2} for the SOURCE II flight. In Figure 2b are shown the SOURCE III spectra corresponding toceiling floatof 3.6 g cm^{-2}

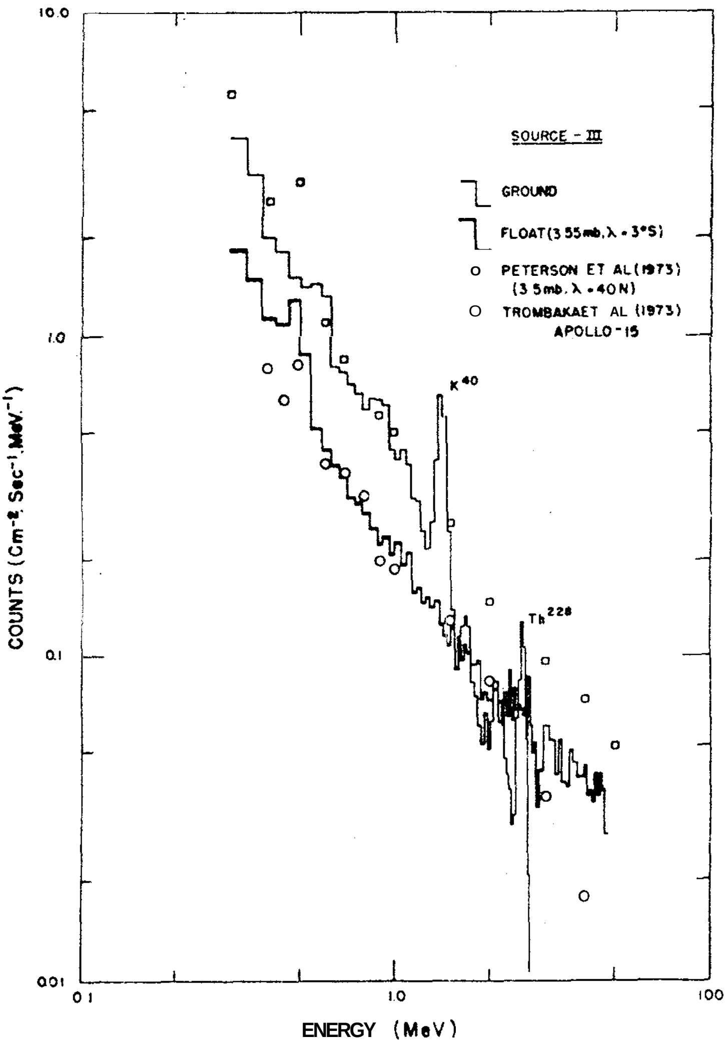

Fig.2b - The gamma ray spectra observed on the graund and at the ceiling for SOURCE III flight conducted at Juazeiro do Norte.

and ground activity. The spectrum registered on ground at Juazeiro do Norte exhibits the environment peaks due to K^{40} (1.46 MeV) and Th^{208} (2.62 MeV). This natural background spectrum falls off sharply begining at ~2.75 MeV and is lower by about two orders of magnitude in comparision with the float altitude atmospheric spectrurn. The spectra at the ceiling and the Pfotzer rnaximum show similar characteristics inthe two flights and power law fits to these spectra in the 0.3 to 1.0 MeV range exhibit indices −2.2. Above this energy the power law indices flatten to approximately −1.3.

The spectral peak at 0.51 MeV is prominently seen in all spectra above 700 g cm^{-2} depth. The photopeak counting rate is estimated from the channels which contain this line and the background contribution deduced from the power law fit to the adjacent channels. The difference in the count rates, attributed to this line, is shown in Figure 3 for different altitudes. These growth curves have characteristics similar to the continuous background count rate.

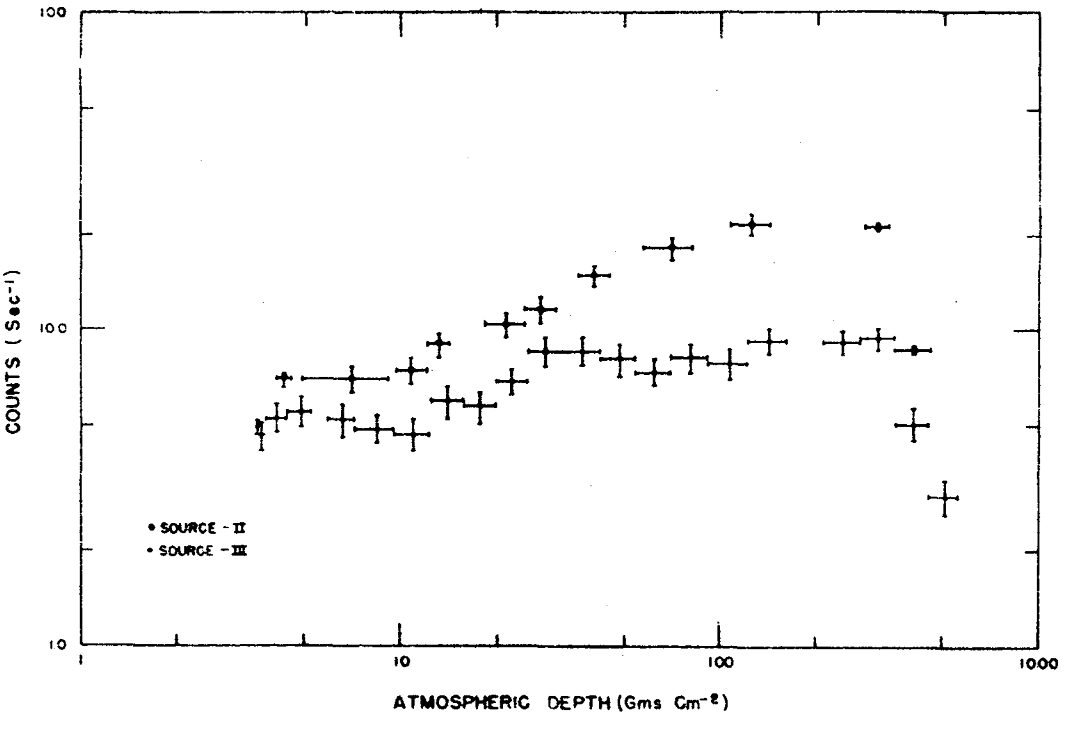

Fig.3 - Atmospheric growth curves of the 0.51 MeV line count rate for SOURCE II and SOURCE III flights.

4. DISCUSSION

Production of atmospheric gamma rays from cosmic rays involve a number of nuclear and electromagnetic processes. The principal mechanisms for the contributions below 10 MeV are y-rays from Π^0 meson decay and those from neutron capture and irielastic scattering. Each Π^0 meson inputs at least 140 MeV into the gamnia ray spectrum near 70 MeV. Since electron-photon interactions are coupled by pair production and compton electrons, we can infer from atmospheric y-ray studies, that the bulk of the low energy photons originate from the soft electromagnetic component. The atmospheric growth curves of the y-rays lead us to estimate the absorption length as -200 g cm^{-2} for altitudes between -200 g cm^{-2} and 600 g cm^{-2}, in essential agreement with values obtained from high latitude and mid latitude studies by Anderson[1] (1961), Peterson[6] *et al.* (1973), Haymes[3] *et al.*(1969) arid Kasturirangan[8] *et al.* (1972). The genetic relationship that exist between the various components in atmosphere y-rays, electrons and niuon component is clearly established by their having approximately the same absorption lengths. As discussed by Kasturirangan[8] *et al.*(1972), these differ considerably from neutrons (10 - 500 MeV) which have -130 g cm^{-2}. It is estimated by Rocchia[11] *et al.* (1965) that nearly 85 percent of y-rays are due to electromagnetic showers and that less than 12 percent are due to excited y-rays from neutron inelastic scatter of N^{14} and 0^{16} species. Some contribution to the observed count rate is expected due to thermal neutron capture in the NaI(Tl) crystal and prompt y-ray emission in star formation. This contribution is believed to be negligible[8] at equatorial latitudes.

The spectra of atmospheric y-ray continuum obtained, have not been corrected for the photopeak efficiency to obtain the raw photon spectrum. The conversion of observed count rate into photons has not been attempted as no simple methods exist n the absence of knowledge about source function. We observe from our two flights, that the continuum spectra have essentially similar shapes at all depths above 600 g cm^{-2} and this shows the equilibrium nature of atmospheric y-ray production. We observe a flattening of the spectrum with spectral index of -1.3 in the 1.0 to 4.5 MeV energy range as compared to the value of -2.2 for the index in the range 0.3 to 1.0 MeV. A part of the steepening can be attributed to photons that result from compton scatter in the detector of high energy photons. This being intrinsic of the detector, can not be avoided. A small fraction of the flattening of the spectrum above 1 MeV results because in our telescope we have not incorporated charge particle rejection system, which can relatively suppress[6] the higher background at above 1 MeV in comparison with lower energies by a factor of -1.5.

The absolute value of y-ray background observed in balloon experiments depends on geomagnetic latitude of observation and detector configuration. Comparison of our two flights, employing detectors of same configuration but conducted at different geomagnetic latitudes 12°S and 3°S, show that the y-ray background is lower at Juazeiro do Norte by a factor ~1,2 especially at energies below 1 MeV. The deep space probe results of Trombka[12] et *al.* (1973) in Apollo 15 (Figure 2b), using NaI(Tl) detector of 7.5×7.5 cm dimension with charge particle rejection system, show lower background values differing byfactors -1.5 to 2.0. Substantial part of this difference can be attributed to the charged particle reactions in our telescope and the larger size of our detector having relatively greater sensitivity. The observationsof Peterson[6] et *al.* (1973) at Palestine (Texas), with a detector of 7.5×7.5 cm incorporating particle rejection system, yield higher background rates at geomagnetic latitude = 40°N compared to our equatorial observations by factors $\geqslant$ 3. Thus we see that the observed y-ray background is essentially minimum at the equatorial latitudes and can be exploited with advantage for y-ray astronomical studies.

The excess of photons around 0.5 MeV in the spectrum can be attributed to positron annihilation line with some neutron contribution $\lesssim$ 5 percent due to induced reactions in the detector. The line intensity expressed in photons cm^{-2}s^{-1}, has been calculated by dividing the count rate by the geometrical factor and the photo peak efficiency of the 10x10 cm crystal at 0.51 MeV which is -0.7. We obtain values equal to 0.085 ± 0.008 and 0.064 ± 0.006 photons cm^{-2} s^{-1} for SOURCE II and SOURCE III flights respectively, for this line intensity at 6 g cm^{-2} atmospheric depth. This normalization at 6 g cm^{-2} is chosen to facilitate comparison with the compilation of Kasturirangan[S] et *al.* (1972) to discern the details of the latitude effect for the y-ray line. In Figure 4 we show the observed intensity of this line plotted as a function of geomagnetic latitude and all correspond to 6 g cm^{-2} depth of float altitude. It is seen from the figure that there is a great variation of this line intensity by a factor -10 in going down from geomagnetic latitudes of 55^{o} to 3^{o} corresponding to cosmic ray rigidity cut offs of 1.3 to 17.0 GeV respectively. This variation is due to the latitudinal variation in primary cosmic ray intensity and cut off energy and pion multiplicity in the atmosphere.

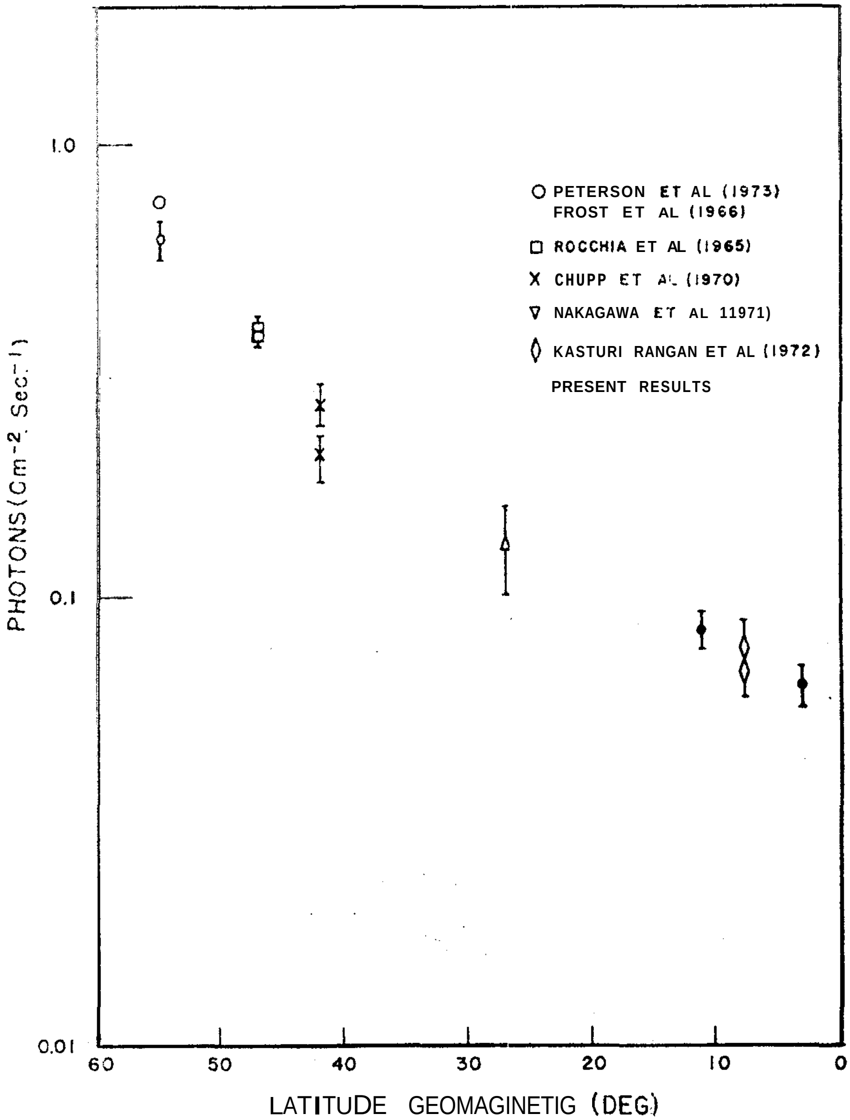

Fig.4 - Latitudinal variation of the observed 0.51 MeV line intensity at 6 g cm^{-2} atmospheric height.

The authors are grateful to Dr. Nelson de Jesus Parada Director of the INPE for his continued support and interest. We thank the National Scientific Balloon Facility, USA, for the launch and flight data recording of flight conducted at Juazeiro do Norte. The financial grant by FINEP CT-537 is acknowledged.

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