THE LOW ENERGY GAMMA-RAY SPECTRUM IN SPACE

BY K. C. ANAND, GEORGE JOSEPH AND P. J. LAVAKARE
(*Tata Institute of Fundamental Research, Bombay-5, India*)

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ABSTRACT

Balloon, satellite and other deep space probe observations on the intensity of low energy (0·1–10 MeV) gamma-rays are carefully examined with a view to understand the existing anomalies in their intensities and energy spectra. The observed spectral data is "unfolded" to deduce the true gamma-ray energy spectrum. The recently observed flattening in the spectral shape at about 1 MeV is shown to be likely to arise as a result of the gamma-ray detector response to a simple power law input spectrum.

1. INTRODUCTION

OBSERVATIONS on the intensity of soft gamma-rays in deep interplanetary space were first made by Metzger *et al.* (1964) in the energy region of 0·1–1·0 MeV using a 4π detector carried in Ranger III; from the relatively small decrease in the counting rate obtained when the boom carrying the detector was extended from the retracted position, these authors deduced that the radiation detected by them was of cosmic origin. Since then many interpretative papers have been written using this data assuming that the counting rate recorded by Metzger *et al.* (1964) is equal to the photon flux.

During more recent years, further measurements have been made in the 0·1–10MeV region with satellite and balloon-borne instruments (Peterson and Schwartz, 1968; Peterson *et al.*, 1966; Chupp *et al.*, 1969; Vette *et al.*, 1969) leading to results which are difficult to compromise with one another. Such results are in turn being employed to deduce further information of great astrophysical and cosmological importance. It is the purpose of this paper to examine critically the existing data and point out certain instrumental effects which are likely to have considerable bearing in their understanding and interpretation.

2. Status of the Existing Data

Available data of relevance in the energy range of 0·1–10 MeV have been summarised in Fig. 1. A careful and critical scrutiny of this figure is revealing in that it brings out a number of apparent anomalies between the different observations, which have been overlooked or ignored in the past. Let us examine these in some detail here.

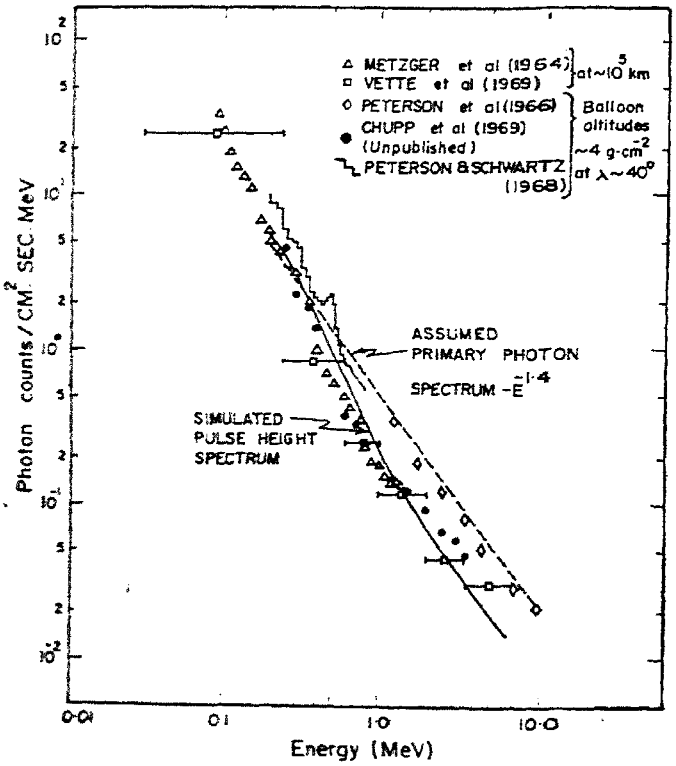

FIG. 1. Low energy gamma-ray data showing balloon, satellite and deep space probe measurements in the energy region 0·1 to 10 MeV. The continuous curve shows the normalized energy loss spectrum to be expected from a $E^{-1\cdot4}$ type primary gamma-ray differential energy spectrum incident on a 1·75″ × 2″ NaI (Tl) crystal by considering the appropriate crystal response functions. The point at 0·51 MeV in the data of Chupp *et al.* is not shown.

(*a*) *Photon counts and photon flux.*—Most of the measurements in the energy interval 0·1–10 MeV have been made by using omnidirectional gamma ray spectrometers consisting of an inorganic crystal (CsI or NaI) surrounded by a charged particle anticoincidence shield. The sizes of the crystals used vary generally from 2″ dia. × 2″ length to 3″ × 3″ and the counting rates are normalized for the variations of the sizes of the crystals by using an isotropic geometric factor G_0 which depends on the diameter d, and length l by the relation

$$G_0 = \frac{\pi dl}{4}\left(1 + \frac{d}{2l}\right).$$

What is measured in all these experiments is the counting rate due to the total energy loss E′ produced in the crystal by a photon of energy $\geqslant$ E′ and the observed data is always presented as 'photon counts'. However, in the interpretative investigations it is always assumed that such a photon counting rate is the same as the absolute photon flux for the same energy. While such an assumption may have reasonable justification at energies $\lesssim$ 0·1 MeV, in the energy region 1–10 MeV this may be an underestimate of the true photon flux by a factor of about 2 to 3. A proper unfolding of the observed energy loss spectrum to the true energy spectrum of photons in the entire energy region 0·1–10 MeV is not thoroughly studied.

(*b*) *The photon count rates from different experiments.*—There are two intriguing aspects with regard to the counting rates obtained from different experiments: (i) At energies of 100–200 keV the "cosmic" photon count rates obtained from balloon experiments (Bleeker *et al.*, 1968; Kasturi Rangan *et al.*, 1969), by extrapolating the observed data to the top of the atmosphere, lead to values which are even lower than those obtained from deep space probes; (ii) At energies $\gtrsim$ 1 MeV the photon count rates obtained under 3 to 4 g. cm.$^{-2}$ of residual air are comparable (within a factor of 2) with those obtained for "cosmic" gamma-rays from deep space probes. In spite of this, balloon observations at energies $\gtrsim$ 0·5 MeV do not reveal the characteristic upturn in the growth curve of cosmic components near the top of the atmosphere suggesting thereby that the bulk of the counting rate at 3 to 4 g. cm.$^{-2}$ is due to atmospheric gamma-rays. One also notices that the balloon observations show an enhancement in the count rate at 0·51 MeV indicating the presence of the positron annihilation line while those of Metzger *et al.* (1964) do not show any such trend.

(*c*) *The flattening of the photon count spectrum at about* 1 *MeV.*—There is evidence from satellite observations (Vette *et al.*, 1969) that there exists a flattening of the spectrum at about 1 MeV. The unpublished balloon observations made while one of us (PJL) was at the University of New Hampshire also show the same kind of flattening of the spectrum at $\sim$ 1 MeV (Chupp *et al.*, 1969). There is already an attempt to interpret the satellite observations as due to cosmological effects operating on gamma-rays resulting from the decay of neutral pions produced in the distant past (Stecker, 1969). If the two observations represent two different types of gamma-rays, namely, cosmic and atmospheric, it has to be considered a coincidence that both spectra show the same shape.

It is thus quite obvious that there exist a number of apparent inconsistencies in the observational data which have to be resolved before acceptable interpretations of importance can be advanced. In the next section we will attempt to unfold the observed photon counts and show that this leads to some important consequences.

3. The Energy Loss Spectrum and the True Energy Spectrum

It is expected that gamma-rays in the few MeV region would interact mainly through the compton effect and would hence have an energy loss, E', in the crystal which is less than the true energy E of the incident photon. Thus it becomes necessary to know the response function of the individual detector system before unfolding the true gamma-ray spectrum. In order to evaluate the effect of this process we used the energy response functions calculated by Berger and Dogett (1956) for six discrete gamma-ray energies in a NaI (Tl) crystal of 1·75" dia. × 2" length. We then used the known cross-sections for the different electromagnetic processes of relevance here and extended these calculations to generate a set of response functions for the entire gamma-ray energy region of 0·2–10 MeV. Thereafter, assuming a differential gamma-ray spectrum of the type E^{-n}, the expected pulse height distributions in the above crystal were calculated for various values of n ranging from 1 to 2·2. It is then found that the calculated pulse height spectrum (being represented as photon counts spectrum) can no longer be represented by a single slope but has a flattening trend near about 1 MeV. The results for $n = 1 \cdot 4$ normalised to the observations of Metzger *et al.* (1964) at about 200 keV are shown in Fig. 1. It is thus seen that the experimental observations on the pulse height distributions can be reasonably well understood in terms of the detector response characteristics for a $E^{-1 \cdot 4}$ type of input gamma-ray spectrum and it is not necessary to invoke any "cosmic" mechanism. The fit to the experimental data is rather sensitive to the exponent n and the best fit can be obtained for a value $n = 1 \cdot 4 \pm 0 \cdot 1$. It should be remembered that we have used the response functions for a 1·75" × 2" NaI crystal when the gamma-ray beam is incident along the axis of the crystal. Small differences are expected to be present for slightly larger crystals and an isotropic gamma-ray flux but the basic effect of flattening of the energy loss spectrum is expected to persist.

An attempt has been made by Forrest (1969) to unfold the observed energy loss spectrum in the region 1–10 MeV for a 3" × 3"NaI crystal. The change in the spectral shape in the observed energy loss spectrum which is only important below ~ 1 MeV will be therefore not evident from the work of Forrest (1969).

4. Summary

It thus appears that the gamma-ray observations made so far have to be interpreted rather carefully as regards information about the flux and energy spectra. The problems of local production and the study of response functions of the detector systems to be used in future should be carefully studied in the region 0·1–10·0 MeV. Since the measurements of cosmic gamma radiation in this energy region are of considerable interest, it is hoped that such work will be undertaken in future.

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