23. DIFFUSE BACKGROUND OF ENERGETIC X-RAYS*

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Abstract. The experimental situation in regard to the extra-galactic diffuse background of photons of energy above 30 keV is critically reviewed in the light of discussions at this Symposium.

There seems to be some doubt about the spectral break at 40 keV. There is an indication of a small bump around 2 MeV and of a shoulder around 20 MeV. The spectrum below 1 MeV (down to 30 keV) can perhaps be represented as 25 $(E/1\ \mathrm{keV})^{-2.1}$. This spectrum also gives, roughly, the OSO III upper limit at 100 MeV, though it lies well below the two bumps mentioned above. A good deal of the discussion centres on the problem of backgrounds in different types of experiments to measure the diffuse X- and γ-ray fluxes.

The subject of diffuse flux of energetic photons has had a unique distinction; it has been showered with a great deal of attention by theorists, who have valiantly, and often successfully, laboured to explain several of its features which have later turned out to be experimentally questionable. Therefore, there was a strong reaction this time and instead of trying to explain the diffuse background, the panel discussion in this area was organised to clarify what is and what is not.

All the papers submitted for this session are greatly concerned with the question of instrumental and environmental background. I shall not discuss the papers individually or in alphabetical order, but will try to fit them into a single theme. The body of this paper was prepared before the symposium, but substantial additions and corrections have been introduced later.

We will be concerned in this review mainly with the results above $\sim$20 keV. The spectrum at lower energies will be referred to only in passing. Also we will mainly talk about the possible cosmic flux, though the cosmic nature may not be so well established for some of the measurements.

1. Features of the Canonical Spectrum of Two Years Ago

The way cosmic photon spectrum looked a couple of years ago is shown in Figure 1. It appeared one had fairly definitive values of flux up to $\sim$5 MeV. The important features of the spectrum were widely believed to be:

(a) The possibility of a break in the spectrum around 40 keV.

(b) The possibility of flattening of the spectrum beyond 1 MeV.

(c) The suggestion of a definite flux beyond 100 MeV.

The work during the last year or so, and some of the papers submitted to this Symposium have cast serious doubts on the first two of these features, and added substantially new information in the energy region 1 MeV to 50 MeV.

* Dr Pal arranged and led the panel discussion on this topic. The other panel members were: D. Brini, L. Peterson, K. Pinkau, J. Trombka, and P. Lavakare.

Bradt and Giacconi (eds.), X- and Gamma-Ray Astronomy, 279–302.

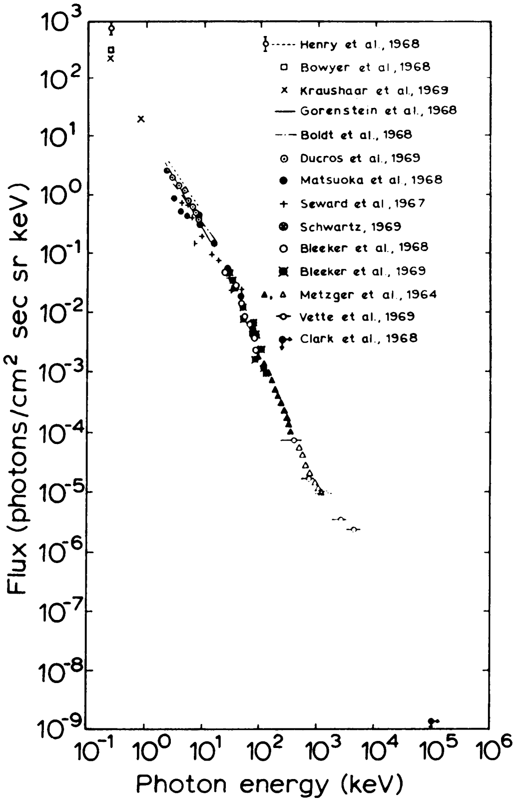

Fig. 1. Summary of X- and γ-ray diffuse spectrum as of 1970 (Brecher and Burbidge, 1970).

2. Work at Energies below 1 MeV

Measurements in the energy range 20 keV to a few MeV are made with alkali halide crystals, aboard balloons, rockets or spacecraft. Most communications to this conference, as well as the papers published during the last year or so, have been largely concerned with the problems of backgrounds encountered in these measurements.

Following the work of Horstman and Horstman-Morretti (1971) and Makino (1970), several balloon people started taking into account the effect of multiple Compton scattering in the attenuation of the primary X-ray flux. It was pointed out (Manchanda *et al.*, 1971; Kasturirangan and Rao, 1972), that this effect is energy dependent, resulting in an apparent enhancement at lower energies, i.e. $\sim$40 keV, where Compton scattering is more important. Thus Manchanda *et al.* (1971) corrected all the balloon experiments for which the data were available, and suggested that, as earlier indicated by Bleeker and Deerenberg (1970), the balloon X-ray data did not require a spectral break around 40 keV. Kasturirangan and Rao (1972), using a similar reduction of data went to the extent of saying that a single power law exponent may fit all data from 1 keV to 1 MeV. Perhaps, in saying this they do some violence to the rocket data below 10 keV.

In a more recent paper, submitted to this symposium, Manchanda *et al.* (1972) have been even more impressed with the problem of the environmental background at balloon altitudes. The background in these experiments is usually taken out by a straight line extrapolation of the counting rate at depths greater than 10 g cm^{-2}, plotted on a log-log scale. These authors present strong empirical arguments to show that the growth curve may not be linear on a log-log plot but may in fact become flat, even rise, at low depths. This seems to be demanded by the requirement that the attenuation of the deduced primary flux exhibit the same behaviour as the difference between the measured growth curve and the extrapolated background growth curve. This is demonstrated in Figures 2 and 3. The consistent behaviour of the growth curve is indicated by the solid curves at small depths. If this is correct, as is likely in

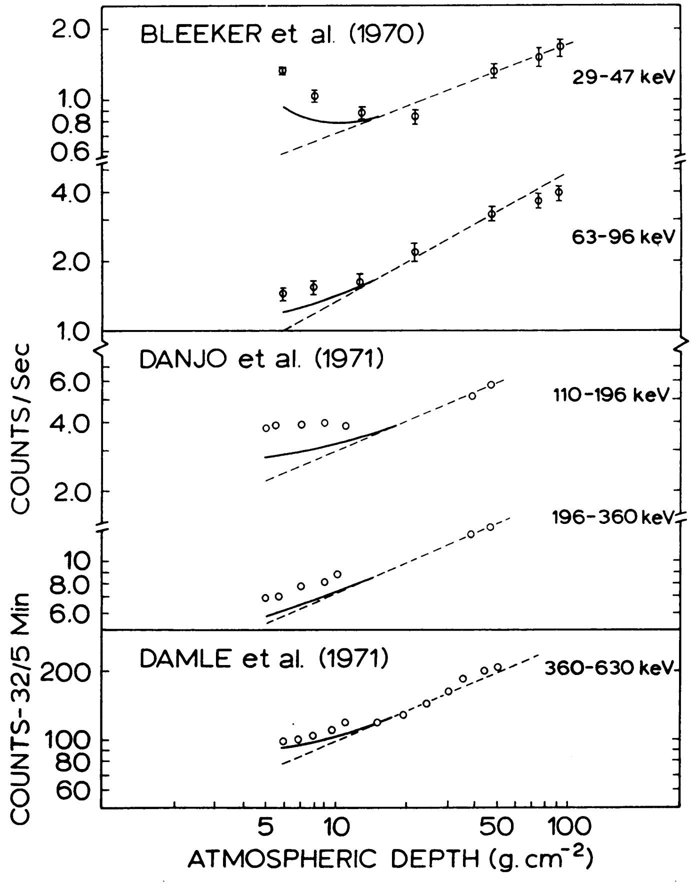

Fig. 2. Growth curves in three balloon experiments to measure primary cosmic photons. The dashed line is the best fit to data points at depths larger than 20 g cm^{-2}. The solid line illustrates the shape of the atmospheric background counting rate required to reproduce the absorption of the primary cosmic X-rays (Manchanda *et al.*, 1972).

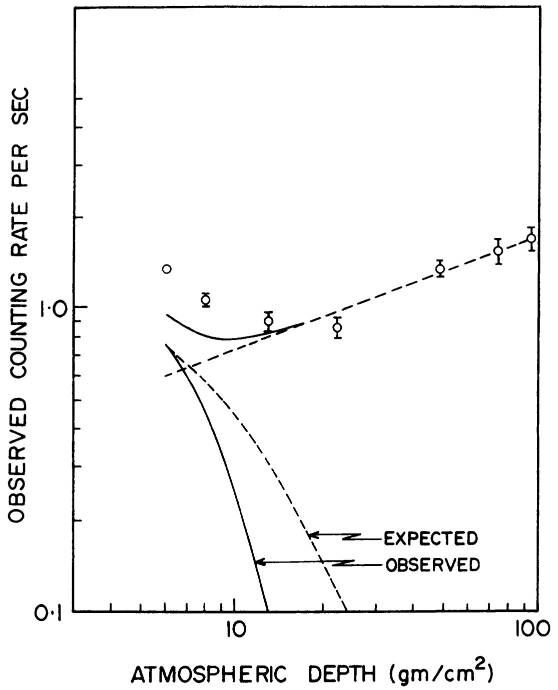

Fig. 3. Counting rate vs atmospheric depth in the energy channel 29–47 keV in the experiment of Bleeker *et al.* (1970). The dashed line gives the best fit to the data points at large depths. Assuming this to be true representation of the atmospheric background the solid line marked 'observed' gives the attenuation of cosmic X-rays. The dashed line marked 'expected' gives the calculated attenuation of this component. The discrepancy between the two suggests that the power law extrapolation of the atmospheric background to lower depths is incorrect. The solid line extrapolation would yield a correct attenuation for the diffuse component. Its shape and position, however, is not uniquely determined (Manchanda *et al.*, 1972).

view of some calculations by Danjo (1972) to be discussed presently, the fluxes seen in all balloon measurements would be upper limits to the true fluxes. We believe this effect will again be more significant for lower energies where the atmospheric build up effects are likely to be greater, thus further reducing the relative values of flux around 40 keV.

Horstman *et al.* (1972) have recommunicated the results of the earlier rocket experiment (Horstman-Moretti *et al.*, 1971) which have been slightly modified by new corrections. Their new slope in the range 25–200 keV is now 2.0 instead of $\sim$1.95 which they had previously published. They argue that the diffuse X-rays entering the open aperture of a collimated detector and falling on the inner wall of the collimator can, if photoelectrically absorbed, produce characteristic KX-rays which can contribute to the counting rate of the main detector. They think this can also happen when the collimating shield is active; K absorption probability is largest for incident photons just above the K absorption edge and when the X-ray escapes, the energy left in the shield is too small to veto the count. Thus OSO III measurements, among others, are also subject to this correction. The significant correction due to this effect will be only in their 22–38 keV channel.

There has been comment on the OSO III X-ray measurements from more than one quarter. I suppose people have worried about this observation because this is perhaps the only one which extends a comfortable distance away on either side of the supposed 40 keV break and does indeed show such a break. It is suggested (Dyer and Morfill, 1971) that the corrections due to induced radio activity produced during passage of the spacecraft through the South Atlantic Anomaly may have been inadequate; through experimental and theoretical investigations of spallation effects Dyer and Morfill (1971) and Dyer *et al.* (1972) conclude that a spurious feature at 40 keV would be seen by alkali halide crystals exposed to the particles levels obtaining at the South Atlantic Anomaly or in the interplanetary space.

Dyer and Morfill (1971) have studied the energy spectra observed, in a Cs I crystal, due to the decay of radioactive isotopes produced by bombardment with 155 MeV protons, as a function of time after irradiation. They find that these spectra are in quantitative agreement with the predictions of the semi-empirical formula of Rudstam (1966). Then using the Rudstam formula they calculate the production of various radio-nuclides, and the consequent activity of the crystal, due to exposure to the inner belt protons in the South Atlantic Anomaly, and due to the ambient flux of cosmic-rays at different latitudes. In Figures 4 and 5 are presented the results of their calculation. It is assumed that the passage through the radiation belt corresponds to a 10 min exposure. Also shown in Figure 4 is the expected counting rate from the diffuse X-ray background taking, presumably, an E^{-2} extrapolated spectrum beyond 1 MeV. The authors point out that the main features of their results, namely the marked peaks at 40 keV and 200 keV and the flat spectrum above 1 MeV are all to be found in the observed 'cosmic' spectrum of photons. Further it is seen that the cosmic-ray produced background in the interplanetary space exceeds the diffuse X-ray flux (extrapolated as E^{-2}) at energies greater than 1 MeV. They claim that essentially similar results will apply for Na I crystals. Similar discussion has been made by Fishman (1972).

From this it would seem that the energy range of a few MeV is best studied from low altitude equatorial satellites or balloon platforms near the geomagnetic equator. More about backgrounds in this energy range will be discussed later.

In his analysis of OSO III data, Schwartz (1969) considered mainly the 15 hr half-life Na_{24} activity and determined the corrections from this activity by fitting the decay rates after leaving the South Atlantic Anomaly to a 15 hr half-life. Dyer *et al.* (1972) point out the importance of the background due to a build-up in the activity of long half-life isotopes; according to them such an increased level of counting rate would not be noticed in the Schwartz analysis and will simulate a fictitious flux of diffuse radiation.

In his remarks at the symposium Dr Peterson mentioned that they recognise through their own measurements in OSO 7 that KX-rays from the collimator would contribute a spurious counting rate to the 22–38 keV channel of the OSO III detector

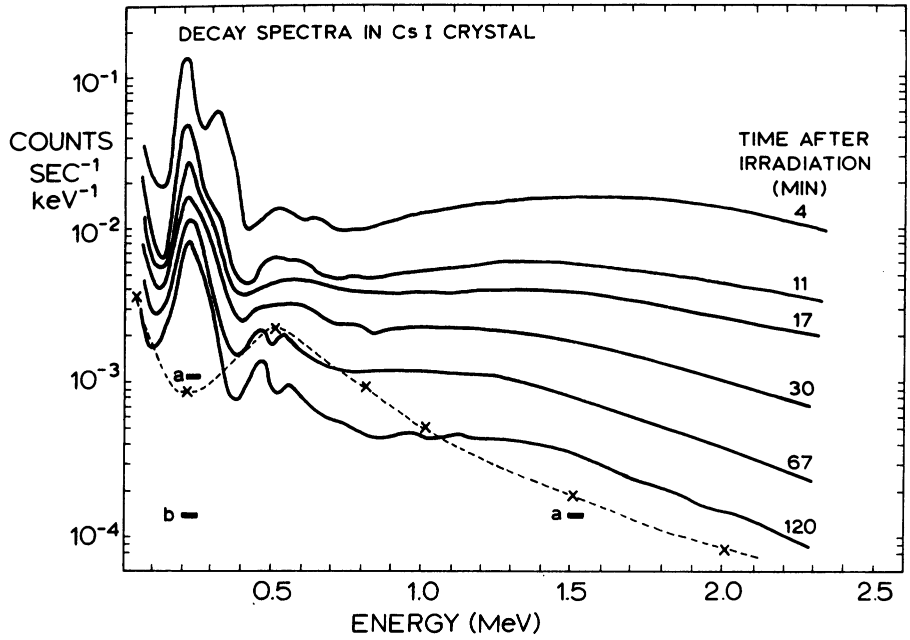

Fig. 4. Predicted spectra (shown solid) for worst case of inner belt traversal, obtained by scaling experimentally observed spectra to 3×10^5 interactions, presented for times up to 2 hr after irradiation. The dotted curve gives the estimated background due to diffuse cosmic X-ray flux (both entry through aperture and leakage through the collimater). '*a*' gives the expected level of background due to cosmic-ray damage for a 2 GV cut-off, and '*b*' the same for a 14.9 GV cut-off (Dyer and Morfill, 1971).

and "will have to be corrected out." They also see a feature at 60 keV, which is not yet understood, and another feature at about 150 keV which comes and goes as the satellite proceeds through the trapped radiation. The latter feature has a time constant of about 10 days and may be associated with a meta-stable state of I_{128} which becomes activated and decays with roughly a 10 day half life.*

To summarise then, there seems to be growing evidence that the old values of the flux around 40 keV were over-estimated, and that there may not be any break in the spectrum around this energy. Since the proportional counter measurements at lower energies give flatter spectra with a particle spectrum slope of about 1.5–1.7, a change in slope, perhaps gradual, would still be needed at around 20 keV. Some of the

* Commenting on various remarks made by different speakers, Dr Peterson said: "I rather agree with the remarks which have been made by various people which summarise the various kinds of corrections and uncertainties that have crept into these analyses... I have not had the benefit of carefully communicating with Dan Schwartz and we have not reanalyzed the OSO III data in any sense in the light of what we know of the various background effects at this time.... The conclusion I want to make on this is, I think, that there are some corrections necessary for the OSO III. I personally do not see how one can completely end up with a spectrum which has at least no bends in it. It seems to me that at rocket energy, 1–10 keV, (the spectrum) does in fact have a flatter slope. Perhaps the break has been moved down to 20 keV from 40 keV".

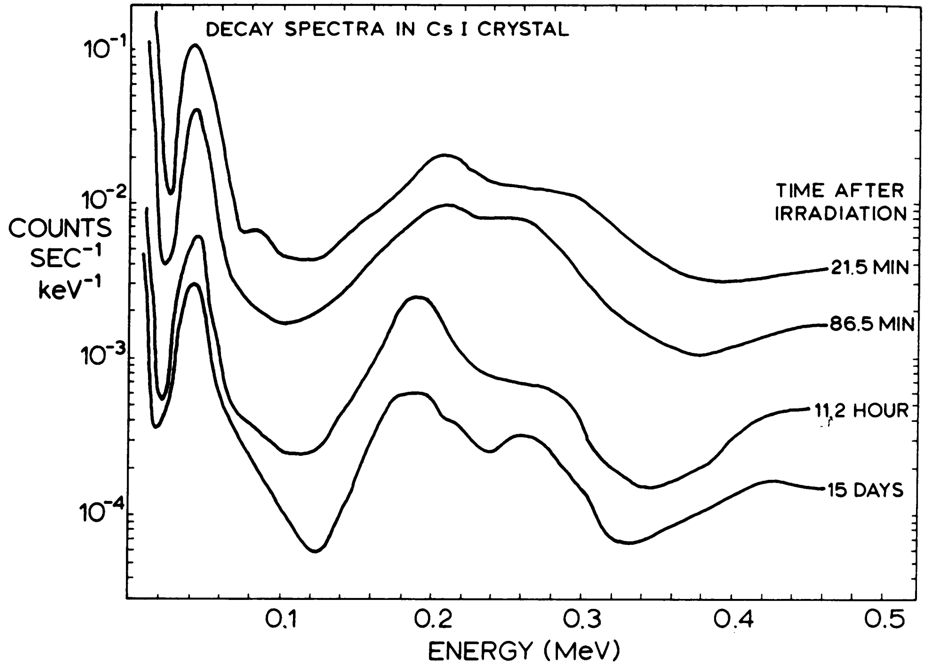

Fig. 5. Predicted spectra due to inner belt spallation for the low energy X-ray region (Dyer and Morfill, 1971).

authors would like to go right down to 1 keV without any change of slope, but I feel that the integrity of rocket experiments in the 1–10 keV regime should be respected.

The theoretical implications of this may be briefly summarised. Following the work of Brecher and Morrison (1969) it was generally believed that the spectral break around 40 keV reflected the break in the intrinsic spectra of electrons leaking out from discrete sources and interacting with the microwave background radiation to produce X-rays. It had already been pointed out (Cowsik and Pal, 1971) that the break in the X-ray spectrum, if real, could not really be explained in terms of this theory, but was put in as an assumption. Later Cowsik and Kobetich (1971) have made a more detailed calculation of the universal inverse Compton for producing X-rays. They show that when the energy and angular distribution of the microwave photons are taken into account, no such break occurs in the X-ray spectrum. Nor do they find any significant flattening of the calculated spectrum at high energies as was found by Brecher and Morrison. They then proceed to take the difference between the observed (à la 1970) spectrum of X-rays and their calculated spectrum and suggest that this difference in spectrum has a thermal distribution and could have been produced by a hot (3.3×10^8 K) intergalactic gas with a density of 3×10^{-6} H atom cm^{-3}. It is clear that a serious reduction in the 40 keV intensity would significantly alter this conclusion; the enhancement in the spectrum may shift to lower energies, and is can probably be accounted for in terms of contributions from discrete sources, at suggested by the UHURU results on various extra-galactic X-ray sources, including galactic clusters.

3. More on Backgrounds and Flux in 1 MeV Range

Several contributions to this Symposium discuss the problem of environmental background in experiments close to the top of the atmosphere. Let us first discuss the experiments of Vedrenne *et al.* (1972). These authors have studied the growth curve of low energy gamma-rays, using a shielded stilbene crystal in three balloon flights at latitudes 62° N, 46° N and 10° N. These growth curves are given in Figure 6. It is seen that at the higher latitudes the curves are fitted well by a p^{α} law (where p is the atmospheric depth), but at equitorial latitude the curve shows an upturn at low values of p. They treat this as evidence for the existence of a cosmic flux. It is also clear that the background reduces by a large factor when working at low latitudes. The authors also measure the neutron component as a reference, and use it to extrapolate the growth curve at the low latitude. Using the growth curves for different energy bins they obtain a cosmic gamma-ray spectrum from 0.7 and 4.5 MeV which is quite consistent with the measurements of Vette *et al.* (1970). These authors specifically disagree with the measurements of Golenetskii *et al.* (1971), who did not find any evidence for flattening of the spectrum beyond 1 MeV.

Golenetskii's experiment was a Cosmos satellite experiment with a shielded Na I crystal. They tried to analyse the data before entry into the South Atlantic Anomaly, and made use of the latitude effect in the background. They managed to put an upper limit to the cosmic contribution by demanding that the total gamma-ray

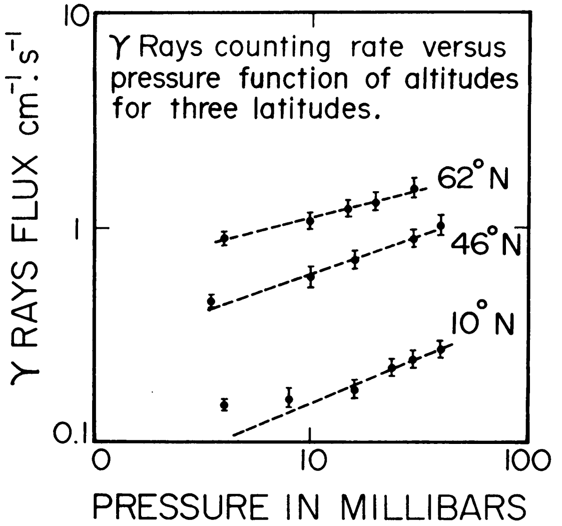

Fig. 6. γ-ray (0.7 to 4.5 MeV) growth curves at three latitudes measured with a $1'' \times 1''$ stilbene crystal surrounded by a plastic anticoincidence jacket (Vedrenne *et al.*, 1972).

atmospheric background vary with latitude in the same manner as the 0.511 MeV positron annihilation line (see Figure 7). In this way they obtain only upper limits which, however, lie on a $E^{-2.3}$ extrapolation of the X-ray spectrum and do not exhibit any flattening. Their energy range was 0.3–3.7 MeV. The results are shown in Figure 8.

We have a comment about the use of neutrons and 0.511 MeV gamma-rays as references for the atmospheric background. When these signals are used in studying growth curves, they may not be physically representative of the growth of the photon component. If one is measuring neutrons above a threshold, say 1 MeV as in the experiment of Vedrenne *et al.* (1972), one will miss those neutrons which are produced at around 1 MeV (as the bulk of the neutrons in the atmosphere are) and propagate and degrade in energy due to scattering. On the other hand gamma-rays propagate through Compton scattering and will merely shift into another energy bin. Similarly 0.511 MeV gamma-rays are removed from the line as soon as they suffer a single Compton scattering, while the background atmospheric photons are not. The importance of propagation characteristics of atmospheric photons to the shape of their growth curve will be discussed shortly in connection with the contribution of Danjo (1972) to this Symposium.

Next we come to the contributions from Damle *et al.* (1971) and Daniel *et al.*

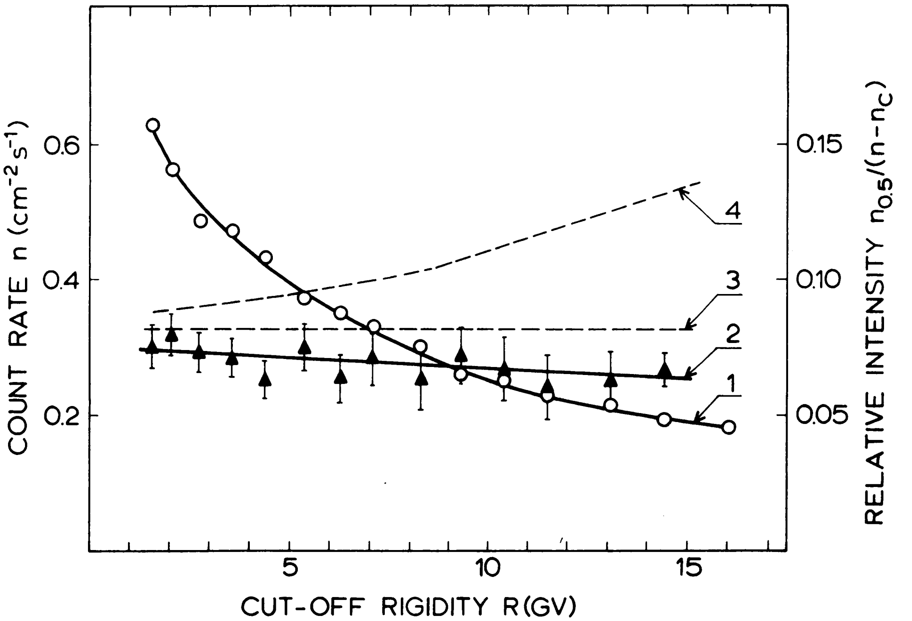

Fig. 7. γ-ray count rate in the energy range 0.4–2.5 MeV vs cut-off rigidity of primary cosmic rays (1); observed relative intensity of 0.511 MeV line (2): (3) and (4) represent the relative intensity dependence on rigidity for two different evaluations of diffuse cosmic γ-ray contribution to the total count rate. Obviously the evaluation (3) is preferred, which gives the upper limits on the diffuse flux given in the next figure (Golenetskii *et al.*, 1971).

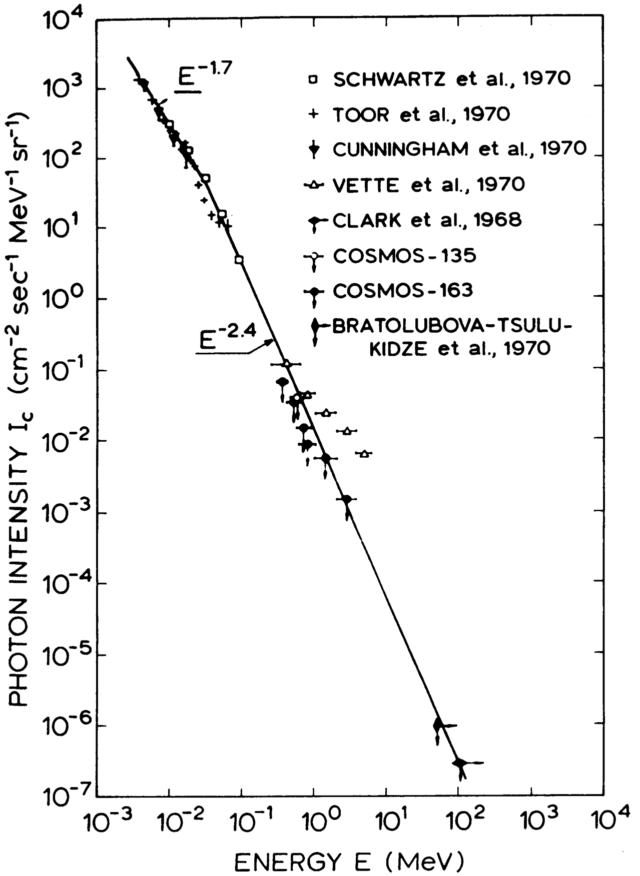

Fig. 8. Some experimental data on the cosmic X-ray and γ-ray fluxes along with the points of Golenetskii *et al.* (from Golenetskii *et al.*, 1971).

(1972). These experiments were performed with shielded Na I crystals using balloon flights at a low geomagnetic latitude (8° N). Some growth curves, measured by Damle *et al.* are given in Figure 9. These authors extrapolated the growth curves as shown and deduced a cosmic spectrum in the energy range 0.25–4.2 MeV, which was flat like that of Vette *et al.* (1970), only slightly lower. Their results were, in fact, very similar to those of Vedrenne *et al.* (1972). Daniel *et al.* (1972) have essentially repeated the experiment, except in this case they used a much thinner anti-coincidence shield. Their measured gamma-ray spectrum at 4.7 g cm^{-2} in the energy range 0.2 to ~10 MeV is shown in Figure 10. From this figure it is clear that even without correcting for the atmospheric background, their count rate is lower than the cosmic flux supposed to have been measured by Vette *et al.* (1970)! Further a comparison of their count rate with that of Peterson *et al.* (1970) (also shown in this figure), obtained with essentially a similar detector but at a latitude of 40° N, shows a large (a factor of 3) latitude effect and hence the presence of a large atmospheric background

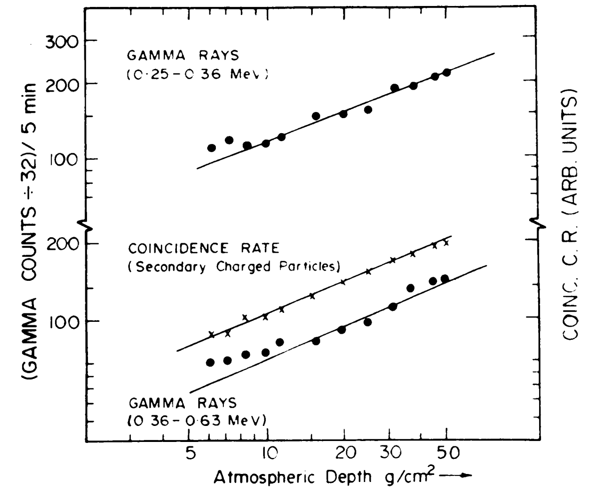

Fig. 9. Growth curves and extrapolations for atmospheric background used by Damle *et al.* (1971) for two different energies.

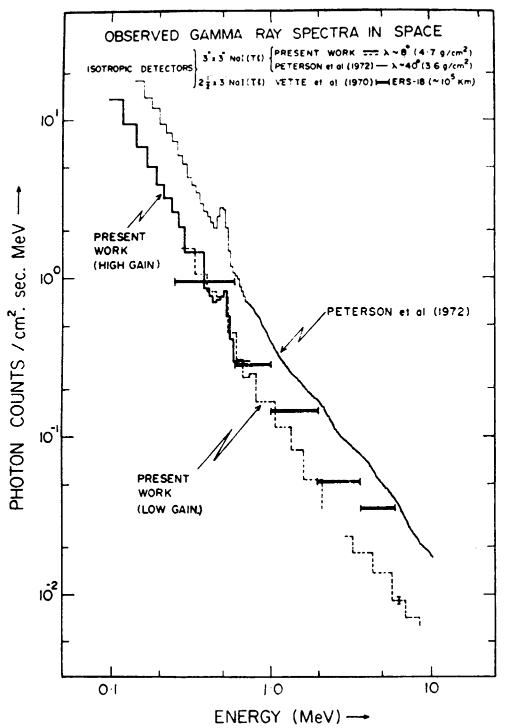

Fig. 10. Comparison of the photon energy loss spectra measured with isotropic detectors, at ceiling in two balloon experiments and in ERS-18 satellite (Daniel *et al.*, 1972).

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in both experiments. Correcting for the atmospheric background using a power law extrapolation of their growth curves, Daniel *et al.* obtain a cosmic spectrum which is shown in Figure 11 along with other experimental points. It is clear that now they do not subscribe to the flattening around 1 MeV and are consistent with the upper

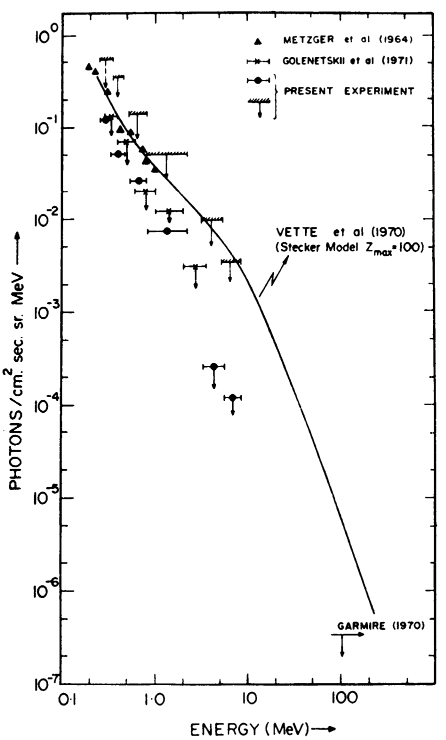

Fig. 11. The diffuse cosmic photon flux in the energy range 0.2 MeV to 8.5 MeV. The count rates of Metzger *et al.* measured in a deep space probe have been unfolded for detector response. Golenetskii *et al.* (1971) points are also given for comparison. The hatched upper limits are obtained by Daniel *et al.* (1972), if all the counting rate at float altitude is attributed to the cosmic component (Daniel *et al.*, 1971).

limits of Golenetskii *et al.* (1971). The difference between the result of Damle *et al.* (1971) and Daniel *et al.* (1972) is an important lesson. These two detectors differ only in the extent that Damle *et al.* had tried to make a better anti-coincidence shield by making it thicker and ended up having a lot more background. Obviously the lower result, namely that of Daniel *et al.* (1972), is to be preferred.

4. Danjo's Calculations

In a paper submitted to the Symposium, Danjo (1972) has attempted to calculate theoretically the expected shapes for the atmospheric growth curves for gamma rays of different energies. His calculation proceeds as follows:

First he calculates the probability $P(E, x; E_0, x_0)$ of a photon of energy $E(<E_0)$ crossing a depth x, when a single photon of energy E_0 is injected isotropically at a depth x_0. Photo-electric effect, Compton effect and pair creation are taken into account. The calculation is done with a Monte Carlo programme where photons are followed in three dimensions till they are degraded to energies below 50 keV or disappear by photo-electric absorption or escape from the top of the atmosphere. Positrons are assumed to annihilate locally and the resulting gamma-rays are followed further. Compton scattering is determined by the Klein-Nishina formula. Computations are carried out for 5000 photons injected at each of the 12 depths between 2 to 100 g cm^{-2} and for each of 13 injected energies between 0.1 and 7.0 MeV.

$P(E, x; E_0, x_0)$ has now to be folded with the source function of photons $S(E_0, x_0)$. Danjo assumes that photons are all generated through bremsstrahlung of electrons. So he needs an electron source function $J(E_{e,x})$. He tries to deduce this function for Hyderabad (16.9 GV cut-off), by calculating the electrons arising from the knock on process and from $\pi \to \mu \to e$ and $\pi^\circ \to 2\gamma \to 4e$ processes. In this he uses the results of Perola and Scarsi (1966) and Beurmann (1971) and makes appropriate corrections for the difference in the primary cut-off rigidity. The total flux of electrons at any depth is obtained by integrating over all angles in the upper hemisphere, assuming that the flux is a function only of the slant depth in the atmosphere. (Note that there might be some approximation here particularly for the flux of electrons from muon decay which may depend on the zenith angle). The source function of X-rays is supposed to be isotropic and is given by

$$S(E_0, x_0)\, dE_0 = dE_0 \int J(E_e, x)\, \sigma(E_e, E_0)\, dE_e,$$

where $\sigma(E_e, E_0)$ is the bremsstrahlung cross-section.

The growth curves for atmospheric X-rays from all directions $I_X(E, x)$ are then given by

$$I_X(E, x) = \int_E^\infty \int_0^\infty S(E_0, x_0)\, P(E, x; E_0, x_0)\, dE_0\, dx_0 .$$

The growth curves for 0.2–0.3 MeV and 0.55–0.75 MeV are shown in Figures 12 and 13. Here the contributions from various depths in the atmosphere are individually shown. It is seen that "the resultant growth curves can be approximated by a power law function for depths greater than 10 g cm^{-2}, grossly reflecting the behaviour of $S(E_0, x_0)$". But for smaller depths the curves flatten due to the build up effect of photons of higher energies generated at higher depths.

Because of these calculations Danjo strongly stresses that flattening of the growth curve at small depths cannot by itself be taken as evidence for the presence of a cosmic component, as has been hitherto assumed. This result has to be viewed in conjunction with the finding of Manchanda *et al.* (1972), at slightly lower energies, that they do need a flattening of the atmospheric background growth curves in order

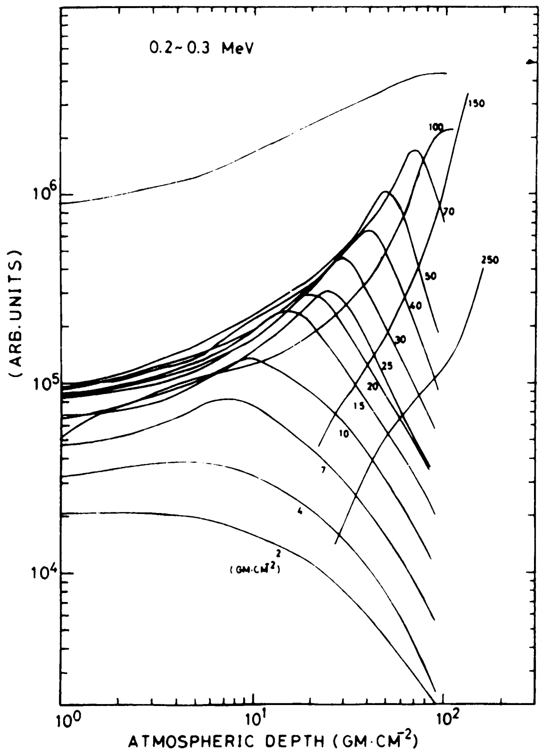

Fig. 12. Calculated growth curves for omni-directional atmospheric photons in the energy range 0.2–0.3 MeV. Curves showing the contributions from various depths are also shown (Danjo, 1972).

that their deduced cosmic component exhibit a proper attenuation behaviour. Though there might be arguments about the details of Danjo's calculation, it seems to us that his main thesis is irrefutable. Danjo concludes that there is so far no definite evidence from a balloon experiment for the existence of cosmic photons of more than 0.2 MeV!

Danjo has also shown that the growth curve of 0.511 positron annihilation gamma-rays would show a steep attenuation with depth, in agreement with observation, because photons on this line are not subject to the build up effect. Furthermore, the downward moving photons are also much less subject to build up than the upward moving photons; the latter are the bulk of photons at small atmospheric depths.

Peterson remarked in this connection, "We have obtained balloon results for many years and we always regarded trying to obtain the spectrum of the diffuse component from balloon results as being a rather dangerous process at best. We feel that the use of a source function such as has been done by Danjo is a much better process than to generate a growth curve with the counting rates. We have generated source functions not based upon a calculation starting from a cosmic ray input but one which is empirically derived from the gamma-ray data itself; this will appear in the literature shortly".

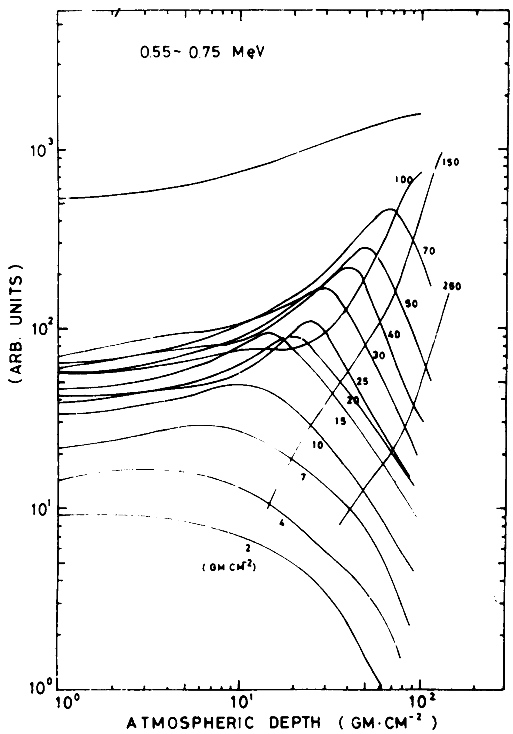

Fig. 13. The same as Figure 12 for the energy range 0.55–0.75 MeV (Danjo, 1972).

5. Positron Annihilation Line at 0.511 MeV

Peterson reported a definite flux of 2×10^{-2} photons cm^{-2} s^{-1} from their Apollo experiments, though he pointed out that the effect of 8 kg of matter in the vicinity of the detector on the extended boom have not been properly evaluated. Lavakare, however puts an upper limit of 3×10^{-2} photons cm^{-2} s^{-1} to such a flux in their balloon measurements from Hyderabad. This has to be viewed in the light that Haymes has reported a flux of 2×10^{-3} photons cm^{-2} s^{-1} at 470 keV from the galactic centre.

6. New Results at Energies Beyond 5 MeV

Several new results have been communicated to this Symposium at energies beyond 5 MeV. Three of these are spark chamber experiments at balloon altitudes, while the fourth is based on an experiment on Apollo 15 and 16. The Apollo experiments also give results in the sub-MeV region.

Share *et al.* (1972) from NRL have made two balloon flights, one over Texas (4.5 GV cut-off) and the other over Argentina (11.9 GV cut-off), in which they observe electron pairs produced in emulsion layers in spark chambers placed below. The threshold energy is quoted as 10 MeV. The growth curves for these events are shown

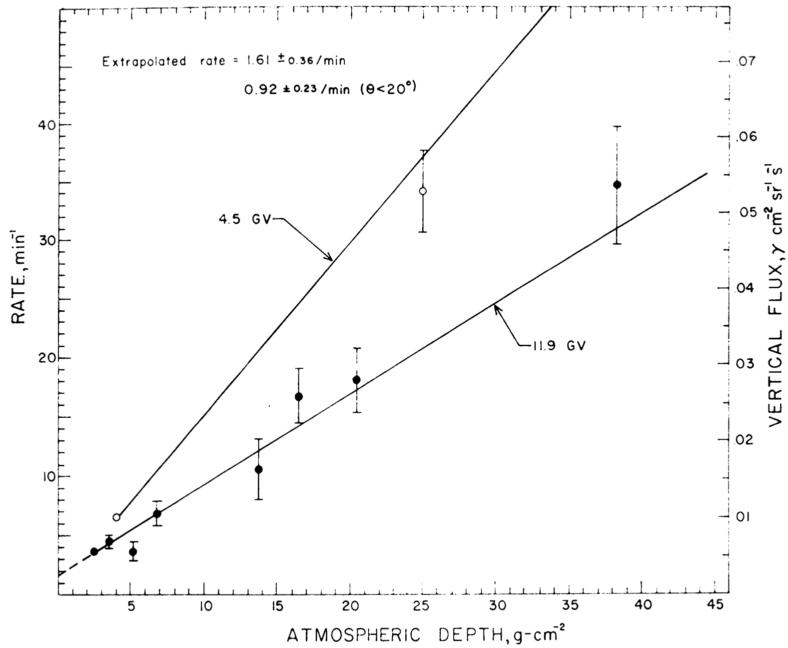

Fig. 14. Growth curves for electron pairs observed in two balloon flights, one over Texas (4.5 GV cut-off) and the other over Argentina (11.9 GV cut-off) by Share *et al.*, 1972).

in Figure 14. The Argentina flight suggests non-zero extrapolated counting rate at the top of the atmosphere. However, when the authors study the azimuthal distribution of the pairs observed at ceiling, they find a strong east-west effect with a (west/east) ratio of 1.42 ± 0.22 for zenith angles greater than 15°. They calculate an expected ratio of 1.40 for charged particles at this location. It is likely that the east-west effect in gamma rays may be caused by particle interactions in the overlaying material of the instrument. The authors suggest, however, that the excess from the West may also be due to the fact that the galactic plane lies in that direction. They quote an upper limit to the integral intensity > 10 MeV as $4 \times 10^{-3}\ \gamma\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}\ \mathrm{sr}^{-1}$. However, they prefer to convert this into a limit of $5.5 \times 10^{-5}\ \gamma\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}\ \mathrm{sr}^{-1}\ \mathrm{MeV}^{-1}$ on the differential flux at 27 MeV, because at this energy the response of their telescope is not very sensitive to the assumed spectral index. This is the limit shown in Figure 21.

Mayer-Hasselwander *et al.* (1972) of the Max Planck Institute have reported the results of two balloon flights in which a gamma-ray astronomy spark chamber was carried to residual pressures of 1.7 g cm^{-2} and 2.2 g cm^{-2} respectively. Figure 15 shows the growth curves for clearly visible electron pairs in these flights. The excess above the power law extrapolation is clearly evident. It is to be noted that the discussion of the build up effect due to Danjo does not apply to this experiment because of their high energy, 30–50 MeV, and also because in this experiment one is dealing with downward moving photons. The authors also study the atmospheric growth curve of the opening angle distribution of the pairs recorded by them and find

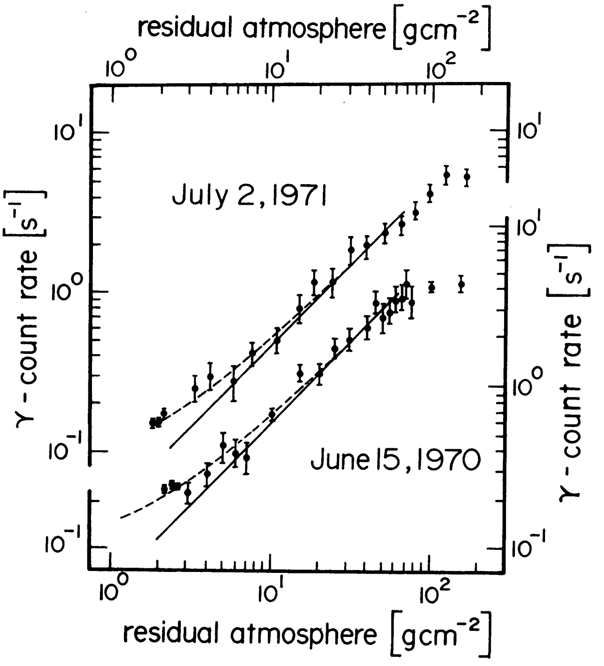

Fig. 15. Growth curve for clearly visible electron pairs in two balloon flights of a γ-ray astronomy spark chamber (Mayer-Hasselwander *et al.*, 1972).

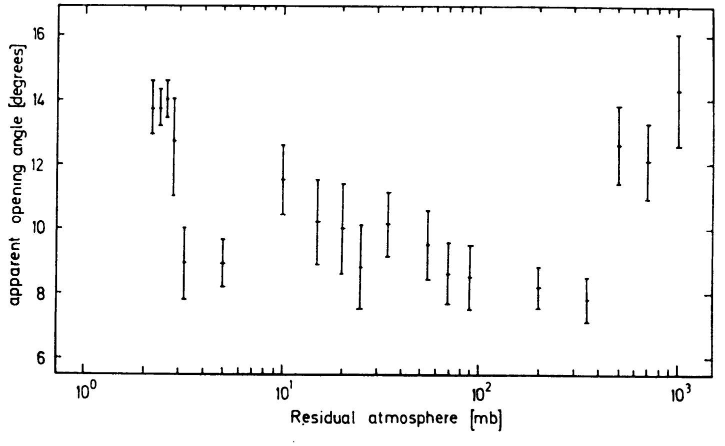

Fig. 16. Apparent opening angle distribution of electron pairs vs atmospheric depth (Mayer-Hasselwander *et al.*, 1972).

(Figure 16) that the spectrum becomes harder (as expected) when one approaches the Pfotzer maximum, but begins to get soft again as one nears the top of the atmosphere. Such an effect has also been noticed by Share *et al.* (1972). This is supposed to show that the observed signal is not of atmospheric origin alone, but is mixed with a soft spectrum of celestial gamma-rays. If some one could find a way of generating a build up of downward moving gamma-rays of this energy range and at this altitude, then this argument would not be a strong support for a celestial contribution, because the build up spectrum would also be soft. However, as mentioned earlier, it is unlikely that such a build-up is possible for these directional detectors at these energies.

Taking into account their response function Mayer-Hasselwander *et al.* find that the flux of celestial gamma rays at 30–50 MeV should be more intense than $0.012 \times E^{-2.3}$ interpolation between the X-ray and OSO III gamma-ray data by a factor of 10. If they take their maximal response function this factor is reduced to 4. Their results are shown in Figure 21.

They do not find any dependence of the gamma ray flux on the galactic latitude, although their observations extend out to $b = 40°$. So their flux is presumably cosmic. The authors emphasise that accelerator calibration of their instrument has not yet been carried out.

Frye discussed the results of their spark chamber experiment to observe gamma-rays. The instrument was switched on only at a height of 3 mb and hence the growth curves could be looked at only over a small range of depth. The ceiling altitude was 1.2 mb. The counting rate was studied for low energy and high energy pairs both on the way up and during the time of slow descent of the balloon. The results are shown in Figure 17. While for the low energy (~ 30 MeV) channel both the growth curves show a non-zero intercept, the high energy (> 100 MeV) curves behave differently on the way up and on the way down. This latter behaviour which is not yet understood, has lead Frye to view his positive flux at low energies with some suspicion. This experience may also be relevant to the other experiments. If however, the positive intercept at low energies is taken seriously, Frye obtains a flux at 30 MeV which is consistent with the result quoted by the Max Planck group.

Finally we come to the results from the flights of Apollo 15 and Apollo 16. Along with the astronauts each of these vehicles also carried a Na I crystal with a plastic anti-coincidence shield. The experiment was conducted by Trombka *et al.* (1973). The preliminary results of this have been published in the Proceedings of Apollo 15 Conference held early this year.

The instrument was located on a boom which could be extended out to a distance of 8 m from the spacecraft, though a mass of about 8 kg was located next to the instrument on the boom. This amount of matter was about the same as for the ERS-18. The energy loss spectra obtained from the instrument were almost exactly the same in Apollo 15 and Apollo 16 experiments and also agreed with the measurements of ERS-18 and Ranger III (Metzger *et al.*, 1964) upto 1 MeV, though above 2 MeV the Apollo points fall considerably below the ERS-18 measurements. The Apollo 15 result (with detector extended) is shown in Figure 18 along with the points from ERS-18 and Ranger III. There is a clear peak at 0.5 MeV, due to positron annihilation, in the Apollo experiment. The general shape of the energy loss spectrum indicates a broad hump around 2 MeV. The procedure for converting this spectrum to a photon spectrum was described at some length by Trombka, (Arnold *et al.*, 1972),

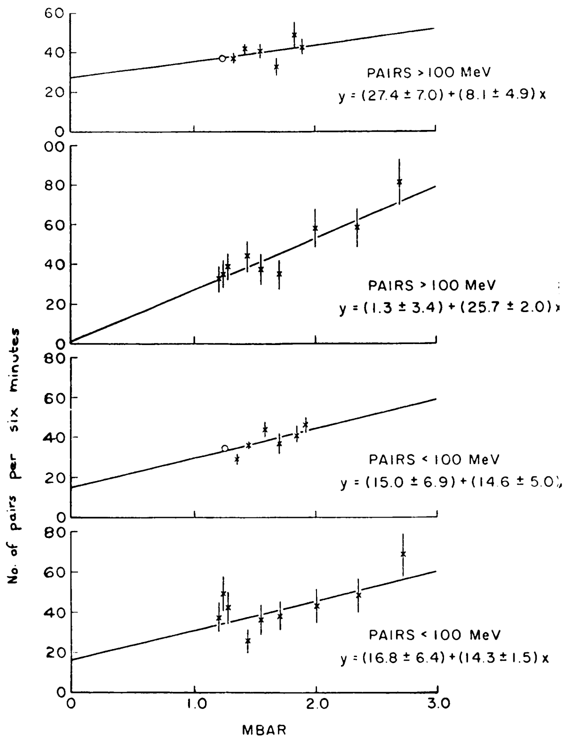

Fig. 17. Growth curves for low energy and high energy pairs reported by Frye (this Symposium). For both energies the curves have been obtained during ascent as well as descent. Though both the low energy curves show a non-zero intercept, the two curves for the high energy (100 MeV) pairs are inconsistent. The equations in the figure give the coordinate representations of the straight line fits drawn.

where he discussed the manner in which the contributions of discrete lines due to spacecraft activity and of spallation products in the crystal to the pulse height spectrum were estimated. Specifically the authors used the exponential form suggested by Fishman (1972) for the pulse height distribution of the spallation products.*

The resulting photon spectrum obtained by these authors is shown in Figure 19. Trombka stressed that the low energy part of this spectrum should not be taken too seriously as the corrections are many and not all complete, but the results above 8 MeV should be good. I tend to more than agree with this; the corrections are just too many and too complex and one cannot be sure that everything conceivable has been taken into account. In particular the spallation contribution is expected to be maximum in the energy region around 2 MeV and a factor of 2 uncertainty in this could wipe out the hump in that place. Also as the authors say, the effect of the 8 kg of matter next to the detector has not been properly evaluated so far.*

* Though the results presented at the Symposium had used Fishman (1972) corrections, the curves later submitted (and included here) by Peterson and Trombka have estimated the spallation effects on the basis of the work of Dyer and Morfill (1971). As a result of this, and possibly some other refinements, the hump around 2 MeV seen in Figures 19, 20 and 21 is slightly less pronounced than was indicated in the preliminary results available at the Symposium.

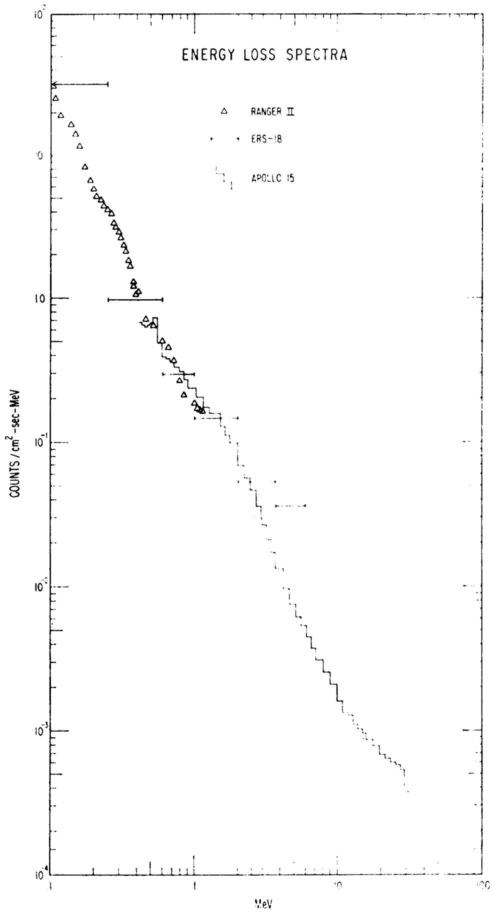

Fig. 18. Energy loss spectrum observed in the Apollo 15 experiment (Arnold *et al.*, 1972). This spectrum (with boom extended and anti-coincidence operational) below 1 MeV is almost exactly the same as that measured in ERS-18 and Ranger III using similar detectors. Above 2 MeV the ERS-18 points lie well above this spectrum.

The value of flux quoted by Trombka is 5×10^{-5} photons cm^{-2} s^{-1} sr^{-1} MeV^{-1} at 30 MeV. This is consistent with the flux of Pinkau (Mayer-Hasselwander *et al.*, 1972) and upper limits of Share and Frye. There is some reason for complacency here, but such coincidences may however be dangerous.

7. Region of 100 MeV

There are no new results in the 100 MeV range and we are left with only one point which comes from the classic OSO III measurement (see Clark *et al.*, 1971). This is sometimes given as a definite flux, though a downward pointing arrow is often added by more conservative people, including the authors of this point.

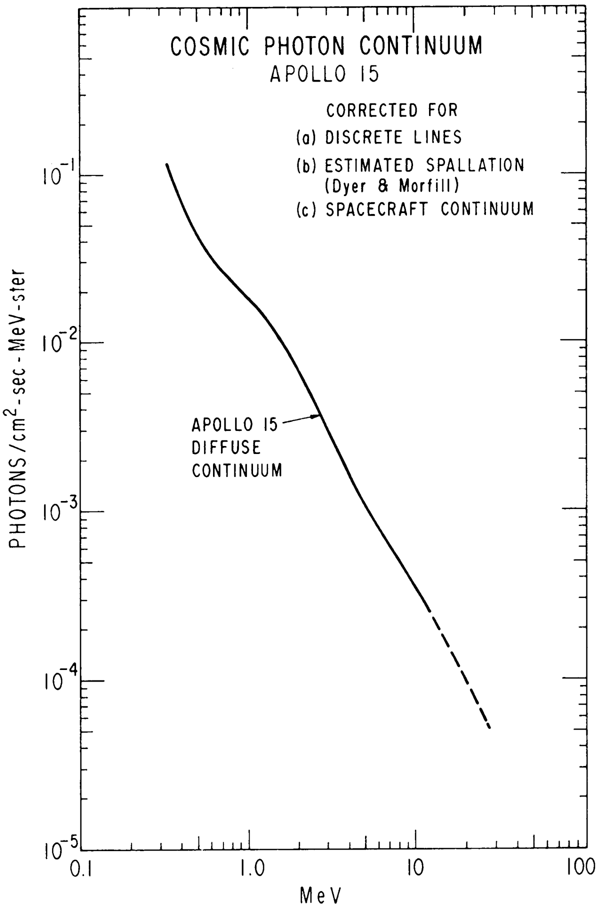

Fig. 19. Photon spectrum deduced from the Apollo experiments (Trombka, this Symposium).

8. The Energetic Photon Spectrum à la this Symposium

Taking congnisance of the discussion about various backgrounds, I would like to bet in favour of the following spectrum from 20 keV to 1 MeV:

$$N(E) = 25\,(E/1\ \text{keV})^{-2.1}\ (\text{cm}^2\ \text{s sr keV})^{-1}.$$

I believe most of the authors who have communicated to this symposium would compromise on this. This spectrum along with some experimental points is exhibited in Figure 20. It is seen that we have opted against the 40 keV break, but we leave open the manner of transition from energies well below 20 keV to those above 20 keV.*

* However, Dr Schwartz comments: "Data contained in the reference Schwartz (1969) show that the suggested further corrections are not large compared to the discrepancy of OSO-III data and the dashed spectrum (in Figure 20). Again, the data (in Figure 20) do not *show* that there is no break at 40 keV, but are merely of poor enough statistical quality that they do not *require* one (even if it really exists)".

The data beyond 200 keV is given in Figure 21. In this we have excluded the Ranger III and ERS-18 data, and show instead the tentative photon spectrum from the Apollo flights presented by Peterson and Trombka at this meeting; this is done because the raw pulse height spectrum measured in Ranger III, ERS-18 and the Apollo flights was about the same. In addition there are the values and limits of Daniel *et al.* (1972), Golenetskii *et al.* (1971), Share *et al.* (1972), Mayer-Hasselwander *et al.* (1972) and OSO III. The Apollo shoulder around 2 MeV, as mentioned earlier is rather uncertain though it is partly supported by Vedrene *et al.* (1972) and not strongly contradicted by Daniel *et al.* (1972). The discrepancy comes in with respect to the two

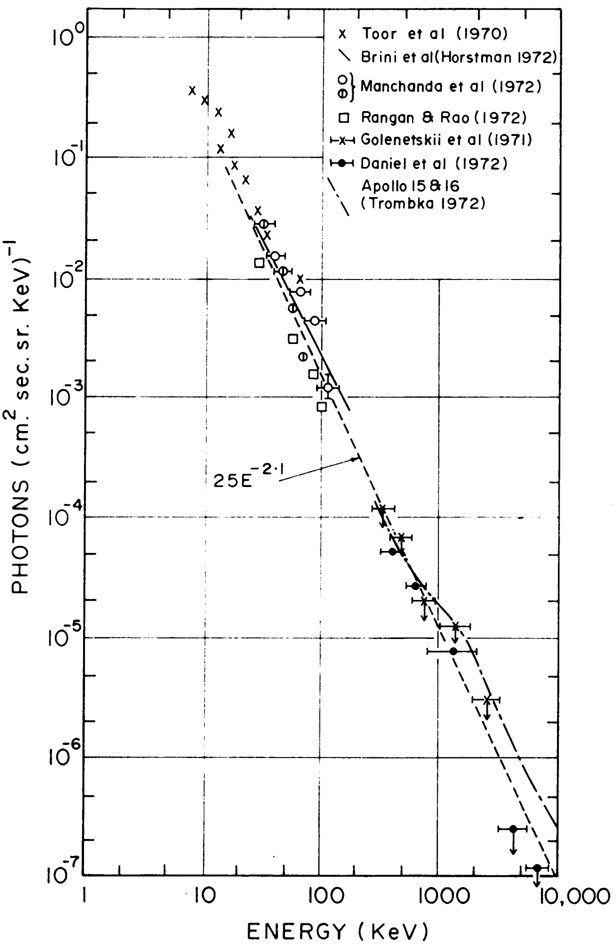

Fig. 20. Spectrum of photons from 20 keV to 1 MeV. It was agreed that Schwartz (1969) points need further correction and hence are not included. Of the others only a few recent representative measurements have been shown in this slide. In particular, from the balloon experiments of Machanda *et al.* (1971), only the points from two higher flights are taken. The doted curve is $N(E) = 25(E/1\ \text{keV})^{-2.1}$ $(\text{cm}^2\ \text{s sr keV})^{-1}$. Note that there is no break around 40 keV. At higher energies the Apollo results are shown while Ranger III and ERS-18 data are excluded (see text).

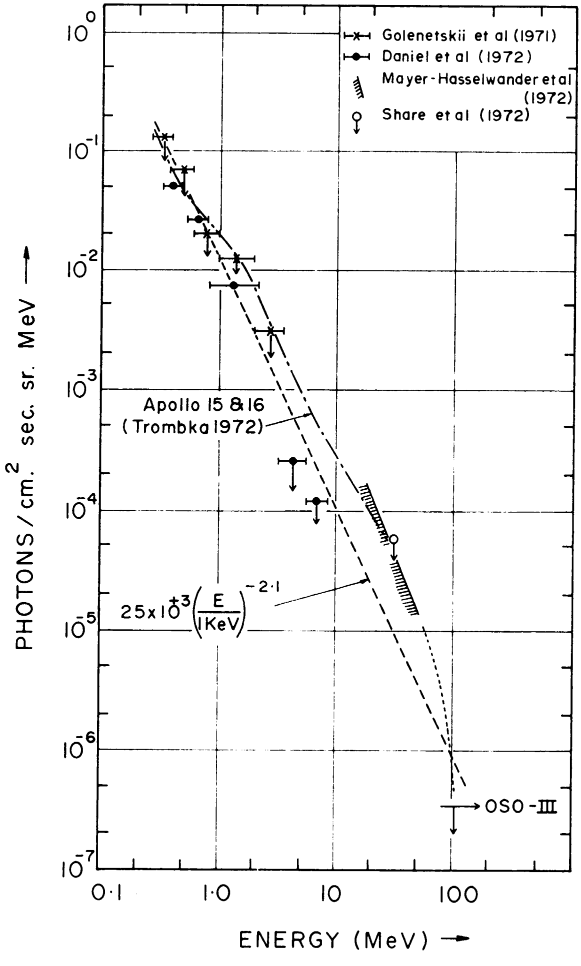

Fig. 21. Selected experimental data beyond 200 keV discussed at this Symposium. See text for discussion.

highest energy (3–6 MeV) limits of Daniel *et al.* and the Apollo measurements. It appears to us that the favourite cosmological epoch of Stecher, $z\sim100$, is a bit out of luck. On the other hand the Max Planck and NRL (and possibly Frye, though he was very cautious about claiming a definite flux inspite of an experimental result which appeared at least as definitive as any other) result, combined with the OSO III measurement at 100 MeV, would seem to demand a shoulder at about 25 MeV. This would give the pride of place to an epoch around $z=2$–3 if the production is via π° decay; however, the phenomenologists would be advised to wait a while before theorising about this.

I would like to emphasise that even though the measurements of Mayer-Hasselwander and OSO III are made with directional detectors there is relatively poor direct evidence so far, for the cosmic (meaning extragalactic) nature of all the flux beyond 1 MeV.

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