The possibility of detectable fluxes of cosmic ray γ rays with energy above 10^{19} eV

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Abstract. Under the assumption that cosmic rays are of extragalactic origin above 10^{18} eV it is shown that the presence of the 2·7 K black body radiation may lead to a detectable flux of very energetic γ rays.

A number of arguments have been put forward which suggest that the majority of cosmic rays at energies above 10^{18} eV are of extragalactic origin. One apparent difficulty is that the black body radiation (Penzias and Wilson 1965) should cause a cut off in the primary energy spectrum at a few times 10^{19} eV, in contrast to the experimentally observed continuous spectrum. It seems, however, that under certain circumstances it is possible to have a high energy cosmic ray spectrum which does not exhibit a sharp cut off, even allowing the particles to be of Universal origin and taking into account the black body radiation: for example, Hillas (1967) considers an evolving Universe in which the production rate of cosmic rays was higher in the past and on this model the cut off is less marked. The same situation would result if the production rate of the Universal component had a maximum somewhere above 10^{20} eV.

The purpose of this letter is to call attention to another phenomenon expected in the case of the Universal origin of the highest energy particles. Interactions of the cosmic rays with the black body radiation can lead to the transference of a relatively high fraction of the primary energy to photons and in view of the fact that the attenuation length for photons of energies above a few times 10^{19} eV becomes comparable with or longer than that of protons one can anticipate a noticeable photon flux at the earth.

Calculations have been made for a steady state Universe under the assumption that the primary cosmic ray spectrum in extragalactic space is described by a single power law with constant exponent to energies exceeding 10^{21} eV. The form of the spectrum adopted is that measured directly (as summarized by Greisen 1966) at energies above 10^{18} eV and is indicated in figure 1. Below 10^{18} eV it is assumed that galactic containment causes the increase over and above the extragalactic spectrum. Use of the steady state Universe is justified, in these preliminary calculations, by the fact that the bulk of the contribution to the intensities comes from distances of the order of a tenth of the Hubble radius.

The method of calculation was as follows. The energy spectrum of high energy photons at production was calculated taking the primary spectrum referred to above and assuming that the back body temperature is 2·7 K. Data for the photoproduction process were taken from accelerator results; in view of the fact that the energy of the photon in the C-system of proton and black body photon is practically always below 1 GeV, the cross section is accurately known.

The energy spectrum of photons at the earth was then calculated taking into account interactions of the photons and their ensuing cascade electrons with the all-pervading black body photons. (It was assumed that the electrons from γ-γ interactions take equal energies; in fact there is a marked asymmetry at high energies causing the present intensity estimates to be too low.)

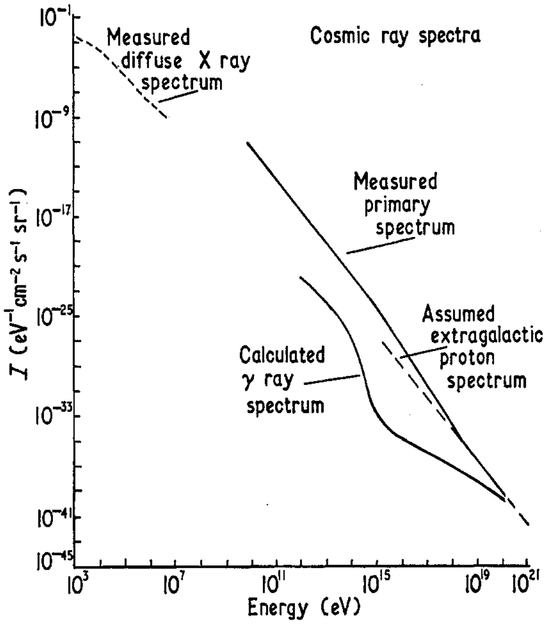

Figure 1.

The result of the calculations is given in figure 1, where the complete primary spectrum is also shown. The measured low energy spectrum of diffuse X rays is also given to set the scale of presently detected cosmic photons (the data are from a recent summary by Ipavich and Lenchek 1970).

It is immediately seen that there are two favoured regions for detection of the energetic photons: at energies in the range 10^{12}–10^{14} eV and again above 10^{18} eV. In both these regions the intensities are comparatively high because of the transparency of space at these energies. In the range 10^{12}–10^{14} eV a further contribution to the expected intensity of photons comes from proton–extragalactic matter interactions and under certain assumptions about matter density this contribution may become large.

At energies above 10^{18} eV there seems to be the possibility of the photon flux being a significant fraction of the total particle flux and the problem of experimental resolution needs active consideration. Assuming that the photons behave in a manner similar to that at lower energies the ensuing showers will be deficient in muons compared with normal showers. Such muon-poor showers have in fact been observed at lower energies, of the order of 10^{15} eV, by the Lodz and Chacaltaya groups (Gawin *et al.* 1966, Toyoda *et al.* 1966), but calculations by Maze *et al.* (1970), and further observations by Catz *et al.* (1969) indicate that the majority of these particular showers are not in fact due to primary photons. Returning to the very highest energies, the detection of muon-poor showers should be possible by way of measurements on the muon to electron ratio in showers selected on the basis of electron size. Such measurements at energies above several 10^{18} eV do not appear to have been made hitherto in view of the usual selection systems based predominantly on muon signal.

The reason for the remark about the assumption of energetic photon behaviour is that there is the possibility of significant electromagnetic suppression effects at these energies, as has been pointed out by Landau and Pomeranchuk (1953) and Migdal (1956). It is thus possible that the extensive air shower produced when a high energy photon enters the atmosphere differs significantly from that predicted from straightforward cascade theory. Further analysis of this aspect is needed.

In conclusion, it can be remarked that if cosmic rays with energy above 10^{18} eV are of Universal origin then there may well be a detectable flux of very energetic primary γ rays. Their number will be dependent on various astrophysical parameters so that if they can be detected experimentally important information will result.

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