# A Limit on the Redshift due to Interaction with Electromagnetic Radiation

IN a recent letter[1] Pecker *et al.* discussed the possibility that a part of the "cosmological" redshift could result from the interaction of photons with an interstellar radiation field. Although this suggestion is old[2,3], it has recently regained prominence with the discovery of the 3 K blackbody radiation. Pecker *et al.* discussed a formula for the energy loss of the propagating photon, $\nu_1$,

$$-\delta\nu_1/\nu_1 = \Delta(\nu_2)n_2\delta l \qquad (1)$$

where $\Delta(\nu_2)$ is the coupling constant between the propagating photon and the radiation field of frequency $\nu_2$, $n_2$ is the number density ($cm^{-3}$) of the photons at $\nu_2$, and $\delta l$ is the length of the interaction path, in cm. Assuming that $\Delta(\nu_2)$ is independent of $\nu_2$, they suggested an experiment to determine an upper limit for its value. The proposed experiment, measuring by the Mössbauer effect the energy loss of gamma rays traversing a laser beam, is very difficult to perform. But another Mössbauer experiment was performed a number of years ago to test just this question. In that experiment[4], gamma rays were propagated through a microwave cavity filled with photons of 9,234 MHz ($\lambda \approx 3$ cm) radiation; the fractional energy shift of the gamma rays due to the microwave field was found to be $0.4 \pm 6.0 \times 10^{-16}$, corresponding to a value of $\Delta(\nu_2) < 10^{-33}$ $cm^{-1}$. This limit is far smaller than the value $\Delta(\nu_2) \approx 10^{-30}$ $cm^{-1}$ proposed in ref. 1 from the analysis of solar redshift data.

We note that the 3 cm wavelength of the microwave radiation used in the experiment of ref. 4 lies near the peak ($\lambda_{max} \approx 0.1$ cm) of 3 K blackbody radiation. Thus the microwave experiment establishes a useful and reliable upper limit for $\Delta(\nu_2)$, provided the Doppler form of equation 1 is valid. This limit is far too small to account for the observed cosmological redshift which requires[1] $\Delta(\nu_2) \approx 10^{-30}$ $cm^{-1}$.

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# Consequences of a Universal Cosmic-ray Theory for γ-ray Astronomy

THE problem of the origin of cosmic rays is well known; but in spite of considerable advances in knowledge concerning energetic extra-terrestrial objects in recent years, no satisfactory solution has appeared. It is not clear, even, whether the important sources are within the Galaxy or outside it[1,2].

Here we consider the possibility of reviving a theory due to Hillas[3] in which the observed shape of the primary spectrum up to about $3 \times 10^{19}$ eV is explained in terms of an evolving sources model with constant spectral index at production, and interactions with the microwave background radiation. Such a model can explain the sharp change of slope at $3 \times 10^{15}$ eV inferred from measurements of the sizes of extensive air

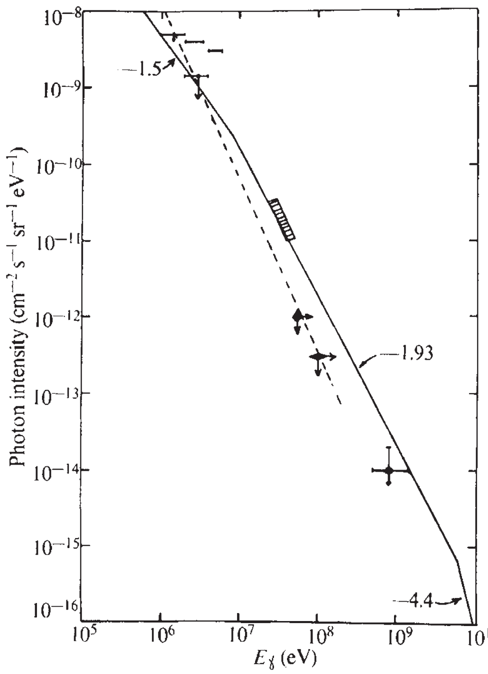


**Fig. 1** The expected γ-ray spectrum (solid line). ◆, Ref. 9 (OSO-3); ♦, ref. 8 (COSMOS-208); ✚, ref. 8 (PROTON-2); ├┬┤, ref. 10 (COSMOS-163); ├─┤ ref. 11 (ERS-18); - - - - -, ref. 10 ($E^{-2.4}$ fit to experimental data); ▭, ref. 12 (balloon experiment).

showers, as well as the high degree of isotropy which is maintained up to at least $10^{19}$ eV (ref. 4).

The objections so far advanced to theories of this type seem to rely on assumptions concerning unknown astrophysical quantities. Thus the problem of a γ-ray excess due to pionization on intergalactic matter[5] can be removed by assuming a low enough density for the inter-galactic medium. An X-ray excess is clearly expected if the proton/electron ratio is equal to its local value, but in the absence of evidence to the contrary the possibility that this ratio may be large enough in metagalactic sources to remove the discrepancy cannot be ruled out.

A more fundamental objection would arise if it could be shown that the energy lost in forming the observed primary spectrum above $3 \times 10^{15}$ eV (which appears initially in the form of electron pairs in this type of theory) will result in a γ-ray flux inconsistent with measurements of the diffuse γ-background. The mechanisms involved are inverse-Compton effect on the microwave background and pair-production on the starlight background, the latter occurring within the Hubble radius for γ-ray energies above about $10^{11}$ eV for reasonable estimates of the starlight background (see, for example, ref. 6). It is assumed that the starlight intensity does not increase with $z$—such changes as might be expected do not affect the results greatly in the energy range of interest to us ($10^6$ to $10^9$ eV).

We have made calculations for a model in which the energetic cosmic rays are protons, with an energy spectrum on production of the form $G(E_p, z)dz = BE_p^{-\gamma} f(z)dz$, where B is a constant, $z$ is redshift and $\gamma = +2.6$. The source efficiency $f(z)$ is taken as

$$f(z) = H_0^{-1} \frac{(1+z)^{\beta}}{(1+z)^2 (1+2q_0 z)^{\frac{1}{2}}} \quad \text{for } z < z_m$$

$$f(z) = 0 \quad \text{for } z > z_m$$

corresponding to the form used by Longair[7] in treating the evolution of powerful radio sources. In the calculations we took $q_0 = \frac{1}{2}$, although the results are insensitive to this parameter.