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Data from the OSO-3 high-energy gamma-ray experiment have indicated an apparent isotropic background flux of gamma-rays having energies greater than 100 MeV.[1] The intensity of this flux has been found to be less than or equal to $(1.1 \pm 0.2) \times 10^{-4}$ cm^{-2} sec^{-1} sr^{-1}. Clark, et. al.[1] have pointed out that this flux may be compatible with an extrapolation of the observed X-ray spectrum below 1 MeV if the isotropic X-rays continue to follow a power-law spectral form. The explanation most usually considered for this power-law spectrum is that the X-rays may be generated by the interaction of metagalactic cosmic-ray electrons with the universal thermal radiation.[2,3] (While the OSO-3 data are compatible with an extrapolation of the X-ray spectrum, these data may indicate a gamma-ray flux greater than this extrapolation. Above 100 keV, the differential X-ray spectrum is of the form $I(E_\gamma) \simeq 1.5 \times 10^{-2} E_\gamma^{-2.3}$ cm^{-2} MeV^{-1} sec^{-1} sr^{-1} with E_γ in MeV. Such a power law would predict an integral flux above 100 MeV of 2.9×10^{-5} cm^{-2} sec^{-1} sr^{-1}, a factor of 4 below the OSO-3 value.)

There is, however, another possible source of metagalactic gamma-rays. They may be produced by the decay of neutral pi-mesons generated in metagalactic cosmic-ray interactions. Under various assumptions as to the time-dependence of the metagalactic cosmic-ray flux and the proper cosmological model describing our universe, it is possible to use the OSO-3 data to place upper limits on the present metagalactic cosmic-ray intensity.

The differential metagalactic gamma-ray flux in a Friedmann-type expanding universe with a Robertson-Walker metric is given by

$$I(E_\gamma) = \int_0^{z_{max}} dz \; n(z) \frac{I(z)}{I_g} \frac{G_g\left[(1+z)E_\gamma\right]}{(1+z)^3} \frac{dl}{dz} \qquad (1)$$

where $n(z)$ is the metagalactic gas density at redshift z and $I(z)$ is the integral flux of metagalactic cosmic-rays above the threshhold energy for pi-meson production. (The absolute threshhold kinetic energy is ~300 MeV but most pi-mesons are produced by cosmic-rays of energies between 1 and 10 GeV.[5]) The quantity, $G_g(E_\gamma)$ is defined as the local (non-redshifted) gamma-ray spectrum generated by the galactic cosmic-ray flux, I_g, in traveling through the intergalactic medium. (This generating spectrum is the same as the quantity $I(E_\gamma)/nL$ calculated previously by the author.[5]) The local generating spectrum, $G_g(E_\gamma)$ is based on the results of detailed calculations utilizing recent accelerator data.[5,6] The factor $(1 + z)^3$ takes into account the reduction in flux due to time-dilation volume-diminuation and proper normalization of the redshifted differential generating spectrum.

Equation (1) is valid under the following assumptions: a) Absorption is negligible. It will be shown elsewhere that this is the case. b) The cosmic-ray spectrum in the metagalaxy has the same form as the galactic cosmic-ray spectrum. This would be the case if cosmic-rays were generated in extra-galactic sources via the same mechanism as in our own galaxy. There is evidence that in radio sources this may be the case at least for the cosmic-ray electrons.[7]

The curvature factor, dl/dz, is given by[8]

$$\frac{dl}{dz} = \frac{cH_0^{-1}}{(1 + z)^2 (1 + 2q_0 z)^{1/2}} \quad (2)$$

where c is the speed of light, H_0 is the present value of the Hubble parameter, and q_0 is the deceleration parameter. We will consider here two model universes: a) an Einstein-de Sitter universe with a present gas density of $n_0 = 10^{-5}$ cm^{-3} and $q_0 = 1/2$. This model is compatible with the most probable value of q_0 as discussed by Sandage[8] and is consistent with the recent X-ray observations by Henry, et. al.[9] b) a low density model with $n_0 = 10^{-6}$ cm^{-3} and $q_0 \simeq 0$.

The gas gensity in both models is given by

$$n(z) = n_0 (1 + z)^3 \quad (3)$$

In order to determine the z-dependence of the metagalactic cosmic-ray intensity, three ideal cases were considered. (They will be described elsewhere in full detail.)

Case I) In this model, all the metagalactic cosmic-rays are produced in a burst at some redshift, z_{max}, which might possibly represent some early epoch of galactic evolution.

Case II) In the model we assume that the cosmic-ray sources have evolved and were much stronger in the past. We assume a cosmic-ray production rate proportional to $(1 + z)^3$ in accordance with the results of Longair.[10] However, it should be noted that his cutoff at $z_{max} \simeq 4$ does not necessarily apply here, since the radio data reflect only a cutoff in the cosmic-ray electrons which may be due to Compton interactions with the universal thermal radiation and such interactions would have little affect on the cosmic-ray nuclei.

Case III) For this case, we assume that metagalactic cosmic-rays are due to a constant leakage from the various cosmic-ray sources in the universe, starting at some z_{max} (which may correspond to the epoch of galaxy formation).

All of these models include the density factor $(1 + z)^3$ and a factor of $(1 + z)^{1.5}$ due to the fact that as the universe expands, some of the cosmic-rays (above 1 GeV energy, where we are assuming an integral power-law spectrum with an index of 1.5) are redshifted below the threshhold energy for pi-meson production.

Equation (1) was solved numerically for the various models, in order to determine the present metagalactic cosmic-ray intensity, I_0, needed to produce a gamma-ray flux above 100 MeV of 1.1×10^{-4} cm^{-2} sec^{-1} sr^{-1}. The flux, I_0, is given in Tables 1 and 2 as a fraction of the galactic cosmic-ray flux, I_g.

The results indicate that a constant leakage model would require very high fluxes of metagalactic cosmic-rays in order to explain the OSO-3 data. It would be more reasonable to consider some evolving source or burst model implying high cosmic-ray production in the past when the gas density was greater and interactions were correspondingly more frequent. A present gas density of 10^{-5} cm^{-3} would also allow a more easily acceptable explanation of the OSO-3 data in terms of secondary meson production.

Although previous estimates have been made of the metagalactic gamma-ray flux from secondary pi-meson decay,[11] none of these estimates have taken into account cosmological factors as has been done in calculating Compton-gamma-ray spectra.[12-14] When these factors are taken into account, it may be shown that the metagalactic spectrum will differ from the galactic (or local) spectrum because of contributions at large redshifts. In particular, a more detailed treatment (to be given elsewhere) indicates that the differential gamma-ray spectrum from pi-meson production in the metagalaxy will peak near $67.5 \left(1 + z_{max}\right)^{-1}$ MeV instead of at 67.5 MeV. Thus, more information on metagalactic cosmic-rays may be gained by studying the isotropic gamma-ray spectrum between 1 and 100 MeV than by studying those above 100 MeV (provided the peak is observable). If pi-meson production is the dominant source of metagalactic gamma-rays in the 1-100 MeV energy range, a study of these gamma-rays may provide an important clue to cosmology and the origin of cosmic-ray sources.

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Table 1
Value of I_0/I_g for $n_0 = 10^{-5}$ cm^{-3}.

Model \ z_{max}	2.2	4	9	100
I) Burst Model	4.7×10^{-2}	2.3×10^{-2}	1.0×10^{-2}	2.8×10^{-3}
II) Evolving Sources	4.4×10^{-2}	1.6×10^{-2}	2.5×10^{-3}	3.0×10^{-4}
III) Constant Leakage	2.4×10^{-1}	2.0×10^{-1}	1.6×10^{-1}	1.3×10^{-1}

Table 2
Value of I_0/I_g for $n_0 = 10^{-6}$ cm^{-3}.

Model \ z_{max}	2.2	4	9	100
I) Burst Model	3.2×10^{-1}	1.3×10^{-1}	4.6×10^{-2}	5.6×10^{-3}
II) Evolving Sources	2.9×10^{-1}	6.9×10^{-2}	5.5×10^{-3}	7.6×10^{-5}
III) Constant Leakage	1.9	1.4	8.0×10^{-1}	2.2×10^{-1}

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