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*Presented at I.A.U. Symposium #37 on Non-Solar X- and Gamma-Ray Astronomy, Rome, Italy, May 8-10, 1969.

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ABSTRACT

We have compared the recent cosmic background gamma-ray observations with spectra predicted by various possible cosmic interactions. We find that the observed isotropic gamma-rays with energies >1 MeV can best be explained as being due to the decay of π°-mesons produced in extragalactic cosmic-ray collisions. This interpretation indicates that extragalactic cosmic-ray sources were more active (or prevalent) in the past and started to form at a redshift of $\sim$100 corresponding to 10^7 - 10^8 years after the "big-bang."

For a present extragalactic gas density of 10^{-7} - 10^{-5} cm^{-3}, the present extragalactic cosmic-ray flux is inferred to be 10^{-5} - 10^{-3} the galactic value.

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Recent theoretical studies by the author[1-4] have indicated the importance of observing isotropic cosmic-gamma-radiation in the 1-100 MeV energy region. These predictions of isotropic gamma-ray spectra from metagalactic inelastic strong interactions[1,3,4], matter-antimatter annihilation,[2] and bremsstrahlung,[4] along with studies of metagalactic Compton gamma-rays[5] and bremsstrahlung gamma-rays below 1 MeV energy[6] have indicated the following qualitative points:

1. Bremsstrahlung and Compton processes may be possible alternative explanations of the observed isotropic X-ray spectrum below 1 MeV. The Compton process, however, requires constant regeneration of cosmic-ray electrons.[7]

2. Inelastic proton-proton interactions may account for the observed isotropic gamma ray flux of Clark, et al.,[8] if the observed flux is considered to be real, rather than an upper limit. Extrapolations of predicted bremsstrahlung ($\sim E_\gamma^{-3.6}$) and Compton ($\sim E_\gamma^{-2.3}$) proton spectra, normalized to fit the X-ray observations, would only be compatible with the measurement of Clark, et al. if that measurement is taken as an upper limit due to a spurious signal.

3. When the predicted gamma-ray spectra were normalized to fit the observations below 1 MeV and above 100 MeV (clark, et al.), it became apparent that a determination of the dominant process, or combination of processes which produce the observed X- and gamma-rays, would only be made possible by a determination of the gamma-ray spectrum between 1 and 100 MeV.

The recent observations of Vette, et al.,[9] have now provided us with measurements of background gamma-rays up to 6 MeV. These data, along with some of those of Metzger, et al.,[10] are shown in the accompanying figure.* The differential intensity at 100 MeV is found from the integral measurement of Clark, et al., by assuming that above 100 MeV the spectrum can be approximated by a power law with an index of ~3 as shown for the theoretical p-p spectrum. Also shown in the accompanying figure, are predicted gamma-ray spectra due to the various possible metagalactic interactions. These spectra have been discussed in detail in References 1-4 and such detailed discussion will not be repeated here.

The new data of Vette, et al., are consistent with the power law trend below 1 MeV as indicated by the Ranger 3 measurements and other observations.[11] However, they indicate a marked departure from the power law above 1 MeV. For example, the 6 MeV point is an order of magnitude higher than what would be expected on the basis of a power law extrapolation of the X-ray data. These data, taken with the data of Clark, et al., being interpreted as a real flux, fit the shape of the theoretical gamma-ray spectrum from p-p interactions integrated to a maximum redshift of ~100 for a burst or evolving sources model where cosmic-ray production was higher in the past.[1,4] They do not seem consistent with the other theoretical spectra for energies above 1 Mev.

These suggestive results make it even more imperative to obtain other gamma-ray observations in the 1-100 MeV region in order to confirm the data of Vette, et al., and to extend the measurements to higher energies. However, on the basis of these first results we present the following interpretation.

*We have also included an upper limit set by a balloon flight of the Rochester group and updated by a recent recalibration (G. Share - private communication).

Comparison of the predicted spectra with the gamma-ray observations indicates that extragalactic gamma-radiation may be due to the decay of neutral pi-mesons produced in inelastic collisions of metagalactic cosmic-ray protons and gas. The peak in the spectrum, which normally occurs at $\sim$70 MeV, is redshifted down to $\sim$1 MeV energy. This effect is due to the increased collision rate at larger redshifts when our expanding universe was in a more compact state as well as increased cosmic-ray production at large redshifts. A cosmic-ray production rate which is constant over all redshifts will not account for the new observations.[3]

Either a burst model or evolving sources model for the time-dependence of cosmic-ray production in the past will fit the predicted spectrum; the position of the peak depends primarily on the maximum redshift at which gamma-rays are produced.[3] However, the assumption of various time-dependence models for cosmic-ray production leads to different requirements for the present metagalactic flux needed to produce the observed gamma-rays.[1,4] The maximum redshift needed to produce the observations is $\sim$100, which corresponds to an epoch when the age of the universe was 10^7 - 10^8 years and the temperature of the universal radiation field was $\sim$270°K. This may correspond to the epoch when objects of galactic mass were beginning to form from the metagalactic medium.[12] There is mounting evidence that radio sources were more active (or prevalent) at earlier epochs,[13] and it is plausible to speculate that in these sources, where electrons are accelerated to cosmic-ray energies, protons may also be accelerated to these energies. Whereas the electrons have short lifetimes at these redshifts due to Compton interactions with the universal radiation field[7,14] possibly restricting their radio emission stage to redshifts of ~10 or less, the protons do not undergo significant depletion from Compton interactions. If we consider present extragalactic gas densities of 10^{-5} to 10^{-7} cm^{-3}, and assume increased cosmic ray production in the past, we find that the present intergalactic cosmic-ray flux need only be $\sim 10^{-3}$ - 10^{-5} of the galactic value in order to account for the observed gamma-ray intensity. Such a flux has been strongly advocated by Ginzburg and Syrovatskii.[15]

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EXTRAGALACTIC HIGH ENERGY PHOTON SPECTRA

OBSERVATIONS:

- △, ◊ RANGER 3 (METZGER, ET. AL.)
- • ERS-18 (VETTE, ET. AL.)
- OSO-3 (CLARK, ET. AL.)
- SHARE

THEORETICAL PREDICTIONS:

- B — BREMSSTRAHLUNG
- C — COMPTON COLLISIONS
- P — COSMIC-RAY INELASTIC P-P COLLISIONS (Z_{MAX} =100)