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NASA TM X-**63658**

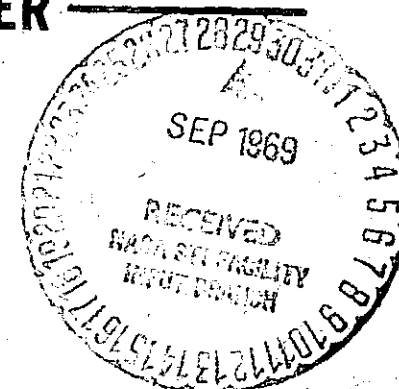# PRIMORDIAL COSMIC-RAY SOURCES

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Abstract:

New gamma-ray observations have provided what
may be evidence for primordial cosmic-ray sources
existing out to redshifts of the order of 100. These
sources, here called "protars", may be galaxies and quasars
in their initial stages of formation. They may have provided
the basic energy source for ionizing the intergalactic gas.

I have recently proposed that the isotropic component of cosmic
gamma-radiation at energies greater than 1 MeV is a remnant of an
earlier epoch in the evolution of the universe and is the result of
interaction of primordial cosmic-rays which may have been produced in
large quantities as a by-product of the galaxy formation process.[1,2,3]
Recent measurements[4,5] of cosmic gamma-rays having energies greater
than 1 MeV have now provided evidence in support of this proposal[6]
and suggest that the galaxy formation stage may have begun at a redshift
of ~ 100.

In particular, the new data of Vette, et al[5], which provide the
first measurements of cosmic gamma-rays in the 1-6 MeV energy range,

have already yielded valuable information. Their preliminary results are shown in Figure 1. These measurements are consistent with the well known power-law X-ray spectrum below 1 MeV. 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[4], being interpreted as a real flux, fit the shape of the theoretical gamma-ray spectrum from cosmic-ray p-p interactions integrated to a maximum redshift of $\sim$ 100 for a burst or evolving source model where cosmic-ray production was higher in the past.[1-3,6] They do not seem consistent with other theoretical spectra for energies above 1 MeV. Vette, et al.[5] have interpreted their results to indicate a new component of the cosmic gamma-ray spectrum above 1 MeV which they find to be consistent with the theoretical interpretation presented here. In addition, Clark, et al[7], have reported qualitative results indicating that the isotropic component of cosmic gamma-radiation above 100 MeV has a softer spectrum than the galactic component. This result is also in agreement with the theoretical predictions presented previously.[2,3]

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 present data and to extend the range of the measurements. However, on the basis of these first results, I present the following interpretation. 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 extragalactic

cosmic-ray protons and gas. The peak in the resultant gamma-ray 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.[2] The assumption of various time-dependence models for cosmic-ray production leads to different requirements for the present metagalactic cosmic-ray flux needed to produce the observed gamma-rays.[3] The maximum redshift needed to fit 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[8]. There is mounting evidence that radio sources were more active (or prevalent) at earlier epochs[9-11] 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 electrons have short lifetimes at high redshifts due to Compton interactions with the universal radiation field[12,13] possibly restricting their radio emission stage to redshifts of $\sim$ 10 or less, the protons do not undergo significant depletion from Compton interactions. Thus, the sources producing gamma-rays at redshifts of $\sim$ 100 will not be visible as radio sources. They may also be unobservable in the optical[14] and X-ray region[15,16] since a dense intergalactic medium becomes opaque to X-rays at redshifts <10. Thus our best chance of studying these sources comes

from gamma-ray observations and their study should be of prime importance to the young field of gamma-ray astronomy.

I will henceforth refer to these primordial cosmic-ray sources as "protars". It seems reasonable to speculate that protars may be early stages in the evolution of quasars and galaxies, i.e., objects of high mass which are in the initial stages of condensing out of the metagalactic medium. The subsequent release of gravitational energy coupled with the generation of strong magnetic fields during the contraction, could then provide energy for the acceleration of cosmic-rays. Recent microwave observations[17] have indicated that the intergalactic medium may have become ionized at a redshift of ~ 100. Cosmic-rays from protars would provide a natural source for heating the intergalactic medium at this epoch. It can be shown[8] that once the ionization occurs, the medium would then remain ionized due to subsequent cosmic-ray heating up to the present epoch. Thus, the protar hypothesis provides a connecting link between the gamma-ray and microwave observations.

It should be pointed out that the redshifts of ~ 100 proposed here for the protars may indicate that they are near the limit of observability for gamma-ray observations. Rees[15] and, independently, Arons and McCray[16] have considered the absorption of gamma-rays by intergalactic gas due to Compton interactions and pair production. In an Einstein-de Sitter universe with a gas density of 10^{-5} cm^{-3}, the gamma-ray absorption coefficient varies as the $3/2$ power of redshift. For a high density universe and a redshift of $z = 100$, Arons and McCray have calculated an optical depth near unity for gamma-rays between 1 and 100 MeV.

Thus, for a high-density universe, the gamma-rays reaching us may be partially depleted by absorption effects. Of course, for models with $n_o < 10^{-5}$ cm^{-3}, absorption effects are negligible at $z \simeq 100$. For a low-density model where $n_o = 10^{-7}$ cm^{-3}, the universe is transparent to gamma-rays out to redshifts of $\simeq 3000$.

It should also be noted that in a high-density model at redshifts of the order of 100, cosmic-ray attenuation by nuclear collisions will also become important. The cross section for cosmic-ray attenuation by nuclear collisions is of the order of 1.5×10^{-26} cm^2. Using this value, we find that in a high-density universe, attenuation effects become important for $z \simeq 100$. Thus, we must increase somewhat the cosmic-ray production requirements for the high-density model. However, for present densities less than 0.5×10^{-5} cm^{-3}, attenuation is negligible. It has been previously shown[2] that the gamma-ray opacity due to interactions with blackbody radiation is negligible for $z \simeq 100$ and $E_\gamma \lesssim 5000$ MeV.

Taking absorption effects into account, and considering models where the present gas density is 10^{-7} - 10^{5} cm^{-3}, we can conclude that if the protar hypothesis is correct, protars have filled intergalactic space with remnant cosmic-rays having a present density of 10^{-4} - 10^{-3} the galactic value[3], i.e., 10^{-16} - 10^{-15} erg/cm^3.

References

1. F.W. Stecker, Nature 220, 675 (1968).

2. F.W. Stecker, Astrophysical Journal, in press.

3. F.W. Stecker and J. Silk, Nature 221, 1229 (1969).

4. G.W. Clark, G. P. Garmire, W. L. Kraushaar, Astrophysical Journal
      Letters, 153, L203 (1968).

5. J.I. Vette, D. Gruber, J. L. Matteson and L. E. Peterson,
      I.A.U. Symposium No. 37 on Nonsolar X-rays and Gamma-Rays,
      Rome (1969).

6. F.W. Stecker, I.A.U. Symposium, op cit.

7. G.W. Clark, G. P. Garmire and W. L. Kraushaar, I.A.U. Symposium, op cit.

8. R. W ymann, Astrophysical Journal 147, 887 (1967).

9. M.S. Longair, Mon. Not. Roy. Ast. Soc. 133, 421 (1966).

10. M. Rowan-Robinson, Mon. Not. Roy. Ast. Soc. 138, 445 (1968).

11. M. Schmidt, Astrophysical Journal 151, 393 (1968).

12. K. Brecher and P. Morrison, Astrophysical Journal Letters 150,
      L61 (1967).

13. R. Bergamini P. Londrillo and G. Setti, Nuovo Cimento 52B, 495 (1967).

14. J.E. Gunn and B.A. Peterson, Astrophysical Journal 142, 1633 (1965).

15. M.J. Rees, to be published.

16. J. Arons and R. McCray, to be published.

17. A.D. Payne, Australian Journal of Physics 22, 59 (1969).

18. G. Share, private communication.

19. A.E. Metzger, E. C. Anderson, M. A. van Dilla, and J. R. Arnold,
      Nature 204, 766 (1964).

Figure Captions

Figure 1. Theoretical[3] and Observed[4,5,18,19] Extragalactic Photon Spectra.

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
    ($Z_{MAX} = 100$)