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Abstract

We have examined the alternative hypotheses of galactic and extragalactic origin of the observed cosmic γ-ray flux between 1 and 6 MeV in the light of the most recent spectral information on cosmic γ-rays above 50 MeV. We conclude that the present data on cosmic γ-rays are not consistent with 1-6 MeV γ-ray spectra generated by diffuse galactic production processes. Thus, the 1-6 MeV flux is, in all likelihood, extragalactic. It is, therefore, a strong background upon which both galactic and extragalactic point-sources in this energy region will be superimposed. This necessitates the use of high angular resolution γ-ray telescopes in order to study possible discrete sources in the 1-15 MeV energy region.

Within the last two years, measurements have been made of the flux of cosmic γ-rays above 1 MeV energy. The nature and extent of these measurements as of early 1970 have been presented in a recent review article by Fazio.[1] The work up to that time, most particularly the work of Clark et al.,[2] established the existence of a detectable flux of γ-rays of cosmic, and especially galactic, origin. Since that time, new results reported on by three experimental γ-ray astronomy groups have provided significant new information the implications of which will be discussed here. Clark et al.[3,4] have reported on a recalibration of their γ-ray telescope which has resulted in a reduction of their flux measurements as previously reported by a factor of between 2 and 4. Vette et al.[5] have published in final form the results previously announced at the 37th I.A.U. Symposium last year on the first positive measurements of cosmic γ-rays between 1 and 6 MeV.[6] Kniffen and Fichtel[7] have also reported their measurement of the cosmic γ-ray flux from the region of the galactic center. In that paper, they reported that a preliminary determination of the ratio of the integral flux above 50 MeV and above 100 MeV indicated a flat spectrum, consistent with that expected from π^0-decay. Such a flat spectrum was also indicated from the crude spectral measurements reported on by Clark et al.[8] The downward revision of their flux intensities also made it possible to construct a reasonable theoretical model of the origin of galactic γ-rays by taking account of clouds of interstellar molecular hydrogen in the galaxy.[9,10] Fichtel and Kniffen[11] have given a conservative two-standard deviation upper limit to the ratio of integral fluxes,

$$\frac{I(E_\gamma > 50\ \mathrm{MeV})}{I(E_\gamma > 100\mathrm{MeV})} < 1.5 \qquad (1)$$

from the galactic center which allows for a minor component of γ-rays from Compton scattering of cosmic-ray electrons off infrared photons in the region of the galactic center as suggested in reference 10 but which would indicate that even at the galactic center pion-decay supplies most of the γ-ray flux. The two-component model of the galactic center spectrum having the largest Compton γ-ray component consistent with the observations of Fichtel and Kniffen[7,11] is shown in Figure 1. By inference, γ-rays from the galactic disk can be attributed to an essentially pure pion-decay origin. (See discussion and references given in reference 10.)

We may well ask if the γ-ray flux reported by Vette et al.[5] may also have an origin in the galactic disk. They discussed the spectral characteristics required of a disk source and did not rule it out as a possibility. Galactic origin was suggested on theoretical grounds by Rees and Silk,[12] who postulated a galactic electron-bremsstrahlung mechanism for producing almost all of the cosmic γ-rays observed at energies above 1 MeV. While it is true that the data obtained by Vette et al. was of a nondirectional nature, thus allowing the possibility of galactic origin, we will show here that, because of the nature and intensity of the flux observed in the 1-6 MeV energy range, such a possibility is extremely remote.

In order to show this, let us construct a hypothetical spectrum of cosmic γ-rays for the galactic disk under the assumption that the 1-6 MeV γ-rays are produced there. Such a spectrum is shown in integral form in Figure 2. This spectrum was constructed using the additional assumptions that (a) the point at 100 MeV represents the revised average γ-ray flux from the galactic disk as reported by Clark et al., and (b) the upper limit at 50 MeV is given by equation (1), this being a conservative upper limit, particularly for the galactic disk. Also shown in Figure 2 are curves corresponding to the calculated γ-ray spectrum from pion-decay,[13] a theoretical Compton γ-ray spectrum with a differential index $\Gamma = 2$ [i.e., one representing a spectrum of the form $I(E_\gamma)\, dE_\gamma \propto E_\gamma^{-\Gamma}\, dE_\gamma$], the photon spectrum of Vette et al. interpreted as a galactic line flux and with an approximate average index, Γ, and a spectrum between 6 and 50 MeV representing the flattest power-law spectrum consistent with the upper limit given at 50 MeV.

A glance at Figure 2 immediately shows that a Compton-type spectrum is not only too soft to explain the data between 50 and 100 MeV (as deduced from the upper limit given by equation 1), but is also too hard and of too low an intensity to explain the break between 6 and 50 MeV consistent with a galactic origin for the 1-6 MeV flux. One should also note that bremsstrahlung radiation from cosmic-ray electrons, as observed in the vicinity of the solar system taking modulation into account, cannot account for the 1-6 MeV flux. In order to force a bremsstrahlung model to work, one would have to devise a means for filling the galaxy with 1-10 MeV electrons of $\sim 10^{-5}$ times the intensity of those which appear to be present in the solar neighborhood, with a much flatter spectrum below 6 MeV than has been observed by Simnett and McDonald[14] at these energies and with an extremely sharp break of at least 3.3 powers in the spectral index between 6 and 50 MeV. Such an ad hoc hypothesis seems extremely remote. Thus, the present data on cosmic γ-rays are not consistent with 1-6 MeV γ-ray spectra generated by diffuse galactic production processes.

Other suggested explanations of the 1-6 MeV γ-ray flux have been discussed by Vette et al.[5] They showed that the galactic point sources model also seemed highly unlikely. In their discussion of various extragalactic models, they pointed out that those models which produce isotropic γ-ray fluxes can account much more easily for the observed γ-ray intensity. Of the extragalactic models, the cosmological pion-decay model,[15-19] suggesting that this flux originated at a very early epoch in the history of the universe, provided a natural quantitative fit to the spectral data in this energy range when added to an extrapolation of the X-ray spectrum below 1 MeV.[5] Other possible cosmological models have been reviewed by Silk.[20] It thus appears that the cosmic γ-ray flux between 1 and 6 MeV is most likely of extragalactic origin and highly isotropic. It can thus be expected to provide a large background upon which both galactic and extragalactic point-sources in this energy range will be superimposed. This will very likely necessitate the use of high-resolution γ-ray telescopes in order to detect the discrete sources in this energy range.

Unfortunately, only very crude directional instruments can presently be constructed for studies of 1-15 MeV γ-rays. Even the large γ-ray source survey experiments that are expected to be flown in the mid-1970's have resolutions of $\sim$0.1 steradians and high intrinsic background count rates, e.g., $\sim 3 \times 10^{-3}$ counts per cm^2-sec-MeV at 3 MeV.

Although in principle it is possible to extract weak sources from such a large background by observing over long periods of time, in practice, systematic effects rather than statistics limit the precision with which background fluxes can be measured. For example, if the precision of the background rate is limited by systematic effects to 1 percent, then a 3σ signal would require a source with a flux of $\sim 2 \times 10^{-4}$ photons/cm^2-sec-MeV at 3 MeV. It appears that of the known sources only the Crab Nebula and M87 may have fluxes of this magnitude.[21] Consequently, it is highly likely that detector systems of much lower true background rates and much higher angular resolution will be needed to study weaker sources.

It should be pointed out that the extension of the techniques used by Vette et al.,[5] i.e., the use of a small satellite in an elliptical orbit, can provide new information on the spectrum of the diffuse component between 1-15 MeV. In addition to employing a multichannel analyzer to realize the $\sim$10 percent energy resolution provided by the detector, a charged particle anticoincidence mantle can be used to shield all local matter of the satellite, except for the solar cells, to reduce any possible background from secondary γ-ray production by cosmic rays. Furthermore, if the active volume of the γ-ray detector is say a 6-in. dia x 1-in. cylinder of CsI and the satellite is spinning such that detector axis of symmetry points alternately in the galactic plane and near the galactic poles, it should be possible to measure a flux from the galactic plane as small as 5×10^{-4} photons/cm^2-sec-rad above an isotropic backround of $\sim 10^{-2}$ photons/cm^2-sec-sr (as observed) with 3 months of observing time.[22] In this manner an experimental test of the main conclusion of this paper can be made.

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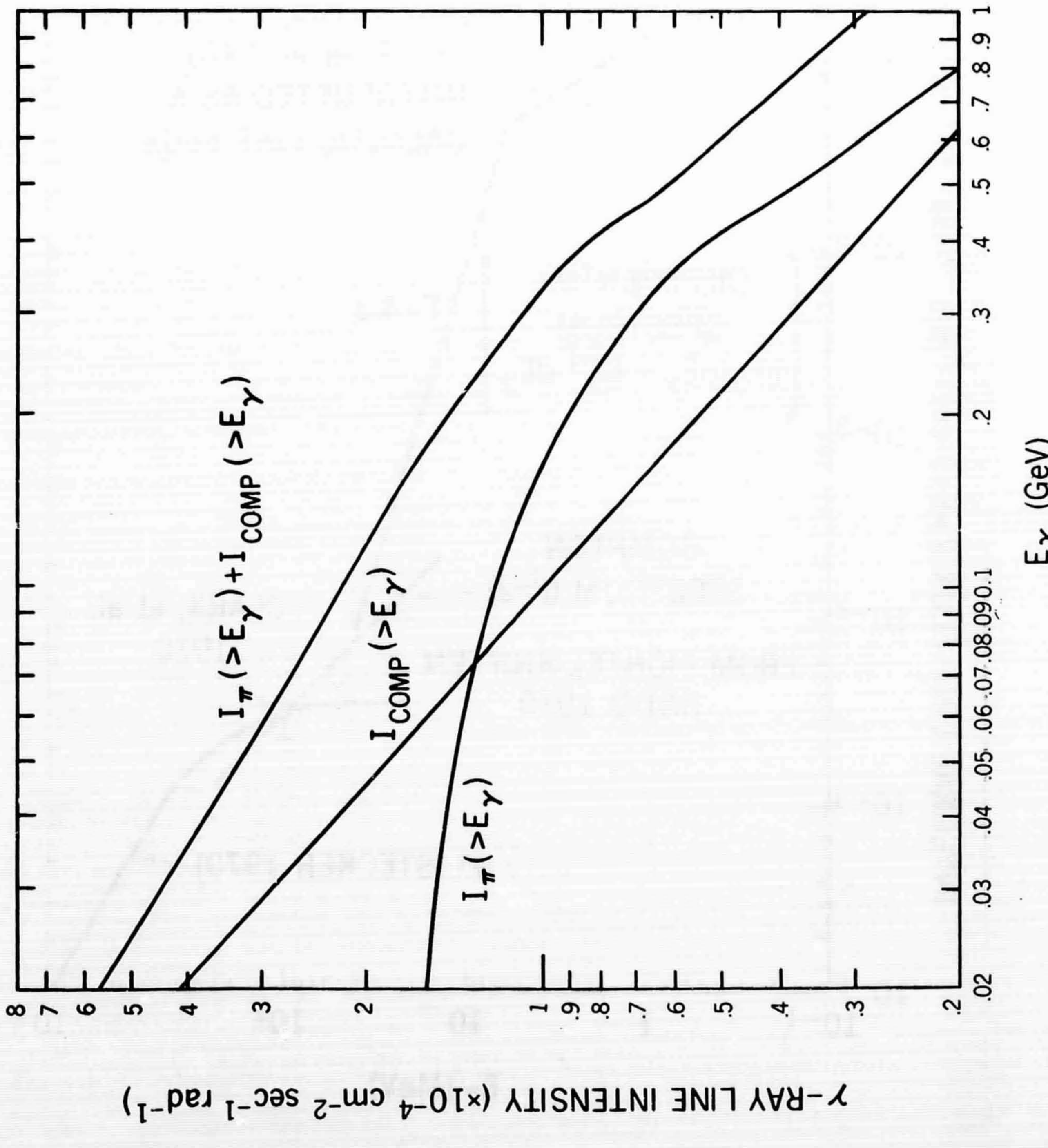
Figure Captions

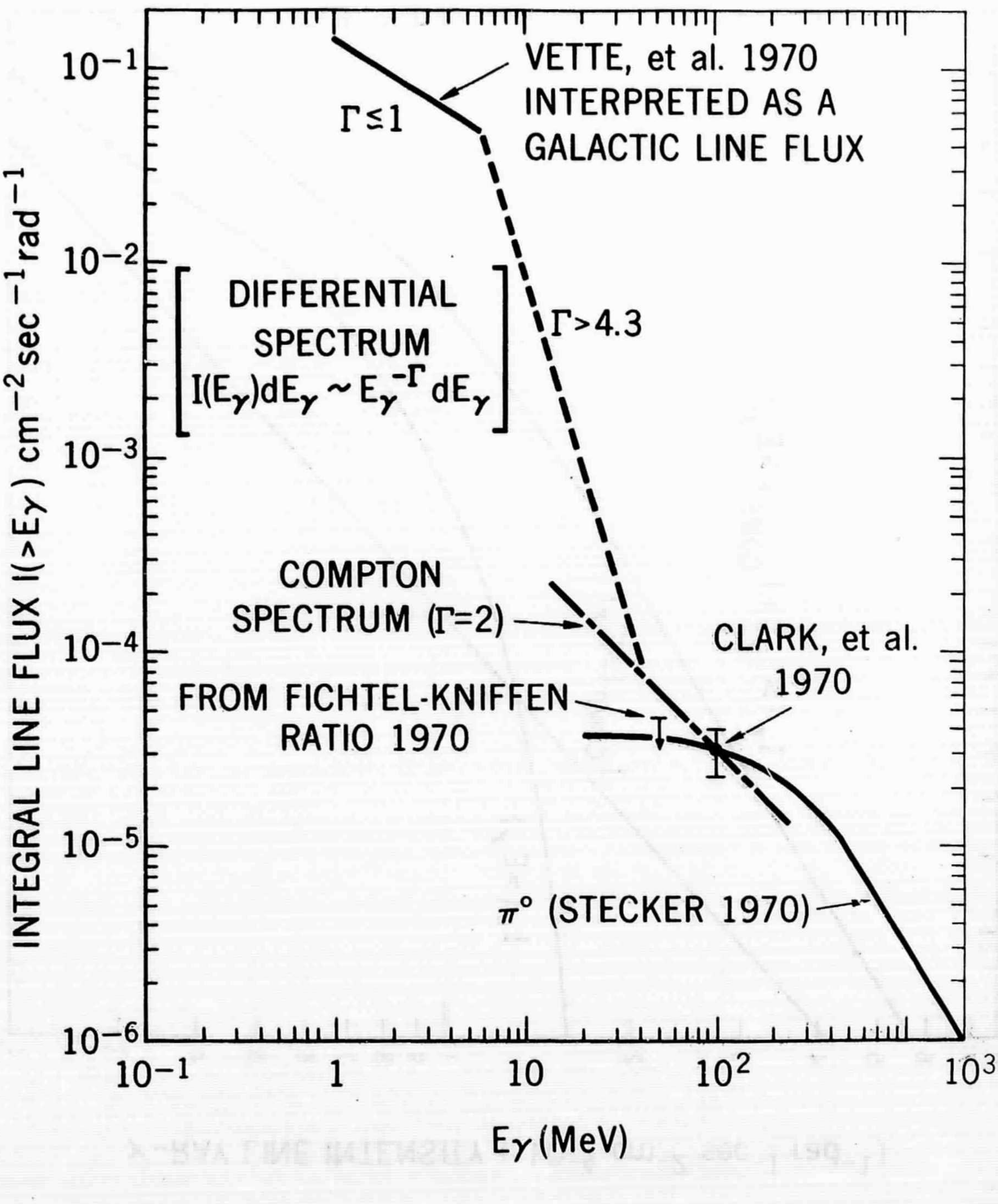
Figure 1: A Two-Component Spectrum Model for the Galactic Center Region Based on the Discussion of Stecher and Stecker (Reference 10).

Figure 2: A Hypothetical Integral γ-Ray Spectrum for the Galactic Disk Under the Disk-Origin Assumption for the Observed 1-6 MeV γ-Ray Flux.



γ-RAY LINE INTENSITY (×10-4 cm-2 sec-1 rad-1)
Eγ (GeV)
Iπ(>Eγ)+ICOMP(>Eγ)
ICOMP(>Eγ)
Iπ(>Eγ)
.02
.03
.04
.05
.06
.07
.08
.09
.1
.2
.3
.4
.5
.6
.7
.8
.9
1
8
7
6
5
4
3
2
1
.9
.8
.7
.6
.5
.4
.3
.2

Fig. 1



VETTE, et al. 1970
INTERPRETED AS A
GALACTIC LINE FLUX
Γ≤1
DIFFERENTIAL
SPECTRUM
I(Eγ)dEγ ~ Eγ^-Γ dEγ
Γ>4.3
COMPTON
SPECTRUM (Γ=2)
CLARK, et al.
1970
FROM FICHTEL-KNIFFEN
RATIO 1970
π° (STECKER 1970)
INTEGRAL LINE FLUX I(>Eγ) cm^-2 sec^-1 rad^-1
Eγ (MeV)
10^-1
1
10
10^2
10^3
10^-6
10^-5
10^-4
10^-3
10^-2

Fig. 2