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# Extragalactic Gamma Radiation: Use of Galaxy Counts as a Galactic Tracer

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EXTRAGALACTIC GAMMA RADIATION:  
USE OF GALAXY COUNTS AS A GALACTIC TRACER

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## SUMMARY

A derivation of the extragalactic diffuse  $\gamma$  radiation with energies above 35 MeV has been carried out using galaxy counts as a tracer of galactic matter. The extragalactic radiation has a differential photon number spectrum which may be expressed as a power law with index 2.35 (+0.4, - 0.3) and an intensity above 35 MeV of  $(5.5 \pm 1.3) 10^{-5}$  photons  $\text{cm}^{-2}\text{s}^{-1}\text{ster}^{-1}$ , consistent with previous derivations. Use of a  $1/\sin|b|$  expression of the galactic component produces a poorer fit, suggesting that the high-latitude galactic  $\gamma$ -ray production may be dominated by cosmic ray interactions with matter rather than by Compton interactions of cosmic rays with photon fields.

**Key words:** Gamma radiation, Galactic structure

## I. INTRODUCTION

The diffuse  $\gamma$  radiation in the energy range above 35 MeV consists of two components, one associated with our Galaxy and the other apparently isotropic, at least within present observational uncertainties. The galactic radiation provides information about cosmic ray interactions with interstellar matter and photon fields (Hartman et al., 1979; Mayer-Hasselwander et al., 1980), and the isotropic component is of interest because it is likely of extragalactic origin and may have significant cosmological implications (e.g., Fichtel, Simpson, and Thompson, 1978; Bignami et al., 1979).

The separation of the galactic and extragalactic components of the diffuse  $\gamma$  radiation relies on the correlation of the galactic radiation with other tracers of galactic interstellar matter and fields. As a first approximation, Fichtel et al. (1977) related the galactic component above a galactic latitude of  $10^\circ$  to the functional form  $1/\sin|b|$ . Fichtel, Simpson, and Thompson (1978) performed the separation using 21 cm observations of the atomic hydrogen column density as the tracer of galactic structure. These two approaches produced consistent results, yielding an isotropic radiation with a characteristically steep energy spectrum.

These methods had recognized shortcomings, however, in that neither accounted for the distribution of all the most relevant interstellar matter, molecular and atomic hydrogen. Puget et al. (1976) had noted that, if the gas-to-dust ratio is sufficiently uniform over the sky, galaxy counts, which are a measure of the optical absorption largely by dust, could provide a tracer of the total gas density. Lebrun (1979) and Strong and Lebrun (1982) suggested that the variations of the ratio of HI to absorption seen in the comparison between galaxy counts and  $N_{\text{HI}}$  are due to local molecular hydrogen. Lebrun and Paul (1980) and Lebrun et al. (1981) have now shown that the SAS-2

and COS-B  $\gamma$ -ray data at intermediate galactic latitudes are better correlated with galaxy counts than with atomic hydrogen column density, indicating that galaxy counts are apparently a better tracer of the sum of atomic and molecular hydrogen. The present work uses galaxy counts as a galactic matter tracer for the purpose of obtaining an independent derivation of the isotropic component of the diffuse  $\gamma$  radiation.

## II. DATA AND ANALYSIS

The  $\gamma$ -ray data used for this study are those of the SAS-2  $\gamma$ -ray telescope (Fichtel et al., 1975 and 1978). The SAS-2  $\gamma$ -ray observations have essentially no instrumental background and may therefore be used directly. The galaxy counts used were those of Shane and Wirtanen (1967). Due to limited statistics, the  $\gamma$ -ray data were compiled into bins with a  $10^\circ$  width in galactic latitude and the same six longitude ranges used by Fichtel, Simpson, and Thompson (1978). The Shane and Wirtanen galaxy counts averaged over large areas (their table X) were further averaged to match the bins for the  $\gamma$ -rays. A total of 43 bins were found in the overlapping regions of the two data sets, with the restriction that  $|b| > 10^\circ$ , in order to limit the effect of more distant parts of the galaxy.

Figures 1 and 2 present the  $\gamma$ -ray data in two energy ranges ( $35 \text{ MeV} < E < 100 \text{ MeV}$  and  $E > 100 \text{ MeV}$ ) as a function of  $\log$  (galaxy counts per square degree) for the bins described above. In each figure, the solid line is the best fit of the form:

$$I_\gamma = A \cdot [1.85 - \log(N_G)] + B \quad (1)$$

where  $I_\gamma$  is the  $\gamma$ -ray intensity and  $N_G$  is the galaxy count density. The  $\chi^2$  per degree of freedom for each fit is approximately 1. In comparison to the similar fits to HI column density of Fichtel, Simpson, and Thompson (1978), these  $\chi^2$  values are not a significant improvement. The use of relatively large bins and a wide range of galactic latitudes appears to smooth out the differences in distribution between the atomic hydrogen and the total matter. The uncertainties in the quantities A and B in the equation are strongly coupled. The range of acceptable values of these parameters ( $1\sigma$  above the minimum  $\chi^2$  value) are also shown in Figures 1 and 2.

The extragalactic component of the  $\gamma$  radiation is found by extrapolating the fitted lines of Figures 1 and 2 to the galaxy count which is estimated to correspond to zero matter thickness within the galaxy,  $N_G^0$ . From the work of Strong and Lebrun (1982) and Heiles (1976), particularly figure 5,  $\log N_G^0$  is found to be between 1.70 and 1.80 and is taken to be 1.75. It is known however that there is an offset in comparing absorption with  $N_{HI}$  which may in part be due to stray radiation (e.g., Kalberla et al., 1980), but is also in part real (Heiles et al., 1981). A +0.10 correction is adopted for this effect giving a final  $\log N_G^0$  of 1.85, with a  $1\sigma$  uncertainty estimated to be about  $\pm 0.07$ .

For both  $\gamma$ -ray energy ranges, the intercept shows a significant positive residual radiation. Due to the limited energy resolution of the SAS-2 instrument, these intercepts cannot be used directly to determine the energy spectrum of the isotropic component, but must be used together with the energy resolution function (Fichtel et al., 1975) and an assumed spectrum. If a power law spectrum is assumed, the differential index of a photon number spectrum is  $2.35 (+0.4, -0.3)$ , and the intensities above 35 MeV and above 100 MeV are  $(5.5 \pm 1.3) \cdot 10^{-5}$  and  $(1.3 \pm 0.5) \cdot 10^{-5}$  photons  $\text{cm}^{-2} \text{ster}^{-1} \text{s}^{-1}$

respectively. For the same quantities, Fichtel, Simpson, and Thompson (1978) found  $2.7 (+0.4, -0.3)$ ,  $(5.7 \pm 1.3) \cdot 10^{-5}$  and  $(1.0 \pm 0.4) \cdot 10^{-5}$  photons  $\text{cm}^{-2} \text{ster}^{-1} \text{s}^{-1}$ , when the comparison was made using atomic hydrogen column densities based on 21 cm measurements.

However, the  $\chi^2$  per degree of freedom for the case where the data are compared to the expression

$$I_{\gamma} = A/\sin |b| + B \quad (2)$$

is 50% or more larger for the two energy ranges than it is for the galaxy count case, suggesting this may be a significantly poorer representation. The  $A/\sin |b| + B$  form might be expected if the Compton radiation dominated at higher latitudes since the scale heights of cosmic rays and photons are thought to be about ten times, or more, that of the matter distribution. Thus, the cosmic rays and photons might be expected to be reasonably uniform in longitude locally for most of their distribution above the plane. An equation which on the average attributes half of the variable intensity to a  $A_1/\sin |b|$  term and half to a  $A_2[1.85 - \log(N_G)]$  term gives a  $\chi^2/\nu$  very nearly the same as a simple  $A_0[1.85 - \log(N_G)]$  variation.

### III. DISCUSSION

The central result of this work is a new derivation of the extragalactic component of the diffuse  $\gamma$  radiation measured by the SAS-2 instrument. Although based on the same  $\gamma$ -ray data as previous derivations, it represents an improvement in method because the galaxy counts trace the total interstellar matter column density. The high-latitude galactic  $\gamma$  radiation is expected

to result largely from cosmic ray interactions with matter (meson production and bremsstrahlung) and from Compton processes. The somewhat poorer fit of the  $A/\sin |b|$  term to the variable part of the  $\gamma$ -ray intensity as compared to the logarithm of galaxy counts suggests that the Compton components may not dominate at high latitudes locally. However, the fact that a uniform disk model and the use of galaxy counts as a galactic tracer give essentially the same result for the spectrum of the extragalactic  $\gamma$  radiation is a strong indication that no significant improvement in the derivation of the properties of the extragalactic  $\gamma$  radiation will be possible until much more detailed  $\gamma$ -ray observations are made. With these future observations, it should be possible not only to define the isotropic component much better, but to separate the Compton and matter components.

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## FIGURE CAPTIONS

- Figure 1: Distribution of the  $\gamma$ -ray intensity ( $E_\gamma > 100$  MeV) as a function of  $1.85 - \log$  (Galaxy counts per square degree) for galactic latitudes  $|b| > 10^\circ$ . Typical statistical uncertainties for the  $\gamma$ -ray data are shown. Points with fewer than 10  $\gamma$ -rays are not shown. Inset: acceptable ( $1\sigma$  above the minimum  $\chi^2$ ) values of the fitted parameters in the equation  $I_\gamma = A(1.85 - \log N_G) + B$ .
- Figure 2: Distribution of the  $\gamma$ -ray intensity ( $35 \text{ MeV} < E_\gamma < 100 \text{ MeV}$ ) as a function of  $1.85 - \log$  (Galaxy counts per square degree) for galactic latitudes  $|b| > 10^\circ$ . Typical statistical uncertainties for the  $\gamma$ -rays are shown. Points with fewer than 10  $\gamma$ -rays are not shown. Inset: acceptable ( $1\sigma$  above the minimum  $\chi^2$ ) values of the fitted parameters in the equation  $I_\gamma = A(1.85 - \log N_G) + B$ .

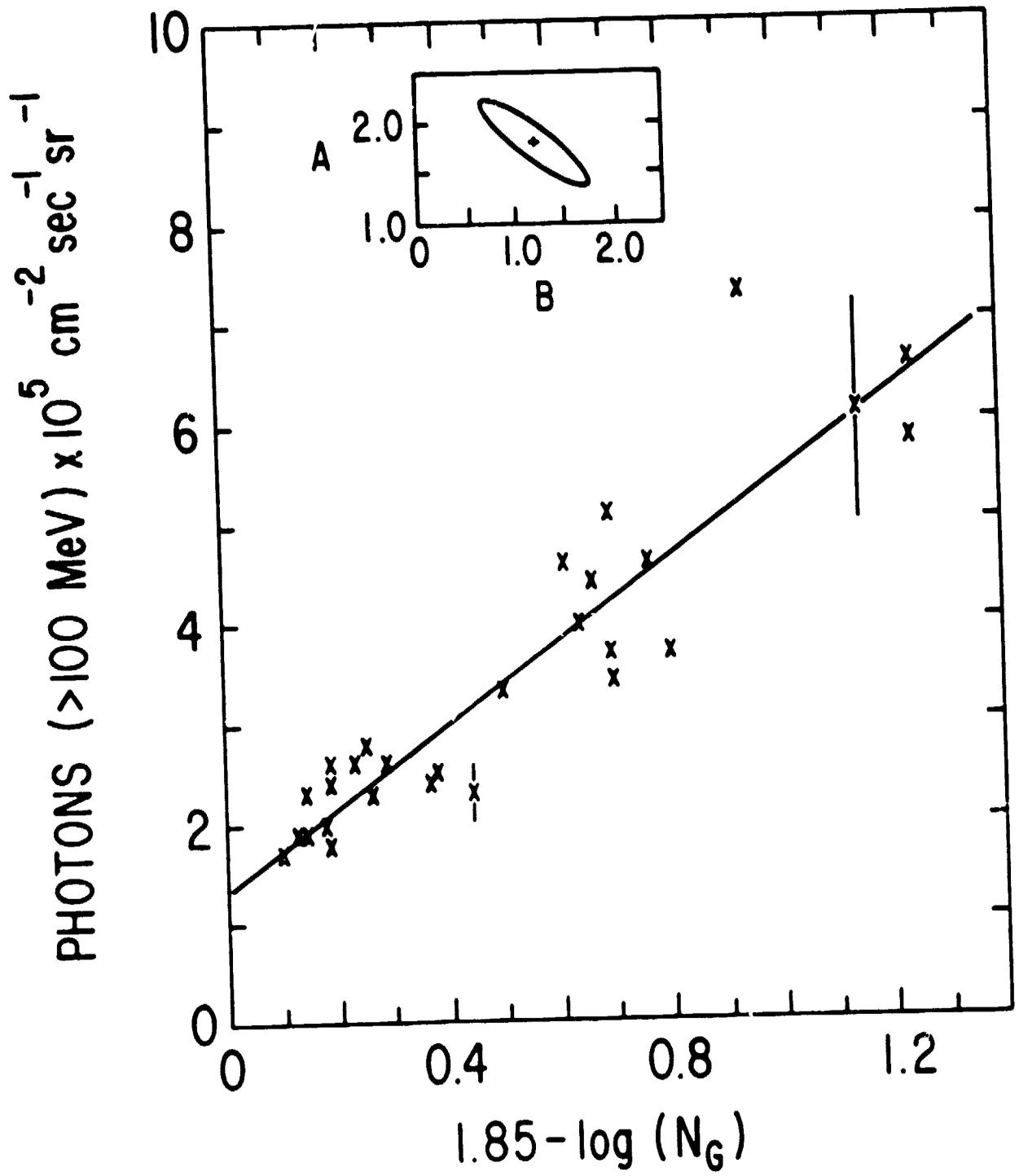


Figure 1

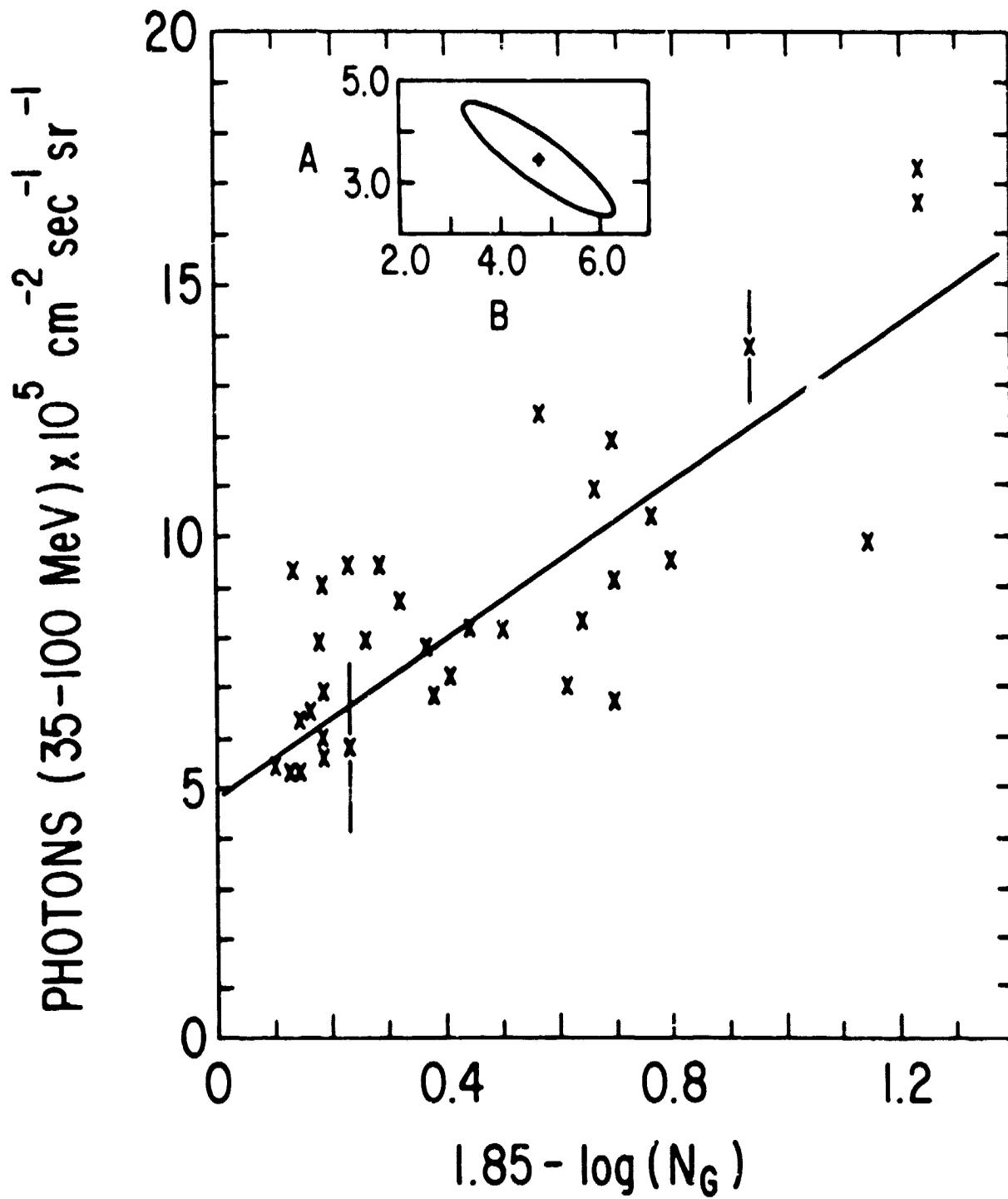


Figure 2