THE GALACTIC GAMMA-RAY DISTRIBUTION AND THE RADIAL COSMIC RAY GRADIENT

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ABSTRACT

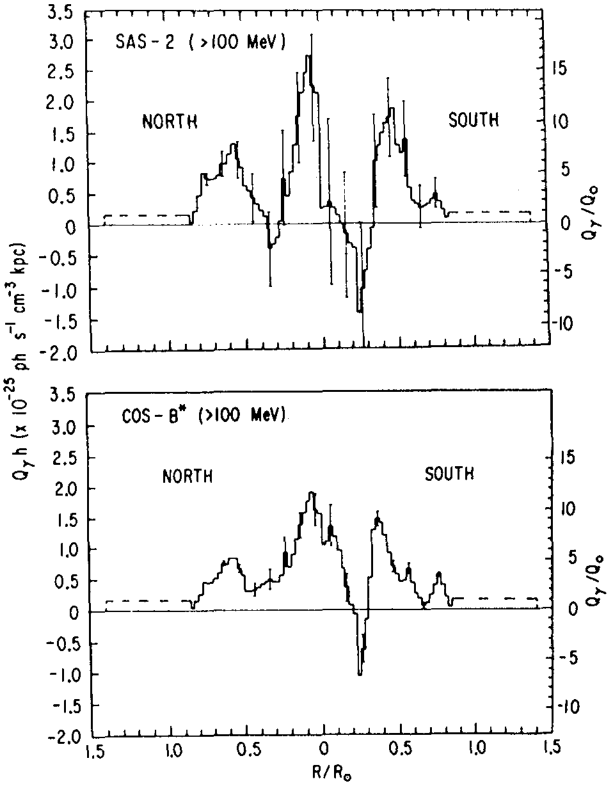
We have derived the radial distribution of gamma-ray emissivity and the cosmic ray intensity in the Galaxy using the final SAS-2 results, the recently corrected COS-B results, and recent CO surveys of the northern and southern galactic hemispheres. In addition to the "5 kpc ring" of enhanced emission, there is evidence for spiral features. We find a strong increase in the cosmic ray flux in the inner Galaxy, particularly in the 5 kpc region, in both halves of the plane.

1. Introduction. Gamma-ray astronomy provides a powerful tool for studying the origin and distribution of cosmic radiation and for revealing the galactic structure (1). The γ-ray emissivity in the galactic plane has a large maximum in a ring at about 5 kpc from the galactic center, related to the 5 kpc ring of giant molecular clouds in the Galaxy (2). Gamma-ray surveys can be used in conjunction with galactic surveys at other wavelengths to provide a "synoptic" approach to the problem of galactic structure (3). There is now information on the distribution of H_2 in the southern hemisphere (4,5). We make use of these new results, as well as SAS-2 γ-ray data, and COS-B γ-ray results, corrected for intrinsic background, to reexamine the galactic structure and galactic cosmic-ray gradient problems.

2. Unfolding Method. We have used the technique of Puget and Stecker (6) to unfold both SAS-2 and COS-B longitude data. The SAS-2 data for energies > 100 MeV from Hartman et. al (7) are integrated over latitudes $b \leq 10°$ with a longitude resolution of 2.5°. Ref.8 gives a COS-B longitude profile for energies > 100 MeV with a background subtraction of 8×10^{-5} ph cm^{-2} s^{-1} sr^{-1} above 70 MeV and a longitude resolution of 2.5° for direct comparison with the SAS-2 profile.

We assume cylindrical symmetry in each half of the galactic plane. Thus, the emissivity Q is only a function of galactocentric radius R. An outer galaxy flux contribution is determined by assuming a constant value $Q_0 = 1.1 \times 10^{-25}$ cm^{-3} s^{-1} (E > 100 MeV) and scale height h = 150 pc between r_o = 8.5 kpc and r_m = 14 kpc. The value of $Q_o = q_o \langle n_H \rangle$ was derived from a local γ-ray production rate $q_o = 1.9 \times 10^{-25}$ s^{-1} for E > 100 MeV (1), taking a local average H-atom density of $\langle n_H \rangle = 0.6$ cm^{-3}. This gives approximately the flux levels observed in the anticenter direction. Our adopted value for q_o agrees with that recently derived by Bloemen et al. (9) to within ~ 15%. They obtain q_o (>100 MeV) = 2.2 x 10^{-25} s^{-1} (extrapolating from a lower energy of 70 MeV). The outer galaxy flux contribution as determined above, was subtracted from the total flux to obtain the inner galaxy flux used in the unfolding.

3. Radial Emissivity Distributions. The radial distributions of γ-ray emissivity for the SAS-2 and corrected COS-B data at energies > 100 MeV are plotted in Fig. 1. The appearance of negative emissivities in



several regions is caused by a breakdown of cylindrical symmetry resulting from strong or local point sources and spiral structure. There is general agreement in the COS-B and SAS-2 emissivity distributions, the dominant features being (A) peaks between 5 and 6 kpc in the North and 4 and 5 kpc in the South which delineate an asymmetric ring of emission and (B) a secondary peak of emission around 7.5 kpc in the South, which is more pronounced in the COS-B data. The position and magnitude of the peak near the galactic center are uncorrected for significant contributions from local emission near $\ell=0°$ in the latitude range $b < 10°$. (see ref. 10). Figure 1 shows the radial emissivity distribution obtained from the COS-B flux

Fig. 1. Gamma-ray surface emissivity as a function of galactocentric radius in units of R_0 = 10 kpc, derived from the SAS-2 and corrected COS-B data at energies greater than 100 MeV. The right hand scale shows the emissivities relative to the local value.

after subtracting a small additional 0.2 X 10^{-4} cm^{-2} s^{-1} sr^{-1} intrinsic instrumental background correction over that of Ref. 8. Recent reanalysis of the COS-B detector background has indicated that such a higher background correction level may be justified, although the precise amount of this correction is still uncertain (Mayer-Hasselwander, private comm.). Within the errors, this emmisivity distribution agrees with the SAS-2 emissivity, but the peak-to-local ratios are still lower.

Our results on the COS-B radial distribution of > 100 MeV γ-rays give an emissivity in the 5 kpc ring which is 4-5 times the local value. This is significantly larger than the ratio of 2-3 obtained in Ref. (8) from an unfolding of the same data set. The discrepancy may be explained by the fact that our assumed value of $\langle n_H \rangle$ = 0.6 cm^{-3} (11) is lower than their assumed value of 1 cm^{-3}. A lower local emissivity gives a smaller flux contribution from the outer galaxy and therefore a larger remaining flux contribution from the inner galaxy. (We were in fact able to reproduce the results of ref. 8 by taking our local emissivity to be twice the value given in Section 2.)

4. Cosmic Ray Distribution. The results presented in the previous section give distributions of the total γ-ray emissivity in the Galaxy. This emission has two basic types of component: 1) diffuse

emission from cosmic rays interacting with gas or with a low energy radiation background, and 2) point source emission from pulsars, accreting compact objects, etc. The total point source contribution is uncertain, but estimates of the emission level from pulsars are in the range 15% - 20% or less and may be distributed like the diffuse emission (12) so that its effect does not distort the overall flux distribution. Therefore, information on the distribution of gas in the Galaxy can be used in conjunction with the γ-ray emissivity to yield information on the galactic cosmic-ray distribution (e.g., ref. 13).

The quantity, q_γ, the γ-ray emissivity per H-atom, is derived from the observed γ-ray volume emissivity, total gas density, n_{TOT}, and gas scale height, h_G. We use here the recent CO survey results of ref. (5) which gives radial distributions of CO emission for the northern and southern galactic hemispheres and scale heights as a function of galactic radius.

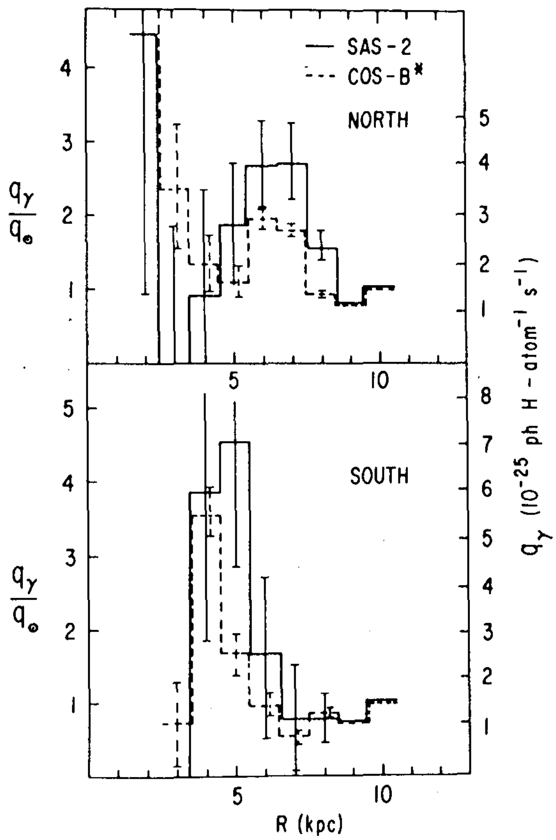


Figure 2 shows the radial distribution of q_γ(> 100 MeV) derived using the SAS-2 and COS-B emissivities plotted in Fig. 1. If all the γ-ray emissivity were from diffuse processes, q_γ would be proportional to the density of cosmic rays. Both the SAS-2 and COS-B data show evidence for an increase in the inner galaxy relative to local values in both the North and the South. The COS-B gradient, however, is smaller than the SAS-2 gradient due to smaller COS-B emissivities in the inner Galaxy. We find no statistically significant variation of the emissivity per H-atom derived from the 0.3 - 5 GeV COS-B data from the lower energy distribution plotted in Fig. 2, indicating that, at least in the inner Galaxy, cosmic-ray protons and electrons probably have the same radial distribution (14).

Fig. 2. Emissivity per H atom above 100 MeV derived from the radial surface emissivity distributions shown in Fig 1.

5. Discussion Of Results. Our results generally confirm the phonomenology of the 5 kpc "Great Galactic Ring" and cosmic ray gradient derived earlier (1) and extend the ring phenomenology to the southern hemisphere region of the Milky Way. In addition, the southern galactic region gives evidence of more structure than the northern region does, in particular, the enhanced γ-ray emission at a radial distance of 7 to 8 kpc from the galactic center. Such emission is more evident in the

COS-B data than the SAS-2 data. The overall emissivity pattern is consistent with the spiral pattern suggested in ref.(15) based on the distribution of HII regions. These indications support the thesis that the galactic γ-ray emission is associated with the youngest regions of star formation in the Galaxy (16).

The E_γ > 100 MeV data reveal evidence of a cosmic-ray gradient in the inner Galaxy on both the northern and southern hemisphere sides of the galactic disk. There is some evidence of this also in the highest energy COS-B data (14), which has the best angular resolution, and which may be the only spectral region clearly dominated by pion decay γ-rays (1).

The cosmic-ray gradient derived for both the northern and southern galactic hemispheres also appears to peak in the region of the Great Galactic Ring where the supernova and pulsar distributions also have a maximum. This naturally argues for a galactic origin of the bulk of the nucleonic cosmic γ-rays, which have energies in the 1-10 GeV range.

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