PUZZLES OF GALACTIC CONTINUUM γ-RAYS

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ABSTRACT Inverse Compton scattering appears to play a more important rôle in the diffuse Galactic continuum emission than previously thought, from MeV to GeV energies. We compare models having a large inverse Compton component with EGRET data, and find good agreement in the longitude and latitude distributions at low and high energies. We test an alternative explanation for the $\geq$1 GeV γ-ray excess, the hard nucleon spectrum, using secondary antiprotons and positrons. At lower energies to fit the COMPTEL and OSSE data as diffuse emission requires either a steep upturn in the electron spectrum below 200 MeV or a population of discrete sources.

KEYWORDS: gamma rays; Galaxy; cosmic rays; ISM; abundances; diffusion.

1. INTRODUCTION

We are developing a model which aims to reproduce self-consistently observational data of many kinds related to cosmic-ray origin and propagation: direct measurements of nuclei, antiprotons, electrons and positrons, γ-rays, and synchrotron radiation (SM98).

Recent results from both COMPTEL and EGRET indicate that inverse Compton (IC) scattering is a more important contributor to the diffuse emission that previously believed. COMPTEL results (Strong et al. 1997) for the 1–30 MeV range show a latitude distribution in the inner Galaxy which is broader than that of HI and H_2, so that bremsstrahlung of electrons on the gas does not appear adequate and a more extended component such as IC is required. The broad distribution is the result of the large z-extent of the interstellar radiation field (ISRF) which can interact cosmic-ray electrons up to several kpc from the plane. At much higher energies, the puzzling excess in the EGRET data above 1 GeV relative to that expected for π^0-decay has been suggested to orginate in IC scattering (e.g., PE98) from a hard interstellar electron spectrum.

2. MODELS

We consider a propagation model with reacceleration using parameters derived from isotopic composition (SM98). A new calculation of the ISRF has been made based on stellar population models and COBE data. The electron injection spectral index is taken as –1.7 (with reacceleration), which after propagation provides

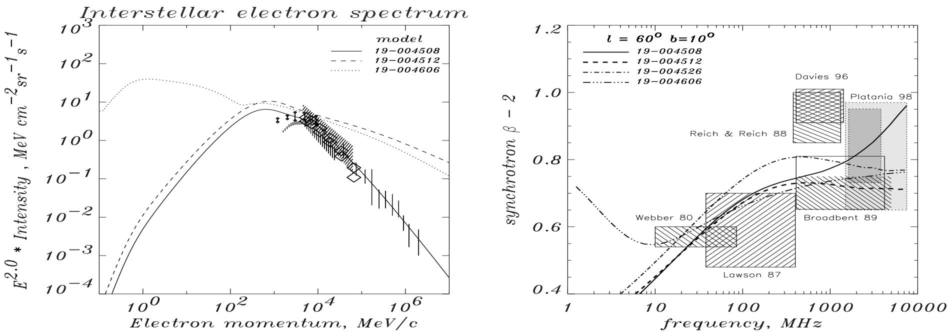

FIGURE 1. Left: Electron spectra at R=8.5 kpc in the plane, for 'normal' and hard electron spectrum models with and without low-energy upturn. Data points: direct measurements, see references in MS98. Right: Synchrotron spectral index for a representative direction for these electron spectra, compared to data.

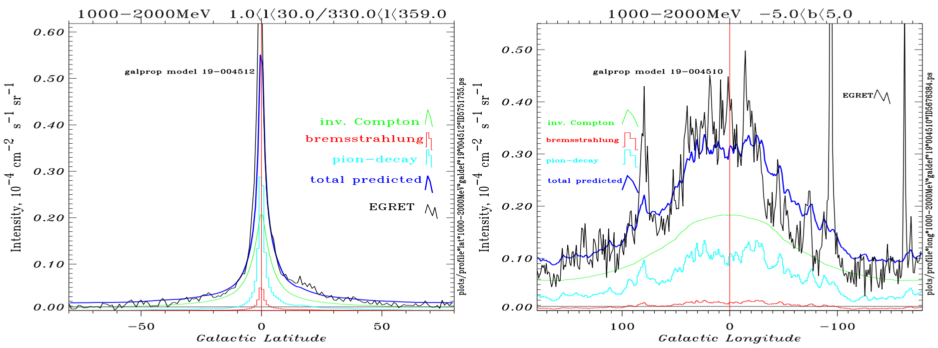

FIGURE 2. Left: Latitude distribution for 1–2 GeV (EGRET data), compared to reacceleration model with hard electron spectrum. Right: Longitude distribution for $|b| < 5°$. Note that point sources have not been removed from the data.

consistency with radio synchrotron data. Fig. 1 shows the electron spectrum at R = 8.5 kpc in the disk for these models, and the synchrotron index. Following PE98, for the present study we do not require consistency with the locally measured electron spectrum above 10 GeV since the rapid energy losses cause a clumpy distribution so that this is not necessarily representative of the interstellar average. The π^0-decay γ-rays are calculated explicitly from the propagated p and He spectra (Dermer 1986, MS98). A halo size (distance from plane to boundary) of z_h=4 kpc is adopted, consistent with our ^{10}Be analysis (SM98).

3. HARD ELECTRON SPECTRUM

Fig. 2 shows the model latitude and longitude γ-ray distributions for the inner Galaxy for 1–2 GeV, convolved with the EGRET point-spread function, compared

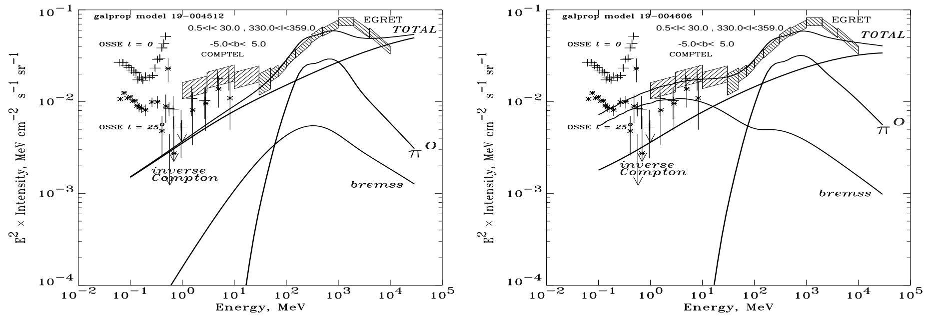

FIGURE 3. γ-ray spectrum of inner Galaxy (OSSE: Kinzer et al. 1997, COMPTEL: Strong et al. 1998, EGRET: Strong & Mattox 1996) compared to models with a hard electron spectrum without (left) and with low-energy upturn (right).

to Phase 1–4 data. It shows that a model with large IC component can indeed reproduce the data. The latitude distribution here is not as wide as at low energies owing to the rapid energy losses of the electrons, so that an observational distinction between a gas-related π^0-component from a hard nucleon spectrum and the IC model does not seem possible on the basis of γ-rays alone. This model does fit above 100 MeV, but does not fit the γ-ray spectrum below $\sim$30 MeV (Fig. 3 left). In order to fit the low-energy part as diffuse emission (Fig. 3 right) requires a rapid upturn in the CR electron spectrum below 200 MeV (e.g., as in Fig. 1). However, a population of unresolved sources seems more probable due to the energetics problems (Skibo et al. 1997) and would be the natural extension of the plane emission seen by OSSE and GINGA.

4. TEST FOR A HARD NUCLEON SPECTRUM USING $\bar{p}$ AND e^+

Fig. 4 shows another possible origin for the >1 GeV excess, an interstellar nucleon spectrum which is harder than observed locally (MSR98).

The $\bar{p}/p$ ratio expected for this case and the 'normal' spectrum compared to recent data is shown in Fig. 5 (left) (MSR98). Our 'normal' model calculation agrees with that of Simon et al. (1998). For the case of a hard nucleon spectrum the ratio is consistent with the data at low energies, but it is larger than the point at 3.7–19 GeV (Hof et al. 1996) by about 5σ. On the basis of the $\bar{p}/p$ data point $\geq$3 GeV we seem already to be able to exclude the hard nucleon spectrum, but confirmation of this conclusion must await more accurate data at high energies.

Fig. 5 (right) shows the interstellar positron spectrum for these cases (the formalism is given in MS98). The flux for the 'normal' case agrees with recent data. For the hard nucleon spectrum the flux is higher than observed; this provides more evidence against a hard nucleon spectrum. However this test is less direct than $\bar{p}$ due to the difference in particle type and the large effect of energy losses.

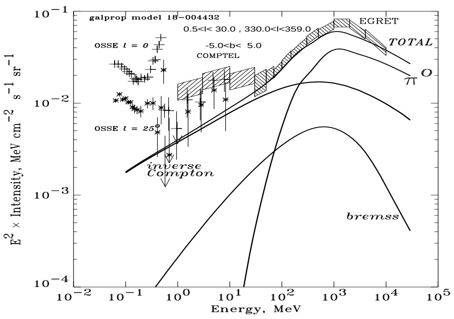

FIGURE 4. The same as in Fig. 3 but for a hard nucleon spectrum.

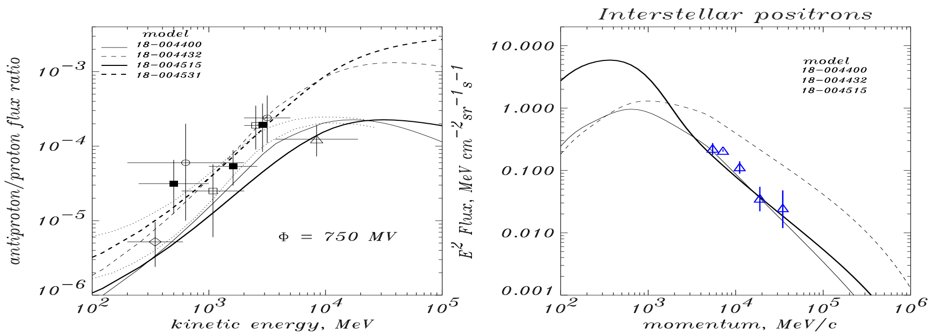

FIGURE 5. Left: $\bar{p}/p$ ratio for the 'normal' spectrum (solid lines) and for the hard nucleon spectrum (dashes) used for the γ-ray calculation. The thick lines show the case with reacceleration. Dotted lines: calculations of Simon et al. (1998). Data: see references in MSR98. Right: Spectra of secondary e^+'s for 'normal' (thin line) and hard (dashes) nucleon spectra (no reacceleration). Thick line: 'normal' case with reacceleration. Data: Barwick et al. (1998).

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