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The Galactic contribution to high latitude diffuse γ-ray emission

Andrew W. Strong[1], **Igor V. Moskalenko**[1,2], **and Olaf Reimer**[1]
[1]*MPI für extraterrestrische Physik, D–85740 Garching, Germany*
[2]*Institute for Nuclear Physics, Moscow State University, 119 899 Moscow, Russia*

Abstract

Recent evidence for a large Galactic halo, based on cosmic-ray radioactive nuclei, implies a significant contribution from inverse Compton emission at high Galactic latitudes. We present predictions for the expected intensity distribution, and show that the EGRET gamma-ray latitude distribution is well reproduced from the plane to the poles. We show that the Galactic component at high latitudes may be comparable to the extragalactic emission in some energy ranges.

1 Introduction:

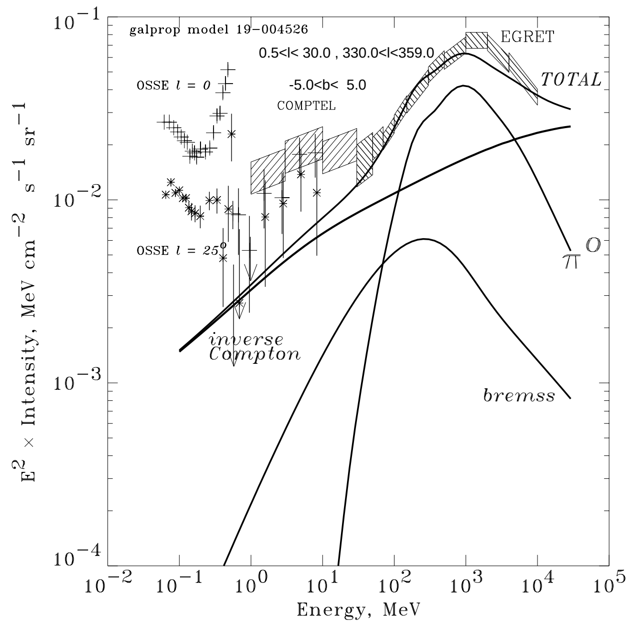
The origin of the truly extragalactic γ-ray background is still unknown. The models discussed range from the primordial black hole evaporation (Page & Hawking 1976) and annihilation of exotic particles in the early Universe (Cline & Gao 1992) to the contribution of unresolved discrete sources such as active galaxies (Sreekumar et al. 1998), while the spectrum of the extragalactic emission itself is uncertain. The latter can be addressed only by the accurate study of the Galactic diffuse emission at high Galactic latitudes. Moreover there is growing evidence for a large halo contribution to the γ-ray background. An indication for a γ-ray halo was also found by Dixon et al. (1998) from analysis of EGRET data. Studies of ^{10}Be (Strong & Moskalenko 1998) gave the range $z_h = 4 - 12$ kpc for nucleons, Webber & Soutoul (1998) find $z_h = 2 - 4$ kpc from ^{10}Be and ^{26}Al data, Ptuskin & Soutoul (1998) find $z_h = 4.9^{+4}_{-2}$ kpc.

Gamma rays provide a tracer of the electron halo via inverse Compton (IC) emission. A study of the Galactic emission requires a systematic approach: computation of a realistic interstellar radiation field and self-consistent calculation of the electron spectrum in 3D. We use our GALPROP model[1], which has been shown to be consistent with many kinds of data related to cosmic ray origin and propagation, to calculate the Galactic contribution to the high latitude diffuse γ-ray emission (Strong, Moskalenko, & Reimer 1999). The models have been described in full detail in Strong & Moskalenko (1998), for a recent review of our results see Strong & Moskalenko (1999).

2 Description of the models:

The models are three dimensional with cylindrical symmetry in the Galaxy. For a given halo size the diffusion coefficient (as a function of momentum) and the reacceleration parameters are determined by the Boron-to-Carbon ratio; the momentum-space diffusion coefficient is related to the spatial coefficient (Berezinskii et al. 1990). The injection spectrum of particles is assumed to be a power law in momentum, if necessary with a break. The magnetic field is adjusted to match the 408 MHz synchrotron longitude and latitude distributions. The interstellar hydrogen and He distribution uses HI and CO surveys and information on the ionized component. Energy losses for particles by ionization, Coulomb interactions, bremsstrahlung, inverse Compton, and synchrotron are included. The distribution of cosmic-ray sources is adjusted (Strong & Moskalenko 1998) to match the cosmic-ray distribution obtained from EGRET γ-ray data (Strong & Mattox 1996). The interstellar radiation field is based on stellar population models and COBE results, plus the cosmic microwave background (Strong, Moskalenko, & Reimer 1999). Inverse Compton scattering is treated as in Moskalenko & Strong (1999) including the effect of the anisotropy of the ISRF, and gas related γ-ray intensities (π^0-decay and bremsstrahlung) are computed using the column densities of HI and H_2 based on 21-cm and CO surveys.

[1]For interested users our model and data sets are available in the public domain on the World Wide Web, `http://www.gamma.mpe-garching.mpg.de/~aws/aws.html`



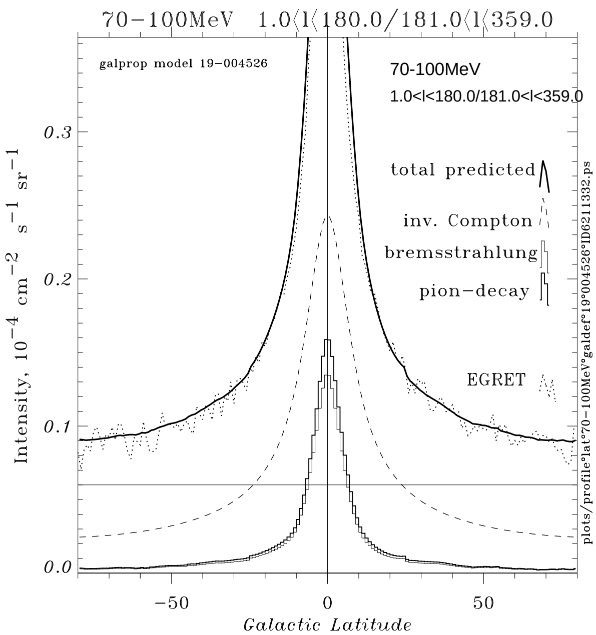


Figure 1: Gamma-ray energy spectrum of the inner Galaxy ($300^\circ \le l \le 30^\circ$, $|b| \le 5^\circ$) compared with our model calculations (electron injection index -1.8, and modified nucleon spectrum). Curves show the contribution of IC, bremsstrahlung, and π^0-decay, and the total. Data: EGRET (Strong & Mattox 1996), COMPTEL (Strong et al. 1999), OSSE ($l = 0, 25^\circ$: Kinzer et al. 1999).

Figure 2: High latitude distribution (enlarged) of 70–100 MeV γ-rays from the EGRET compared to our model calculation. Separate components: IC (dashes), bremsstrahlung (thin histogram), π^0-decay (thick histogram), horizonal line: isotropic background. EGRET data (point sources removed): dotted line.

3 Inner Galaxy:

Recent results from both COMPTEL and EGRET indicate that IC scattering is a more important contributor to the diffuse emission that previously believed. The puzzling excess in the EGRET data > 1 GeV relative to that expected for π^0-decay has been suggested to originate in IC scattering from a hard interstellar electron spectrum (e.g., Pohl & Esposito 1998). Our combined approach allows us to test this hypothesis (Strong, Moskalenko, & Reimer 1999).

Our first concern was to reproduce the γ-ray spectrum of the inner Galaxy. This is possible by invoking a hard electron spectrum with injection spectral index –1.8, which after propagation (with reacceleration) provides consistency with radio synchrotron data. Following Pohl & Esposito (1998), for this model we do *not* require consistency with the locally measured electron spectrum above 10 GeV because the rapid energy losses cause a clumpy distribution so that this is not necessarily representative of the interstellar average. For this case, the interstellar electron spectrum deviates strongly from that locally measured.

Further improvement can be obtained by allowing some freedom in the nucleon spectrum at low energies. Some freedom is allowed since solar modulation affects direct measurements of nucleons below 20 GeV, and the locally measured nucleon spectrum may not necessarily be representative of the average on Galactic scales either in spectrum or intensity due to details of Galactic structure (e.g. spiral arms). By introducing some flattening of the nucleon spectrum below 20 GeV, a small steepening above 20 GeV, and a suitable normalization, an improved match to the inner Galaxy EGRET spectrum is indeed possible (Fig. 1).

The modified nucleon spectrum must be checked against the stringent constraints on the *interstellar* spectrum provided by antiprotons and positrons. (Such tests sample the Galactic-scale properties of CR p and He

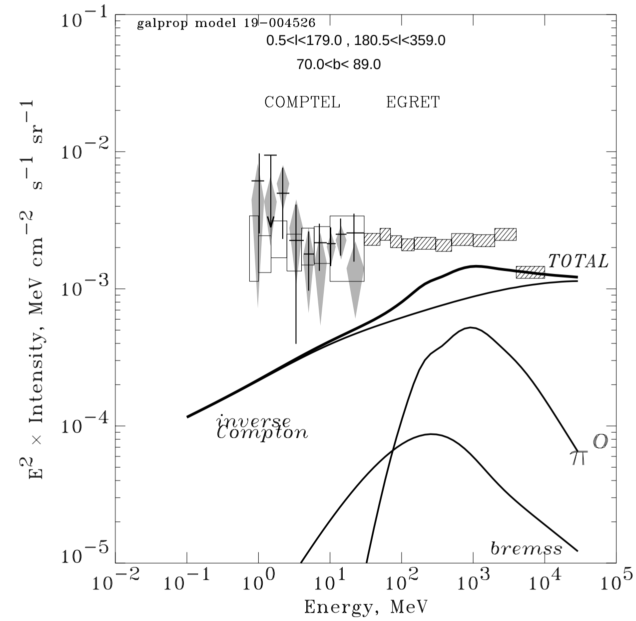


Figure 3: Energy spectrum of γ-rays from high Galactic latitudes ($|b| \geq 70°$, all longitudes) for $z_h = 4$ kpc (left) and $z_h = 10$ kpc (right). Shaded areas: EGRET total intensity from Cycle 1–4 data. COMPTEL data: high-latitude total intensity (open boxes: Bloemen et al. 1999, diamonds: Kappadath 1998, crosses: Weidenspointner et al. 1999).

rather than just the local region, independent of fluctuations due to local primary CR sources.) As expected the $\bar{p}$ and e^+ predictions are higher than for the conventional model (with nucleon spectrum matching the local measurements) but still within the observational limits (Strong, Moskalenko, & Reimer 1999).

This is our best model so far. Further tests against the γ-ray longitude and latitude profiles at all the EGRET energies show a good overall agreement (an example is shown in Fig. 2).

In order to reproduce the low-energy ($<$ 30 MeV) γ-ray emission via diffuse processes it is necessary to invoke an upturn of the electron spectrum below about 200 MeV to compensate the increasing ionization losses. (A steep slope continuing to higher energies would violate the synchrotron constraints on the spectral index.) However, the adoption of such a steep low-energy electron spectrum has problems associated with the very large power input to the interstellar medium (Skibo et al. 1997), and is *ad hoc* with no independent supporting evidence. Moreover the OSSE-GINGA γ-ray spectrum is steeper than E^{-2} below 500 keV (Kinzer et al. 1999) which would require an even steeper electron injection spectrum than adopted here. It is more natural to consider that the COMPTEL excess is just a continuation of the same component producing the OSSE-GINGA spectrum. Most probably therefore the excess emission at low energies is produced by a population of sources such as supernova remnants, as has been proposed for the diffuse hard X-ray emission from the plane observed by RXTE (Valinia et al. 1998), or X-ray transients in their low state as suggested for the OSSE diffuse hard X-rays (Lebrun et al. 1999).

4 High latitude γ-rays and the size of the electron halo:

We use our model for calculation of the Galactic contribution to the high latitude diffuse γ-ray emission. The high latitude γ-ray intensity increases with halo size due to IC emission (though much less than linearly due to electron energy losses), which allows us to put an upper limit on the halo size. Fig. 3 shows the γ-ray spectrum towards the Galactic poles for $z_h = 4$ kpc, and 10 kpc. $z_h = 10$ kpc is possible although the latitude profiles around 100 MeV are then very broad and at the limit of consistency with EGRET data. Further the isotropic component would have to approach zero above 300 MeV, so that this halo size can be considered an upper limit.

If the halo size is 4–10 kpc as we argue, the contribution of Galactic emission to the total at high latitudes is larger than previously considered likely and has consequences for the derivation of the diffuse extragalactic emission (e.g., Sreekumar et al. 1998). An evaluation of the impact of our models on estimates of the extragalactic spectrum is beyond the scope of the present work.

5 Conclusions:

The large electron/IC halo suggested here reproduces well the latitude variation of γ-ray emission from the plane to the poles, which can be taken as support for the halo size deduced from independent studies of cosmic-ray composition. Halo sizes in the range $z_h = 4 - 10$ kpc are favoured by both analyses.

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