Evidence for a discrete source contribution to low-energy continuum Galactic $\gamma$-rays

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Abstract. Models for the diffuse Galactic continuum emission and synchrotron radiation show that it is difficult to reproduce observations of both of these from the same population of cosmic-ray electrons. This indicates that an important contributor to the emission below 10 MeV could be an unresolved point-source population. We suggest that these could be Crab-like sources in the inner Galaxy. Alternatively a sharp upturn in the electron spectrum below 200 MeV is required.

I INTRODUCTION

Although ‘diffuse’ emission dominates the COMPTEL all-sky maps in the energy range 1–30 MeV, its origin is not yet firmly established; in fact it is not even clear whether it is truly diffuse in nature. This is in contrast to the situation at higher energies where the close correlation of the EGRET maps with HI and CO surveys establishes a major component as cosmic-ray interactions with interstellar gas. This paper discusses recent studies of the low-energy diffuse continuum emission based on the modelling approach described in [1]. The high energy (> 1 GeV) situation is addressed in [2,3]. The present work uses observational results reported in [4]; new imaging and spectral results from COMPTEL are presented in [5] but differences are not important for our conclusions.

II ELECTRONS, $\gamma$-RAYS AND SYNCHROTRON

Conventionally the low-energy $\gamma$-ray continuum spectrum has been explained by invoking a soft electron injection spectrum with index 2.1–2.4, and this could reproduce the 1–30 MeV emission as bremsstrahlung plus inverse Compton emission (see e.g. [6]). Fig 1 shows a range of electron spectra which result from propagation of injection spectral indices 2.0–2.4; the model is from [2]; in order to illustrate more...
FIGURE 1. Electron spectrum after propagation for various electron injection spectra. Injection index 2.0 to 2.4 (narrow full lines). Also shown is a spectrum which reproduces the high-energy \( \gamma \)-ray excess (dashed line) and a spectrum with a sharp upturn below 200 MeV which can reproduce the low-energy \( \gamma \)-rays without violating synchrotron constraints (dash-dot line). The thick solid line is a spectrum consistent with both local measurements and synchrotron constraints. For the data compilation see [2].

clearly the effect these spectra are without reacceleration. The nucleon spectrum is consistent with local observations and is described in [2]. Fig 2 shows the inner Galaxy \( \gamma \)-ray spectrum for the same electron spectra. The best fit is evidently obtained for index 2.2–2.3.

A problem with this, which was noted earlier but has become clearer with more refined analyses, is the constraint from the observed Galactic synchrotron spectrum on the electron spectral index above 100 MeV. The synchrotron index is hard to measure because of baseline effects and thermal emission, but there has been a lot of new work in this area, in part because of interest in the cosmic microwave background. Fig 3 summarizes relevant measurements of the synchrotron index together with the predictions for the range of electron spectra in Fig 1. The new 22–408 MHz value from [7] is of particular importance here; it is consistent with that derived earlier in a detailed synchrotron modelling study [8]. The \( \gamma \)-rays fit best for an injection index 2.2–2.3, but the synchrotron index for 100–1000 MHz is then about 0.8 which is above the measured range. Although we illustrate this for just one family of spectra for a particular set of propagation parameters, it is clear that it covers the possible range of plausible spectra so that changing the propagation model would not alter the conclusion. Hence we are unable to find an electron speci-
trum which reproduces the γ-rays without violating the synchrotron constraints. If there were a very sharp upturn in the electron injection spectrum below 200 MeV, as illustrated in Fig 1, then we could explain the γ-rays as bremsstrahlung emission without violating the synchrotron constraints, but even then it would not reproduce the intensities below 1 MeV measured by OSSE [9].

III AN UNRESOLVED SOURCE POPULATION?

In view of the problems with diffuse emission we suggest that an important component (at least 50%) of the γ-ray emission below 10 MeV originates in a population of unresolved point sources; it is clear that these must anyway dominate eventually as we go down in energy from γ-rays to hard X-rays (see e.g. [10]), so we propose the changeover occurs at MeV energies. For illustration we have tried adding (with arbitrary normalization) to the diffuse emission possible spectra for the unresolved population (Fig 4): a low-state Cyg X-1 type [11] appears too steep, but a Crab-like type ($E^{-2.1}$) would be satisfactory, and would require a few dozen Crab-like sources in the inner Galaxy. These would not be detectable as individual sources by COMPTEL and such a model not violate any observational constraints which we know of. In the examples in Fig 4 we have used the hard electron injection spectrum (index 1.8) required to fit the $>1$ GeV excess [2,3] so that with Crab-like sources we can finally reproduce the entire spectrum from 100 keV to 10 GeV.

This hypothesis has many observational consequences which can only be investigated by detailed modelling of source populations.

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FIGURE 2. Gamma-ray spectrum of the inner Galaxy for various electron injection spectra. Injection index 2.0 to 2.4 (from top to bottom), no reacceleration. Data: [9,4,12] (for details see [2]).
**FIGURE 3.** Synchrotron index for the electron injection spectra shown in Fig. 1. Thin solid lines (from bottom to top): injection index 2.0 to 2.4. Data: [7,8,13–17] (for details see [2]).

**FIGURE 4.** Gamma-ray spectrum of the inner Galaxy with possible unresolved source population components. The dashed lines show the assumed source contribution and the sum of source and diffuse components. The solid lines are the diffuse components alone. Left: Cyg X1- (low soft X-ray state) like source spectrum; Right: Crab-like source spectrum. The electron injection spectrum is hard (see text). Data as Fig 2.