Predictions for the magnitude of the Galactic Plane excess at TeV gamma ray energies

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Abstract

Our supernova remnant (SNR) model [3a] has been used, together with data on the distribution of gas in the galaxy, to predict the gamma ray intensity as a function of longitude and latitude (l, b). A prominent feature of the predictions for high energy gamma rays, $E_\gamma > 1$ TeV, is the presence of rather large fluctuations in intensity from one l, b to another—due to the stochastic nature of SN explosions which give rise to apparent 'sources' of various sizes.

Here we make predicitions for the expected Galactic Plane excess intensities at TeV energies. The analysis includes a brief consideration of the EGRET data [6] and the first TeV measured excess at MILAGRO [4].

1. Introduction

With the advent of precision measurements of low energy gamma rays ($\leq$ 30 GeV) by the EGRET detector [5,6,9] and the start of TeV observations of the Galactic disk by the MILAGRO detector [4] there is the possibility of examining cosmic ray spectra at remote locations, specifically in the Galactic Centre and Anti-Centre regions.

The EGRET observations have already revealed that the gamma-ray-initiating cosmic ray spectrum is flatter (harder) in the Inner Galaxy than in the Outer Galaxy [6]. We have explained this [3b] by changing the mode of particle propagation from the normal Gaussian form to 'anomalous' diffusion [7] and we have argued that there are good physical reasons for the particular choice of anomalous diffusion parameters in various regions of the Galaxy.

When observations at TeV energies are of similar precision to those from EGRET it will be possible to study the equivalent situation for CR in the tens of TeV region.

2. The Calculations

The adopted distribution of the SN rate and gas is shown in Figure 1. The fit for the SN rate distribution was taken from [8]. The model for cosmic ray acceleration and propagation is described in [3a]. The basic data for the gas

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distribution come from [1] and relate to the surface density of HI and H_2.

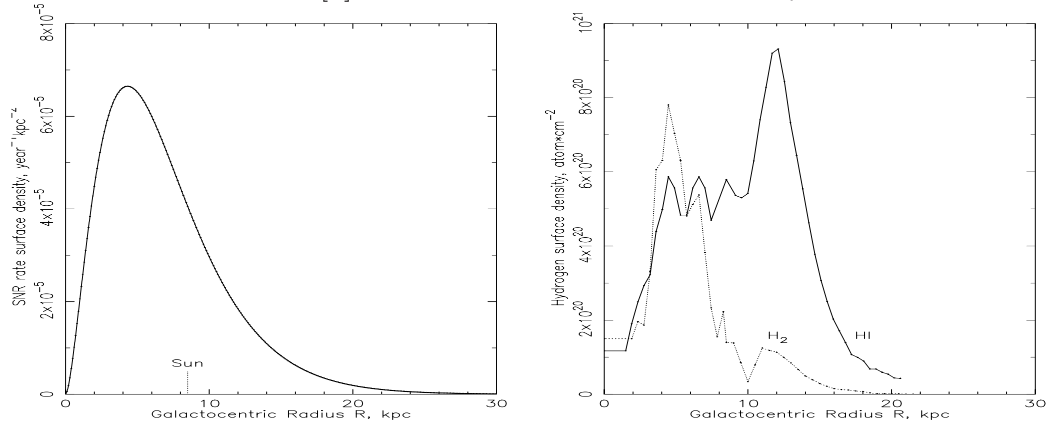

Fig. 1. The adopted distributions of SN rate and gas. The Sun is at $R = 8.5$ kpc.

Neither is known with great precision because of uncertainty about the Galactic rotation curve in the Outer Galaxy and the standard problem (for H_2) of not knowing accurately what value to adopt for the conversion factor, X, to go from the measured CO-signal to the column density of molecular hydrogen. Here we study both the case where X is constant (and equal to 1.8, in the usual units) and where $X = X(R) = 10^{0.0933(R-8.5)} X_{\text{local}}$, where R is the Galactocentric distance in kpc. The motivation for the latter comes from the connection of X with the metallicity in the ISM and it will be given elsewhere.

As for the gamma ray emissivity our recent work [3c] gives values close to those of [2] for p-p interactions. Inclusion of heavier nuclei in the CR beam and in the ISM leads to an increase in the gamma ray yield by 2.30 for the lower energy band ($E_\gamma > 0.1$ GeV) and 2.8 for $E_\gamma > 1$ TeV.

A consequence of the adoption of anomalous diffusion is that the lateral distribution of particles has a very long tail and in consequence the Halo is well-populated. The result is that more energy needs to be injected into CR than our canonical 10^{50} erg and/or the relevant SN rate is higher than adopted 10^{-2} y^{-1}.

3. The Results

Figure 2 shows the longitude distributions derived, for 3 latitudes and for the 'basic' set of gas parameters, both for $E_\gamma > 0.1$ GeV and for $E_\gamma > 1$ TeV. The irregular structure—due to the resolution of individual SNR—is particularly marked for the higher-energy data. The singularly large fluctuations at the highest energies arise because of the very slow diffusion of particles from their sources in the anomalous diffusion case. With 'normal' Gaussian diffusion the fluctuations will be smaller but still significant insofar as that, in the model, CR spend $\sim$20% of their time, before escape from the Galaxy, inside their parent SNR.

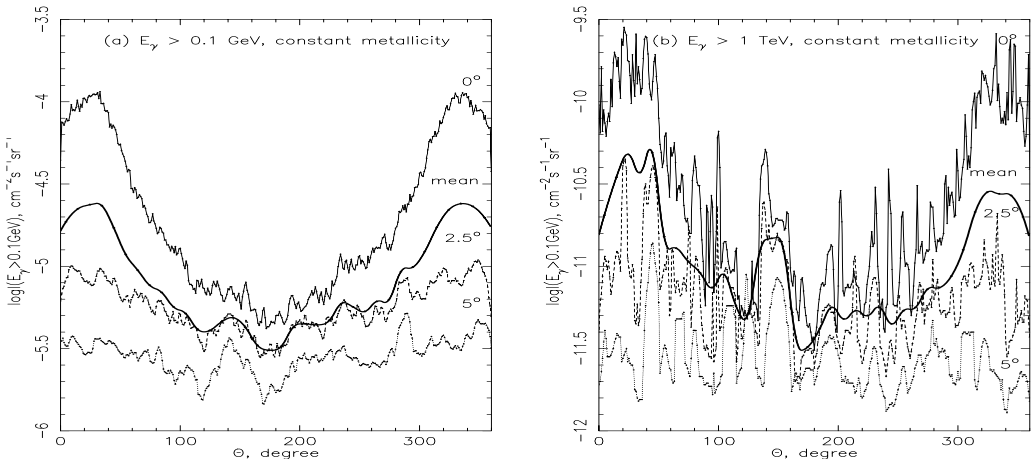

Fig. 2. Predicted longitude distributions of gamma ray intensity above the energies shown, for three latitudes and the mean over $|b| < 5°$. The absolute values need increasing.

4. Comparison with Experiment

4.1. The EGRET Results

The EGRET results [6] have been examined in detail and Figure 3 shows a comparison with our predictions. Our spectrum has been normalised at 300 MeV for the reasons given previously. Inspection of the Figure shows the flattening in the Inner Galaxy.

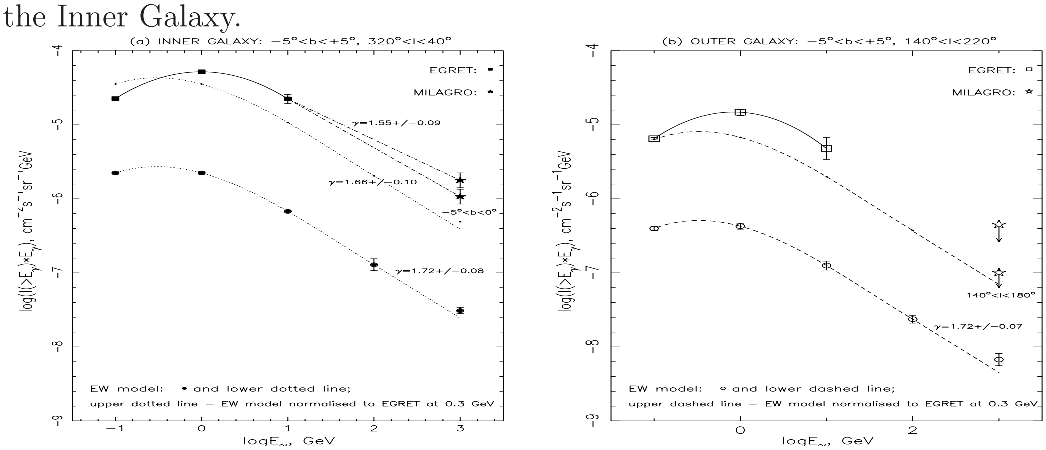

Fig. 3. Integral spectra for the Inner and Outer Galaxy. The EGRET intensities are from the work [6] and the MILAGRO points are from the (preliminary) work [4]. The latter for the Inner Galaxy having a mean longitude of about 60° have been displaced upwards to correspond to the longitude range $|l| < 40°$ using our calculations of $I_\gamma(l)$. MILAGRO mean intensities are also given for l, b regions without those affected by the strongest source, or source complex; these are the lower values.

Our calculations *with* $X(R)$ lead to an increase in $\log I$ by 0.40 in the Inner Galaxy: $l = 0°$, $b = 0°$. For the Anti-centre: $l = 180°$, $b = 0°$, the effect is a reduction in $\log I$ by 0.20. Application to the EGRET results for the energy range $E_\gamma > 0.1$ GeV to $E_\gamma > 10$ GeV gives good agreement when X is a function of R. This result was also found (but not interpreted in this way) in [9].

4.2. The MILAGRO Results

In [4] a Galactic Plane excess is reported for $|b| < 5°$ for the Inner Galaxy ($20° < l < 100°$). The intensity is quoted as $(9.5 \pm 2.0) \times 10^{-10}$ cm^{-2} sr^{-1} s^{-1} for $E_\gamma > 1$ TeV. Analysing the TeV map of the Inner Galaxy from MILAGRO we identify a region of high emission in the Cygnus region. This is a region where SASII and COSB saw 'sources' and where EGRET reported eight unidentified sources. It seems very likely that the MILAGRO excess in the region $0° < b < +5°$ and $60° < l < 100°$ is due in part to these sources and to the well known excess in the Cygnus region. In consequence, we have estimated the Inner Galaxy intensity for $-5° < b < 0°$ only; this is some 60% of that for the whole region (Figure 3).

Turning to the Outer Galaxy ($140° < l < 220°$), [4] quotes a mean intensity above 1 TeV, for $|b| < 5°$, with a 99% (3σ) upper limit of 4.5×10^{-10} cm^{-2} sr^{-1} s^{-1}. However, it is our view that Geminga contributes significantly and for a 'clear' area ($140° < l < 180°$) the 99% upper limit is $\sim 1 \times 10^{-10}$ cm^{-2} sr^{-1} s^{-1} only.

5. Discussion and Conclusions

There is support for the spectrum of gamma rays from the Inner Galaxy being flatter than that predicted by our initial model. The upper spectrum (no source rejection) in Figure 3, with $\gamma = 1.55 \pm 0.09$, is flatter than that predicted by the model ($\gamma = 1.72 \pm 0.08$). Since our model has a constant mode of diffusion throughout the Galaxy ($\alpha = 1$) it means that $\alpha < 1$ in the Inner Galaxy [3b].

Concerning the Outer Galaxy the result is less clear cut because the observations only give an upper limit to the intensity at the 99.9% c.l. A more conventional upper limit (say 90%) coupled with neglect of the longitudinal range occupied by Geminga would give a steeper spectrum in the Outer Galaxy than locally, again in agreement with our contention.

There is evidence for the dependence of a cosmic-ray-relevant astrophysical quantity on Galactocentric radius. The case for X being higher in the Outer Galaxy than in the Inner seems strong.

6. References

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