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What do the New Detections of the Galactic Disk in the TeV region Tell Us ?

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Latest measurements of diffusive TeV gamma rays from the Inner Galaxy (MILAGRO) indicate that the cosmic ray (CR) energy spectrum in the Inner Galaxy is the same as that locally.

1. Introduction

The EGRET observations of the diffuse GeV gamma-rays in our Galaxy showed that there are variations of the gamma-ray intensity with longitude and latitude in the Galactic Disk. The energy spectrum of gamma rays in the Inner Galaxy ($-40^\circ < l < 40^\circ$) at low Galactic latitudes ($|b| < 2^\circ$) turned to be flatter than in the Outer Galaxy ($140^\circ < l < 220^\circ$) [1], a result which attracted considerable interest and gave rise to a number of models for its explanation [2, 3, 4, 5]. We ourselves explained this effect by the difference of the turbulence spectrum and consequently of the character of anomalous diffusion in the Inner Galaxy where the rate of supernova (SN) explosions is higher and in the Outer Galaxy where SN activity is low [6].

Until recently all the observations of the Galactic Disk in gamma rays at higher, TeV and sub-PeV energies gave only upper limits [7, 8, 9, 10]. Two years ago the MILAGRO collaboration presented the first positive observations of the Galactic Disk in TeV gamma rays [11, 12]. The flux of gamma rays in the region covering a substantial part of the Inner Galaxy: $20^\circ < l < 100^\circ, |b| < 5^\circ$ turned out to be $F_{in}(> 1TeV) = (9.5 \pm 2.0) \cdot 10^{-10} cm^{-2}s^{-1}sr^{-1}$ in [11] and $(8.0 \pm 3.3) \cdot 10^{-10} cm^{-2}s^{-1}sr^{-1}$ in [12]. The upper limit on the flux in the Outer Galaxy ($140^\circ < l < 220^\circ$) was obtained as $F_{out}(> 1TeV) < 4.5 \cdot 10^{-10} cm^{-2}s^{-1}sr^{-1}$ [11].

In order to compare these preliminary MILAGRO results with those of EGRET taken in another longitude range we applied a correction factor to convert the intensity in the $20^\circ - 100^\circ$ longitude range to that in the -40° to $+40^\circ$ range using our calculations of the gamma ray fluxes [13]. We obtained the slope of the gamma ray integral spectrum in the Inner Galaxy ($-40^\circ < l < 40^\circ, |b| < 5^\circ$) equal to $\gamma = 1.55 \pm 0.09$ in the 10 -1000 GeV energy range. Comparing it with the slope of $\gamma = 1.72 \pm 0.08$ expected from our model assuming the same spectrum of CR all over the Galaxy we concluded that the CR energy spectrum in the Inner Galaxy could indeed be flatter than locally and, moreover, flatter than in the Outer Galaxy.

2. New measurements and calculations

. The latest measurements made by MILAGRO collaboration were presented for a reduced longitude interval: $40^\circ < l < 100^\circ$. The gamma ray flux is quoted as being lower than in their preliminary publications: $F_{in}(> 1TeV) = (5.1 \pm 1.0 \pm 0.7) \cdot 10^{-10} cm^{-2}s^{-1}sr^{-1}$ [14, 15] as expected for the different longitudinal range. We used our updated calculations of the gamma ray flux to re-estimate the conversion factor from the $40^\circ < l < 100^\circ$ to $-40^\circ < l < 40^\circ$ longitude interval. The updated calculations are shown in Figure 1, the intensities are higher by a factor of 2, fluctuations reduced slightly, but the slopes of the energy spectra remain practically the same. In Figure 2 we compare the EGRET with the new MILAGRO result recalculated by us for the 'true' Inner Galaxy, i.e. for $-40^\circ < l < 40^\circ$ longitudes. It is seen that the reduction of the intensity in the new

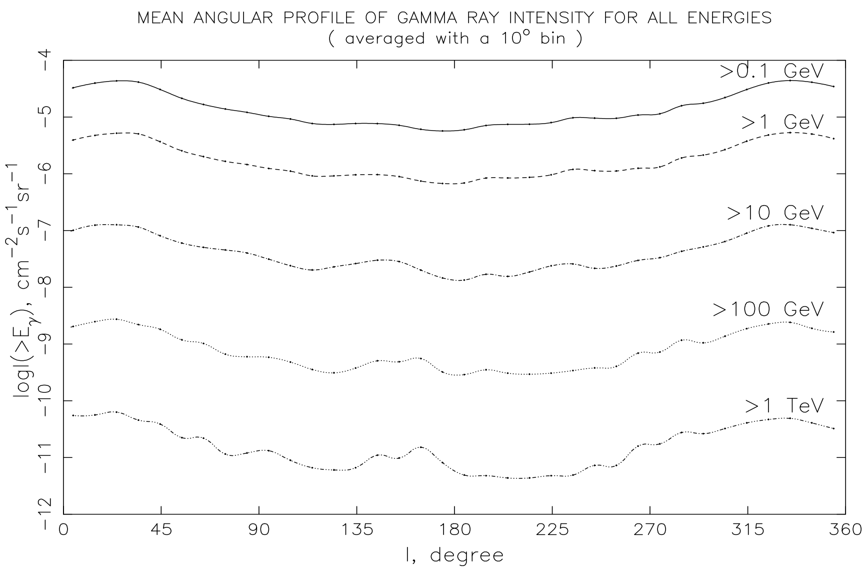

Figure 1. Calculated Galactic longitude dependence of the gamma ray intensity above energies 0.1, 1, 10, 100 and 1000 GeV for latitudes $|b| < 5°$. To reduce big fluctuations an averaging has been made within $10°$ longitude bins.

MILAGRO measurements is not compensated by the increase of the conversion factor from $40° \div 100°$ to $-40° \div 40°$ longitudes and the new intensity in the Inner Galaxy is now lower than before. The slope of the integral energy spectrum between 10GeV (EGRET) and 1 TeV (MILAGRO) now is larger than before and equal to $\gamma = 1.63 \pm 0.09$ which coincides with that expected for our model $\gamma = 1.66 \pm 0.04$ within error bars.

3. Discussion and Conclusions

We have to say that our estimate of the flux in the Inner Galaxy at $-40° < l < 40°$ made on the basis of MILAGRO measurements at $40° < l < 100°$ and our calculated conversion factor from $40° \div 100°$ to $-40° \div 40°$: 2.43±0.55, may in fact be an upper limit. The longitude dependence of the gamma ray intensity at $E_\gamma > 0.1GeV$ shown in Figure 1 shows a larger gradient than that found by EGRET. At higher energies *eg* at $E_\gamma > 1TeV$ our calculations show that the gradient is about the same. If it is actually lower then our conversion factor has to be also lower and the actual intensity has to be correspondingly lower and an agreement between slopes of the spectra in the model and in the measurements seems to be even better.

The smaller radial gradient and the similarity of gamma ray energy spectra in the Inner Galaxy and locally can indicate the presence of the mechanism smoothing the effect of the radial distribution of the supernova and the interstellar gas. We attribute this smoothing to the substantial contribution of the Galactic Halo to the CR intensity at these energies [16]. However, there are problems about metallicity gradients in the Galaxy and the need for a Halo at low energies is still the subject of study. Above CR knee, however, a Halo appears to be certainly needed.

Turning to the conclusions we confirm the conclusion made by the MILAGRO collaboration that the intensity of diffuse gamma rays in the $40° \div 100°$ longitude interval at $E_\gamma > 1TeV$ reported by them agrees with that

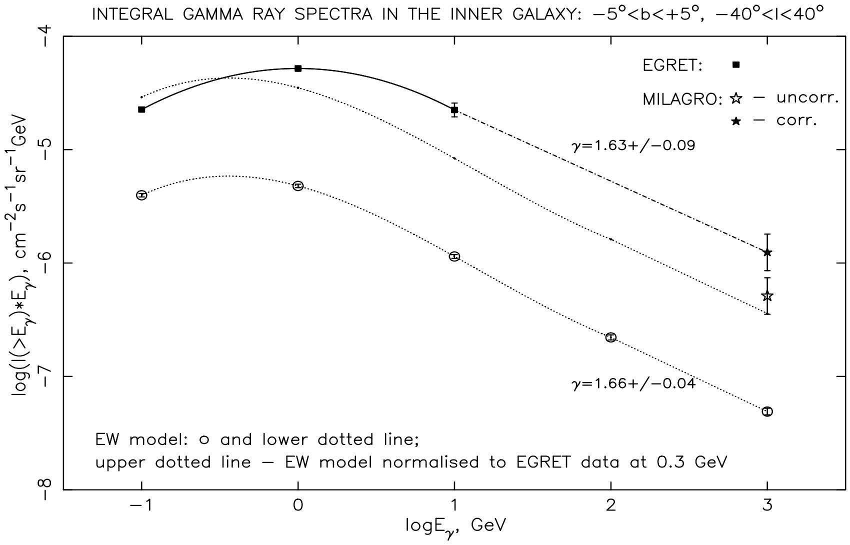

Figure 2. Integral spectra of the gamma rays for the Inner Galaxy ($|l| < 40°$). EGRET intensities are from [1] and the MILAGRO points are from [14]. The latter for the MILAGRO latitude range $40° - 100°$ have been displaced upward to correspond to the range $|l| < 40°$, using our calculations of $I_\gamma(E,l)$. The calculated spectrum shown by the lower dotted curve has been normalized to the EGRET intensity at 0.3 GeV - the upper dotted curve. Slopes of the spectra are indicated in the Figure.

expected from the extrapolation of EGRET data at about 10 GeV and extend it to the 'true' Inner Galaxy, i.e. to $-40° \div 40°$ longitude interval.

The integral energy spectrum between 10 GeV and 1 TeV has the slope $\gamma = 1.63 \pm 0.09$ which agrees with that calculated on the basis of the model of the CR in the Galaxy which implies the universal character of their acceleration and propagation independent of the distance from the Galactic Centre: $\gamma = 1.66 \pm 0.04$. However, if the calculated spectrum is normalized to EGRET measurements at 0.3 GeV, the 'GeV excess' found at $E_\gamma > 1$ GeV still holds.

Since there should be a dependence $\gamma(R)$ of the spectrum slope on the Galactocentric distance connected with the higher supernova rate in the Inner Galaxy, we explain the observed independence by the substantial contribution of the Galactic Halo to the observed smooth distribution of CR. Another option is that a flatter CR energy spectrum can be confined in the region $|l| < 40°$ of the Inner Galaxy invisible by MILAGRO.

A number of other relevant points should be made:
(i) Much of the MILAGRO Inner Galaxy signal comes from the CYGNUS region ($l : 80° \pm 5°$, $|b| < 5°$). The inferred spectrum for this region is flatter than the ambient one both for the EGRET data themselves ($\gamma \approx 1.5$ for $0.3 < E_\gamma < 1$ GeV) and for the combined EGRET/MILAGRO set ($\gamma = 1.48 \pm 0.1$).
(ii) The likelihood of flatter spectra for regions of higher than average CR activity (chance - or expected (SN clusters) - associations) can be seen in Figure 1 for our model where, at $l \sim 160°$ the relative intensity of the blob increases with increasing E_γ. An analysis of the origin of such blobs shows that they are a consequence of the recent SNR with their intrinsic flat CR energy spectra observed either *on* or *very close* to the line of sight and not necessarily close to the observer.
(iii) EGRET shows other longitude regions where the spectra are flatter than 'normal'.
(iv) The effect of large scale CR anisotropies on the data is not clear cut. Our analysis of the world's data in

the region of 10^{13}eV suggests that there should be very little difference in 'background' intensity between the Inner and Outer MILAGRO regions but this conclusion is not a firm one.

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