The Galactic Diffuse Gamma-rays at Extremely High Energies

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Abstract

The Galaxy is not transparent to PeV gamma-rays due to loss by pair production with cosmic microwave background radiation: however, it becomes transparent again above about 100 PeV. Diffuse gamma-rays produced in collisions of cosmic-rays with interstellar matter should have a spectrum extending to this extremely high energy regions as long as extreme-high-energy cosmic-rays prevail in the Galaxy. Here we present a new calculation of their expected flux and discuss its detectability.

1 Introduction

Most of the high-energy photons detected by the Energetic Gamma Ray Experiment Telescope (*EGRET*) on board the *Compton Gamma Ray Observatory* consist of diffuse gamma-rays, i.e., secondary gamma-rays produced in collisions of cosmic-rays and interstellar medium. Its energy spectrum measured by *EGRET* extends up to about 50 GeV and shows a harder spectral index expected from cosmic-ray origin [1]. Since the diffuse gamma-rays above about 200 MeV are produced mostly from decay of neutral pions produced in cosmic-ray interactions with interstellar matter, this fact may indicate a possible difference in the spectral indice of cosmic-ray spectra between the solar neighborhood and the Galactic center region [2]. In any way, the diffuse gamma-ray flux should extend to higher energies as long as the cosmic-ray spectrum extends. Some authors have calculated this flux up to TeV energy region [3, 4]: since PeV gamma-rays are severely absorbed by the cosmic microwave background radiation ($\gamma + \gamma \rightarrow e^+ + e^-$), their calculations were confined below this energy. Here we present a new calculation applicable to extremely high energies where the absorption does not play a significant role and explore the possibility to detect the Galactic center as a point source at these energies.

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2 Gamma-ray production in cosmic-ray interactions

The gamma-ray source function via neutral pion decay produced in cosmic-ray interactions with interstellar matter is given by Stecker [5]:

$$q(E_\gamma) = 4\pi n_H \int_{E_\gamma + m_\pi^2/4E_\gamma}^{\infty} \mathrm{d}E_\pi \cdot 2 \int_{T_p^{\min}(T_\pi)}^{\infty} \mathrm{d}T_p \frac{j_p(T_p)}{\sqrt{E_\pi^2 - m_\pi^2}} \frac{\mathrm{d}\sigma(T_p, T_\pi)}{\mathrm{d}T_\pi} \epsilon^{\mathrm{M}}(T_p)$$

where the cosmic-ray proton flux is denoted by $j_p(T_p)$ [$\mathrm{cm}^{-2}\mathrm{s}^{-1}\mathrm{sr}^{-1}\mathrm{GeV}^{-1}$], $\mathrm{d}\sigma(T_p, T_\pi)/\mathrm{d}T_\pi$ is the differential cross section for the production of a π^0 with kinetic energy T_π in the Galactic (rest) system due to a collision of a cosmic-ray proton of kinetic energy T_p with a H atom at rest, E_π is the total pion energy and m_π is its mass, and n_H is the atomic hydrogen density. $T_p^{\min}(T_\pi)$ is the minimum proton kinetic energy that contributes to the production of a pion with energy T_π which can be calculated from the kinematics easily. ϵ^{M} is the nuclear enhancement factor to take account of the contribution of cosmic-rays heavier than protons and of non-hydrogen targets [6].

Following Dermer [7], we write $\mathrm{d}\sigma(T_p, T_\pi)/\mathrm{d}T_\pi = \langle\zeta\sigma_\pi(T_p)\rangle \mathrm{d}N(T_p, T_\pi)/\mathrm{d}T_\pi$, where $\langle\zeta\sigma_\pi(T_p)\rangle$ is the inclusive cross section for the reaction $p + p \rightarrow \pi^0 +$ anything (ζ is the π^0 multiplicity) and $\mathrm{d}N(T_p, T_\pi)/\mathrm{d}T_\pi$ is the normalized π^0 spectrum. The inclusive cross section was taken from Dermer [8] below 1 TeV and a fit from the PYTHIA Monte Carlo simulation [9], $163(s/1876\,\mathrm{GeV}^2)^{0.21}$ mb (s is the center-of-mass energy of a collision), was used above 1 TeV. The gamma-ray spectra from fixed-energy p-p collisions, $2\int_{E_\gamma + m_\pi^2/4E_\gamma}^{\infty} \mathrm{d}E_\pi [j_p(T_p)(E_\pi^2 - m_\pi^2)^{1/2} \mathrm{d}N(T_p, T_\pi)/\mathrm{d}T_\pi]$, were calculated using the Monte Carlo code COSMOS [10] in order to treat collisions consistently up to extremely high energies, which are shown in Fig.1.

The cosmic-ray proton spectrum was fit in the form

$$j_p(E_p) = \begin{cases} 6.08 \times 10^{-6} (E_p/10^2\,\mathrm{GeV})^{-2.66} & ; E_p < 2.7 \times 10^6\,\mathrm{GeV} \\ 1.70 \times 10^{-25} (E_p/10^9\,\mathrm{GeV})^{-3.03} & ; \text{otherwise} \end{cases} \quad (1)$$

based on the compilation by Gaisser and Stanev [11]. For the nuclear enhancement factor, $\epsilon^{\mathrm{M}} = 1.52$ [12] was used as a constant.

3 Results

The preliminary results are given as a ratio (gamma-ray flux) / (cosmic-ray flux) for the direction toward the Galactic center ($|\ell| < 1^\circ$, $n_H = 5.75 \times 10^{22}$ cm^{-2} [3]) in Fig.2, taking into account of the gamma-ray absorption by the cosmic microwave background radiation [13] where the distance to the Galactic center is assumed to be $d = 8$ kpc. One can see that this ratio falls off rather rapidly above about 1 PeV, even if the γ-γ absortion is switched off. This is partly because of the so-called "knee" feature of the cosmic-ray spectrum around several times 1 PeV, but another reason may be the scaling breaking assumed at the extremely-high-energy interactions which reduces the particle density in the fragmentation region.

In summary, the preliminary result from the calculation of extreme-high-energy diffuse gamma-ray flux from the Galactic center region is presented and may imply the difficulty to detect such gamma-rays among the ovewhelming background of charged cosmic-rays.

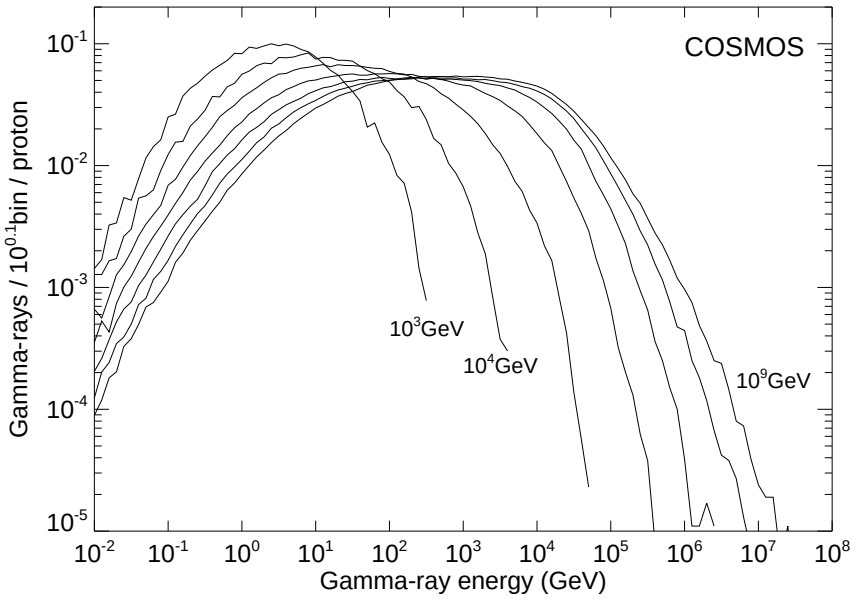

Figure 1: Gamma-ray spectra produced in p-p collisions simulated by the COSMOS Monte Carlo code. Each curve correspond to $E_p = 10^3, 10^4, \ldots, 10^9$ GeV from upper left to lower right, respectively.

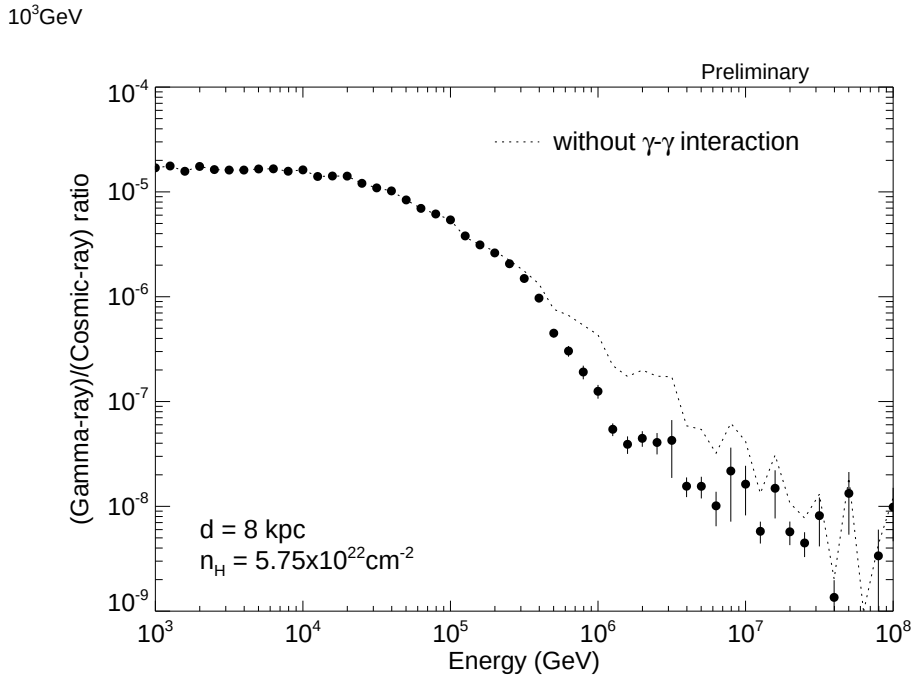

Figure 2: The (gamma-ray)/(cosmic-ray) ratio for the direction toward the Galactic center ($|\ell| \leq 1°, d = 8\,\mathrm{kpc}, n_\mathrm{H} = 5.75 \times 10^{22}\,\mathrm{cm}^{-2}$) as a function of energy. Error bars show statistical errors due to Monte Carlo calculation.

References

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