Diffuse Gamma Rays from the Galactic Plane in the TeV region

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Abstract

The diffuse gamma rays beyond 1 TeV from the Galactic plane have been considered as mainly due to the inverse Compton(IC) scattering of the interstellar photons with the high-energy cosmic-ray electrons. In the recent studies of the evolution of SNR, the electron spectrum inside the SNR at the high energy side are suppressed by the synchrotron loss or the insufficient time for the acceleration. The electron spectrum is approximated as the power law spectrum with exponential form of $E^{-\gamma}exp[-E/E_{max}]$ [12]. We calculate the diffuse gamma-ray spectrum for E_{max}=10,20,50,100 TeV, and discuss the significance of these results by comparing with the gamma-ray flux observed by experiments. In addition to these IC gamma rays by the interstellar electrons, the electrons inside the sources also contribute significantly to the high-energy gamma rays.

1. Introduction

Porter and Prothroe have evaluated the Galactic diffuse gamma-ray spectrum with Monte Carlo method [10]. We also reported the gamma-ray spectrum of latitude range $|b| \leq 5°$ and $|b| \leq 2°$ from the electrons of power law spectrum, and compared with the experimental data [14]. Beyond 1 TeV, main contribution to the Galactic diffuse gamma rays is due to the IC process of electrons. The direct observations of cosmic-ray electrons become more difficult with increasing their energies [8][9][15], because of low flux of high energy electrons, and difficulties of identification of an electron shower from the copious background showers by cosmic-ray protons. Futhermore, the electron spectrum beyond around 1 TeV is suffered by a large fluctuation due to small numbers of the nearby contributing sources [1][8][9]. Thus, it is essentially difficult to estimate the high energy electron spectrum in the intersteller space by the direct observations around the Solar system. Observations of diffuse gamma rays above TeV region give us a clue on the average feature of the electron spectrum, because we observe the integration of the contribution from the location of each IC scattering in the Galaxy.
In the study of the evolution of shell-type SNRs, the free expansion phase con-

pp. 2285–2288

tinues until total mass of gas swept out by the shock equals to the initial ejected mass taking $10^2 \sim 10^3$ yr, and then the Sedov phase follows. The maximum energy of accerelated electrons in these phases are limited by the synchrotron losses and the duration in the accerelation cite. The studies of the observed X-ray spectrum of 24 SNRs indicate that the electron spectrum is approximated as a form of $N(E) = KE^{-\gamma} exp(-E/E_{max})$ with E_{max} of 10 to 80 TeV[5][12]. Thus the flux of the gamma-rays is suppresed depending on the value of E_{max} .

2. Gamma-ray Energy Spectrum

We calculate the electron spectrum by using a diffusion model . Ignoring the effect of the radial diffusion, electron flux J_e at a distance, z, perpendicular to the Galactic plane accelerated t years ago, is given by,

$$
\begin{aligned}
J_e(E, z, t) &= Q_0 E^{-\gamma} \frac{(1 - bEt)^{\gamma - 2}}{\sqrt{4\pi D1}} \exp\left(\frac{-z^2}{\sqrt{4\pi D1}} - \frac{E}{E_{max}(1 - bEt)}\right) \\
D1 &= D_0 (E/GeV)^{\delta} (1 - bEt)^{1-\delta} / ((1 - \delta) bE),
\end{aligned}
$$

where b is the coefficient of energy loss by synchrotron and inverse Compton processes. The production spectrum at the source is assumed to be a form of $Q_0 E^{-\gamma} exp[-E/E_{max}]$. Numerical values of δ and D_0[8][9] are listed in Table 1. Assuming the thickness of the source distribution as $z_0 \sim 100$ pc, the electron spectrum is gived by a power law with a spectral index of $-\gamma - (1+\delta)/2$ [3] around 10 GeV$\sim$100 TeV, if we ignore the suppression by $exp[-E/E_{max}]$. The absolute flux of the electrons was normarized to agree with the observed data at 10 GeV [9]. The radial distribution of electron sources in the Galactic plane, $\phi(R, l)$, was assumed the Gaussian distribution with σ=10 kpc. $\psi(R, z)$ is the total energy density of radiation field of CMB, stellar and dust components[13].
The IC gamma-ray energy spectrum, $J_\gamma(\epsilon, l, b)\mathrm{d}\epsilon$, is given by

$$
\begin{aligned}
J_\gamma(\epsilon, l, b)\mathrm{d}\epsilon &= \mathrm{d}\epsilon \int\int\int \phi(R, l)\psi(R, z) J_e(E, z, t) \frac{\mathrm{d}^2 N_{\gamma,\epsilon}}{\mathrm{d}t\mathrm{d}E} \mathrm{d}t\mathrm{d}l\mathrm{d}E \\
R^2 &= L\mathrm{cos}b^2 + R_s^2 - 2LR_s \mathrm{cos}b\mathrm{cos}l,
\end{aligned}
$$

where $d^2 N_{\gamma,\epsilon}/\mathrm{d}t\mathrm{d}E$ is the production rate of gamma rays by the inverse Compton process with Klein-Nishina cross section. R_s is the distance from the Sun to the Galactic center. R is the distance from the Galactic center to the location of the Compton scatteriing in the plane and L is the line-of-sight distance. We assume that the radius of the Galaxy and Rs are 15kpc and 8.5 kpc, respectively. The calculated energy spectrum of gamma rays, averaged over the latitude range $|b| \leq 2^\circ$ and $|b| \leq 5^\circ$ for l=0°, are shown in Fig. 1 with the observed the data. Fig.

Table 1. Injection spectral index of the electrons at the source and diffusion coefficient. $< B^2 >^{1/2}$ is assumed to be 6.7 μG [16],$1/b$=2.3×10^5 yr.TeV.

Index γ	2.4	2.2	2.0
δ	0.3	0.5	0.5
$D_0(\mathrm{cm}^2/\mathrm{s})$	$4{\times}10^{28}$	10^{28}	10^{28}

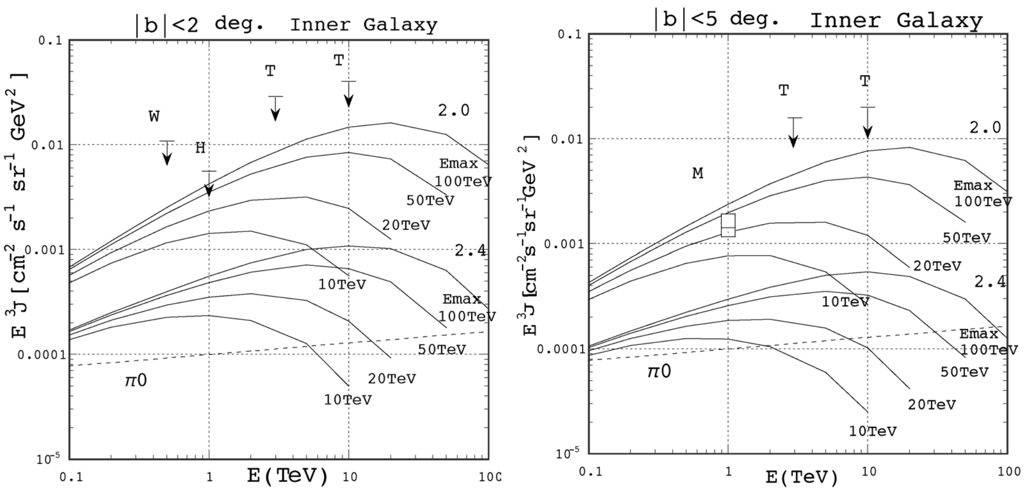

Fig. 1. The diffuse gamma-ray spectra with γ=2.0,2.4. The observed data are T [2], W [11] H [7] and M [4]. M is the flux estimated by thier observed integral flux.

2 shows the the energy spectra of gamma rays with γ= 2.2 for E_{max} = 10,20,50 and 100 TeV. We can exclude the hard spectral index than 2.0 of the injection spectral index of the electrons at the source.

3. Discussions and Conclusions

We calculate the gamma-ray spectrum with the electron spectrum of exponential suppression at high energy side and compare to the observed data.
1. The spectral index of electrons at the source with smaller than 2.0 is excluded by the comparison to the results of the experiments.
2. In addition to the IC gamma rays by the interstellar electrons, we expect the contribution from electrons at the acceleration cite. Assuming the dwelling time of the electrons inside the source is a few times of $10^3 \sim 10^4$ yr, about 100-1000 such active Galactic sources are expected if the SN rate is 1/30yrs. Most of them are not identified as point sources, but are classified as unresolved point sources. The contribution of those electrons is shown in Fig. 2 assuming the dwelling time is 10^4 yr inside the source. The flux of gamma rays of 10TeV from

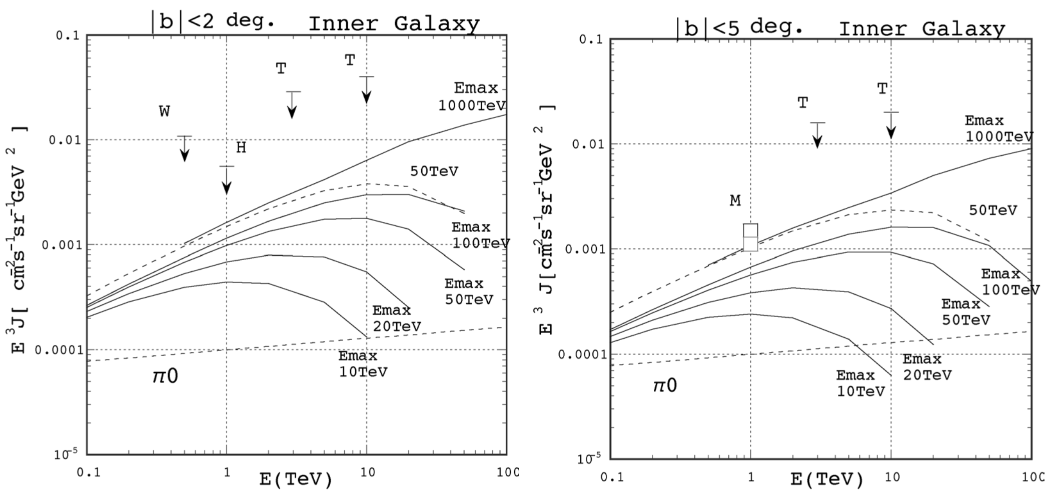

Fig. 2. The diffuse gamma-ray energy spectra with γ=2.2 for l=0°. The dotted line indicates an example of the contribution from the unresolved electron sources, in the case of E_{max} =50TeV with dwelling time of the electrons are 10^4 yr. The contibutin of π^0 is for |b|$\leq$ 10° [6].

unresolved sources is about 2 times of that due to the interstellar electrons. The unresolved point sources give significant contributions for the diffuse gamma rays at high-energy region depending on their residence time in the source.

4. References

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