Fermi LAT Observations of the Supernova Remnant G8.7-0.1


Yoshitaka Hanabata (Hiroshima Univ.), Hideaki Katagiri (Ibaraki Univ.), Takaaki Tanaka (KIPAC/Stanford), Elizabeth Hays (NASA/GSFC) for the Fermi LAT collaboration

Sep 22 2011
ASJ meeting@Kagoshima Univ.
SNR G8.7-0.1

- Mixed Morphology SNR
- Distance: 3.2-6 kpc
- Middle-Aged: $1.5 - 2.8 \times 10^4$ yr
- Molecular clouds (MCs) and single OH maser are found in the vicinity of the G8.7-0.1.

The relationship among G8.7-0.1 and TeV unidentified source HESS J1804-216 is interesting for diffusion process of cosmic rays.

π$^0$ decay gamma rays from the interaction of the MCs and the SNR are expected.
Analysis Procedures

- Data set: ~23 months survey mode data from Aug 4, 2008 to July 9, 2010 (MET: 239557417 - 300403505)

- Science Tools: v9r15p2

- Selections:
  - 0.2-100 GeV, P6_V3_Diffuse, Zenith cut < 105 deg
  - ROI: 20x20 deg
  - No LAT GRB in ROI

- Binned likelihood with gtlike
  - Diffuse model: gll_iem_v02.fit, isotropic_iem_v02.txt
  - 1FGL sources included in the model
Comparison with other wavelength images

VLA 90cm (25,50,75%)

NANTEN(\textsuperscript{12}CO J=1-0) 20-30km/s (25,50,75%)

HESS (25,50,75%)

Source E: major emission part, significantly extended (Disk radius of $\sigma=0.37^\circ$) and positional coincidence with the radio emission.

Source W: consistent with a point source model and has no counterpart. The GeV gamma rays overlap with spatially-connected MCs.

+: PSR J1803-2137, +: PSR J1806-2125, +: Suzaku J1804-2140, $\circ$: SNR G8.31-0.09
Morphological Correlation

Morphological correlation with emissions of other wavebands were evaluated with binned likelihood using 2-100 GeV data.

<table>
<thead>
<tr>
<th>Spatial Model</th>
<th>-2Δlog(L_0/L)</th>
<th>Additional Degree of Freedom</th>
</tr>
</thead>
<tbody>
<tr>
<td>Null Hypothesis</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3 point sources</td>
<td>433.4</td>
<td>12</td>
</tr>
<tr>
<td>VLA 90 cm + Source W</td>
<td>436.5-462.4*</td>
<td>6</td>
</tr>
<tr>
<td>HESS</td>
<td>404.8-408.0*</td>
<td>2</td>
</tr>
<tr>
<td>Uniform disk and point source</td>
<td>477.8</td>
<td>9</td>
</tr>
</tbody>
</table>

*To allow for background fluctuation, fits were performed with various extracted regions, where a lower limit is changed 0-15% of the peak emission.

The radio morphology correlates reasonably well with the GeV emission while the TeV morphology does not.
The GeV emission is dominated by Source E.

**Total spectrum**
- Having a spectral break around $\sim 2.4$ GeV ($4.4\sigma$).
- Not consistent with the extrapolation of the TeV spectrum. (Quantitatively evaluated by Chi-square test.)
The GeV gamma-ray spectrum is naturally explained by $\pi^0$ decay produced by the interaction of the MCs and particles accelerated by G8.7-0.1. The emission from secondary particles does not affect to the conclusion.

Leptonic models struggle to match the GeV emission.

- Brems.: $K_{ep}$ is required much larger than $\sim 0.01$ (local cosmic-ray abundance).
- IC: A large amount of electron energy ($\sim 10^{51}$ erg) is required unless the radiation filed is 10 times larger than our best guess.
One Explanation of the TeV emission

- The GeV emission: interaction of particles confined in the SNR and adjacent MCs.
- TeV spectral index: 2.72 +/- 0.06
  - Consistent with the particle spectral index predicted by a theory assuming the energy-dependent diffusion of particles accelerated in an SNR (e.g., Aharonian & Atoyan 1996)

Performing the modeling for the GeV and TeV spectra with the above theory.

For the TeV emission, particle spectrum (Gabici et al., 2009)

\[ f(E, R, t) = \frac{N_0 E^{-s}}{\pi^{3/2} R_{\text{diff}}^3} \exp \left( -\frac{R^2}{R_{\text{diff}}^2} \right) \, \text{GeV}^{-1} \, \text{cm}^{-3} \]

\[ R_{\text{diff}} = 2\sqrt{D(E)(t - \chi(E))} \]

\( \chi(E) \) represents the confinement of particles

Diffusion coefficient (free parameter)

\[ D(E) = D_{10}(E/10 \, \text{GeV})^\delta \]
Modeling for GeV-TeV spectrum

Assumption for the modeling
spectral index $s=2.0$, $K_{ep}=0.01$
$n_H=100 \text{ cm}^{-3}$ for the GeV and TeV MCs

Diffusion coefficient is constrained to be
$D_{10}: 0.75-5.4 \times 10^{26} \text{ cm}^2/\text{s}, \delta = 0.6$

$D_{10} \sim 10^{26} \text{ cm}^2/\text{s}$ is expected in a dense environment (Orems et al. 1988).

$D_{10}$: Lower limit

Obtained by the cutoff energy of particle spectrum:
$$R_{\text{TeV}}^2/R_{\text{diff}}^2 = R_{\text{TeV}}^2/[4D_{10}(E/10 \text{ GeV})^\delta (t - \chi(E))], \quad R_{\text{TeV}} > 26 \text{ pc} \text{ (apparent size of the SNR)}$$

Upper limit

Observed flux $F_{\text{TeV}} \propto W_{\text{tot}}D_{10}^{-3/2}10^{3\delta/2}M_{\text{TeV}}/4\pi d^2$

Upper limit of $M_{\text{TeV}}$ is constrained to be $2.0 \times 10^6 M_{\odot}$ by NANTEN.

TeV emission is naturally explained by the interaction of the escaped particles and MCs. (Although PWN origin cannot be ruled out.)
Summary

- Detailed investigation of GeV gamma rays around the SNR G8.7-0.1.
  - The major emission part is significantly extended and positional coincidence with G8.7-0.1.
  - They are overlapped with spatially-connected MCs.
  - The GeV spectrum is naturally explained by the $\pi^0$ decay in MCs interacting with the particles accelerated by G8.7-0.1.

Relation between the GeV and TeV emission

- The GeV morphology does not correlate well with the TeV emission and the GeV spectrum is not consistent with the extrapolation of the TeV spectrum.
- The TeV spectrum is explained by the interaction of the energy-dependent diffusion of particles accelerated in G8.7-0.1 and MCs.
Back-up Slids
The average surface brightness of the G8.7-0.1 region is \( \sim 2 \) times larger than that of the Galactic plane.

No gamma-ray pulsations are found around G8.7-0.1.
Modeling Assumption

- Particle injection: impulsive source assumption (injected at $t=0$).
- Particle spectrum: smoothed broken power-law (constrained by the radio spectrum).
- Electron Energy loss: ionization (Coulomb scattering), bremsstrahlung, synchrotron processes, IC scattering (The modification of the electron spectral distribution calculated by Atoyan (1995).)
- Distance: 4.0 kpc
- Age: $2.5 \times 10^4$ yr
# Modeling Results

Table 2: Parameters of the models for the Fermi LAT sources.

<table>
<thead>
<tr>
<th>Model</th>
<th>$K_{ep}$ $^a$</th>
<th>$s_L$ $^b$</th>
<th>$p_b$ $^c$</th>
<th>$s_H$ $^d$</th>
<th>$B$</th>
<th>$\bar{n}_H$ $^e$</th>
<th>$W_p$ $^f$</th>
<th>$W_e$ $^f$</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) Pion ($\bar{n}_H = 100 \text{ cm}^{-3}$)</td>
<td>0.01</td>
<td>2.0</td>
<td>3</td>
<td>2.7</td>
<td>100</td>
<td>100</td>
<td>2.8</td>
<td>4.6 \times 10^{-2}</td>
</tr>
<tr>
<td>(b) Pion ($\bar{n}_H = 1000 \text{ cm}^{-3}$)</td>
<td>0.01</td>
<td>2.0</td>
<td>3</td>
<td>2.7</td>
<td>400</td>
<td>1000</td>
<td>0.30</td>
<td>7.2 \times 10^{-4}</td>
</tr>
<tr>
<td>(c) Bremsstrahlung</td>
<td>1</td>
<td>2.0</td>
<td>5</td>
<td>2.7</td>
<td>25</td>
<td>100</td>
<td>0.22</td>
<td>0.36</td>
</tr>
<tr>
<td>(d) Inverse Compton$^g$</td>
<td>1</td>
<td>2.0</td>
<td>15</td>
<td>3.5</td>
<td>1</td>
<td>0.1</td>
<td>48</td>
<td>99</td>
</tr>
</tbody>
</table>