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

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

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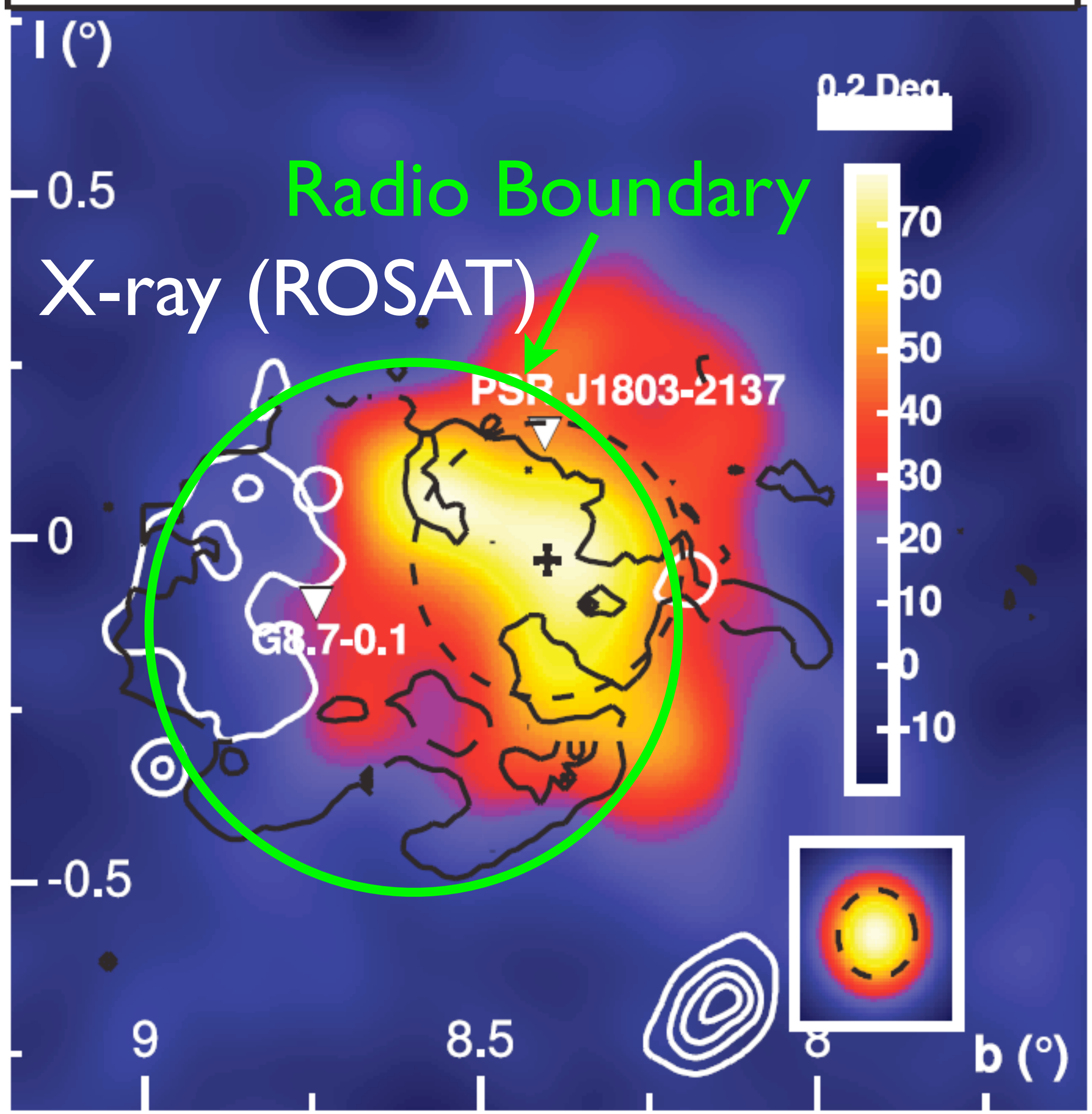
SNR G8.7-0.1

TeV count map:
HESS J1804-216
(Aharonian et al. 2006)



- Mixed Morphology SNR
- Distance: 3.2-6 kpc
- Middle-Aged: 1.5 - 2.8x10^4 yr
- Molecular clouds (MCs) and single OH maser are found in the vicinity of the G8.7-0.1.

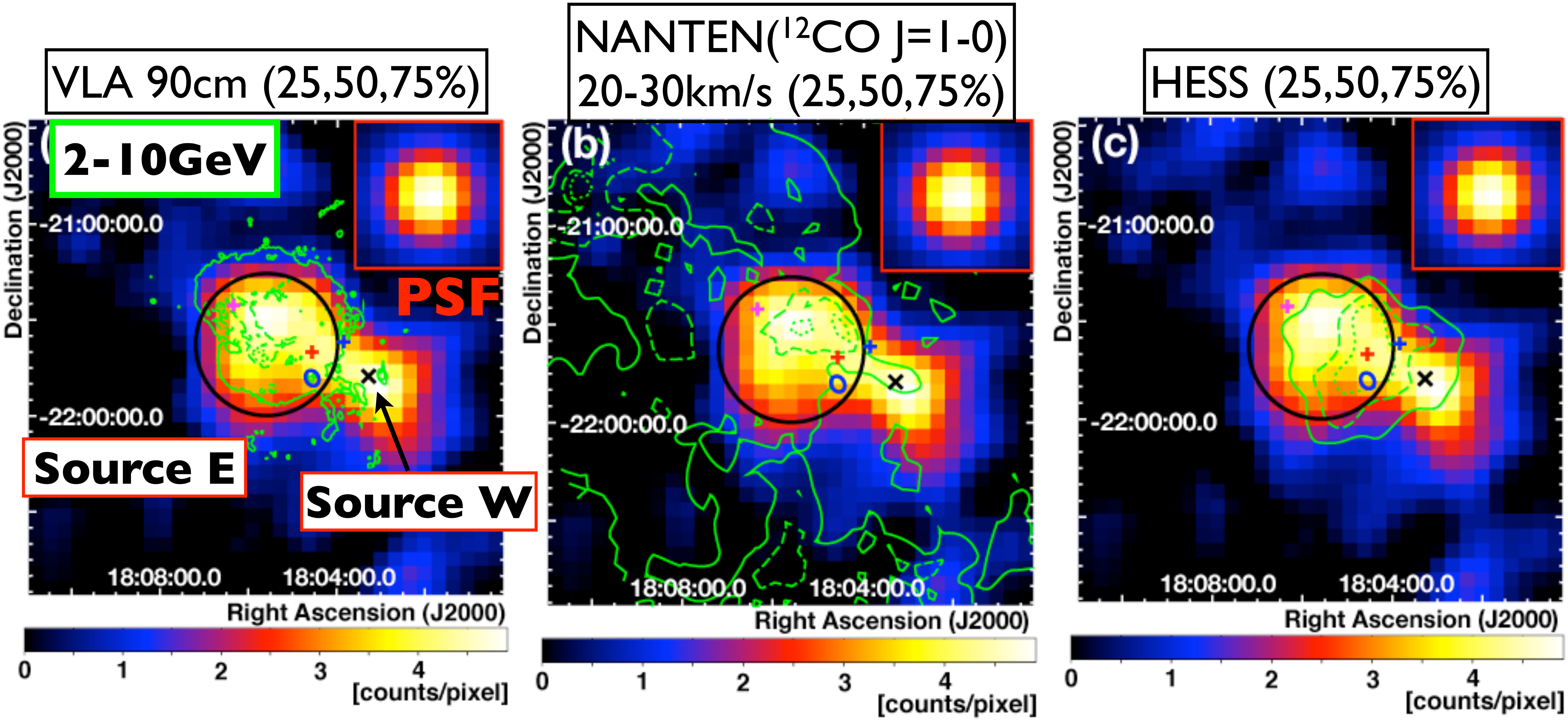
π^0 decay gamma rays from the interaction of the MCs and the SNR are expected.

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

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



+: PSR J1803-2137, +: PSR J1806-2125, +: Suzaku J1804-2140, O: SNR G8.31-0.09

- Source E: major emission part, significantly extended (Disk radius of σ=0.37°) 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.

Morphological Correlation

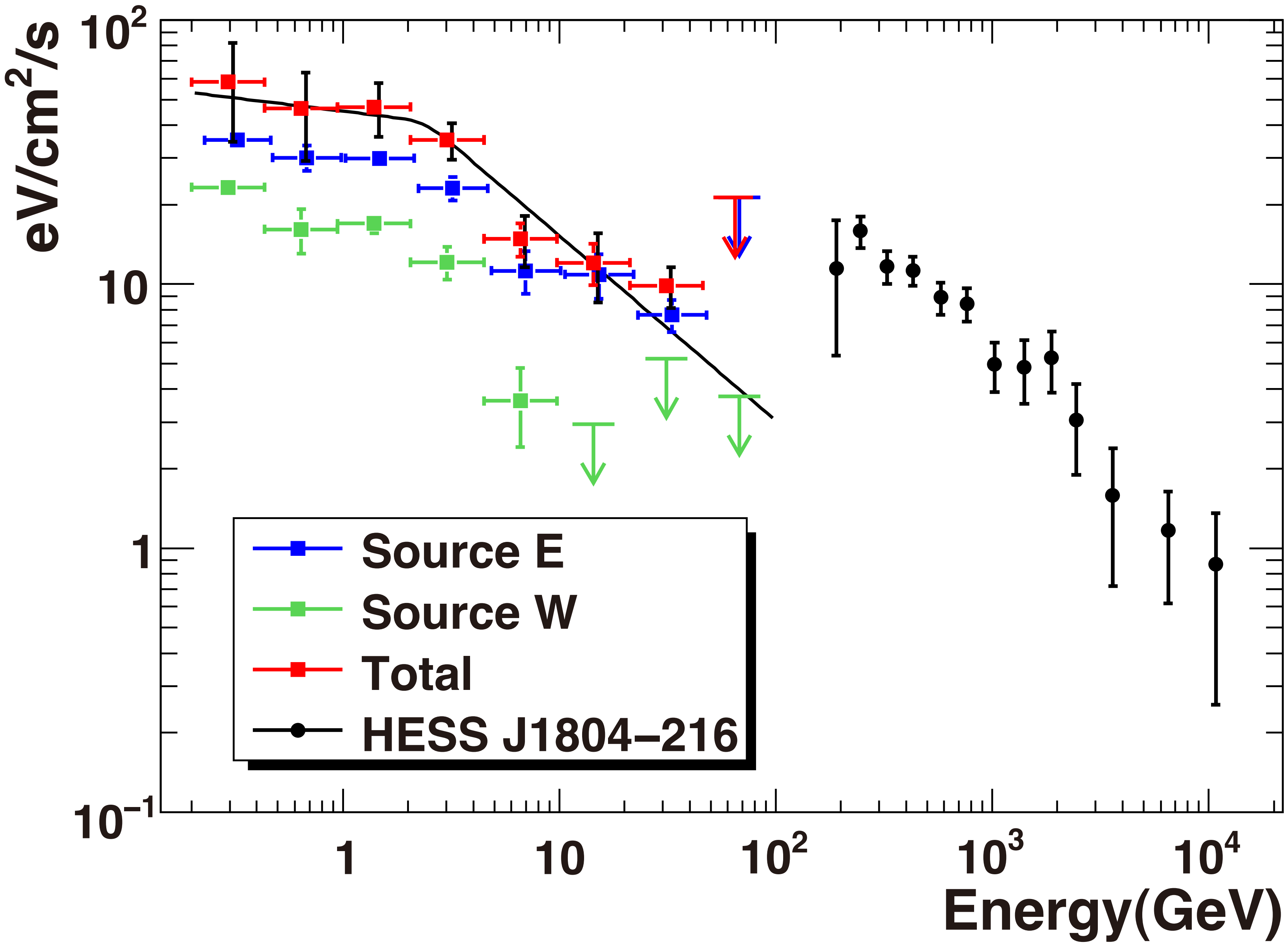
Morphological correlation with emissions of other wavebands were evaluated with binned likelihood using 2-100 GeV data.

Spatial Model	$-2\Delta\log(L_0/L)$	Additional Degree of Freedom
Null Hypothesis	0	0
3 point sources	433.4	12
VLA 90 cm + Source W	436.5-462.4*	6
HESS	404.8-408.0*	2
Uniform disk and point source	477.8	9

*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.

SEDs



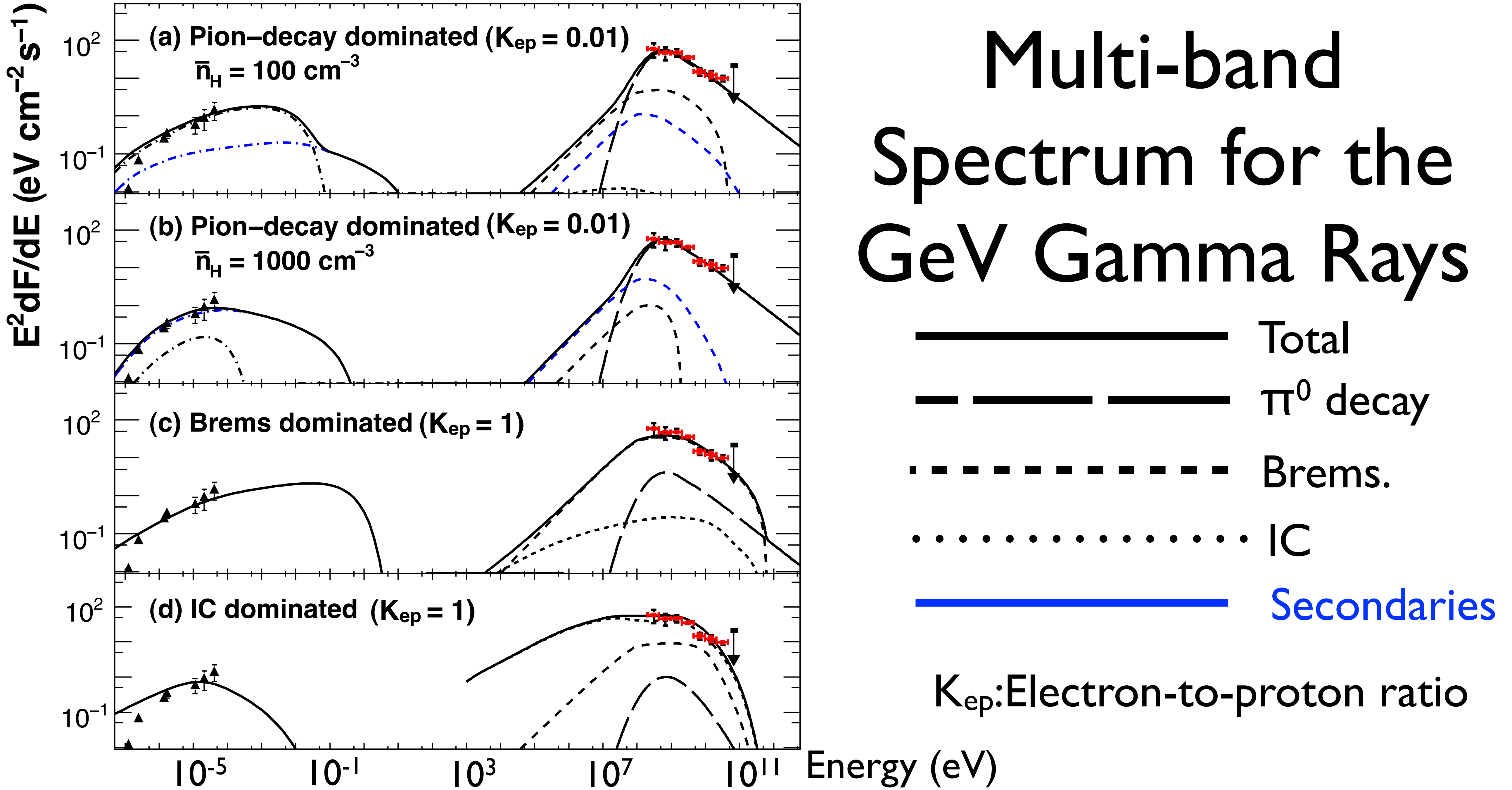
- Statistic errors
- Systematic errors
(Size of spatial template, effective area, diffuse model)

The GeV emission is dominated by Source E.

<u>Total spectrum</u>

- Having a spectral break around ~2.4 GeV (4.4σ).
- Not consistent with the extrapolation of the TeV spectrum.
(Quantitatively evaluated by Chi-square test.)

Multi-band Spectrum for the GeV Gamma Rays



K_{ep}:Electron-to-proton ratio

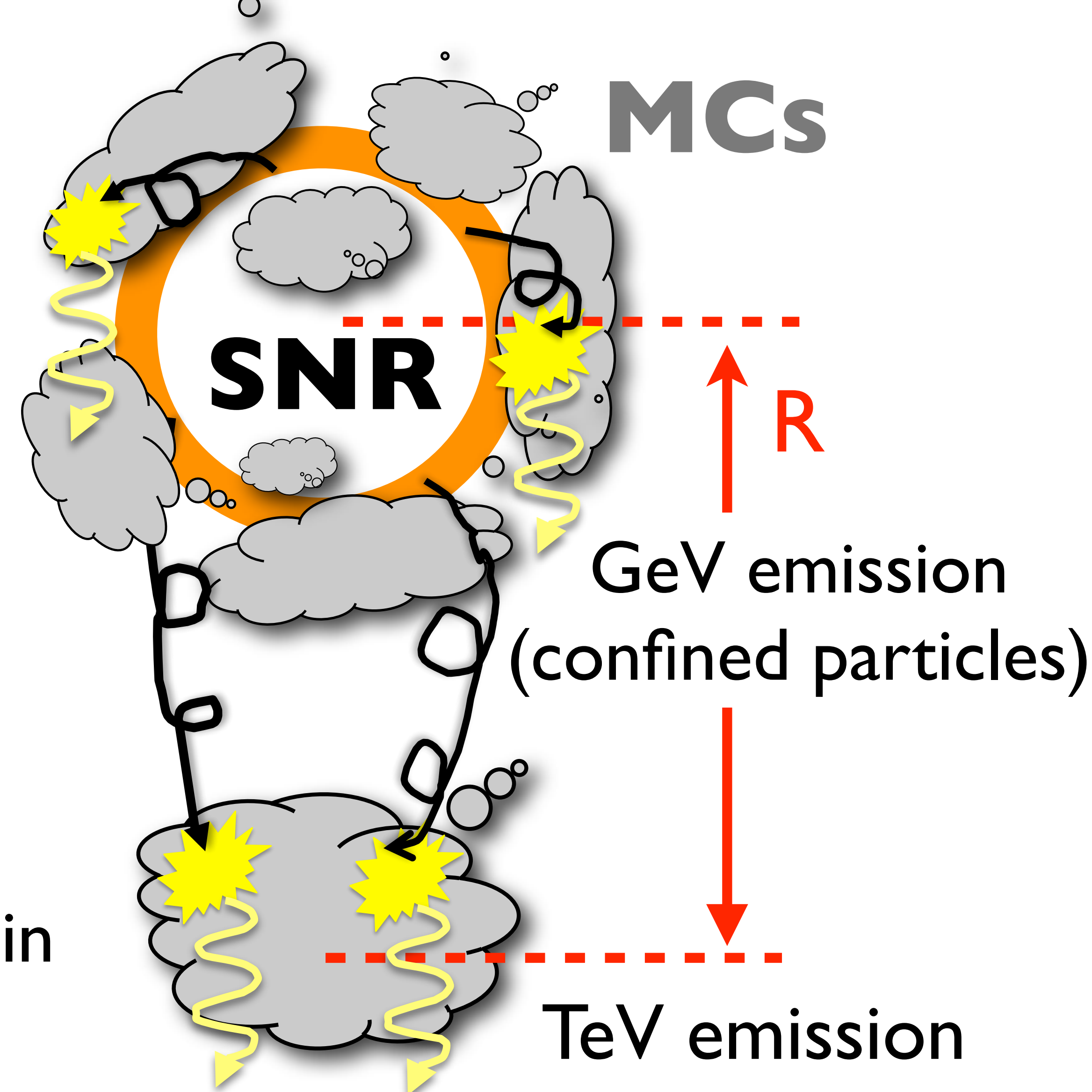
■The GeV gamma-ray spectrum is naturally explained by π^0 decay produced by the interaction of the MCs and particles accelerated by G8.7-0.1.

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 ~0.01 (local cosmic-ray abundance).
- IC: A large amount of electron energy (~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.

$$R_{diff} = 2\sqrt{D(\mathrm{E})(t-\chi(E))}$$

χ(E) represents the confinement of particles

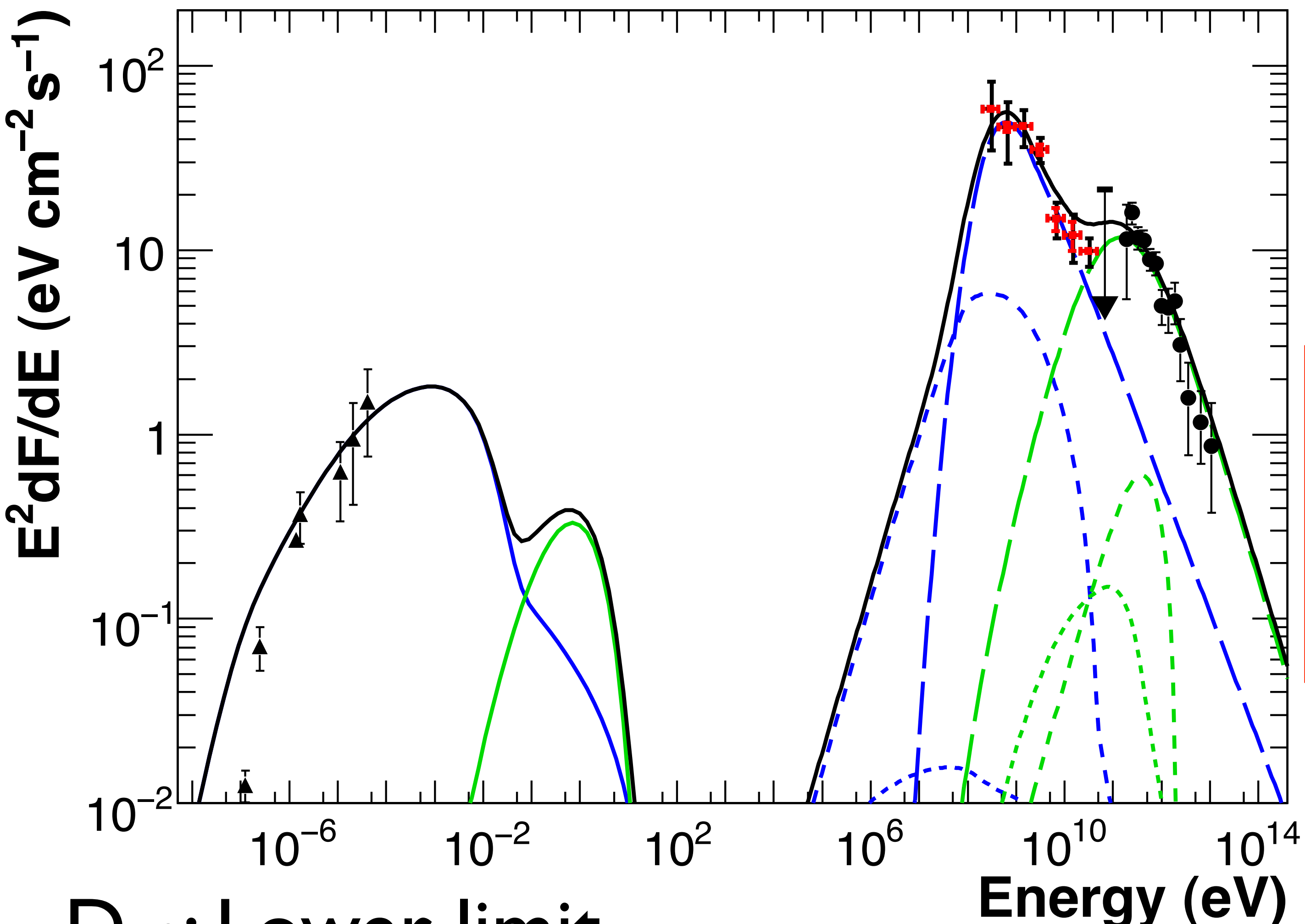
For the TeV emission,
particle spectrum (Gabici et al., 2009)

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

Diffusion coefficient (free parameter)

$$D(E) = D_{10}(E/10\ \mathrm{GeV})^{\delta}$$

Modeling for GeV-TeV spectrum



Assumption for the modeling

spectral index s=2.0, K_{ep}=0.01

n_H=100 cm^{-3} for the GeV and TeV MCs

Diffusion coefficient is constrained to be D_{10}: 0.75-5.4×10^{26} cm^2/s, δ= 0.6

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

D_{10}: Lower limit

Obtained by the cutoff energy of particle spectrum:

$$R_{TeV}^2/R_{diff}^2 = R_{TeV}^2/[4D_{10}(E/10\ \mathrm{GeV})^{\delta}\ (t-\chi(E))],$$

R_{TeV} >26 pc (apparent size of the SNR)

Upper limit

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

Upper limit of M_{TeV} is constrained to be 2.0×10^6 M_{solar} by NANTEN.

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

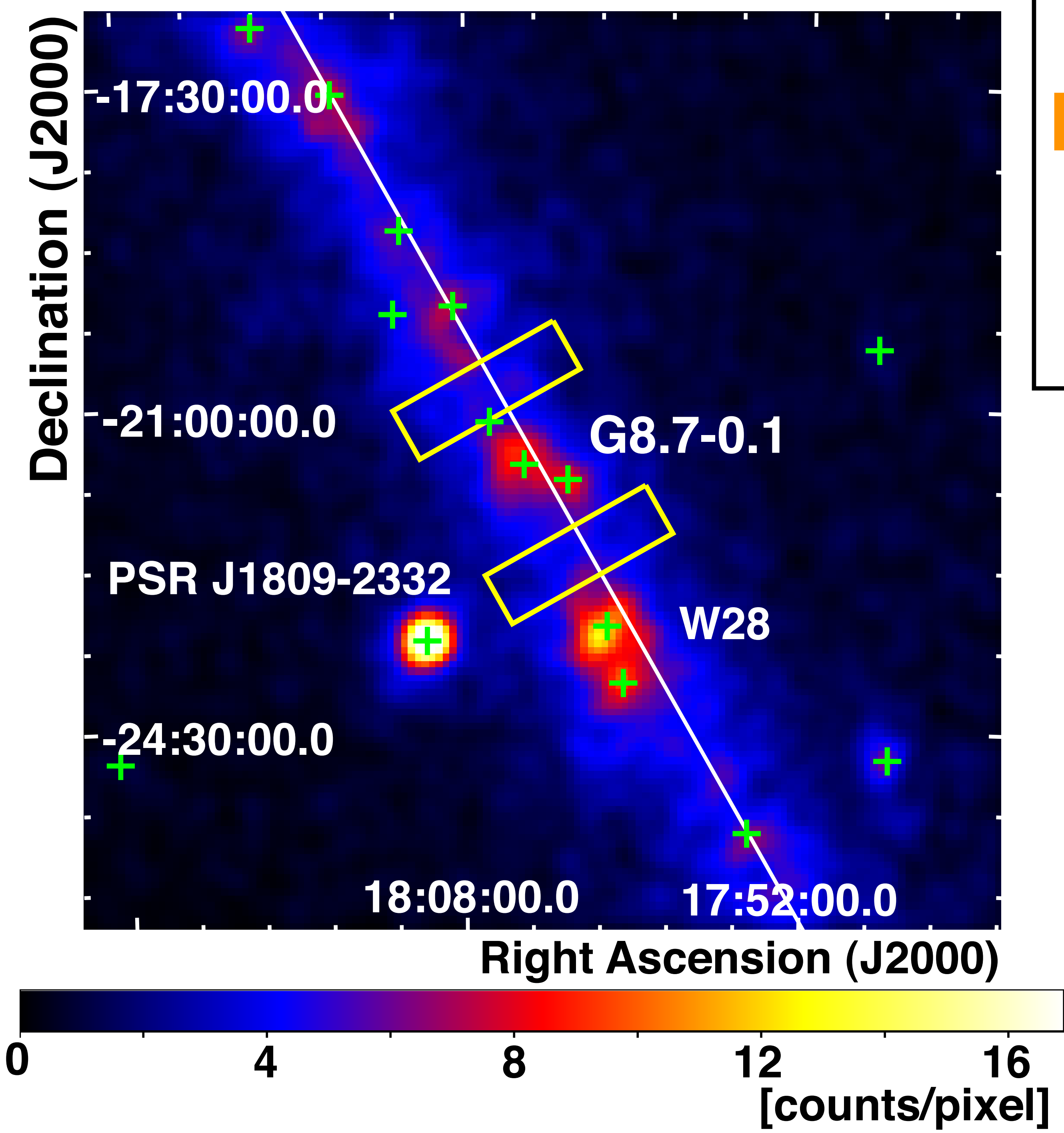
Summary

- 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 π^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

LAT Count Map

2-10 GeV (10°x10°)



+: 1FGL Catalog Source

Regions used to evaluating the systematics for the energy dependence of the Galactic diffuse model

The average surface brightness of the G8.7-0.1 region is ~ 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: 2.5×10^4 yr
- Secondary spectrum: calculated by Kamae et al 2006.

Modeling Results

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

Model	K_{ep} [a]	s_L [b]	p_b [c] (GeV c^{-1})	s_H [d]	B (μG)	$\bar{n}_H$ [e] (cm^{-3})	W_p [f] (10^{49} erg)	W_e [f] (10^{49} erg)
(a) Pion ($\bar{n}_H$ = 100 cm^{-3})	0.01	2.0	3	2.7	100	100	2.8	4.6×10^{-2}
(b) Pion ($\bar{n}_H$ = 1000 cm^{-3})	0.01	2.0	3	2.7	400	1000	0.30	7.2×10^{-4}
(c) Bremsstrahlung	1	2.0	5	2.7	25	100	0.22	0.36
(d) Inverse Compton[g]	1	2.0	15	3.5	1	0.1	48	99