Fermi-LAT Study of Galactic Cosmic-Rays by Observing Diffuse Gamma-rays
(Fermi衛星による拡散γ線放射の観測と銀河系宇宙線)
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HE $\gamma$-rays are produced via interactions between Galactic cosmic-rays (CRs) and the interstellar medium (or interstellar radiation field).

A powerful probe to study CRs in distant locations

Pioneering theoretical works by Hayakawa (1952), Morrison (1958), etc.

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[1]: GMCs (e.g., Orion, Cham): matter distribution, correlation with mol. gas tracer
[2]: Mid/low-latitude region (EGRET GeV excess). submitted to PRL.
See also ArXiv:0907.0294

[3]: Mid/high-latitude region to study local CRs. (Abdo et al. 2009; contact: T. Mizuno)
[4]: Galactic plane (CR distribution in the MW)
Fermi衛星による拡散γ線放射の観測 (2)

[1]: GMCs物質分布

[2]: non-GeV-excess GeV-excessの否定

Orion MC (M~10^5 M_{\odot})

EGRET
LAT

0.1                  1                  10 GeV

[3]: local CRs
近傍の宇宙線はLISに酷似

Cham MC (M~10^4 M_{\odot})

LAT data
t model for the LIS

nucleon-nucleon
electron-bremsstrahlung

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宇宙線の空間分布は、起源・伝播を探る鍵

・CR distribution in our Galaxy is a key to understand their origin and propagation
・Distribution of SNRs not well measured
・Previous Gamma-ray data suggests a flatter distribution than SNR/pulsar distributions (e.g., Strong et al. 2004)

Fermi-LAT is able to map out CR distributions in the Galaxy with unprecedented accuracy
・Large scale analysis in progress. (arXiv:0907.0304)

・We will focus on the preliminary analysis of the 3rd quadrant (outer Galaxy). See also the relevant study of the 2nd quadrant (arXiv:0907.0312)
Fermi-LATのカウントマップ

- One of the best studied regions in $\gamma$-rays
  - Vela, Geminga, Crab and Orion A/B
- Galactic plane between Vela and Geminga (green square) is ideal to study diffuse $\gamma$-rays and CRs.
  - small point source contamination, kinematically well-separated arms (local arm and Perseus arm)

宇宙線分布の研究に適した領域

Count Map (E>100 MeV)
$\Gamma$ 線 = 星間物質からの放射 + 点源

- Fit $\gamma$-ray data with 8 maps + 15 point sources (11 month source list)
- CR spectrum ($\gamma$-ray emissivity) is assumed to be uniform in each Galactocentric ring

+ 1 CO map + excess $E(B-V)$ map (Grenier et al. 2005)
+ IC map (galprop model) + point sources (11 month list)

$I(E, I, b) = \Sigma A(E) * H_l(l,b) + \Sigma B(E) * W_{co}(l,b) + \Sigma$ others $+ \Sigma$ point_sources
HI Emissivity Spectrum of each ring

- Emissivity (CR) spectrum of local arm (R=8.5-10 kpc) is slightly smaller than the model for LIS
- Decreasing emissivity (local arm => interarm => Perseus arm) are consistent with decreasing CR density across the Galaxy
- Similar CR spectral shape up to R=16 kpc
- Can constrain the CR source distribution and propagation parameters
  - study in progress

Point sources with Ts>=100 are included in the fitting

*Preliminary*
• Diffuse gamma-ray emission is a powerful probe to study the CR (and matter) distribution in distant locations in our Galaxy
• Extensive analysis by Fermi-LAT is in progress
  ➢ individual GMCs
g• non-GeV-excess
  ➢ Mid/high-latitude region (local CRs)
  ➢ large scale analysis (CR distribution throughout the Galaxy)
• Preliminary analysis of the 3rd quadrant is disucssed
  ➢ See also the relevant study of the 2nd quadrant
  ➢ Similar CR spectral shape up to R=16 kpc
  ➢ CR density gradient toward the outer Galaxy is obtained
  ✓ Comparison with the CR source/propagation model prediction is in progress

Thank you for your attention!
Backup Slides
LAT vs pre-Fermi Model

- Compare with a CR propagation model prediction based on pre-Fermi CR data (Strong et al. 2004, Porter et al. 2008)
  - $\pi^0$-decay, e-Brems, Inverse Compton
- Source and isotropic (w/ residual BG) component come from fitting the data to the sky above 30 deg latitude with model fixed
- Although there is a uniform excess above the model, data is reasonably reproduced by the model

The model is successful considering it is *a priori* pre-Fermi model
Probing CRs using Gamma-rays from ISM

- Correlation with gas column density reveals the CR spectrum
- Fermi-LAT’s high performance + CR propagation model (e.g. GALPROP) to predict IC

  Sensitivity significantly improved

Gamma-ray intensity
(Fermi LAT data)

ISM
(e.g., LAB HI survey)
(http://www.astro.uni-bonn.de/~webaiub/english/tools_labsurvey.php)

Mid/high latitude region & Galactic plane:
Study of the local CRs and CR gradient in the outer Galaxy

(From Wikipedia)
Accurate Measurements of Local CRs (1)

Mid-high lat. region in 3\textsuperscript{rd} quadrant:
- small contamination of IC and molecular gas
- correlate $\gamma$-ray intensity and HI gas column density


\begin{align*}
\text{400-560 MeV} & \quad \text{HI column density (10}^{20} \text{ cm}^{-2}) \\
\text{1.6-2.3 GeV} & \quad \text{E}^2 \times \text{Intensity (10}^{-3} \text{ NeV} \text{s}^{-1} \text{cm}^{-2} \text{ sr}^{-1} \text{ MeV}^{-1})
\end{align*}
Accurate Measurement of Local CRs (2)

- Best quality $\gamma$-ray emissivity spectrum in 100 MeV-10 GeV ($T_p = 1$-100 GeV)
- Agree with the model prediction from the local interstellar spectrum (LIS)

- Prove that local CR nuclei spectra are close to those directly measured at the Earth
- $E_\gamma < 100$ MeV constrain the e- spectrum
CR Flux Distribution

- Emissivity gradient traces the CR density. Robust against the thresholds for point sources included.
- Significantly flatter than the SNR distributions
  - may indicate more CR sources than previously thought in the outer Galaxy, large halo size, etc.
- Comparison with the model prediction is in progress.