the First Fermi-LAT Catalog of Supernova Remnants

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Fermi-Detected $\gamma$-ray Emission
13 identified SNRs, including
- 9 interacting
- 4 young SNRs
Fermi-Detected SNRs

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+ 43 2FGL candidates,
  excluding identified PSRs, PWN, AGN
SNR Catalog:

To better understand SNRs in a statistically significant manner within a MW context.

- Characterize GeV emission in regions containing SNRs
- Examine multi-wavelength (MW) correlation, including spectrum + morphology for radio, X-ray, and TeV and CO, maser, IR, …
- Determine statistically significant SNR classification(s) and perform spectral modeling

With particular efforts from:
F. Acero, J. W. Hewitt (NASA/Goddard)
F. de Palma, F. Giordano (INFN/Bari)
CTB 37a: an Example

Detection: Fermi-LAT data shows non-variable emission from a region coincident with the MW SNR.

Spectral study: MW model fitting shows emission is best-fit with $\pi^0$-decay + bremsstrahlung.

Energetics: $\sim$5% of the energy goes into (hadronic) CRs.

Particle populations’ and environment constraints:
- Particle power laws: flux, index, (lepton) cutoff E
- B-field: first lower limit, constraining UL
Data Set:
- 3 years of P7SOURCE_V6 LAT data
- E: 1-100 GeV
- Region Of Interest: 10° around each SNR

Green’s Catalog: (2009)
- 278 SNRs

Starting Model:
- 2FGL

Overlapping sources?
- = None: Add a new extended source
- = 1 source (not PSR): Replace w extended source
- > 1 source: Replace (non-PSR) source closest to radio centroid w extended source. Delete all other (non-PSR) sources.

Localize source, fit extension
- Disk extension seed = radio size
- Spectral model: power law
- Normalization of Galactic diffuse and all sources w/in 5° of candidate are free during minimization procedure.

Output:
- Position, extension, significance
- Spectral energy distribution
- Region and residual maps
- Diagnostics
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Effect of starting model:
- See J. Cohen’s poster!

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- Disk extension seed = radio size
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- Normalization of Galactic diffuse and all sources w/in 5° of candidate are free during minimization procedure.

Characterizing systematic error from the interstellar emission model:
- See F. de Palma’s poster!

Details of analysis pipeline:
- See F. Giordano’s poster!

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SNR Catalog:

- Fermi-LAT has the ability to spatially resolve a large number of the 278 known SNRs.
Fermi-LAT has the ability to spatially resolve a large number of the 278 known SNRs. Spatial extension measured for 15 SNRs, including 6 new candidates, permitting clear identification.
Radio synchrotron emission indicates the presence of relativistic leptons. LAT-detected SNRs tend to be radio-bright:

- **Interacting SNRs**: general correlation suggests a physical link
- **Young** SNRs show more scatter

![Graph showing Radio vs. 1-100 GeV Flux](image-url)

- **Upper limits**: $(i=2.5, 99\%)$
If radio and GeV emission arise from the same particle population(s), under simple assumptions, the GeV and radio indices should be correlated:

- **Young** SNRs: seem consistent
- Others, including *interacting* SNRs: softer than expected

GeV-Radio slope correlation for:
- $\pi^0$ decay or $e^+/-$ bremsstrahlung
- inverse Compton

Data now challenge model assumptions!
- Underlying particle populations may have different indices.
- Emitting particle populations may not follow a power law; breaks?
- Multiple emission zones?
Indication of break at TeV energies

Caveat: TeV sources are not uniformly surveyed.
Indication of break between GeV and TeV

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Environment?

Interacting SNRs tend to be more luminous than young SNRs.

Young SNRs:
- Low $L_\gamma$ => evolving into low density medium?

Interacting SNRs:
- Higher $L_\gamma$ => encountering higher densities?
Young SNRs tend to be harder than older, interacting SNRs.

Due to
- decreasing shock speed allowing greater particle escape?
- decreasing maximum acceleration energy as SNRs age?
Conclusions

➢ Our systematic study of a statistically significant population of galactic SNRs
  ➢ has identified 6 new extended and >25 new point-like SNR candidates
  ➢ in at least 2 GeV-luminous classes: young and interacting SNRs.

➢ Combining our GeV with MW observations
  ➢ suggest that some SNRs’ emitting particle populations are linked
  ➢ demonstrates that our simple assumptions are no longer sufficient and
  ➢ allows us to test more complex acceleration and emission models for a variety of environments, ages, and progenitors.

➢ Improved observations and modeling will
  ➢ give us greater insight into SNRs, their acceleration mechanisms and their accelerated particles
  ➢ yield further evidence for CR origin and acceleration

➢ Accurately estimating SNRs’ aggregate particle acceleration ability will also allow us to better quantify SNRs’ ability to produce the observed CRs.
Primary Nuclei Spectra

- C x 10^5
- O x 10^2
- Ne
- Mg x 10^{-3}
- Si x 10^{-6}
- Fe x 10^{-9}


CREAM II, Cal
△ HEAO-3
□ CRN
○ ATIC 2
★ TRACER

--- Power law fit to CREAM II

T. J. Brandt Bari
Volatile: low boiling point
Refractory: found in interstellar dust

Super-TIGER adds
- Refractory: Zr (A=91) and Mo (A=96)
- Volatile: Kr (A=84) and Rb (A=86)

TIGER + Super-TIGER:
- Statistical error reduced by ~factor of 3
CR Source:

- ~20% massive star ejecta
- ~80% solar system

Acceleration:

- Mass-dependent:
  - refractory $\sim A^{2/3}$
  - volatile $\sim A^1$
- More efficient for refractories than volatiles

Check:

- ~12% O sequestered in dust grains
- O excess is ~12% of the expected abundance for a refractory at A=16