Recent Results on SNRs and PWNe from the Fermi Large Area Telescope

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On behalf of the Fermi LAT Collaboration
Fermi LAT Collaboration

- **France**
  - IN2P3, CEA/Saclay

- **Italy**
  - INFN, ASI, INAF

- **Japan**
  - Hiroshima University
  - ISAS/JAXA
  - RIKEN
  - Tokyo Institute of Technology

- **Sweden**
  - Royal Institute of Technology (KTH)
  - Stockholm University

- **United States**
  - Stanford University (SLAC and HEPL/Physics)
  - University of California at Santa Cruz - Santa Cruz Institute for Particle Physics
  - Goddard Space Flight Center
  - Naval Research Laboratory
  - Sonoma State University
  - Ohio State University
  - University of Washington

~390 Scientific Members (including 96 Affiliated Scientists, plus 68 Postdocs and 105 Students)

**Principal Investigator:**
Peter Michelson (Stanford University)

**Managed at SLAC**
Galactic Results from LAT

- 1FGL Galactic populations
- New GeV source classes in the Galaxy

Recent Highlights

- Pulsars and Pulsar Wind Nebulae
  - Which pulsars produce GeV nebulae and what are we learning from them?
- Supernova Remnants
  - Solid detections, structure, and spectral features
A GeV, wide-field Instrument

Incidence Angle Dependence

Energy Dependence

68% Containment

Effective Area

1 GeV

May 28, 2010

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The 1FGL Catalog

March 18 2010 Astro pic of the day
# The Fermi LAT 1FGL Source Catalog

1,451 sources

<table>
<thead>
<tr>
<th>Description</th>
<th>Designator</th>
<th>Number Assoc. (ID)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pulsar, X-ray or radio, identified by pulsations</td>
<td>psr (PSR)</td>
<td>7 (56)</td>
</tr>
<tr>
<td>Pulsar, radio quiet (LAT PSR, <em>subset of above</em>)</td>
<td>PSR</td>
<td>24</td>
</tr>
<tr>
<td>Pulsar wind nebula</td>
<td>pwn (PWN)</td>
<td>2 (3)</td>
</tr>
<tr>
<td>Supernova remnant</td>
<td>† (SNR)</td>
<td>41 (3)</td>
</tr>
<tr>
<td>Globular Cluster</td>
<td>glc (GLC)</td>
<td>8 (0)</td>
</tr>
<tr>
<td>Micro-quasar object: X-ray binary (black hole or neutron star)</td>
<td>mqb (MQO)</td>
<td>0 (1)</td>
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<tr>
<td>Other X-ray binary</td>
<td>hxb (HXB)</td>
<td>0 (2)</td>
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<tr>
<td>BL Lac type of blazar</td>
<td>bzb (BZB)</td>
<td>295 (0)</td>
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<tr>
<td>FSRQ type of blazar</td>
<td>bzo (BZO)</td>
<td>274 (4)</td>
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<tr>
<td>Non-blazar active galaxy</td>
<td>agn (AGN)</td>
<td>28 (0)</td>
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<tr>
<td>Active galaxy of uncertain type</td>
<td>agu (AGU)</td>
<td>92 (0)</td>
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<tr>
<td>Normal galaxy</td>
<td>gal (GAL)</td>
<td>6 (0)</td>
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<tr>
<td>Starburst galaxy</td>
<td>sbg (SBG)</td>
<td>2 (0)</td>
</tr>
<tr>
<td>Unassociated</td>
<td></td>
<td>630</td>
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</table>
Unidentified Gamma-ray Sources

- Previous MeV-GeV energy gamma-ray missions left a legacy of “unidentified” sources (~2/3 of 3EG catalog)
  - Unidentified meant multiple possible candidates OR no plausible candidates (unassociated)
- LAT first catalog <50% unassociated
- LAT associations greatly aided by
  - Dramatically improved gamma-ray localization
  - Dedicated catalogs of potential gamma-ray counterparts
  - Multiwavelength searches
- LAT identifications from
  - Periodicity
  - Spatial morphology
  - Correlated variability with other observations
Variability in 1FGL Sources

- No association
- Possible association with nearby SNR or PWN
- AGN – blazar
- Starburst Gal
- Pulsar
- Pulsar w/PWN
- AGN – unknown
- Galaxy
- PWN
- Globular cluster
- AGN – non blazar
- Galaxy
- SNR
- XRB or MQO
Curvature in 1FGL Sources
Spectral-Variability Classification

Blazars and pulsars in the variability-spectral curvature plane

- Blazars
- Pulsars
- Other
- Unassociated

![Graph showing blazars and pulsars in the variability-spectral curvature plane.](image-url)
Gamma-ray Pulsars and MSPs

More than 56 gamma-ray pulsars in the first year
Plus gamma-selected MSPs

GeV PWN - where to look?

- Known high-energy PWNe
  - From X-ray and TeV observations
  - For example, Crab, Vela X, MSH 15-52
- Gamma-ray pulsars
  - PWN Catalog based on off-pulse searches from LAT team underway
- Young, energetic radio pulsars
- TeV nebula candidates
Hyper-exponential cutoff excluded at ~5 sigma. Consistent with emission well above the neutron star surface.

Inverse Compton emission consistent with mean magnetic field in nebula 100 \( \mu \text{G} < B < 200 \mu \text{G} \)

Vela X Nebula of Vela Pulsar

LAT Test Statistic Map

Radial Profile above 800 MeV

GeV significantly extended
Disk radius = 0.88° +/- 0.12

Better match to radio than TeV


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PSR B1509-58 only detected in timing analysis
Nebula not significant below $\sim 1$ GeV


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GeV PWNe Spectra

Crab Nebula

MSH 15-52

Halo

Vela X

Slane et al. (submitted to ApJ)
**GeV Nebula Limits**

**PSR J1907+0602**
- $E\dot{\nu} = 2.8 \times 10^{36}$ erg/s
- Char. Age = 19.5 kyr
- Distance estimate = 3 kpc

**LAT residual map**
Off-pulse selection

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**GeV upper limits require a low energy turnover between 20 and 300 GeV**


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Nebula Search of LAT Pulsars

LAT is producing a more complete sample of young, energetic, nearby pulsars

Catalog under development to characterize off-pulse nebula components for the LAT pulsars

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Supernova Remnants

- Which remnants are GeV emitters?
- Where are the emission regions?
- What is producing the gamma rays?
SNRs W51C, W44, IC 443, W28 North source resolved by LAT. Cas A unresolved. Good agreement with shell structures.

LAT counts map (2-8 GeV) X-ray (0.1-2.4 keV, black) and radio (1.4 GHz, green) contours

LAT counts (2-10 GeV) Infrared contours (4.5 um)

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SNR: Molecular Connection

GeV emission from SNRs interacting with molecular clouds IC 443, W51C, W44, W28...

PSR B1853+01

W44

Shockened H2

W51C

CO (J=1-0) contours NANTEN

H II regions

Source S

Source N

W44

W28

W28

W28

NO
SNR: GeV Breaks

W51C
Few GeV

HESS

W44
Whipple 2 GeV

HEGRA
Milagro

IC 443
3.3 GeV

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SNR: Young vs. Old

Cas A
~300 yrs

W44
20 kyr

W51C
30 kyr
Summary

- GeV SNR population growing
  - Some preference for middle-aged remnants near dense regions (only young SNR at high significance is Cas A)
  - Pion decay scenarios generally favored; leptonic scenarios not completely ruled out
- GeV PWNe
  - Morphology and spectral studies for the bright elite
  - Multiwavelength context, particularly with TeV and radio/WMAP, probes electron populations
  - Population not well-defined yet
- Both of these classes benefit from additional LAT exposure

http://fermi.gsfc.nasa.gov
Extras
Pulsars everywhere…

- >50 gamma-ray pulsars so far
- >40 young, energetic pulsars
- 9 old, recycled millisecond pulsars
- Identifying EGRET unidentifieds and LAT unidentifieds
- Gamma-ray beam is bigger than radio beam
- Pulsar spectra have exponential cutoffs in the GeV band
- Gamma rays from outer magnetosphere preferred
- Bonus: LAT unidentifieds also turning up new radio millisecond pulsars
LAT Unassociated Transient Detections

- Unassociated transients from daily search
- Low latitude blazars from First LAT Catalog

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The Fermi Observatory

Large Area Telescope (LAT)

- Large field of view (>2.4 sr)
- Entire sky every 3 hrs (every 2 orbits)
- Broad energy range (20 MeV - >300 GeV)

Gamma-ray Burst Monitor (GBM)

- Views entire unocculted sky
- **NaI**: 8 keV - 1 MeV
- **BGO**: 150 keV - 40 MeV

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Large Area Telescope (LAT)

**ACD**
scintillator
89 tiles

**Tracker**
Si strip detectors
Tungsten foil converters
pitch = 228 um
8.8x10^5 channels
18 planes

**Calorimeter**
CsI crystals
hodoscopic array
6.1x10^3 channels
8 layers

Large Field of View >2.4 sr
Broad Energy Range 20 MeV - >300 GeV

4x4 detector array
Transient Science: Flares, bursts, multiwavelength campaigns, unidentified transients

Accumulated Science: New source types, populations, long-term monitoring, spatially extended and diffuse studies

Deepest and most uniform survey of the sky at these energies

All-sky coverage in ~3 hrs (2 orbits)

Minor asymmetry due to passages through South Atlantic Anomaly