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

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On behalf of the Fermi LAT Collaboration

Galactic Results from LAT

+ 1FGL Galactic populations
  + The seen, the unseen, and the unknown
+ Selected Highlights
  + Pulsars
  + Pulsar Wind Nebulae
  + Supernova Remnants
  + Transients
+ Future Prospects
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
  - Multibandwidth searches
- LAT identifications from
  - Periodicity
  - Spatial morphology
  - Correlated variability with other observations

Variability in 1FGL Sources

- Variability is a key characteristic of gamma-ray sources
- Periodic and aperiodic variability can provide insights into the nature of the sources

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Curvature in 1FGL Sources

Spectral-Variability Classification

+ Separability of blazars and pulsars in the variability-spectral curvature plane

Pulsars and their wind nebulae

+ Bright Nebulae in the GeV band

Gamma-ray Pulsars and MSPs

More than 50 gamma-ray pulsars in the first year

Plus gamma-selected MSPs

GeV PWN Search

- Known high-energy PWNe
  - From X-ray and TeV observations
  - Crab, Vela X, MSH 15-52 nebulae...
- Off-peak searches of gamma-ray pulsars
  - Catalog from LAT team underway
- Young, energetic radio pulsars
- TeV nebula candidates

Crab Pulsar and Nebula

- Pulsar 100 MeV to 20 GeV
  - Nebula from MeV to TeV

Vela X: Nebula of the Vela Pulsar

- Excess counts $E > 800$ MeV
  - Data compared with a simulated point source at position of Vela Pulsar

MSH 15-52
Bright gamma-ray sources associated with several supernovae interacting with molecular clouds. Extension resolved in LAT data.

LAT counts map (0-10 GeV)
X-ray (0.1-2.4 keV, black) and radio (1.4 GHz, green) contours.

Galactic Transients

LAT Unassociated Transient Detections

Unassociated transients from daily search
Low latitude blazars from First LAT Catalog.
Gamma rays from a Nova

- Fermi J2102+4542
- Located in the direction of the Cygnus region
- Bright, high confidence, detected over several days by automated processing
- No likely blazars in error circle...

V 407 Cygni - a symbiotic nova

- Bright, high confidence, detected in outburst - 2 days before the Fermi report
- Position and timing consistent with V 407 Cygni, a recurrent nova detected in outburst - 2 days before the Fermi report
- Spectrum does not look typical - a symbiotic recurrent nova?
- Very few systems explode on decade timescales (RS Ophiuchi - 20 yr period)

V407 Cygni: a variable star

- Symbiotic binary: White dwarf star and red giant star orbiting each other
- Near Dwarf in Cygnus
- Variability from:
  - Mira variable star
  - White dwarf accretion
  - Binary interaction
- A complex and fascinating system!
- V407 Cyg ~ 6000 light years away

March 11 - A Nova!

- Hydrogen accreting on to the surface of the white dwarf ignites a nuclear explosion (30-60 of these per year in Milky Way)
- Candidate nova discovered by amateur astronomers, Noishigama and Kobus
- Fermi detects a new gamma-ray source in the same field on March 13 (ATEL #2487)
- Optical lightcurve
- Spectrum does not look typical - a symbiotic recurrent nova?
**Symbiotic Nova**

- Symbiotic Binary System: White dwarf + red giant system
- Nova: White dwarf builds up mass envelope to the point of thermonuclear fusion
- Dramatic increase in visual magnitude
- Recurrent Nova?
  - Hints but no strong confirmation of previous nova
- Pre-nova activity
  - White dwarf shows ongoing variability at level of several in magnitude
  - V407 Cyg companion is a Mira star showing variability at level of several in magnitude
  - Dusty envelope with stellar wind
- Origin of the gamma rays?
  - Strong shock propagating into dense medium around giant star (and stellar wind)
  - Plan dense in electron processes & shock interactions

**Summary**

http://fermi.gsfc.nasa.gov

**Pulsars everywhere...**

- >50 gamma-ray pulsars so far
- >40 young, energetic pulsars
- >10 old, recycled millisecond pulsars
- Identifying EGRET unidentified and LAT unidentified
- 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 unidentified also turning up new radio millisecond pulsars
**Blazars**

- Preliminary
- 1079 TS > 25
- 10^10 sources
- 668 AGNs (56%)
- 110 BL Lacs
- 264 BL (Lac) sources
- 16 Basic galactic
- Differences between Northern Hemisphere and Southern one (FSRQs: 7%, BL, LAC: 15%)

**LAT as an Electron Detector**

- ~90% efficient for 0.1-20 GeV
- Good hadron rejection (up to 1:10^6 at 1 TeV)
- Detailed simulations and comparisons with data
- Systematics < 20%
- MAC data acceptance, proton spectrum, energy calibration

**The Large Area Telescope**

- Cosmic-ray e^+e^- spectrum from 20 GeV to 1 TeV
- LAT error band includes systematics
- Model assumes standard CR injection and propagation

**Anti-Coincidence Detector (ACD):**
- Tracker (TKR):
  - Segmented (60 layer)
  - Collected (250 layer)
  - 24% of total carbon
- Calorimeter (CAL):
  - 1036 CsI crystals
  - 8.5 radiation lengths
  - Reconstruction efficiency
  - Shower profile reconstruction (energy connection)
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

Tracker

- High Tungsten foil converters
  - Pitch = 228 um
  - 8.8x10^4 channels
  - 18 planes

Calorimeter

- 260 crystals
  - Hoodoscope array
  - 6.1x10^4 channels
  - 8 layers

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

LAT Sensitivity with Time

Transient Science: Flares, bursts, multiwavelength campaigns,
undertaken by LAT.

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
3 orbits

Minor asymmetry due to passage through South Atlantic Anomaly

Candidate Gamma-ray Events

- Green boxes = associated emission of the "transient object"
- Blue boxes = non-associated emission in the calorimeter
- Yellow boxes = non-associated emission in the calorimeter
- Red boxes = associated gamma-rays at the calorimeter
**On-orbit Energy Calibration**

- Occasional charge injection runs
- Low energy - protons
- High energy "heavy ion" triggers that overlap low and high range readout
- Energy scale monitored heavy cosmic-ray nuclei
  - 560 MeV Carbon
  - 8 GeV Iron

**On-orbit Rates**

- Overall trigger rate - few KHz
- Huge variations due to orbital effects
- Downlink rate - 400-500 Hz
- >90% from gamma filter
- ~20-30 Hz from diagnostic filter
- ~5 Hz from heavy ion filter
- Photon-selected event rate (passing standard background rejection cuts) - 1 Hz

**Gamma ray... Cosmic ray... Both?**

On-orbit effect - reduced effective area at low energy due to signals from out-of-time particles in the readout
Post-launch update - properly modeled in simulations
Planned update - improve reconstruction to regain area

**1 year sky map**
LAT Automated Science Processing

**Automatic transient monitoring**
All-sky search runs every 6 hours, 1 day, 1 week

LAT flare advocates monitor results and trigger multwavelength follow-up.
Reports at [http://fermisky.blogspot.com/](http://fermisky.blogspot.com/)

Typical count map for 6 hours (E>100 MeV)

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Reported GeV Flares

+ Astronomers Telegrams
+ >70 since July 2008
+ Associated blazars plus 6 initially unidentified transients
+ Fermi Gamma-ray Sky Blog
+ notes on daily and weekly source activity
+ [http://fermisky.blogspot.com](http://fermisky.blogspot.com)

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Early Activity and Spectacular Flare

**3C 454.3**

Photon flux of brightest persistent GeV source, Vela Pulsar (~1 every 2 min)

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Gamma-ray Transients near the Galactic Plane

**GRO J1838-04**

EGRET observed 3.5 day flare near the Galactic Plane in June 1995

No blazar candidates found

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Two Early Unassociated Transients

Counts per day
- 2 deg radius
- Exposure corrected
- Counts per day
- Average background rate
- High confidence
- > 10 sigma
- Counts per day
- (E>200 MeV)
- > 3 deg radius
- Exposure corrected
- Counts per day
- Average background rate
- Fermi J0910-5041
- Average background rate
- Fermi J0903-3531

Counterpart Search - Fermi J0910-5041

LAT 95% error circle contains Swift XRT source (Katić et al. ATEL 1178) consistent with flat spectrum radio source from SUMSS and AT20G (Sadler ATEL 1184)

Counterpart Search - 3EG J0903-3531

J0903-3531
- October 5, 2008, gamma-ray increase over 3 days
- 5x above 3EG flux
- 10x above average gamma-ray flux
- Swift XRT TOO within 2 days

A New LAT Transient - J1057-6027

Fermi J1057-6027
- June 11, 2009, gamma-ray increase over 1 day
- Coincident with a known LAT source
- > 0.07 confidence radius
- 10x above average gamma-ray flux
- Swift XRT TOO within 1 day (ATELs #2082, #2083)
- AG Carinae, luminous blue variable (LBV) star with X-ray and radio emission, 7.7 away