News from Space-based Gamma-ray Astrophysics

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Gamma-rays cover a huge swath of the electromagnetic spectrum.

The gamma-ray sky is relatively poorly studied.

High-Energy gamma-rays probe the non-thermal universe.

Explore extreme environments hosting powerful particle accelerators.
The AGILE Small Mission:

It combines for the first time a gamma-ray imager (50 MeV-30 GeV) with a hard X-ray imager (18-60 keV) with large FOVs (1-2.5 sr) and optimal angular resolution.
Large Area Telescope (LAT)
Observes 20% of the sky at any instant, views entire sky every 3 hrs
20 MeV - >300 GeV - includes unexplored region between 10 - 100 GeV

International and interagency collaboration between NASA and DOE in the US and agencies in France, Germany, Italy, Japan and Sweden

Gamma-ray Burst Monitor (GBM)
Observes entire unocculted sky
Detects transients from 8 keV - 40 MeV

• Unique Capabilities for GeV astrophysics
  – Large effective area
  – Good angular resolution
  – Huge energy range
  – Wide field of view

Mission Lifetime: 5 year requirement, 10 year goal
Observations Summary

Fermi
- Almost exclusively in nominal data taking in survey mode
  - 50 deg rocking angle from May 27 2009 onwards
- ARR (C~2/month)
  - 2.5 hours duration (5 hour before Nov 2010)
- Target of Opportunity/pointed mode observations
  - Crab nebula, Sun, flaring blazars, galactic center
- Modified survey mode observation
  - PSR B1259 periastron, sun, Mrk 421
- Galactic Center biased pointing (Dec 2013 – Dec 2014)
  - Maintain all-sky coverage, but bias observations towards Galactic Center (increasing exposure by 2x)

AGILE
- First part of mission in sequence of pointed observations
- Now in spin stabilized survey mode
The Variable Gamma-ray Sky
Shockingly bright flares in Sept 2010 and April 2011 observed by AGILE and Fermi-LAT

Rapid (hourscale) variability of PeV electrons poses severe challenges for acceleration mechanisms
April 2011 Crab Flare

Lightcurve in bins of equal exposure (mean 9 minutes!)

Flux doubling in 8 hours constrains emission region size <0.0003 pc

Beginning of LAT TOO

The rapid variability and high energy extension of the synchrotron component poses severe challenges to standard models of particle acceleration.
GRB130427A – A nearby ordinary monster

- Redshift = 0.34
- One of the brightest GRBs in gamma-rays ever detected
- Highest energy photon (95 GeV)
- Longest lasting GeV emission – LAT detected emission for over 20 hours
The very high energy photons at late times are inconsistent with the standard model that the afterglow emission is produced by synchrotron emission from electrons accelerated in the forward shock of the ejecta.
GBM Triggers

- GBM is currently the most prolific detector of GRB and TGFs
- ~240 GRB/year
  - 17% short (~40/year)
Quasi-period Oscillations in “normal” Magnetar outbursts

- Coupled magneto-torsional oscillations of crust/core
- Frequencies depend on mass, radius, superfluidity, crust composition, magnetic field strength and geometry (e.g. see Gabler et al 2013, 2014; Huppenkothen, Watts and Levin 2014)

93 Hz, 127 Hz from combined analysis of bursts from SGR J1550-5418 with potential 260 Hz QPO in a single burst from SGR J1550-5418
GRBs and Gravitational Waves

*Fermi*-GBM and Advanced LIGO (>2016) should see coincident Gravitational wave/Electromagnetic emission or rule out NS-BH mergers as the progenitors of short GRB

Large rate of short bursts in GBM is key to coincident detections

GBM Short GRBs in ALIGO horizon:

\[ N(z<0.11, \text{NS-NS}) \sim 2^{+4}_{-1} \text{ yr}^{-1} \]

\[ N(z<0.22, \text{NS-BH}) \sim 8^{+6}_{-3} \text{ yr}^{-1} \]

Both observations bring complementary information: ALIGO → inspiral characteristics; *Fermi* → jet properties & environment
Fermi-LAT Performance Continues to Improve
LAT Event Reconstruction – Pass 8

The LAT collects a significant amount of data for each gamma-ray event from the tracker, calorimeter and anticoincidence detector subsystems

- Take into account improved understanding of the LAT based on orbit experience
  - In particular, account for residual signals that arrive within a few µs of the event of interest (particularly important in the calorimeter)
- Improved track fitting at high energies
- Use full covariant error when propagating tracks back to the ACD
- Improve detector Monte Carlo

In addition to substantial performance benefits, these improvements reduce systematic uncertainties, effectively shifting analyses of some faint sources, crowded regions and extended sources from the systematic to the statistics limited regime
LAT Analysis Upgrades: Pass 8

A major upgrade of the LAT (aka Pass 8) was released in 2015

- Complete revamp of LAT event reconstruction algorithms
- More than double acceptance below 100 MeV
- Retroactively updated entire *Fermi*-LAT data archive
- Open new discovery space for *Fermi* to explore
Angular resolution

Everything is better when we know what we are looking at!
NASA’s Fermi telescope resolves supernova remnants at GeV energies!
A broad (and increasing) Energy Range
The Fermi Sky (>1 GeV)
Fermi Sky (>50 GeV)

61,000 photons $E > 50$ GeV
22,100 photons $E > 100$ GeV
2,000 photons $E > 500$ GeV

80 months of P8 data (50 GeV – 2 TeV)
Spectral Energy Distributions

2FHL J0617.2+2234e (IC 443)

2FHL J1419.3-6047e (PSR J1420-6048)

2FHL J1104.4+3812 (Mkn 421, z = 0.031)

2FHL J0222.6+4301 (3C 66A, z = 0.444)
**Galactic Sources**

- **103 sources at |b|<10°**
  - 42 blazars, 39 Galactic objects, 13 unassociated and 9 Dark Acc.
  - PWNe/SNRs represent 87% of the Galactic population
  - Half of the unassociated sources are hard and thus (likely) Galactic

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**Preliminary**
Gamma Ray Searches for Dark Matter

All-sky map of simulated gamma ray signal from DM annihilation (Baltz 2006)

Dwarf Spheriodal Galaxies

Galactic Center

Milky Way Halo

Large statistics but diffuse background

Extragalactic (sum all the contributions from all galaxies)

Galactic Center GeV Gamma-ray Excess


- Spectral Properties - Rises at energies below 1 GeV, peaks around ~2 GeV (in $E^2dN/dE$, power per logarithmic interval), falls off above ~5 GeV

- Spatial properties - Generally consistent with spherical symmetry around the Galactic Center; centered on SgrA*; extends to at least 10 deg from GC
Dwarf Galaxies

- Dwarf galaxies: DM-dominated systems, provide a clean independent test of DM-annihilation hypothesis.
- Currently provide best current limits on sub-TeV DM annihilating through most channels
- Additional Fermi observations of dSphs should either confirm DM hypothesis for GC excess or refute it
Fermi Highlights and Discoveries

- Terrestrial $\gamma$-ray Flashes
- Fermi Highlights and Discoveries
- GRBs
- Blazars
- Radio Galaxies
- Starburst Galaxies
- LMC & SMC
- Globular Clusters
- Fermi Bubbles
- Nova
- SNRs & PWN
- Pulsars: isolated, binaries, & MSPs
- Sun: flares & CR interactions
- Terrestrial $\gamma$-ray Flashes
- Unidentified Sources (577/1873)

e$^+e^-$ spectrum
Summary

- The first 7 years of Fermi and 9 year of AGILE have been very successful
  - Resolved question of the location of gamma-ray emission regions in pulsars
  - Rejected simplest explanations for broad-band emission in blazars
  - Forced a rethink of acceleration mechanisms in the Crab Nebula
  - Severely challenge standard models of GRB afterglow
  - Discovered many new classes of gamma-ray sources
  - Set stringent limits on WIMP dark matter annihilation/decay
  - And lots more...

The future

- One of our strengths is the study of the time domain – each day brings something new
- Our energy reach extends further to high energies with increasing exposure
- Ongoing work in low level analyses result in improvements in instrument performance with time