Status Overview of Gamma-ray Astronomy

Increasing Capabilities, Key Discoveries and Future Promise

Elizabeth Hays
NASA GSFC
Overview

• Overview of gamma-ray science and instrumentation
• A few interesting things we have learned
• Some questions for the future
It is a great time for gamma rays!

• The gamma-ray sky is full of sources
  – Detailed spectral and spatial measurements for the brightest
  – Population studies

• The era of catalogs
  – Deeper exposures over all or large regions of sky
  – Broad spectral coverage
  – Increasing variety of sources
  – Rich multiwavelength data sets

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Demographics: High Energy

- >3033 sources
- >100 MeV
- Based on 3FGL

80% extragalactic
Demographics: Very High Energy

14% Supernova Remnants
6% SNR Shell
8% SNR Mol. Cloud
21% Pulsar Wind Nebulae
3% Massive Star Clusters
3% Binaries
16% Unknown
37% Blazars
Globular Clusters
Starburst Galaxies
FRI Galaxies

40% extragalactic

>150 sources
>~100 GeV

TeVCat
http://TeVCat.uchicago.edu
Bridging the Gap

Second Catalog of Hard Fermi-LAT Sources

- >3033 sources
- >100 MeV
- 360 sources
- >50 GeV
- >150 sources
- >~100 GeV

Preliminary

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Friday Highlight Talk
Notable Absences

Galaxy Clusters


GRBS at E>100 GeV

GRB 130427A at 71 - 75 ks

Aliu et al. 2014

Waiting for the right burst...

Dwarf Spheroidals

Ackermann et al. 2015

Sensitivity improves with new dwarf galaxies (DES)

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Transients

Fermi GRBs as of 141202

Friday AM and Monday AM parallel sessions

Plus solar flares, Galactic binaries, and terrestrial gamma-ray flashes

1500 GBM GRBs
202 Swift GRBs
93 LAT GRBs

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Resources!

**Fermi Science Support Center** hosts Fermi catalogs and a variety of data products
http://fermi.gsfc.nasa.gov/ssc/data/access/
Analysis tools and documentation for Fermi instrument data
http://fermi.gsfc.nasa.gov/ssc/

**ASI Science Data Center** hosts resources for both Fermi and AGILE
http://www.asdc.asi.it

**TeVCat** provides an online VHE gamma-ray catalog
http://tevcat.uchicago.edu/

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Gamma-ray Detectors

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Photon Energy [eV]

$10^7$  $10^8$  $10^9$  $10^{10}$  $10^{11}$  $10^{12}$

Pair conversion in the detector

Pair conversion in the atmosphere

AGILE

Fermi LAT

LAT 10 yrs

HAWC

HAWC 1 yr/5 yrs

ARGO-YBJ

Sample shower particles at ground level

LAT 10 yrs

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Gamma-ray Detectors

Photon Energy [eV]

- Pair conversion in the detector
- Pair conversion in the atmosphere

- AGILE
- Fermi LAT
- VERITAS
- H.E.S.S.
- MAGIC
- LAT

Sample Cherenkov light cone at ground level

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Fermi-LAT Upgrade - Pass 8

• What?
  – The data reconstruction we always wanted
  – Comparable to a “servicing mission” (years of effort)

• So what?
  – Wider energy range
  – Wider field of view
  – Increased effective area
  – Refined angular resolution capability
  – Refined energy resolution capability

More photons!
7 Years of LAT All-sky Coverage

E > 1 GeV

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Wide Field Coverage of the TeV sky

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150 days
E \gtrsim 100 \text{ GeV}

Wednesday Highlight Talk
Connecting the GeV and TeV Skies

HAWC-95+111 Gamma-Ray Sky (Preliminary)
What Have We Learned?

• About accelerators?
  – Gamma rays probing a variety of astrophysical shocks, but the devil is in the dissipation

• About dark matter and fundamental physics?

• About the high energy Universe?
Gamma-ray Novae

Radio imaging of the shock evolution for V959 Mon.

Nova expansion into binary creates asymmetrically expanding shock and polar wind from the white dwarf.

V959 Mon, 5 GHz EVN
Chomiuk et al. 2014

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Wednesday PM parallel session talk
Rise of Reconnection

Standard shock acceleration scenario does not fit observations in some cases, e.g. Crab Nebula flares.

- Hard electron spectrum
- Electron energy exceeds synchrotron limit at ~160 MeV
- Time scale shorter than that of Larmor gyration

Lots of work happening!
E.g. Sironi & Spitkovsky, Cerutti et al., Porth et al., Guo et al., Lyutikov et al.,
Rapid Variability

Current gamma-ray detectors have comparatively poor angular resolution within broader astronomy. However fast photon counting enables excellent time resolution and requires substantial resolution in multiwavelength observations.

IC 310

Crab       LAT E>100 MeV    12-hr

IC 310

Aleksic et al. 2014

Friday PM parallel session talk

Rudy et al. in press

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Gravitationally Lensed Blazars

PKS 1830-211, FSRQ, at $z=2.507$

LAT Flare 1
$E>100$ GeV

Abdo et al. 2014


Saturday AM and Wednesday PM parallel sessions
Gamma-ray Science

Supernova Remnants

Younger
Appear dominated by inverse Compton

Older

Appear dominated by hadronic processes

Photon Energy [eV]

\(10^7\)  \(10^8\)  \(10^9\)  \(10^{10}\)  \(10^{11}\)  \(10^{12}\)  \(10^{13}\)  \(10^{14}\)

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Resolving Supernova Remnants

LAT $E > 5$ GeV 83 mo (Pass 8)

PRELIMINARY

Wednesday AM parallel session on SNRs
Gamma-ray Science

- **Pulsar**
- **Curvature Radiation**
- **Secondary Inverse Compton**

Photon Energy [eV]:
- $10^7$
- $10^8$
- $10^9$
- $10^{10}$
- $10^{11}$
- $10^{12}$
- $10^{13}$
- $10^{14}$

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VHE Pulsars

Aliu et al. 2011

Tuesday and Wednesday PM parallel session talks

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Gamma-ray Mythbusters

- The Crab pulsar wind nebula is a steady source of high energy emission.

- Pulsars are persistent sources of gamma rays.

- Pulsars do not pulse at very high energies.

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Transitional Pulsars

Millisecond pulsar (redback system) in the process of ablating low mass companion (~0.2 Msol, orbital period <1 day)

Gamma-ray spectral modes for PSR J1227-4853

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Milky Way – Fermi Bubbles

Su et al. 2010
Characterizing the Fermi Bubbles

“Sharp” edges

Spectra for North and South in good agreement

Recent outburst from the black hole or longer activity driven by star formation or tidal disruption?
Crocker et al. 2015, Lacki 2014, Muo et al. 2014, Yang et al.
Excess GeV emission from the Galactic Center

The inner Galaxy:
- Supermassive black hole
- Candidate for dark matter
- Unresolved sources
- Interstellar emission
- Lots of recent work here!

Friday AM parallel session
Saturday Highlight Talk
Big Questions

• Can we find and map dark matter using gamma rays?
• Can we distinguish acceleration mechanisms in play for particles generating rapidly varying gamma-ray emission?
• How similar are cosmic ray population properties across our Galaxy, in other galaxies?
• Population of gamma-ray “probes” within and far beyond the Milky Way is growing. How else will we use these?

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The Future

In terms of mapping gamma rays, we have barely opened our eyes.

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Gamma-ray Detectors

Pair conversion in the detector
Pair conversion in the atmosphere

Fermi LAT
Inner Galaxy
Cherenkov Telescope Array

Monday PM parallel session

Photon Energy [eV]

10^7 10^8 10^9 10^{10} 10^{11} 10^{12} 10^{13} 10^{14}
Gamma-ray Detectors

- Pair conversion in the detector
- Compton scattering in the detector

 photon energy [eV] $10^9 - 10^{12}$

- Inner Galaxy
- Fermi LAT
- 10 yrs

Graph showing source sensitivity vs. energy (MeV) for various detectors:
- T=10^6 s
- IBIS-PIcsIT
- SPI
- COS-B
- COMPTEL
- EGRET
- IBIS-ISGRI
- JEM-X
- ComPair
- FERMI-LAT

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My Wish List

- Extend gamma-ray spectra below 100 MeV
  - Features and components, transition into the nonthermal Universe, nuclear lines
  - Technology exists for next generation and is in development for instruments beyond that.

- More resolution
  - Transformational capability
  - On the ground – systematics are important and challenging
  - In space – will be confusion limited in portions of the spectrum with current instruments, particularly in key regions of the sky.

- Polarization capability
  - New capability – discovery space!
  - Transformational science with sufficient sensitivity

- More acceptance at 1 GeV

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Thank you!
Spectral Complexity

Features
Breaks
Cutoffs
Multiple components
Gamma-ray Science

Blazars

Inverse Compton scattering

Photon Energy [eV]

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Gamma-ray Science

Pulsar Wind Nebula

Inverse Compton

Photon Energy [eV]

$10^7$ $10^8$ $10^9$ $10^{10}$ $10^{11}$ $10^{12}$ $10^{13}$ $10^{14}$

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Bridging the Gap

Second Catalog of Hard Fermi-LAT Sources

Ajello – Fri. Highlight

360 sources
>50 GeV

Preliminary
Pushing synchrotron limits

LAT photon energies and times compared to predictions for maximum synchrotron photon energy

GRB 130427A
Gamma-ray Science

Photon Energy [eV]

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ComPair

A Wide-Aperture Discovery Mission for the MeV Band

- Science focus: extreme astrophysics - high matter densities, strong magnetic fields, powerful jets
- Monitor the whole gamma-ray sky in the energy range 200 keV – > 500 MeV with sensitivity \( \sim 100 \) times better than COMPTEL at \( \sim 1 \) MeV and improved angular resolution over Fermi LAT
- Optimized for continuum sensitivity and field of view but also will provide other ground-breaking capabilities, e.g. polarization, spectroscopy
Thoughts

• Sensitivity across *most* of the gamma-ray band now allows access to a wealth of gamma-ray source classes
  – Commonalities among classes are interesting
  – Differences within classes are even more interesting
  – Outliers are baffling

• What are we missing?
  – We find what we seek. It is no accident that typical spatial and variability studies are matched to current instrument capabilities.

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Data Prospects

• Wide-field TeV observations
  – New sources
  – Extended sources
  – Large scale structures

• Deep IACT observations and lower energy thresholds
  – Spectral detail
  – Capturing rapid variability

• Fermi continues
  – New analysis capability and extension to higher and lower energies
  – Sensitivity linear with time in upper range
  – Best localization accuracy approaching ~arcminute
  – New dwarf spheroidal discoveries enhance dark matter sensitivity
  – New territory for long baseline studies for blazars, binaries, and pulsars
  – Search for neutrino counterparts
  – Overlap with enhanced gravitational wave observatories

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Transient Detection

• Fermi GBM is a GRB machine
  – >xxxx bursts since launch (plus solar flares, soft gamma-ray repeaters, and terrestrial gamma-ray flashes)