GLAST and High Energy Gamma-Ray Astrophysics

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Outline

• General comments.

• Sources of high energy gamma-rays.

• Detection of high energy gamma-rays.

• Future prospects.
High Gamma-Ray Astrophysics

- Exploring the Universe from 100 MeV – 100 TeV, production of these photons require very energetic particles -> exploring the most energetic and extreme astrophysical sources.
  -- Natural connections to Neutrino and Cosmic-ray astrophysics.

- Each photon carries a lot of energy, so even for very luminous objects, the photon flux is low -> important implications for detectors (the brightest TeV flux ever observed was just ~4 photons/m²/week)

- Some definitions: GeV astrophysics <~100 GeV, TeV astrophysics >~100 GeV

- Gamma-rays are neutral, so they point back to their source.

- Require large detectors for TeV astrophysics.
Production of High Energy Gamma-rays

Often produced by a different component/physical process than the “usually” better studied radio-optical -> important handle on the underlying astrophysics

For many gamma-ray sources, the bulk of the energy is emitted in high energy gamma-rays

3C279
(Wehrle et al 1997)

Crab Nebula
(Aharonian et al 1997)
Attenuation of High Energy Gamma-rays

\[ \gamma_{\text{TeV}} + \gamma_{\text{soft}} \rightarrow e^+e^- \] Allows us to probe physical conditions in emission regions.

The photons can also be attenuated as they traverse intergalactic space.
- Limits volume of observable Universe.

Density and spectrum of Optical/IR background is not well measured

Assuming a given cosmological scenario, one can calculate the opacity of the Universe as a function of distance and gamma-ray energy. The converse is also true.

(Bullock 1999)
The GeV Gamma-ray Sky

- 3EG J1835+5918 (Isolated Neutron Star?)
- 3EG J0010+7309 (CTA 1 SNR?)
- 3EG J2020+4017 (γ Cygni SNR?)
- 3C279 (blazar)
- Vela (radio pulsar)
- Geminga (radio-quiet pulsar)
- 3EG J1746-2851 (Galactic Center?)
- PKS 0208-512 (blazar)
- LMC (Cosmic ray interactions with ISM)
- Orion Cloud (Cosmic ray interactions with ISM)
Transient and variable sources

- **Active Galactic Nuclei (AGN)** – Galaxy with an active core (generally believed to be powered by accretion onto a black hole). Variable on timescales from hours to years.
- **Gamma-ray Bursts (GRB)** – Short (ms to 1000s duration), very bright flashes of keV-MeV gamma-rays followed by a faint fading afterglow.
- **Be star/pulsar binary system** – Very high energy gamma-ray emission seen at the point in the orbit where the pulsar and massive star are close to one another.

With all these sources the time of the gamma-ray observation matters. Very important to understand the relationship of the high energy gamma-ray emission with respect to the lower energy (x-ray, optical and radio) emission.
Active Galactic Nuclei

- Enormous energy output coming from a compact source in the center of some galaxies
- Most numerous class of GeV and TeV sources, but little overlap between the two catalogs.

- Many of these objects have peak luminosity at high energy gamma-rays.
- High energies + rapid variability => close to the base of the jet.
- High energy photons require high energy particles => study particle acceleration and energetics
- Observations of correlated variability allows a detailed understanding of conditions in the emission region.
Gamma-Ray Bursts

- Short, very bright bursts of gamma-rays.
- Faint, fading afterglows have been measured from radio to X-ray energies.
- Cosmologically distributed -> enormously energetic ($10^{48}$-$10^{54}$ ergs, for isotropic emission).
- Very rapid variability-> Small emission region-> Huge photon density.
In one GRB, EGRET observed emission above 30 MeV for more than an hour after the prompt emission.

18 GeV photon was observed (the highest ever seen by EGRET from a GRB).

Due to Earth occultation, it is unknown for how long the high energy emission lasted.

Unlike optical/X-ray afterglows, gamma-ray luminosity did not decrease with time -> additional processes contributing to high energy emission?
Similar processes with different energy and distance scales?
Pulsars

Physics in extreme magnetic and electric fields.

Location and nature of particle acceleration and interaction

from J. Dyks et al.
Particle Acceleration
SNRs – Origin of Cosmic-rays?

Electron vs proton acceleration.
Interactions with interstellar medium.
Upper limit of SNR acceleration of cosmic-rays.
Indirect detection of Dark Matter: anomalous fluxes of gamma-rays from neutralino annihilation.

Using GRB and AGN as a probe of cosmological volumes:
- Lorentz invariance violation: some classes of QG models imply a linear photon velocity dispersion. Expect distance dependent lags in photon arrival times from GRB.
- Diffuse optical/IR background radiation, will cause distance dependent upper energy cutoffs.

To avoid confusing these effects with properties intrinsic to GRB and AGN -> need large numbers of sources.
Representative of windows opened by measurements at such large distances and energy scales.
Detect the air-shower induced by the gamma-ray as it interacts in the atmosphere, either via:
Cherenkov light produced in the atmosphere (Atmospheric Cherenkov telescopes) or
Detecting the air-shower particles that reach ground-level.
The current/next generation of ACTs
Milagro Gamma-Ray Detector

Produce the first TeV all-sky survey. Don't need to be theory guided, can find the unexpected!! Particularly good for finding bright transients and diffuse sources. Detected 3 known TeV sources, 2 new diffuse sources (no known counterpart) and a detection of the Galactic plane.

Excess Coincident with Unidentified EGRET source 3EG J0520+2556
GLAST Overview

Two Instruments:
Large Area Telescope (LAT)
PI: P. Michelson (Stanford University)
   20 MeV - 300 GeV

GLAST Burst Monitor (GBM)
PI: C. Meegan (NASA/MSFC)
   10 keV – 25 MeV

Launch: 2007
Lifetime: 5 years (requirement)

Partnership between NASA and DOE
Pair Conversion Technique

- Photon converts to an e+e- pair in one of the conversion foils.
- The energy is measured in the calorimeter.
- The anti-coincidence shield vetos incoming charged particles.
- The directions of the charged particles are recorded by particle tracking detectors, the measured tracks point back to the source.

Tracker: angular resolution is determined by:
- Multiple scattering (at low energies) => Many thin layers
- Position resolution (at high energies) => Fine pitch detectors

Calorimeter:
- Enough $X_0$ to contain shower, shower leakage correction.

Anti-coincidence detector:
- Must have high efficiency for rejecting charged particles, but not veto gamma-rays.
The GLAST Large Area Telescope

- **Precision Si-strip Tracker (TKR)**
  18 XY tracking planes. 228 μm pitch. High efficiency.
  12 x 0.03 $X_0$ front end => reduce multiple scattering.
  4 x 0.18 $X_0$ back-end => increase sensitivity >1GeV

- **CsI Calorimeter (CAL)**
  Array of 1536 CsI(Tl) crystals in 8 layers.
  Hodoscopic => Cosmic ray rejection.
  => shower leakage correction.
  8.5 $X_0$ => Shower max contained <100 GeV

- **Anticoincidence Detector (ACD)**
  Segmented (89 plastic scintillator tiles)
  => minimize self veto

Height/Width = 0.4
=> Large field of view

**Systems work together to identify and measure the flux of cosmic gamma rays with energy 20 MeV - >300 GeV.**
Sensitivity and Field of View

The Field of view of the LAT is huge > 20% of the sky.

Rocking mode provides an efficient way of observing the entire sky with reasonably uniform exposure on timescales of hours.

more exposure => greater sensitivity
more coverage => excellent for monitoring the sky on timescales from hours to years
EGRET -> GLAST

CGRO/EGRET

- Energy Range: 30 MeV – 30 GeV
- Energy Res. (ΔE/E): 0.1
- Effective Area (1 GeV): 1500 cm²
- Field of View: 0.5 sr
- Angular Resolution: 5.8° @ 100 MeV
  - 0.5° @ 10 GeV
- Sensitivity (>100 MeV): ~10⁻⁷ cm⁻² s⁻¹
- Deadtime: 100 ms

GLAST/LAT (requirements)

- Energy Range: 20 MeV – 300 GeV
- Energy Res. (ΔE/E): 0.1
- Effective Area (1 GeV): 8,000 cm²
- Field of View: 2 sr
- Angular Resolution: 
  - ~3.5° @ 100 MeV
  - 0.1° @ 10 GeV
- Sensitivity (>100 MeV): 3x10⁻⁹ cm⁻² s⁻¹
- Deadtime: <100 μs
Gamma-ray Bursts

Larger field of view
Larger effective area
Lower dead time (factor of 10000!)
-- will see more photons from more GRB

GBM is very important to connect LAT observations of GRB to the traditional energy range.
Active Galactic Nuclei

The number of AGN that GLAST will detect depends on the luminosity function and distance distribution. Estimates range from 2000 – 10000. (c.f. ~80 known gamma-ray AGN)

- GLAST will allow us to monitor all AGN continuously.
- How does the gamma-ray intensity vary with alignment angle?
- How does the gamma-ray intensity and variability relate to radio to X-ray properties?
Spatial Resolution

- For SNR candidates, the LAT sensitivity and resolution will allow mapping to separate extended emission from the SNR from possible pulsar components.

- Energy spectra for the two emission components may also differ.

- Resolved images will allow observations at other wavelengths to concentrate on promising directions.

(a) Observed (EGRET) and (b) simulated LAT (1-yr sky survey) intensity in the vicinity of γ-Cygni for energies >1 GeV. The dashed circle indicates the radio position of the shell and the asterisk the pulsar candidate proposed by Brazier et al. (1996).
Source Localization

The localization of a source depends on the source spectrum as well as the flux and background intensity.

GLAST will provide much more accurate GeV source locations. With ~30 arcsec - 10 arcmin localizations.

- Rosat or Einstein X-ray Source
- 1.4 GHz VLA Radio Source

Cygnus region (15x15 degrees)
Overlap with TeV instruments

TeV and GeV techniques will overlap for the first time.

Possibility to do joint spectral fits.

Likely to be much more overlap in the GeV and TeV catalogs.
Conclusions

Entering a new era, dramatic improvements in detectors. Several new instruments coming online over the next 5 years.

GLAST will increase the GeV source catalog by more than an order of magnitude:
- many more sources from known classes of gamma-ray emitters (separate the generic features of the sources and the acceleration mechanisms from the individual characteristics of individual objects.)
- More classes of GeV emitters.

Efficient observing mode, improved sensitivity and increased effective area combine to provide superb monitoring of the entire GeV sky on timescales from hours to years.

Greatly improved sensitivity at higher energies than was accessible by EGRET will open up a new window (discovery potential!) and will ensure a much closer overlap with TeV instruments.