GLAST

The Gamma-ray Large Area Space Telescope

The next great step in space-based gamma-ray astrophysics

8 May 2007

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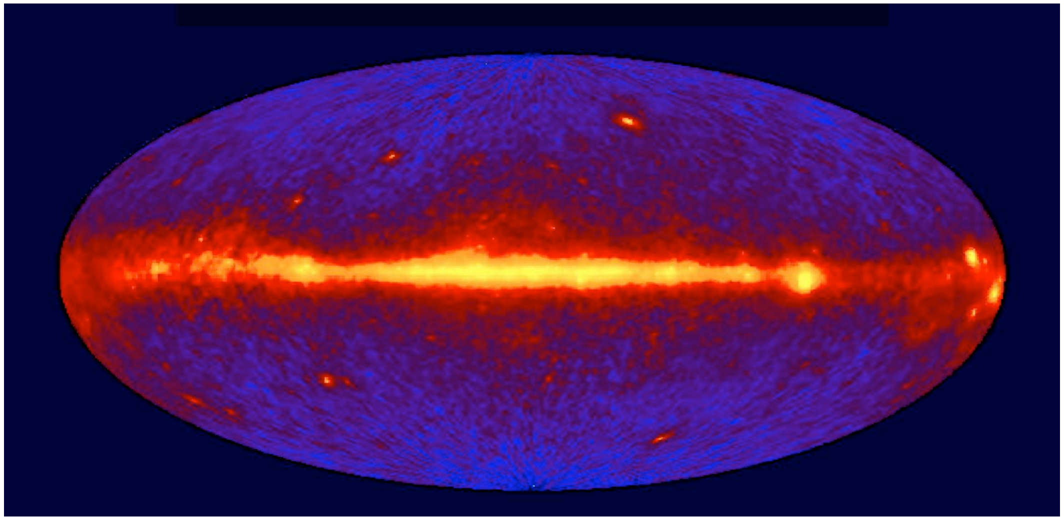
see http://glast.gsfc.nasa.gov/ and links therein

Why study cosmic γ's?

- γ rays offer a direct view into Nature's largest accelerators.
- the Universe is mainly transparent to γ rays: can probe cosmological volumes. Any opacity is energy-dependent.
- conversely, γ rays readily interact in detectors, with a clear signature.
- γ rays are neutral: no complications due to magnetic fields. Point directly back to sources, etc.

Features of the gamma-ray sky



EGRET all-sky survey (galactic coordinates) E>100 MeV

diffuse extra-galactic background (flux ~ 1.5×10^{-5} $cm^{-2}s^{-1}sr^{-1}$)

galactic diffuse (flux ~O(100) times larger)

high latitude (extra-galactic) point sources (typical flux from EGRET sources O(10^{-7} - 10^{-6}) $cm^{-2}s^{-1}$

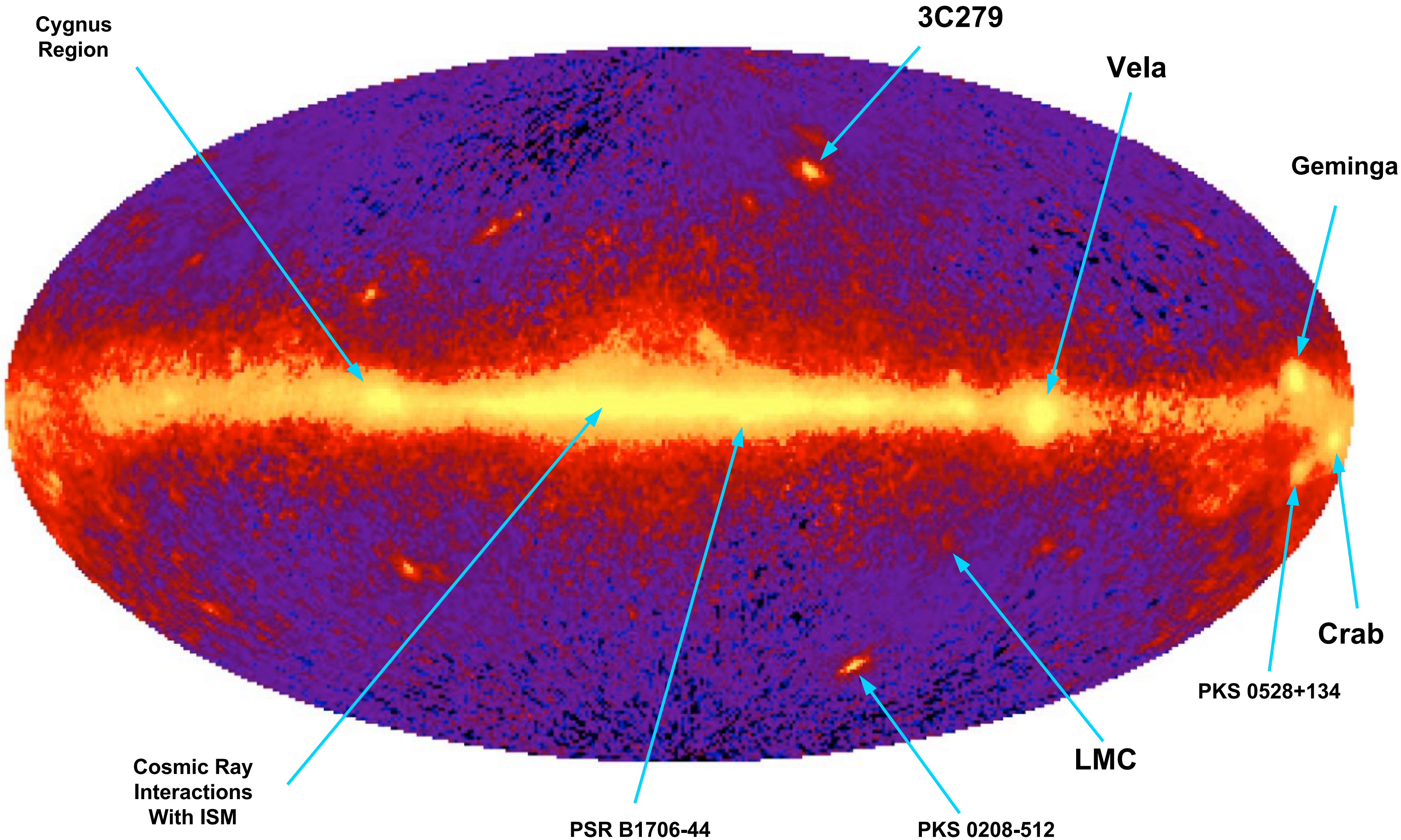
galactic sources (pulsars, un-ID'd)

An essential characteristic: VARIABILITY in time!

Field of view important for study of transients.

In sky survey mode, GLAST will cover the entire sky every 3 hours, with each region viewed for ~30 minutes.

EGRET All Sky Map (>100 MeV)

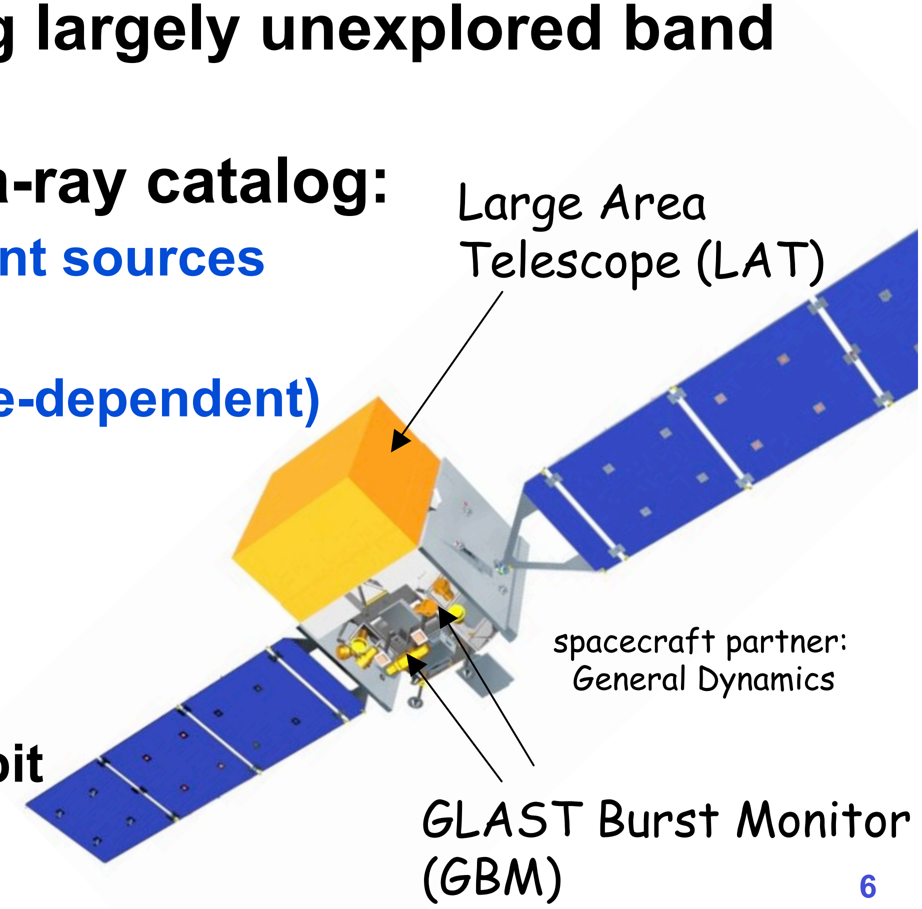


Note the energy scale!

- Typical gamma-ray energies >> $m_e c^2$

GLAST Key Features

- **Huge field of view**
  - **LAT: 20% of the sky at any instant; in sky survey mode, expose all parts of sky for ~30 minutes every 3 hours. GBM: whole unocculted sky at any time.**
- **Huge energy range, including largely unexplored band 10 GeV - 100 GeV**
- **Will transform the HE gamma-ray catalog:**
  - **by > order of magnitude in # point sources**
  - **spatially extended sources**
  - **sub-arcmin localizations (source-dependent)**



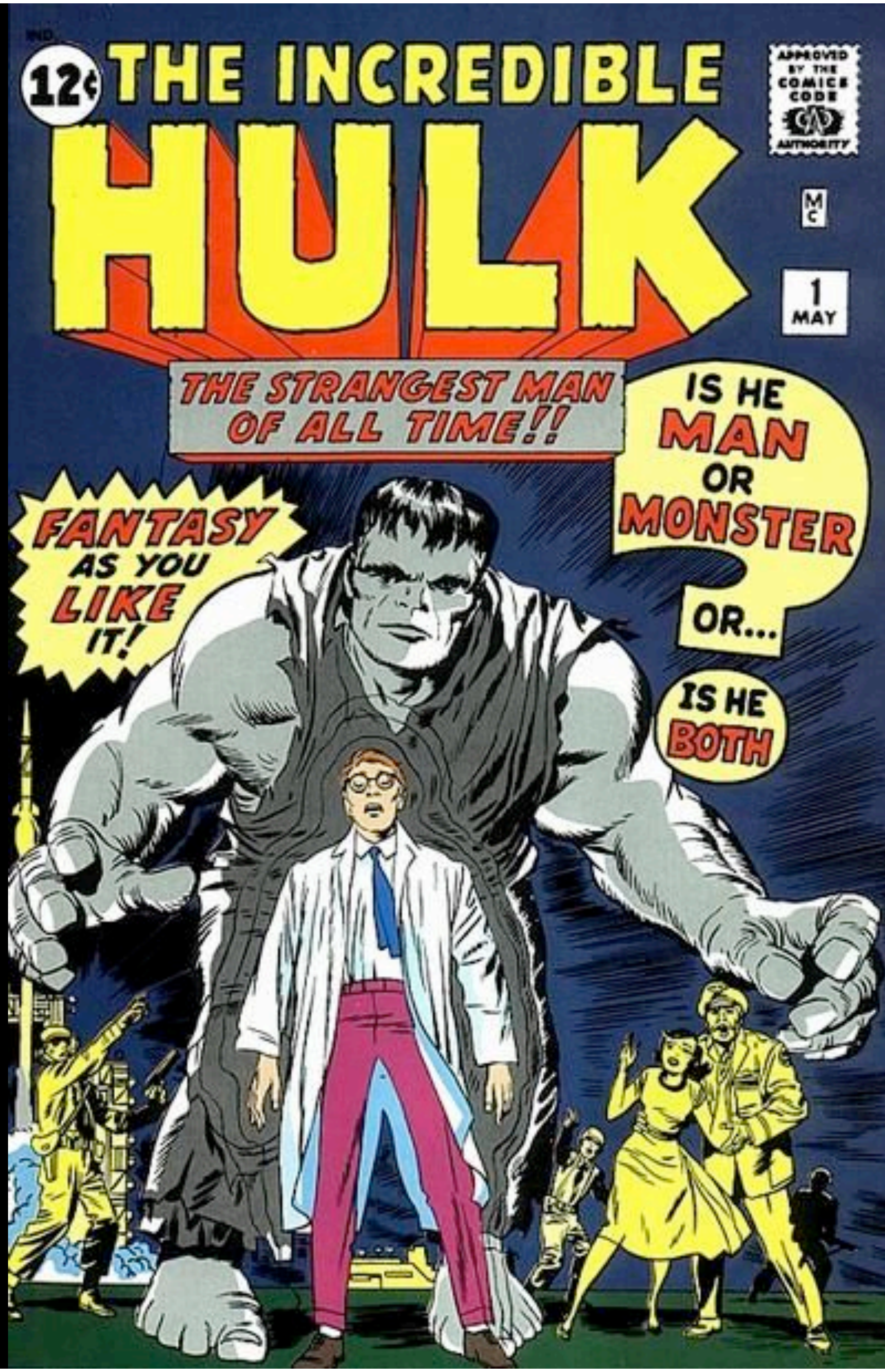
<u>Two GLAST instruments</u>:

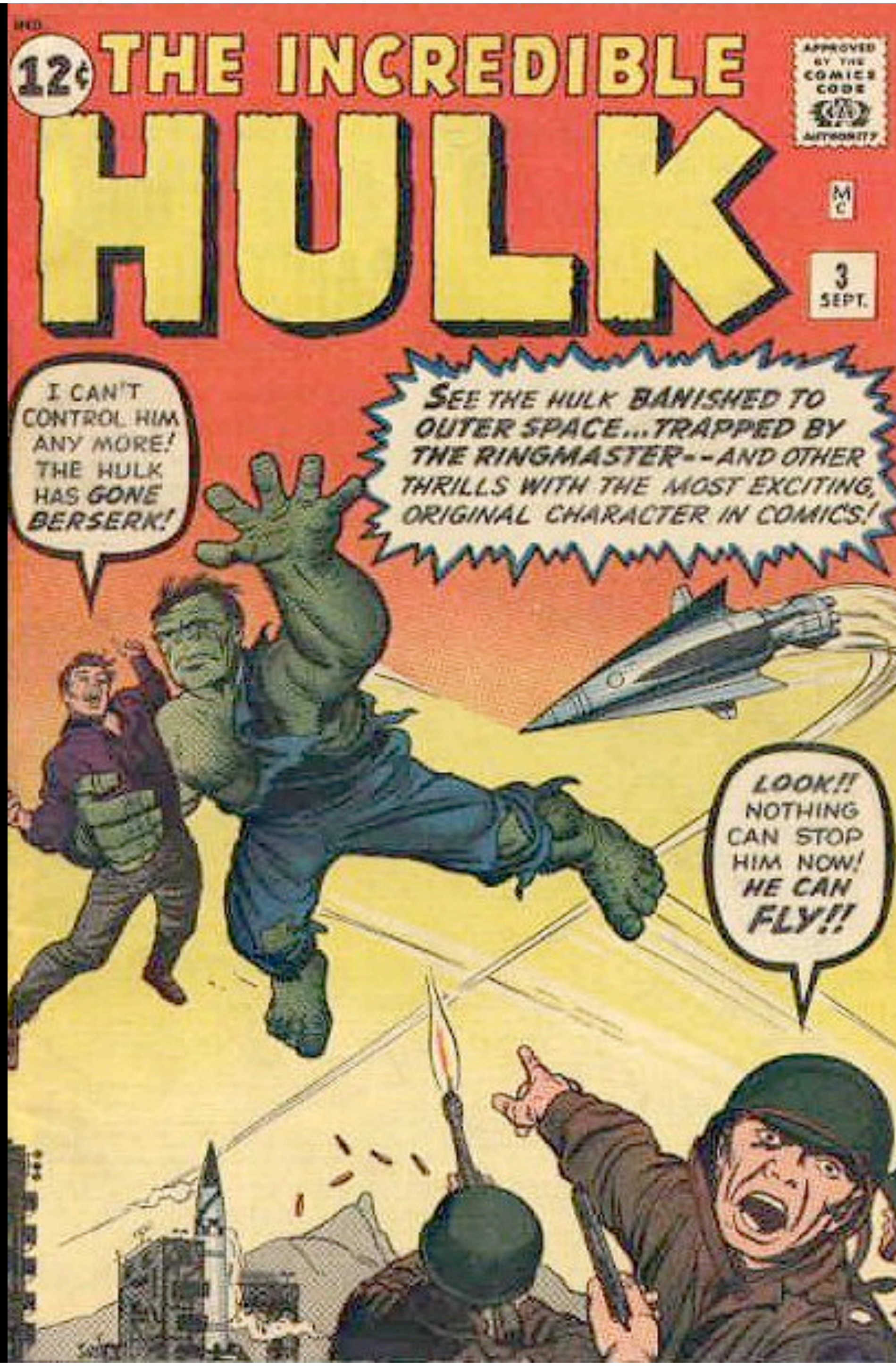
LAT: 20 MeV – >300 GeV

GBM: 10 keV – 25 MeV

Launch: Fall 2007. 565 km, circular orbit

5-year mission (10-year goal)


12¢
THE INCREDIBLE
HULK
APPROVED BY THE COMICS CODE AUTHORITY
MC
1 MAY
THE STRANGEST MAN OF ALL TIME!!
IS HE MAN OR MONSTER
OR...
IS HE BOTH
FANTASY AS YOU LIKE IT!

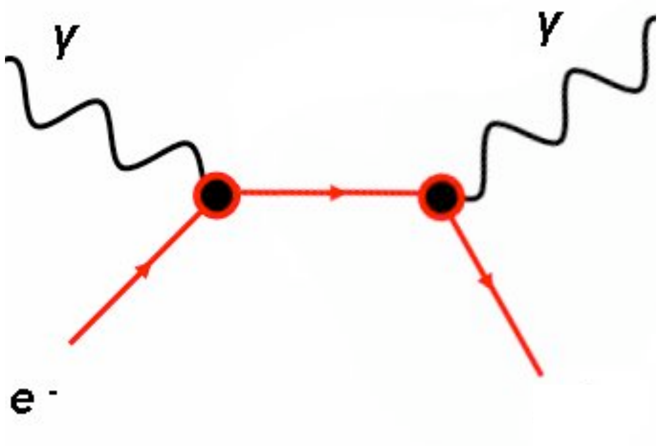

12¢
THE INCREDIBLE
HULK
APPROVED BY THE COMICS CODE AUTHORITY
MC
3
SEPT.
I CAN'T CONTROL HIM ANY MORE! THE HULK HAS GONE BERSERK!
SEE THE HULK BANISHED TO OUTER SPACE...TRAPPED BY THE RINGMASTER--AND OTHER THRILLS WITH THE MOST EXCITING, ORIGINAL CHARACTER IN COMICS!
LOOK!! NOTHING CAN STOP HIM NOW! HE CAN FLY!!

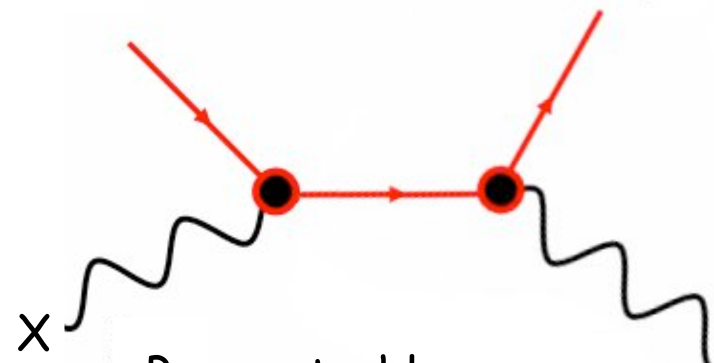
Latest Picture of GLAST Observatory

http://glast.gsfc.nasa.gov/public/resources/images/

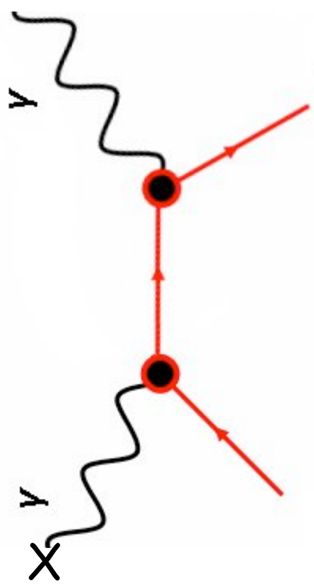
time

Compton Scattering





Bremsstrahlung

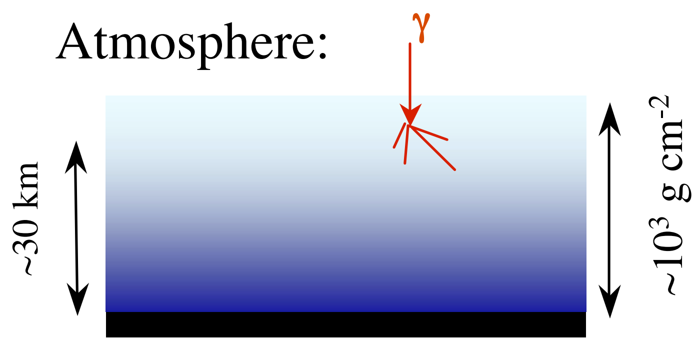


Pair Conversion

Electromagnetic shower cascades in matter: pair-brem-pair-brem….
shower grows until electron energies degraded to point when bremsstrahlung is not the dominant process. # particles in shower ∝ kinetic energy of initial particle!

Why Space?

Atmosphere:



To detect these gamma rays, must have an instrument above the atmosphere.

[Note, for extremely high-energy gamma rays, information from showers penetrates to the ground.]

Photon interaction mechanisms:

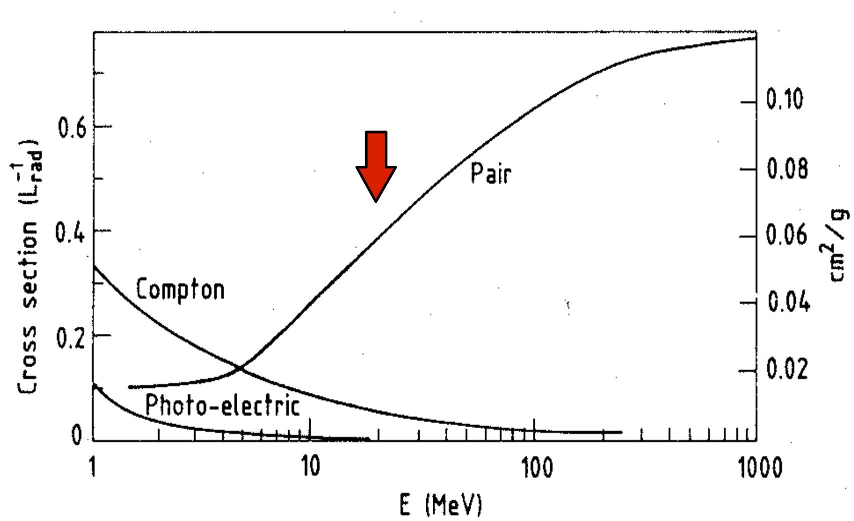
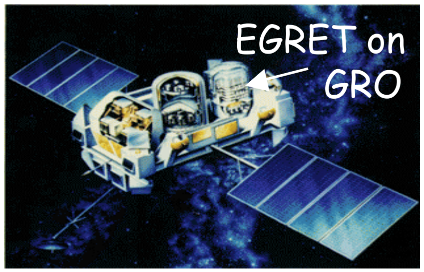
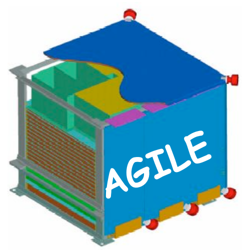


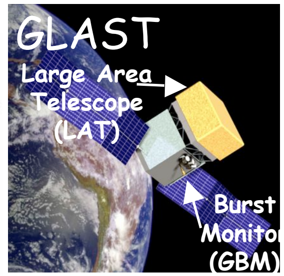
Fig. 2: Photon cross-section σ in lead as a function of photon energy. The intensity of photons can be expressed as $I = I_0 \exp(-\sigma x)$, where x is the path length in radiation lengths. (Review of Particle Properties, April 1980 edition).

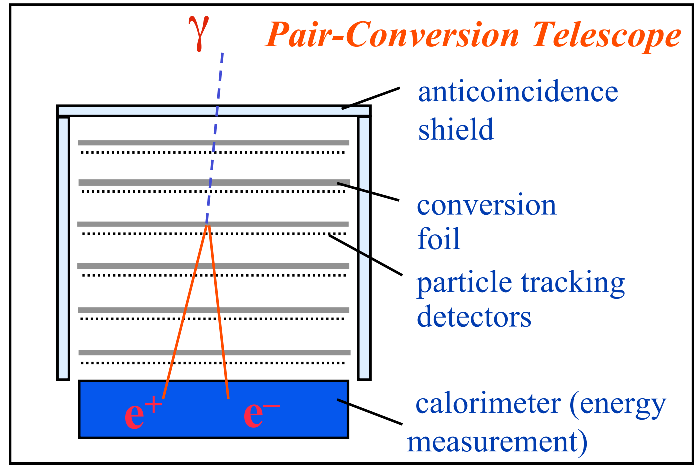
HE Gamma-ray Experiment Techniques

- **Space-based:**
  - use pair-conversion technique





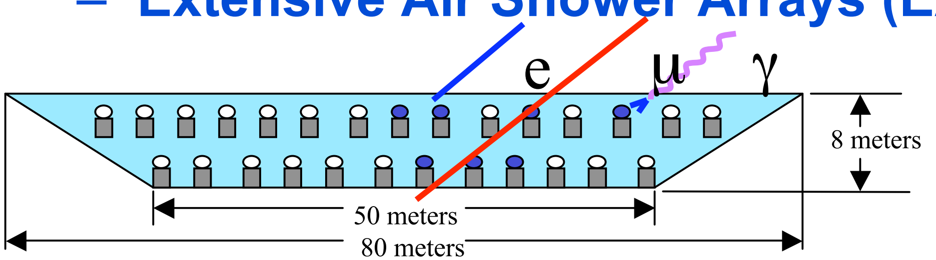




- **Ground-Based:**
  - Airshower Cerenkov Telescopes (ACTs)

image the Cerenkov light from showers induced in the atmosphere. Examples: Whipple, CANGAROO, HEGRA, STACEE, VERITAS, MAGIC, HESS

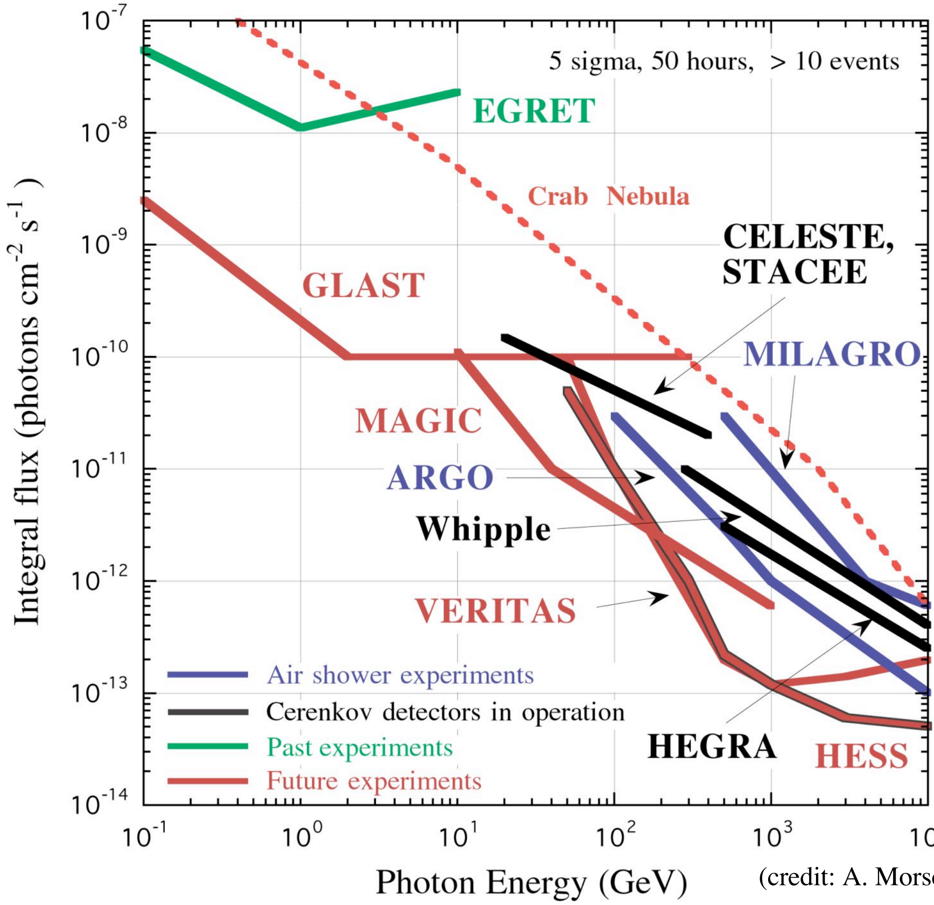
  - Extensive Air Shower Arrays (EAS)



Directly detect particles from the showers induced in the atmosphere. Example: <u>Milagro</u>

VERITAS

High-energy Gamma-ray Observatories



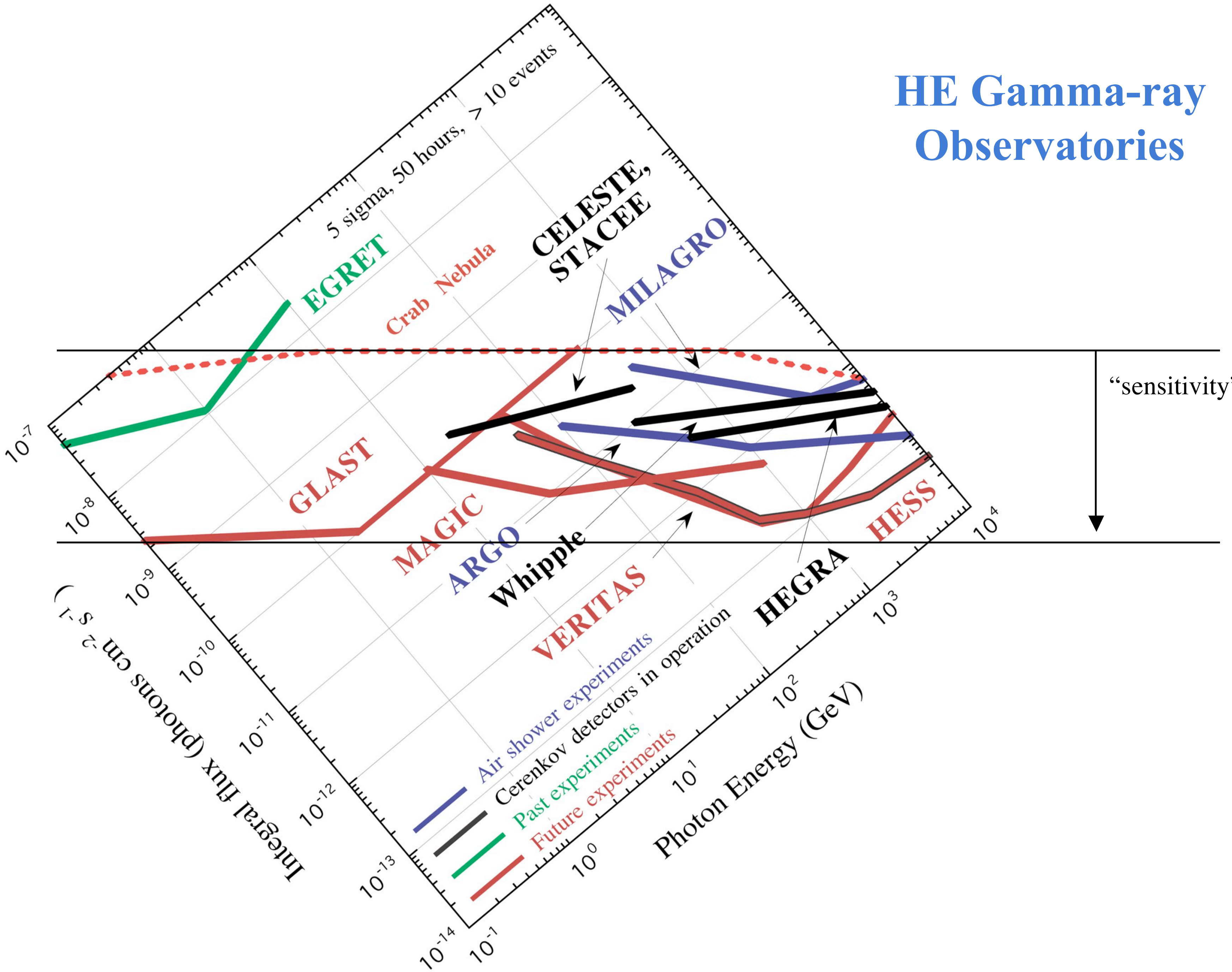
(credit: A. Morselli et al.)

Complementary capabilities

	ground-based		space-based
	ACT	EAS	Pair
angular resolution	good	fair	good
duty cycle	low	high	high
area	large	large	small
field of view	small	large	large +can reorient
energy resolution	good	fair	good, w/ smaller systematic uncertainties

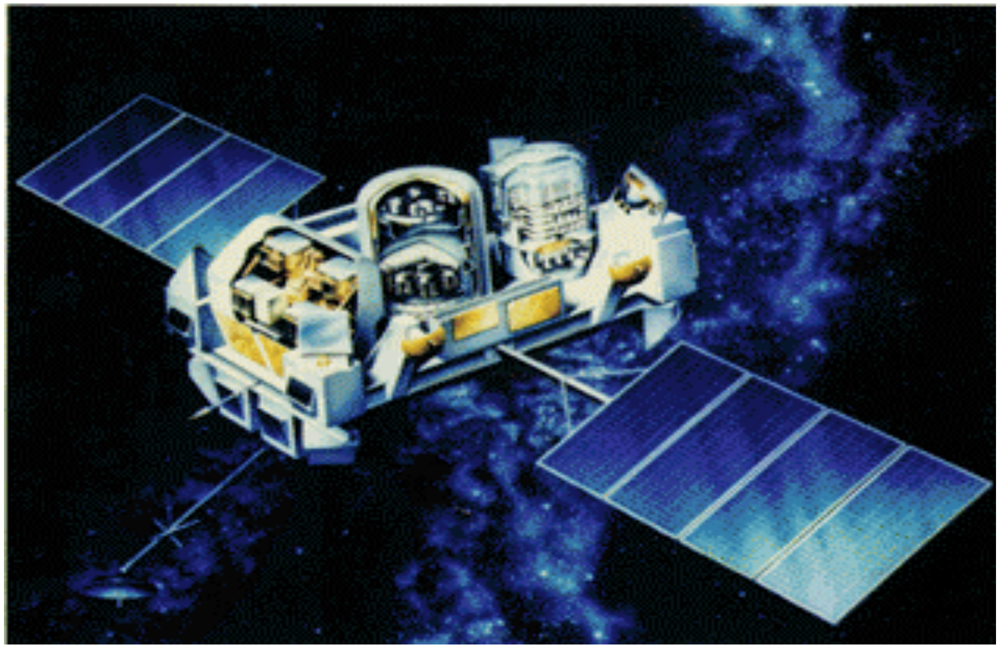
The next-generation ground-based and space-based experiments are well matched.

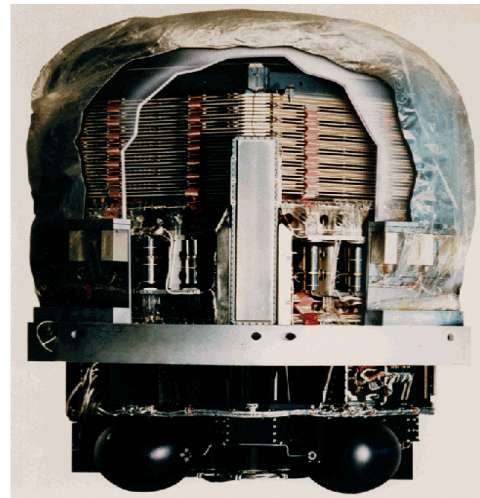
HE Gamma-ray Observatories

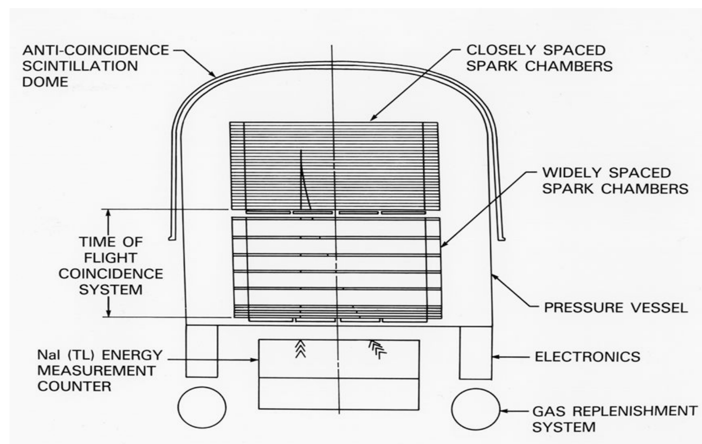


EGRET

The high energy gamma ray detector on the Compton Gamma Ray Observatory (20 MeV - ~20 GeV), 1991-2000







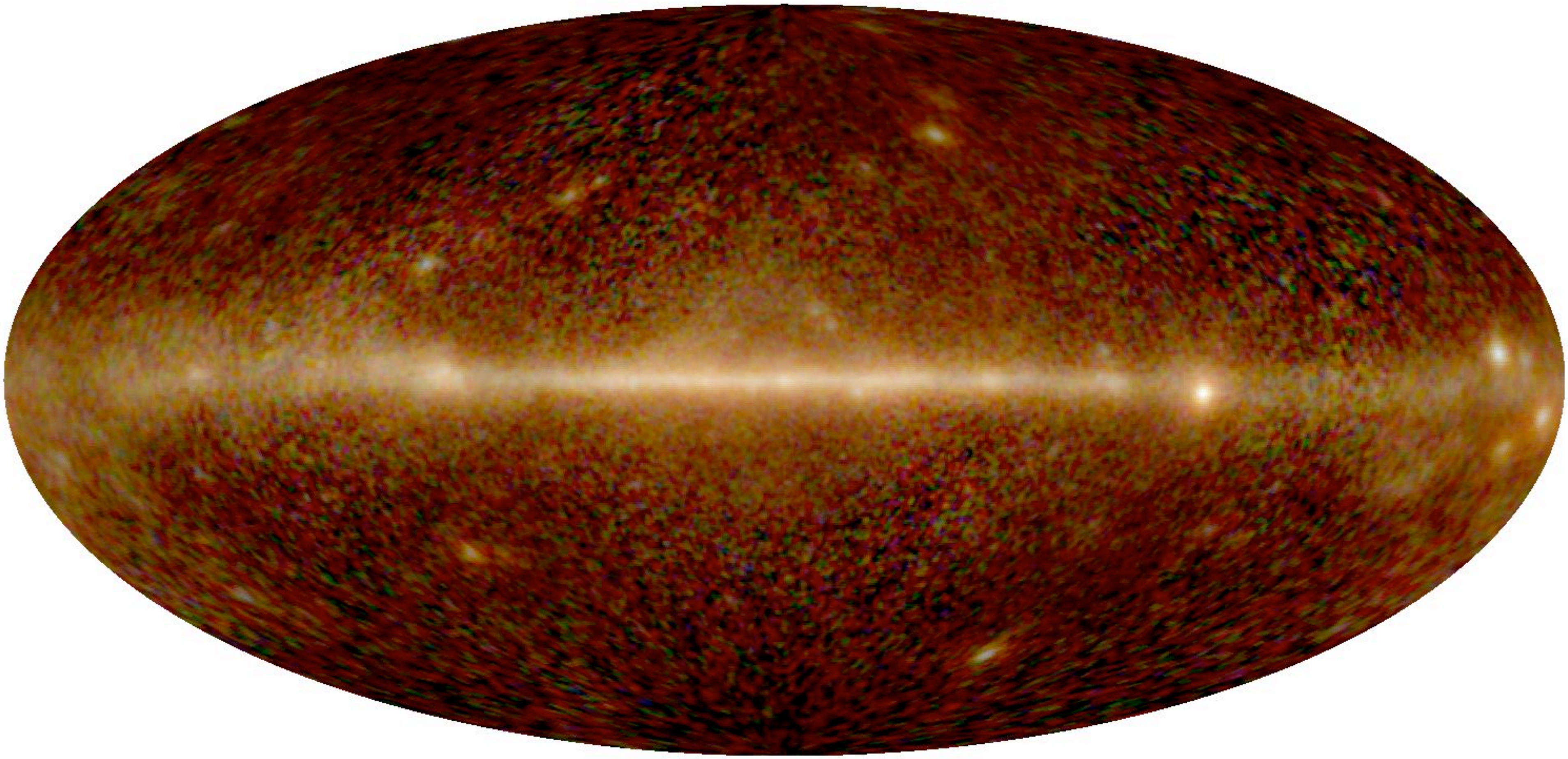
GLAST LAT High Energy Capabilities

EGRET on GRO firmly established the field of high-energy gamma-ray astrophysics and demonstrated the importance and potential of this energy band.

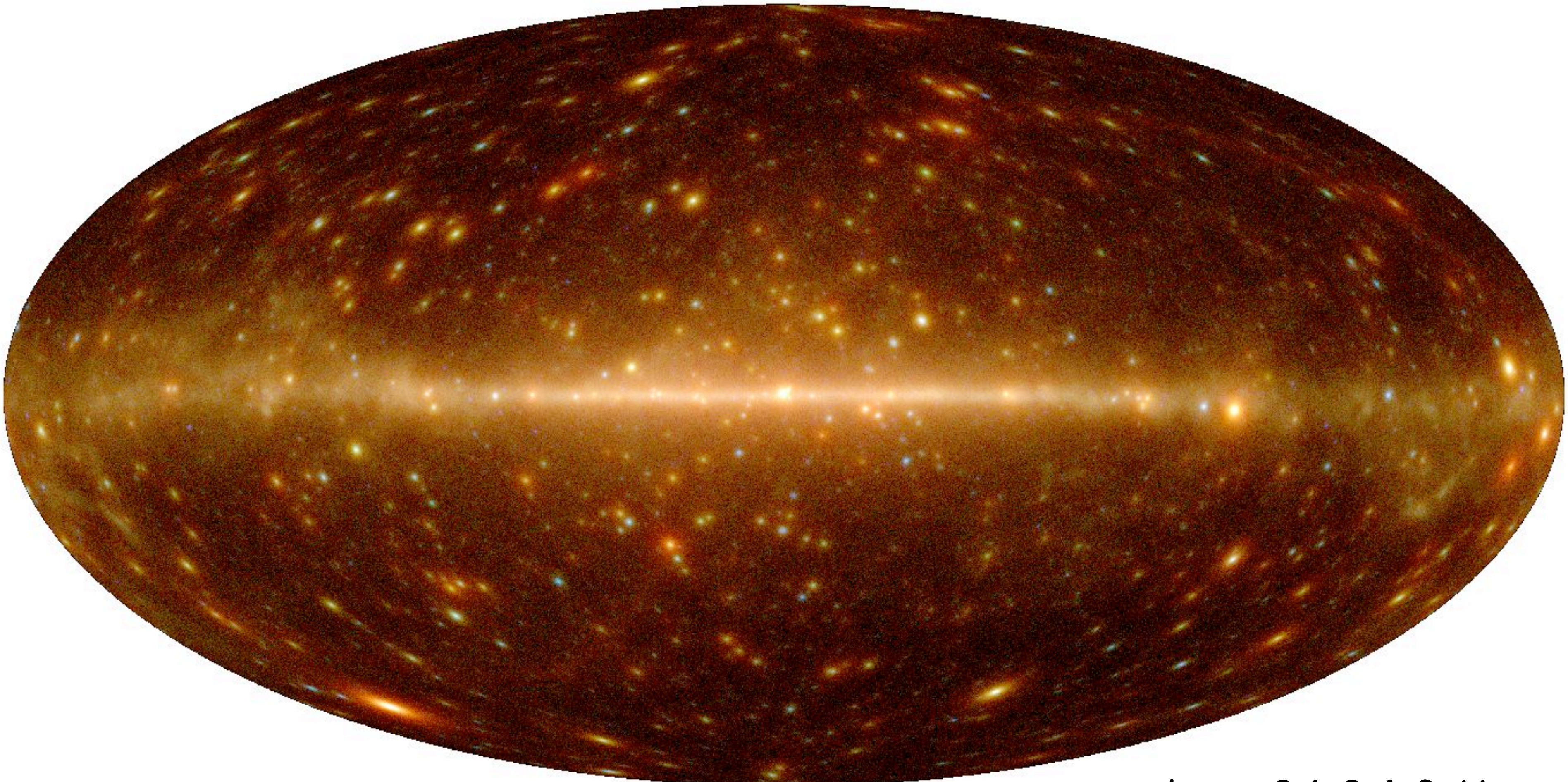
GLAST is the next great step beyond EGRET, providing a huge leap in capabilities:

- *Very large FOV (~20% of sky), factor 4 greater than EGRET*
- *Broadband (4 decades in energy, including unexplored region E > 10 GeV)*
- *Unprecedented PSF for gamma rays (factor > 3 better than EGRET for E>1 GeV)*
- *Large effective area (factor > 5 better than EGRET)*
- *Results in factor > 30 improvement in sensitivity*
- *Much smaller deadtime per event (27 microsec, factor 4,000 better than EGRET)*
- *No expendables → long mission without degradation*

EGRET



GLAST One-year Service Challenge Simulation

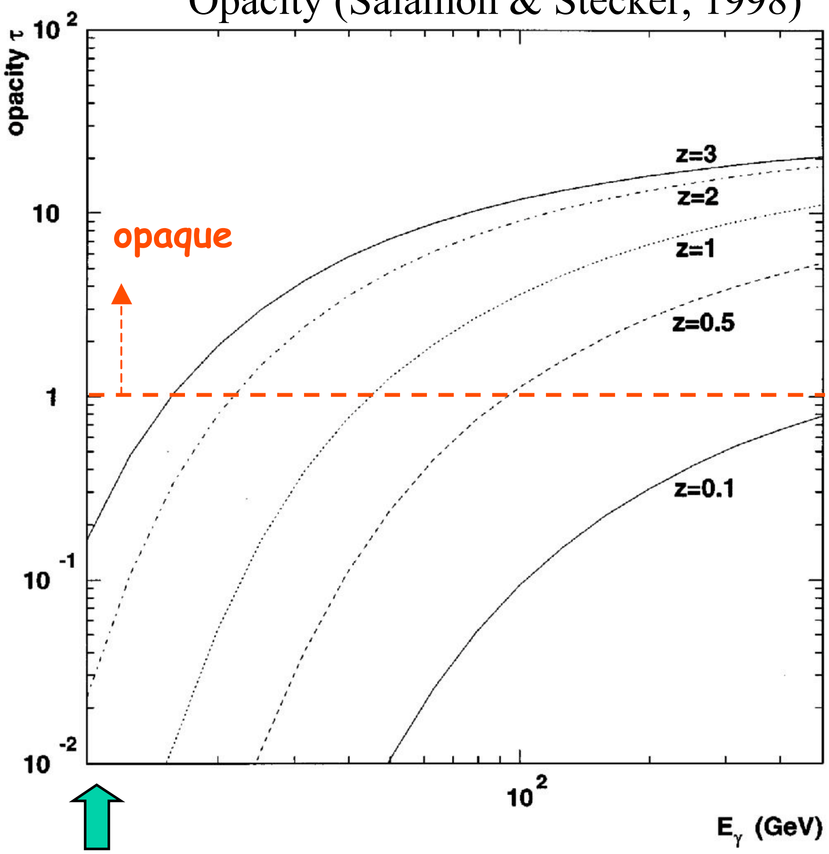


red: 0.1-0.4 GeV
green: 0.4-1.6 GeV
blue: >1.6 GeV

An Important Energy Band

Photons with E>10 GeV are attenuated by the diffuse field of UV-Optical-IR extragalactic background light (EBL)

Opacity (Salamon & Stecker, 1998)



No significant attenuation below ~10 GeV.

only $e^{-\tau}$ of the original source flux reaches us

EBL over cosmological distances is probed by gammas in the 10-100 GeV range. <u>Important science for GLAST!</u>

In contrast, the TeV-IR attenuation results in a flux that may be limited to more local (or much brighter) sources.

A dominant factor in EBL models is the star formation rate -- <u>attenuation measurements can help distinguish models</u>.

GLAST Science

GLAST will have a very broad menu that includes:

- Systems with supermassive black holes (Active Galactic Nuclei)
- Gamma-ray bursts (GRBs)
- Pulsars
- XRBs, microquasars
- Solar physics
- SNRs, Origin of Cosmic Rays
- Probing the era of galaxy formation, optical-UV background light
- Solving the mystery of the high-energy unidentified sources
- Discovery! New source classes. Particle Dark Matter? Other relics from the Big Bang? Testing Lorentz invariance.

Huge increment in capabilities.

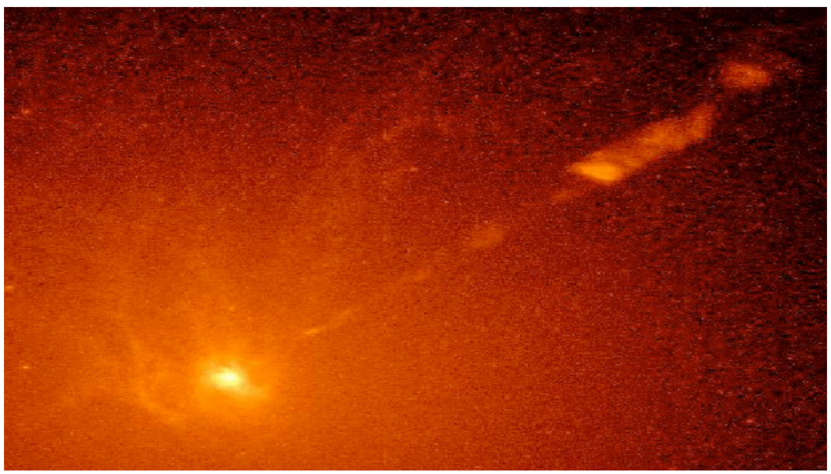
GLAST draws the interest of both the High Energy Particle Physics and High Energy Astrophysics communities.

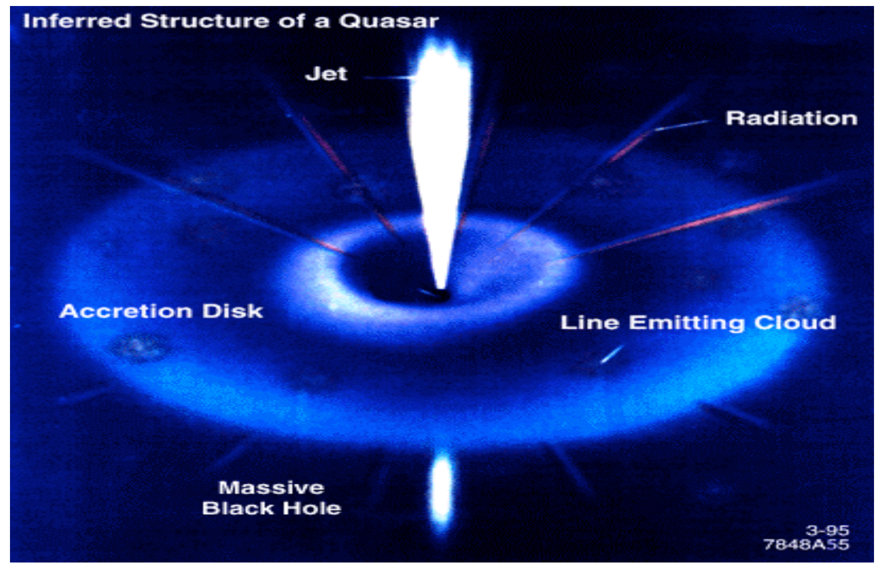
Active Galactic Nuclei (AGN)

Active galaxies produce vast amounts of energy from a very compact central volume.

Prevailing idea: powered by accretion onto super-massive black holes (10^6 - 10^{10} solar masses). Different phenomenology primarily due to the orientation with respect to us.

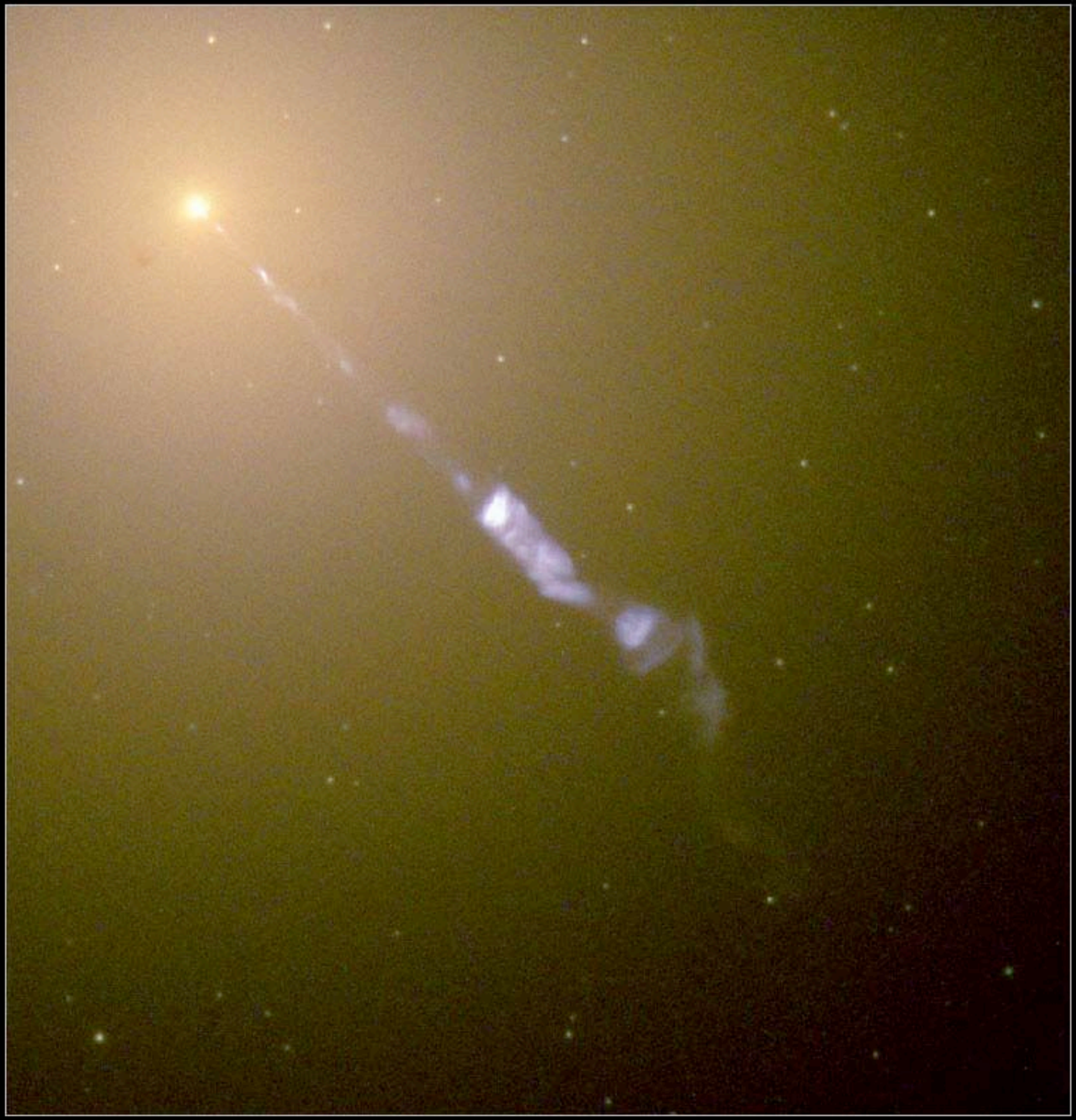
HST Image of M87 (1994)





Models include energetic (multi-TeV), highly-collimated, relativistic particle jets. High energy γ-rays emitted within a few degrees of jet axis. Mechanisms are speculative; γ-rays offer a direct probe.

The M87 Jet



Hubble Heritage

PRC00-20 • Space Telescope Science Institute • NASA and The Hubble Heritage Team (STScI/AURA)

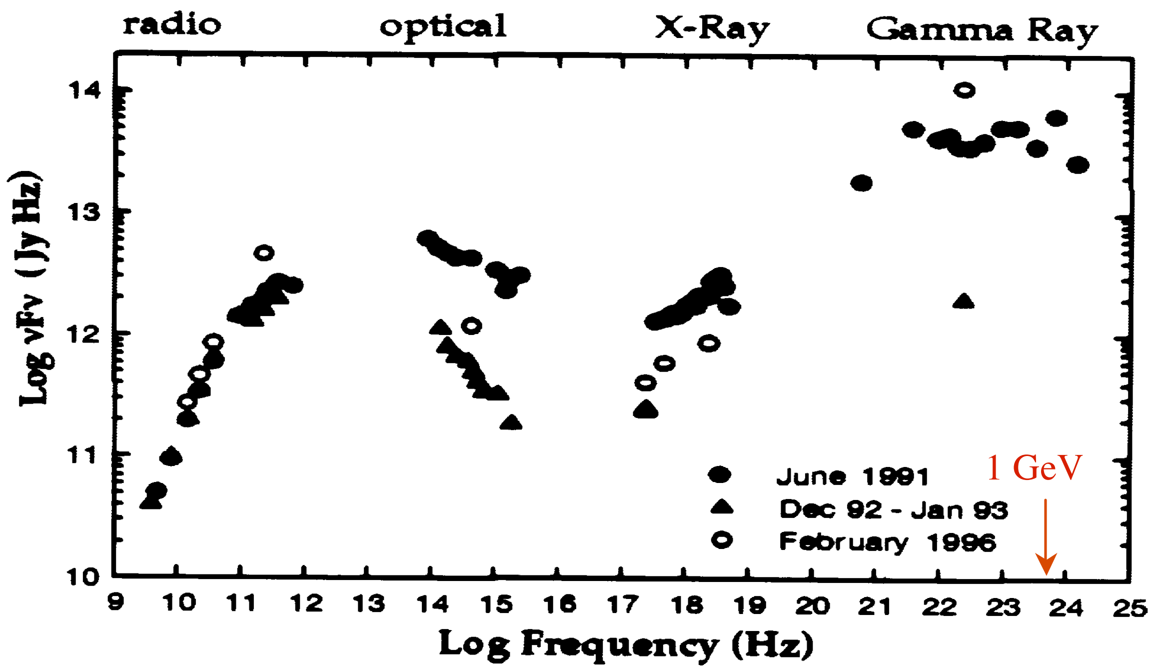
AGN Shine Brightly in GLAST Energy Range

Power output of AGN is remarkable. Multi-GeV component can be dominant.

Estimated luminosity of 3C 279:

~ 10^{45} erg/s

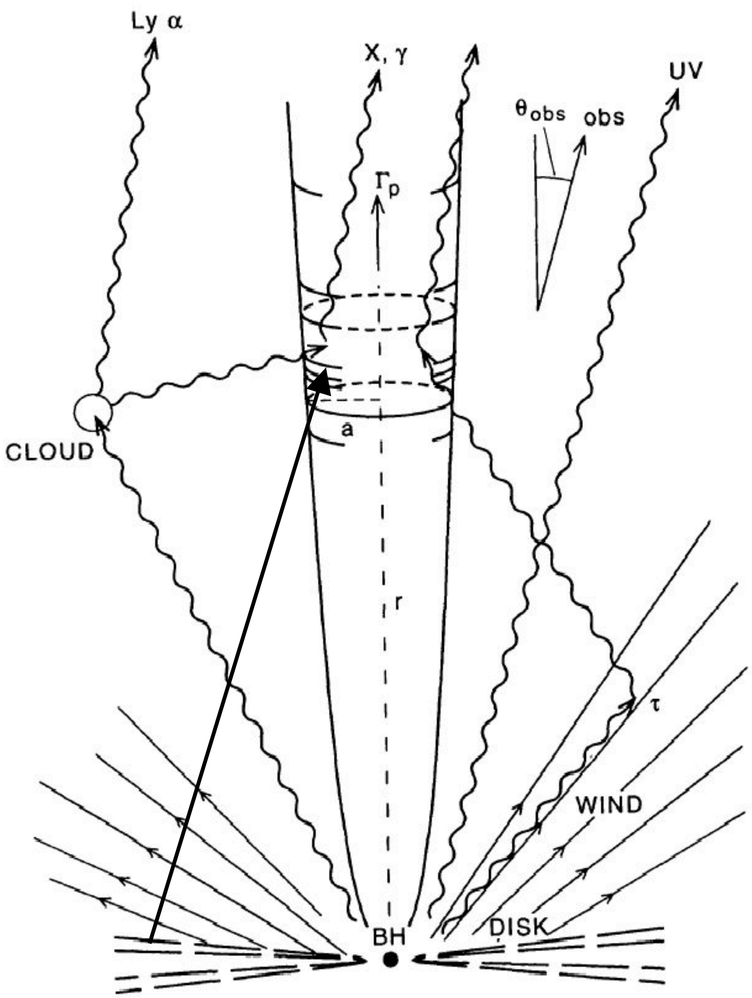
corresponds to 10^{11} times total solar luminosity just in γ-rays. Large variability within days.



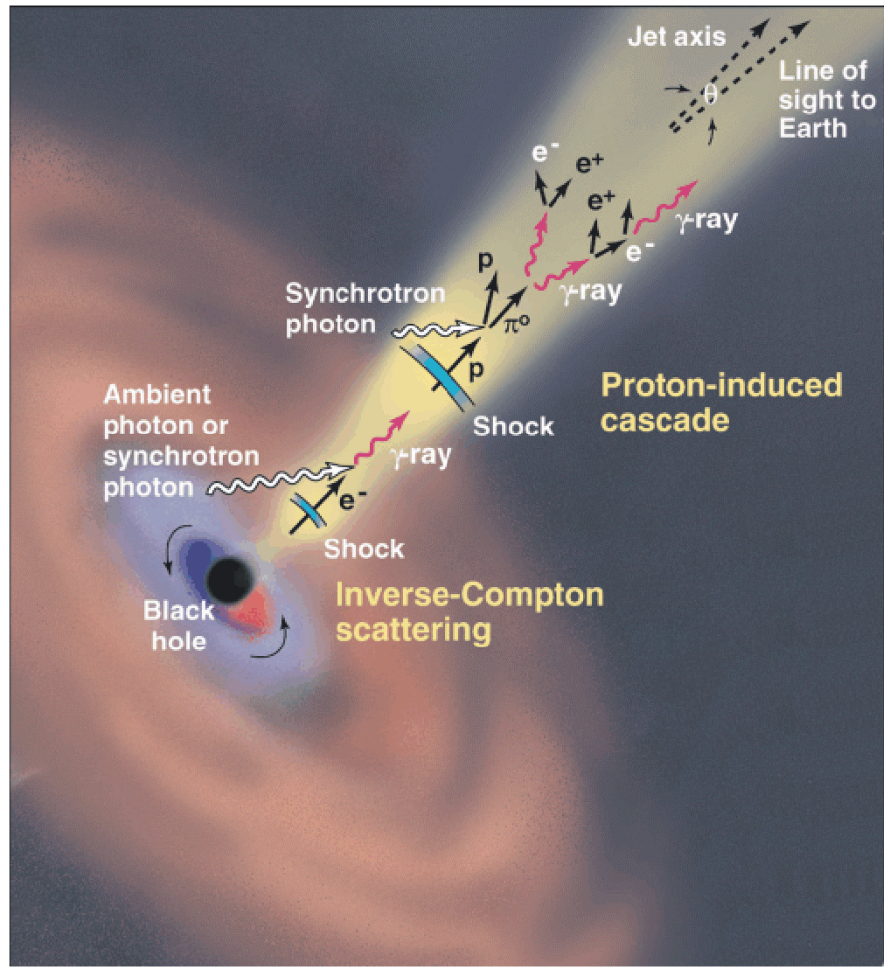
Multiwavelength Spectrum of 3C 279

Sum all the power over the whole electromagnetic spectrum from all the stars of a typical galaxy: an AGN emits this amount of power in JUST γ rays from a very small volume!

Models of AGN Gamma-ray Production



(from Sikora, Begelman, and Rees (1994))

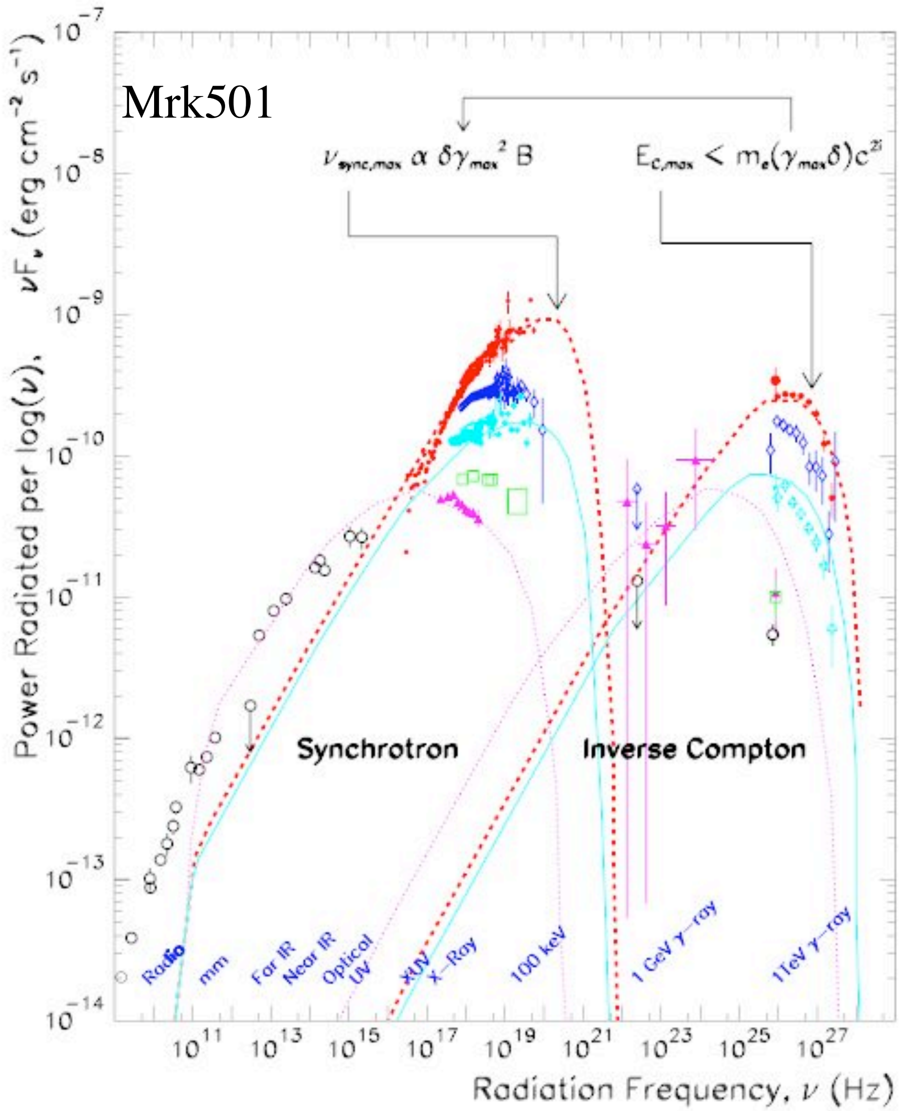


(credit:J. Buckley)

AGN: Future Prospects

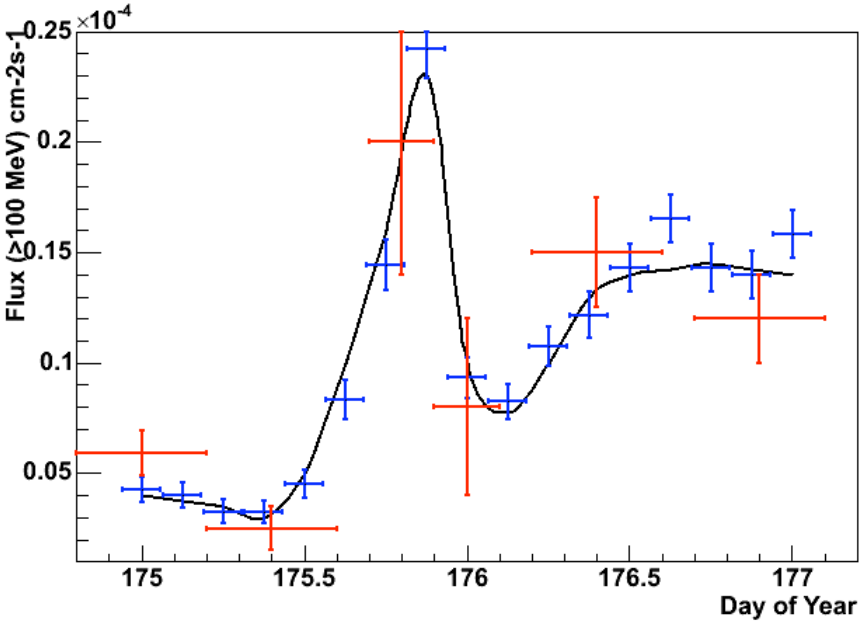
- **Multiwavelength studies will continue to be the key to understanding how the engines work**

- **Models: same population of HE electrons produces both components**

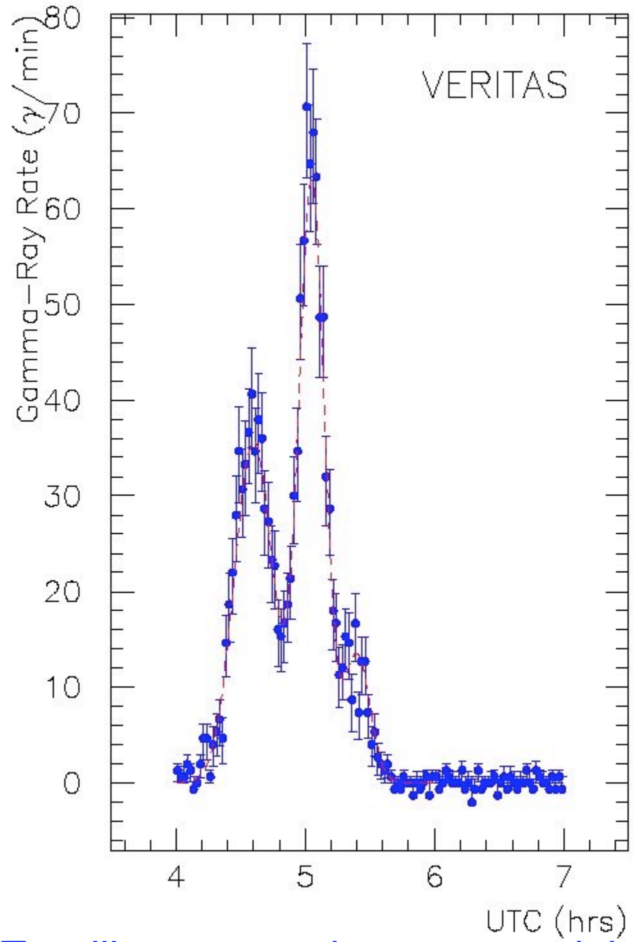


Flares and variability

Large effective area key for studying variability (geometry, dynamics)



EGRET observations (red points) of a flare from PKS 1622-297 in 1995 (Mattox et al), the black line is a lightcurve consistent with the EGRET observations and the blue points are simulated LAT observations.



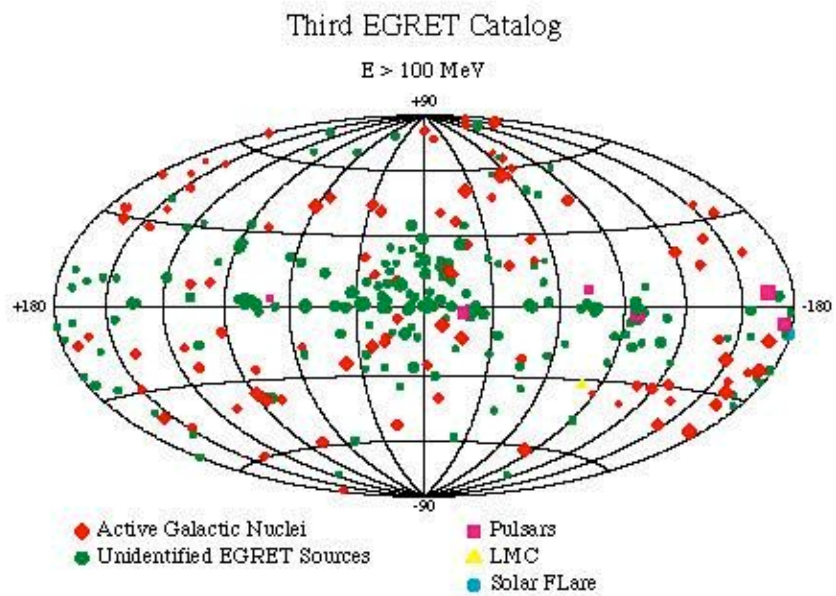
ACTs will measure short-term variability with dramatically better precision. GLAST will help guide them where to look.

A surprise from EGRET:

detection of dozens of AGN

shining brightly in

γ-rays -- Blazars



- a key to solving the longstanding puzzle of the extragalactic diffuse gamma flux -- is this integrated emission from a large number of unresolved sources?
- blazars provide a source of high energy γ-rays at cosmological distances. The Universe is largely transparent to γ-rays (any opacity is energy-dependent), so they probe cosmological volumes.

AGN and the Extragalactic Background Light (EBL)

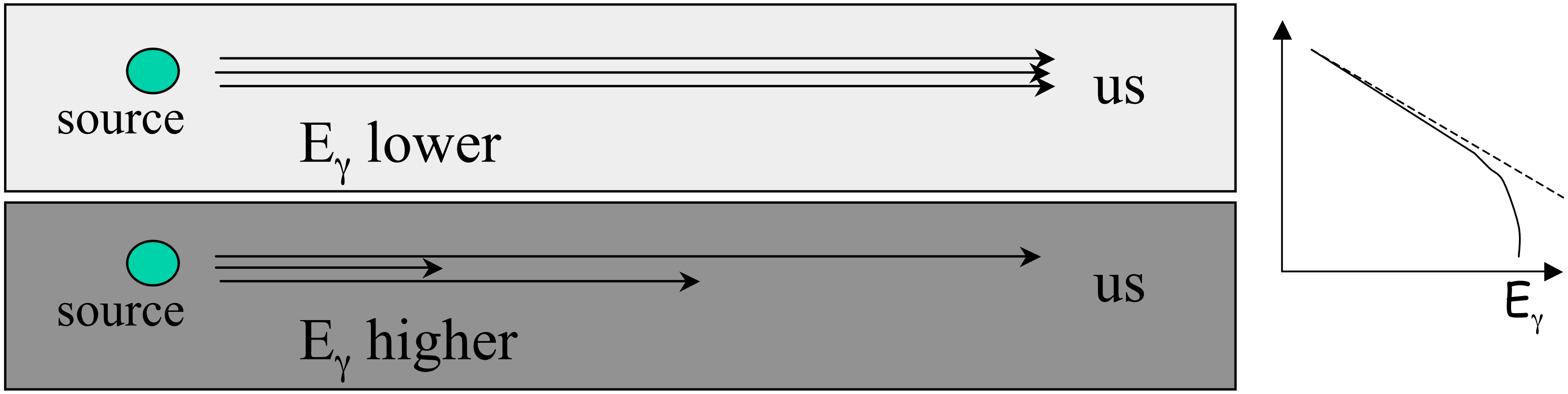
Look for roll-offs in blazar spectra due to attenuation:
(Stecker, De Jager & Salamon; Madau & Phinney; Macminn & Primack)

the start: A.I. Nikishov, Sov. Phys. JETP 14 (1962) 393.

If $\gamma\gamma$ c.m. energy > $2m_e$, pair creation will attenuate flux. For a flux of γ -rays with energy, E, this cross-section is maximized when the partner, ε, is

$$\epsilon \sim \frac{1}{3}\left(\frac{1TeV}{E}\right)eV$$

For 10 GeV- 100 GeV γ - rays, this corresponds to a partner photon energy in the optical - UV range. Density is sensitive to time of galaxy formation.



GLAST Can Probe the Optical-UV EBL

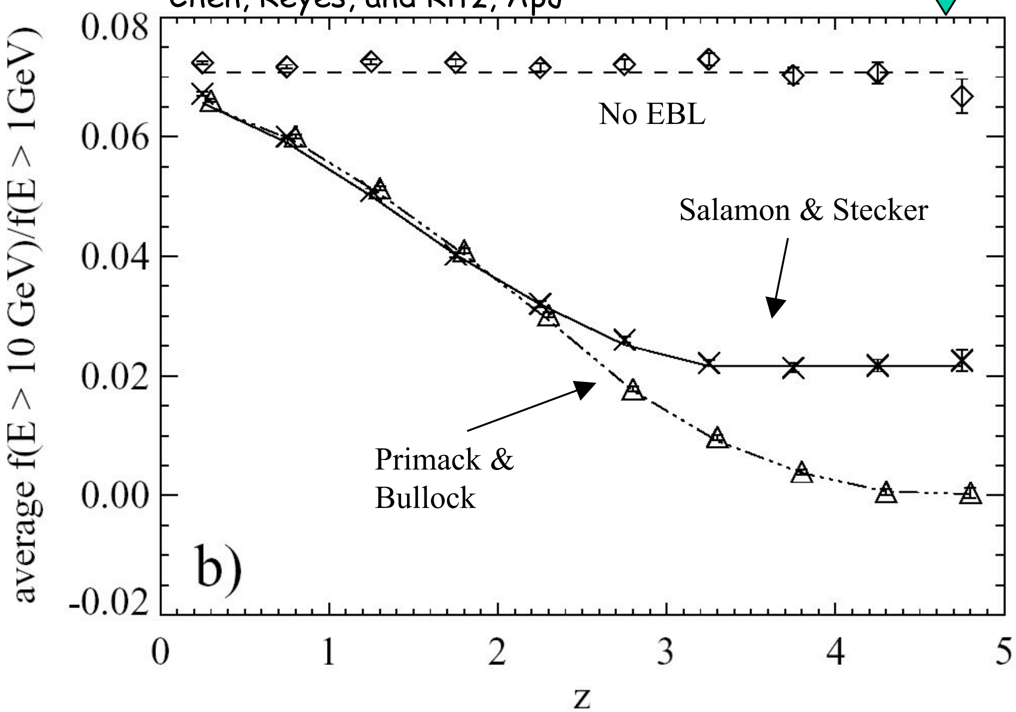
- **Important advances offered by GLAST:**

  (1) thousands of blazars - instead of peculiarities of individual sources, look for <u>systematic</u> <u>effects</u> vs redshift.

  (2) key energy range for cosmological distances (TeV-IR attenuation more local due to opacity).

- Effect is model-dependent (this is good):

Chen, Reyes, and Ritz, ApJ



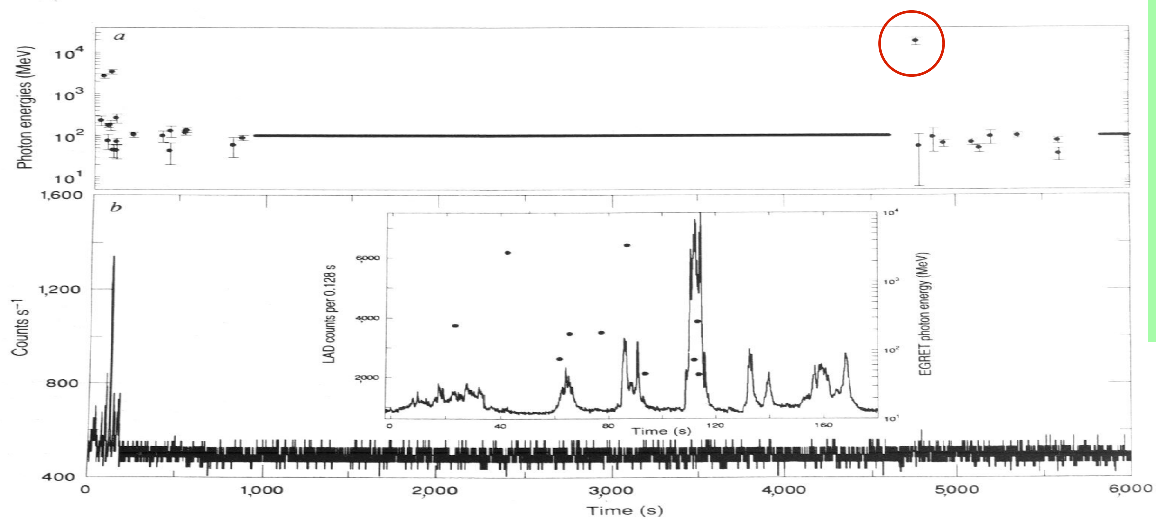
<u>Caveats</u>

- How many blazars have intrinsic roll-offs in this energy range (10-100 GeV)? (An important question by itself for GLAST!)
- What if there is conspiratorial evolution in the intrinsic roll-of vs redshift? More difficult, however there may also be independent constraints (e.g., direct observation of integrated EBL).
- Must measure the redshifts for a large sample of these blazars!

Gamma Ray Bursts

Highest-energy emission from bursts is intriguing:

EGRET detected a ~20 GeV photon ~75 minutes after the start of a burst:



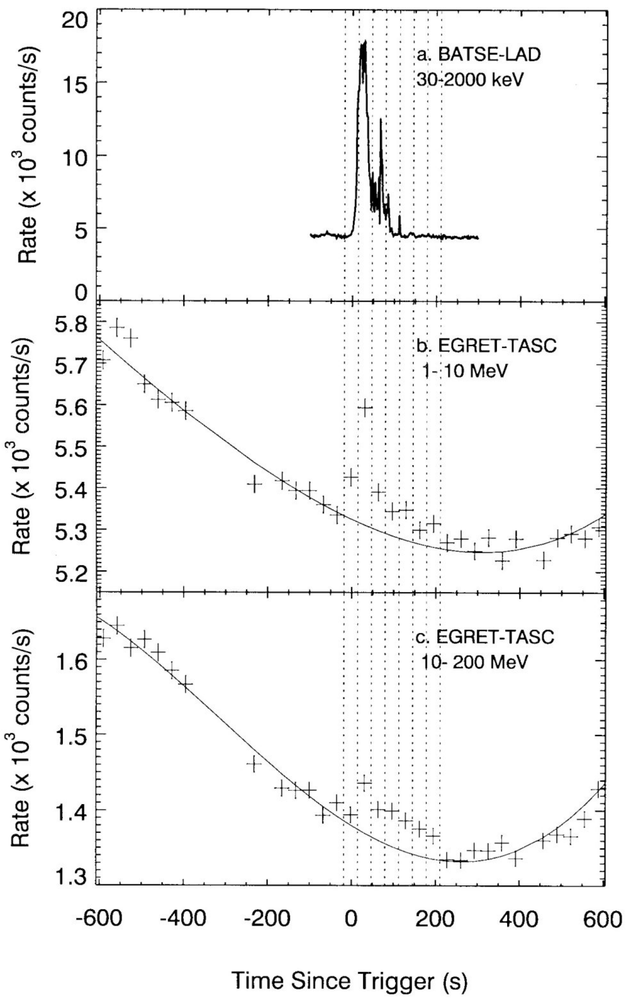
+ **Milagrito** evidence for TeV emission from GRB 970417 ApJ 533(2000)533.

Hurley et al., 1994

Future Prospects: GLAST will provide definitive information about the high energy behavior of bursts: LAT and GBM together will measure emission over >7 decades of energy. Place your bets on additional TeV burst detections!

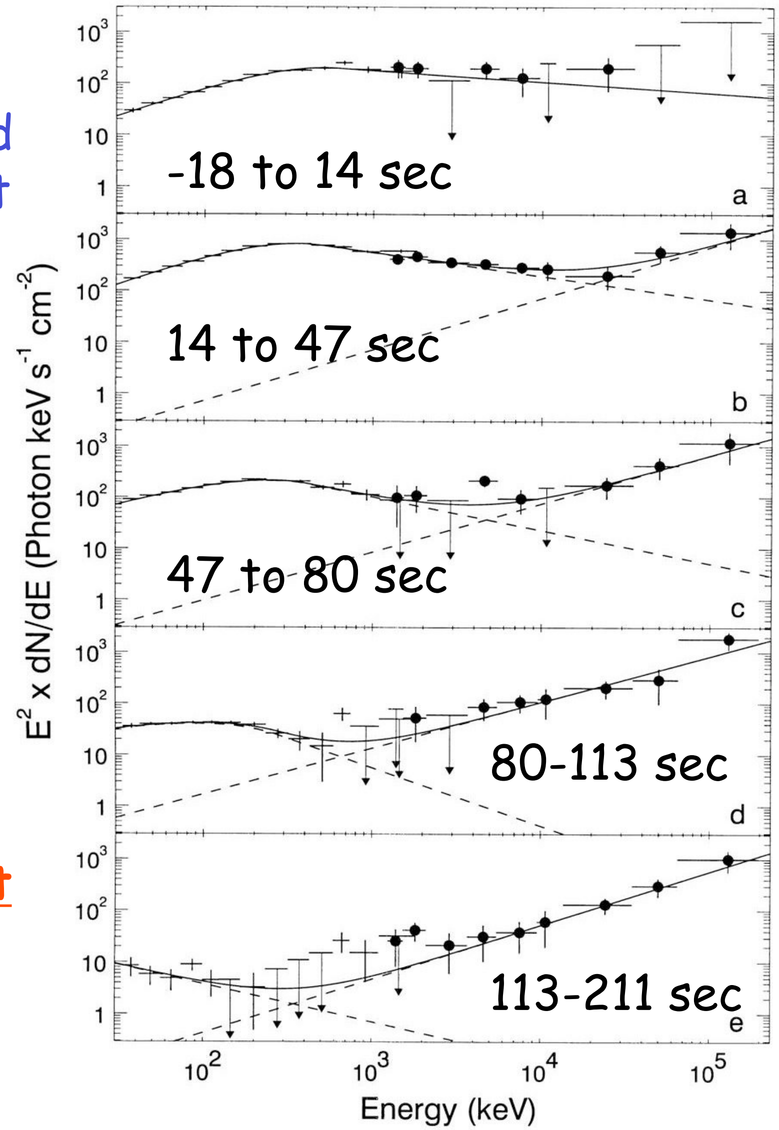
GRB941017

Gonzalez et al., published in Nature



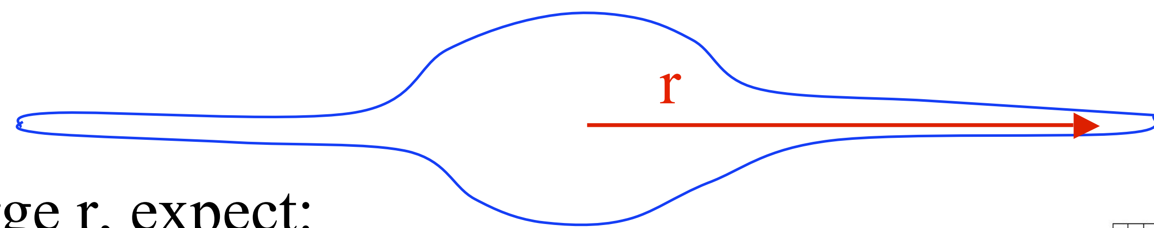
Compare data from EGRET and BATSE: Distinct high-energy component has different time behavior.
What is the high-energy break and total luminosity?
<u>Need GLAST data!</u>

<u>Learn important lessons from the past.</u>



The Dark Matter Problem

Observe rotation curves for galaxies:

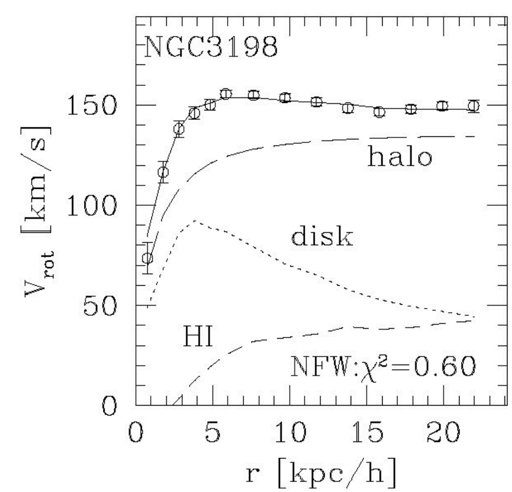


For large r, expect:

$$G\frac{M}{r^2} = \frac{v^2(r)}{r} \qquad v(r) \sim \frac{1}{\sqrt{r}}$$

see: flat or rising rotation curves

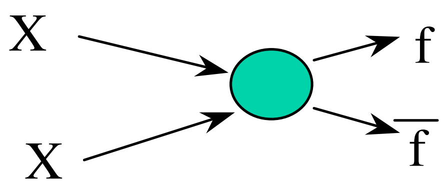
Begeman/Navarro



Hypothesized Solution: the visible galaxy is embedded in a much larger halo of dark matter.

Particle Dark Matter

Some important models in particle physics could also solve the dark matter problem in astrophysics. If correct, these new particle interactions could produce an anomalous flux of gamma rays ("indirect detection").



anomalous continuum or $\gamma\gamma$ or $Z\gamma$ "lines"?

- Key interplay of techniques (see Baltz et al., astro/ph-0602187):
  - colliders (TeVatron, LHC, ILC)
  - direct detection experiments
  - indirect detection (best shot: gamma rays)
    - GLAST full sky coverage look for clumping throughout galactic halo, including off the galactic plane (if found, point the way for ground-based facilities)
    - Intensity highly model-dependent
    - Challenge is to separate signals from astrophysical backgrounds

Just an example of what might be waiting for us to find!

Testing Lorentz Invariance

- **Lorentz Invariance breaking models can lead to different maximum velocities by particle type (Stecker&Glashow, Coleman&Glashow, Jacobson et al):**

$$c_e \equiv c_\gamma (1+\delta), \quad 0 < |\delta| << 1$$

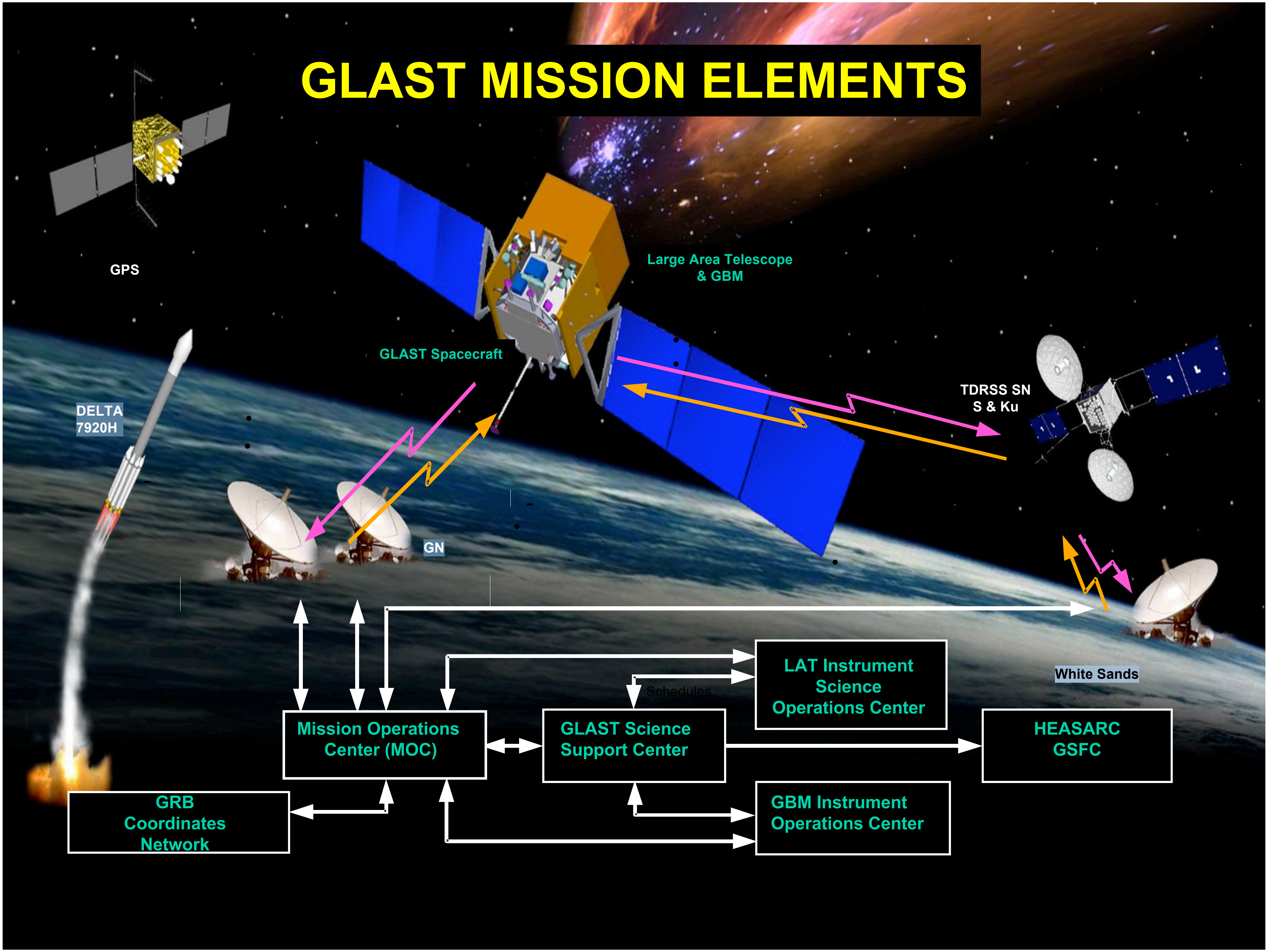
  - **For δ<0, photons can decay to e+e- pairs if $E_\gamma > m_e \sqrt{2/|\delta|}$ Observations of the Crab (E>50 TeV) implies $-\delta < 2\text{x}10^{-16}$**
  - **For δ>0, superluminal electrons will emit vacuum Cerenkov radiation and the threshold for pair creation will be altered. Cosmic ray data and inferred information from Mrk501 blazar observations => $\delta < 3\text{x}10^{-14} – 1.3\text{x}10^{-15}$.**

- **Some classes of QG models imply a linear photon velocity dispersion (Amelino-Camelia et al., Ellis, Mavromatos, Nanopoulos):**

$$V = c\,(1 - \xi \cdot \frac{E}{E_{QG}} + \ldots)$$

Use GRBs! Effects could be O(100) ms or larger, using GLAST data alone. But ?? effects intrinsic to bursts?? Look for systematic change with distance.

Representative of window opened by measurements at such large distance and energy scales.


GLAST MISSION ELEMENTS
GPS
Large Area Telescope
& GBM
GLAST Spacecraft
DELTA
7920H
TDRSS SN
S & Ku
GN
White Sands
Schedules
LAT Instrument
Science
Operations Center
Mission Operations
Center (MOC)
GLAST Science
Support Center
HEASARC
GSFC
GRB
Coordinates
Network
GBM Instrument
Operations Center

The Accelerator

Mars Exploration Rover (MER) B

Delta II Heavy

GLAST LAT Collaboration

United States

- University of California at Santa Cruz - Santa Cruz Institute of Particle Physics
- Goddard Space Flight Center – Laboratory for High Energy Astrophysics
- Naval Research Laboratory
- Ohio State University
- Sonoma State University
- Stanford University (SLAC and HEPL/Physics)
- University of Washington
- Washington University, St. Louis

France

- IN2P3, CEA/Saclay

Italy

- INFN, ASI, INAF

Japanese GLAST Collaboration

- Hiroshima University
- ISAS, RIKEN

Swedish GLAST Collaboration

- Royal Institute of Technology (KTH)
- Stockholm University

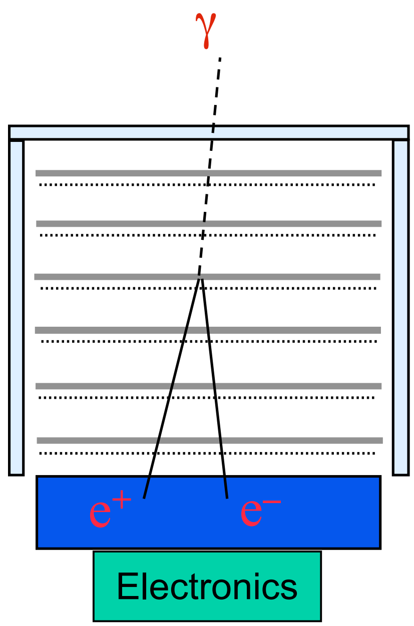
PI: Peter Michelson (Stanford & SLAC)

~230 Members (including ~84 Affiliated Scientists, plus 24 Postdocs, and 36 Graduate Students)

Cooperation between NASA and DOE, with key international contributions from France, Italy, Japan and Sweden.

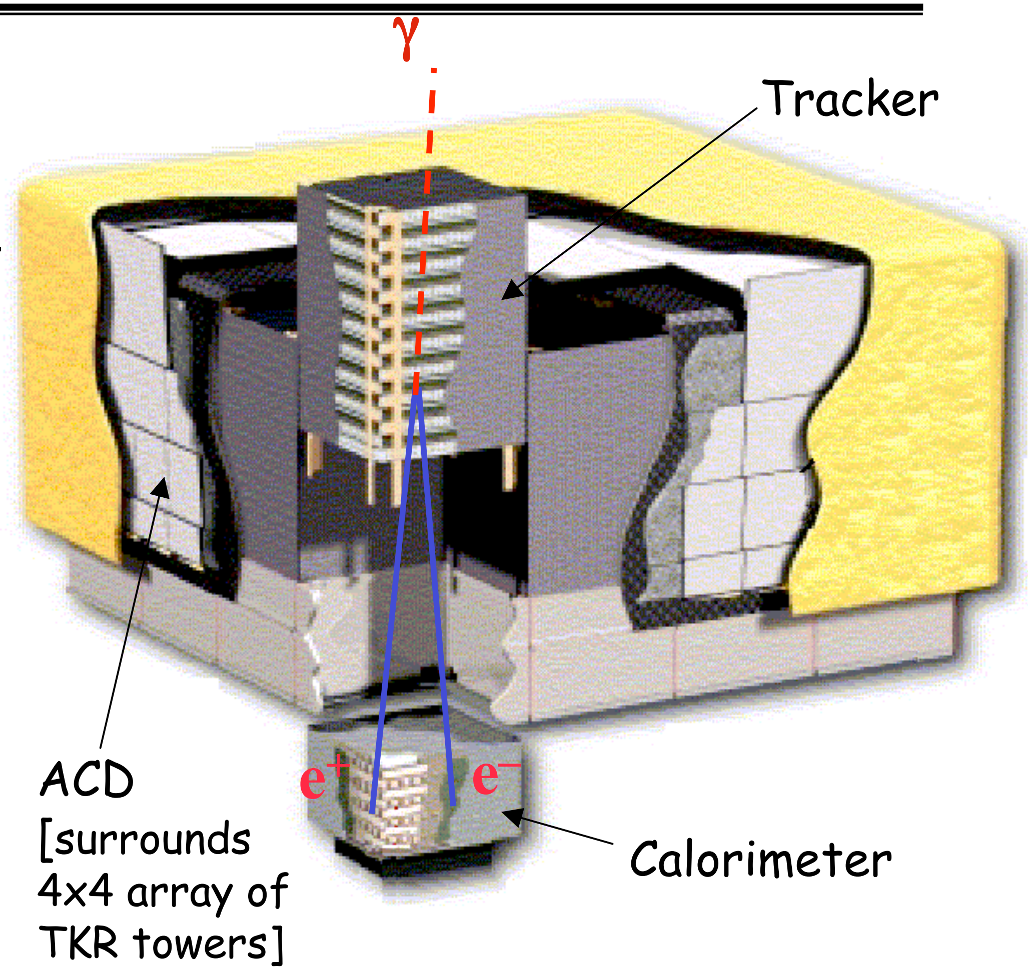
Managed at Stanford Linear Accelerator Center (SLAC).

Pair Conversion Telescope



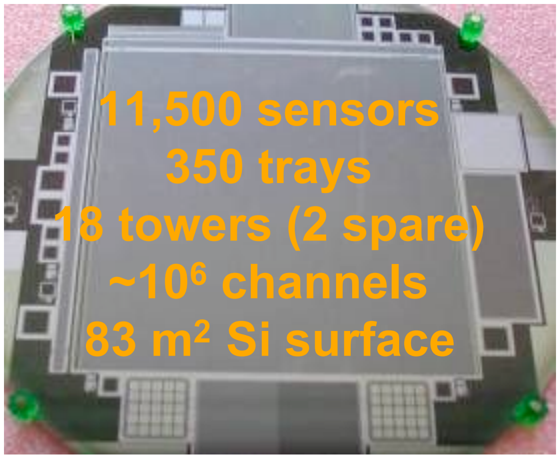
Overview of LAT

- Precision Si-strip Tracker (TKR)
  18 XY tracking planes. Single-sided silicon strip detectors (228 μm pitch) Measure the photon direction; gamma ID.
- Hodoscopic CsI Calorimeter(CAL)
  Array of 1536 CsI(Tl) crystals in 8 layers. Measure the photon energy; image the shower.
- Segmented Anticoincidence Detector (ACD) 89 plastic scintillator tiles. Reject background of charged cosmic rays; segmentation removes self-veto effects at high energy.
- Electronics System Includes flexible, robust hardware trigger and software filters.

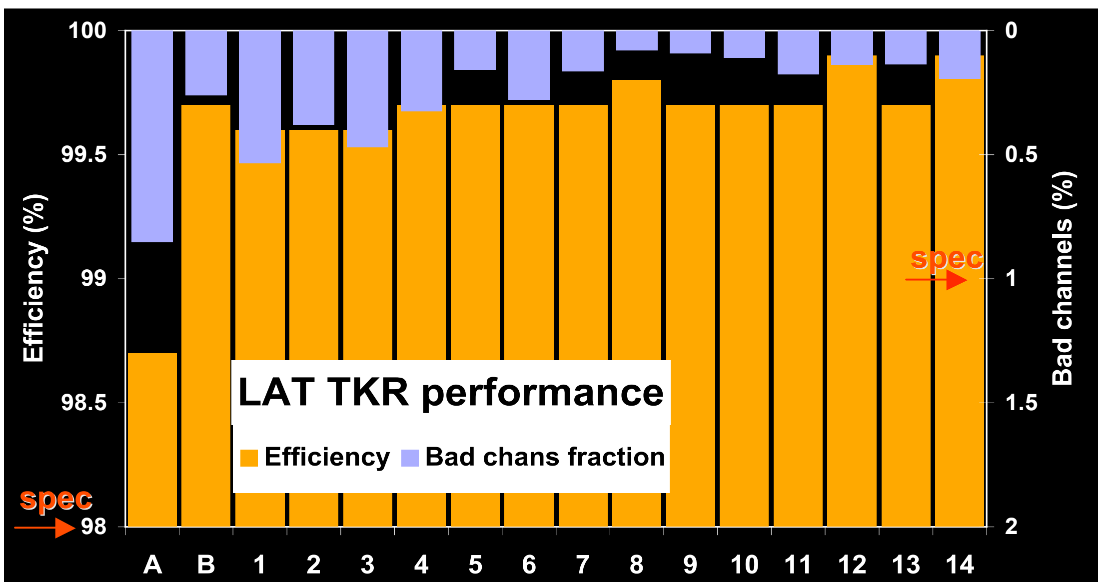


Systems work together to identify and measure the flux of cosmic gamma rays with energy 20 MeV - >300 GeV.

LAT Silicon Tracker

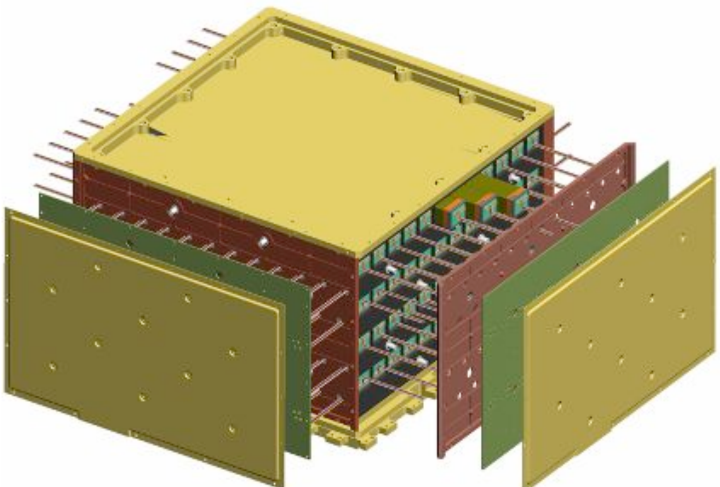


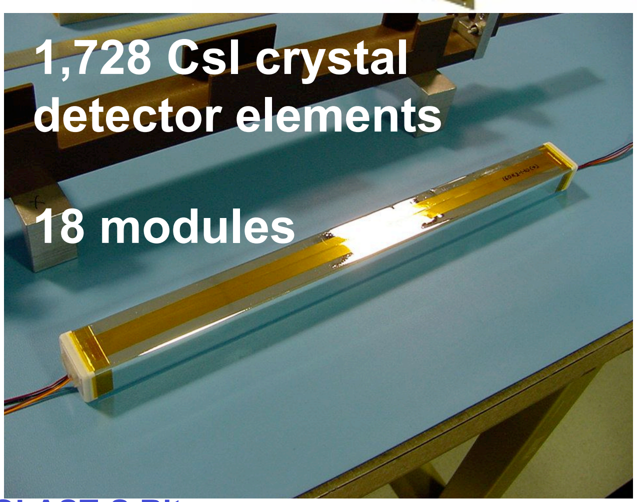
Team effort involving physicists and engineers from Italy (INFN & ASI), the United States, and Japan

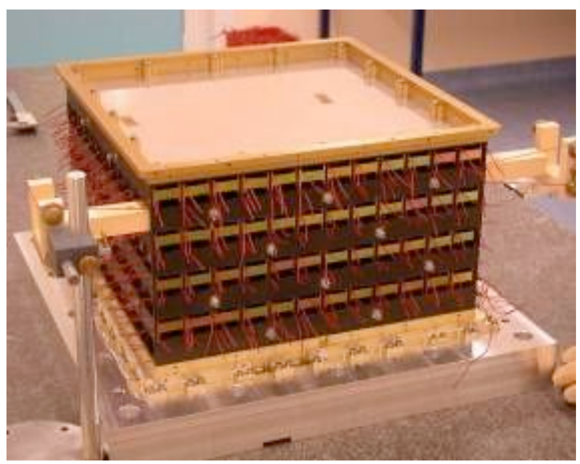


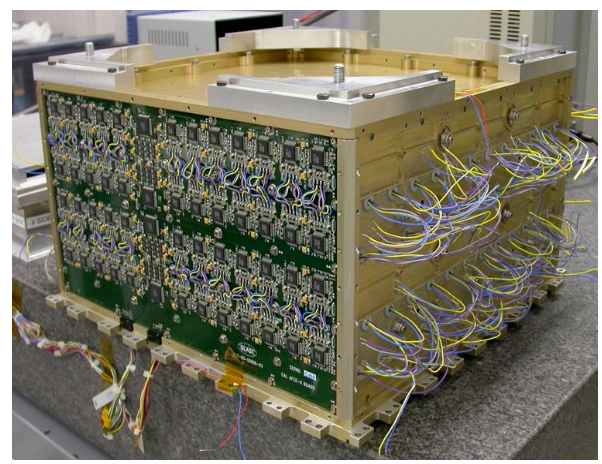
LAT Calorimeter

Team effort involving physicists and engineers from the United States, France (IN2P3 & CEA), and Sweden





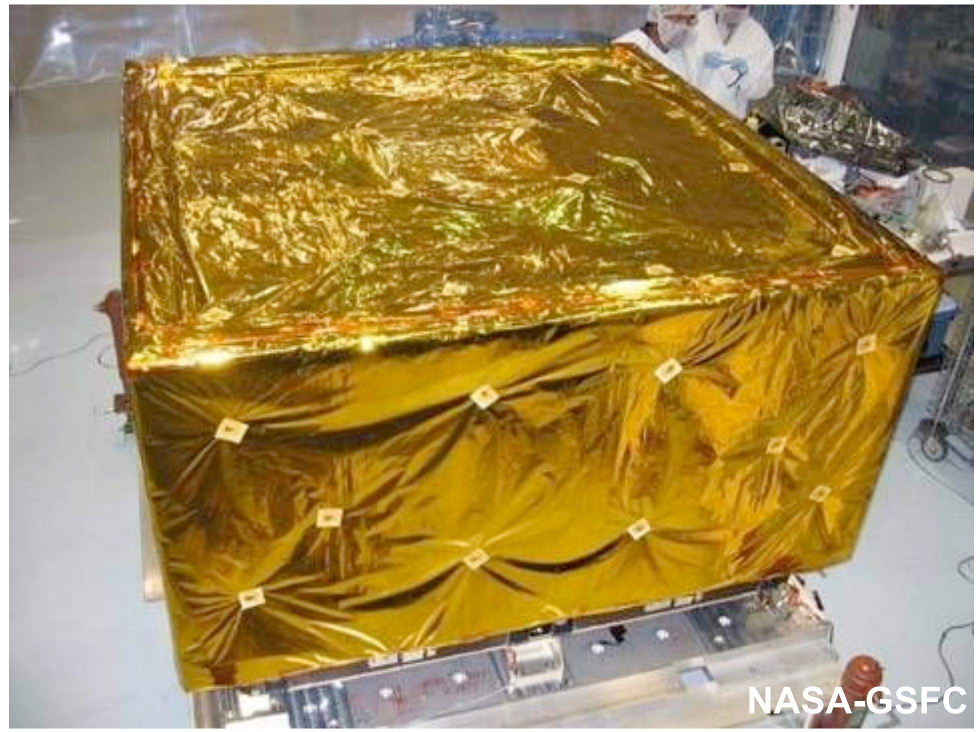




LAT Anti-Coincidence Detector

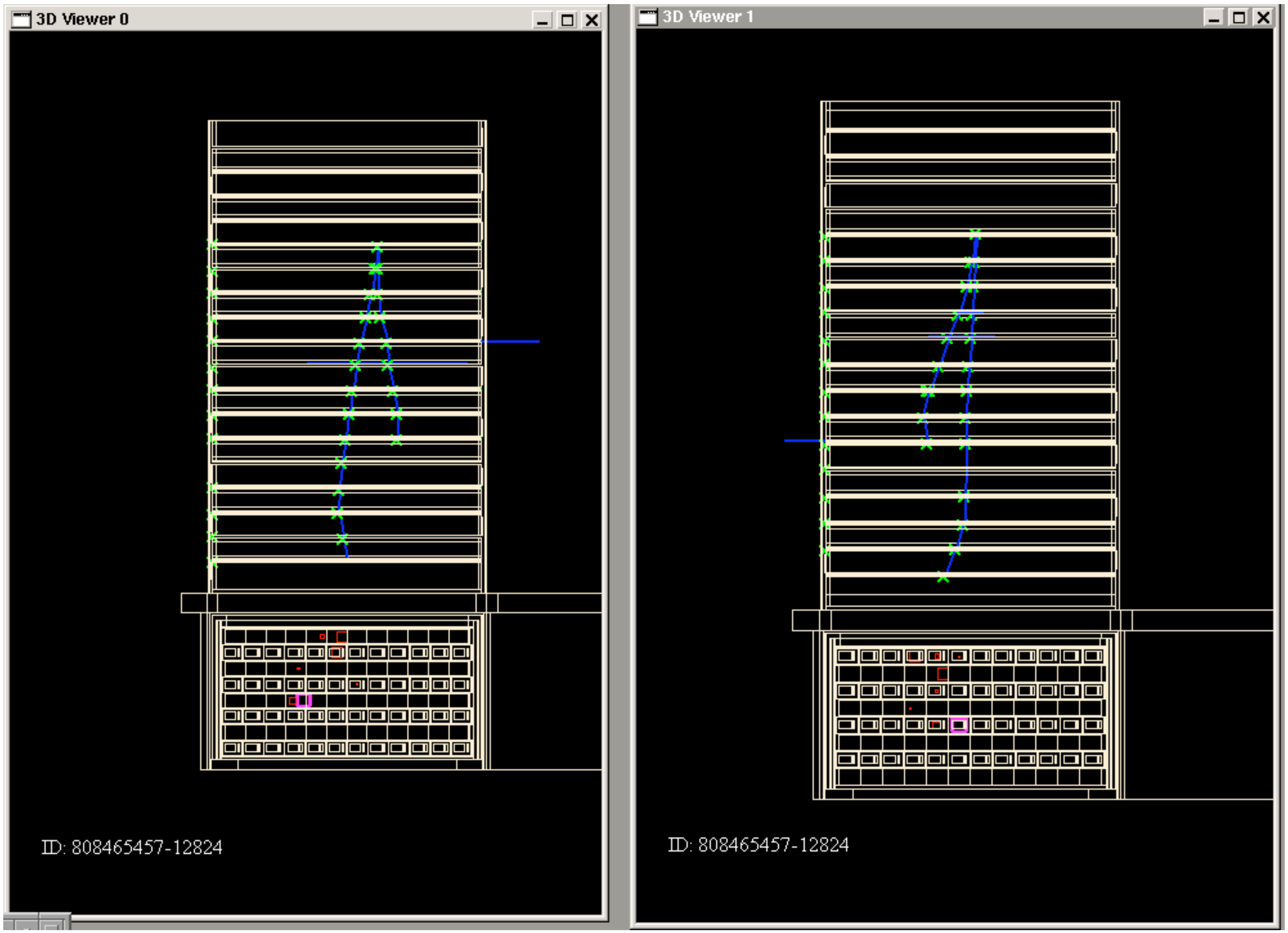
Team effort involving physicists and engineers from Goddard Space Flight Center, SLAC, and Fermi Lab

ACD before installation of Micrometeoroid Shield

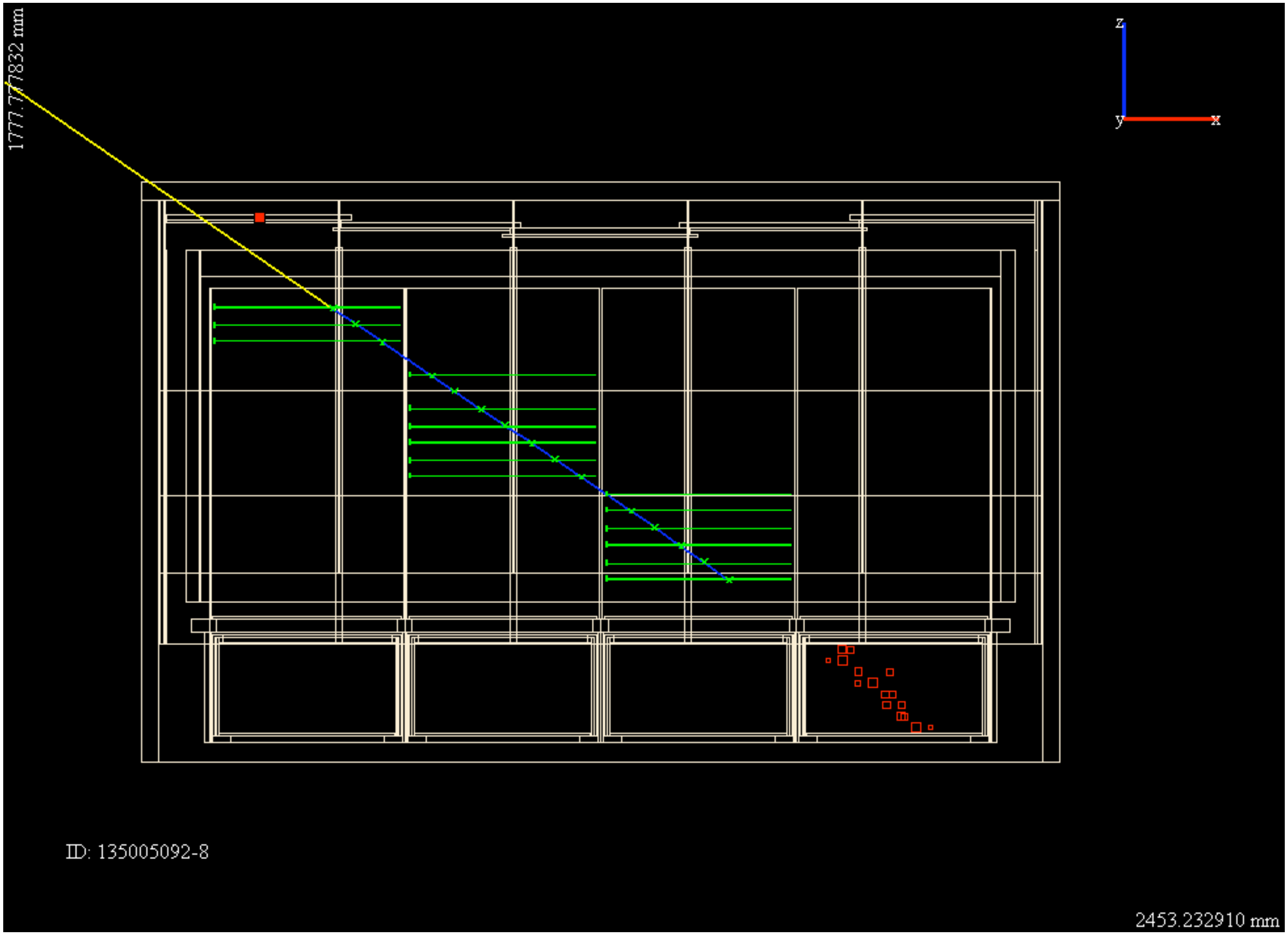


ACD with Micrometeoroid Shield and Multi-Layer Insulation (but without Germanium Kapton outer layer)

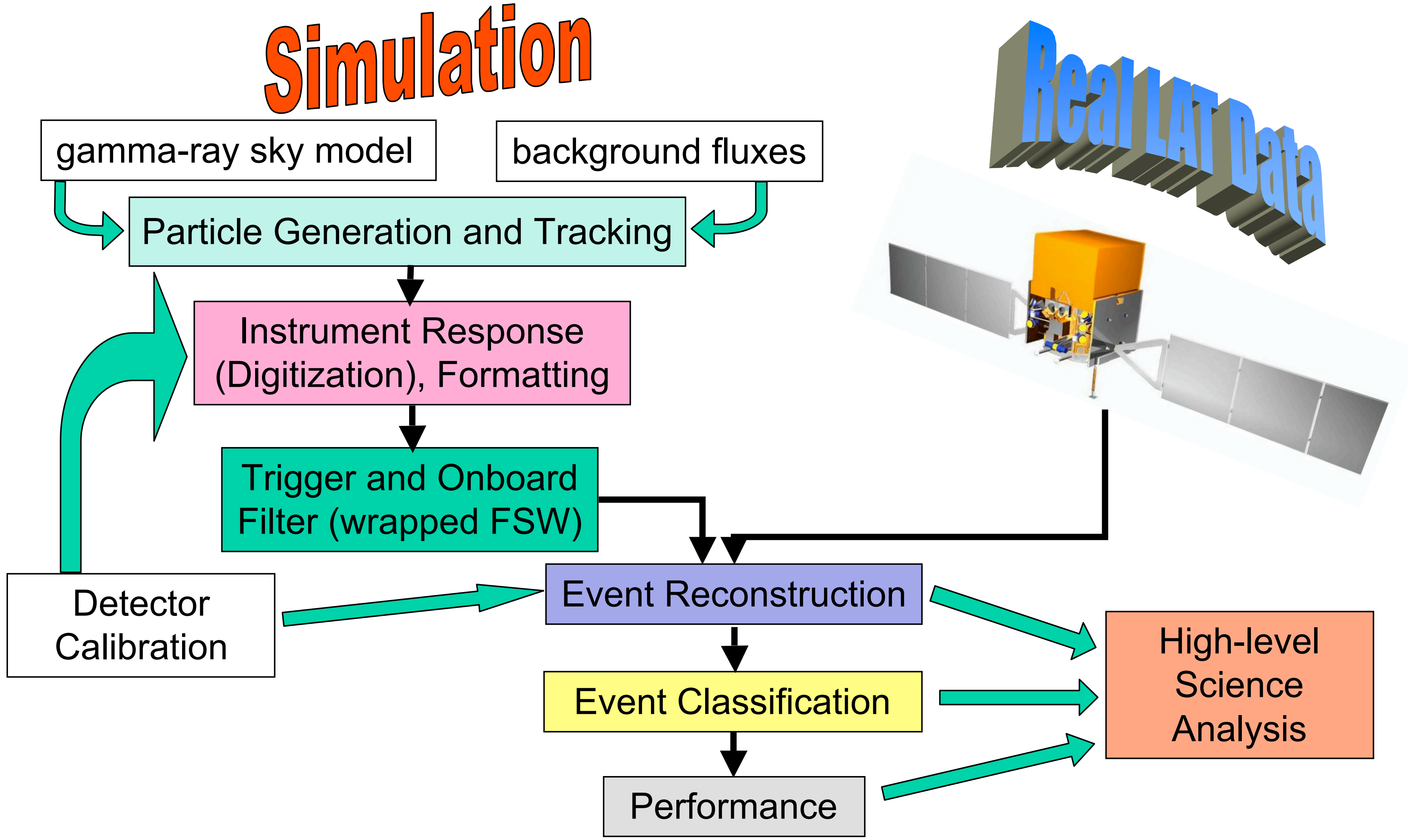
Gamma Candidate in First Integrated Tower!



16 Towers with ACD



Components of Simulation & Analysis



GLAST LAT Simulation

Geometry Detail
> 500k Volumes
Includes Tracker Electronics Boards

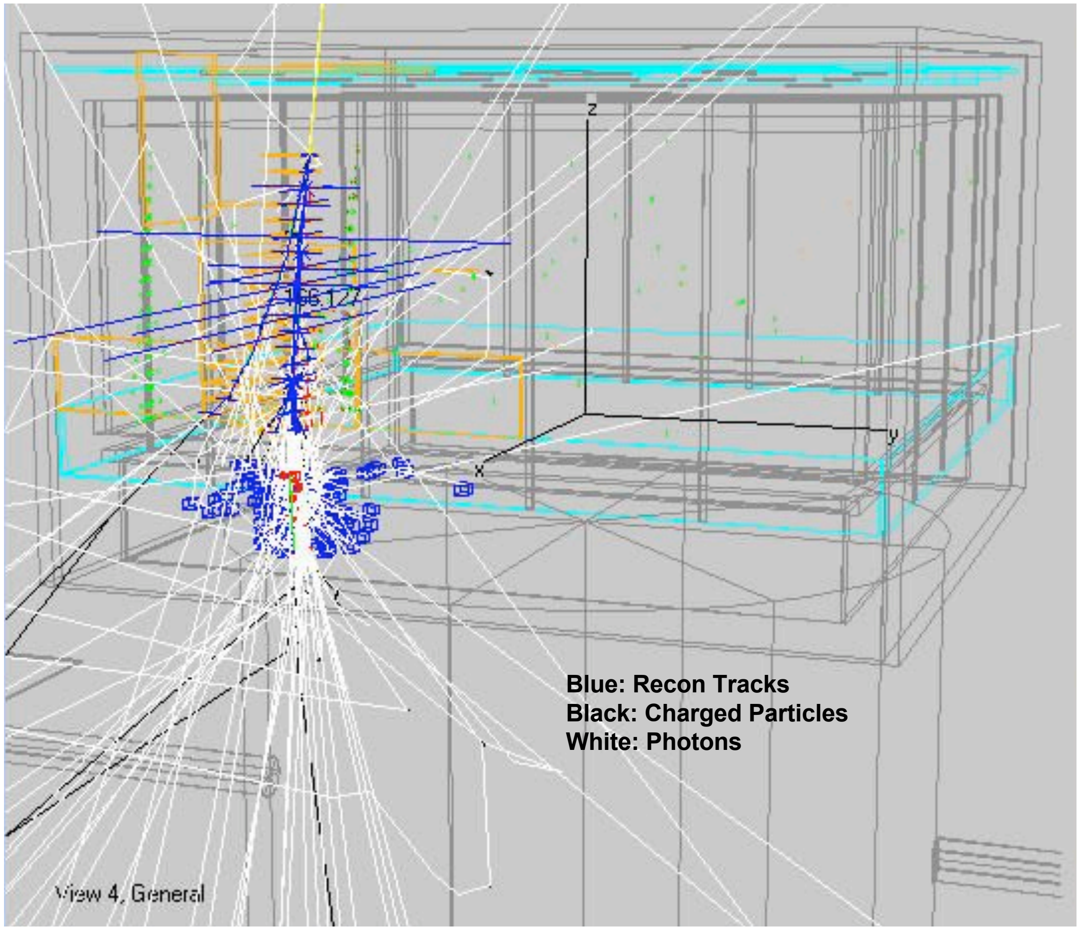
Spacecraft details
and much, much more

Geant 4 Interaction Physics
QED: based on original EGS code)
Hadronic: based Geisha (can use FLUKA as well as others)

Propagation
Full treatment of multiple scattering
Surface-to-surface ray tracing.

Connection to detector Response
Energy deposits in Active Volumes
Parametric Detector response based on energy and location

High energy γ interacts in LAT

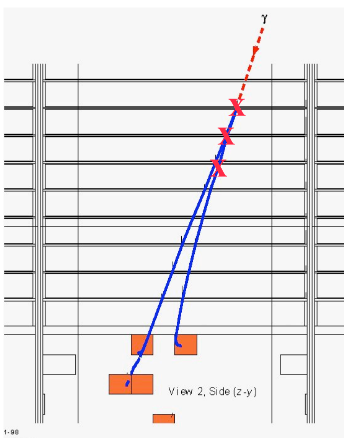


Instrument Triggering and Onboard Data Flow

Hardware Trigger

Hardware trigger based on special signals from each tower; initiates readout

Function: • "did anything happen?"
• keep as simple as possible



- TKR 3 $x \cdot y$ pair planes in a row
  workhorse γ trigger

OR

- CAL:
  LO – independent check on TKR trigger.
  HI – indicates high energy event ⟶ disengage use of ACD.

Upon a L1T, all towers are read out in ~27μs

Instrument Total Rate: <3 kHz>**

**using ACD veto in hardware trigger

On-board Processing

full instrument information available to processors.

Function: reduce data to fit within downlink

Hierarchical filter process: first make the simple selections that require little CPU and data unpacking.

- **based on subset of full background rejection analysis, with loose cuts**
- **leak a fraction of otherwise-rejected events to the ground for diagnostics, along with events ID for calibration**
- **complete event information**
- **signal/bkgd tunable, depending on analysis cuts:**
  γ rate: few Hz

Total Rate: <~400 Hz>**

On-board science analysis:
transient detection (bursts)

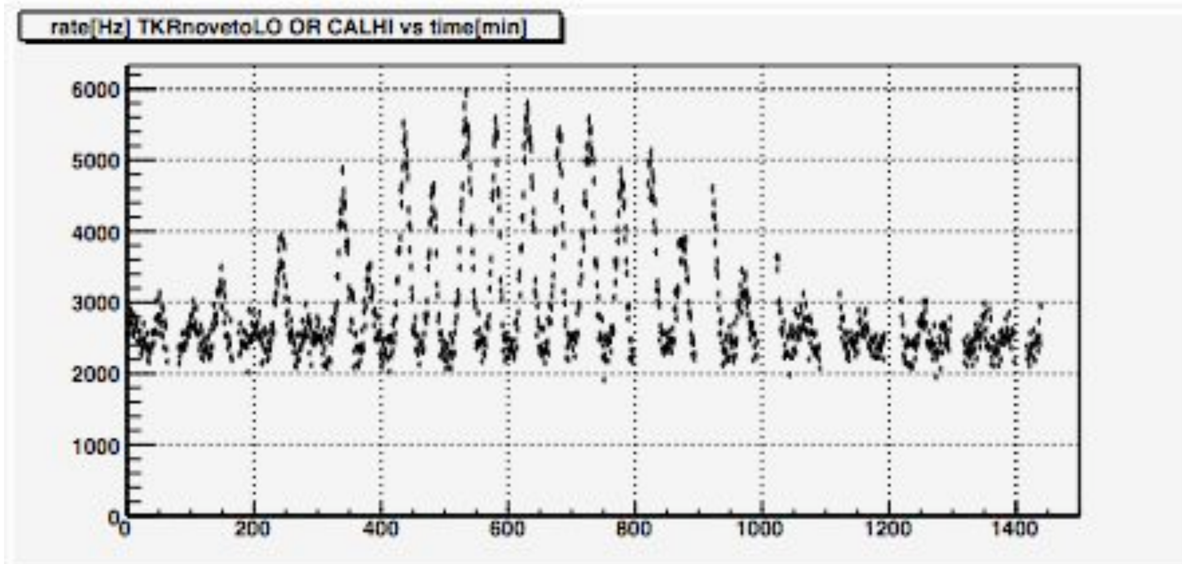
Spacecraft

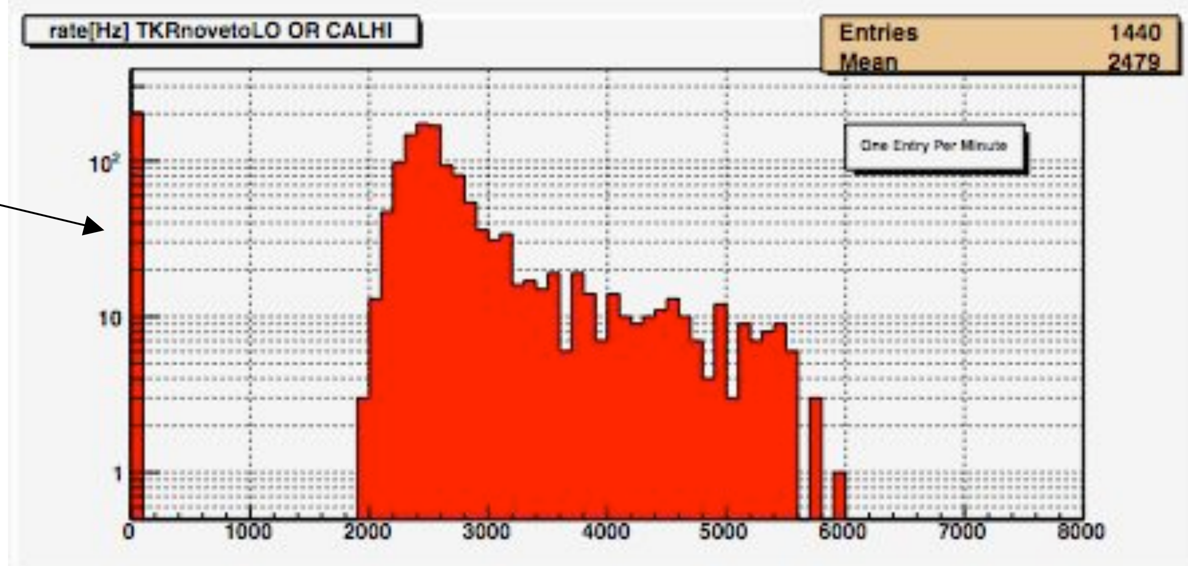
**CBE, assumes compression, 1.2 Mbps allocation.

Trigger Rates Summary

- **v9r6**
- **[TKR&&(Noveto||CAL-LO)] ||CAL-HI||(CAL-LO*x) setting <u>x=0</u> (no CAL-LO only triggers)**

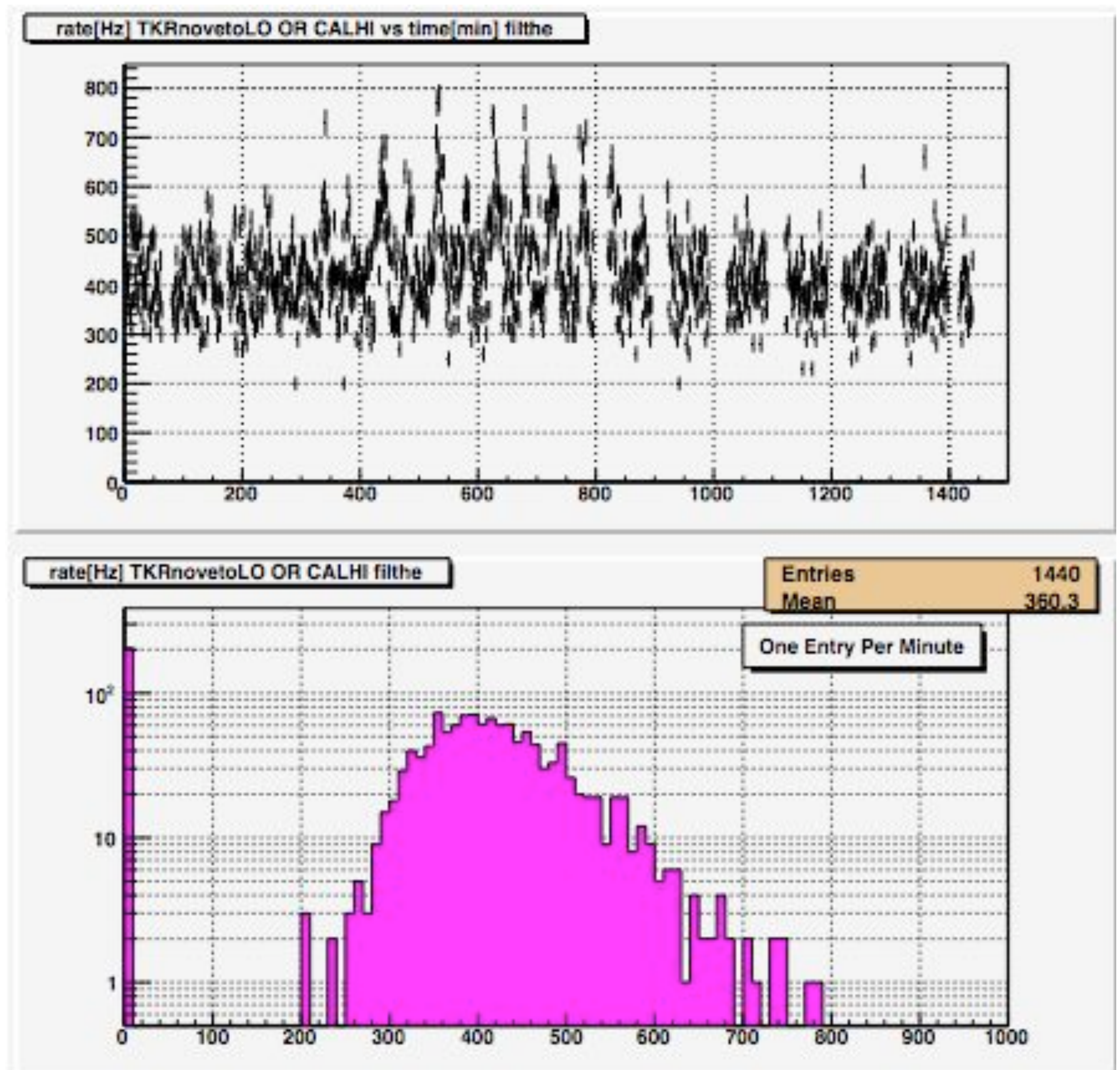
- **Operating daily-average rate is 2.9kHz**
- **Peak rate is 6 kHz**
- **For this simulated day, 201 minutes spent in SAA (14%).**



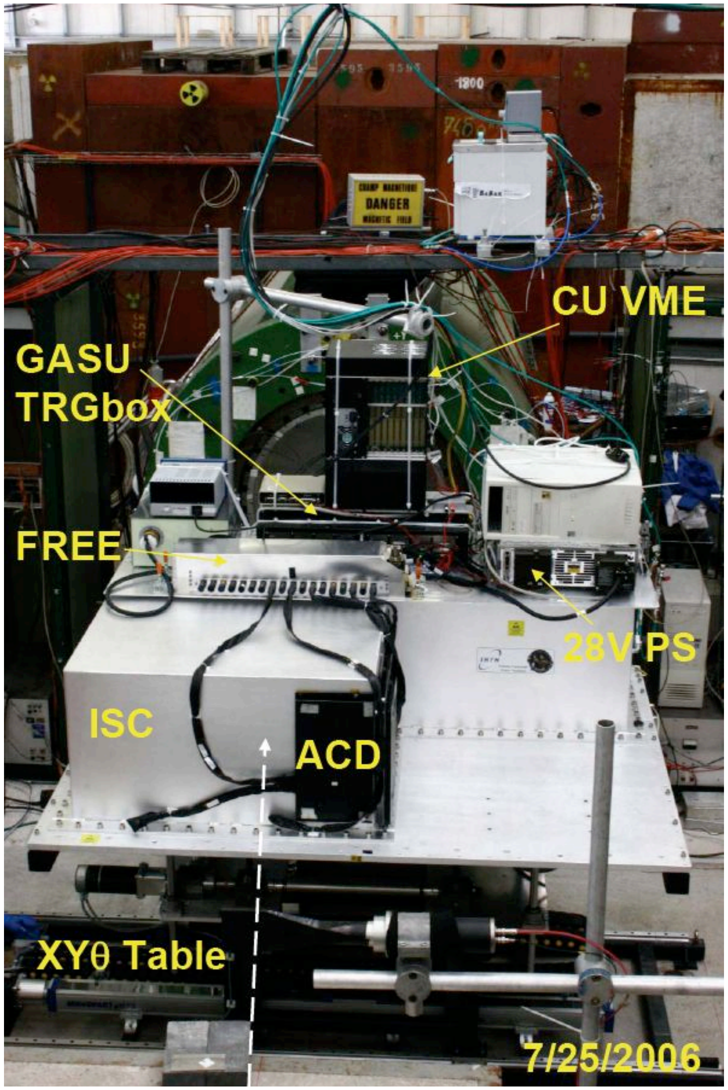


Onboard Filter Results Summary

- **v9r6**
- **daily-average event rate passing filter in this configuration (existing FSW) is 360 Hz.**
- **adding the pass of any event with E>20 GeV raw raises the mean rate to 400 Hz.**
- **There are handles to reduce this rate significantly if needed.**
  - **what matters here is not the rate but the data volume.**

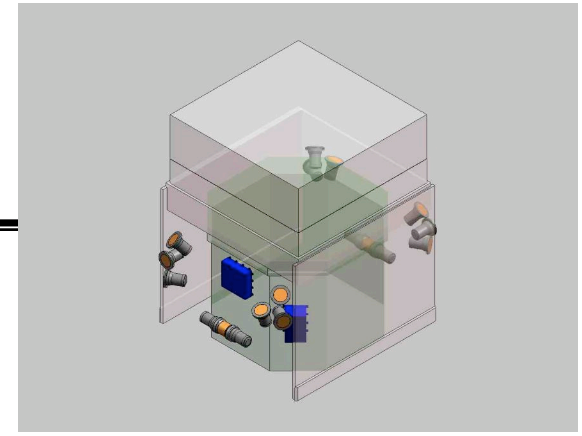


The CERN Beam Test Campaign



- 4 weeks at PS/T9 area (26/7-23/8)
  - Gammas @ 0-2.5 GeV
  - Electrons @ 1,5 GeV
  - Positrons @ 1 GeV (through MMS)
  - Protons @ 6,10 GeV (w/ & w/o MMS)
- 11 days at SPS/H4 area (4/9-15/9)
  - Electrons @ 10,20,50,100,200,280 GeV
  - Protons @ 20,100 GeV
  - Pions @ 20 GeV
- Data, data, data…
  - 1700 runs, 94M processed events
  - 330 configurations (particle, energy, angle, impact position)
  - Mass simulation
- A very dedicated team
  - 60 people worked at CERN
  - Whole collaboration represented

GBM Collaboration



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Volker Schönfelder
Roland Diehl
Jochen Greiner
Helmut Steinle

On-board processing, flight software, systems engineering, analysis software, and management

Detectors, power supplies, calibration, and analysis software

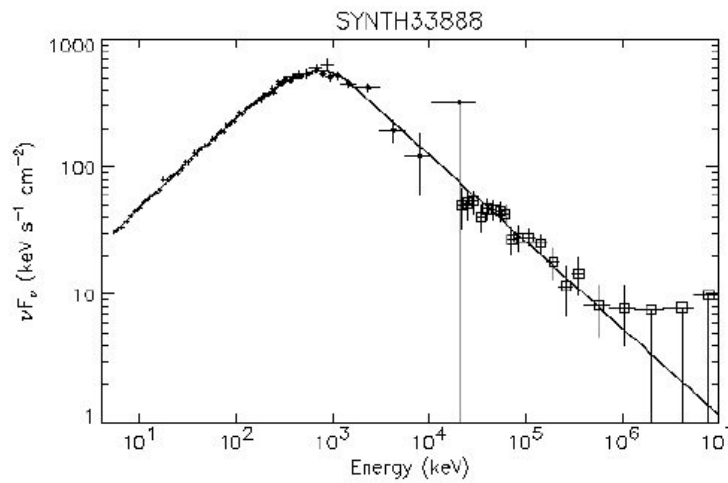
GBM

- provides spectra for bursts from 10 keV to 30 MeV, connecting frontier LAT high-energy measurements with more familiar energy domain;

Simulated GBM and LAT response to time-integrated flux from bright GRB 940217

Spectral model parameters from CGRO wide-band fit

1 NaI (14 º) and 1 BGO (30 º)



- provides wide sky coverage (>8 sr) -- enables autonomous repoint requests for exceptionally bright bursts that occur outside LAT FOV for high-energy afterglow studies (an important question from EGRET);
- provides burst alerts to the ground.

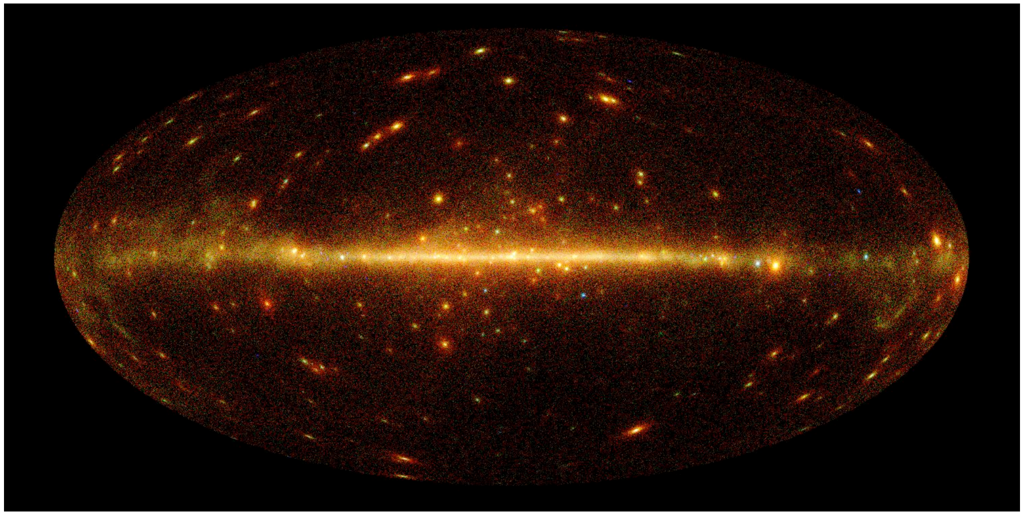
GBM Requirements

Parameter	Level 1 Requirements	Intra-Project Goals	Expected Performance
Energy range	10 keV – 25 MeV	5 keV – 30 MeV	8 keV – 30 MeV (1)
Energy resolution	10% (1σ; 0.1 – 1.0 MeV)	7% (1σ; 0.1 – 1.0 MeV)	<8% at 0.1 Mev (2) <4.5% at 1.0 Mev (3)
Effective area	NaI: >100 cm^2 at 14 keV BGO: >80 cm^2 at 1.8 MeV	NaI: >50 cm^2 at 6 keV BGO: none	NaI: 47.5 – 78 cm^2 at 14 keV BGO: >95 cm^2
On-board GRB locations	(none)	15° accuracy (1σ radius) within 2 seconds	<15°; 1.8 seconds (<8° for S/C <60° zenith)
GRB sensitivity (on ground)	0.5 photons cm^{-2} s^{-1} (peak flux, 50–300 keV)	0.3 photons cm^{-2} s^{-1} (peak flux, 50–300 keV)	0.47 photons cm^{-2} s^{-1} (peak flux, 50–300 keV)
GRB on-board trigger sensitivity	1.0 photons cm^{-2} s^{-1} (peak flux, 50–300 keV)	0.75 photons cm^{-2} s^{-1} (peak flux, 50–300 keV)	0.71 photons cm^{-2} s^{-1} (peak flux, 50–300 keV)
Field of view	>8 steradians	10 steradians	9 steradians

(1) Supported by measurements of window absorption
(2) Measured NaI-system resolution
(3) Measured BGO-system resolution

- **on-ground location accuracy: < ~few degrees**
- **expected burst-detection rate of the GBM:**
  - **~60 bursts/year in 55° FoV of LAT**
  - **~200 bursts/year will be detected in total**

Data Challenges



Data challenges provide excellent testbeds for science analysis software.

Full observation, instrument, and data processing simulation. Team uses data and tools to find the science. "Truth" revealed at the end.

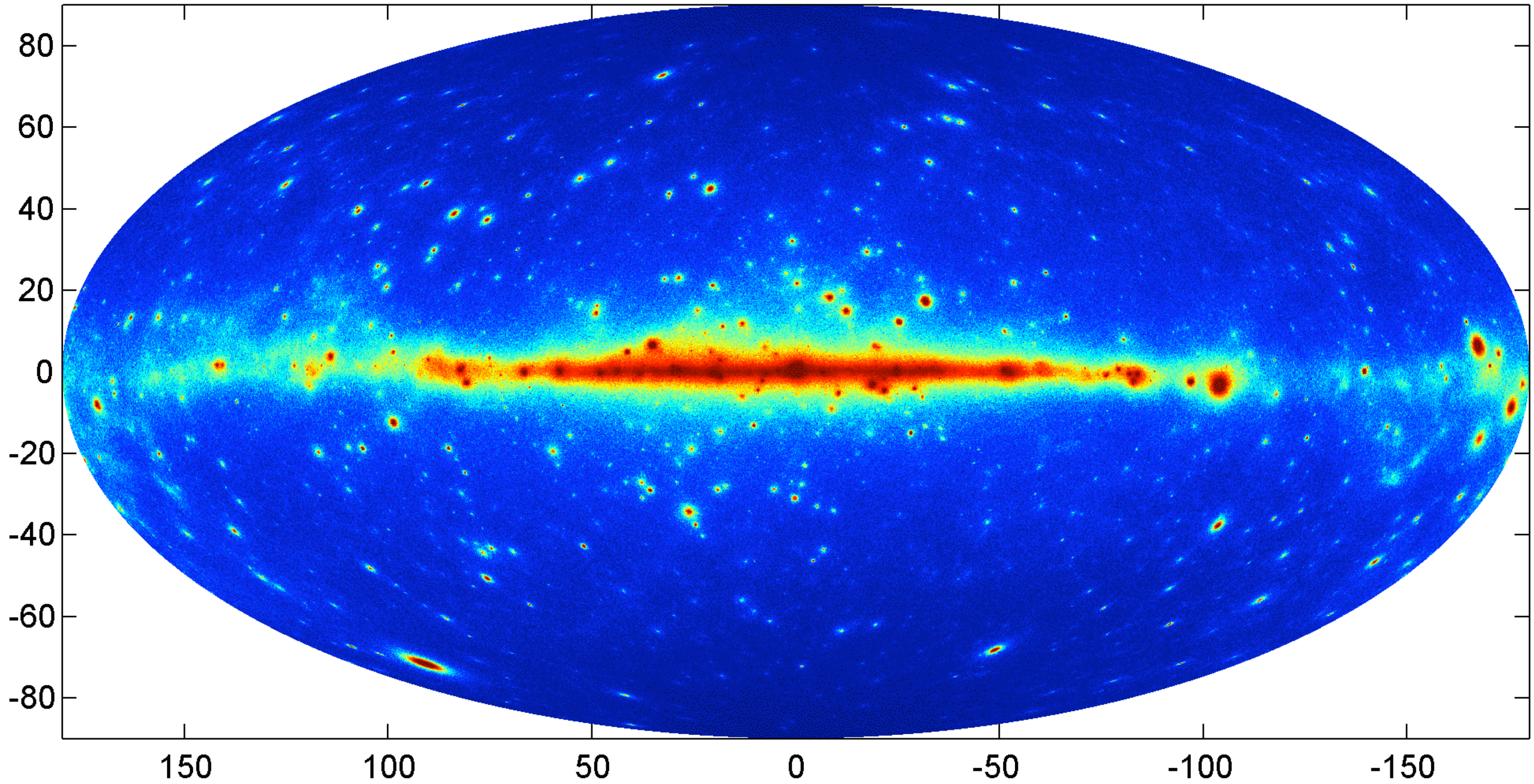
+ Users Committee beta test of the tools in November

- **A progression of data challenges.**
  - **DC1 in 2004. 1 simulated week all-sky survey simulation.**
    - **find the sources, including GRBs**
    - **a few physics surprises**
  - **DC2 in 2006, completed in June. 55 simulated days all-sky survey.**
    - **first catalog**
    - **add <u>source variability</u> (AGN flares, pulsars). lightcurves and spectral studies. correlations with other wavelengths. add GBM. study detection algorigthms. benchmark data processing/volumes.**

[SC movie]

Service Challenge

1 year sky simulation



- the movie

Leap in Capabilities: Implications

- **Dynamic Range Frontier; Variability Frontier** Whole-sky aperture for transients and variable sources: longterm, evenly sampled lightcurves; dynamic range of emission.
- **Depth Frontier** Deepening exposure over whole mission lifetime.
- **Energy Frontier** Discovering energy budgets and characteristics of wide variety of cosmic accelerator systems on different scales.
  - Getting to know 10 - 100 GeV sky
  - Connecting with TeV facilities: variability, spectral coverage
  - 7 decades of GLAST GRB energy coverage
- **Spatial Frontier** Breaking through to sub-arcmin point-source localizations (source dependent) -- ID the sources; PLUS starting to move beyond point sources: capabilities to resolve spatially, spectrally, and temporally.
- **Timing Frontier** Transient and periodic pulse profiles, searches.
- **Measurement Frontier** A rich data set to mine, touching many areas of science. Sources we know (AGN, SNR, XRBs, pulsars, PWN, galaxy clusters, solar flares, moon,…) and those awaiting discovery.

<u>Even greater multiwavelength/multimessenger needs and opportunities</u>

Summary

- GLAST will address many important questions:
  - How do Nature's most powerful accelerators work?
  - What are the unidentified sources found by EGRET?
  - What is the origin of the diffuse background?
  - What is the origin of cosmic rays?
  - What is the high energy behavior of gamma ray bursts?
  - What is the history of the optical-UV EBL?
  - What else out there is shining gamma rays? New sources? Are there high-energy relics from the Big Bang? Are there further surprises in the 10-100 GeV energy region?
- Huge leap in key capabilities enables large menu of known exciting science and large discovery potential.
- Part of the bigger picture of experiments at the interface between particle physics and astrophysics.

Summary

- All the parts of GLAST are coming together:
  - the instruments are beautiful!
  - observatory integration is nearing completion
- Preparation for science and operations in full swing
  - good connections among all the elements
  - MW observations are key to many science topics for GLAST. See *http://glast.gsfc.nasa.gov/science/multi/*
- Looking forward to launch in late 2007.
- Guest Investigator Program starts this year, with many opportunities for GIs. Join the fun!

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