GLAST

The Gamma-Ray Large Area Space Telescope

GLAST and its potential for physics and astrophysics: mission overview and science opportunities

Peter F. Michelson
Stanford University

on behalf of the GLAST Large Area Telescope Collaboration
and
the GLAST Mission Team

TeV Particle Astrophysics, Venice, August, 2007

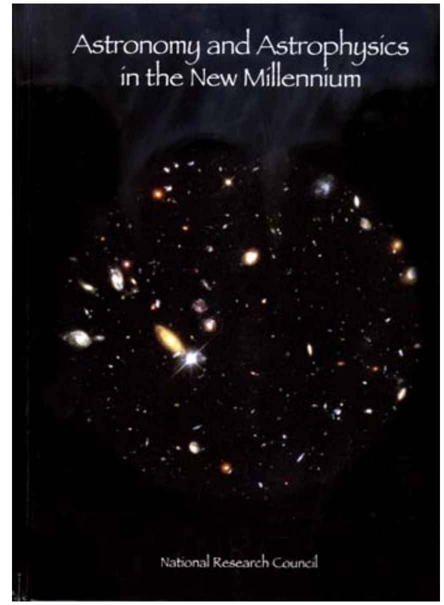
Acknowledgement to Trevor Weekes

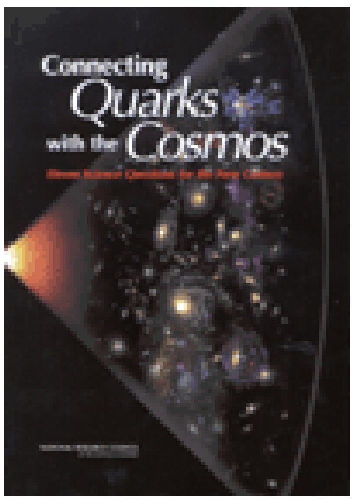
Nearly 10 years agoTrevor Weekes and Peter Michelson agreed that if GLAST achieved first light before Veritas, then Weekes would provide 1 litre of Irish Whiskey to Michelson, and vice versa.

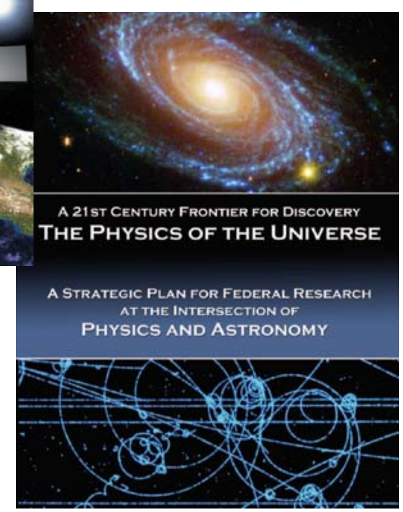
Trevor, You win!

GLAST: Exploring the High-Energy Universe

- ***gamma rays provide a direct view into Nature's largest accelerators (supermassive black holes)***
- ***gamma rays probe cosmological distances***
- ***huge leap in key capabilities, including a largely unexplored energy range; great potential for* Discovery**
  - *recognized by the National Academy of Sciences 2000 Decadal Survey (Taylor-McKee): GLAST is **top-ranked** mission in its category*
- ***also featured in NAS Connecting Quarks with the Cosmos and the Physics of the Universe 2004 Strategic plan:***







"…GLAST will focus on the most energetic objects and phenomena in the universe…it will also search for Dark Matter candidate particles."

THE UNIVERSITY OF CHICAGO
CHICAGO 37 · ILLINOIS
INSTITUTE FOR NUCLEAR STUDIES

March 12, 1949

Professor G. Cocconi
Cornell University
Laboratory of Nuclear Studies
Ithaca, New York

Dear Cocconi:

Excuse my answering in English your letter, since by doing so I can dictate to my secretary. I have been very much interested by your statement that you have evidence of the existence of large showers up to 10^{17} eV.

The reason why, according to the theory on the origin of cosmic rays that I have proposed, no electrons should be found, is that I postulate the existence throughout the interstellar space of a magnetic field with an intensity of about 10^{-5} - 10^{-6} gauss. If this assumption is correct, the radiation loss for a fast electron is quite large and prevents it from acquiring a sizeable energy. This mechanism of energy loss by electrons is much more efficient in removing fast electrons than the mechanism of the inverse Compton effects discussed by Feenberg and Primakoff. On the other hand, the existence of this last effect is much less hypothetical because all that is needed to produce it is the existence of the stellar light in the space traversed by the cosmic rays during their life. I have not read the article of Feenberg and Primakoff with particularly great attention, but as far as I can see, their conclusions seem to me to be sound.

You probably know that Teller recently has maintained that the cosmic radiation may be of solar origin and may be held within the limits of the planetary system by some suitable kind of magnetic field. Even if this hypothesis is correct, one could hardly expect to find electrons of high energy in the cosmic radiation. Probably the main reason to eliminate them is the same inverse Compton effect considered by Feenberg and Primakoff, which becomes much stronger because the particles are supposed to travel in the vicinity of the sun and are exposed, therefore, to a much stronger radiation than they would be in the interstellar space.

For all these reasons, it seems to me highly improbable that electrons of as high energy as you mention could be found in the cosmic radiation. On the other hand, all these arguments should not be over estimated, and an experimental check on them, if possible, is certainly worth while.

I will send to you a copy of my manuscript, as soon as reprints are available.

Very sincerely yours,

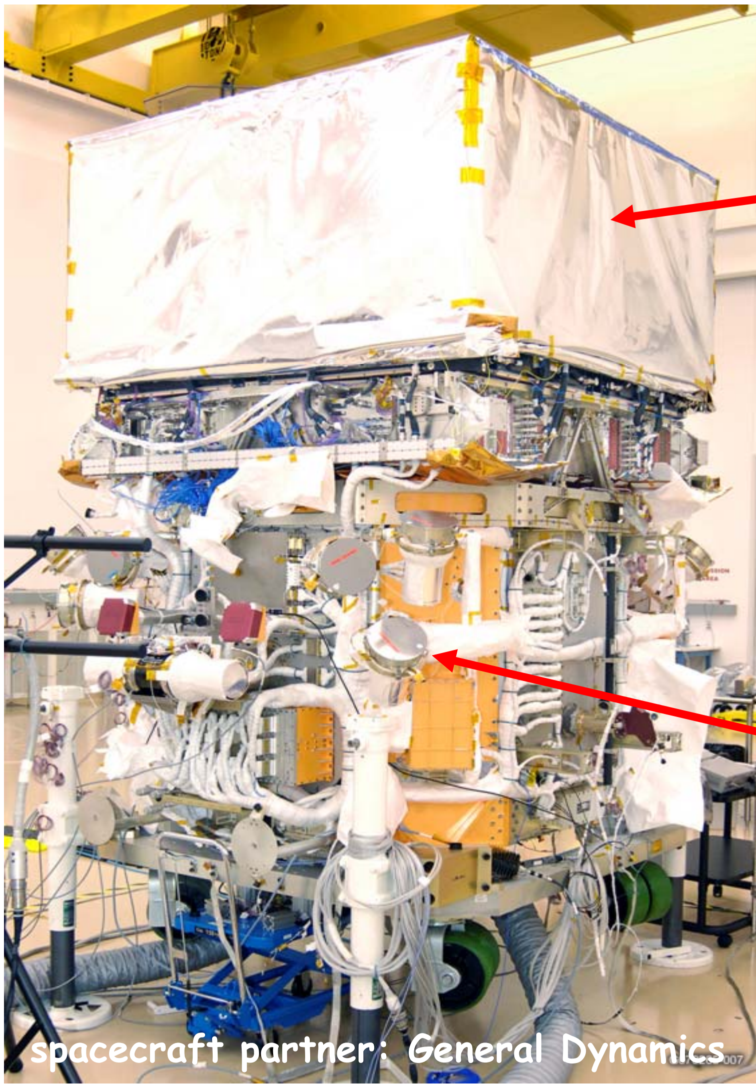
Enrico Fermi

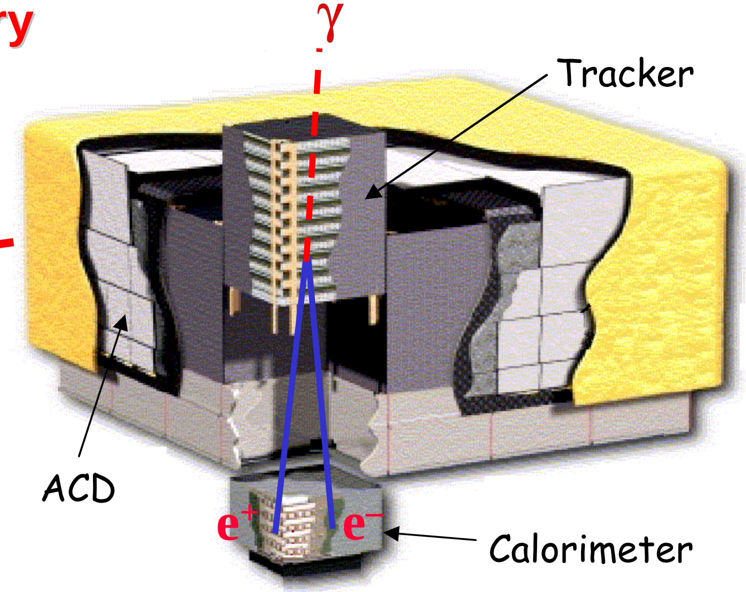
Enrico Fermi

EF:al
encl.

GLAST Observatory

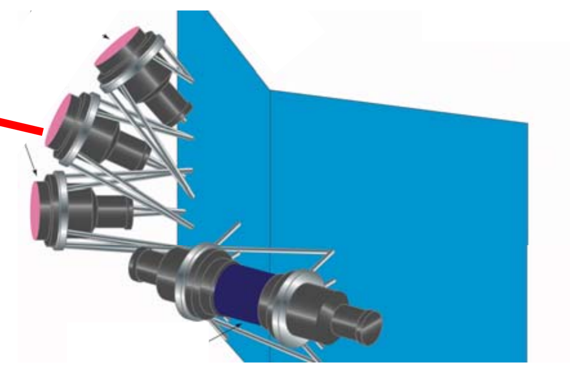
spacecraft and two instruments (LAT and GBM) now integrated and functioning as a single observatory





Large Area Telescope

(20 MeV – > 300 GeV)



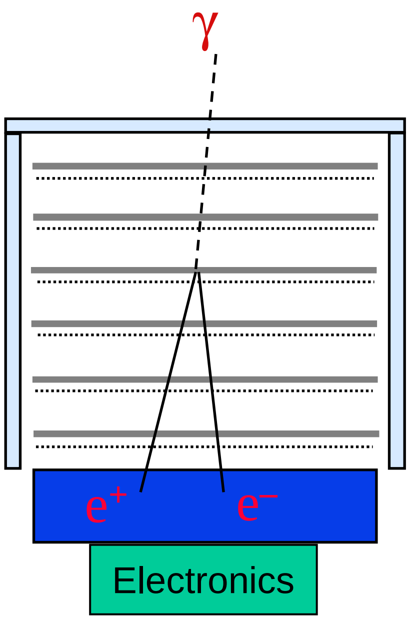
Glast Burst Monitor

(10 keV – 25 MeV)

Latest picture of GLAST Observatory

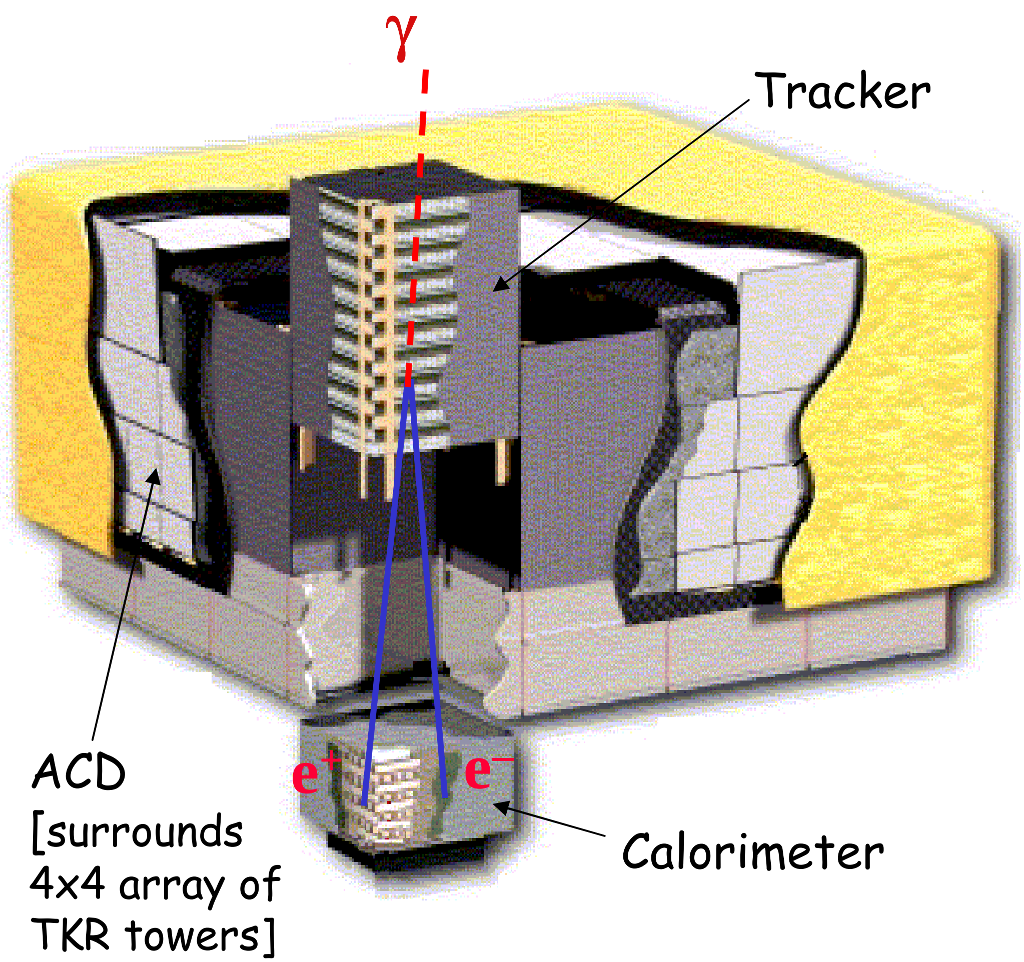
General Dynamics, Gilbert, AZ

Pair Conversion Telescope



Overview of LAT

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

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, HEPL/Physics & KIPAC)
- 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 University)

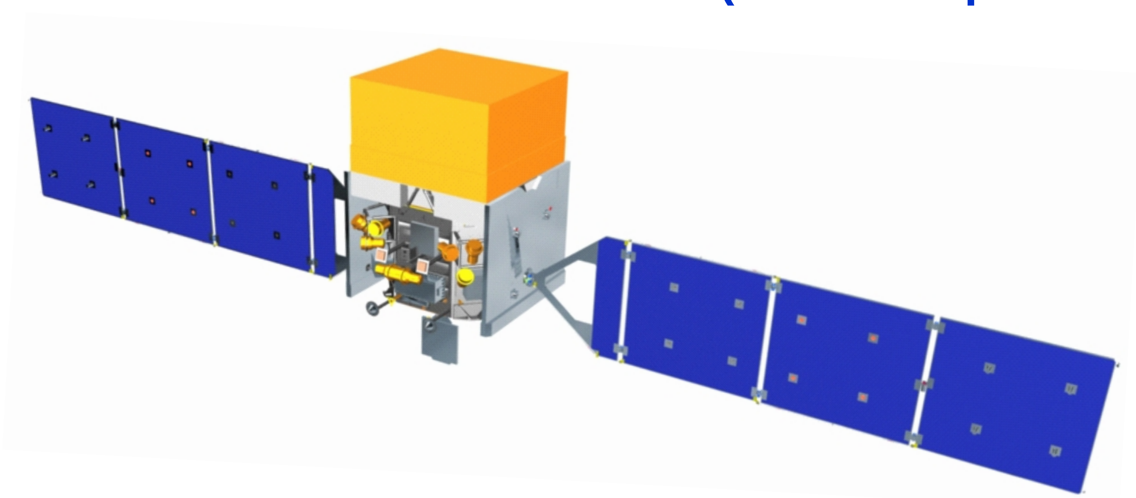
~230 Members (including ~84 Affiliated Scientists, plus 24 Postdocs, and 36 Graduate Students)

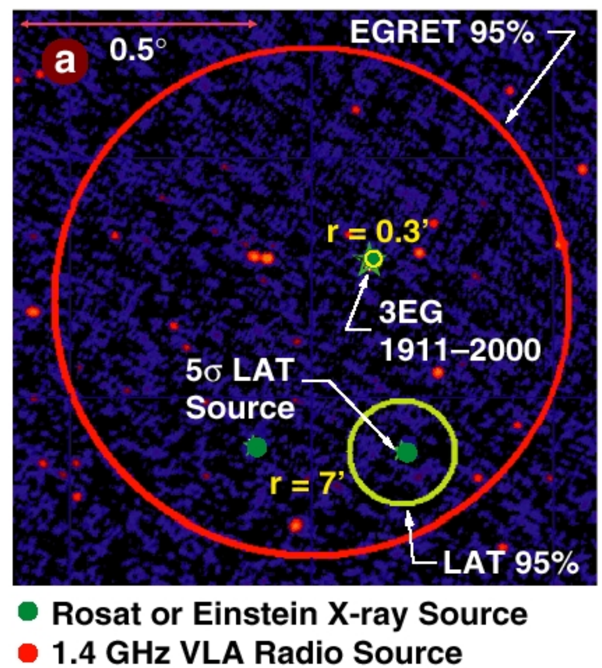
Cooperation between NASA and DOE, with key international contributions from France, Italy, Japan and Sweden.

LAT construction managed at Stanford Linear Accelerator Center (SLAC).

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)



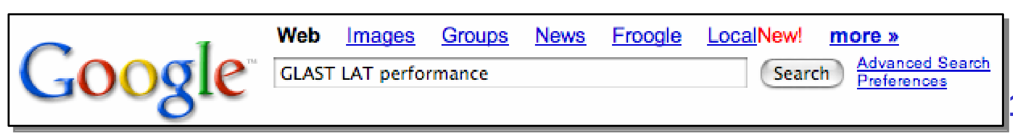


GLAST LAT High Energy Capabilities

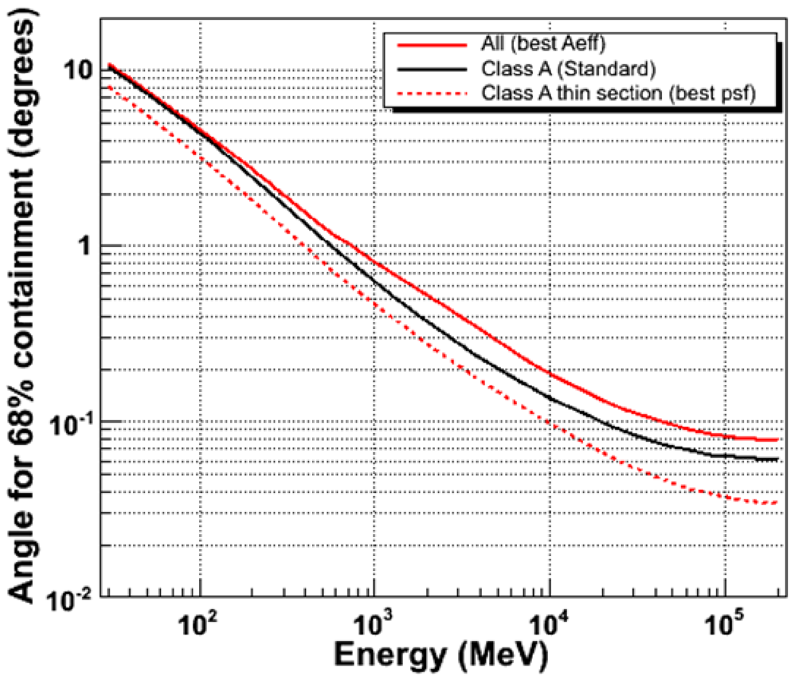
GLAST is the next great step beyond EGRET in the GeV band, providing a huge leap in capabilities:

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

latest performance plots on Web



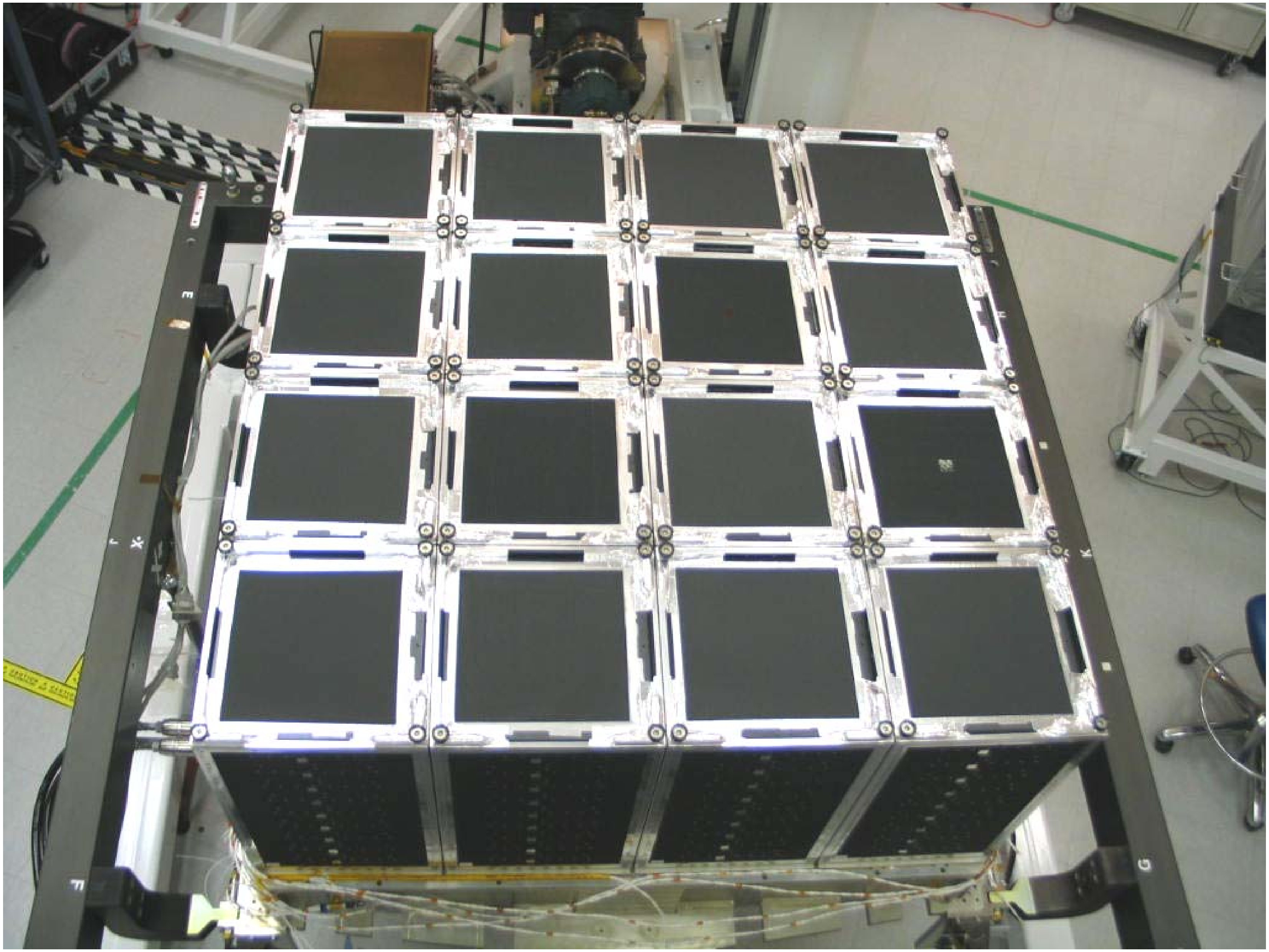
LAT performance summary



LAT performance plots available at
www-glast.slac.stanford.edu/software/IS/glast_lat_performance.htm

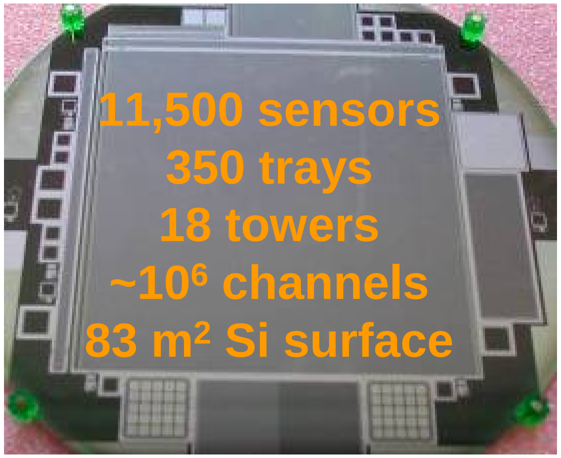
or google “GLAST LAT performance”

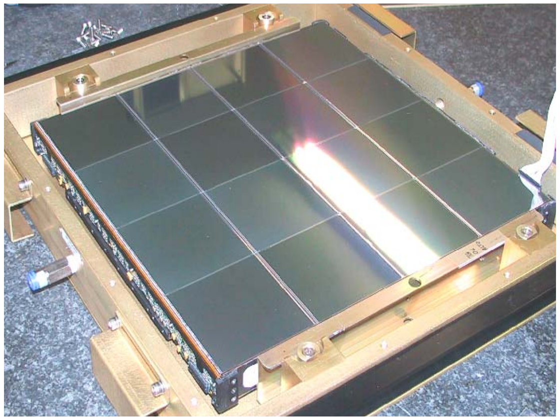
The Large Area Telescope

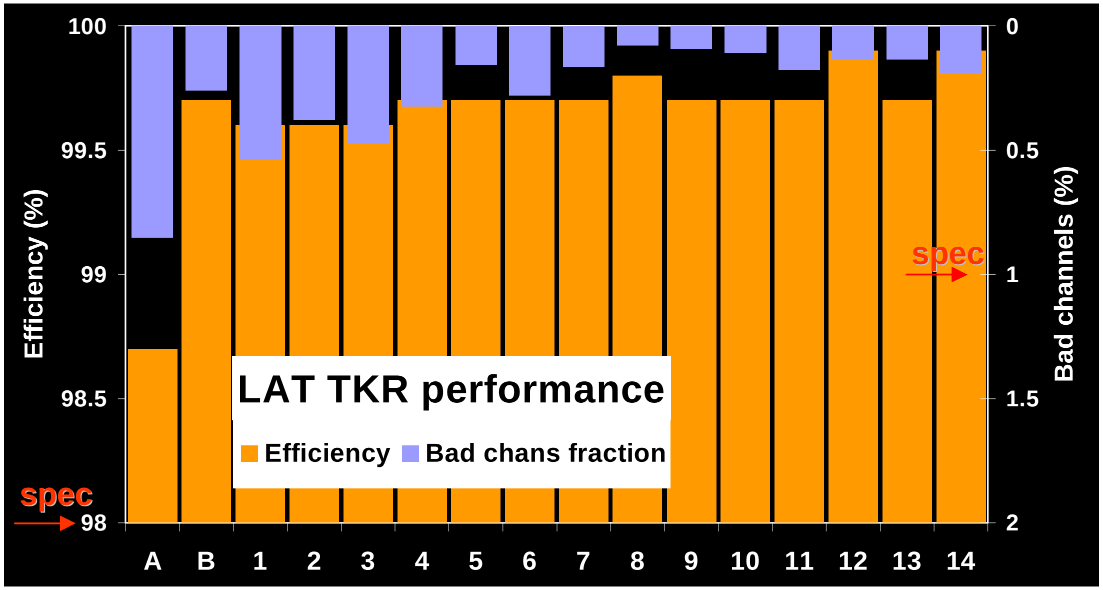


LAT Silicon Tracker

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

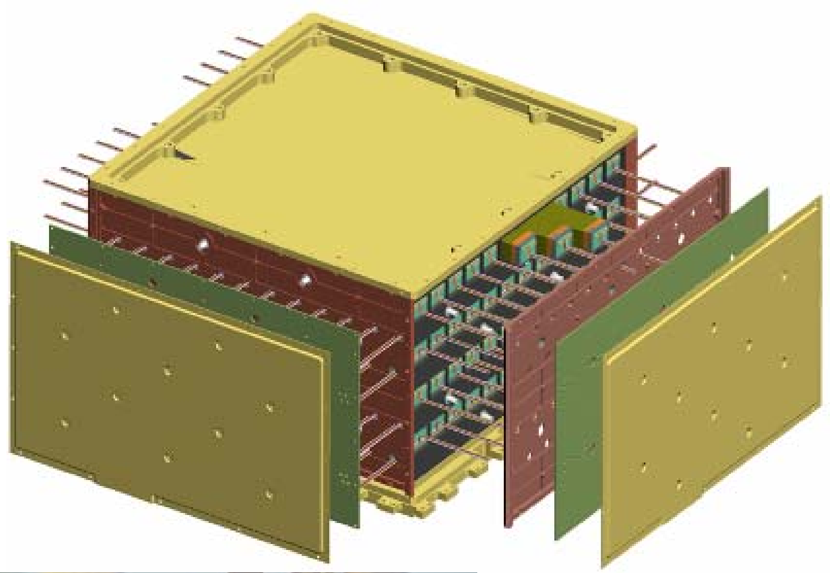


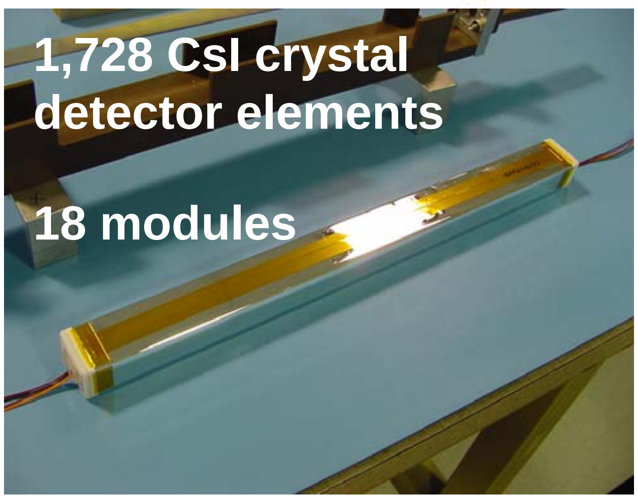


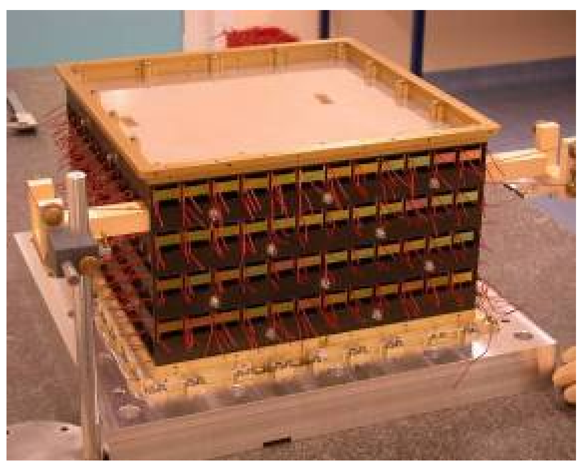


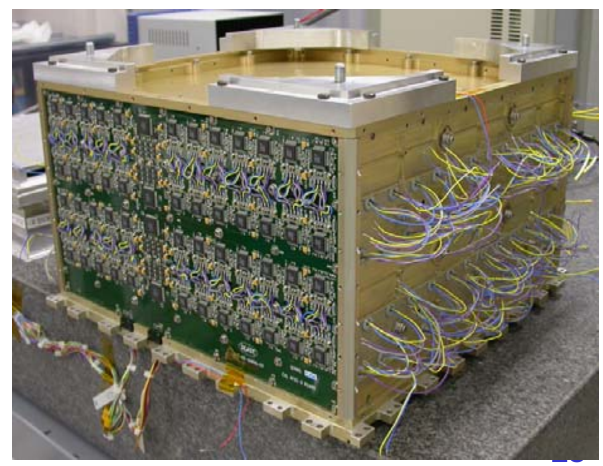
LAT Calorimeter

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

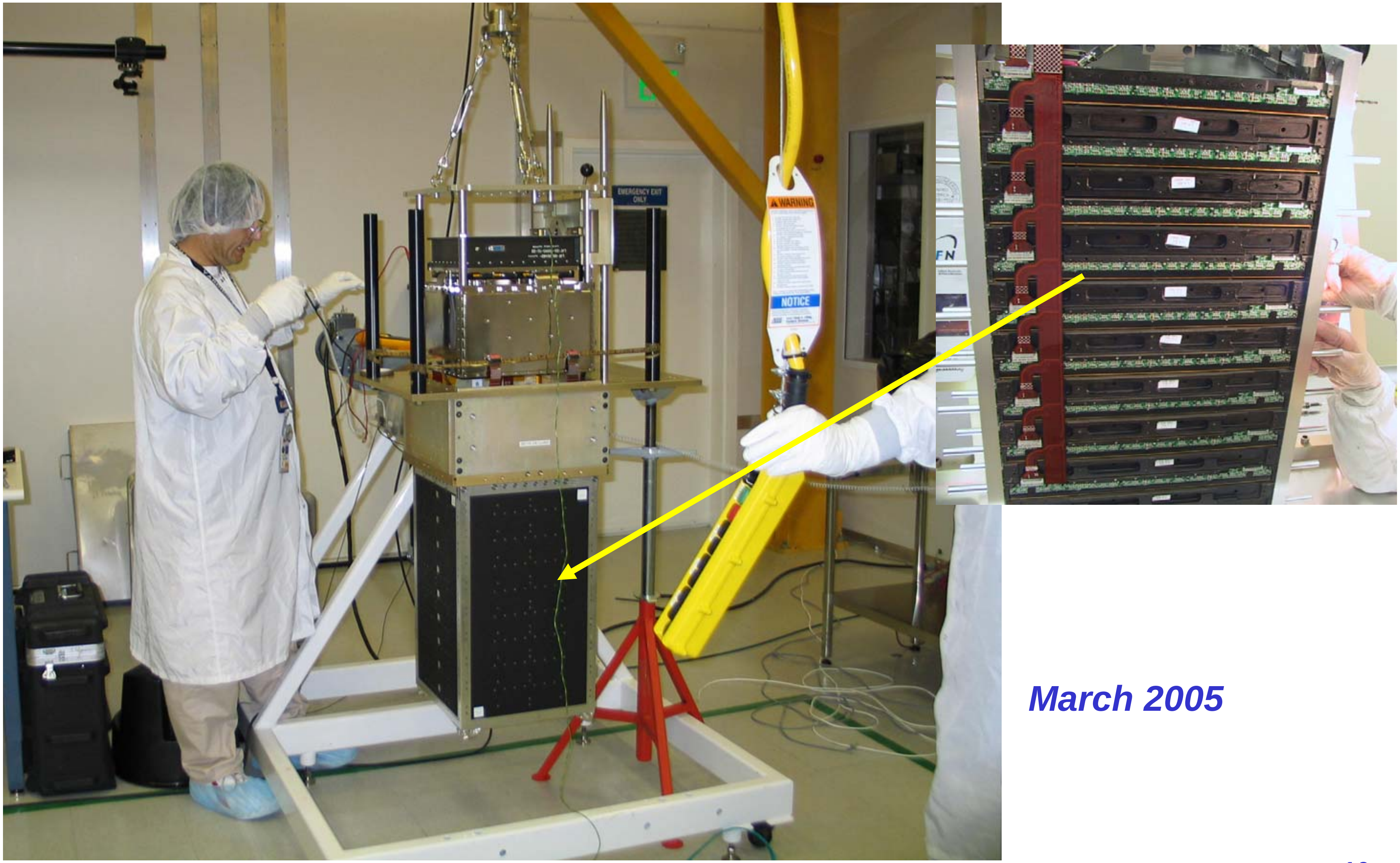






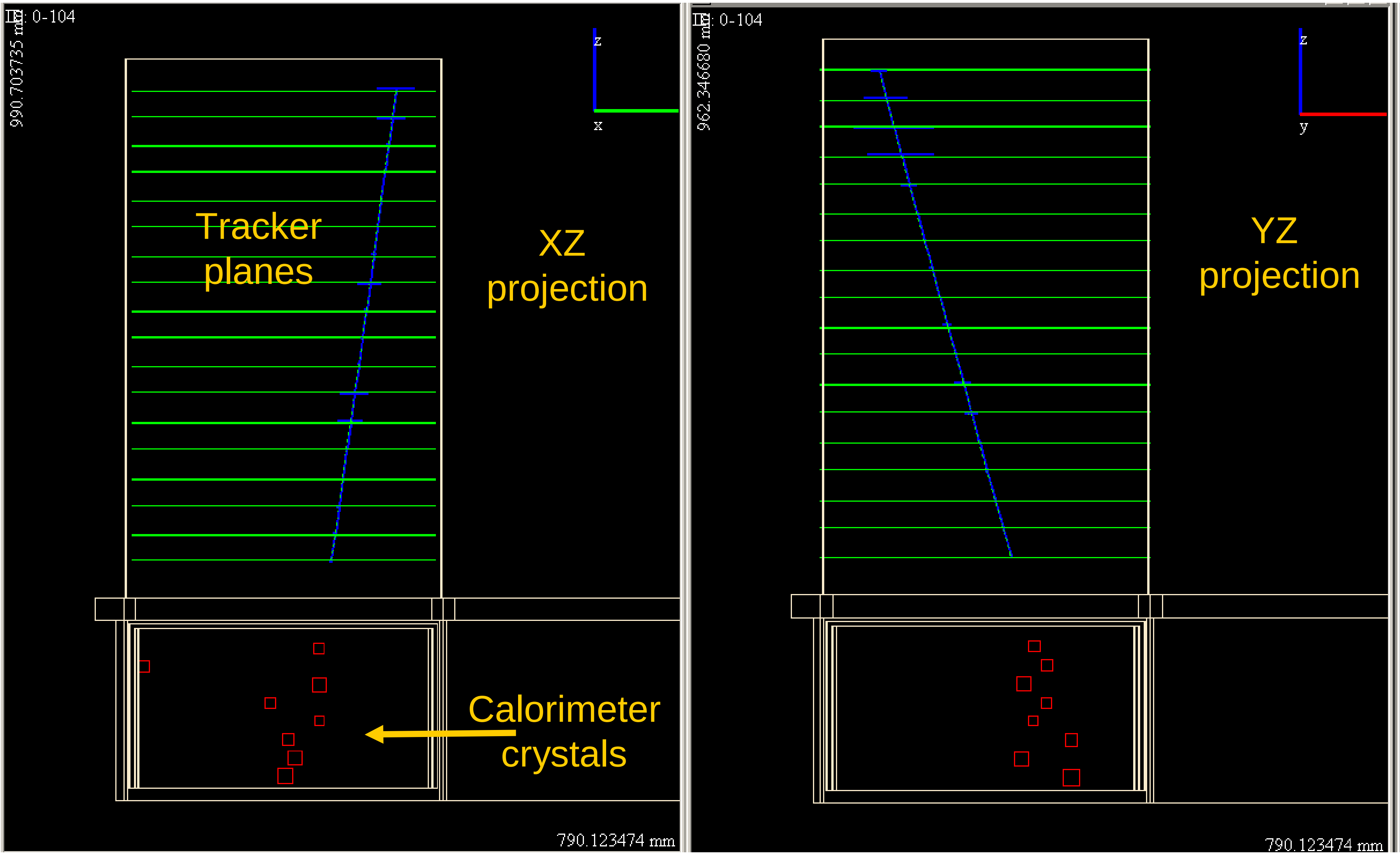


First Flight Tower in I&T

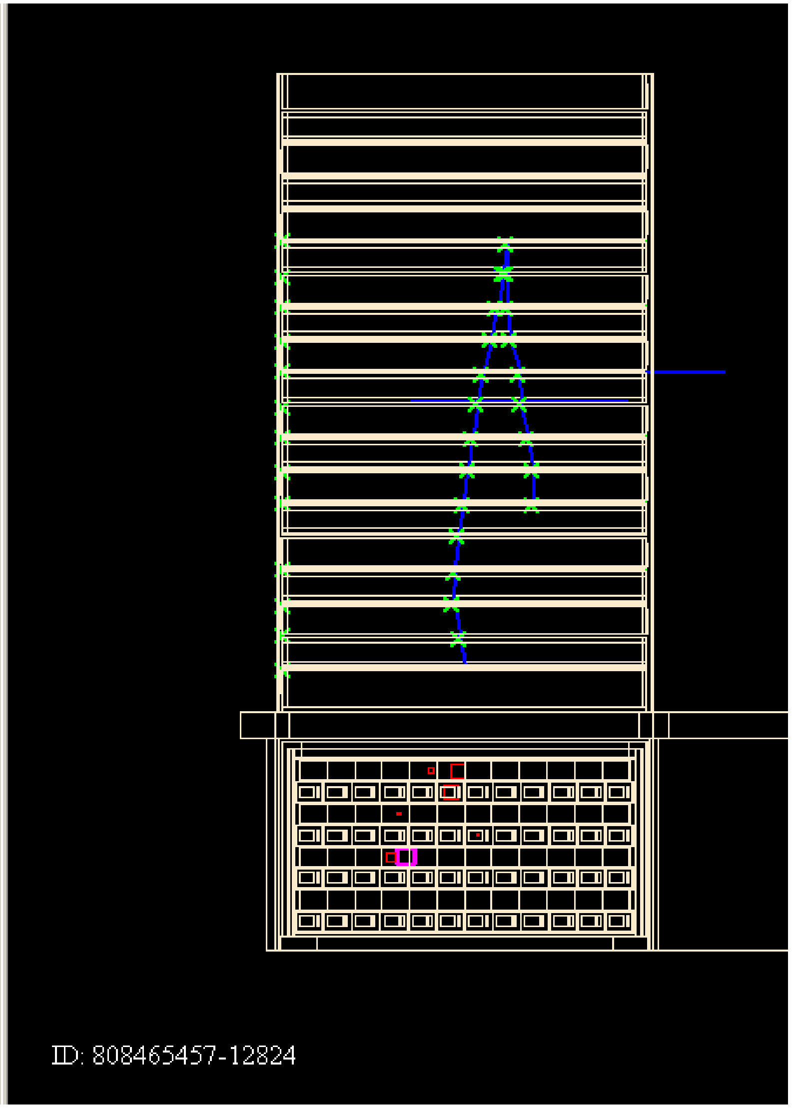


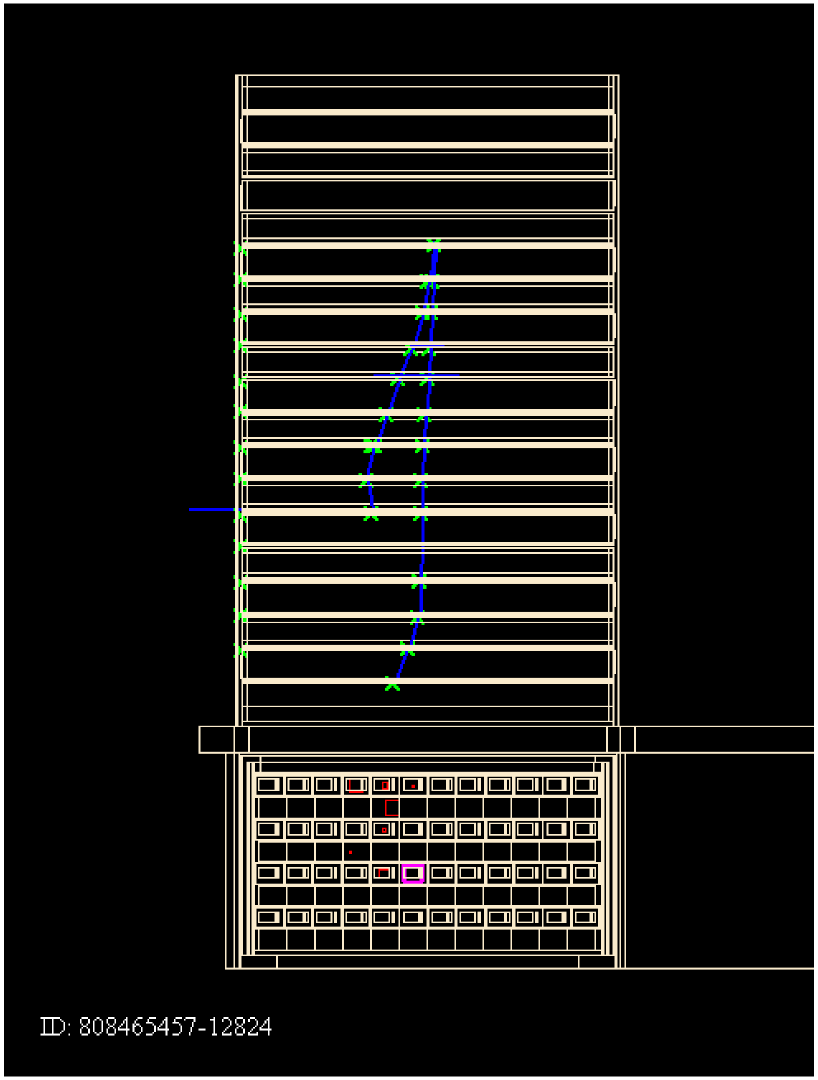
March 2005

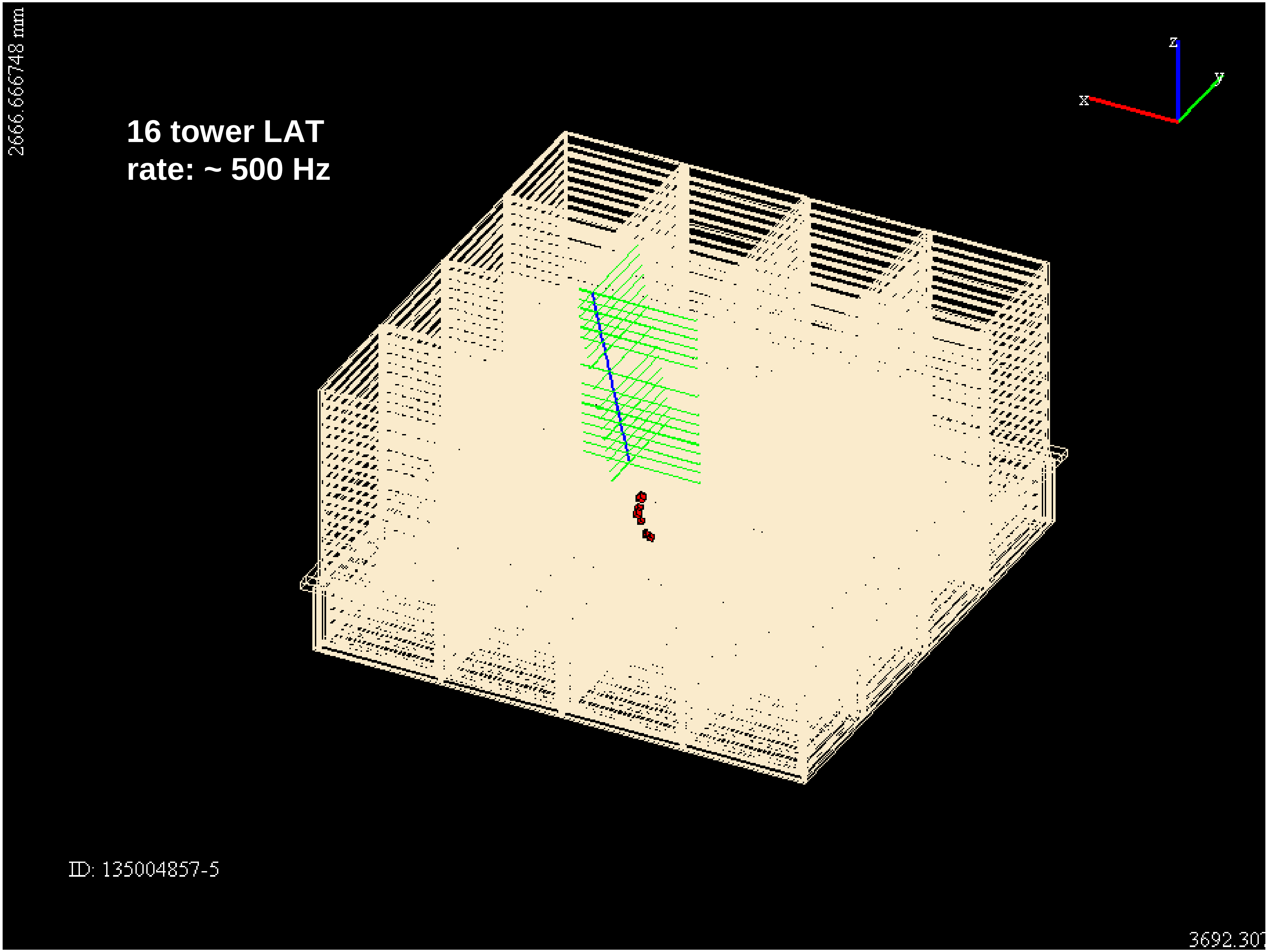
First Integrated Tower – Muon Candidate Event



First integrated tower: Gamma-ray pair conversion







16 tower LAT
rate: ~ 500 Hz
2666.666748 mm
z
y
x
ID: 135004857-5
3692.307

The Large Area Telescope

GLAST Science

A very broad menu including:

- 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 capabilities push several frontiers

- **Dynamic Range; Variability** Whole-sky monitor for transients and variable sources: long-term, evenly-sampled light curves; dynamic range of emission.
- **Depth** Deepening exposure over whole mission lifetime.
- **Energy** Discovering energy budgets and characteristics of wide variety of cosmic accelerator systems on different scales.
  - get to know 10 - 100 GeV sky
  - connect with TeV facilities: variability, spectral coverage
  - 7 decades of GLAST GRB energy coverage
- **Spatial** 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** Transient and periodic pulse profiles, searches.

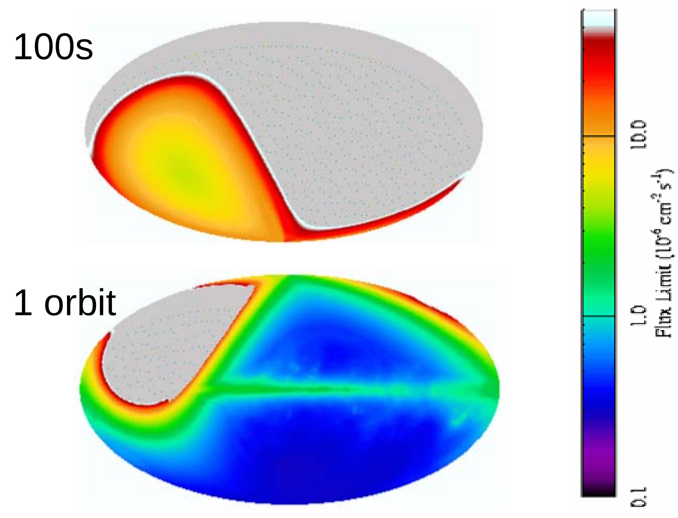
A rich data set to mine, touching many areas of science. Sources we know (AGN, SNR, XRBs, pulsars, PWN, galaxy clusters, solar flares, moon,…) and those awaiting discovery.

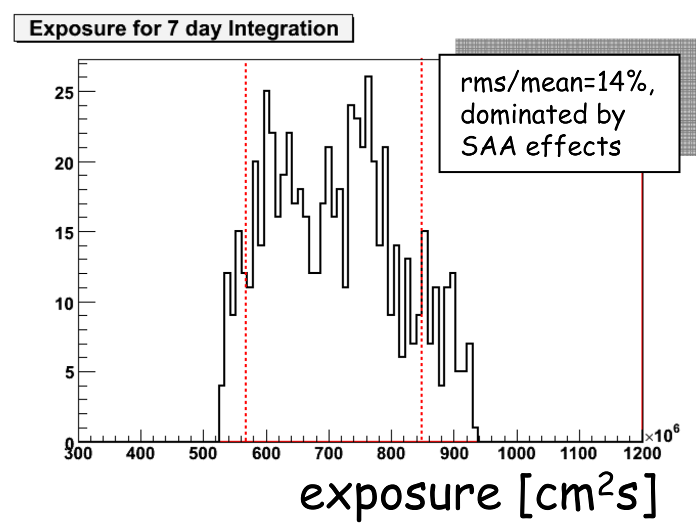
<u>Even greater multiwavelength - multimessenger needs and opportunities</u>

Operating modes

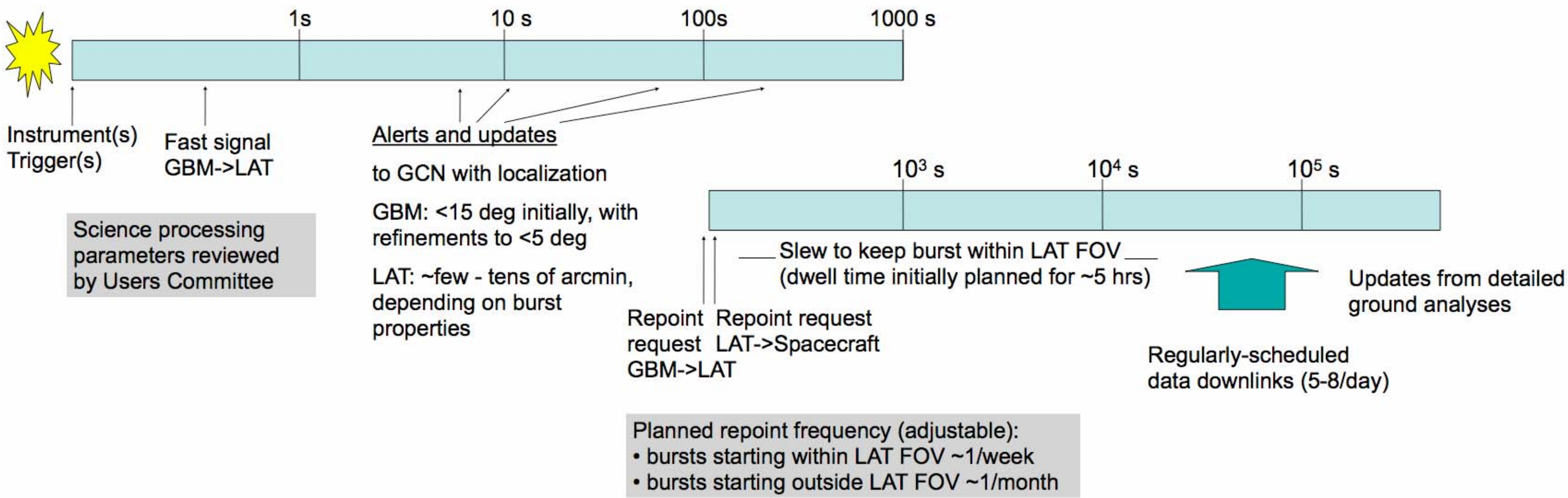
- **Primary observing mode is Sky Survey**
  - **Full sky every 2 orbits (3 hours)**
  - **Uniform exposure, with each region viewed for ~30 minutes every 2 orbits**
  - **Best serves majority of science, facilitates multiwavelength observation planning**
  - **Exposure intervals commensurate with typical instrument integration times for sources**
  - **EGRET sensitivity reached in O(1) days**
- **Pointed observations when appropriate (selected by peer review) with automatic earth avoidance selectable. Target of Opportunity pointing.**
- **Autonomous repoints for onboard GRB detections in any mode.**

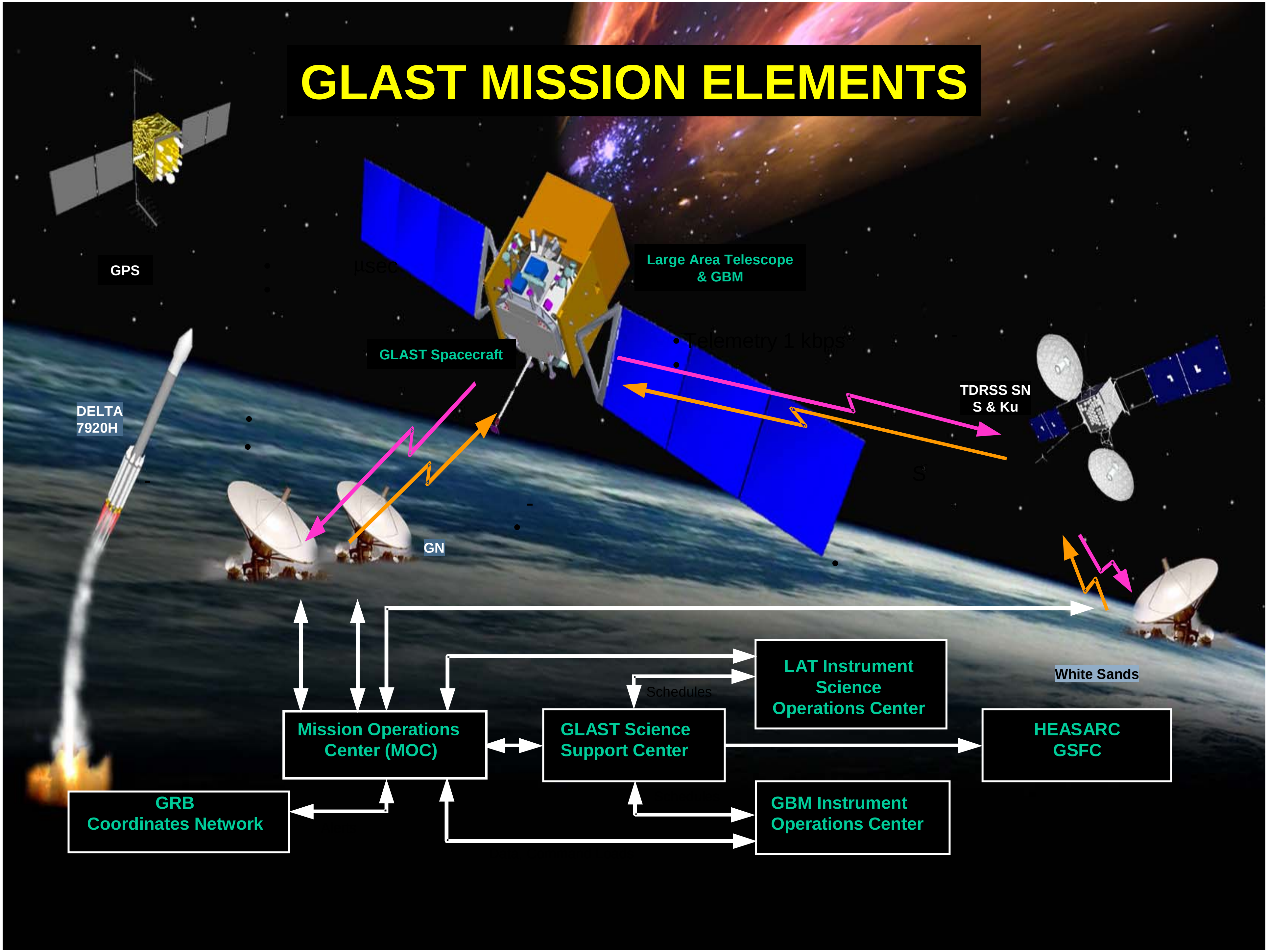
Sensitivity



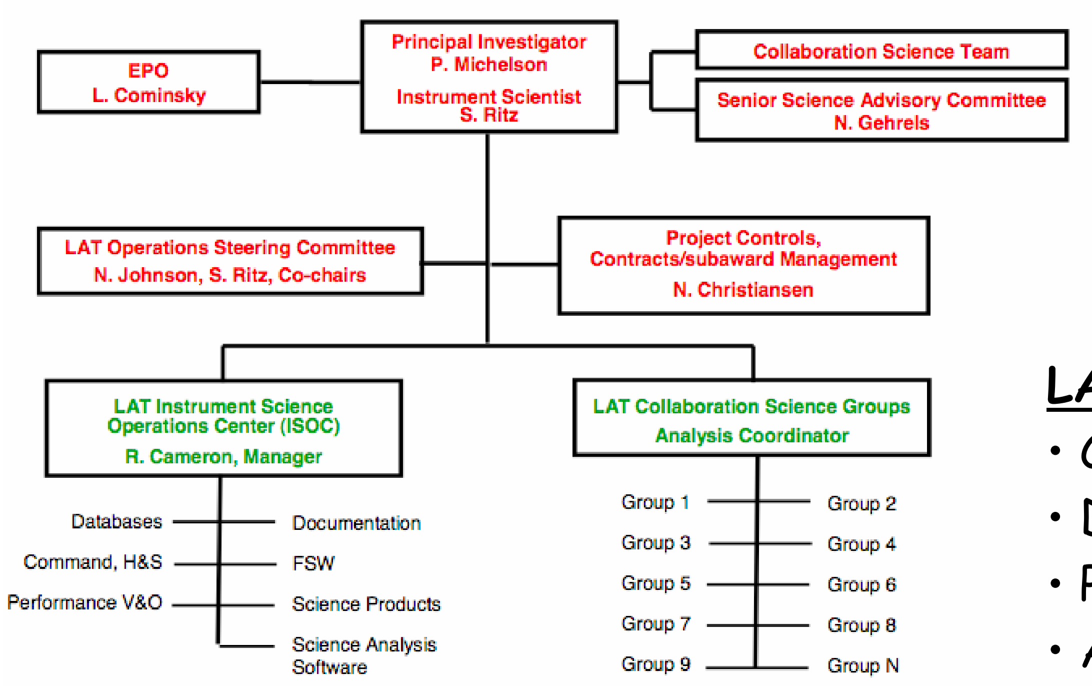


Typical GLAST GRB timeline




GLAST MISSION ELEMENTS
GPS
Large Area Telescope & GBM
GLAST Spacecraft
Telemetry 1 kbps
TDRSS SN S & Ku
DELTA 7920H
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

LAT Organization, Science Groups



see http://www-glast.stanford.edu/

and

http://www-glast.slac.stanford.edu/

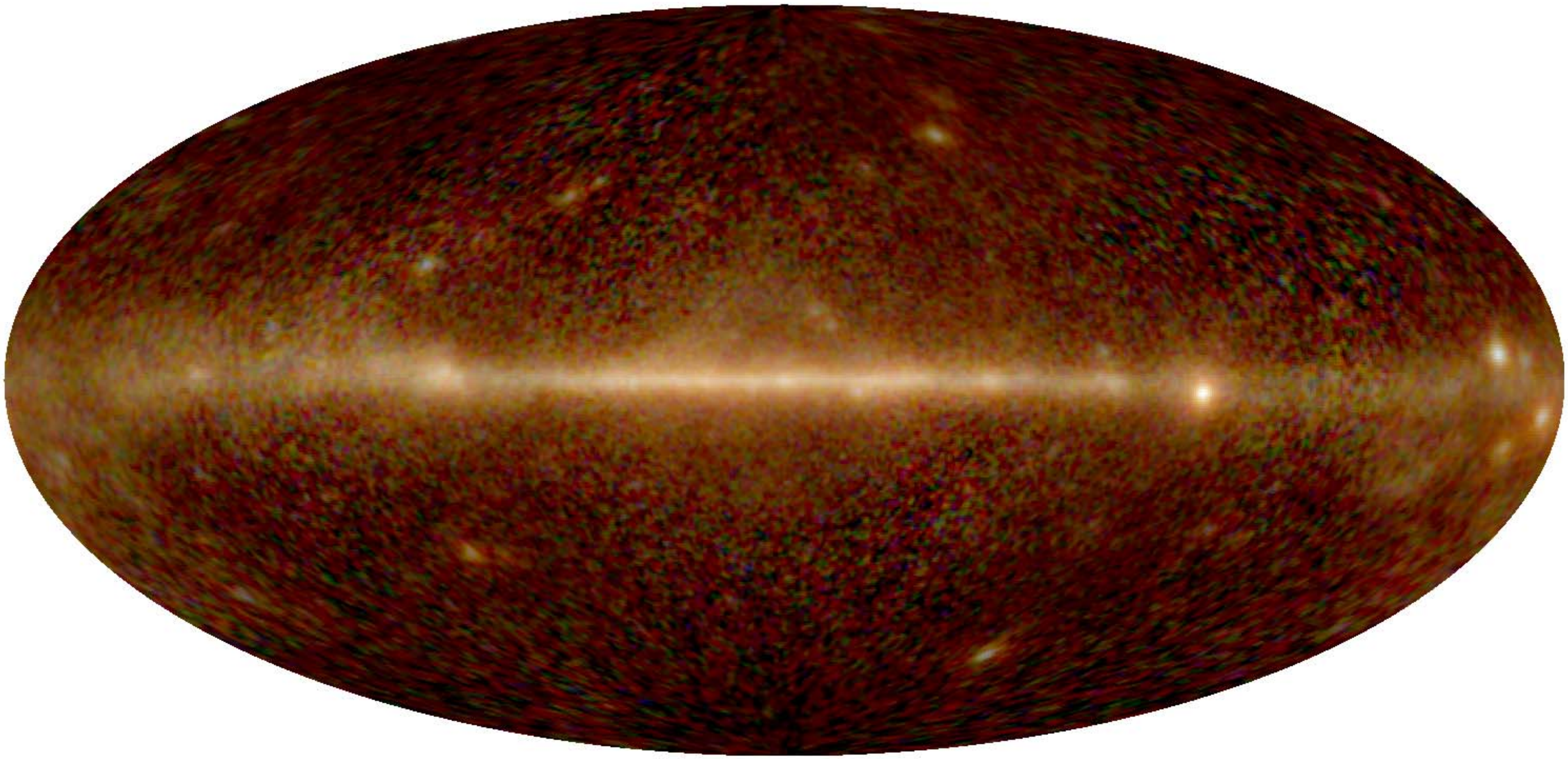
Group Coordinators report to Analysis Coordinator (J. McEnery)

each group identifies MW needs and submits proposals and makes connections through LAT MW Coordinator (D.J. Thompson)

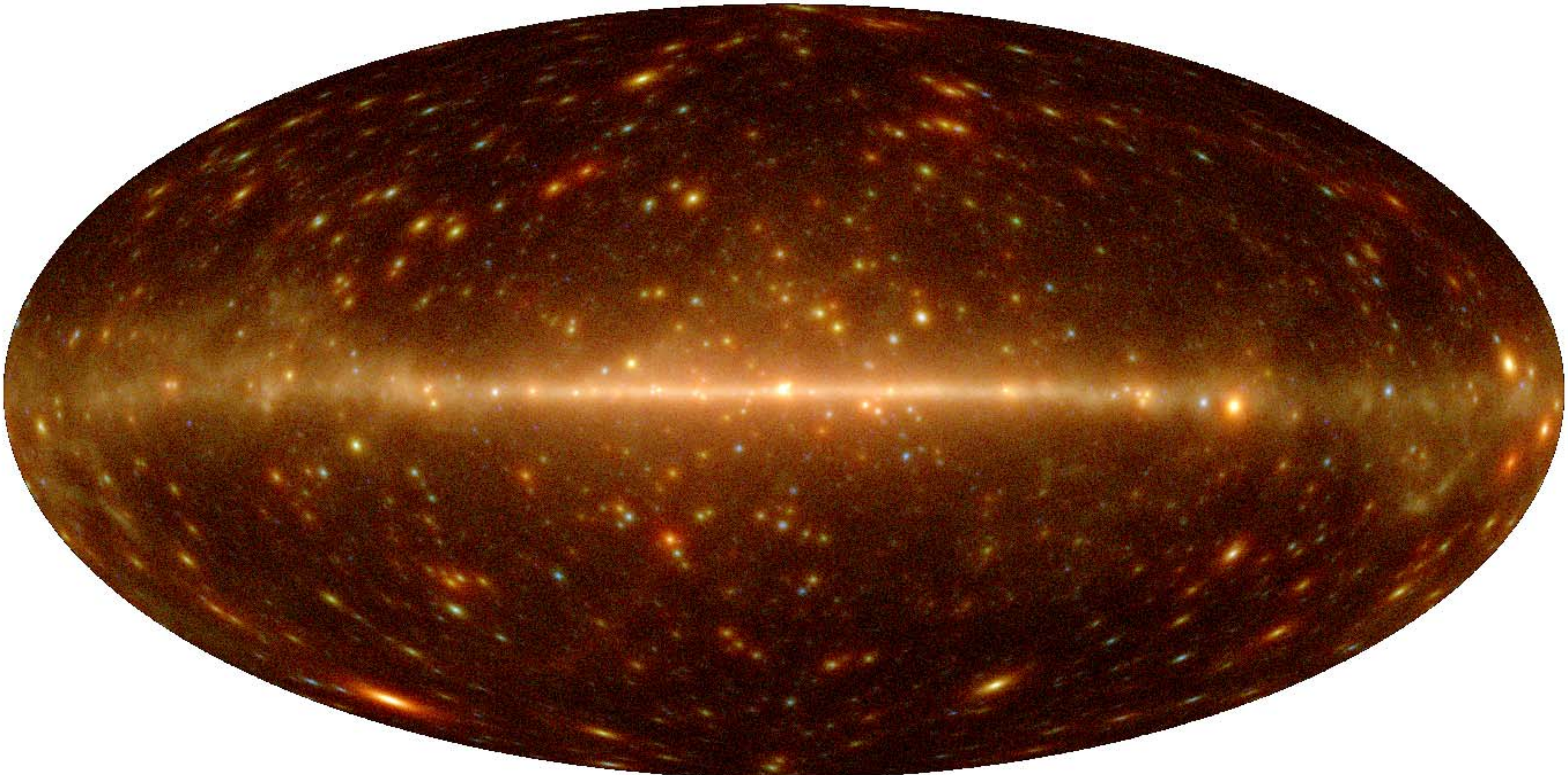
LAT Science Group Coordinators

- Catalog: Grenier, Digel, Ballet
- Diffuse: Porter, Grenier
- Pulsars/SNR: Harding, Romani
- AGN: Tosti, Lott
- UNID: Caraveo, Reimer
- GRB: Omodei, Connaughton
- Solar: Longo, Share
- DM and New Physics: R. Johnson, Conrad
- Calibration and Analysis Methods: Bruel, Latronico

EGRET



GLAST One-year Service Challenge Simulation

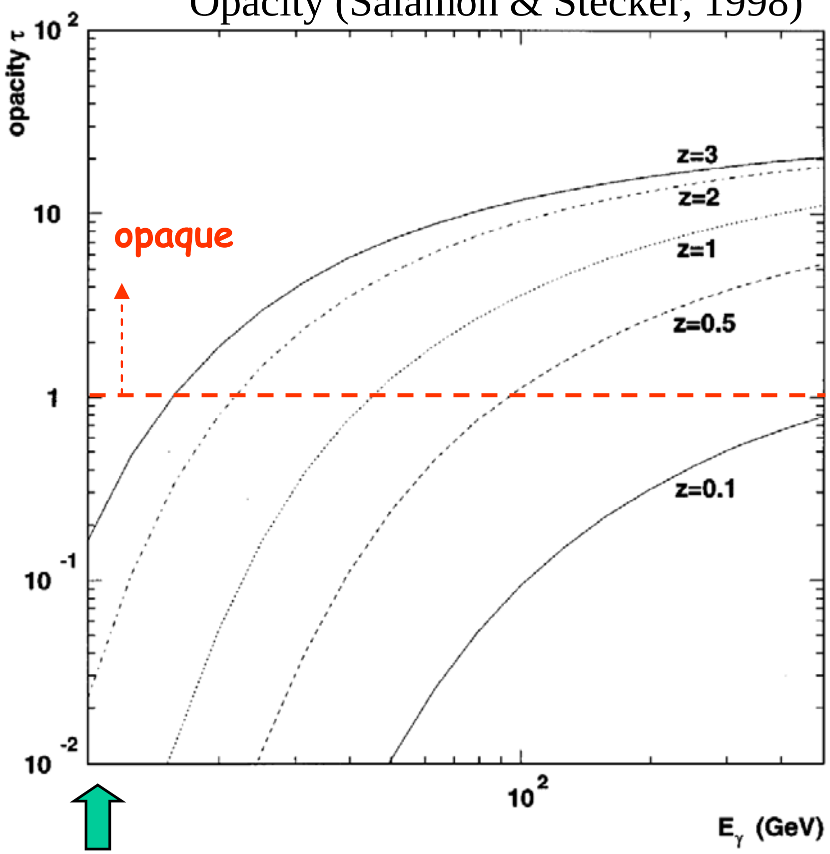


red: 0.1-0.4 GeV
green: 0.4-1.6 GeV
blue: >1.6 GeV

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>

$\gamma\gamma \rightarrow e^+e^-$, *maximum when*

$\varepsilon_{EBL} \sim$ ½ (1000 GeV / E_γ) eV

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>.

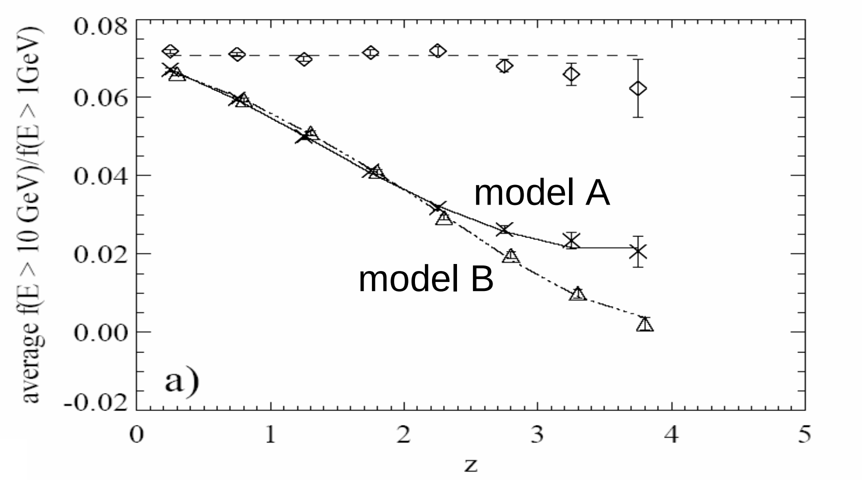
Probing Extragalactic Background Light with Blazars

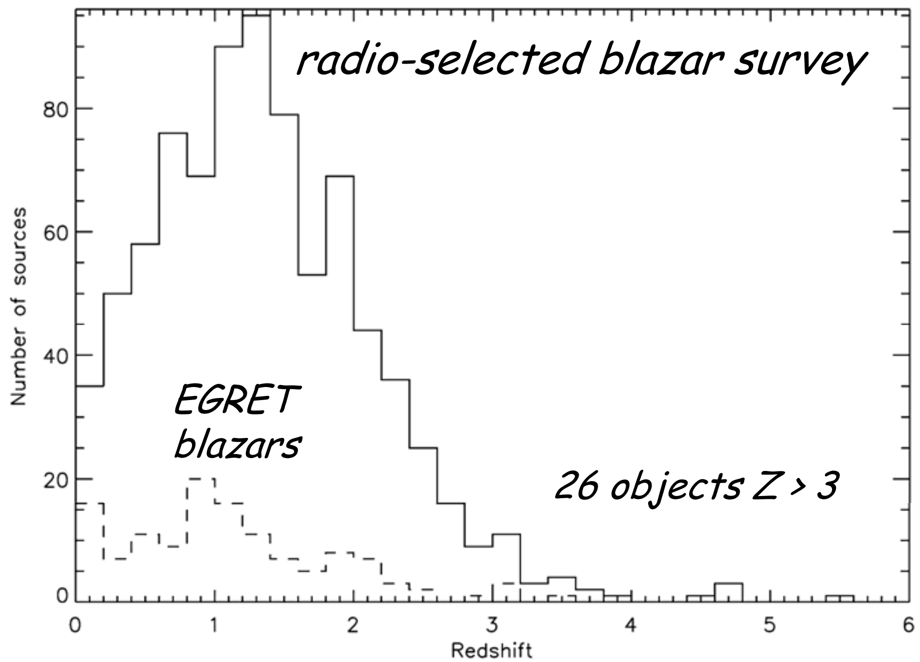
- ► *measure the redshift dependence of the attenuation of flux above 10 GeV for a sample of high-redshift blazars*

sensitive to optical-UV EBL

must disentangle from source evolution effects
– e.g. A. Reimer (2007)

measure flux E>10 GeV/flux E>1 GeV





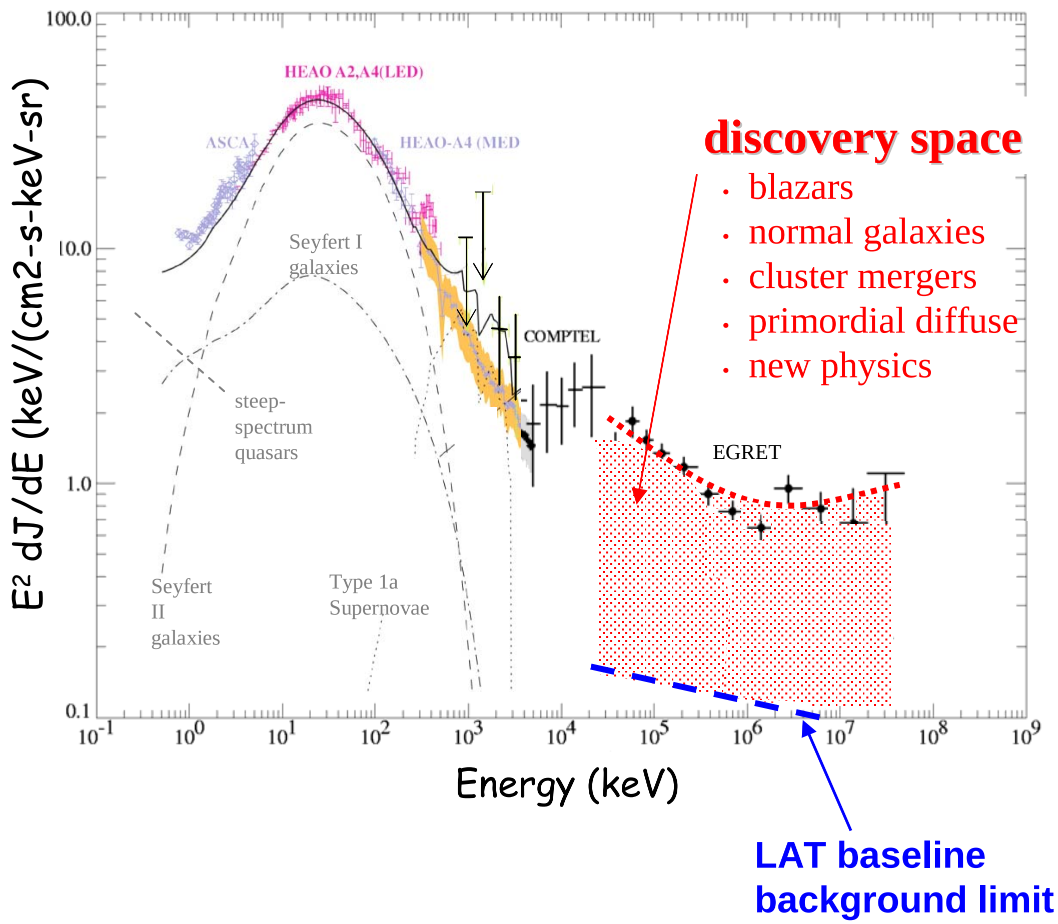
70% of EGRET sources (|b|>10º) are blazars

4.8 GHz radio survey; chose bright flat-spectrum sources

95% of radio-selected sources are blazars

Discovery Space: Extragalactic γ-ray background

- *origin is a mystery; either sources there for GLAST to resolve (and study!) OR there is a truly diffuse flux from the early Universe*



MW Info and Coordination

- **Multiwavelength observations are key to many science topics for GLAST.**
  - **GLAST welcomes collaborative efforts from observers at all wavelengths**
    - **For campaigners' information and coordination, see** *http://glast.gsfc.nasa.gov/science/multi*
    - **To be added to the Gamma Ray Multiwavelength Information mailing list, contact Dave Thompson,** *djt@egret.gsfc.nasa.gov*

- **GI Program will support correlative observations and analysis**
  - **See** *http://glast.gsfc.nasa.gov/ssc/proposals*

Operations Phases, Guest Observers, Data

- **After the initial on-orbit checkout, verification, and calibrations, the first year of science operations will be an all-sky survey.**
  - **all GBM data released**
  - **LAT high-level data on flaring sources, transients, and “sources of interest” will be released, with caveats**
  - **Individual photon data released at the end of year one. Subsequent photon data released immediately after processing.**
  - **burst alerts and repoints for bright bursts**
  - **extraordinary ToO’s supported**
  - **workshops for guest observers on science tools and mission characteristics for proposal preparation**
- **Observing plan in subsequent years driven by guest observer proposal selections by peer review -- default is sky survey mode. Data released through the science support center (GSSC).**

GI Opportunities

- **Annual cycles**
- **Cycle 1:**
  - **expect to fund ~50 investigations (US investigators) for**
    - **analyses of released data**
    - **GLAST-related MW observations**
    - **GLAST-related theory**
    - **GLAST-relevant data analysis methodology**
  - **<u>can propose for time on NRAO and NOAO facilities to enhance science return from GLAST observations</u>**
- **Cycle 2 and onward:**
  - **expect to fund ~100 investigations for all of the above plus detailed analyses of LAT photon candidate event lists.**
  - **may propose pointed observations, as well as ensured sky-survey periods (expect <20% time on pointed observations)**
- **Schedule for Cycle 1 (2007)**
  - **NRA in ROSES, proposals due Sept 7, Cycle 1 funding starts in early 2007**

GLAST Fellows Program Plan

- Similar to other observatory Fellows programs
- Tentative schedule:
  - first call for proposals Fall 2007, selections announced early 2008, start in September 2008
- Three new Fellows selected each year, for three-year periods

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 now together:**
  - **the instruments are beautiful!**
  - **observatory nearly ready for final environmental testing**
- **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 February 2008.**
- **Guest Investigator Program starts at the end of the year, with many opportunities!**

Started monthly GLAST news email. Sign up!

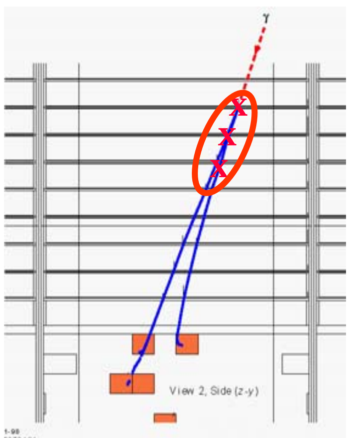
Instrument Triggering and Onboard Data Flow

Hardware Trigger

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

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

Combinations of trigger primitives:



- TKR 3 *x•y* pair layers in a row

  workhorse γ trigger

- CAL:

  LO – independent check, energy info.

  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

Onboard filters: reduce data to fit within downlink, provide samples for systematic studies.

- **flexible, loose cuts**
- **FSW filter code is wrapped and embeded in full detector simulation**
- **leak a fraction of otherwise-rejected events to the ground for diagnostics, along with events ID for calibration**
- **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.**