Gamma Ray Large Area Space Telescope

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SLAC/KIPAC

DOE Review – Jun 6, 2006

Outline

- Introduction
  - Features of the gamma ray sky and gamma ray telescopes
  - Overview of the GLAST Observatory
- GLAST Science
  - Highlights of LAT Instrument Capabilities
  - Selected Physics Topics
    - Particle Acceleration
    - Relativistic Outflows
    - Dark Matter and New Physics
- GLAST/LAT Current Activities
  - Pre-launch Integration and Tests
  - LAT Beam Test
  - LAT Instrument Science Operations Center
  - Interfaces with LAT Collaboration
    - Instrument Analysis Workshops
    - Data Challenges
  - GLAST/SLAC Science Organization
- GLAST Timeline

Why γ rays ?

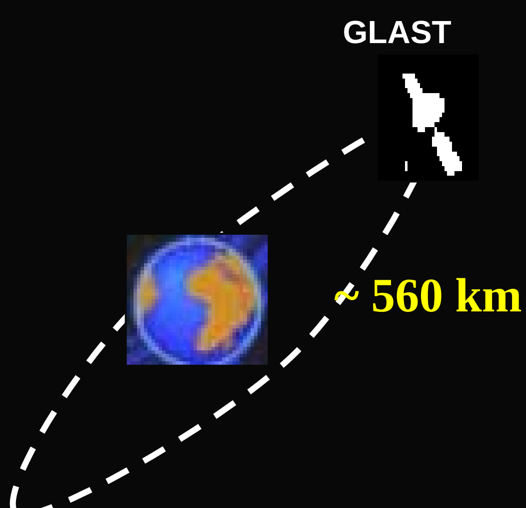
- Universe is transparent to γ rays
- γ rays are not affected by magnetic fields
- γ rays probe cosmological volumes

(opacity/energy dependent)

γ

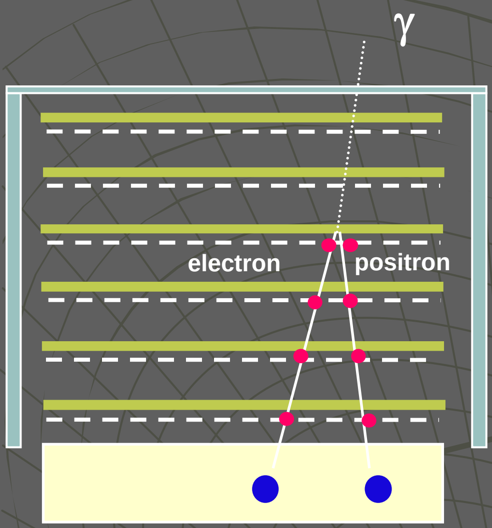
Active Galactic Nuclei

Gamma Ray Bursts

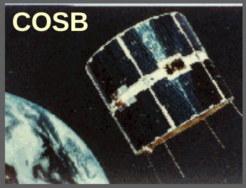


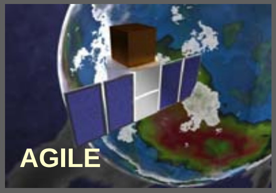
Gamma rays provide insight on high energy processes and represent a discovery window of new phenomena

Gamma Ray Detection Techniques

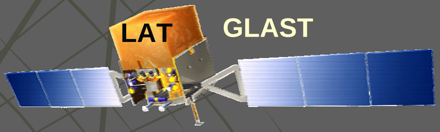


Pair
Conversion
Telescopes



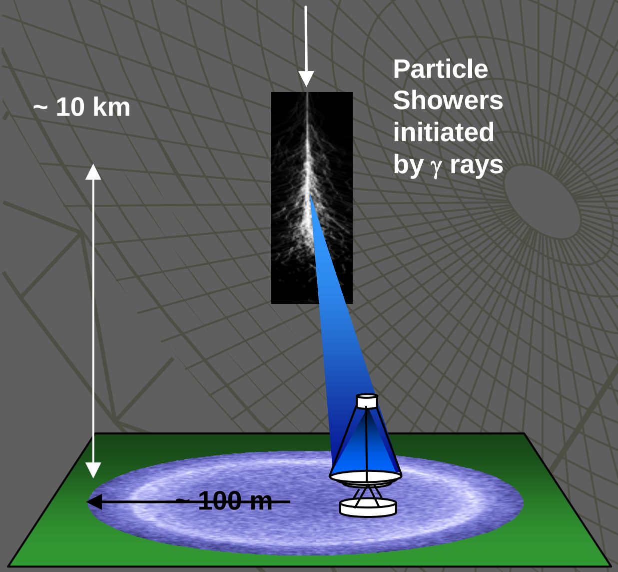


GLAST
silicon detectors 2007 to ?
20 MeV to > 300 GeV
~100 Million γ rays per year



SPACE

GROUND

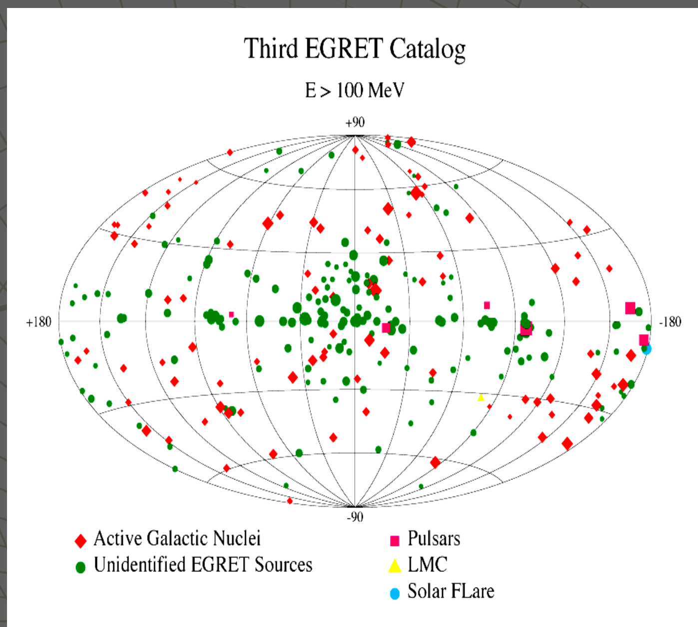


Imaging
Atmospheric
Cerenkov
Telescopes

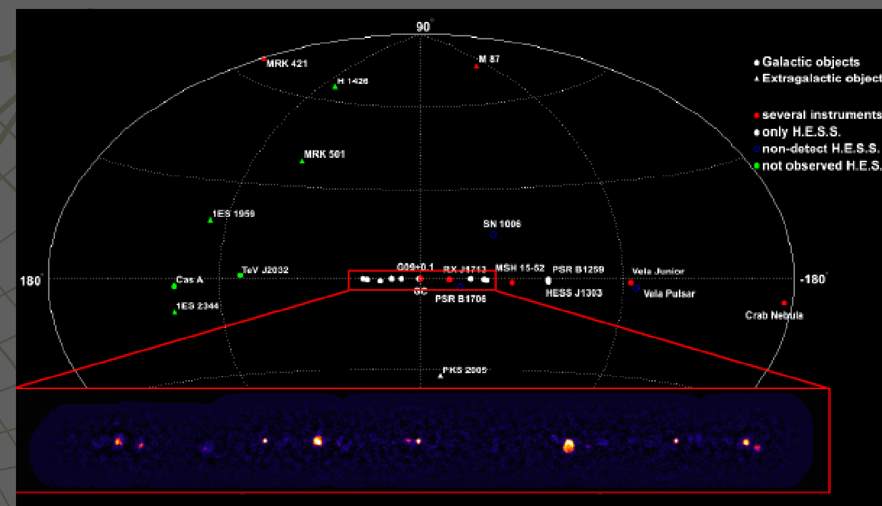
GLAST/LAT Energy Range: Discovery Window

The LAT will probe the unexplored energy range of 10 to 100 GeV

From space



From ground…



← X rays

EGRET

~ 30 MeV ⟷ 10 GeV

Ground Telescopes

100 GeV ⟷ 10 TeV

LAT

20 MeV ⟷ 300GeV

GLAST Observatory : Overview

GLAST will measure the direction, energy and arrival time of celestial γ rays

GBM Principal Investigator: Charles Meegan

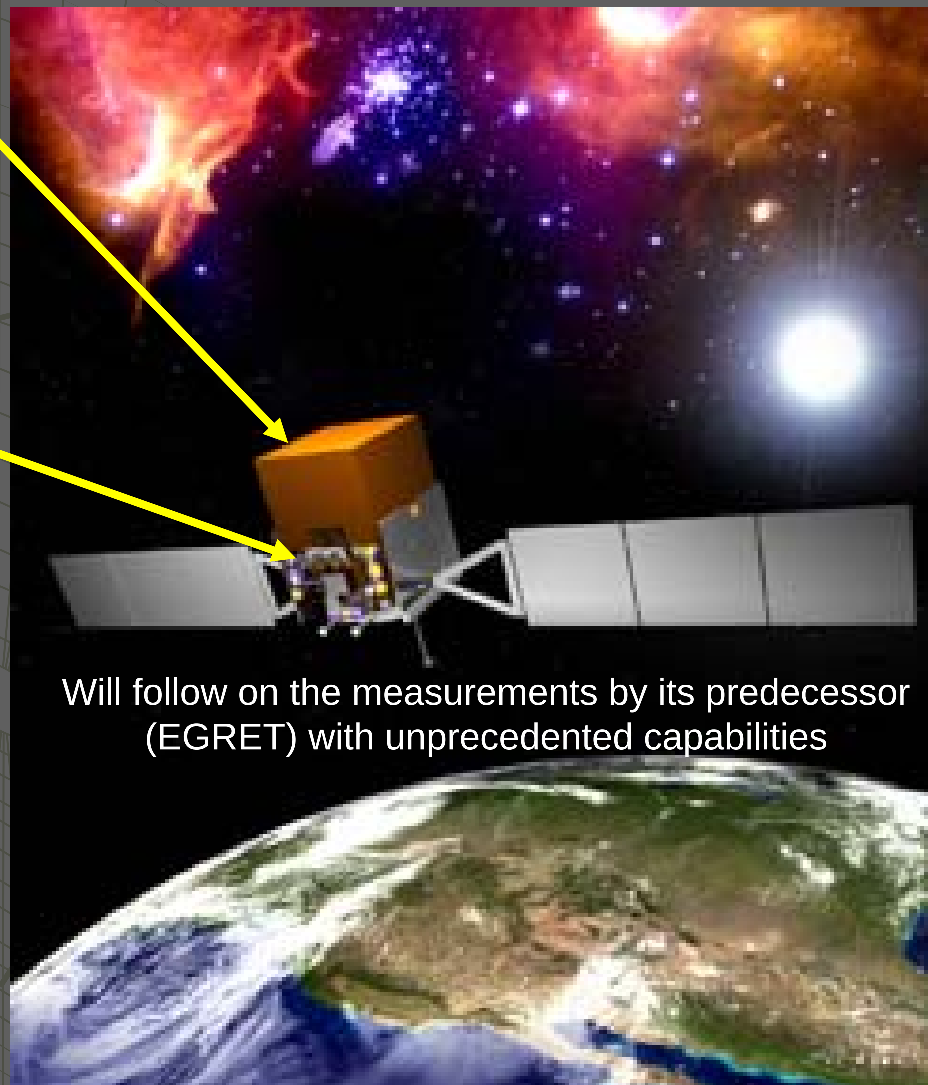
LAT Principal Investigator: Peter Michelson

LAT
will record gamma-rays in the energy range
~ 20 MeV to >300 GeV

GBM
will provide correlative observations of transient events in the energy range
~10 keV – 25 MeV

Observing modes
All sky survey
Pointed observations

Re-pointing Capabilities
Autonomous
Rapid slew speed
(75° in < 10 minutes)



Orbit
565 km, circular

Inclination
28.5°

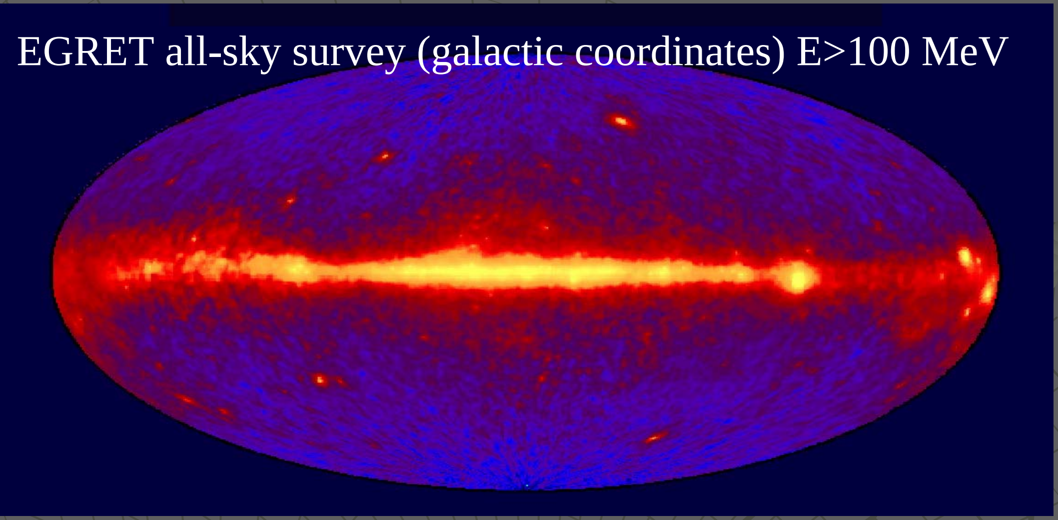
Lifetime
5 years (min)

Launch Date
Sep 2007

Launch Vehicle
Delta 2920H-10

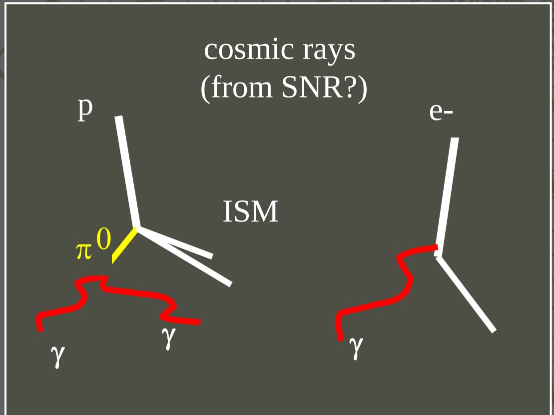
Launch Site
Kennedy Space Center

Features of the gamma-ray sky



- 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, unidentified sources

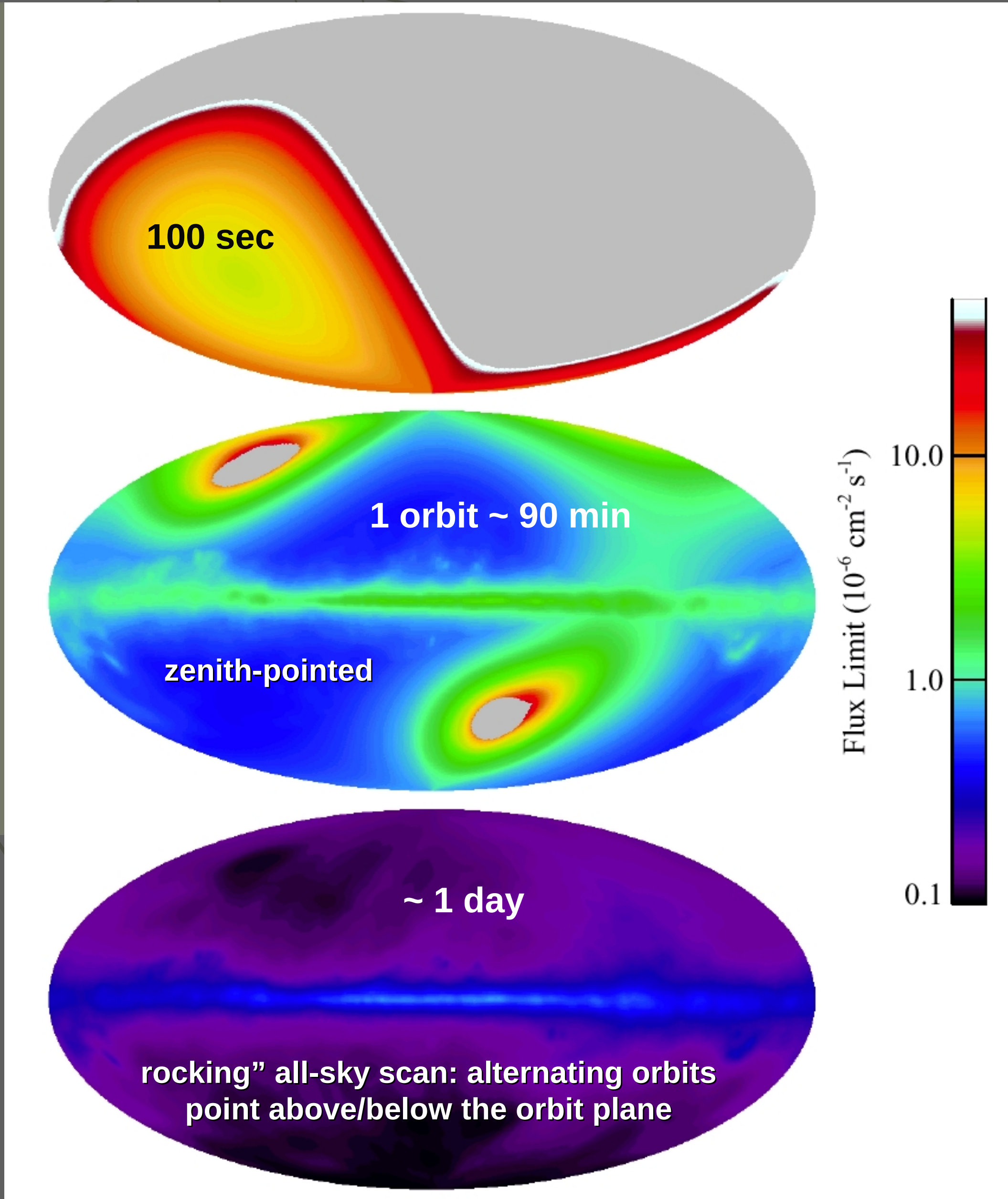
An essential characteristic: VARIABILITY in time!



Field of view, and the ability to repoint, 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.

All Sky Monitoring with Improved Sensitivity



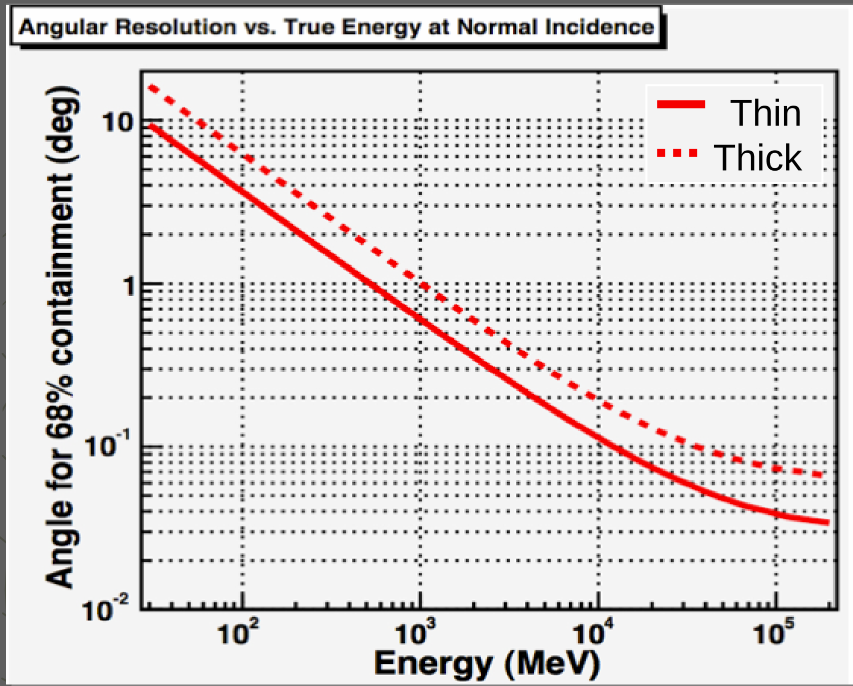
All-sky survey: sensitivity after O(1) day to detect the weakest EGRET sources at (5σ) level !

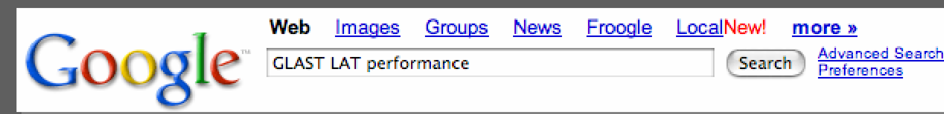
GRB940217 (100sec)
PKS 1622-287 flare
3C279 flare
Vela Pulsar

Crab Pulsar
3EG 2020+40 (SNR γ Cygni?)

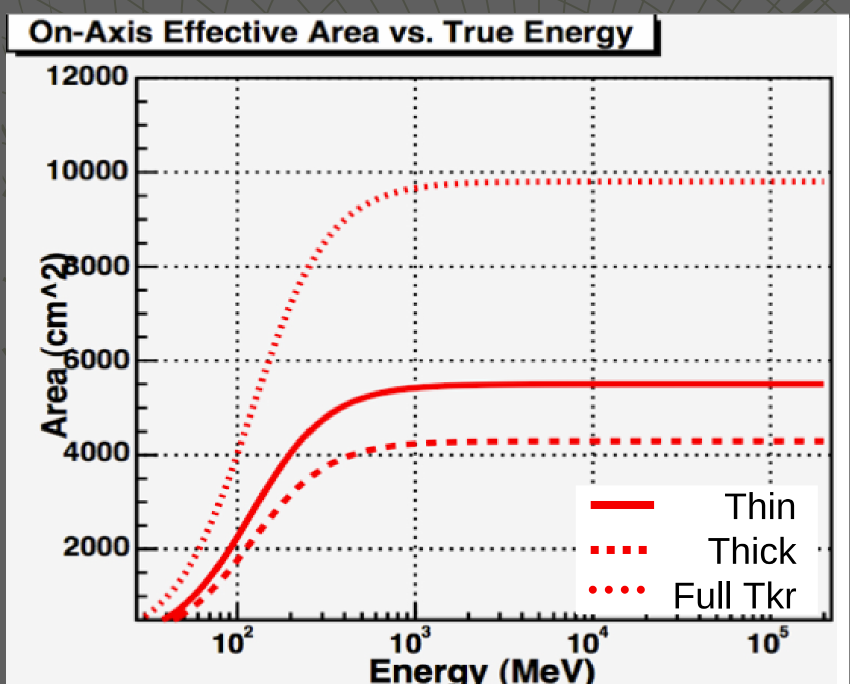
3EG 1835+59
3C279 lowest 5σ detection
3EG 1911-2000 (AGN)
Mrk 421
Weakest 5σ EGRET source

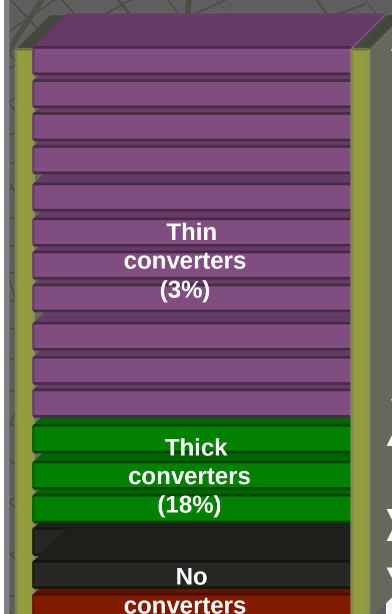
GLAST/LAT performance

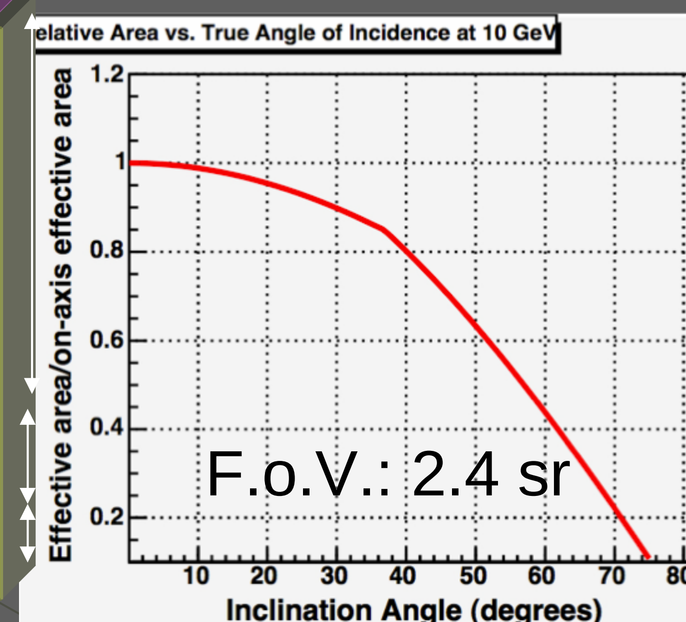




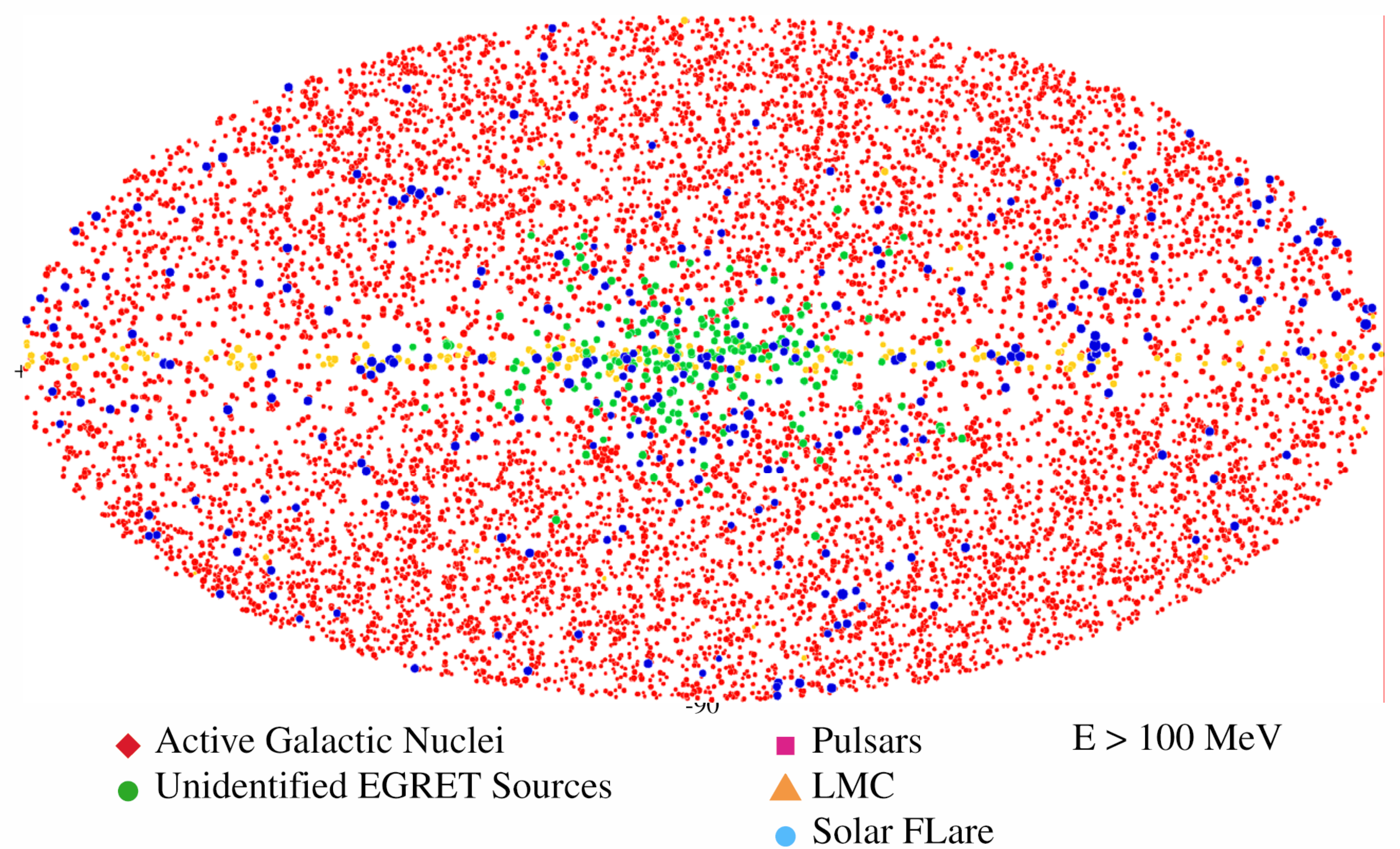
Energy Resolution: ~10% (~5% off-axis)
PSF (68%) at 100 MeV ~ 5°
PSF (68%) at 10 GeV ~ 0.1°
(3 times better than EGRET for E>1 GeV)
Field Of View: 2.4 sr
Point Source sens. (>100 MeV): 3×10^{-9} cm^{-2} s^{-1}
(>30 times better than EGRET)







GLAST Survey: ~10,000 sources (2 years)



Science with GLAST

GLAST is the highest-ranked initiative in its category in the National Academy of Sciences 2000 Decadal Survey Report.

- **High Energy Sky Survey**
  - Unidentified EGRET sources and GLAST Source Catalog
  - Population Studies
  - Diffuse Gamma ray emission
  - New classes of Astrophysical Objects
- **High Energy Outflows**
  - Physics of jets and Particle Acceleration
  - Radiation Processes
  - High energy behaviour of transients
- **Cosmic Ray Acceleration**
  - Gamma ray Emission from hadronic interactions
  - Shock physics
- **Dark Matter, New Physics and Early Universe**
  - Extragalactic Background Light and galaxy formation
  - Searches for Dark Matter and Extra Dimensions
  - Tests of Lorentz Invariance

LAT strengths:

All-sky monitoring

Broad range of time scales

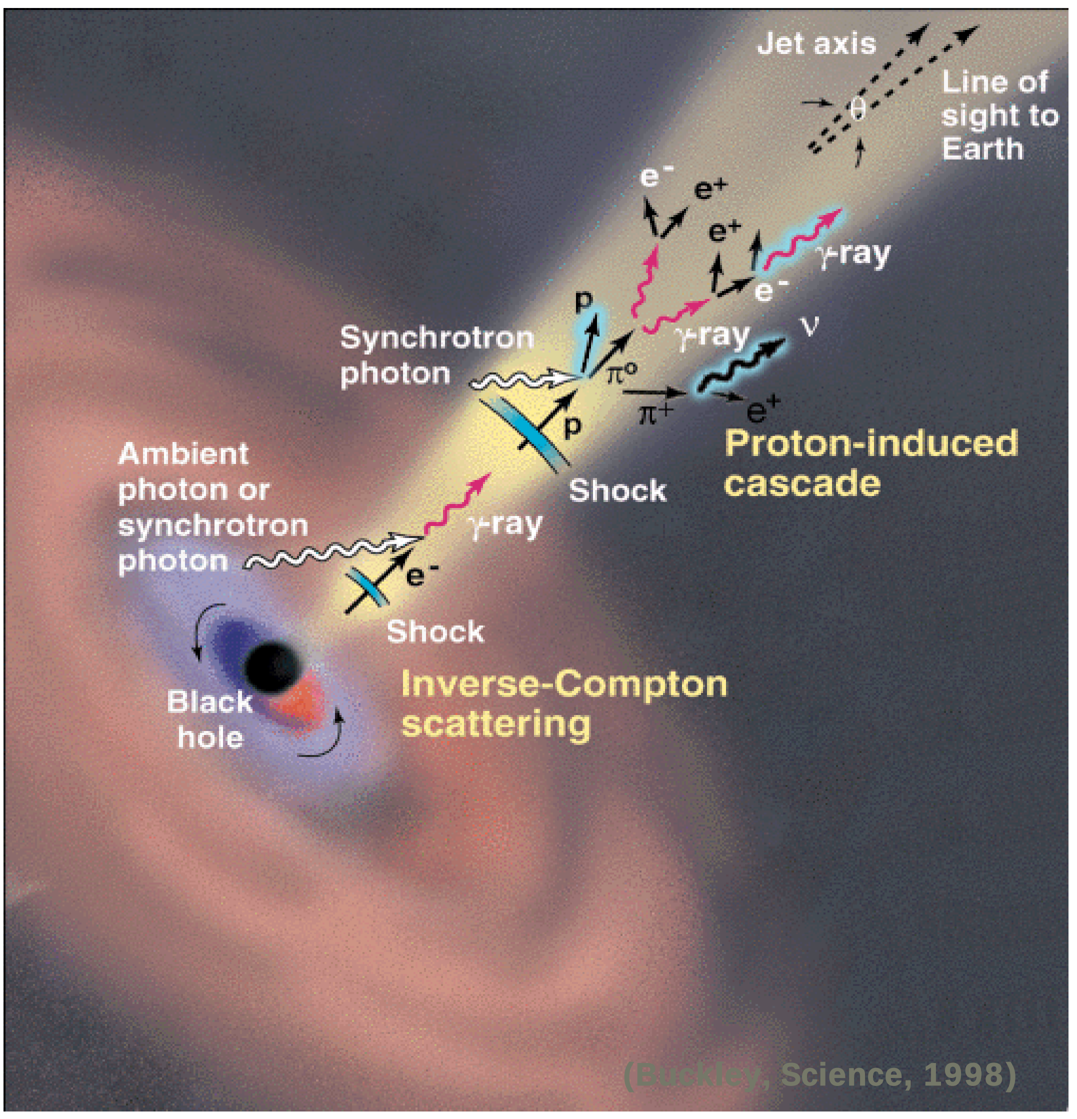
Several decades in energy

Discovery Window

We will cover only selected topics where SLAC is mostly focused

and much more…

AGN (Blazars): Emission Mechanisms



Most of the EGRET AGNs were blazars

- Variability: relativistic jets
- Jets point towards us !

Radiation is produced by one or more of the following processes

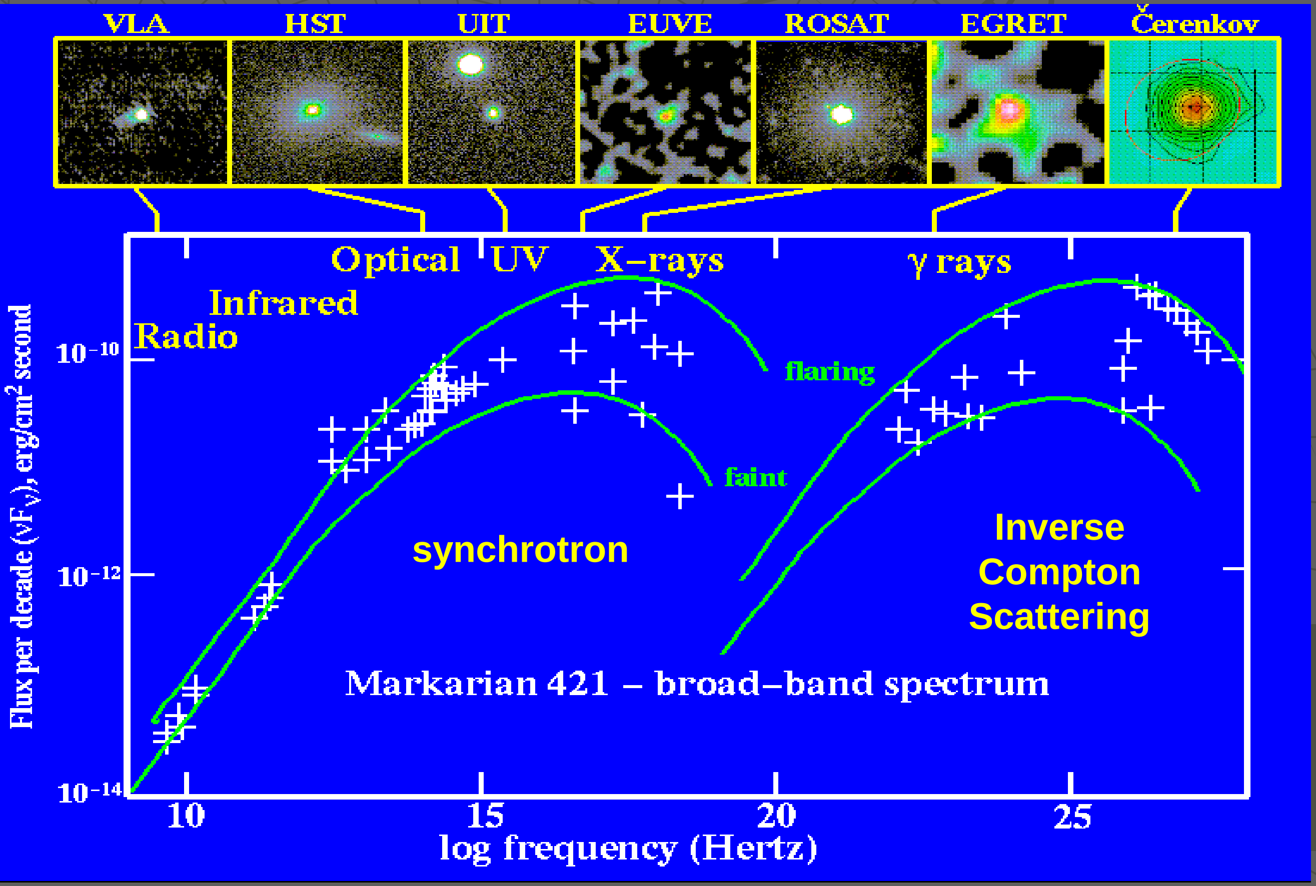
- Synchrotron Self Compton
- External Compton
- Proton Induced Cascades
- Proton Synchrotron

Key issues to be addressed

- Energetics of the source
- jet formation
- jet collimation
- nature of the plasma
- particle acceleration

Multiwavelength Observations

- Contemporaneous observations with other wavelengths
  - disentangle effects from state changes within individual sources
- GLAST will provide "continuous" baseline in GeV
  - helpful to ground based TeV γ–ray telescopes



For more details see G. Madejski's Talk in the Breakout Session

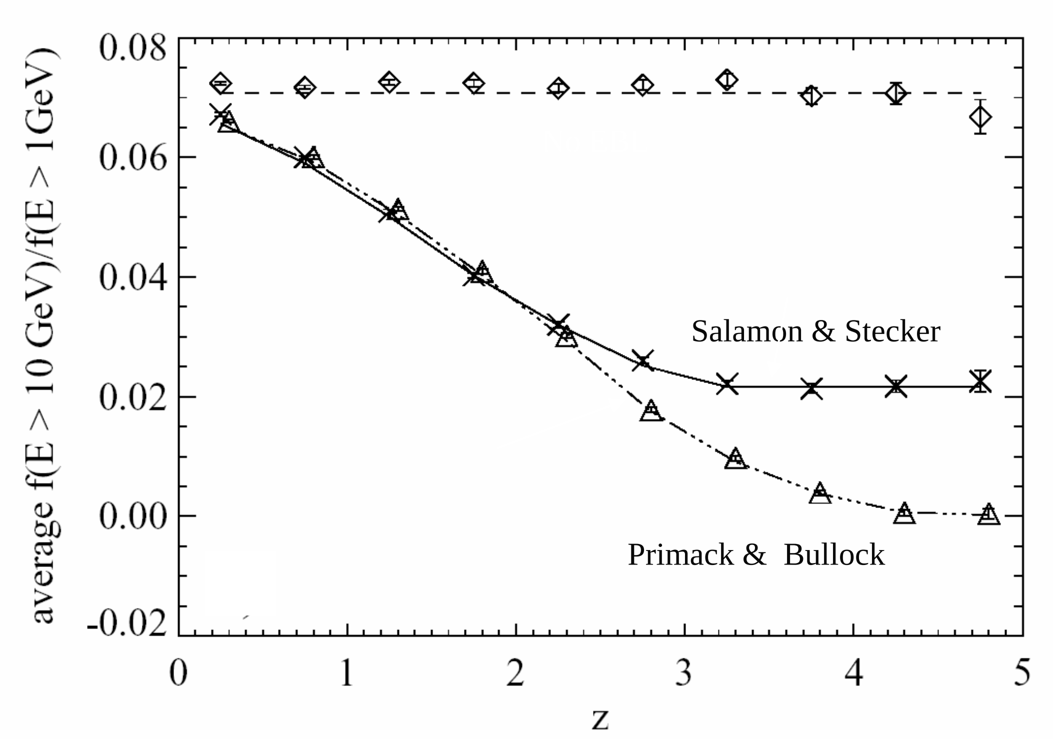
GeV-TeV campaigns will complement GLAST science! Multiwavelength planning in progress: http://glast.gsfc.nasa.gov/science/multi

AGN: Extragalactic Background Light

- High Energy photons (e.g. from AGN) can be absorbed via pair production
  - GeV (TeV) photons interact with intergalactic low energy photons UV(IR)
  - strong dependence on the distance from the source (inferred from redshift)

- GLAST will see thousands of AGN
  - look for systematic effects vs redshift
  - key energy range for cosmological distances

effect is model-dependent (this is good!!):



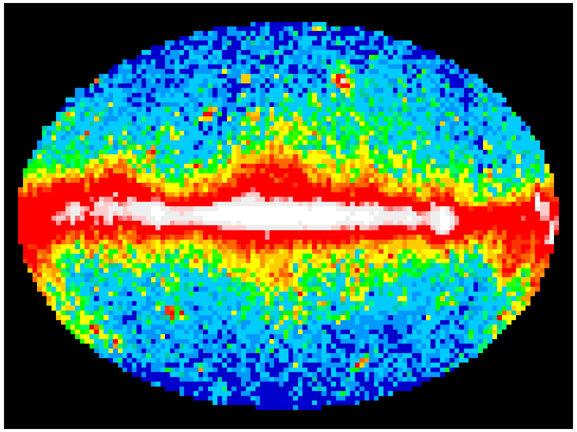
Chen, Reyes, and Ritz, ApJ 2004

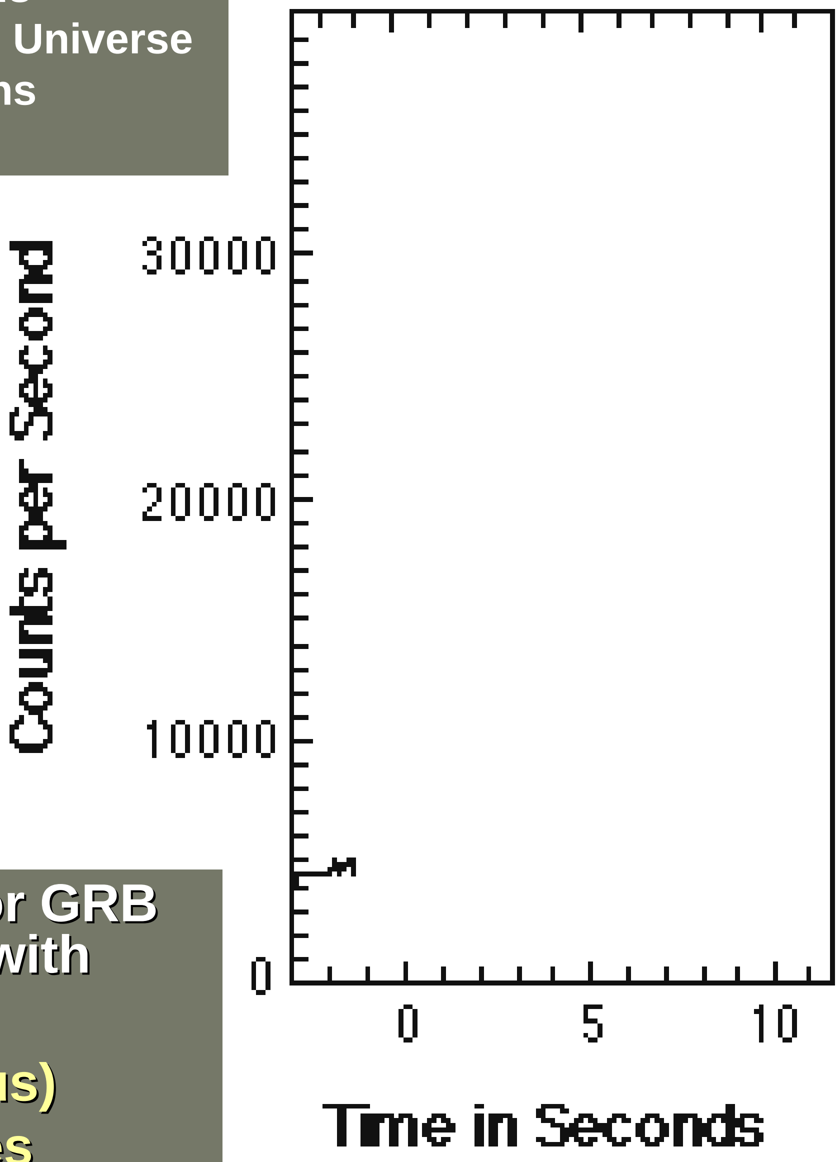
A dominant factor in EBL models is the era of galaxy formation

AGN roll-offs may help distinguish models of galaxy formation

Gamma-Ray Bursts

Last from ms to ~ 100 seconds
Brightest transient phenomena in the Universe
Several per day - no repetitions
Progenitors still not known

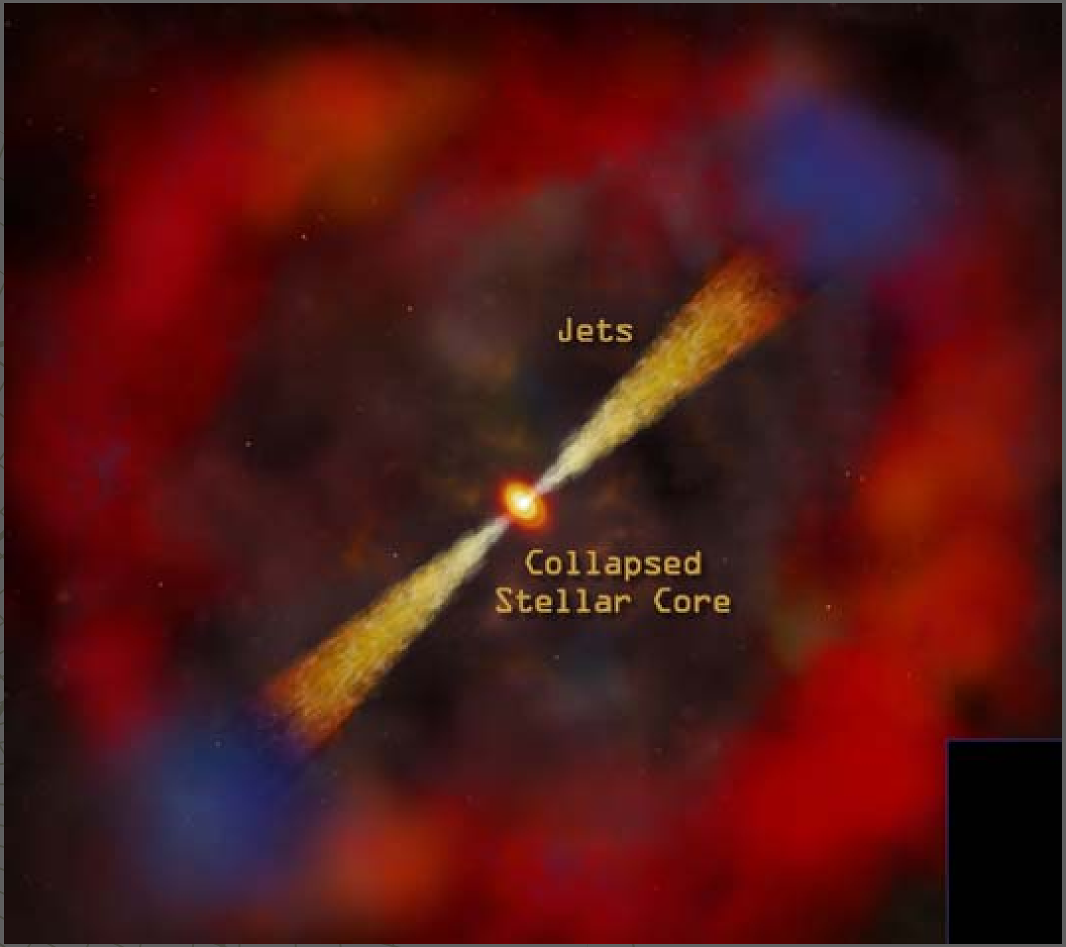




LAT will continuously monitor GRB emissions for E >20 MeV with
wide Field of View
short deadtime (~30 μs)
repointing capabilites

Key Issues: Gamma Ray Bursts

- **GRB Origin**
  - **Triggering mechanism**
  - **Energy source**
  - **Jet production**
- **GRB Evolution**
  - **Particle content of GRB outflow**
  - **Efficiency in energy transport and conversion**
  - **Role of B fields**
  - **Nature of high energy emissions**



GLAST will….

place strong constraints on physical conditions within the source region

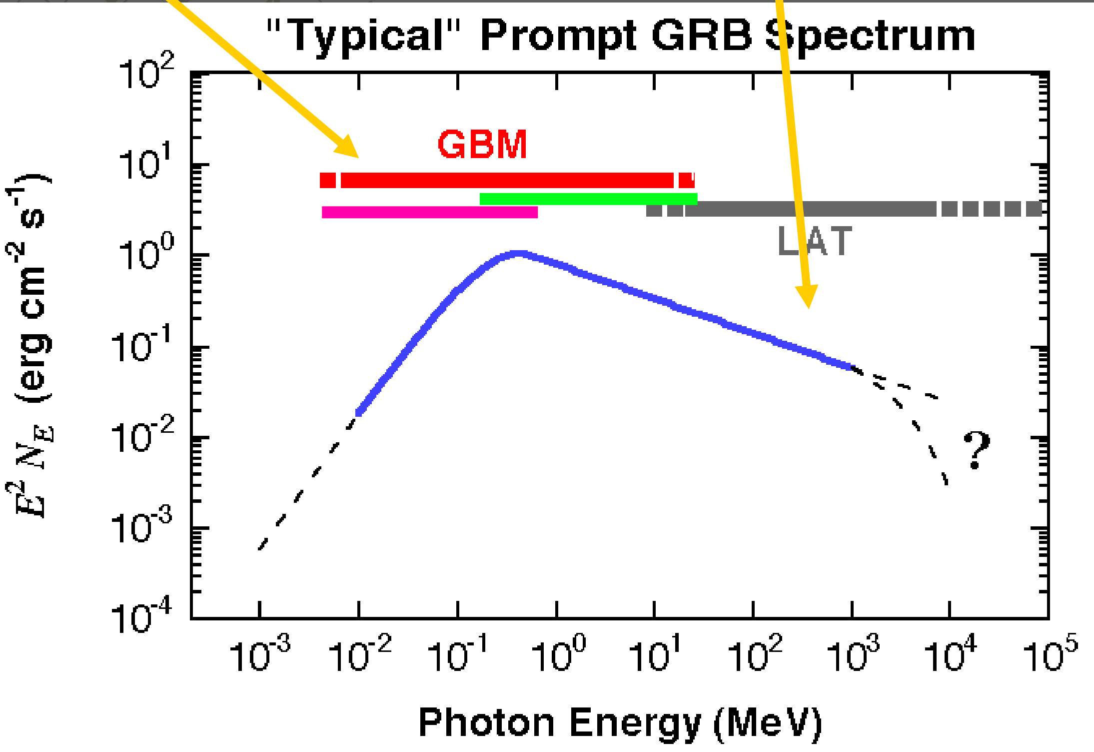
(may include bursts from the first generation of stars)

Gamma Ray Bursts: GBM and LAT

- GBM
  - Huge field of view (8sr)
  - Measure spectra for bursts from 10 keV to 25 MeV
- LAT
  - Wide field of view (>2sr)
  - Extends spectral coverage to higher energies

GLAST

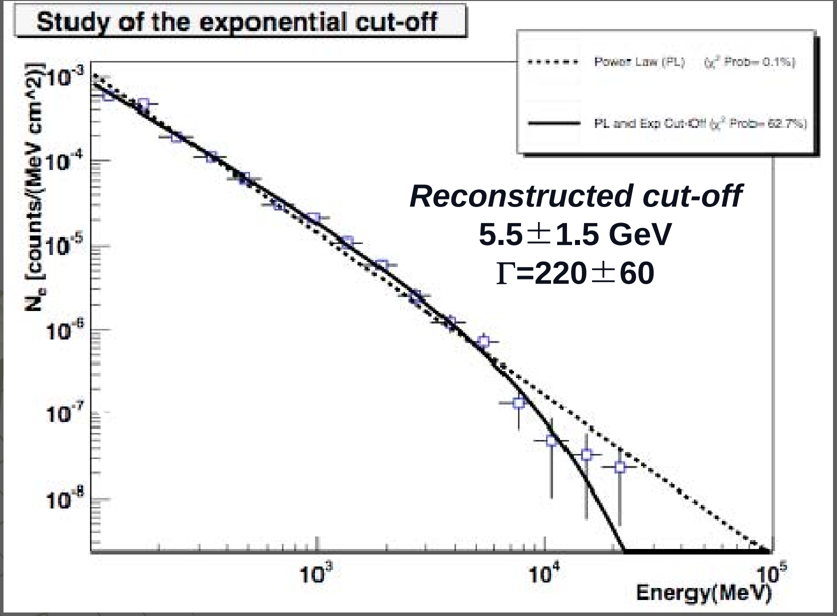
Can be re-pointed to catch exceptionally bright bursts that occur outside the LAT field of view



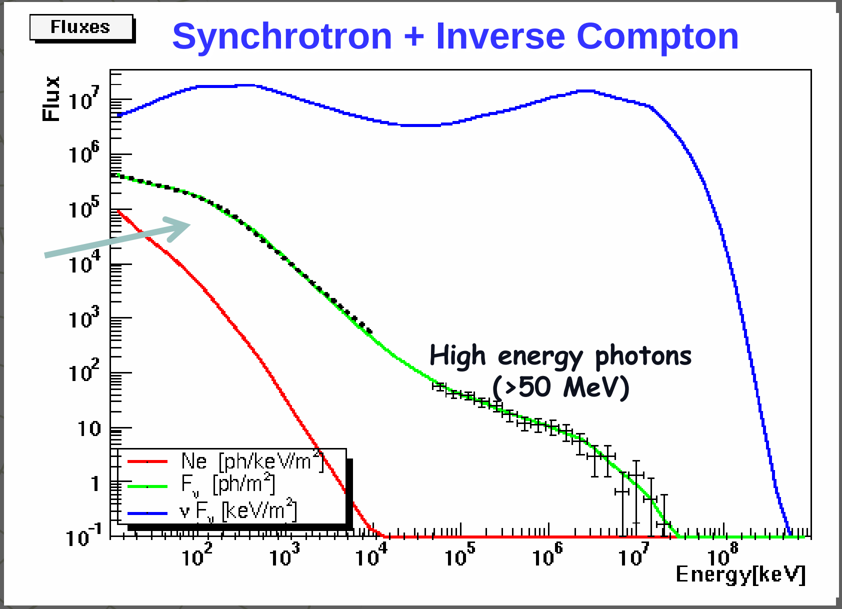
GLAST all-sky monitoring will be follow transient phenomena to a wide range of time scales
from ~ 30 μs (GRB, solar flares) to hours or longer (AGN)

High Energy Emission in Gamma Ray Bursts

- High Energy Spectral cut-off
  - Lower Limit on the relativistic boost of the outflow
    - bulk Lorentz Factor of the expanding shells
  - Cosmological cut-off:
    - EBL absorption

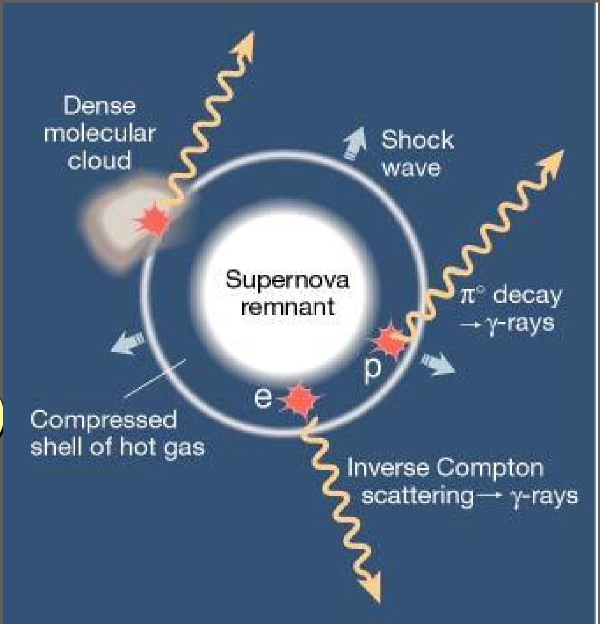


- high energy component of the gamma ray flux
  - multiple emission processes
  - Important for understanding the Energy reservoir of the source

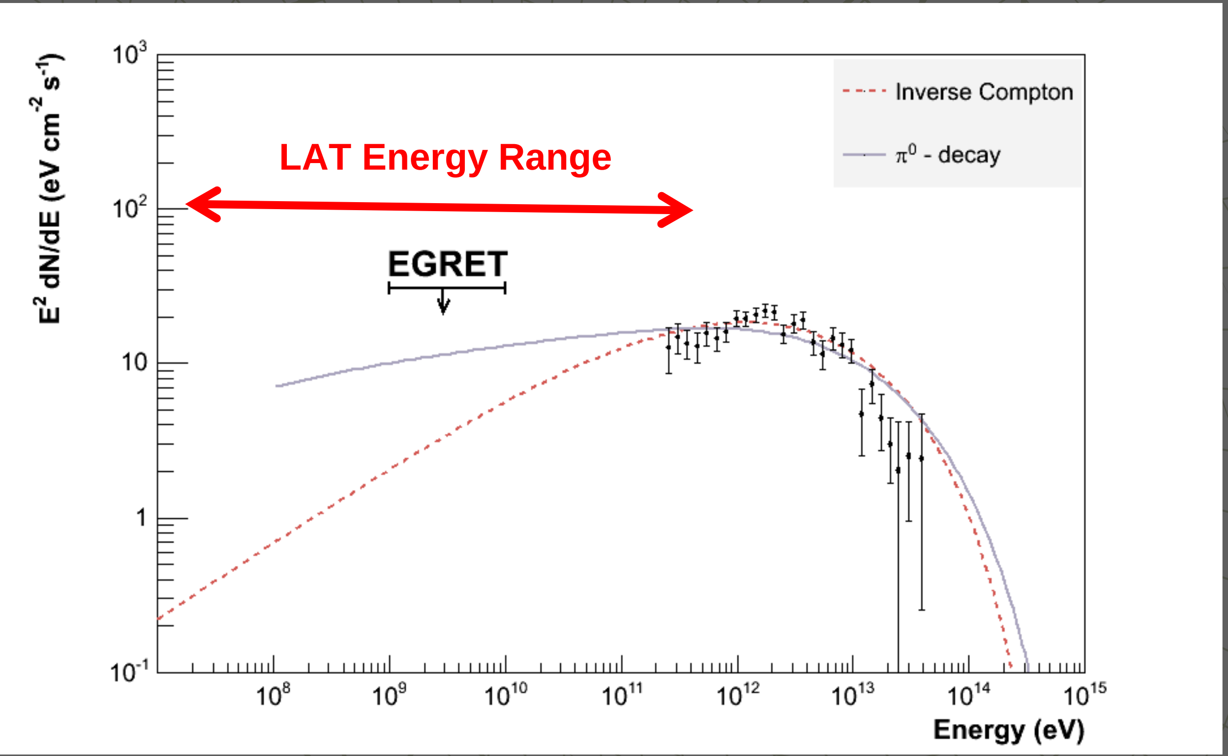


SNR: Sites of Hadronic Acceleration?

- Supernova Remnants:
  - by-products of Supernova explosions
  - expected sites of galactic cosmic ray acceleration
  - non-thermal emission (X-rays and γ-rays)
- Measurements in the range of 100MeV-100GeV
  - essential ingredient to resolve the origin (*p* vs *e+/-*)



Adapted from Aharonian's talk at the Texas Symposium 2004



Question:

Do γ rays originate from hadronic or leptonic processes?

For more details see H. Tajima's Talk in the Breakout Session

How Can we solve the Dark Matter Problem?

See E. Baltz's Talk in the Plenary Session

- Key interplay of techniques
  - 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 is highly model-dependent
  - Challenge is to separate signals from astrophysical backgrounds

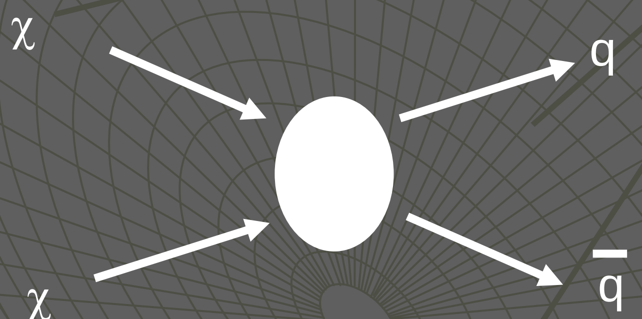
Dark Matter Candidate: Neutralino

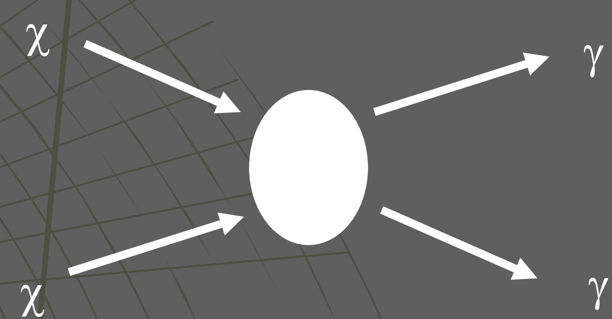
If true, there may well be observable halo annihilations

$$\chi_1^0 = a_{11}\tilde{B} + a_{12}\tilde{W}^3 + a_{13}\tilde{H}_1^0 + a_{14}\tilde{H}_2^0$$

For more details see L. Wai's Talk in the Breakout Session

- **Good particle physics candidate for galactic halo dark matter**





continuum energy spectrum
Higher statistics…
but higher background
knowledge of galactic diffuse background is critical

Distinct signature
a "peak" in the energy spectrum !!
Lower background…
but lower statistics too

GLAST LAT Collaboration

- **France**
  - IN2P3, CEA/Saclay
- **Italy**
  - INFN, ASI
- **Japan**
  - Hiroshima University
  - ISAS, RIKEN
- **United States**
  - California State University at Sonoma
  - 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
  - Stanford University (SLAC and HEPL/Physics)
  - University of Washington
  - Washington University, St. Louis
- **Sweden**
  - Royal Institute of Technology (KTH)
  - Stockholm University

Principal Investigator:
Peter Michelson (Stanford & SLAC)

~225 Members
(includes ~80 Affiliated Scientists, 23 Postdocs, and 32 Graduate Students)

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

Managed at Stanford Linear Accelerator Center (SLAC).

Large Area Telescope: Overview

Principal Investigator: Peter Michelson

The LAT is a pair-conversion telescope of 16 towers surrounded by plastic scintillators

Silicon Microstrip Tracker

~ 80 m^2 of silicon

8.8×10^5 readout channels

Strip pitch = 228 μm

xy layers interleaved with W converters

~1.5 X^0

Calorimeter

Hodoscopic array

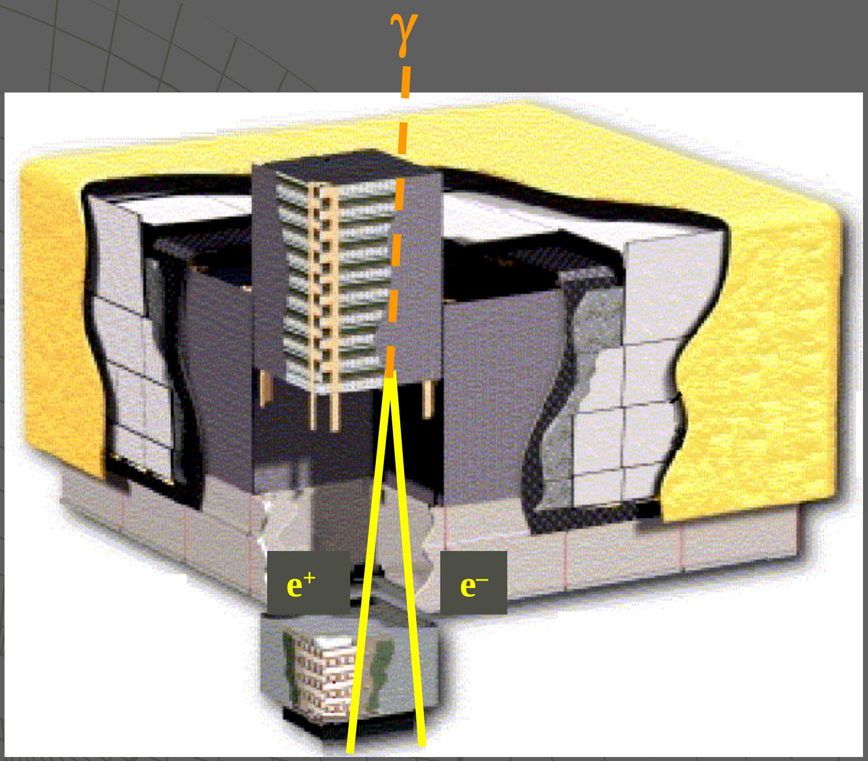
Array of 1536 CsI(Tl) crystals in 8 layers

~8.5 X^0

Anti-Coincidence Detector

89 scintillator tiles

Segmented design



LAT

3000 kg, 650 W (allocation)

1.8 m × 1.8 m × 1.0 m

20 MeV – 300 GeV

Silicon Microstrip Tracker

Measures γ direction

γ identification

Calorimeter

Measures γ energy

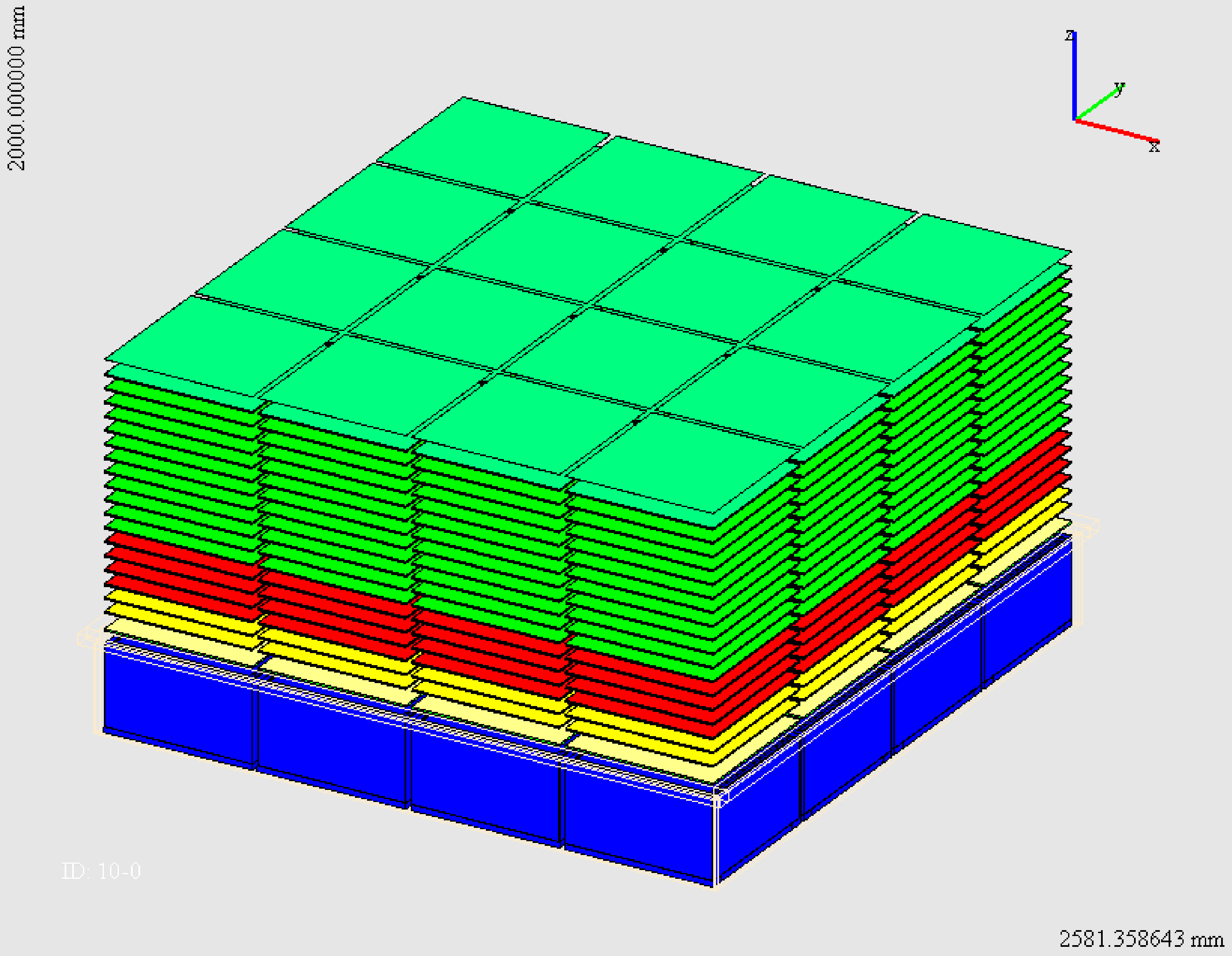
Shower imaging

Anti-Coincidence Detector

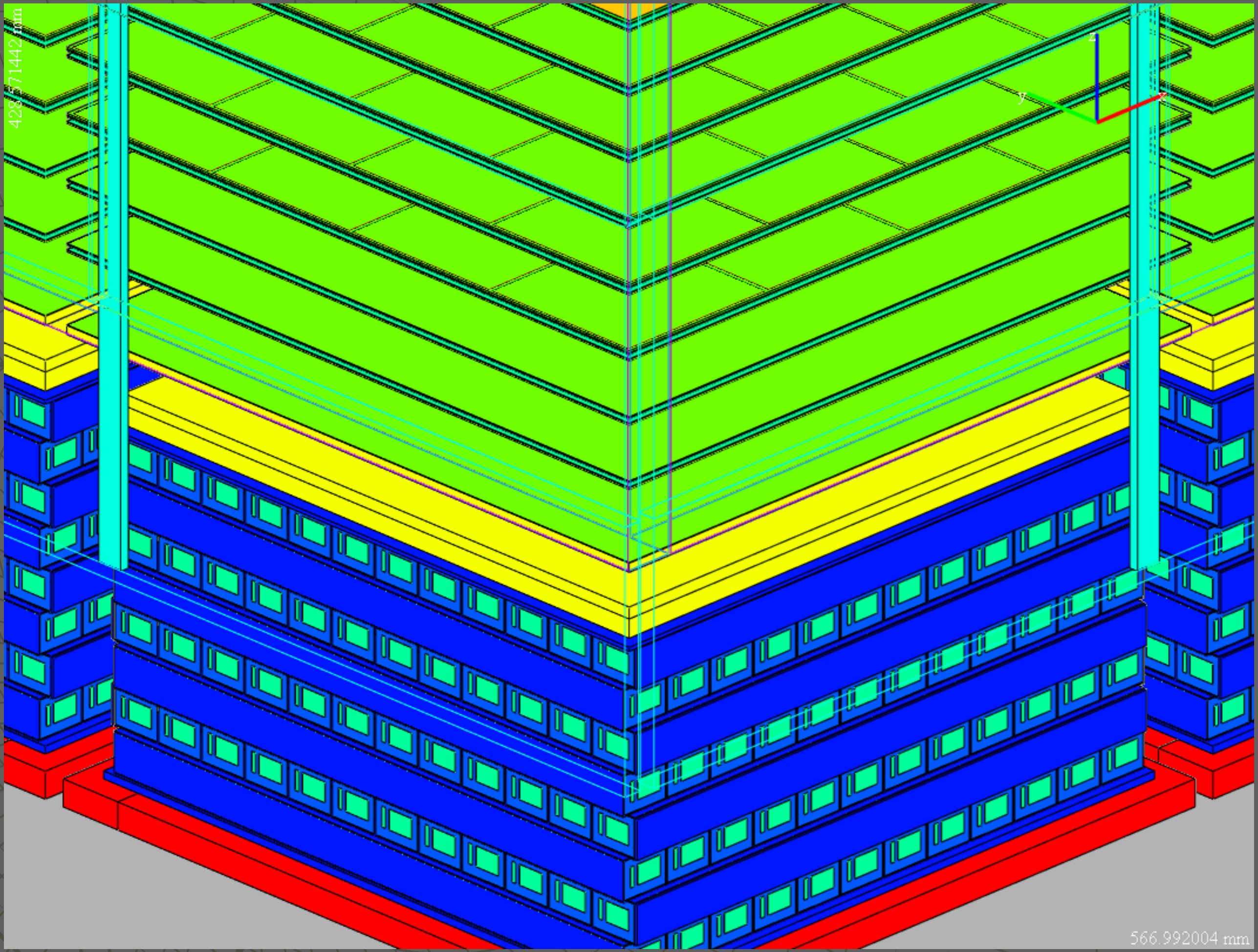
Rejects background of charged cosmic rays

segmentation removes self-veto effects at high energy

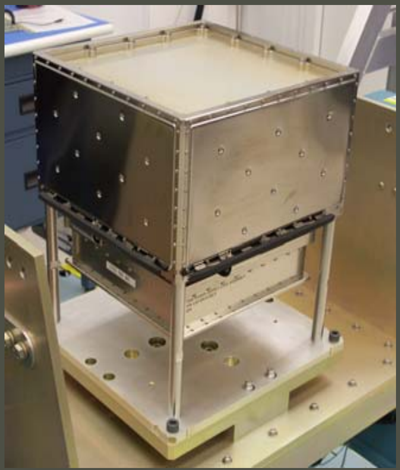
LAT Detector Elements



LAT Detector Elements

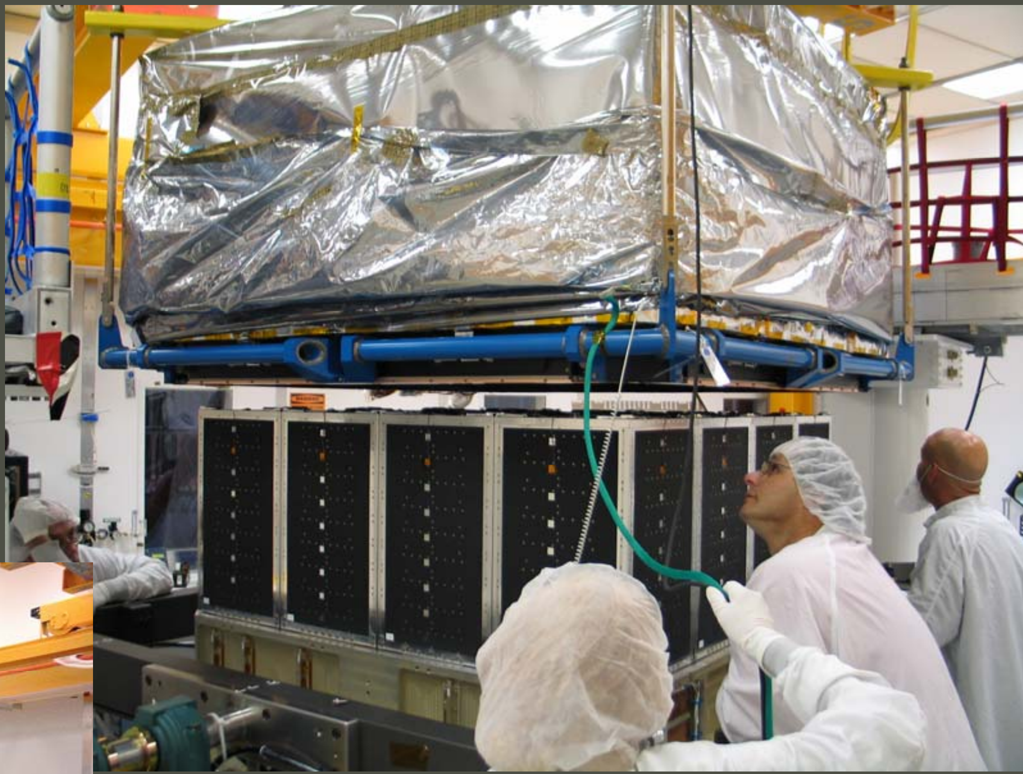


LAT Integration @ SLAC



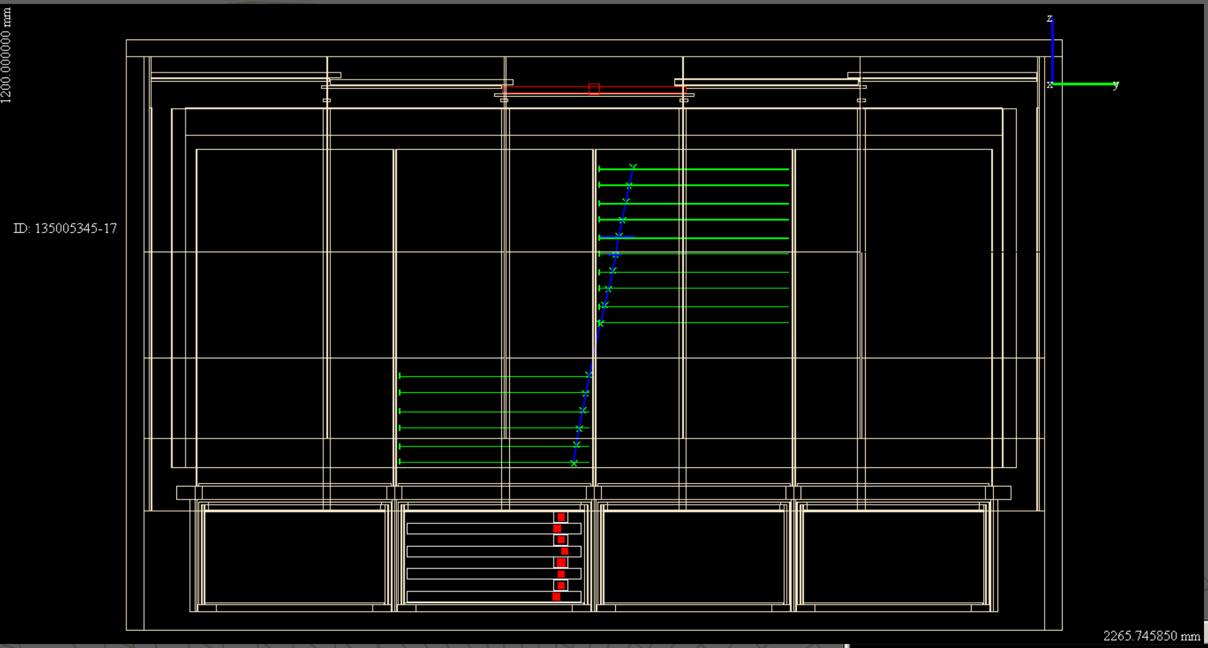
Calorimeter module

Tracker module



Anti Coincidence Detector being integrated with 16 towers

LAT Data from Tests at SLAC

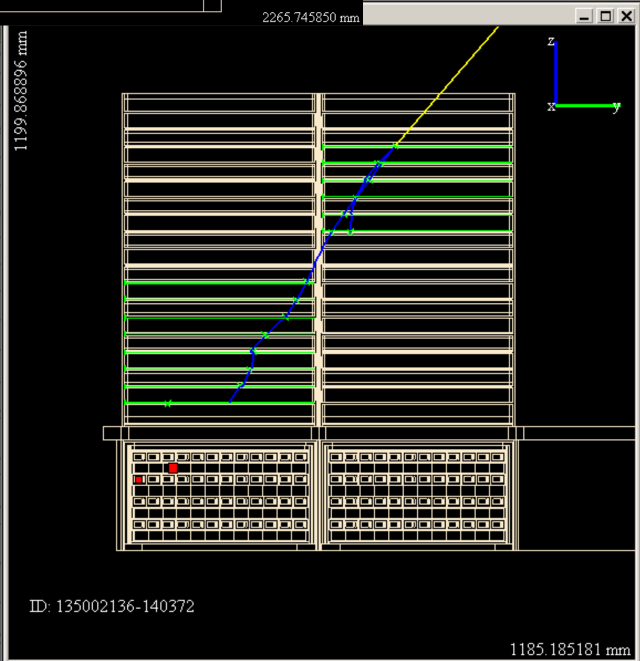


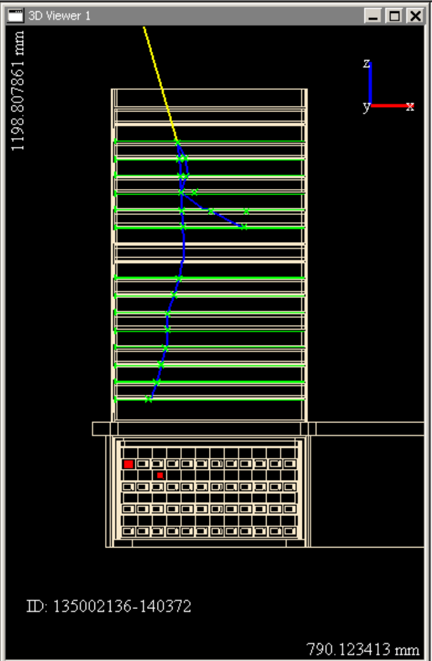
Muon candidates

Most of the 500 Hz of triggers recorded are muons

Photon Candidates

~20% of cosmic ray showers are not muons





GLAST/LAT Current Activities

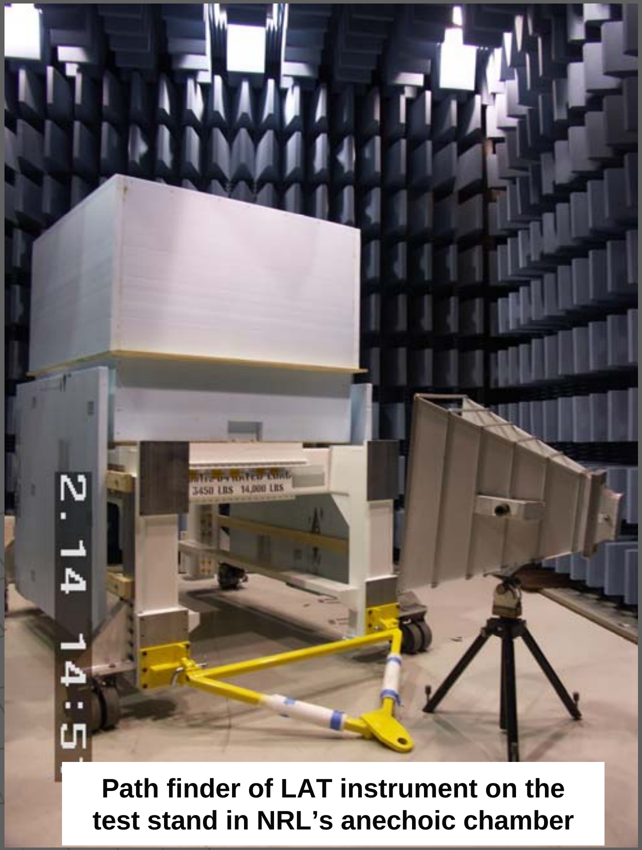
- **LAT Pre-launch Integration and Test**
  - **LAT was delivered from SLAC to Naval Research Laboratory (NRL)**
    - **May 2006**
  - **Environmental Tests @ NRL**
    - **May – Sep 2006**
  - **Spacecraft Integration @ SpectrumAstro**
    - **Sep 2006 – Sep 2007**
  - **Launch @ Kennedy Space Center (KSC)**
    - **Sep 2007**

- **Main activities with SLAC involvement**
  - **Support pre-launch integration tests**
    - **NRL, SpectrumAstro, KSC**
  - **Co-coordination of beam test at CERN**
    - **Aug –Sep 2006**
  - **Development of the Instrument Science Operation Center**
  - **Preparations for GLAST Science**

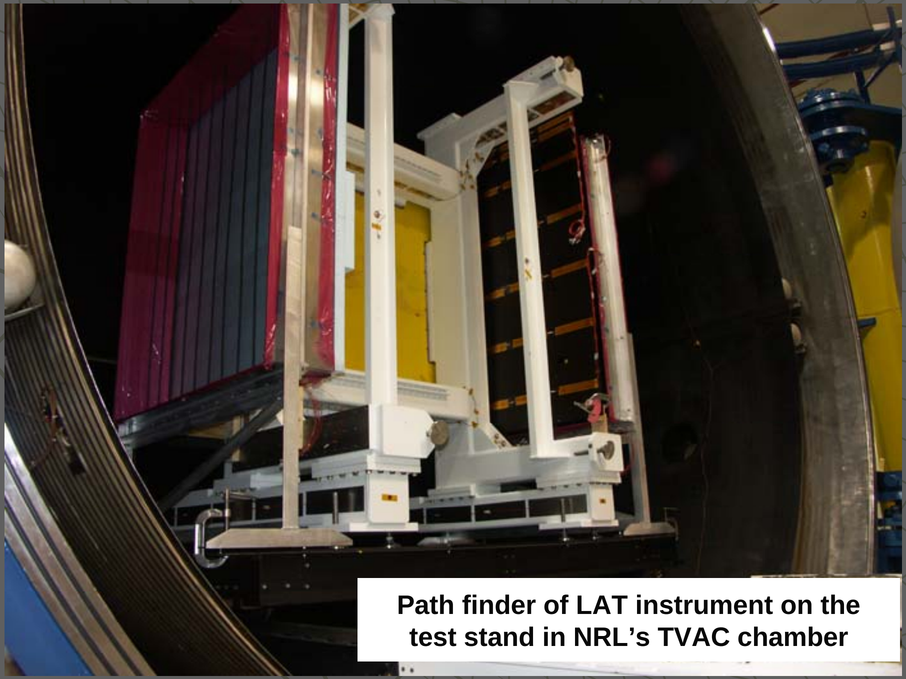
LAT delivery May 2006
(major accomplished of this year)

Environmental Tests @ NRL

- Test Series
  - Sine Vibration
    - mount radiators after test
  - EMI/EMC Emissions/ Susceptibility
  - Acoustic
  - Thermal Vacuum
    - remove radiators after test
  - Weight CG
    - pack and ship to SpectrumAstro after test



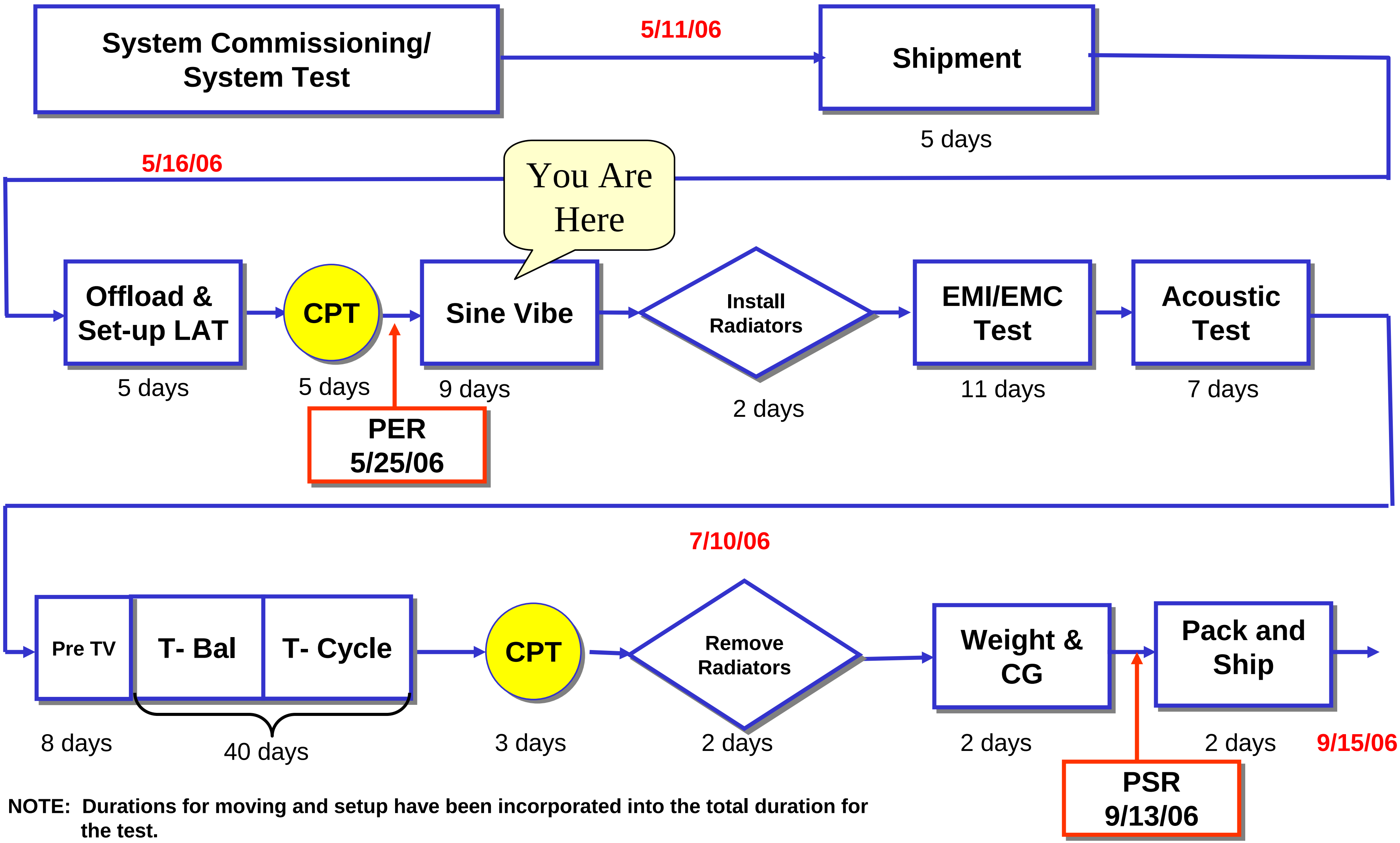
Path finder of LAT instrument on the test stand in NRL's anechoic chamber



Path finder of LAT instrument on the test stand in NRL's TVAC chamber

Environment in space requires extensive tests of telescopes

LAT Test Flow



NOTE: Durations for moving and setup have been incorporated into the total duration for the test.

GLAST/LAT Beam Test @ CERN (1)

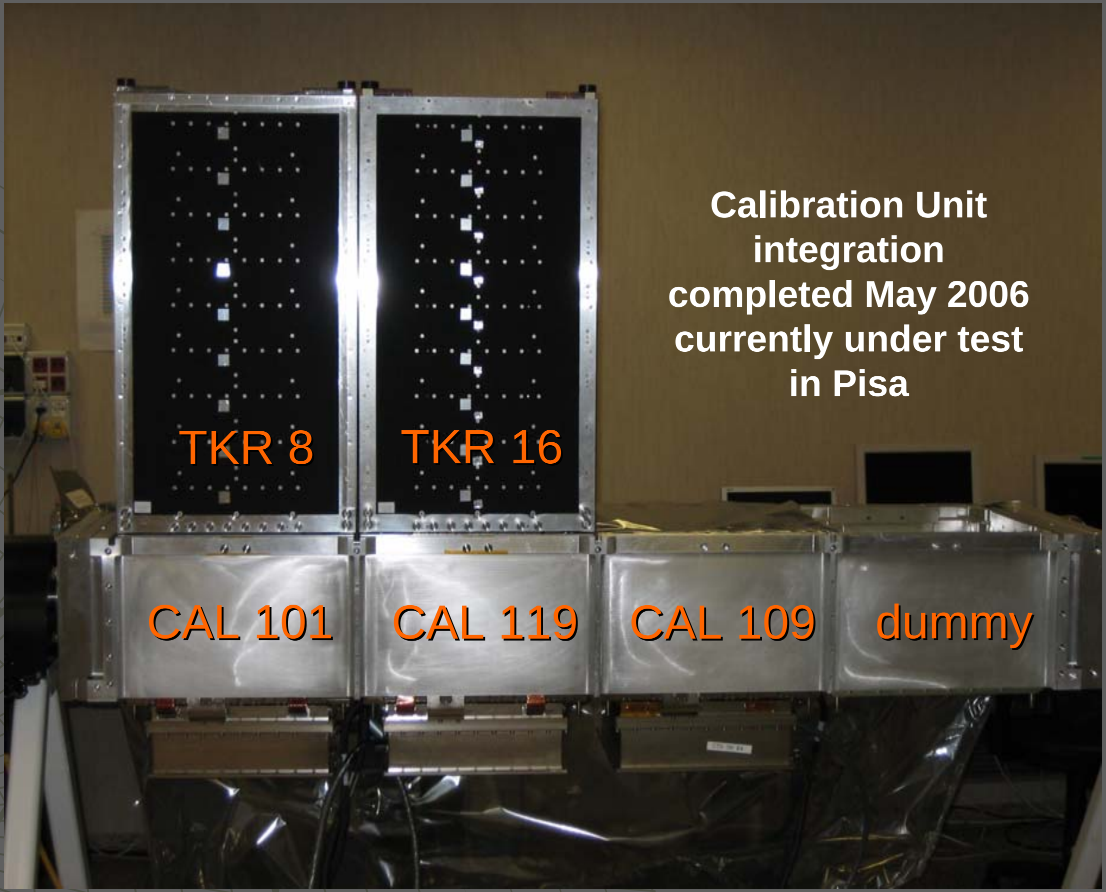
- Science performance verification strategy
  - LAT performance phase space is huge
    - MC simulation used to verify requirements by analysis
    - Beam test used to tune and check the simulation and aspects of the reconstruction.
      - Essential component of our overall strategy
      - Previous beam tests 1997, 1999/2000

- Objectives
  - Characterize performance at high energies
    - corrections for leakage, inter-tower gaps, and backsplash (SSD in TKR and ACD).
    - trigger performance (e.g., CAL-HI), comes “free” with same data
  - Verify MC simulations of detector’s response
    - electromagnetic showers (gamma, electron)
    - Point Spread Function and Energy reconstruction methods.
    - Compare distributions of quantities related to those used in background rejection with hadron beams.

Primary purpose is to constrain systematic uncertainties in science analysis

GLAST/LAT Beam Test @ CERN (2)

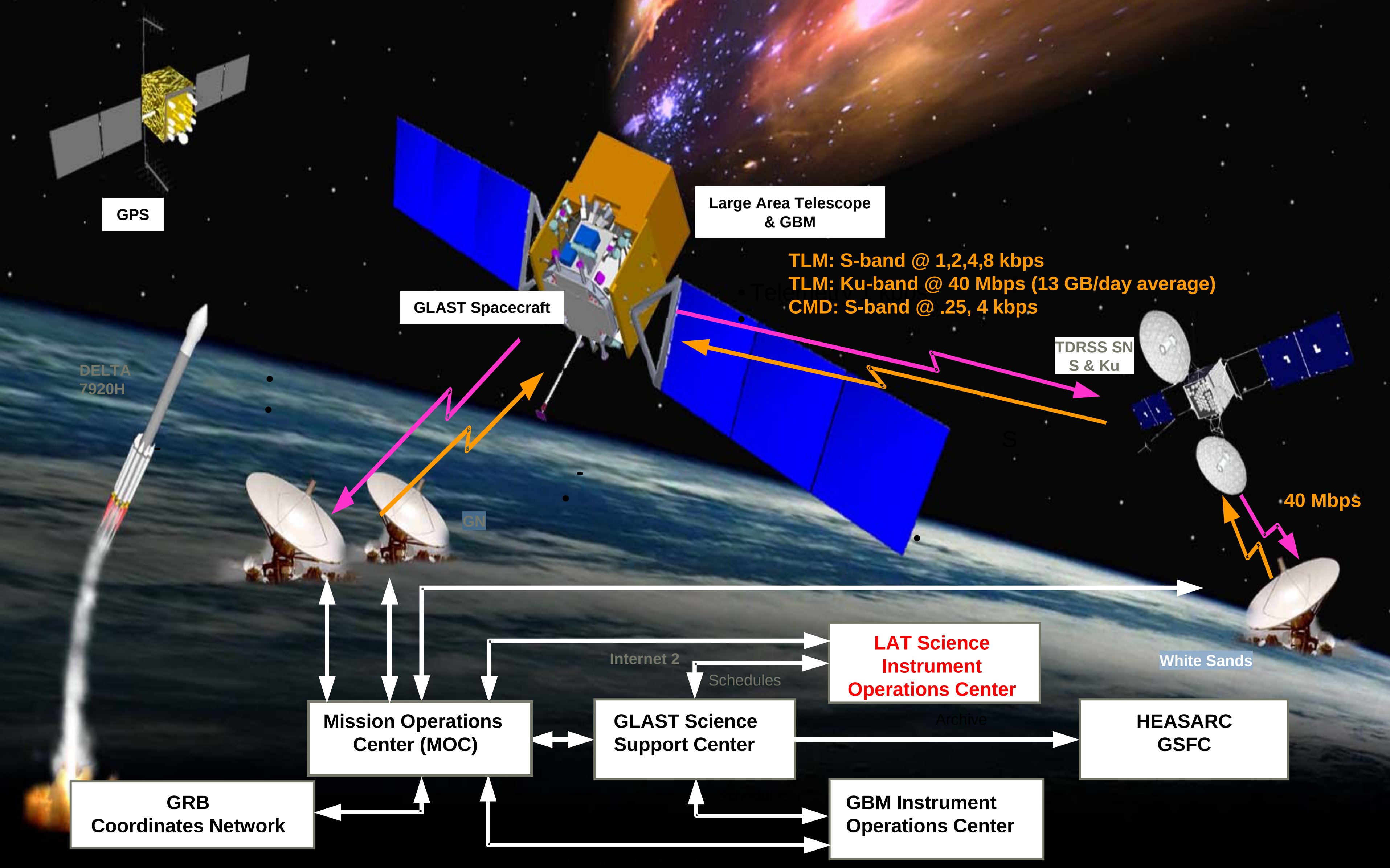
- Date
  - Aug-Sep 2006
- Experimental Beams
  - PS (< 10 GeV)
    - Tagged γ
    - p, e+, e-
  - SPS (100's of GeV)
    - γ
    - p, e-



- Spokespersons @ CERN
  - R. Bellazinni (INFN/Pisa – Italy)
  - B. Lott (CENBG – France)
- Coordinators
  - L. Latronico (INFN/Pisa – Italy)
  - B. Lott (CENBG – France)
  - E. do Couto e Silva (SLAC – USA)

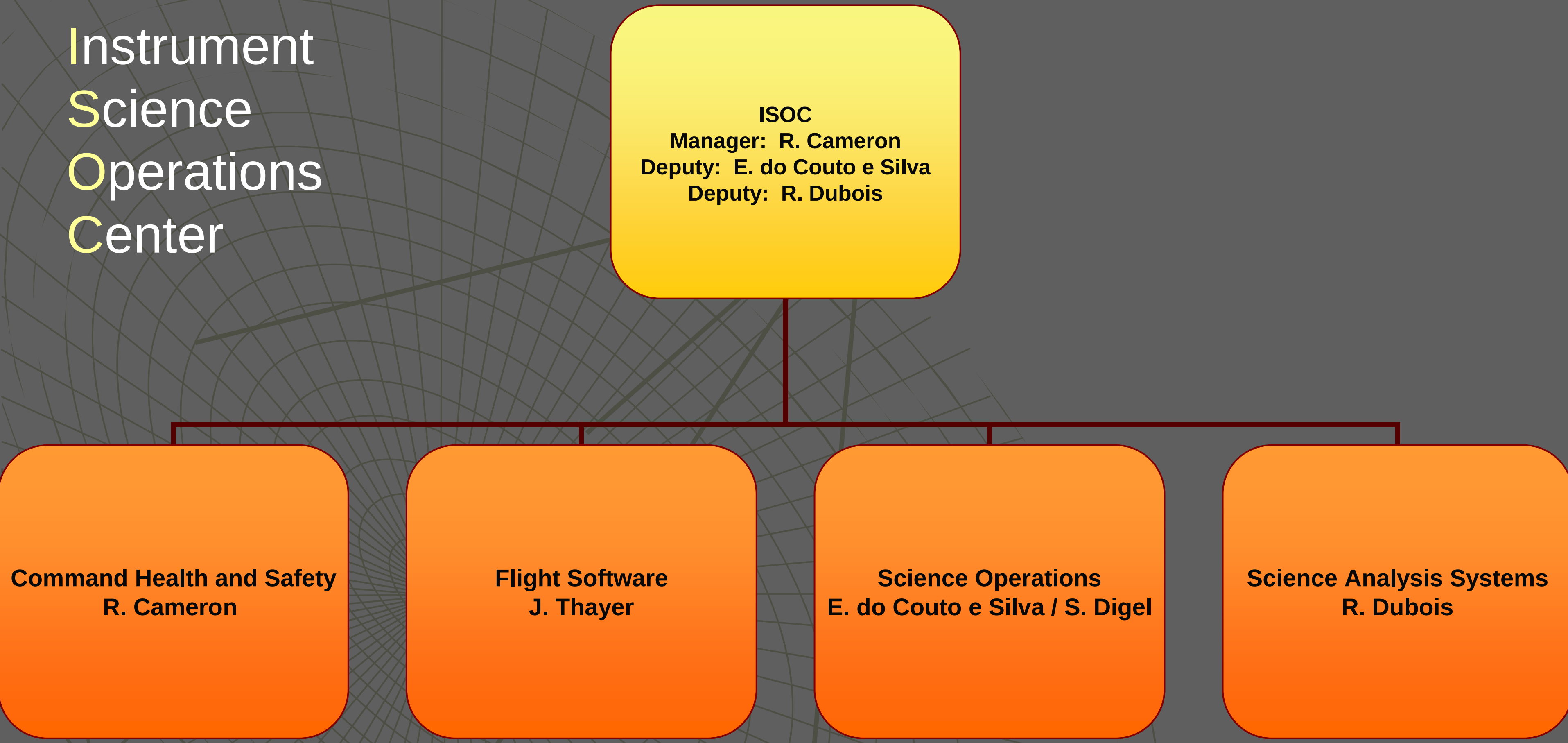
- SLAC involvement
  - coordination and planning
  - Data Acquisition
  - Online support
  - Offline infrastructure
  - Data analysis

GLAST MISSION ELEMENTS



GLAST/LAT ISOC Organization

Instrument
Science
Operations
Center

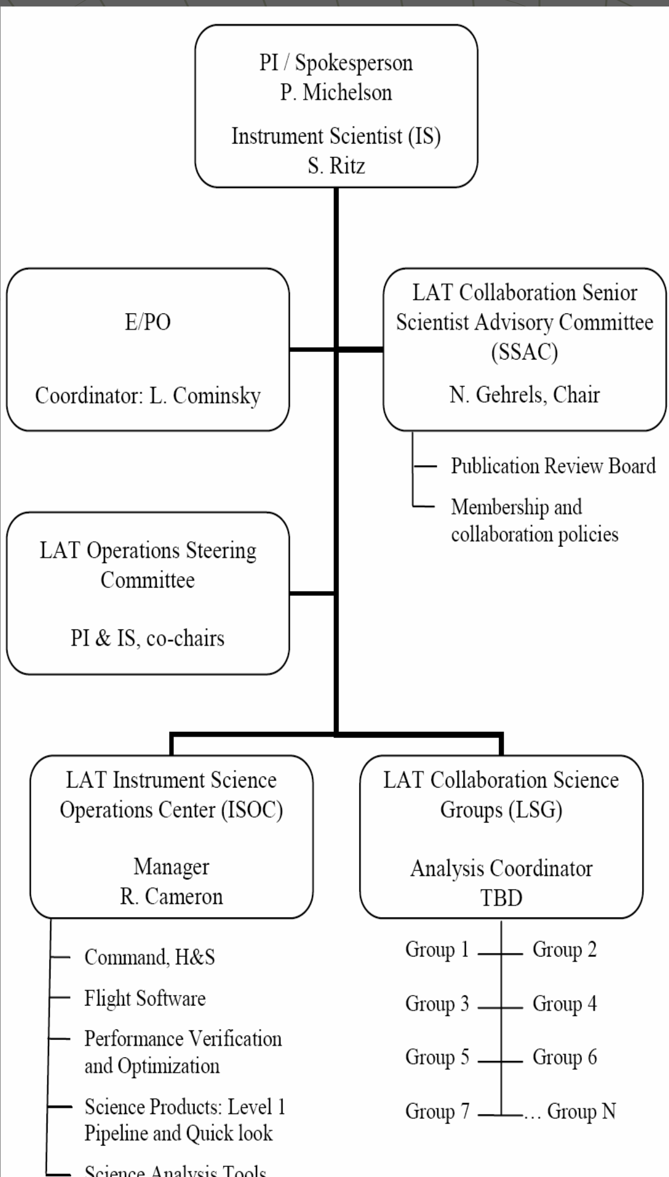


For more details see R. Cameron's Talk in the Breakout Session

GLAST/LAT Operation Phases

- First year of science operations
  - initial on-orbit checkout, verification, and calibrations, followed by an all-sky survey
    - detailed instrument characterization
    - refinement of the alignment
  - key projects needed by the community
    - source catalog, diffuse background models, etc.
  - Transients
    - data on transients will be released, with caveats.
    - repoints for bright bursts and burst alerts enabled.
- Baseline observing mode is sky survey
  - guest observer proposals selected by peer reviews, may request pointed observations in subsequent years
- After first year all data will be publicly released through the GLAST Science Support Center (GSSC) at GSFC.

LAT Operations and Science



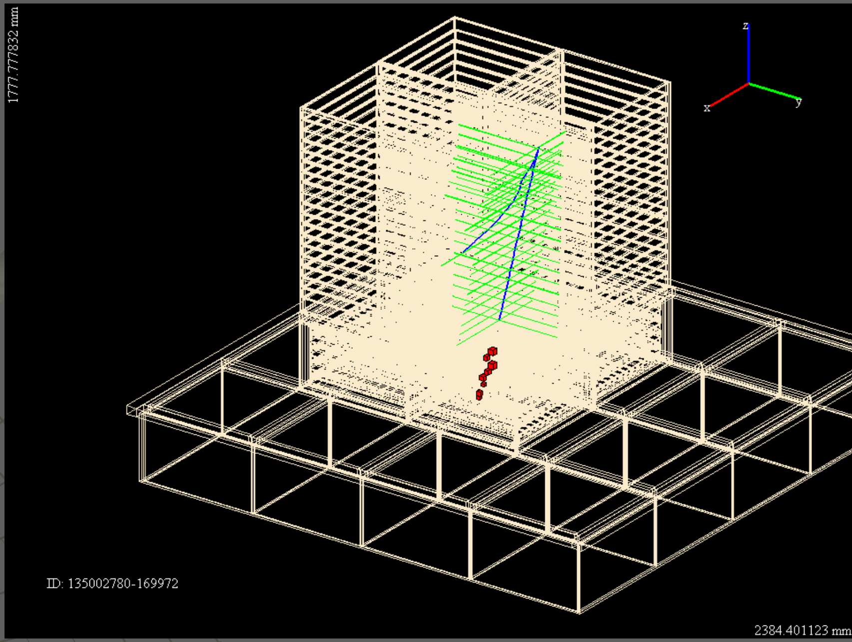
- **ISOC Highlights**
  - **Optimize Scientific return of the LAT instrument**
    - ensure health and safety
    - Monitor and optimize instrument performance
    - monitor background rates and celestial sources
    - develop data processing/analysis framework
  - **Strong connection with the LAT collaboration**
    - Heritage from Instrument Analysis Workshops and Data Challenges (see next slides)
  - **Provide data to LAT collaboration**
    - during first year of mission, and beyond

SLAC co-coordinates 3 GLAST science groups

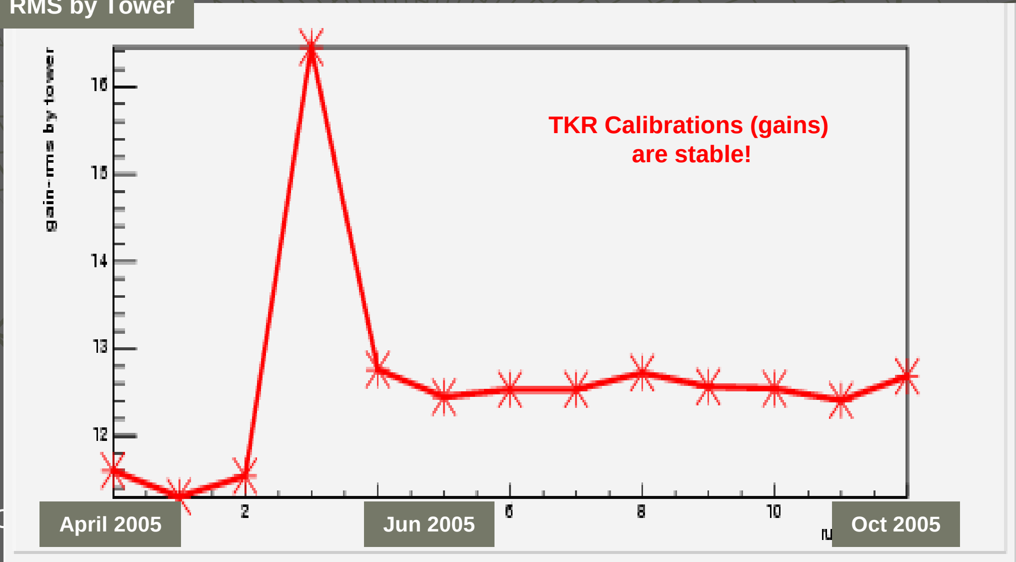
- **GLAST Catalog**
  - S. Digel (SLAC) and I. Grennier (CEA)
- **Diffuse (Galactic & Extragalactic) and Molecular Clouds**
  - S. Digel (SLAC) and I. Grennier (CEA)
- **Dark Matter and New Physics**
  - E. Bloom (SLAC) and A. Morselli (INFN/Rome)

Instrument Analysis Workshops

- Exercise reconstruction algorithms and data analysis tools
  - Use simulated and real data
- Uncover and quantify instrumental effects
  - Could potentially affect science data
- Create a core and trained group
  - to participate in the analysis of the beam test data
  - to lay foundations of the LAT Science Operations Group of the ISOC



RMS by Tower



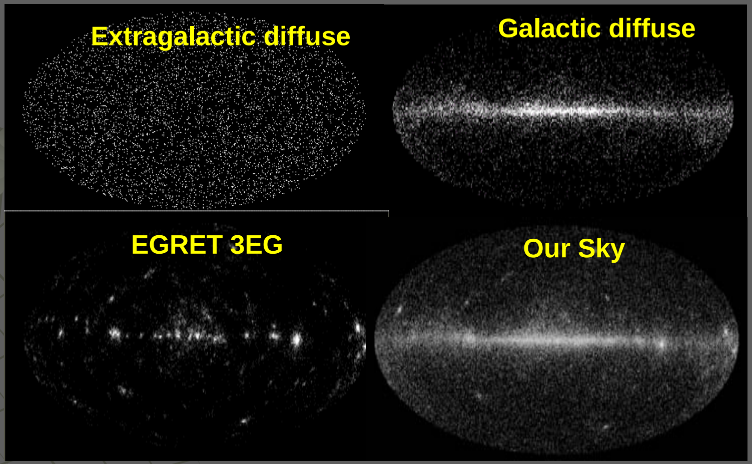
6 Workshops at SLAC
from Jun/2004 to Feb/2006

Data Challenges

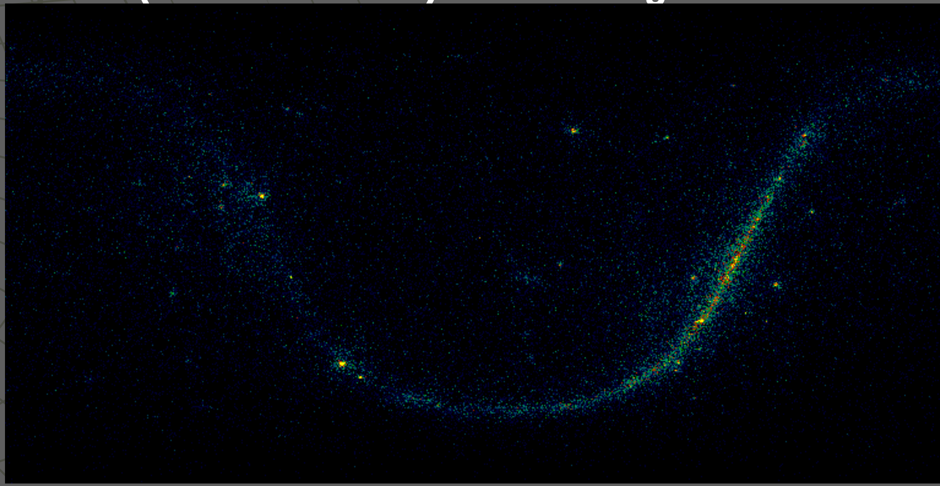
For more details see R. Dubois's Talk in the Breakout Session

- Data Challenges
  - Original idea
    - Mark2 HEP experiment at SLAC
  - Test the data analysis system
    - HEP software and Astro FTOOLS
  - "Blind " Analysis
    - Details of physics and detector performance not revealed to the collaboration until closeout
  - Engage the collaboration
    - to start thinking science

DC1: Essential features of a data challenge



DC2: Two months with celestial sources (also variable) and background



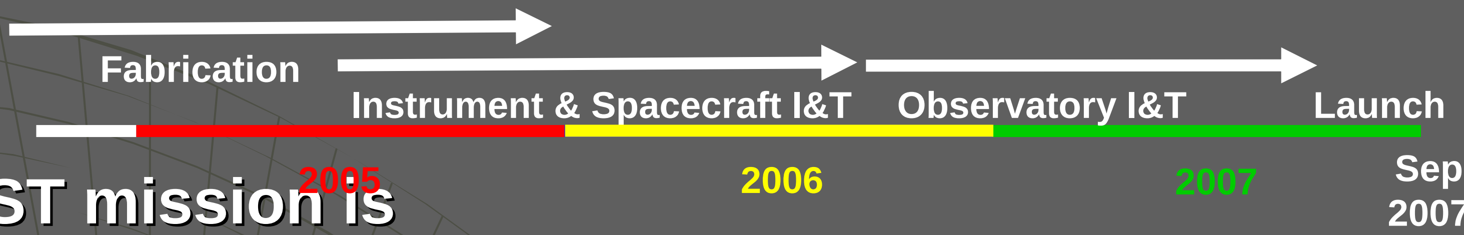
We will have DC3 in 2007…

GLAST Science @ SLAC

- GLAST Physics Dept @ SLAC is part of KIPAC
  - managed by R. Blandford/E. Bloom
  - prepare SLAC scientists for science with GLAST
  - strengthen ties with local astrophysics community and GLAST members
- Currently there are 4 GLAST/SLAC Post-Docs participating in the following areas
  - beam test and instrument data analysis
    - calibrate LAT response and validate LAT MC simulations
  - science tools and data challenges
    - Develop science software for on-orbit data analysis
  - ISOC
    - Understand instrument idiosyncrasies, acquire operations experience and obtain a better handle on instrument systematics
- GLAST Stanford Rotation Students
  - co-coordinated by E. do Couto e Silva(SLAC) / O. Reimer (SU)
    - strengthen ties between SLAC and Campus
  - average of 4 per quarter
    - projects involve LAT instrument data analysis and LAT science
- DOE/SULI Fellowship Program
  - average of 1 to 2 GLAST students per summer
- DOE/INFN Fellowship Program
  - average of 2 GLAST students per summer

See science talks by
SLAC staff members
in the breakout session
H. Tajima. L. Wai, G. Madejski

The Look Ahead



- **The GLAST mission is**
  - **well into integration.**
- **Delivery of the LAT and GBM instruments**
  - **for observatory integration in Fall 2006.**
- **Observatory integration and test**
  - **Fall 2006 through summer 2007.**
- **Major scientific conference,**
  - **the First GLAST Symposium, being planned for early 2007.**

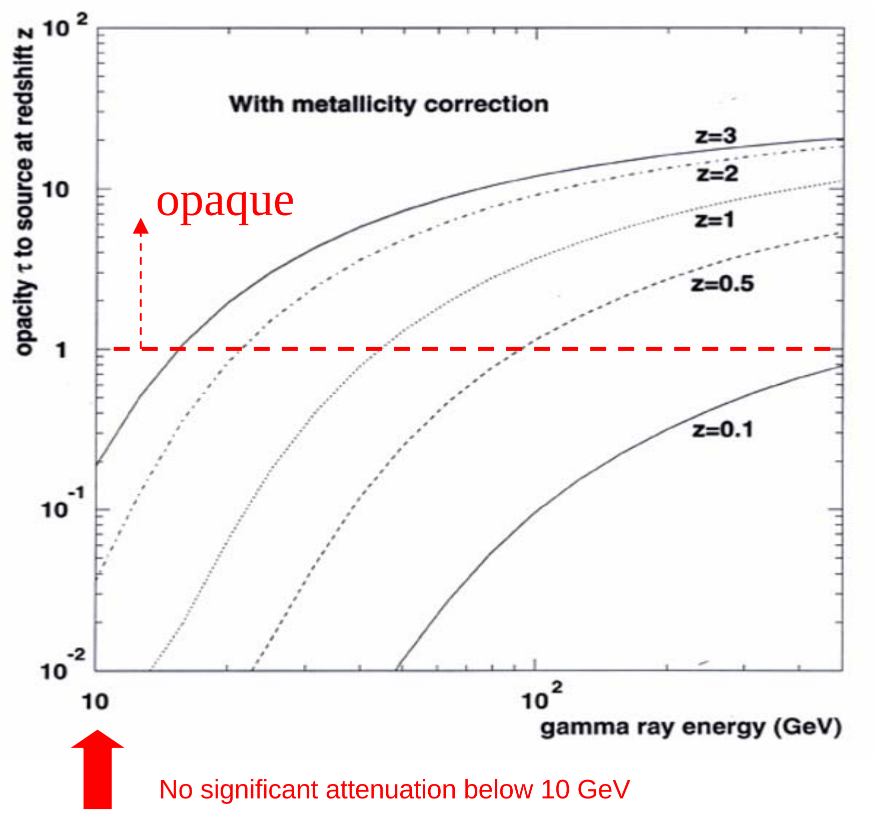

GLAST
September 2007 launch
SLAC

Back up slides

AGN: Extragalactic Background Light

- High Energy photons (e.g. from AGN) can be absorbed via pair production
  - GeV (TeV) photons interact with intergalactic low energy photons UV(IR)
  - strong dependence on the distance from the source (inferred from redshift)

Salamon & Stecker, ApJ 493, 547 (1998)



No significant attenuation below 10 GeV

Energy Range from 10 to 100 GeV is key to understand EBL

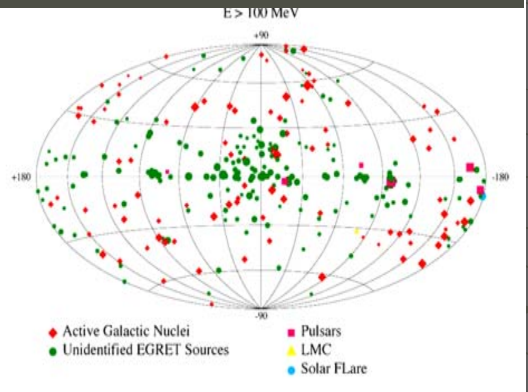
A dominant factor in EBL models is the era of galaxy formation

AGN roll-offs may help distinguish models of galaxy formation

Comparison of Instrument Performance

3rd EGRET Catalog

E > 100 MeV



EGRET

Pointing

1991-2001

LAT

All sky

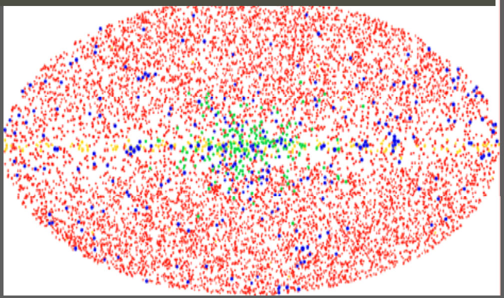
2007 - ?

5 yr operation requirement

10 yr operation goal

LAT Simulation

E > 100 MeV

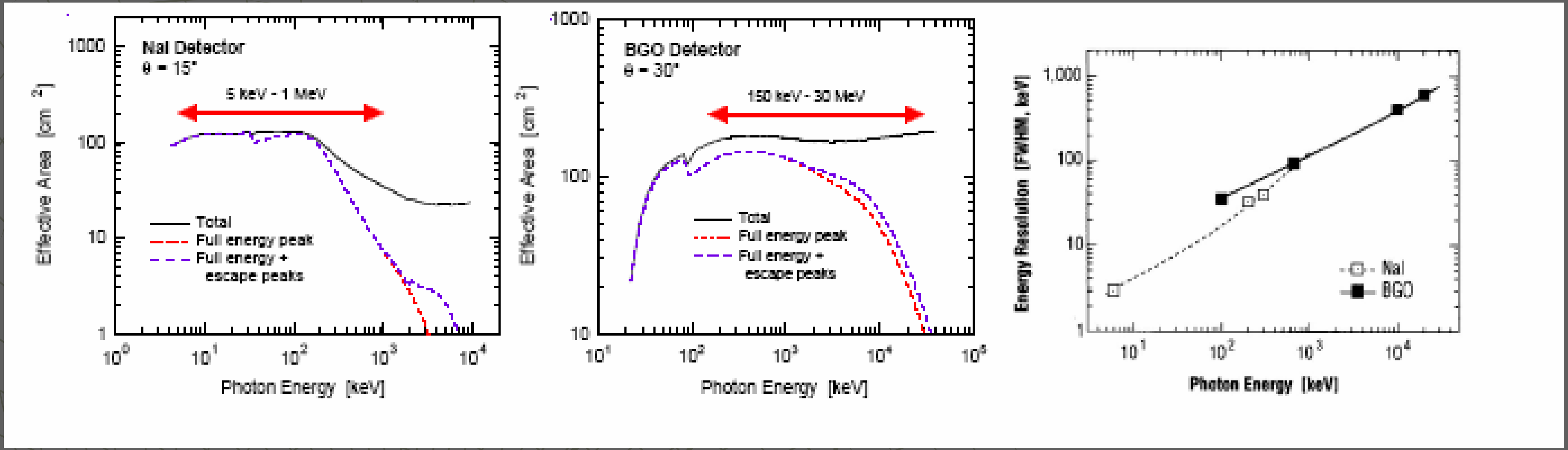


	EGRET	LAT	Improvement
Energy	30 MeV - 30 GeV	20 MeV - 300 GeV	
Peak effective area	1500 cm^2	> 8000 cm^2	> 5
Field of view	0.5 sr	> 2.0 sr	> 4
Sensitivity (1yr)	~ 10^{-7} γ cm^{-2} s^{-1}	< 6 10^{-9} γ cm^{-2} s^{-1}	> 20
Localization (bright source)	15 ’	< 0.5 ’	> 30
Deadtime	100 ms	< 30 μs	> 1000

Large area
Low instrumental background

GBM Performance

The GLAST Burst Monitor for GLAST, A. von Kienlin et al., in Proc of the SPIE-Conference, Glasgow 2004



- **GBM NaI Location**
  - **6 in the equatorial plane**
  - **4 at 45°**
  - **2 at 20°**
- **GBM BGO Location**
  - **2 in opposite sides of the spacecaft**

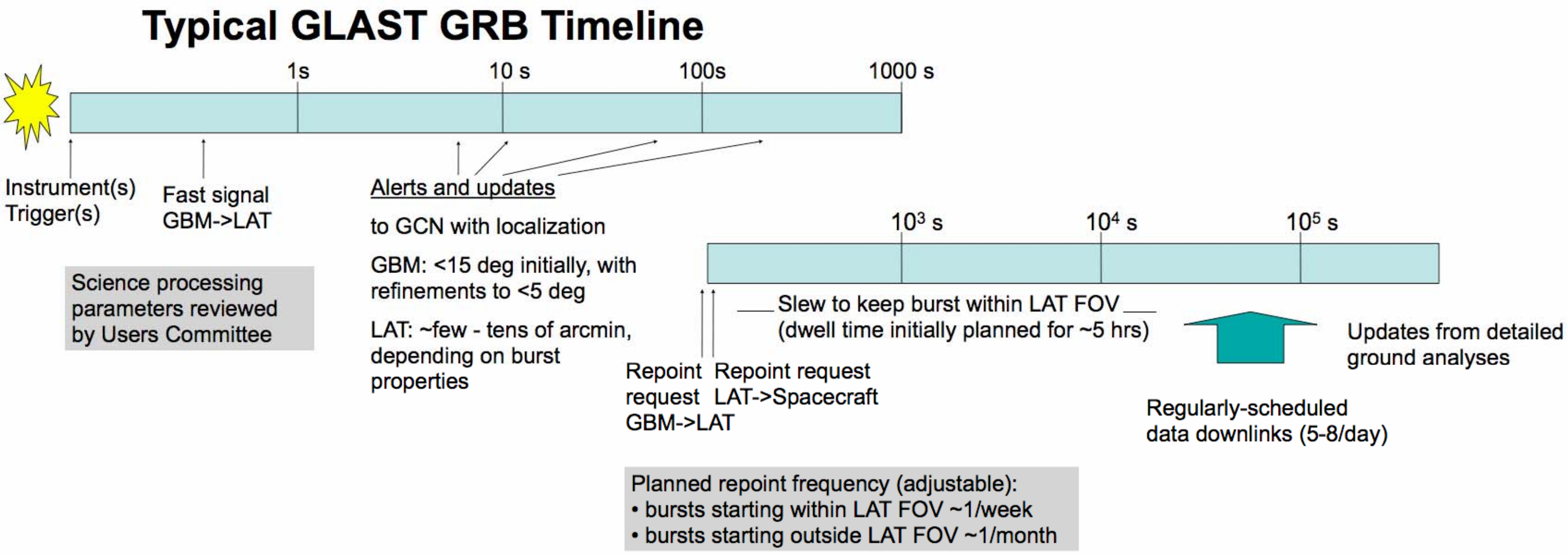
- **GBM Trigger**
  - **compare count rates for 2 of the modules**
    - **same as BATSE**
- **GBM Trigger Sensitivity**
  - **< 1 ph $cm^{-2}s^{-1}$**
    - **BATSE: 0.2 ph $cm^{-2}s^{-1}$ (5σ)**
- **GBM Burst Localization**
  - **< 15° within 1.8s (on board)**
    - **can be used as a LAT trigger**
    - **if outside LAT FOV**
      - **possible to repoint to catch delayed emissions**
  - **< 5° within 5s (ground)**
    - **< 3° within 1 day (ground)**

GLAST and GRBs

Slide from N. Omodei
(GLAST GRB SWG)

- Full sky survey every 3 hours
- Number of Bursts
  - GBM ~ 200 bursts/yr
  - > 60 bursts within FoV of the LAT
    - 1 burst/month ~ 100 photons
- Alert and Localization
  - Alert to GCN ~ 10 s
  - GBM < 15^0 initially, update 5^0
  - LAT > 10 arcmin depending on the burst
- Downlink and Communications
  - near real-time (TDRSS)
  - full science data ~ 6-8 times a day
- Downlink and Communications
  - Intense burst: GLAST can repoint
    - keep LAT in the FoV
    - Dwell time: 5 hr (adjustable)

GLAST GRB Timeline



GLAST and SWIFT era

Slide from N. Omodei
(GLAST GRB SWG)

- **GLAST can provide alerts to GRBs**
  - **Swift can point for follow on observations.**
    - **Precise measurements of the position will be given by Swift!**
- **GLAST will frequently scan the position of the bursts hours after the Swift alerts**
  - **monitoring for High energy emission.**
  - **In these cases, we will have a broad spectral coverage of the GRB spectrum (from 0.1 keV to hundreds of GeV > 9 decades!!).**
- **Swift is seeing 100 bursts per yr: ~ 20/yr will be in the LAT FoV**