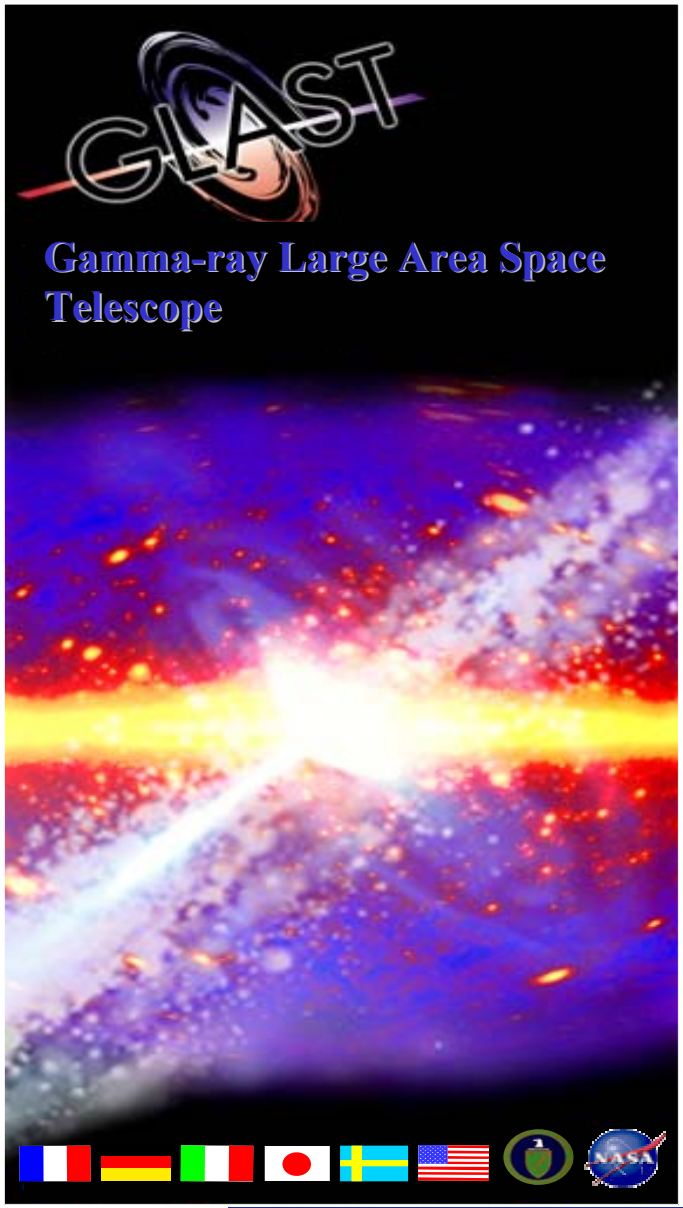


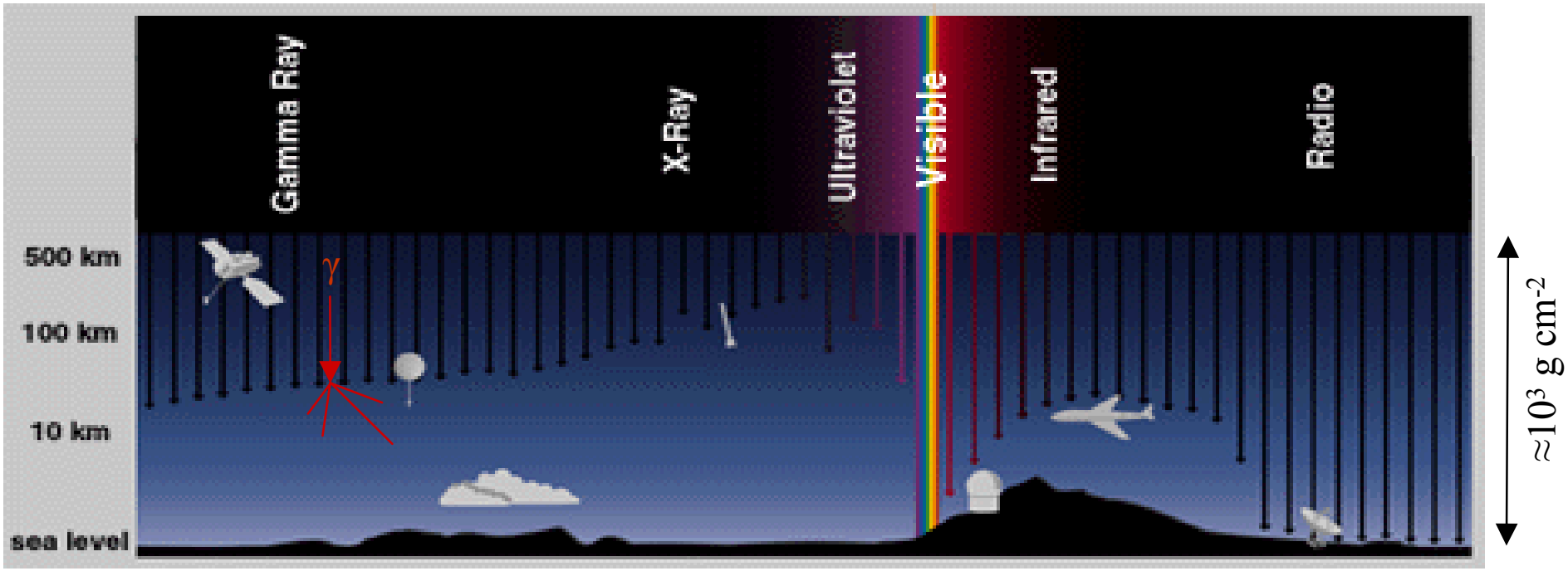
GLAST and the Gamma-Ray Sky

Michael Kuss

INFN PISA
ISTITUTO NAZIONALE DI FISICA NUCLEARE

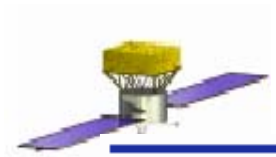
Jefferson Laboratory
11 November 2003

Cosmic γ–ray Measurement Techniques



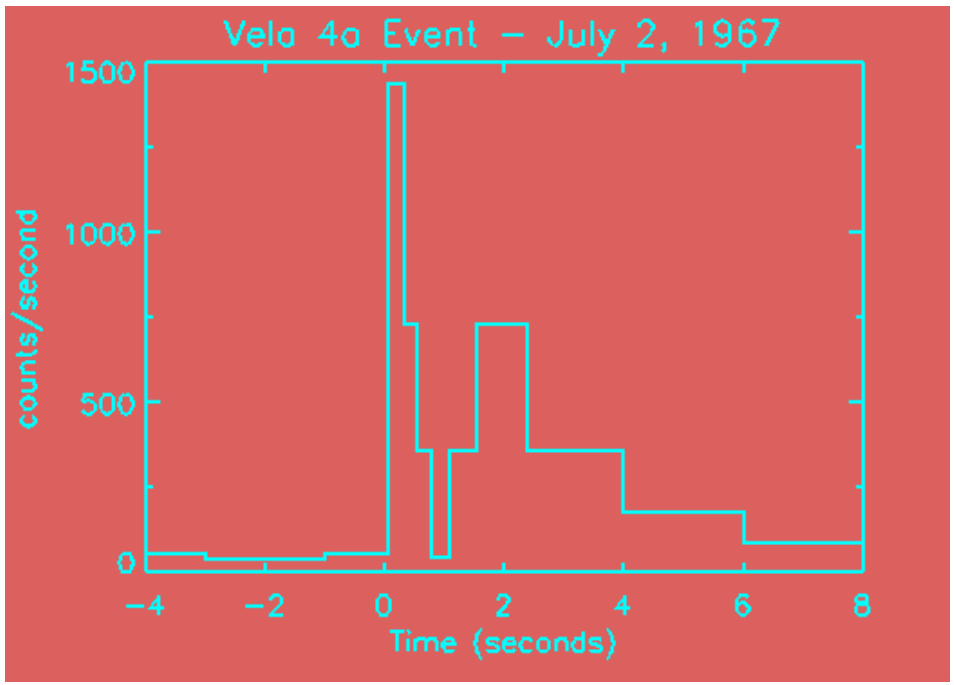
$E_\gamma < \approx 100$ GeV: must detect above atmosphere (balloons, satellites)

$E_\gamma > \approx 100$ GeV: information from showers penetrates to the ground (Air Cerenkov Telescope ACT)



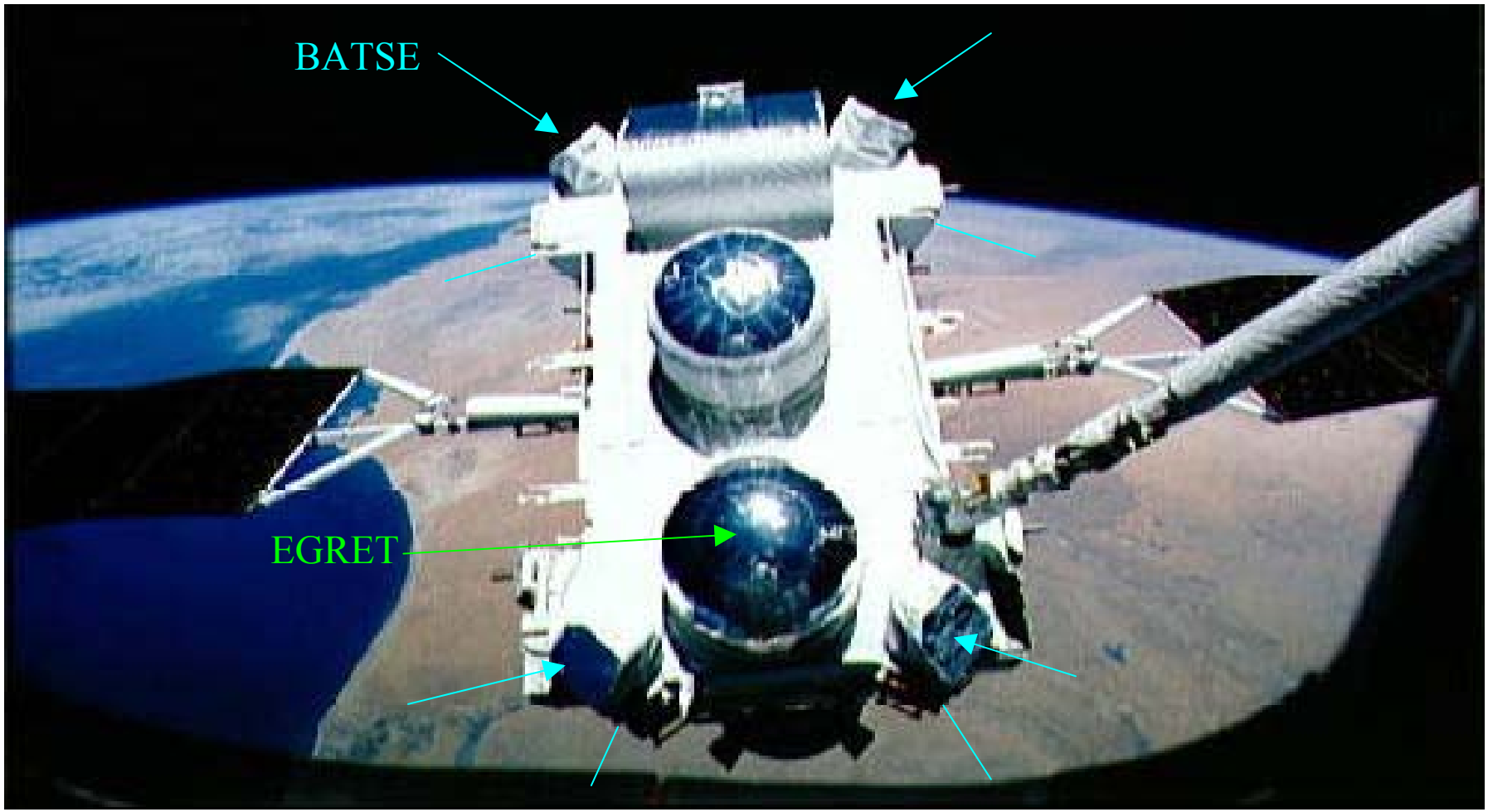
Early Gamma-Ray Astronomy

1961: Explorer-XI, <100 cosmic γ's. Isotropic distribution ⇒ gamma-ray background
1967: OSO-3, 621 events
1967: Vela program sees flashes of γ-rays. ★ USSR bombs?
1972: SAS-2, various point sources, 2 identified as pulsars (Crab, Vela)
1973: Klebesadel, Strong, Olsen, first paper on 16 GRB's 69-72
1975-82: COS-B, about 25 sources, most unidentified, but Geminga, sky map
1976: paper on The First Burst
1977: NASA announces CGRO



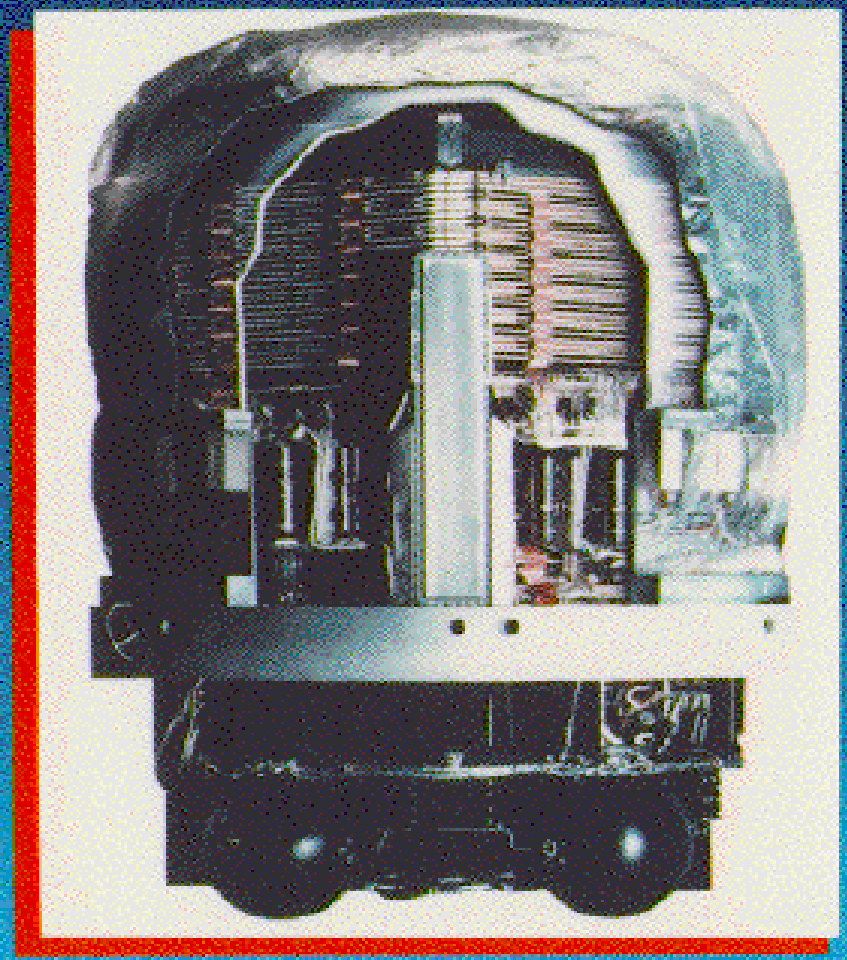
CGRO (1991-2000)

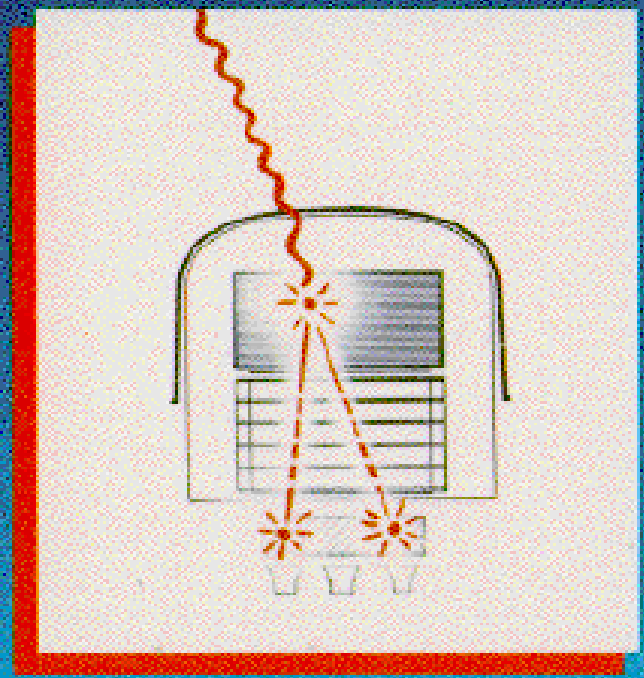
Compton Gamma-Ray Observatory (CGRO)



EGRET

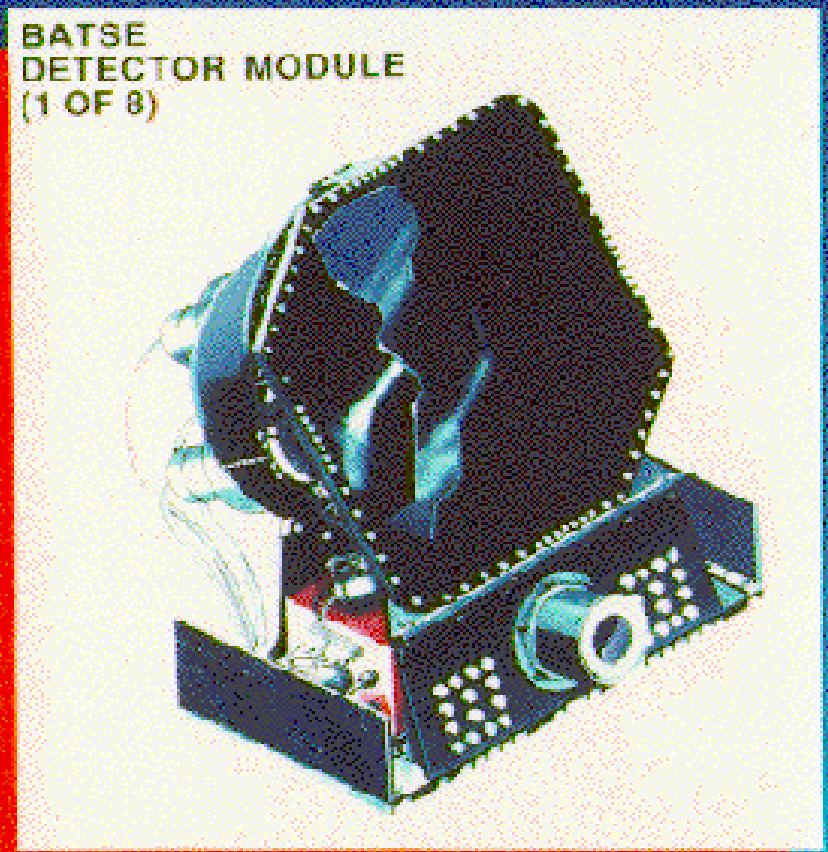
Energetic Gamma Ray Experiment Telescope (EGRET)

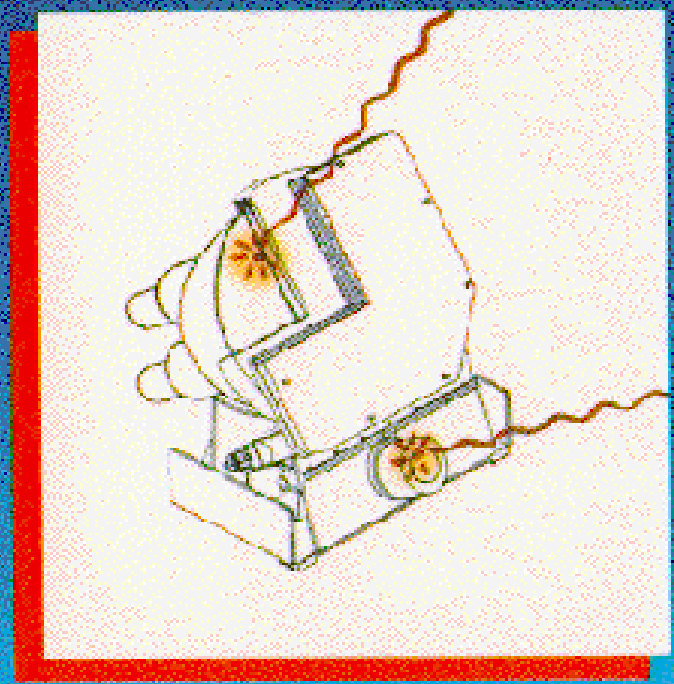




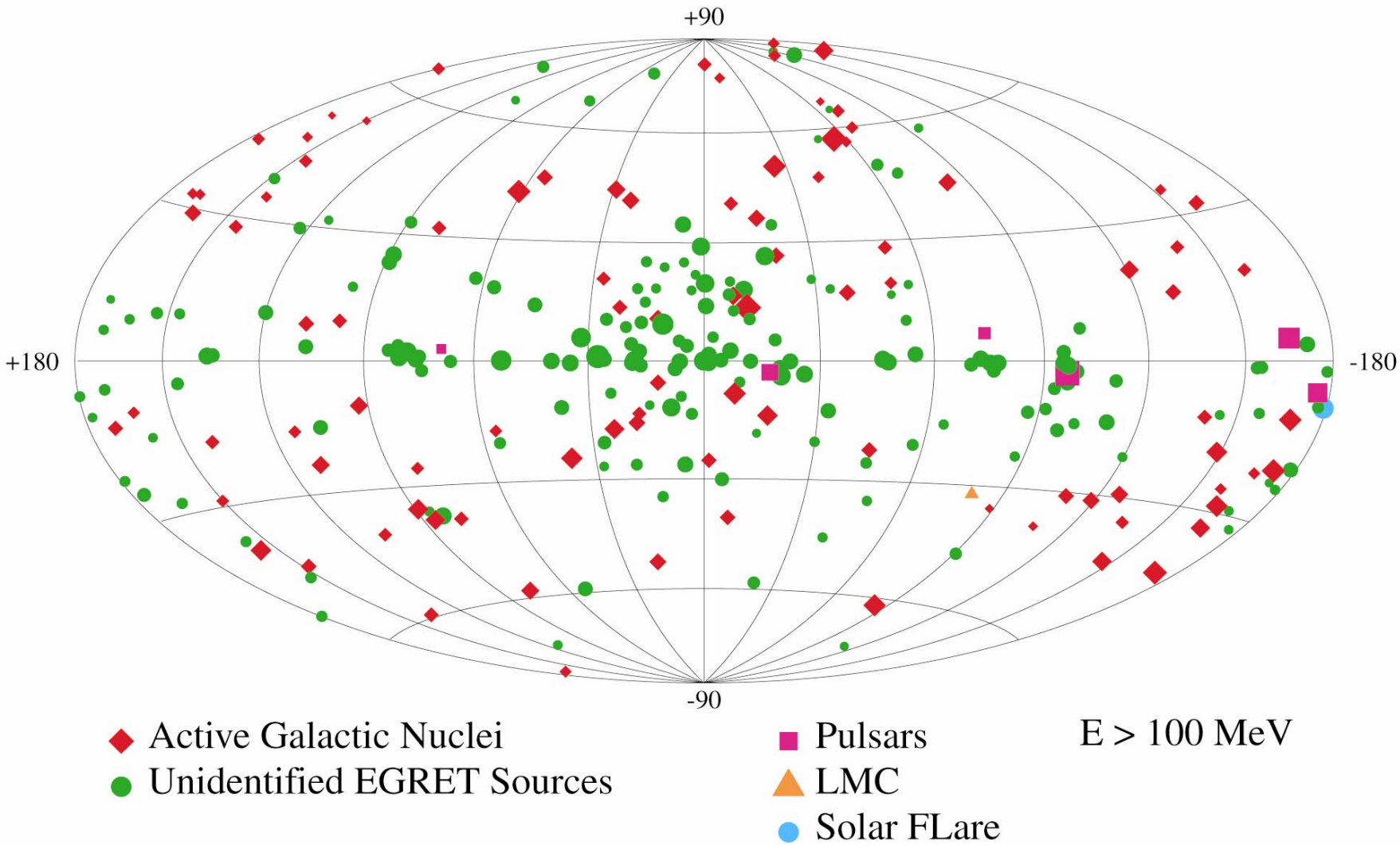
BATSE

Burst and Transient Source Experiment (BATSE)

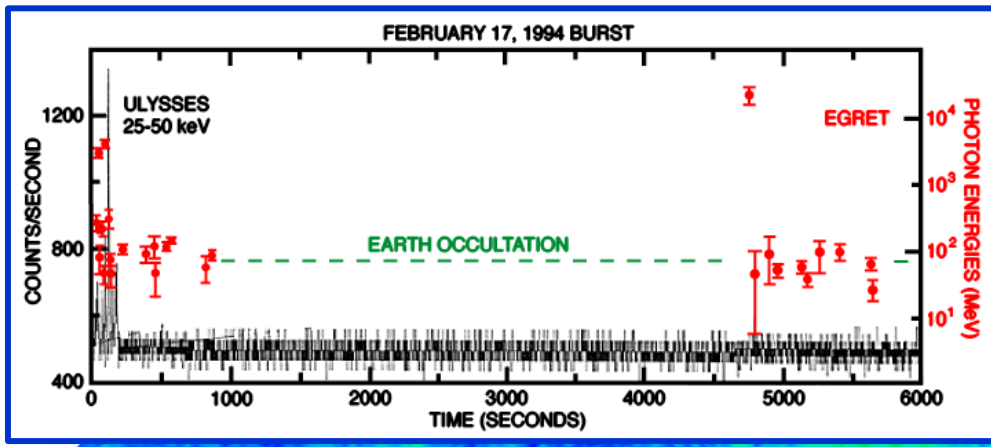


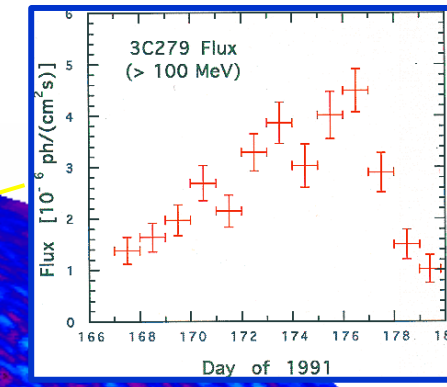


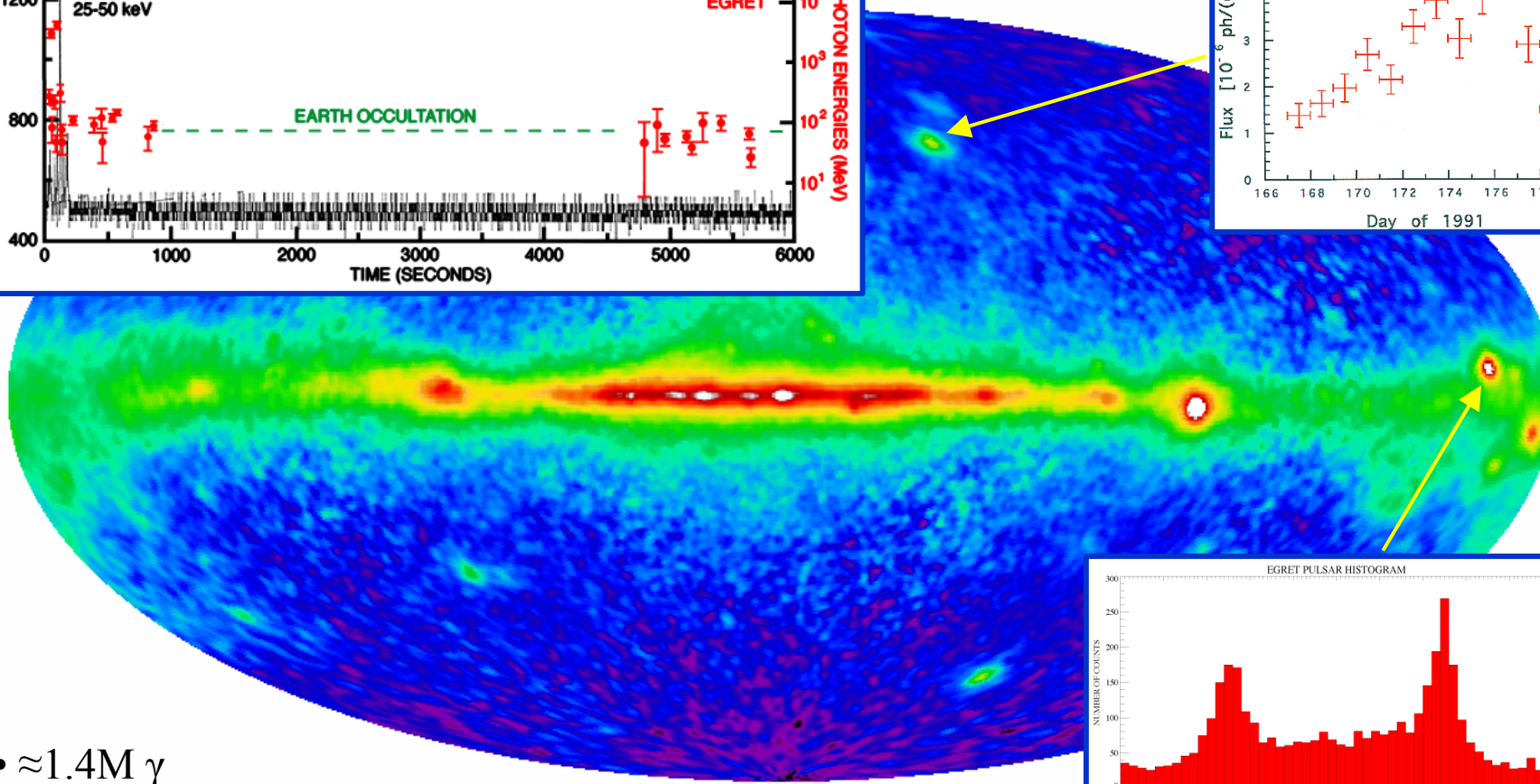
3rd EGRET Catalogue

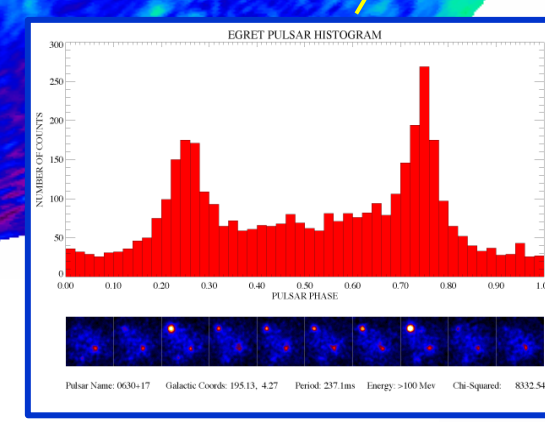


EGRET all-sky survey (70 MeV-10 GeV)



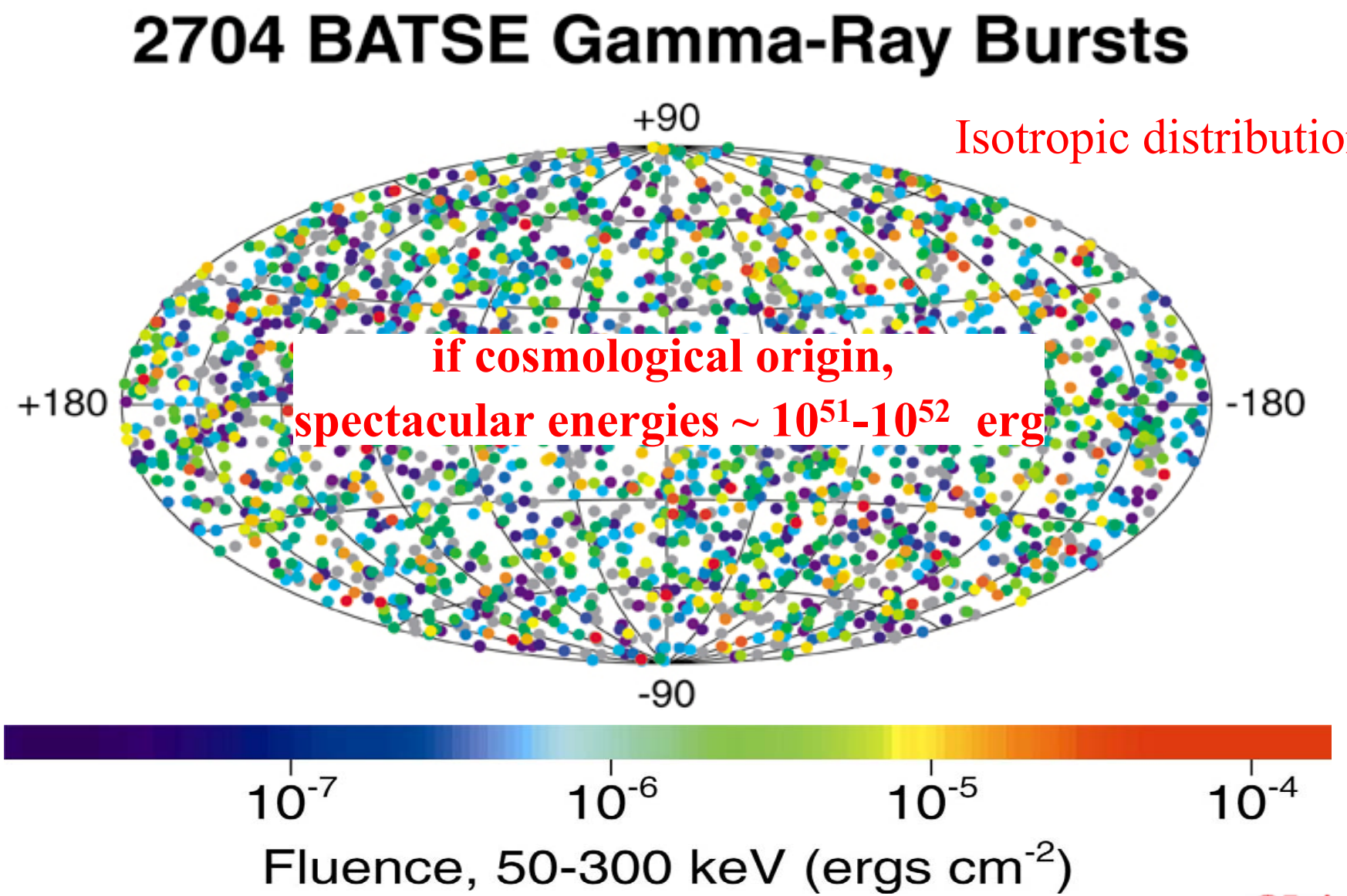






- ≈1.4M γ
- ≈60% interstellar emission from the MW
- ≈10% are cataloged (3EG) point sources

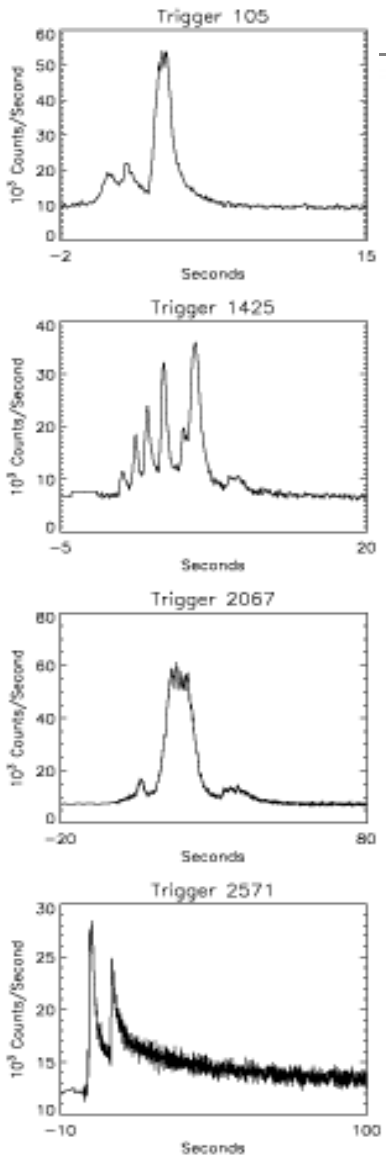
BATSE Transients Sky Map

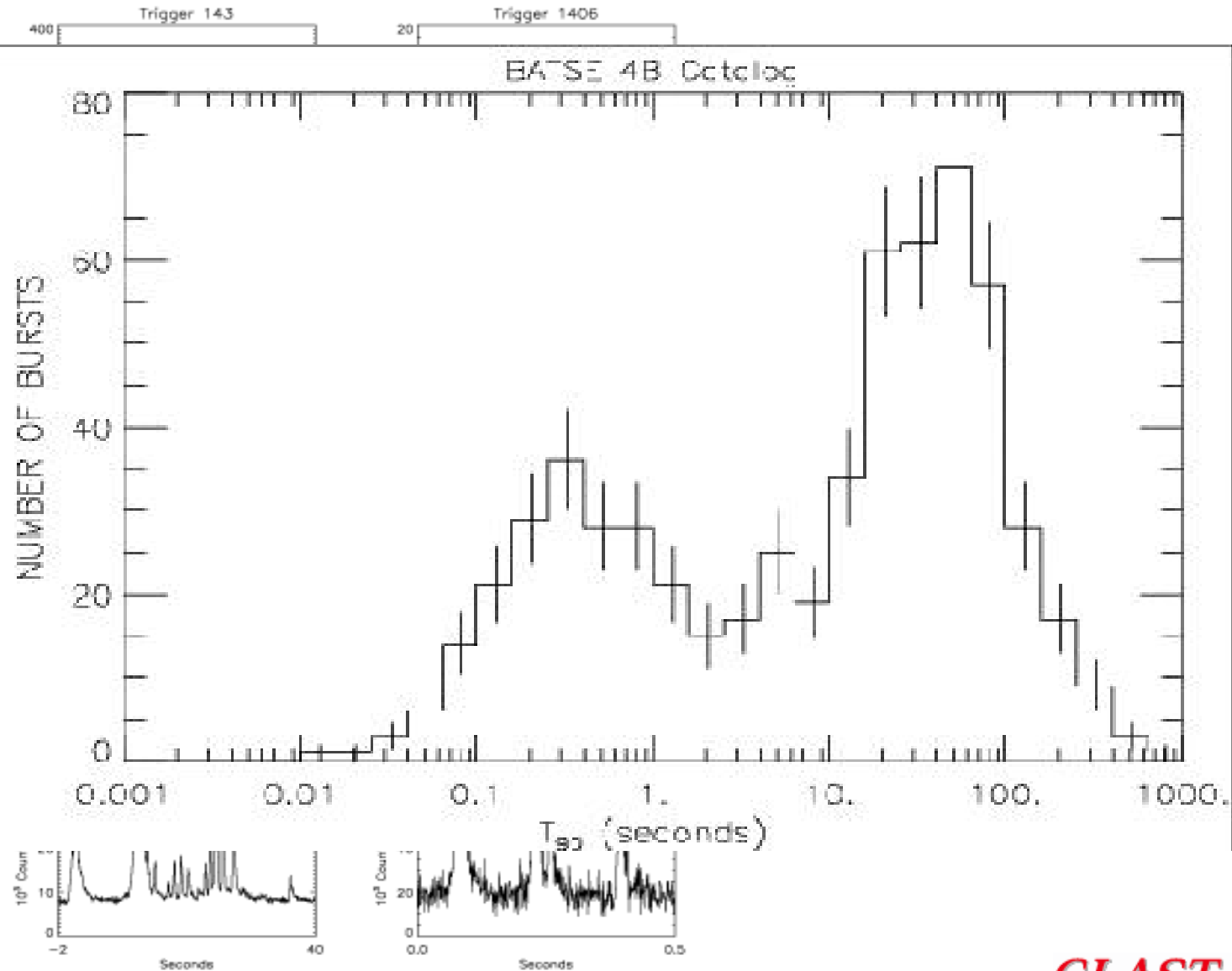


Isotropic distribution!

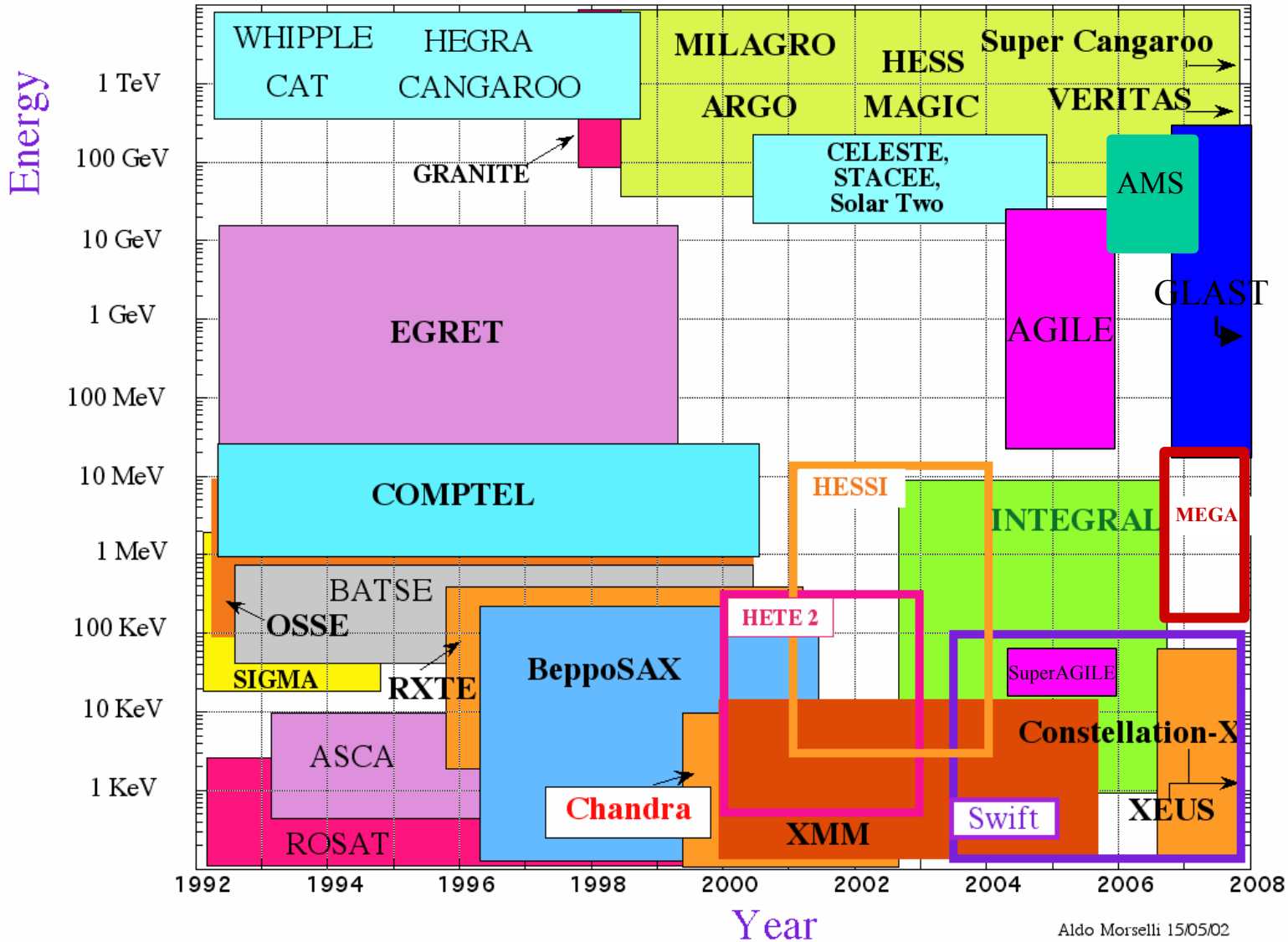
if cosmological origin,
spectacular energies ~ 10^{51}-10^{52} erg

Gamma-Ray Burst Classification

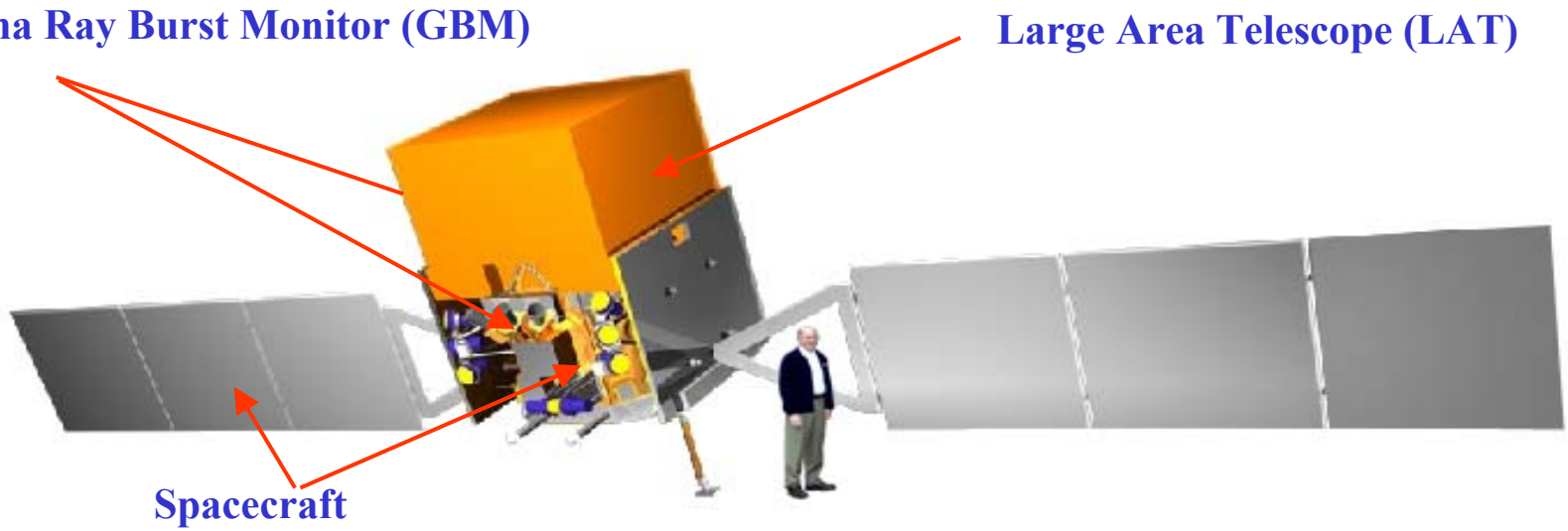




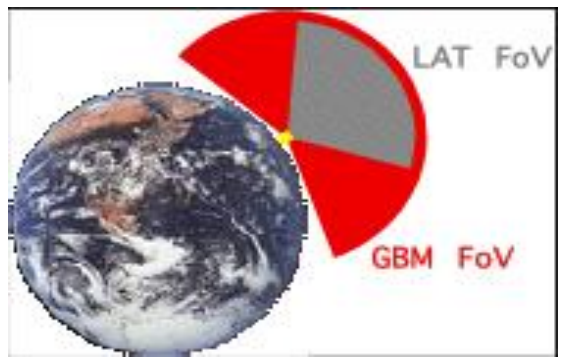
X- and γ-ray detectors

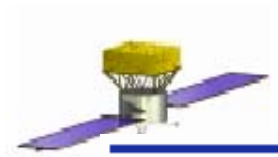


The GLAST Observatory



Launch Vehicle	Delta II – 2920-10H
Launch Location	Kennedy Space Center
Orbit Altitude	575 km
Orbit Inclination	28.5 degrees
Orbit Period	95 Minutes
Orientation	away from the earth
Launch Date	December 2006
Payload:	
LAT mass	3000 kg
LAT power	650 W





Institutions

American Team Institutions

SU - Stanford University, Physics Department and EGRET group, Hanson Experimental Physics Lab
SLAC - Stanford Linear Accelerator Center, Particle Astrophysics group
GSFC-NASA - Goddard Space Flight Center, Laboratory for High Energy Astrophysics
NRL - U. S. Naval Research Laboratory, E. O. Hulburt Center for Space Research, X-ray and gamma-ray branches
UCSC - University of California at Santa Cruz, Physics Department
SSU - Sonoma State University, Department of Physics & Astronomy
UW - University of Washington
TAMUK - Texas A&M University-Kingsville

Italian Team Institutions

INFN - Instituto Nazionale di Fisica Nucleare: Units of Bari, Perugia, Pisa, Rome 2, Trieste, Udine
ASI - Italian Space Agency
IFC/CNR - Istituto di Fisica, Cosmica, CNR

Japanese Team Institutions

University of Tokyo
ICRR - Institute for Cosmic-Ray Research
ISAS - Institute for Space and Astronautical Science
Hiroshima University

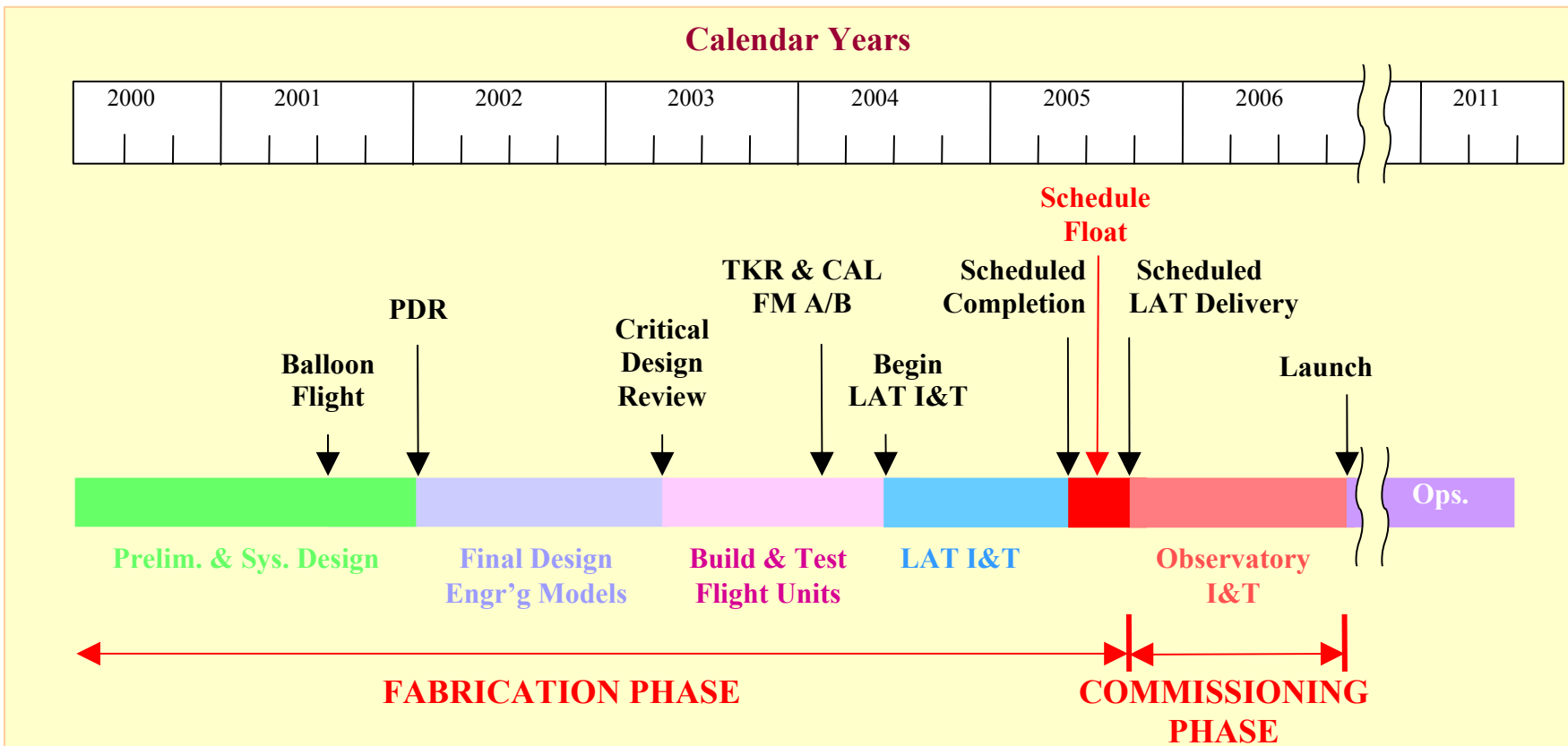
French Team Institutions

CEA/DAPNIA - Commissariat à l'Energie Atomique, Département d'Astrophysique, de physique des Particules, de physique Nucleaire et de l'Instrumentation Associée
IN2P3 - Institut National de Physique Nucléaire et de Physique des Particules, IN2P3
IN2P3/LPNHE-X - Laboratoire de Physique Nucléaire des Hautes Energies de l'École Polytechnique
IN2P3/PCC - Laboratoire de Physique Corpusculaire et Cosmologie, Collège de France
IN2P3/CENBG - Centre d'études nucléaires de Bordeaux Gradignan

Swedish Team Institutions

KTH Royal Institute of Technology
Stockholms Universitet

LAT Schedule highlights



GLAST scheduled for launch in December 2006

Experimental Technique

Instrument must measure the direction, energy, and arrival time of high energy photons (from approximately 20 MeV to greater than 300 GeV). The photon interactions with matter in the GLAST energy range are dominated by pair conversion.

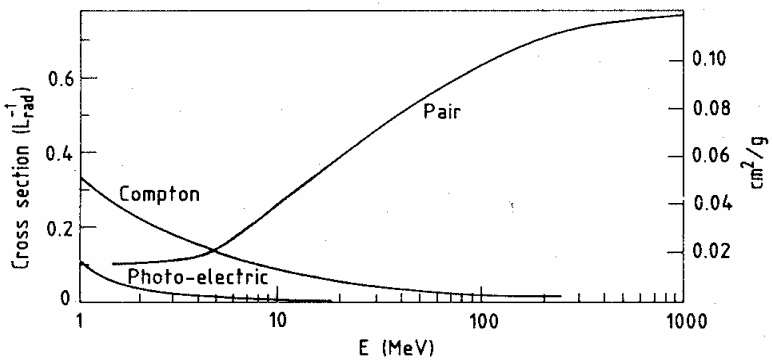
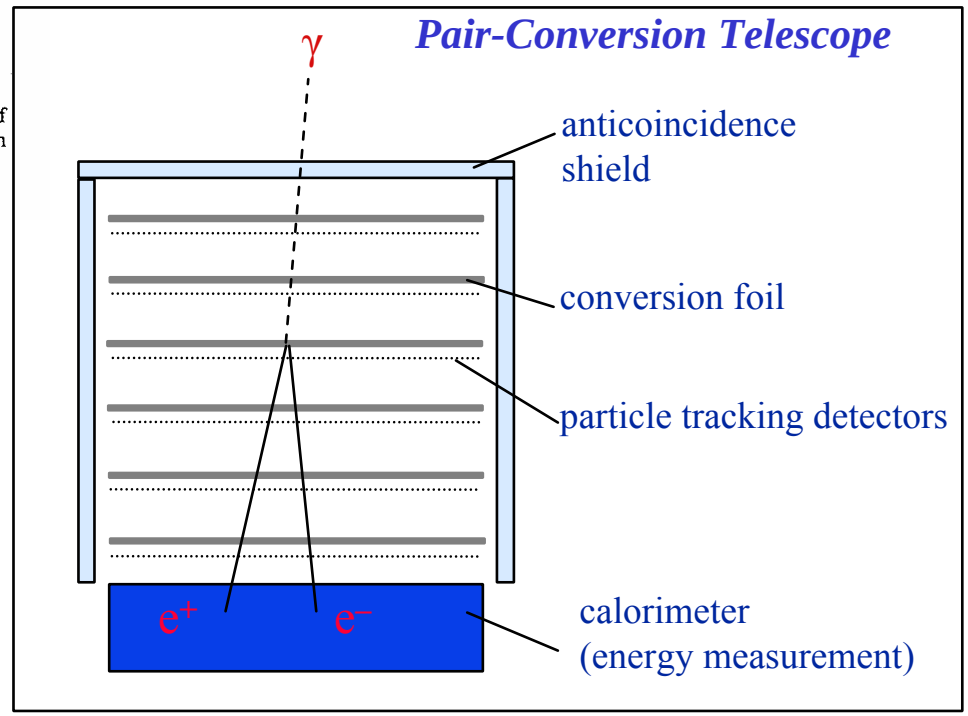


Fig. 2: Photon cross-section σ in lead as a function of photon energy. The intensity of photons can be expressed as $I = I_0 \exp(-\sigma x)$, where x is the path length in radiation lengths. (Review of Particle Properties, April 1980 edition).

- determine photon direction
- clear signature for background rejection

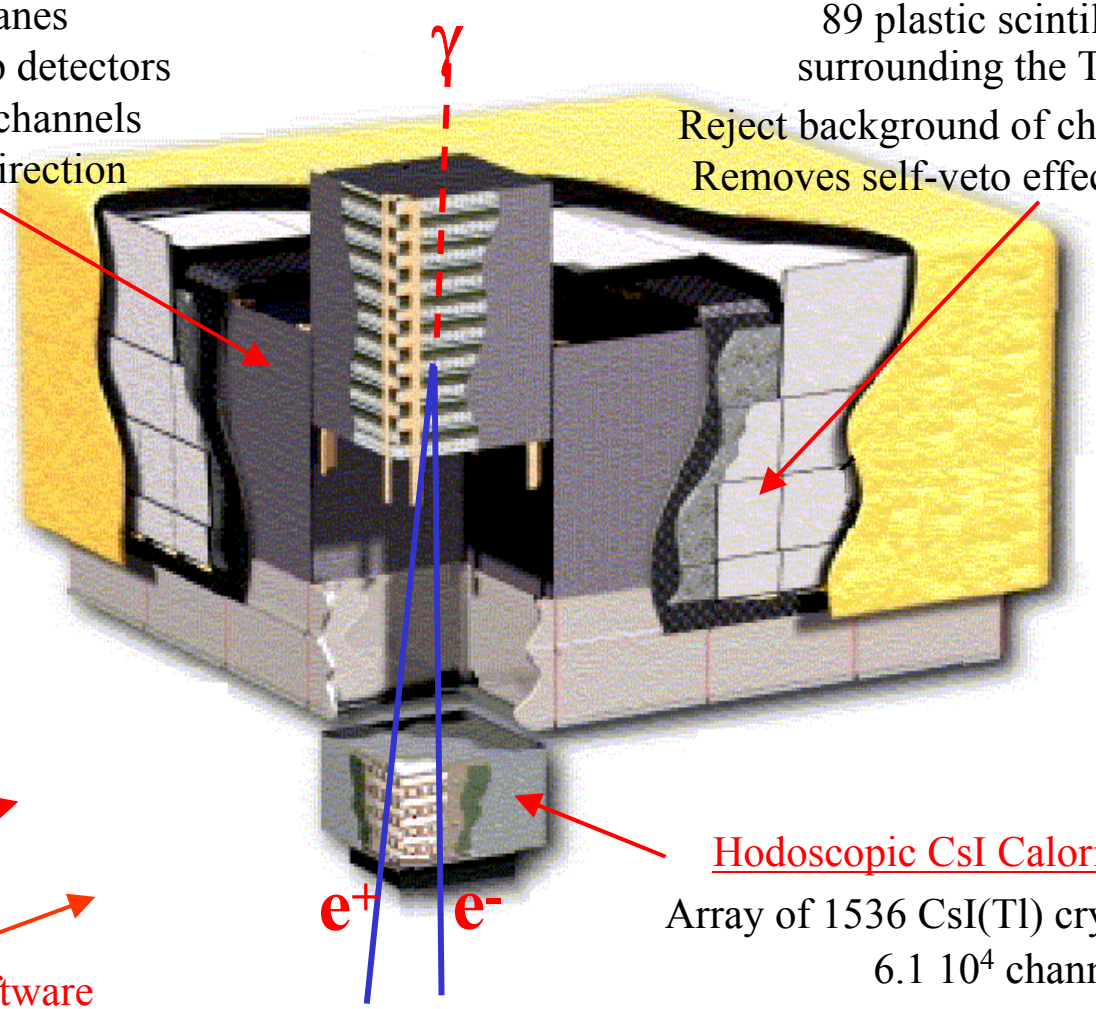


- Must detect γ-rays with high efficiency and reject the much larger (~10^4:1) flux of background cosmic-rays, etc.
- Energy resolution requires calorimeter of sufficient depth to measure buildup of the EM shower. Segmentation useful for resolution and background rejection.

Large Area Telescope (LAT)

Precision Si-strip Tracker (TKR)
18 XY tracking planes
Single-sided silicon strip detectors
228 µm pitch, 8.8 10^5 channels
Measure the photon direction

Segmented Anticoincidence Detector (ACD)
89 plastic scintillator tiles
surrounding the TKR towers
Reject background of charged cosmic rays
Removes self-veto effects at high energy



LAT:
4 x 4 modular array
3000 kg, 650 W

GRID
Mechanical
backbone

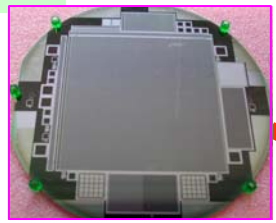
Electronics & Flying Software
Data Acquisition System

Hodoscopic CsI Calorimeter(CAL)
Array of 1536 CsI(Tl) crystals in 8 layers
6.1 10^4 channels
Measure the photon energy, image the shower

Tracker Detector - Construction Workflow

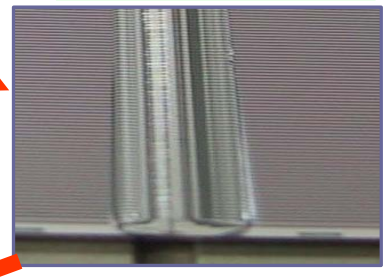
Module Structure Components
SLAC: Ti parts, thermal straps, fasteners.
Italy (Plyform): Sidewalls

SSD Procurement, Testing
SLAC,Japan, Italy (HPK)



10,368

SSD Ladder Assembly
Italy (G&A, Mipot)



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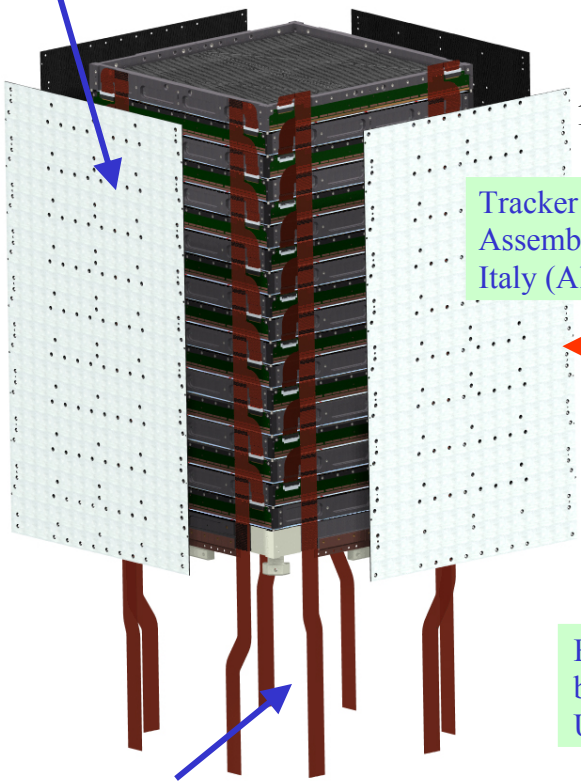
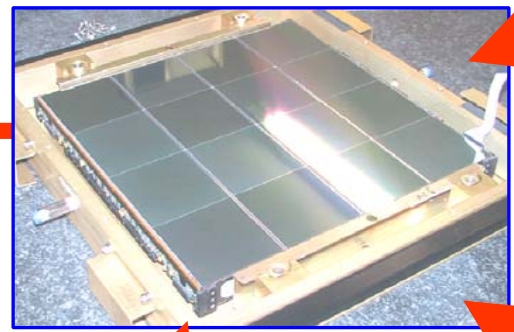


18

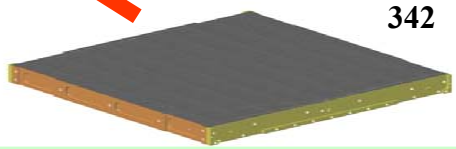
Tracker Module
Assembly and Test
Italy (Alenia Spazio)

342



Tray Assembly and Test
Italy (G&A)

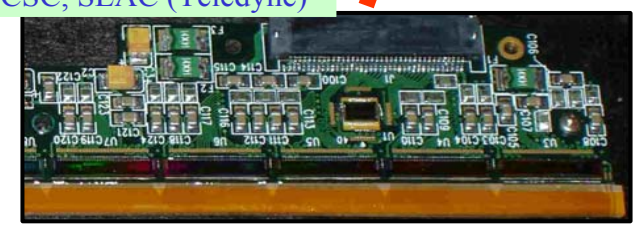
342



Composite Panel, Converters, and Bias Circuits
Italy (Plyform): fabrication
SLAC: CC, bias circuits, thick W, Al cores

Electronics Fabrication,
burn-in, & Test
UCSC, SLAC (Teledyne)

648

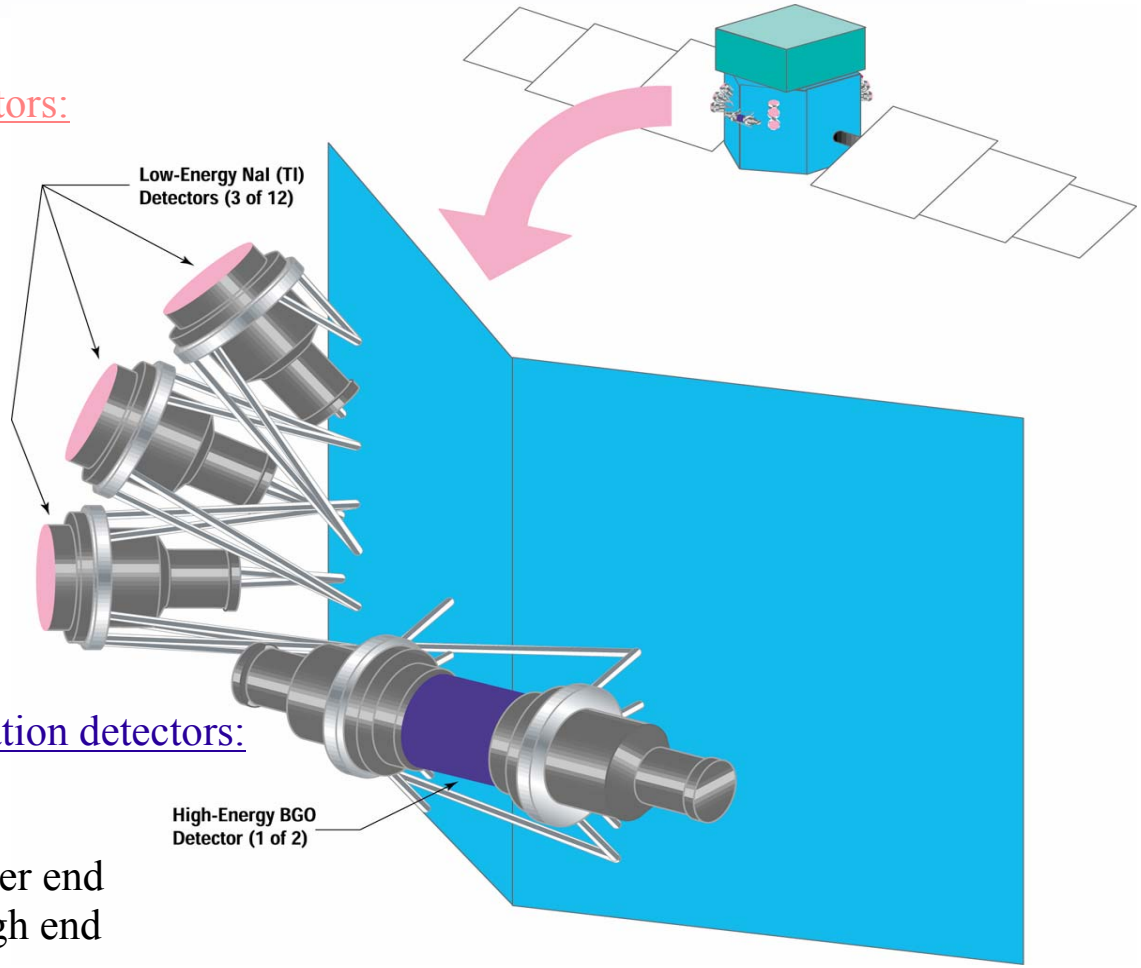


Readout Cables
UCSC, SLAC (Parlex)

GLAST Burst Monitor (GBM)

12 Sodium Iodide (NaI) scintillation detectors:

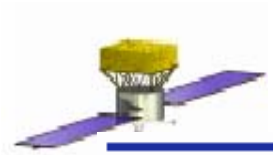
- (few keV to about 1 MeV)
- provide burst triggers and locations



2 Bismuth Germanate (BGO) scintillation detectors:

- ~150 keV to ~30 MeV
- good overlap with the NaI at the lower end
- good overlap with the LAT at the high end

similar characteristics to BATSE, but cover a wider energy range and have a smaller collection area.



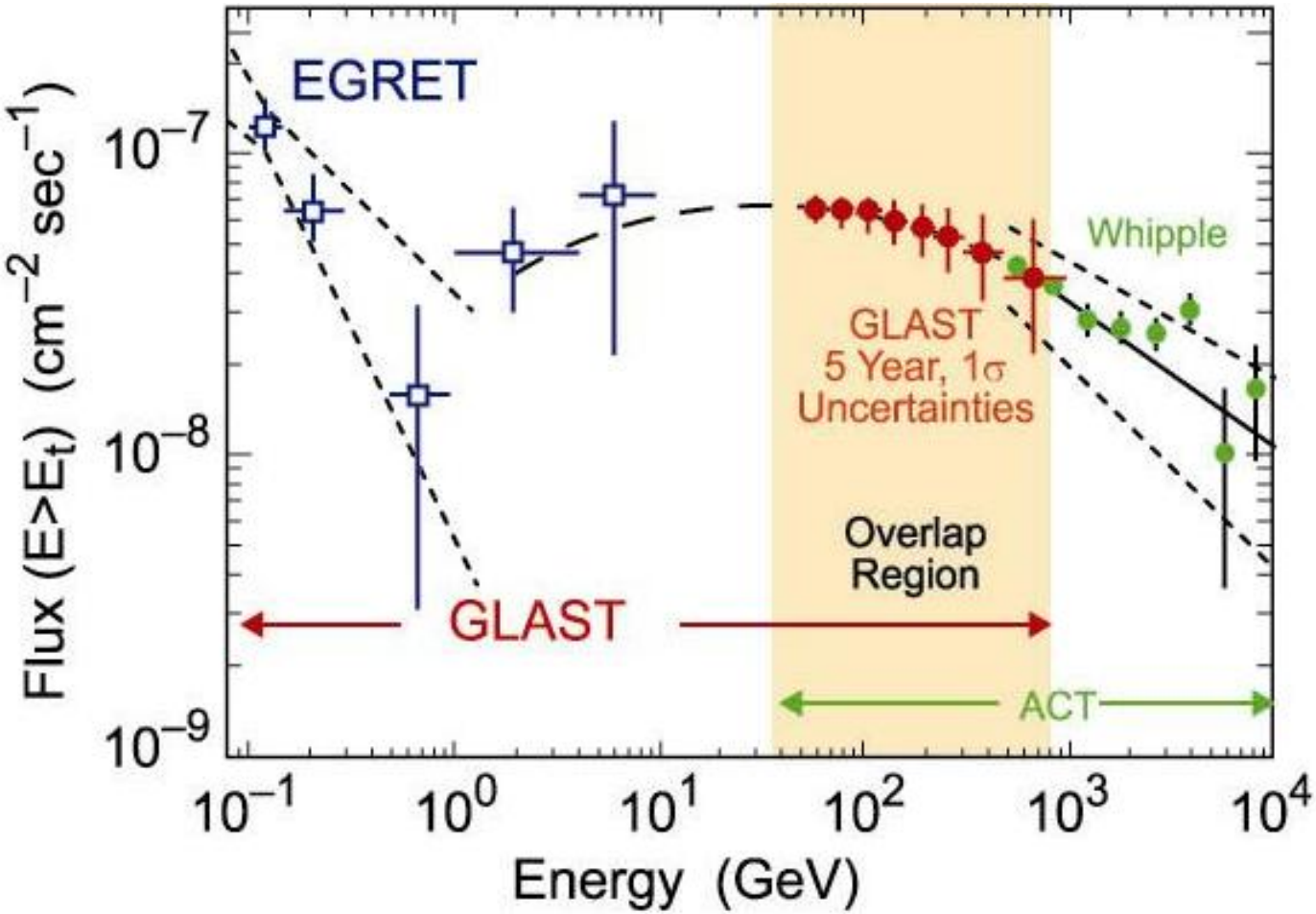
LAT Parameters

	CGRO/EGRET	GLAST/LAT	Change
Energy Range	20 MeV - 30 GeV	20 MeV - > 300 GeV	10 to 300 GeV
Energy Resolution (ΔE/E)	0.1	0.1	
Effective Area (1GeV)	1500 cm^2	10,000 cm^2	6.6
Field of View	0.5 sr	2.4 sr	4.8
Angular Resolution	5.8° @ 100 MeV 0.5° @ 10 GeV	~ 3.5° @ 100 MeV ~ 0.1° @ 10 GeV	Area = 1/2.7 Area = 1/25
Sensitivity (> 100 MeV)*	~ 10^{-7} cm^{-2} s^{-1}	~ $3 \cdot 10^{-9}$ cm^{-2} s^{-1}	1/30
Deadtime	100 ms	<10 μs	
Mass	1810 kg	3000 kg	
Lifetime	1991 - 2000	2006 - 2016	

** 1 year survey at high latitudes*

Increased area, field of view, angular resolution, extended energy range and operational efficiency provide a powerful combination!

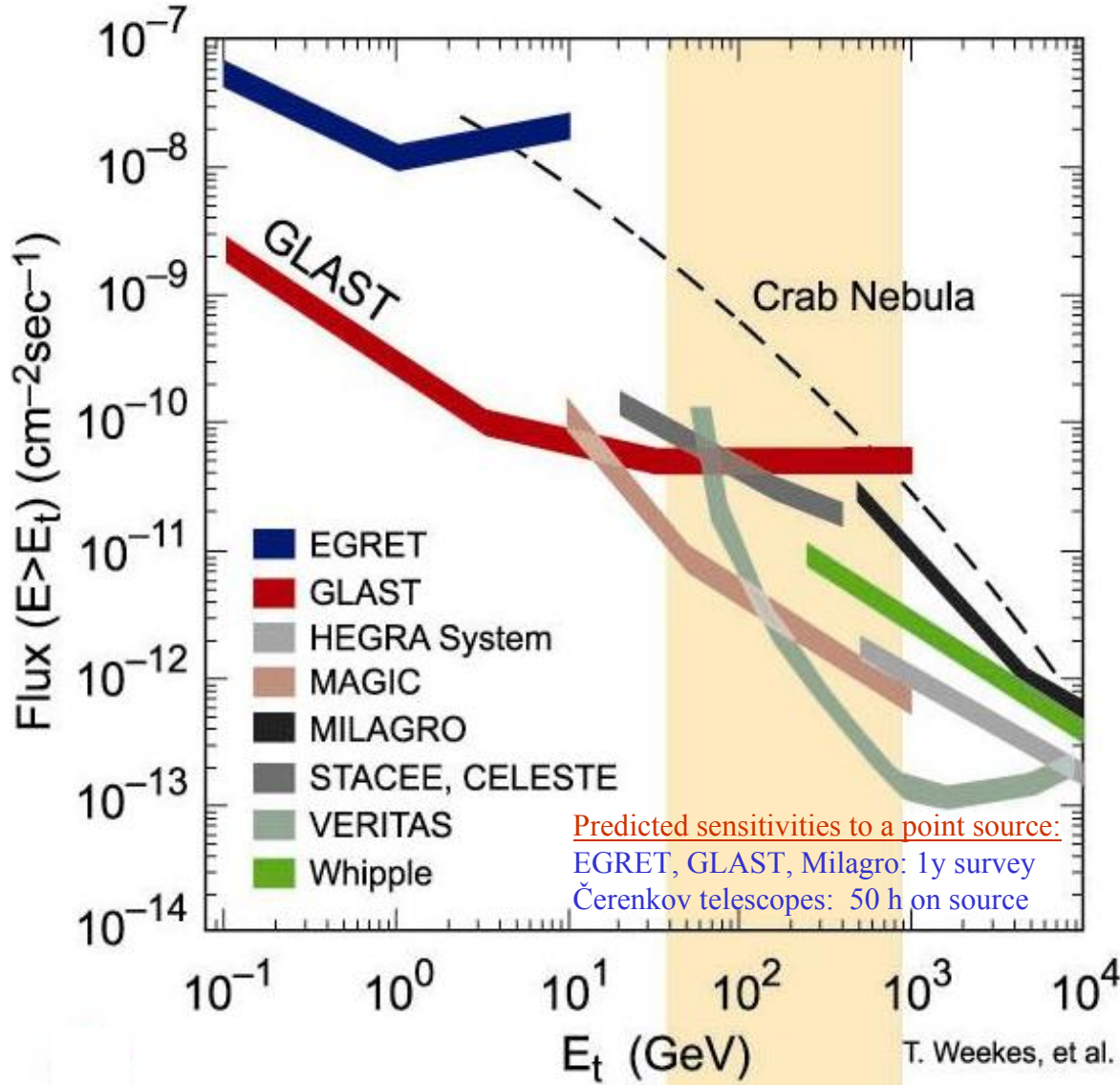
Overlap of GLAST with ACT's

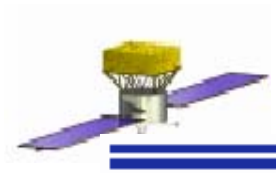


Predicted GLAST measurements of the unpulsed flux of the Crab pulsar in the overlap region with ground-based atmospheric Čerenkov telescopes.

Covering the Gamma-Ray Spectrum

- Broad spectral coverage is crucial for studying and understanding most astrophysical sources.
- The GLAST observatory and ground-based experiments cover complimentary energy ranges and performances (wide FOV and alert capabilites for GLAST, large effetive area and energy reach for ground-based)
- The improved sensitivity of GLAST is necessary for matching the sensitivity of the next generation of ground-based detectors.
- GLAST goes a long ways toward filling in the energy gap between space-based and ground-based detectors—there will be overlap for the brighter sources





Observations

Concept: GLAST can point anywhere, anytime.

Survey Mode: the default, designed for uniform sky exposure. The pointing is offset ±30°from the zenith above and below the orbital plane. The offset is changed every orbit, giving a 2 orbit periodicity.

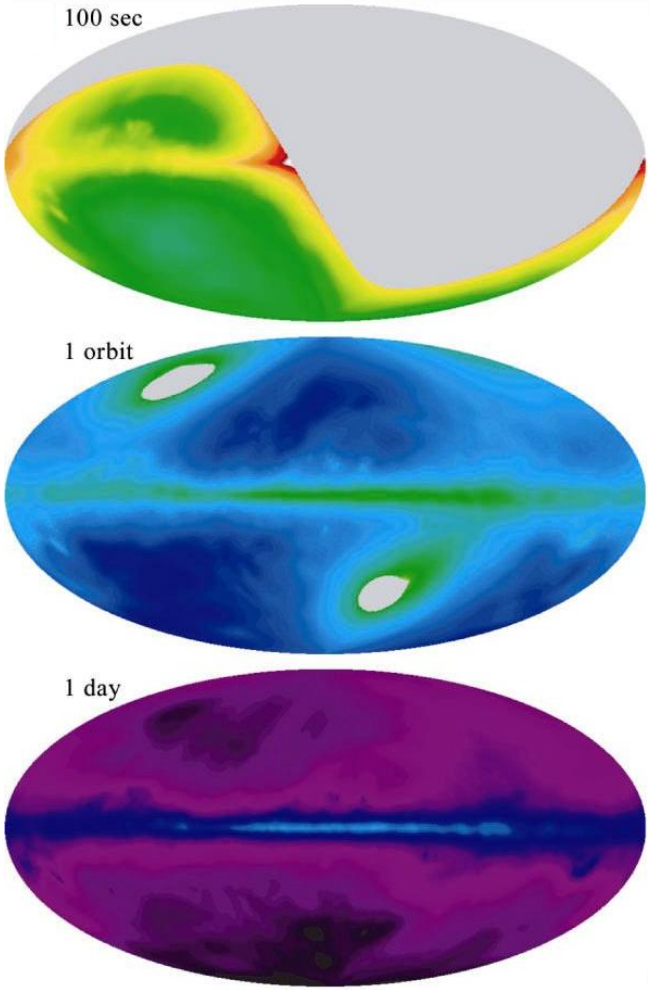
Pointed Mode: inertial pointing at a target. The Earth is kept out of the central 30° to avoid albedo gamma-rays.

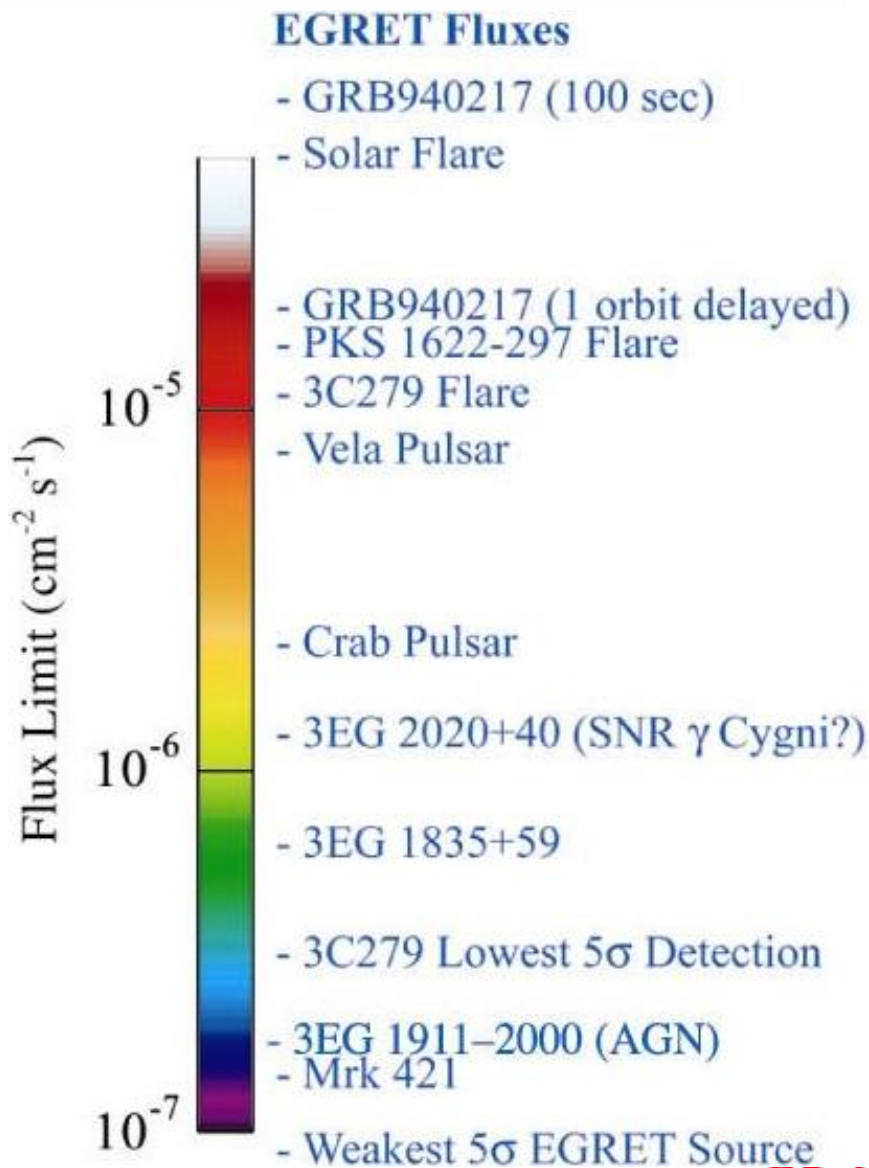
Pointed-Scan Mode: the target is kept within the central 30° to maximize target exposure and avoid the Earth.

Autonomous repoint: when the GBM or LAT detects a sufficiently bright burst, GLAST will repoint towards the burst location for 5 hours, except for Earth occultations.

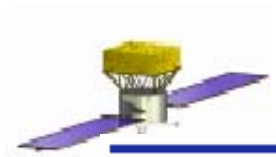
Target of Opportunity (TOO): repointing commanded from the ground in response to an astronomical event. Repointing should occur within 6 hours of the approval of the TOO.

Scanning Mode Sensitivity





(a) In scanning mode GLAST will achieve after one day a sensitivity sufficient to detect (5σ) the weakest EGRET sources.



Sensitivity and Sky Map

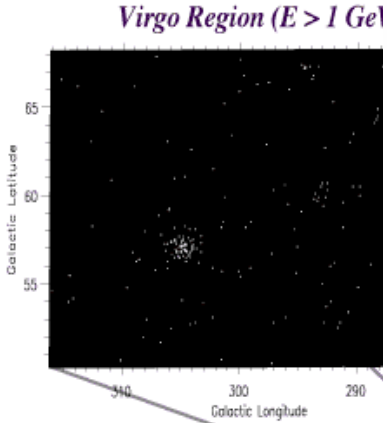
EGRET

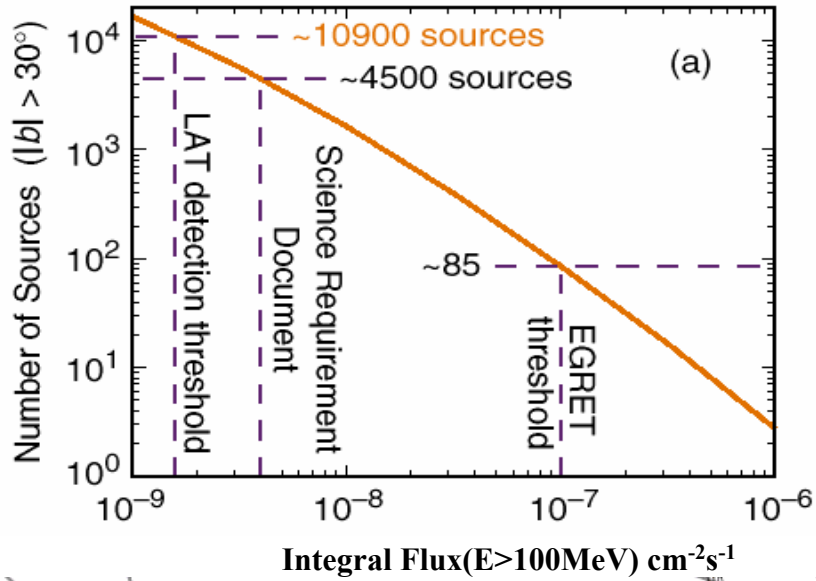
GLAST

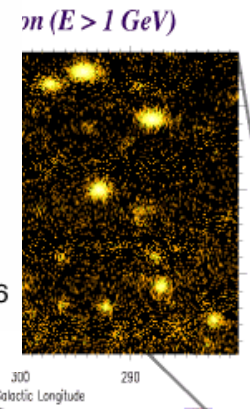
⇒ larger effective area

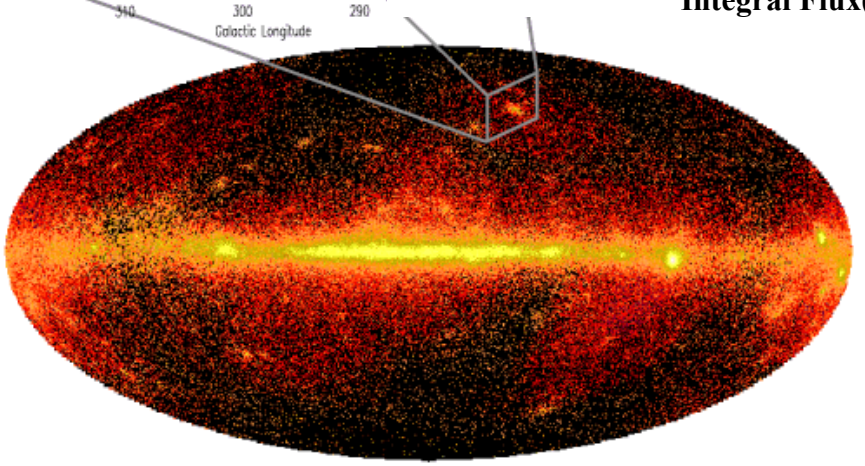
⇒ larger field of view

⇒ increased sensitivity

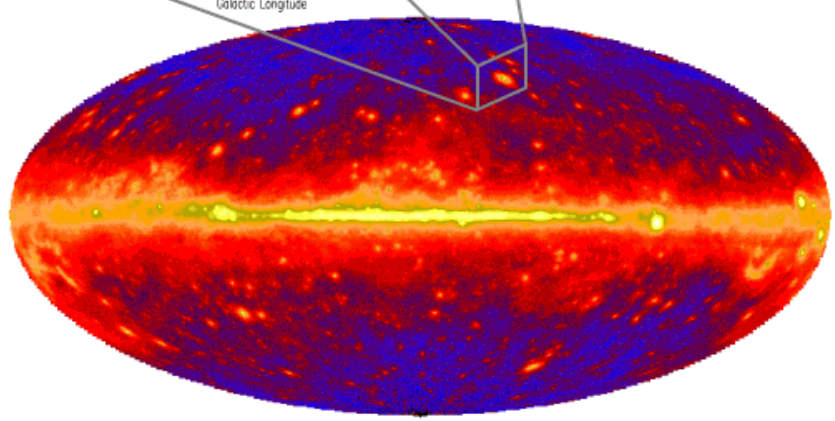








EGRET One-Year, All-Sky Survey (E > 100 MeV)

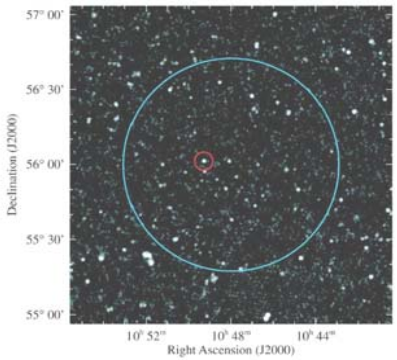


GLAST One-Year, All-Sky Survey (E > 100 MeV)

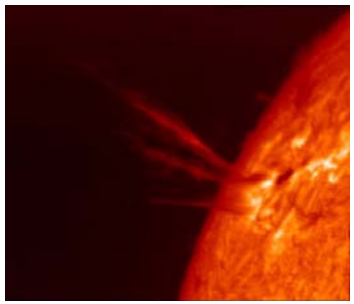
Science Performance Requirements

Parameter	SRD Value	Present Prediction
Peak Effective Area (in range 1-10 GeV)	>8000 cm^2	10,000 cm^2 at 10 GeV
Energy Resolution 100 MeV on-axis	<10%	9%
Energy Resolution 10 GeV on-axis	<10%	8%
Energy Resolution 10-300 GeV on-axis	<20%	<15%
Energy Resolution 10-300 GeV off-axis (>60□)	<6%	<4.5%
PSF 68% 100 MeV on-axis	<3.5°	3.37° (front), 4.64° (total)
PSF 68% 10 GeV on-axis	<0.15°	0.086° (front), 0.115° (total)
PSF 95/68 ratio	<3	2.1 front, 2.6 back (100 MeV)
PSF 55°/normal ratio	<1.7	1.6
Field of View	>2sr	2.4 sr
Background rejection (E>100 MeV)	<10% diffuse	6% diffuse (adjustable)
Point Source Sensitivity(>100MeV)	$<6x10^{-9}$ $cm^{-2}s^{-1}$	$3x10^{-9}$ $cm^{-2}s^{-1}$
Source Location Determination	<0.5 arcmin	<0.4 arcmin
GRB localization	<10 arcmin	5 arcmin

GLAST Science

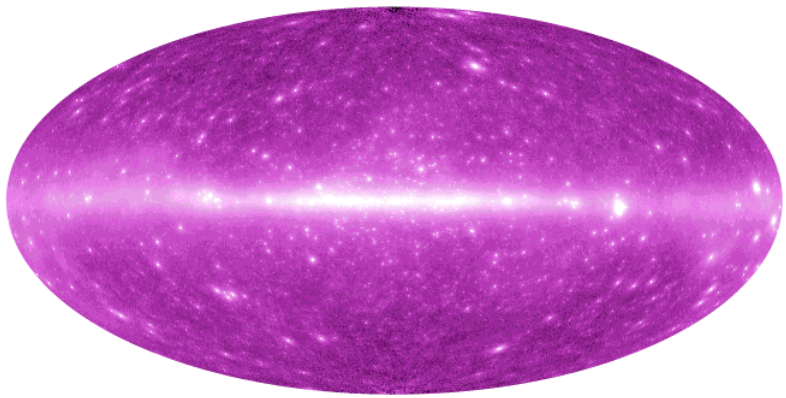


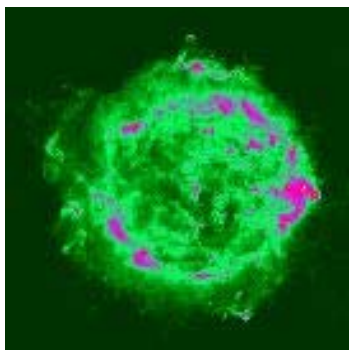
Unidentified sources



Solar flares

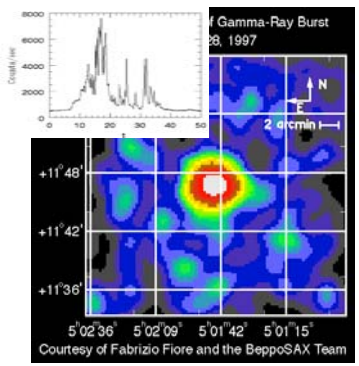
Pulsars



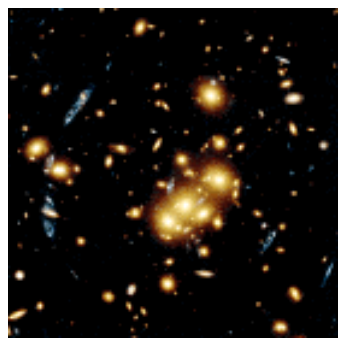


Cosmic ray acceleration

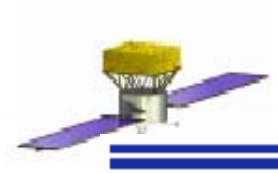
Active Galactic Nuclei



Gamma Ray Bursts

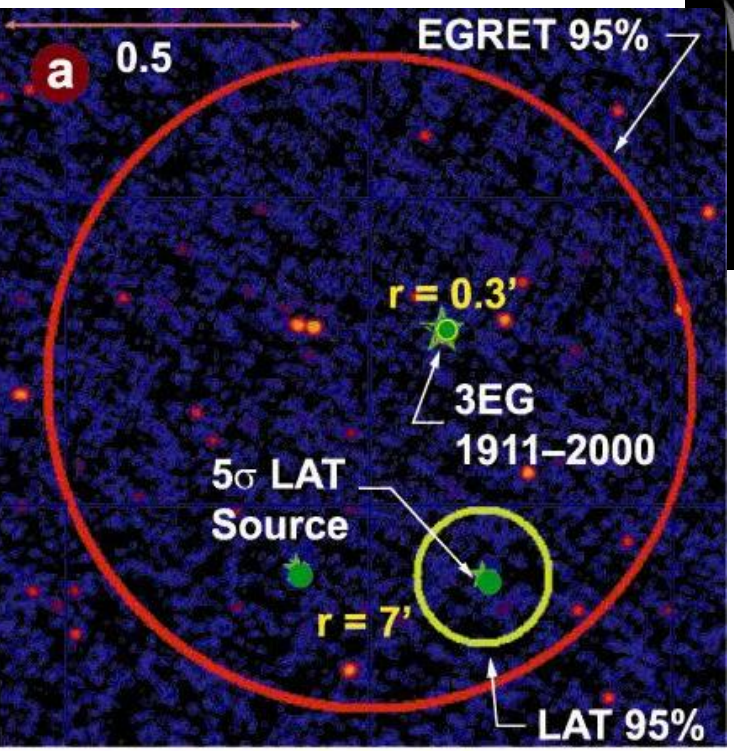


Dark matter

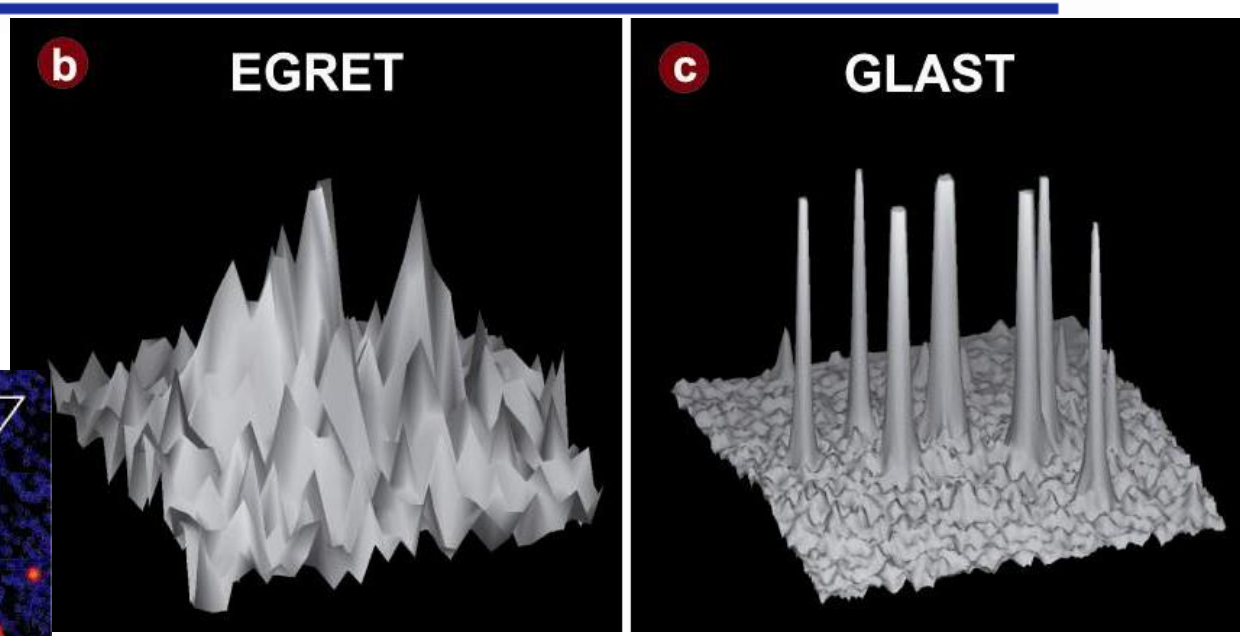


Identifying Sources

GLAST 95% confidence radii localizations of a 5σ source in the one-year sky survey and of the EGRET source 3EG 1911-2000.



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



Conparision of EGRET and GLAST simulated observations of the Cygnus region E>1GeV (15x15).

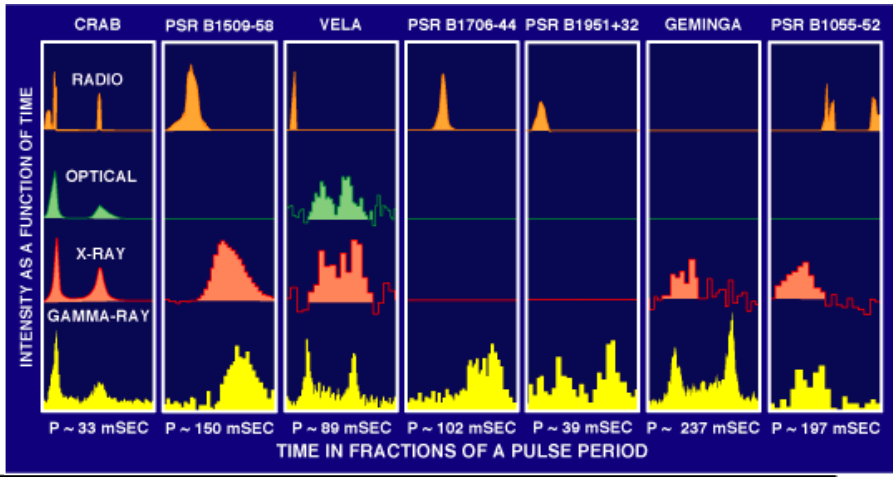
GLAST high resolution and sensitivity will:

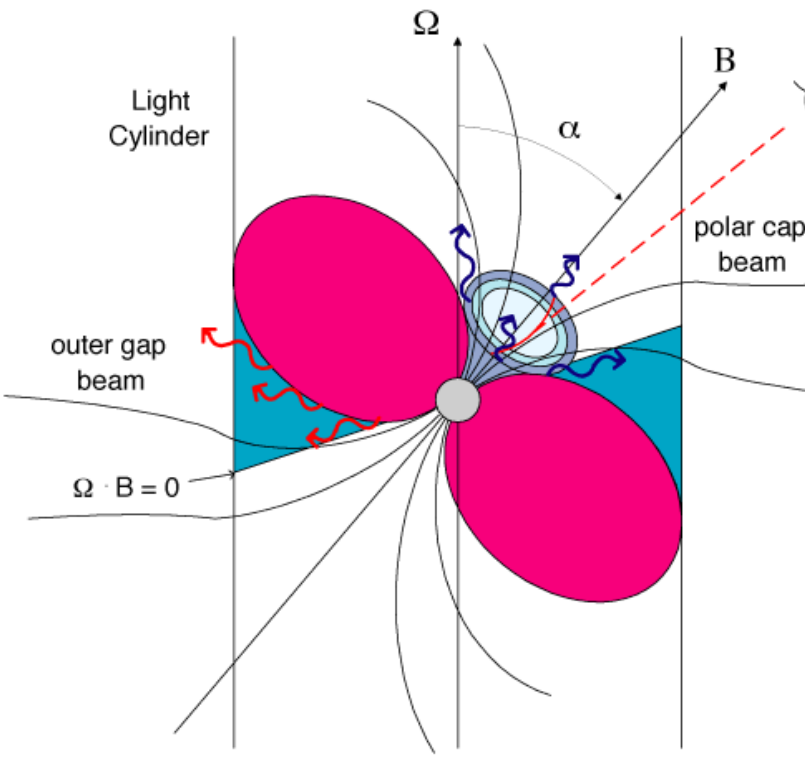
- Resolve gamma-ray point sources at arc-minute level
- Detect typical signatures (e.g. spectra, flares, pulsation) for identification with known source types

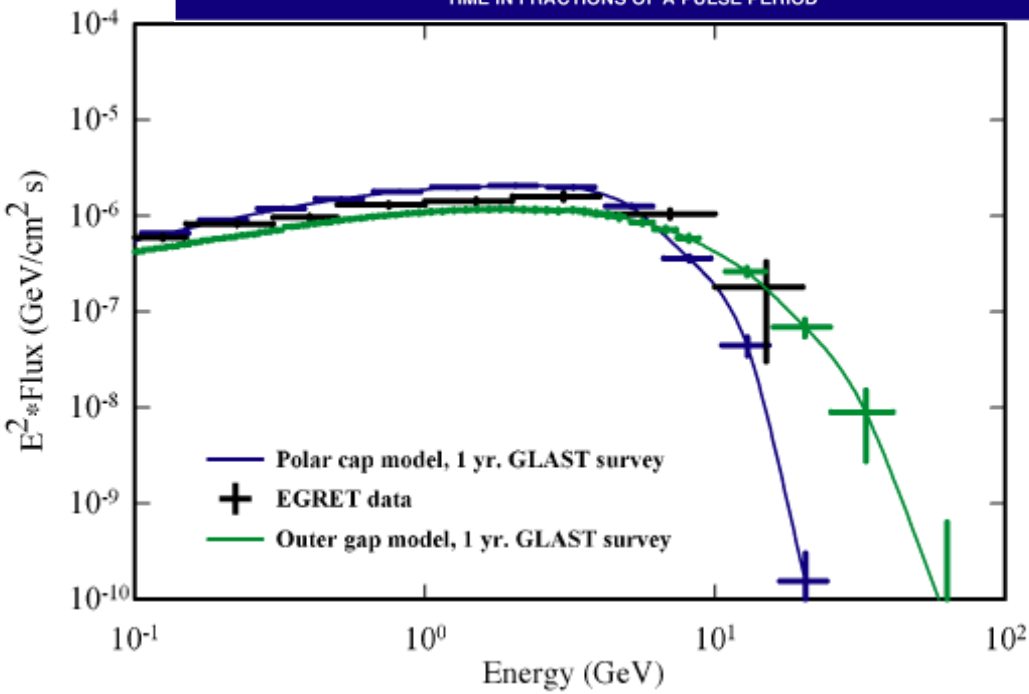
Pulsars

high time resolution
- direct pulsation search in the γ-ray band

large effective area
- detect new gamma-ray pulsars (~250)
- precise test of polar cap vs outer gap emission models







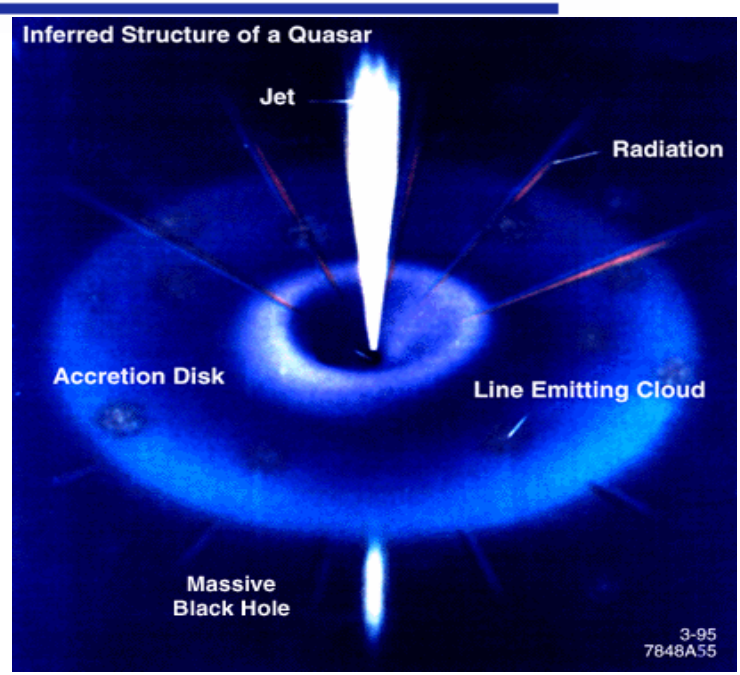
Active Galactic Nuclei

AGN signature:

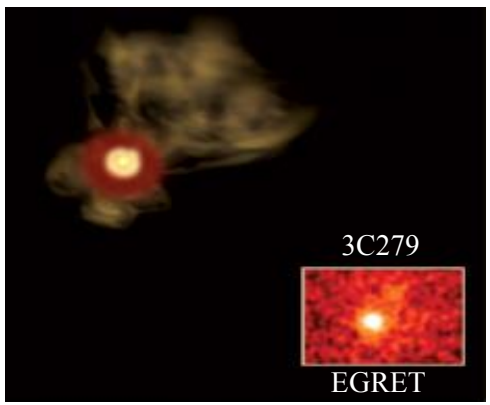
- vast amounts of energy (10^{49} erg/s) from a very compact central volume
- large luminosity fluctuations in fractions of a day
- energetic (multi-TeV), highly-collimated, relativistic particle jets

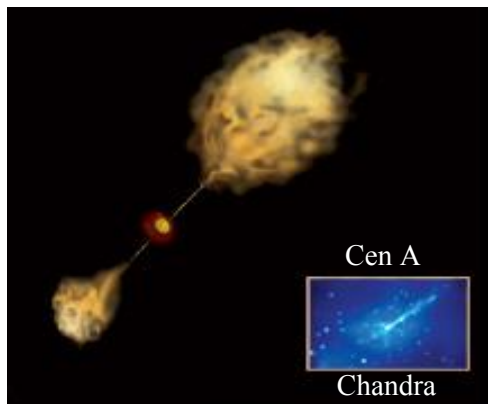
Prevailing idea:

accretion onto super-massive black holes (10^{6} - 10^{10} solar masses)

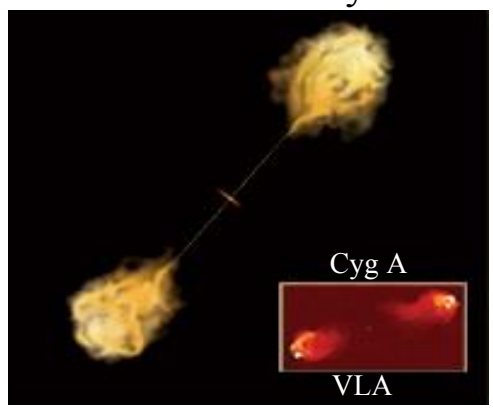


Blazar

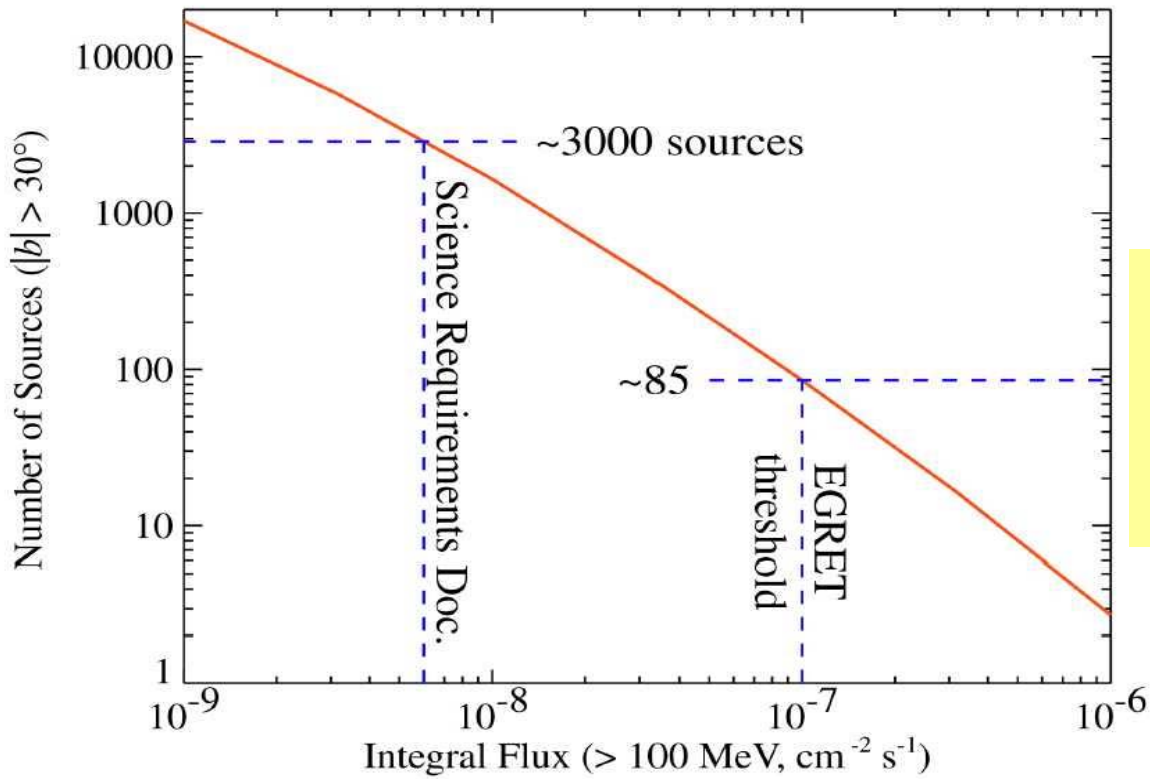




Radio Galaxy



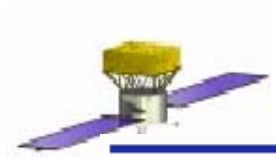
Active Galactic Nuclei II



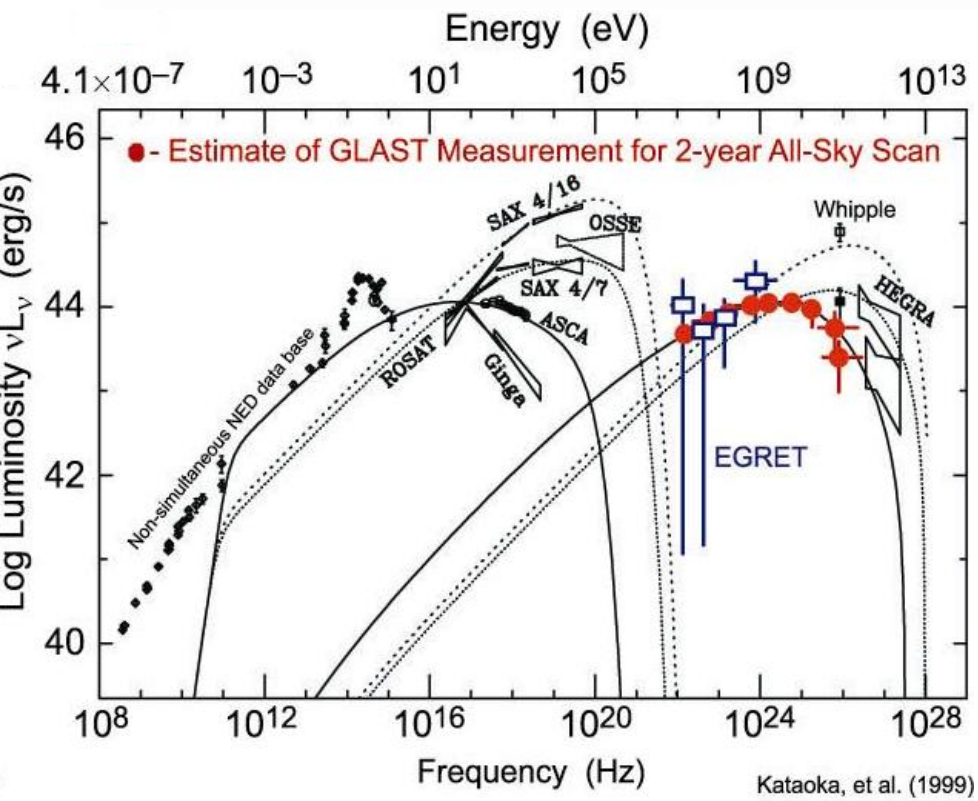
- high sensitivity
- large effective area
- small PSF

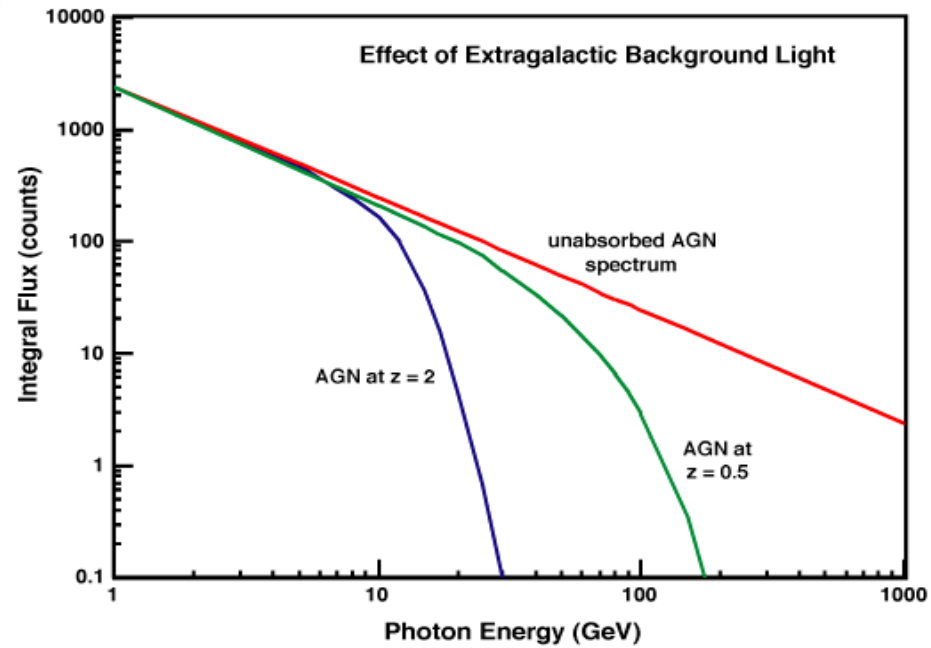
AGN physics *to-do* list:

- catalogue AGN classes with a large data sample (~>3000 new AGNs)
- distinguish different emission models studying high statistics spectra
- resolve diffuse background
- study redshift dependence of spectra exploiting overlap with other wavelength observations and alert capabilities



Active Galatic Nuclei III





Blazar physics:

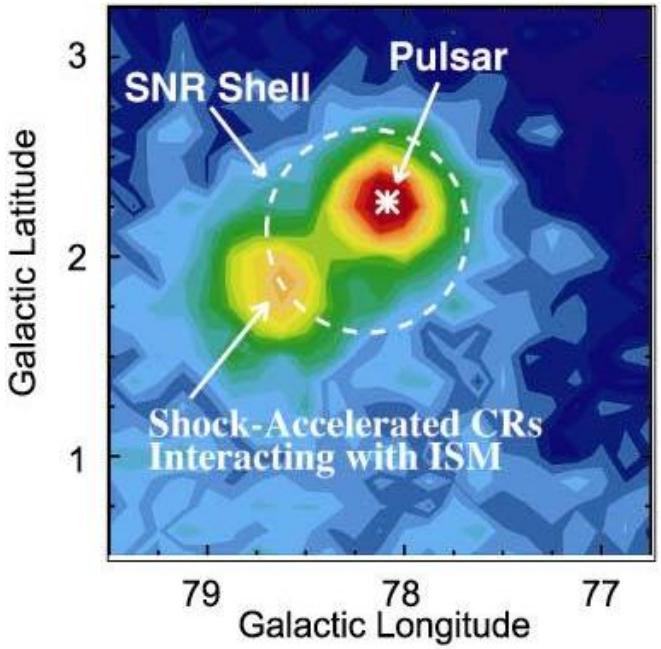
- measure spectrum in uncovered gamma-ray energy band
- identify leptonic (SSC/ESC) and hadronic (π^0 decay) contributions
- track flares (time scale of minutes) and correlate to other wavelengths

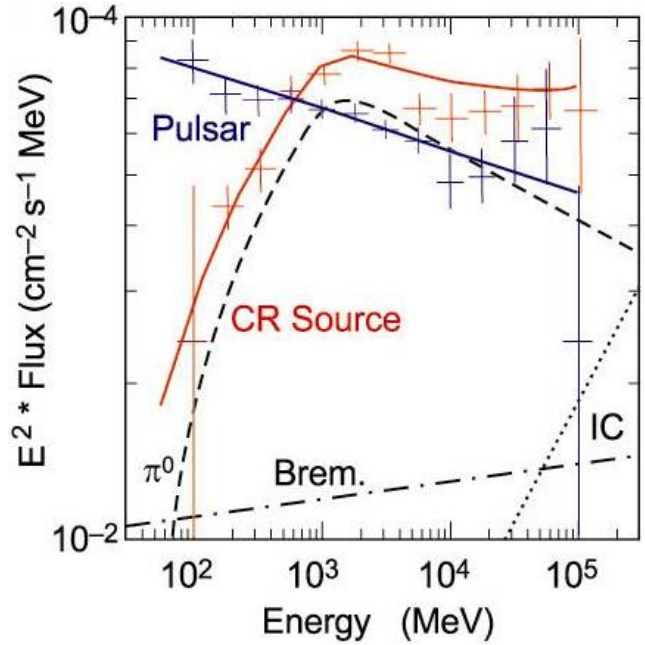
Cosmology models:

- Roll-offs in the γ-ray spectra from AGN at large z probe the extragalactic background light (EBL) over cosmological distances and may help to distinguish models of galaxy formation
- GLAST will measure 1000's of Blazars
- ACT's (STACEE, CELESTE, Whipple, ...)

CR production and acceleration in SNR

SNR widely believed to be the source of CR proton acceleration after shell interaction with interstellar medium. π^0 bump in the galactic spectrum detected by EGRET

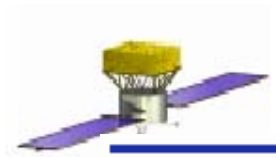




GLAST simulations showing SNR γ-Cygni spatially and spectrally resolved from the compact inner γ-ray pulsar. A clear π^0 decay signature from the shell would indicate SNR as a source of CR protons.

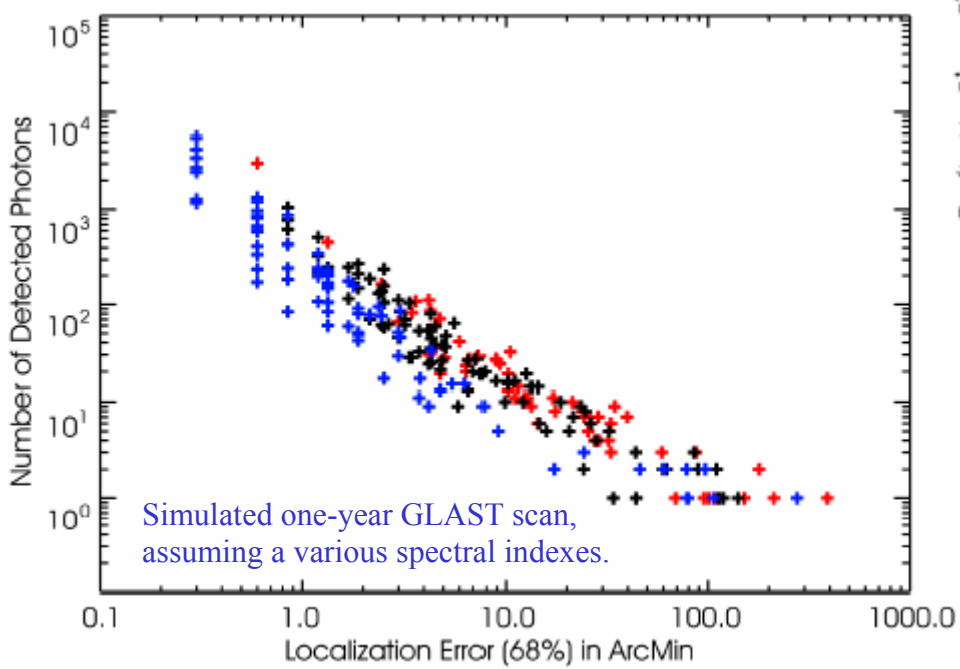
GLAST will:

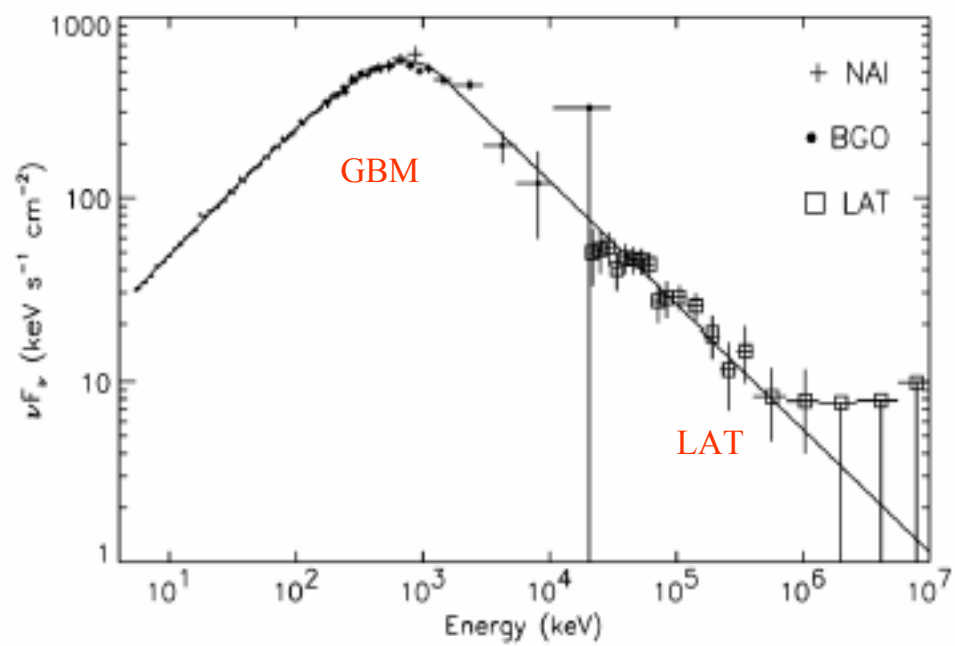
- locate SNR
- resolve SNR shells at 10′ level
- measure SNR spectra



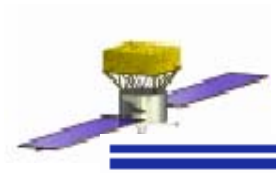
Gamma-Ray Bursts

- GLAST LAT will be best suited to studying the GeV tail of the gamma-ray burst spectrum. The GLAST GBM will cover the energy range 10keV-25MeV and will provide a hard X-ray trigger for GRB.
- GLAST should detect ~200 GRB per year with E>100MeV, with a third of them localized to better than 10´, in real time.
- Excellent wide field monitor for GRB. Nearly real-time trigger for other wavelength bands, often with sufficient localization for optical follow-up.
- With ~10μs dead time, GLAST will see nearly all of the high energy photons.

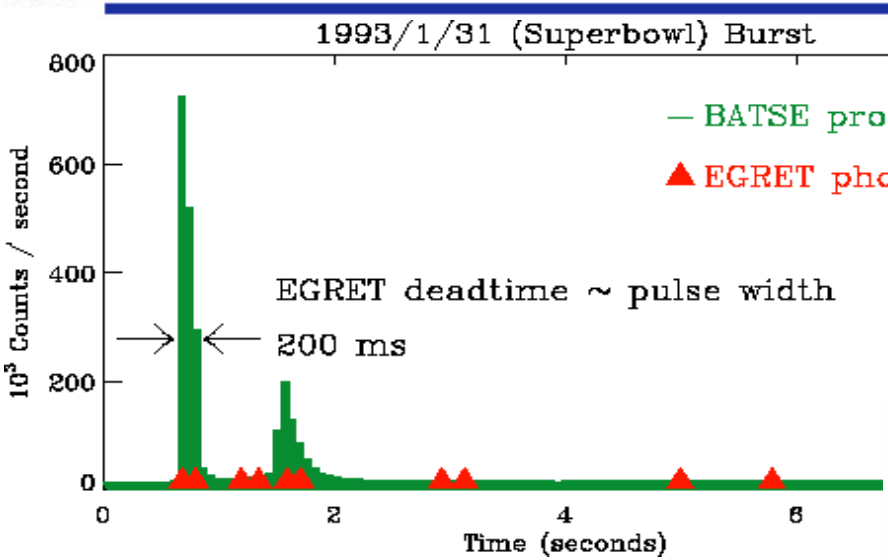




LAT – GBM complimentarity



Gamma-Ray Bursts II



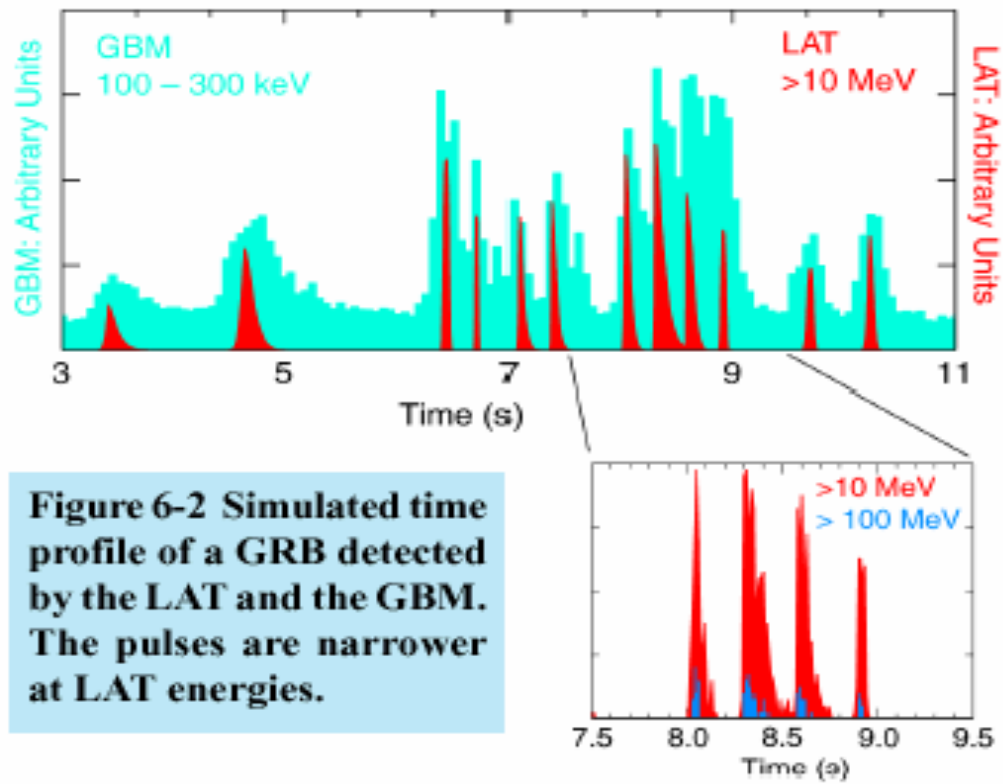


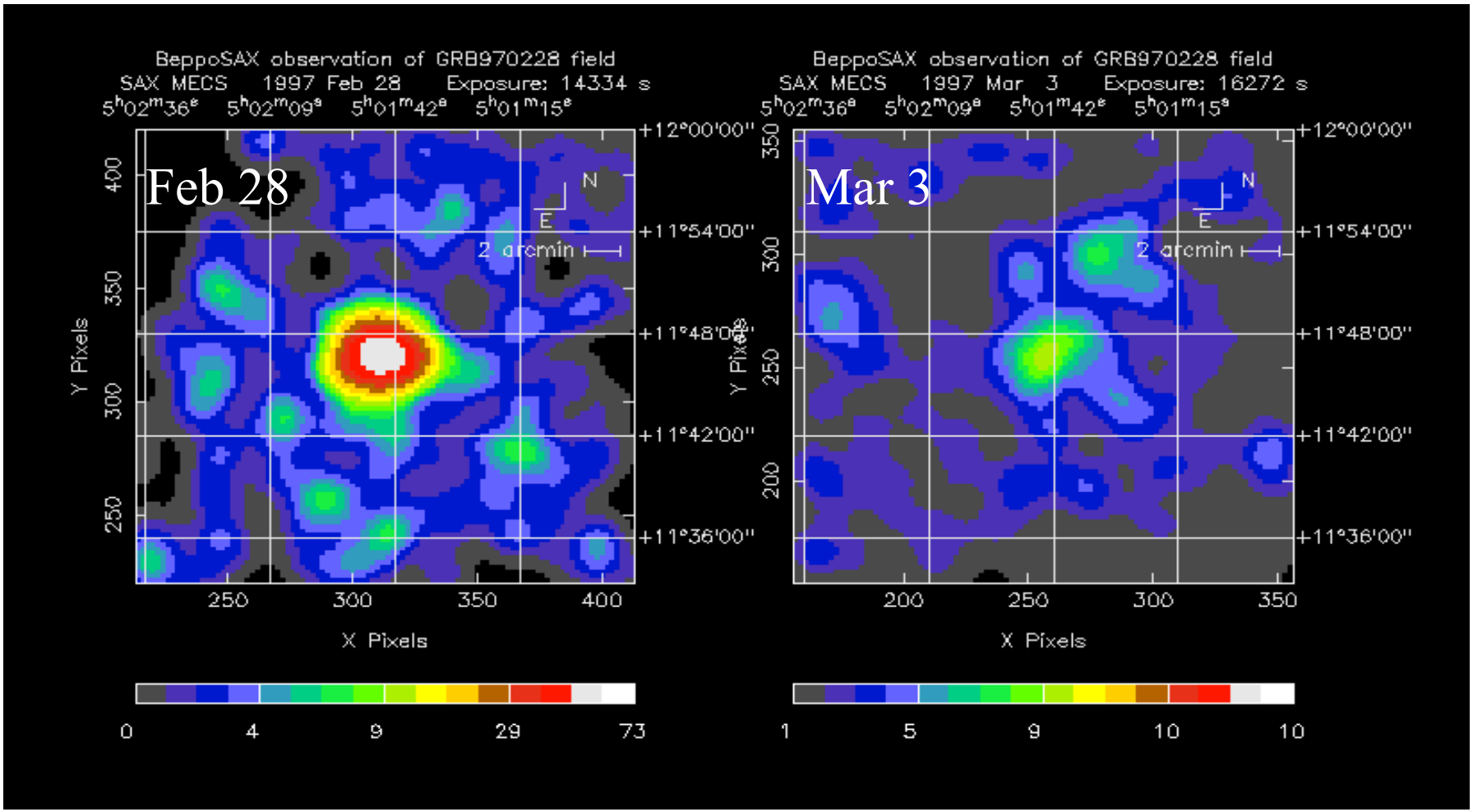
Figure 6-2 Simulated time profile of a GRB detected by the LAT and the GBM. The pulses are narrower at LAT energies.

fast response/ short dead time:

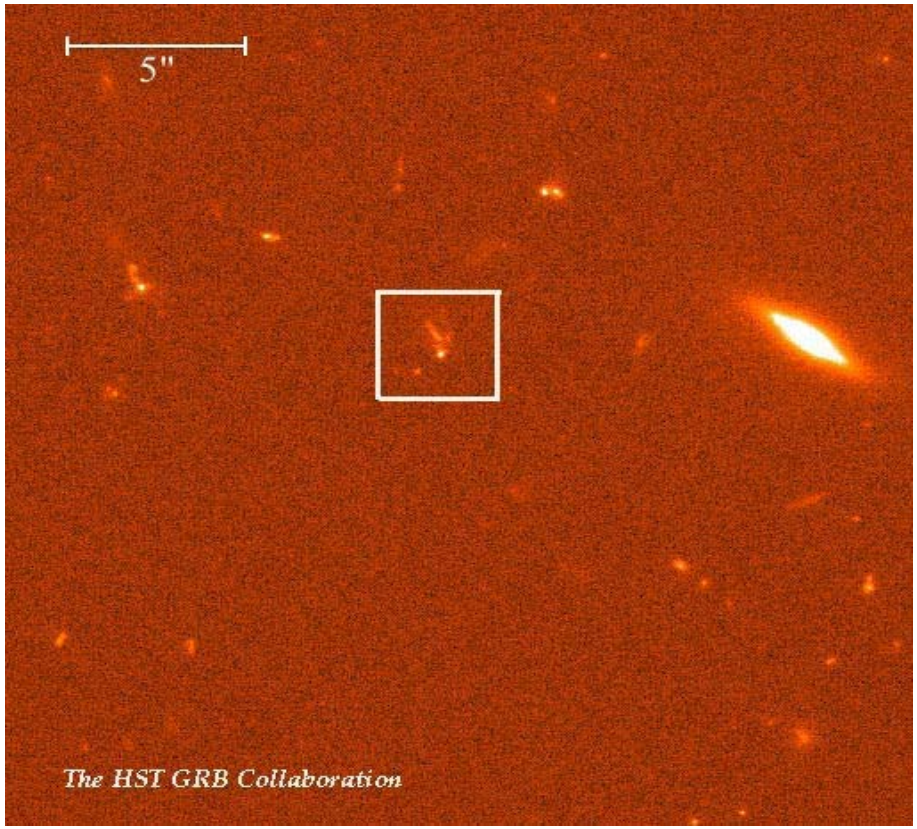
- transient signal, ≈100 μs time scale
- light curve vs. energy

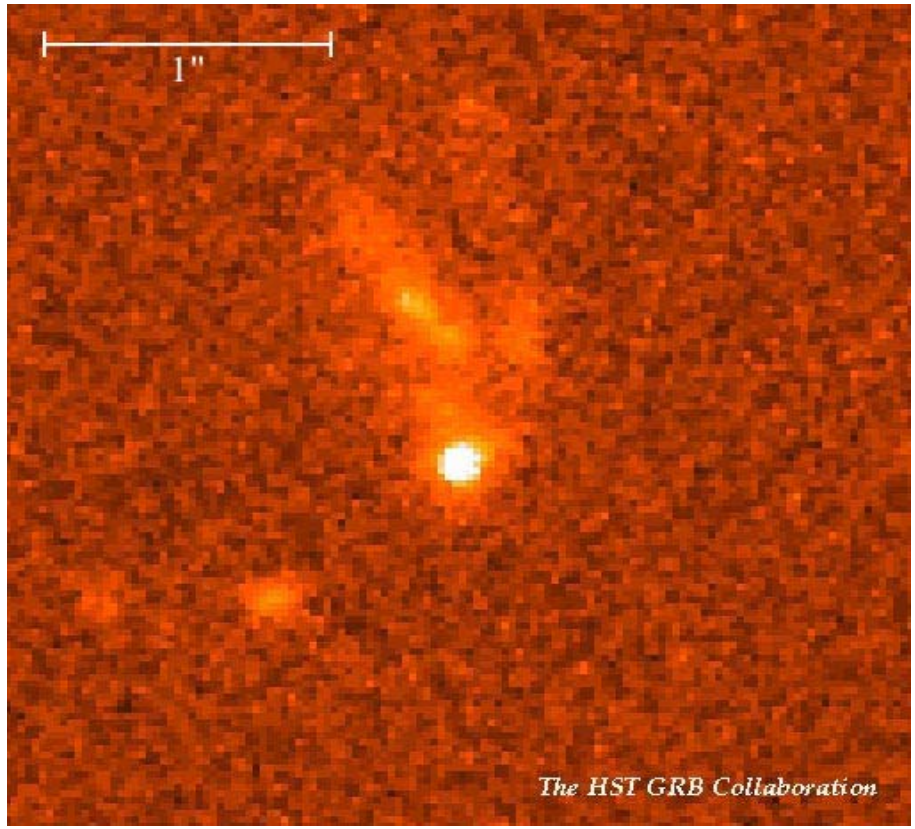
The Afterglow Era

GRB970228, discovered by BeppoSAX

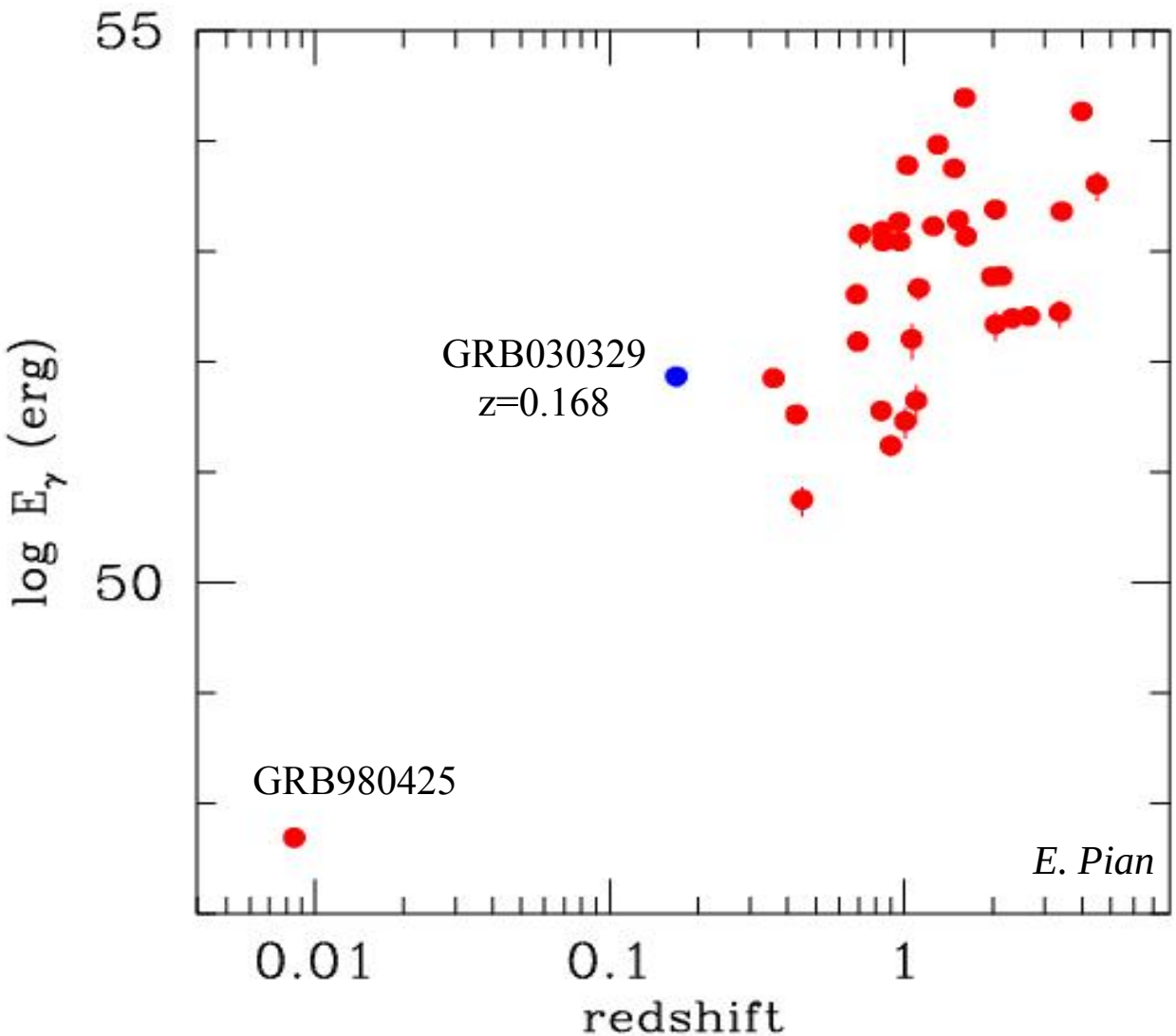


The Afterglow Era II

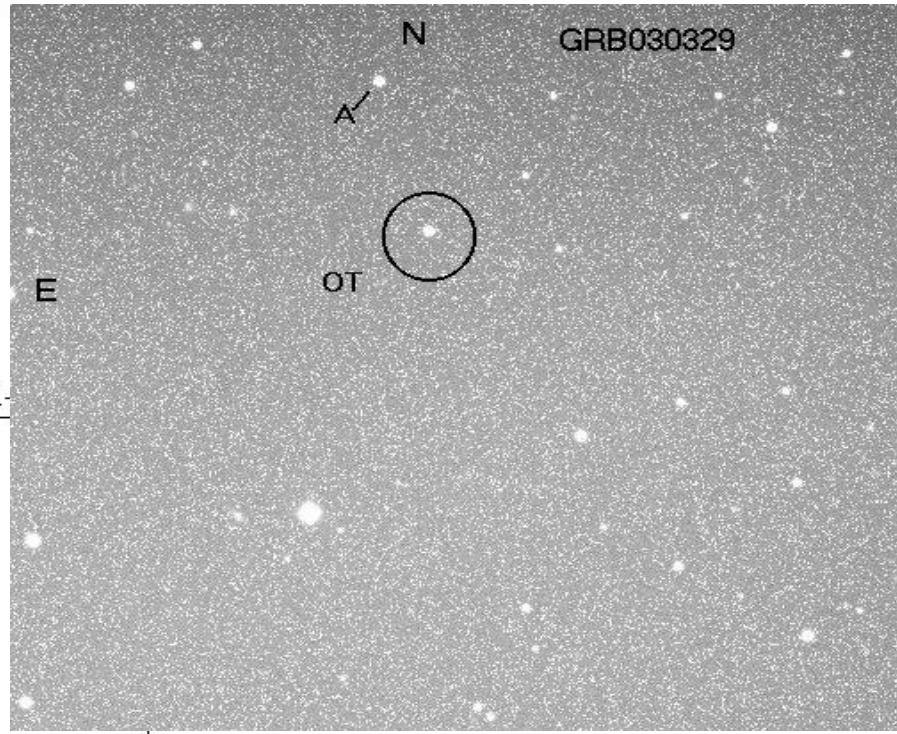




The Red-Shift of GRB's



GRB030329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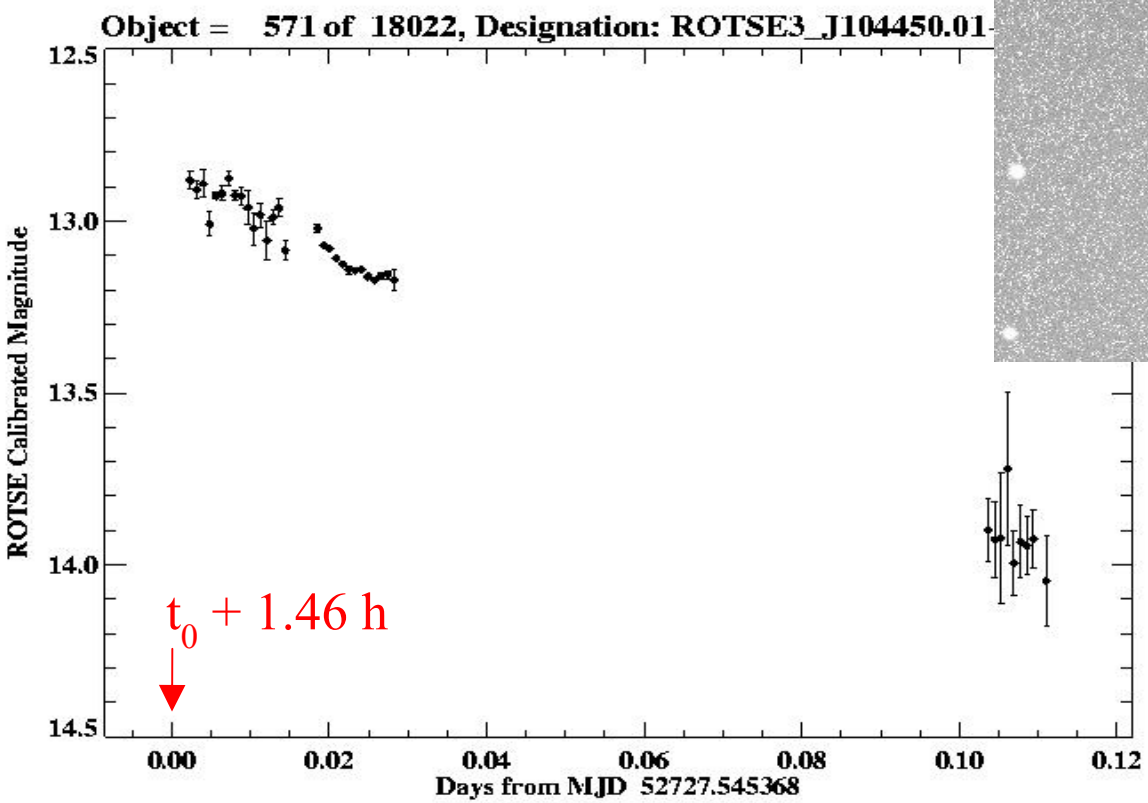
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ROTSE Calibrated Magnitude
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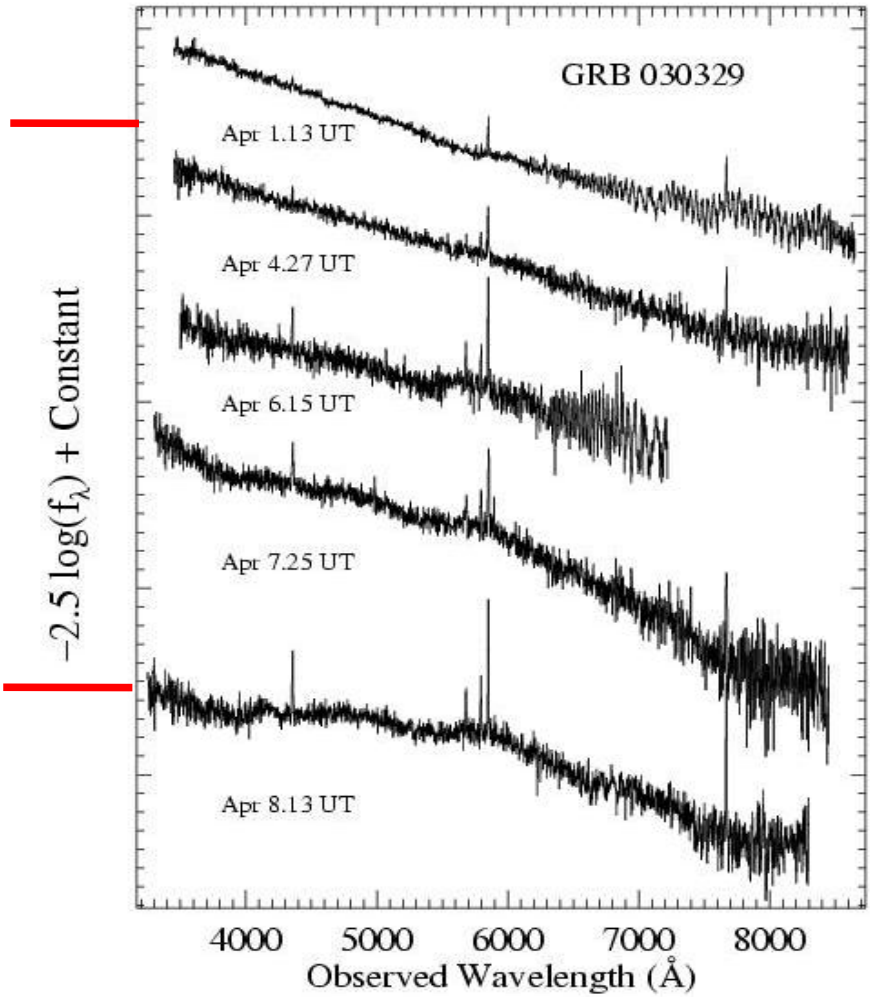
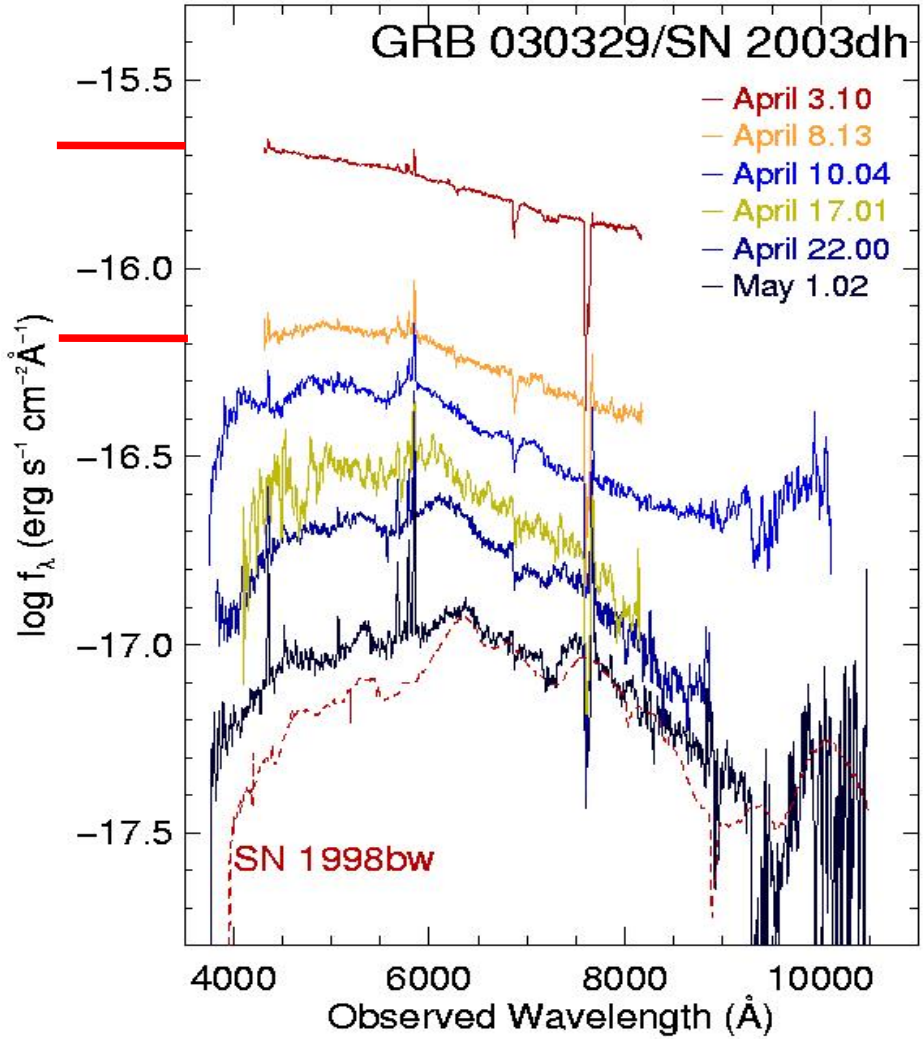
13.0
13.5
14.0
14.5
0.00
0.02
0.04
0.06
0.08
0.10
0.12
Days from MJD 52727.545368
t_0 + 1.46 h

GRB030329 Spectra



MMT (6.5m)
astro-ph/0304173

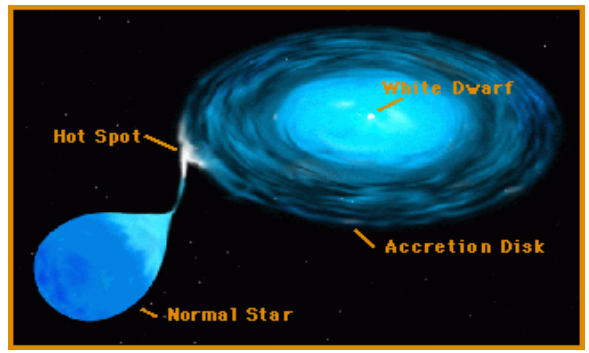


VLT FORS (8m)
astro-ph/0306347

Supernovae

Classification by spectra (historically):

- Type I: no Hydrogen lines
  - Ia: strong Si line
  - Ib: no H, no Si, but He
  - Ic: no H, no He, no Si
- Type II: Hydrogen lines



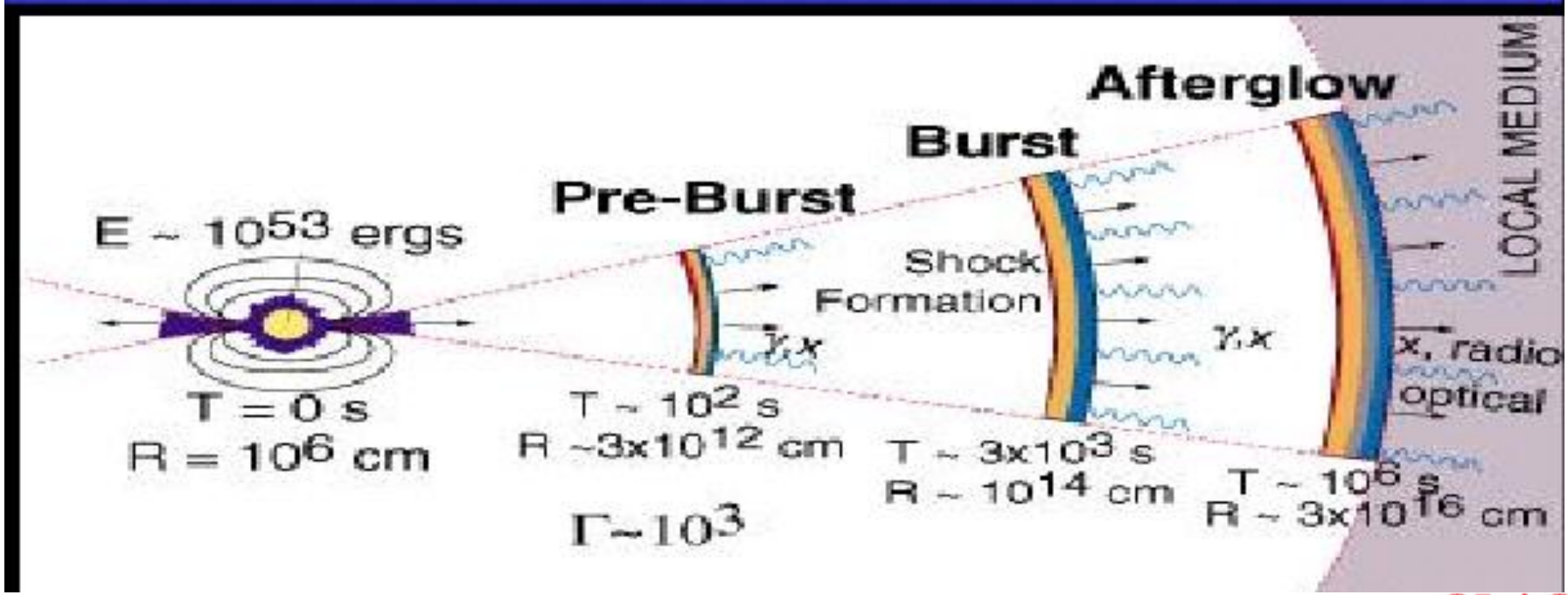
Classification by origin:

- Type Ia: seen in all type of galaxies, white dwarf in binary system
- Type Ib/c,II: seen only in spiral arms of spiral galaxies, massive stars
  - Ib/c: core collapse of massive stars

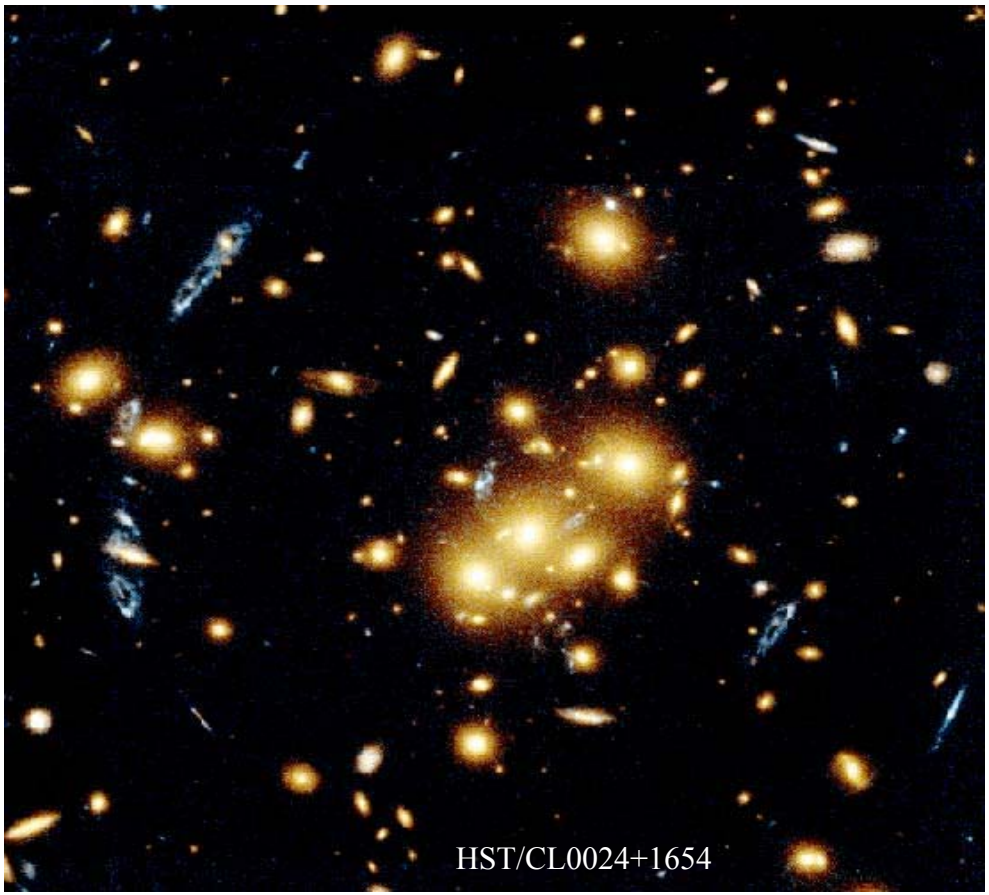
Population III supermassive stars (>100M_{sun}): Hypernova?

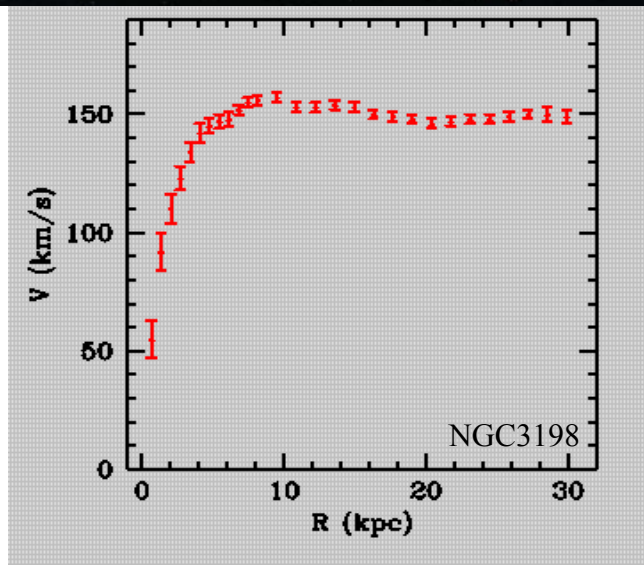
Fireball Model

- Central engine emits shells of matter (e-, e+)
- The shells move with Lorentz Factors ~ 10^3
- The faster shells collide against the slower ones, producing an inelastic shock
- The shock wave accelerates e- and e+, which emit by synchrotron radiation
- Inverse Compton scattering (self synchrotron Compton) can produce high energy photons
- The afterglow is due to the interaction with the ISM (External Shock)



Dark Matter

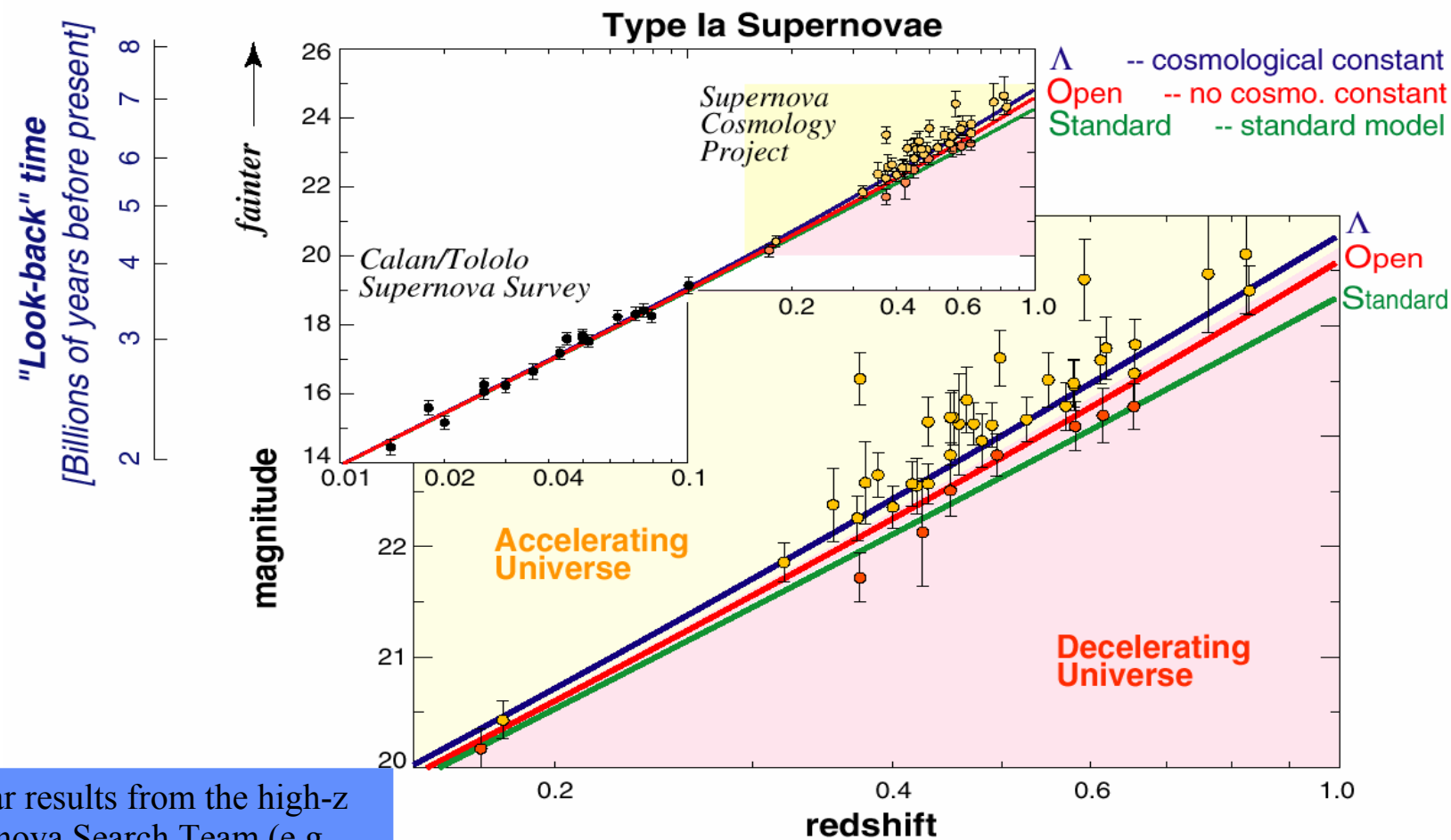




Dark Matter makes up over 90% of the matter in the Universe!

Cosmology

Use type Ia supernovae corrected candles to measure the expansion rate. Ground-based work thus far has uncovered a major surprise:

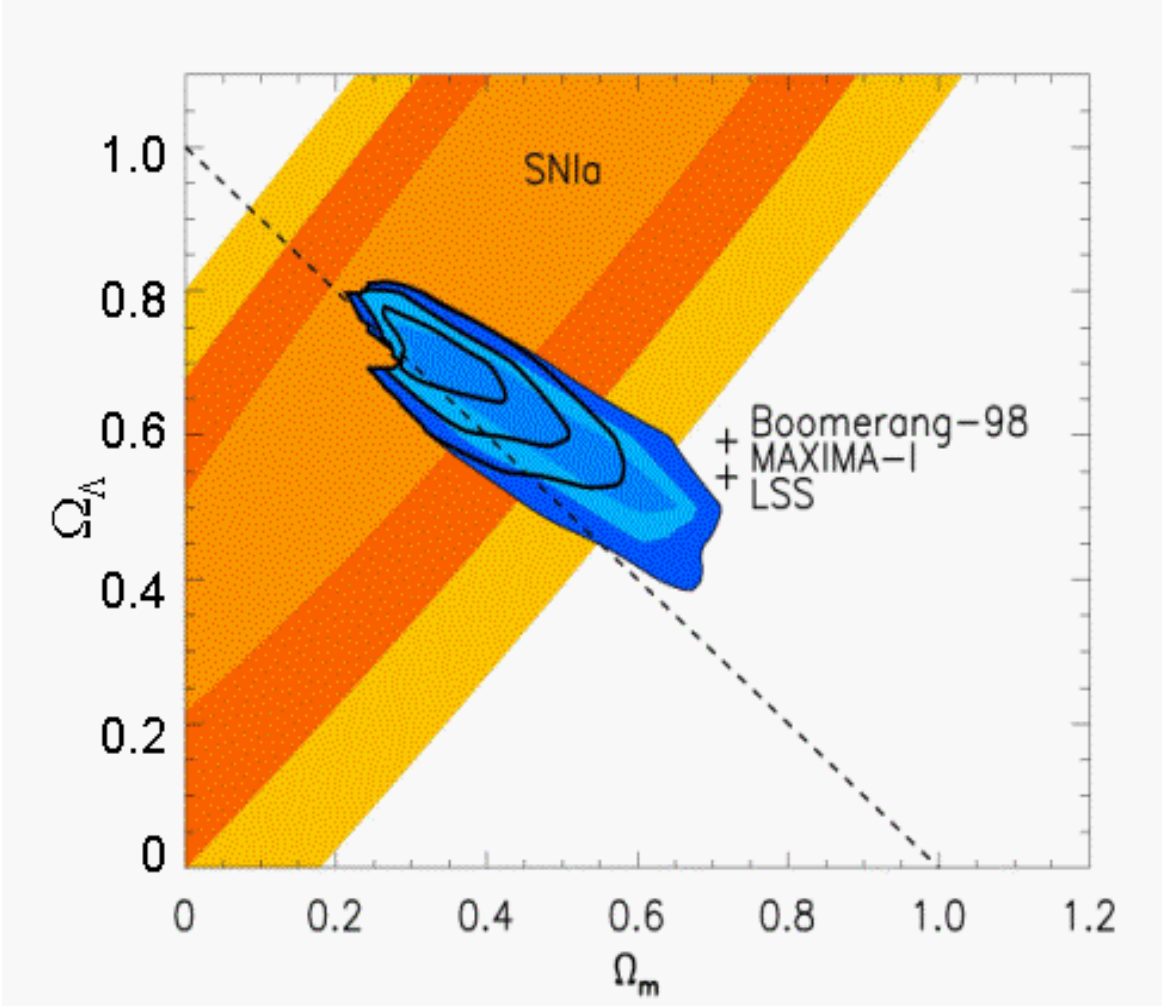


Similar results from the high-z Supernova Search Team (e.g. Riess et *al.* AJ116(1998))

Observational constraints on Ω_m and Ω_λ

Bright stars: 0.5%
Baryons (total): 4% ± 1%
Nonbaryonic dark matter: 29% ± 4%
Neutrinos: at least 0.1% (up to 5%?)
Dark Energy: 66% ± 6%

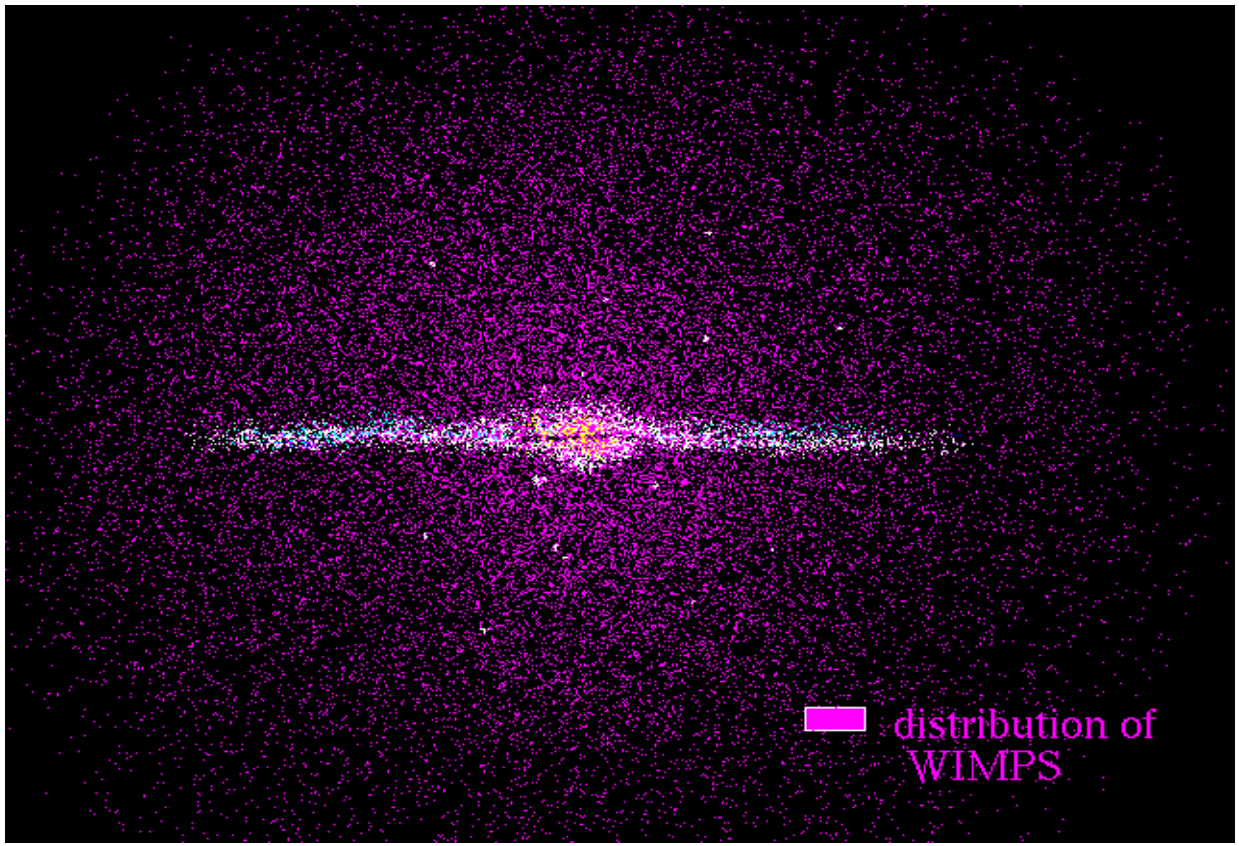
(Michael S. Turner *astro-ph/0207297*)



A.H. Jaffe et al., *astro-ph/0007333*

WIMP's

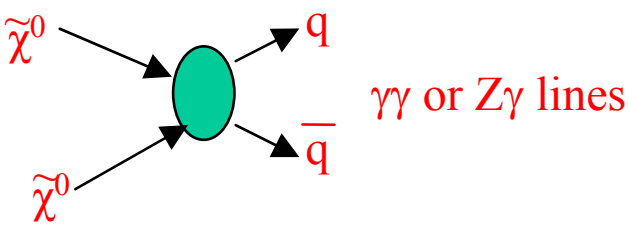
Dark matter may be Weakly Interacting Massive Particles

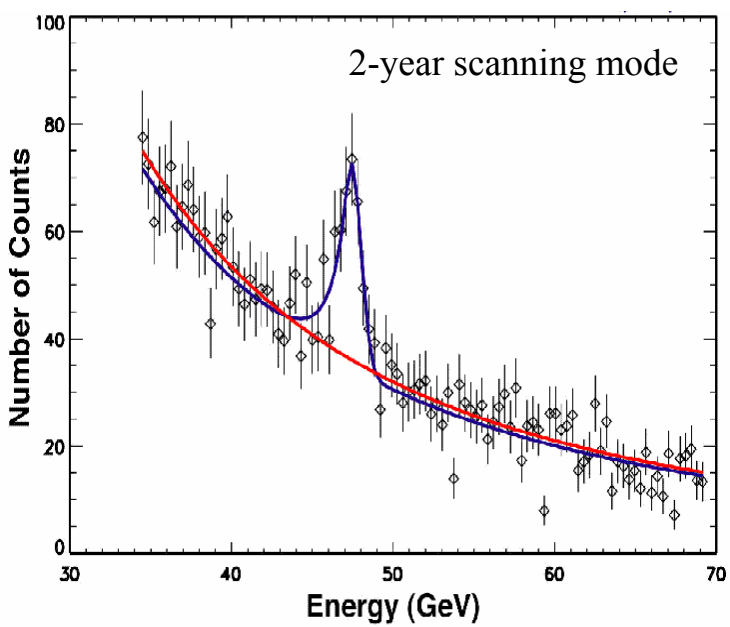


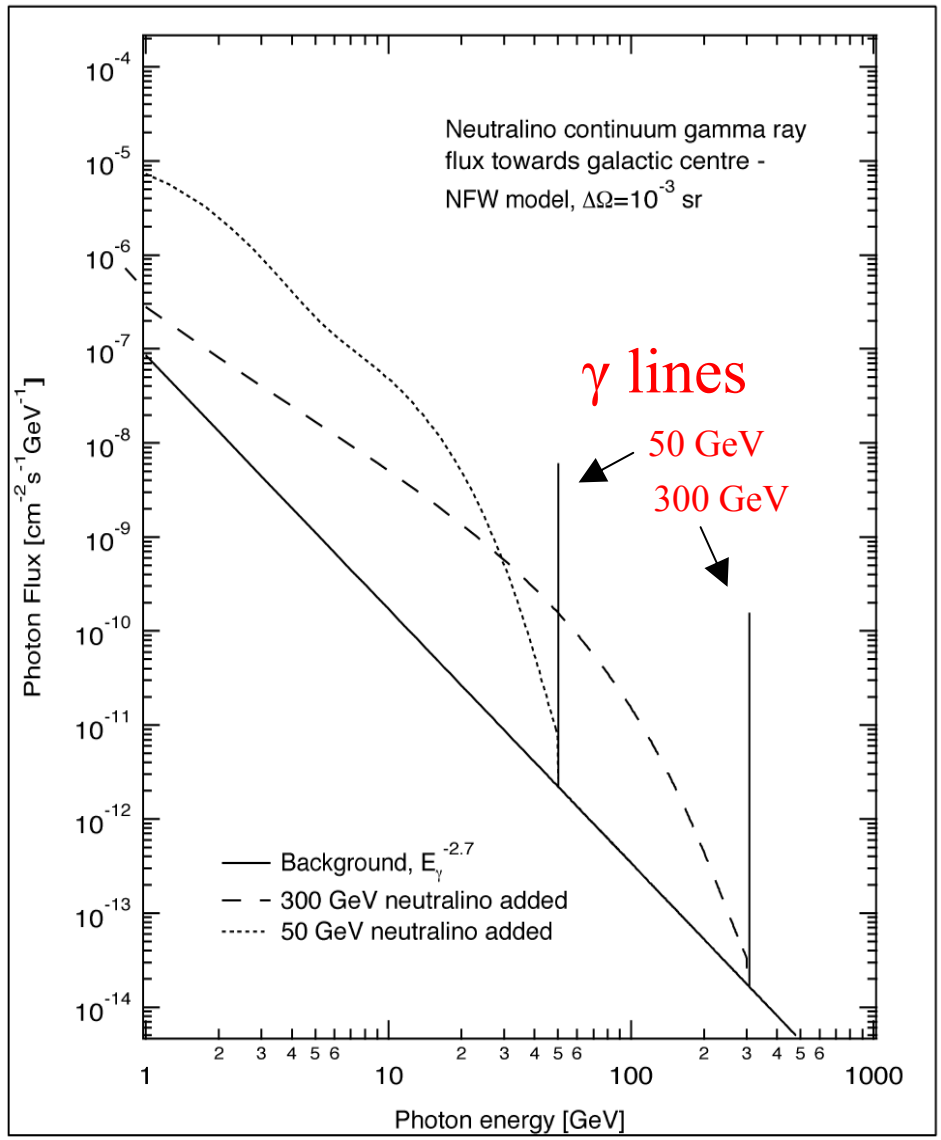
a simulation of WIMP's in the halo of our galaxy

Halo WIMP Signal

Good particle physics candidate for galactic halo dark matter is the LSP in R-parity conserving SUSY

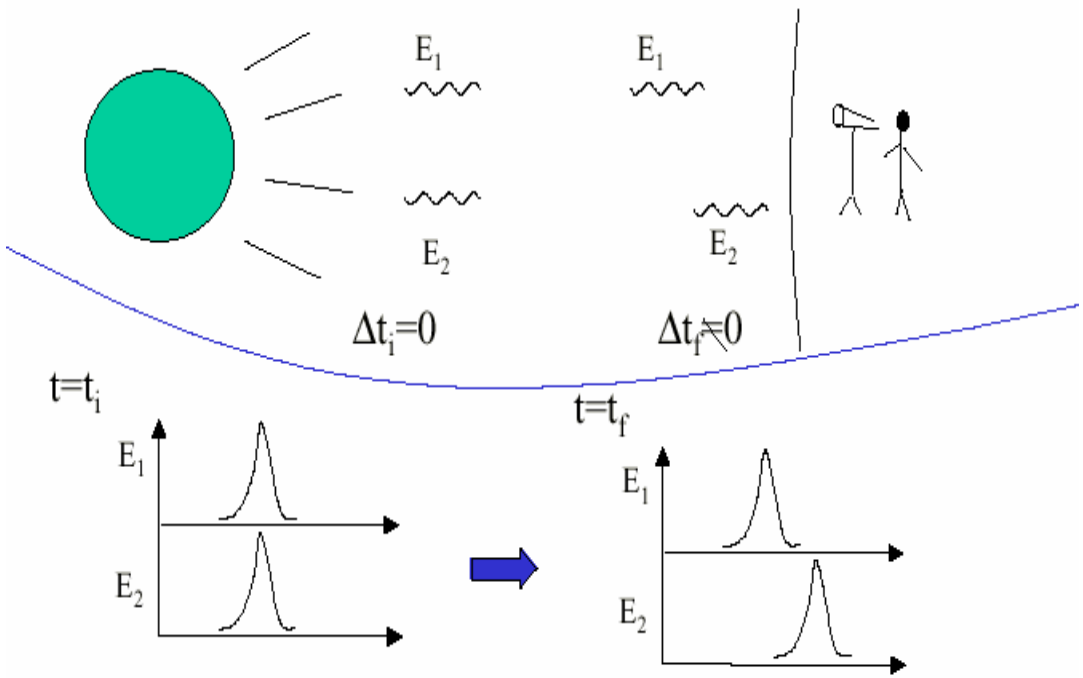


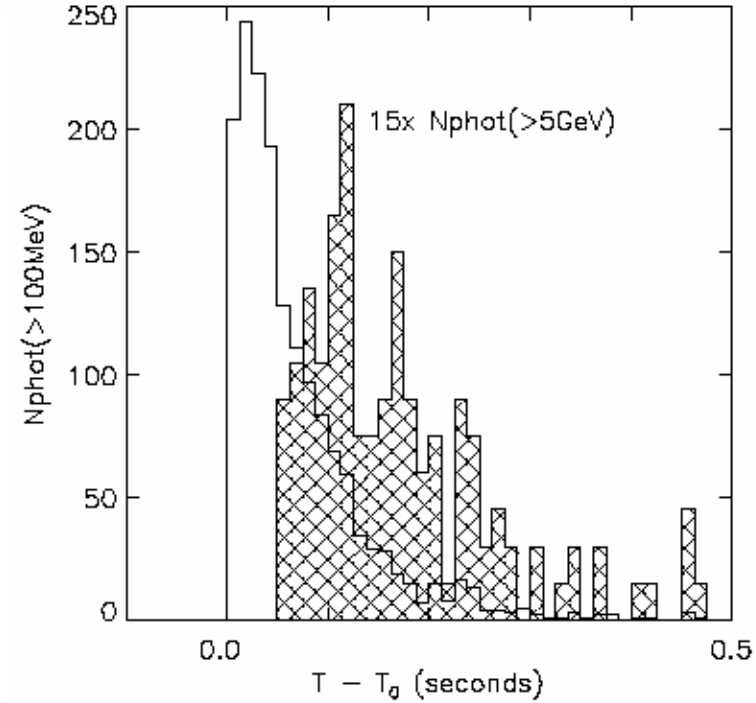




Quantum Gravity

Test of Quantum Gravity $\Delta t = \sim \alpha\, E/E_{QG}\, D/c$





Arrival time distribution for two energy cuts 0.1 GeV and 5 GeV (cross-hatched)

$D \sim 2\ 10^{28}$ cm $E_{QG} \sim 10^{19}$ GeV $c \sim 3\ 10^{10}$ cm ➡ $\Delta t(\text{ms}) \sim 60\ \Delta E(\text{GeV})$

even at pulsars distance: $D \sim 6\ 10^{21}$ cm $\Delta t(\mu\text{s}) \sim 100$ ➡ $E_{QG} \sim 10^{14}$ GeV

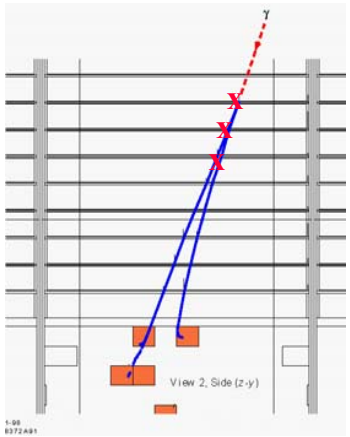
Using only the 10 brightest bursts yr^{-1}, GLAST would easily see the predicted energy- and distance-dependent effect.

Instrument Trigger & Onboard Data Flow

Level 1 Trigger

- hardware trigger
- single tower
- initiates readout

Function: "did *anything* happen?"



- **TKR 3 *x•y* pair planes in a row**

workhorse 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 within 20μs

Instrument Total L1T Rate: <4 kHz>*

* peak ~12 kHz (down to 3.8 kHz with throttle)

* possible because of no consumables, little dead-time, fast CPUs

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.

- **subset of full background rejection analysis, with loose cuts**
- **only use quantities that**
  - **are simple and robust**
  - **do not require application of sensor calibration constants**
- **complete event information**
- **signal/bkgd tunable, depending on analysis cuts:**
  - **cosmic-rays~ 1:~few**

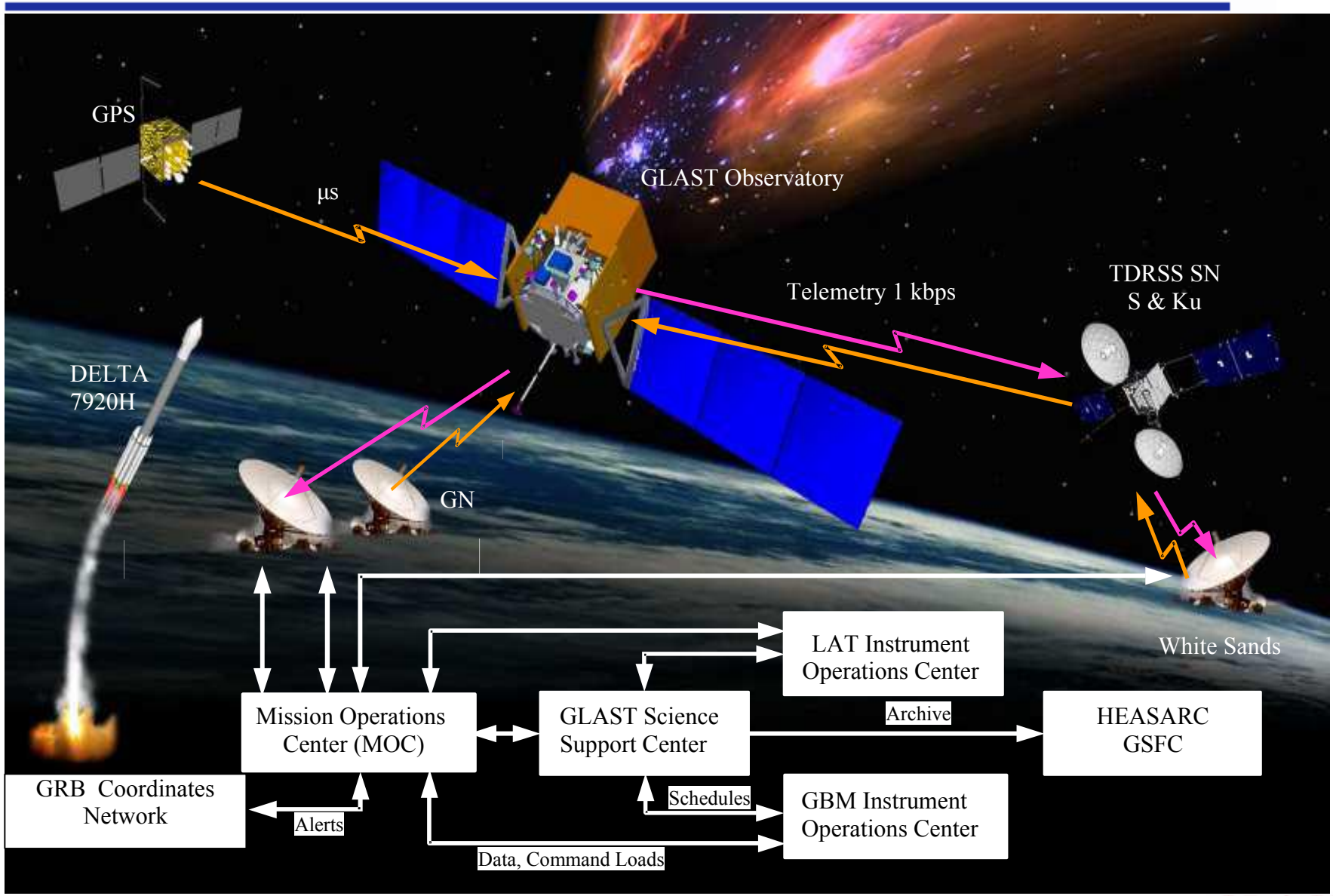
Total L3T Rate: <25-30 Hz>

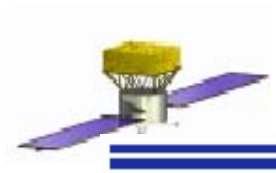
(average event size: ~8-10 kbits)

On-board science analysis:
transient detection (AGN flares, bursts)

Spacecraft

GLAST Mission Elements





Telemetry

The mission data (science & housekeeping) are downlinked ~4-5 times per day through a 40 Mbps Ku-band TDRSS link, while commands are uplinked on a 4 kbps S-band link.

If necessary (e.g., to uplink a large flight software update or to implement a TOO), additional S-band uplinks can be scheduled.

GLAST can initiate a downlink for a burst or mission alert.

- If either the LAT or the GBM trigger on a burst, a burst alert will reach the GCN within 7 s of the trigger. Burst telemetry with onboard localizations and basic burst data will continue to be downlinked, primarily through TDRSS.

Residual S-band ground-network up and downlinks will be maintained as a back-up, and to assist with the mission checkout.

Purposes of the Data Challenges

- End-to-end testing of analysis software.
- Familiarize team with data content, formats, tools and realistic details of analysis issues (both instrumental and astrophysical).
- If needed, develop additional methods for analyzing LAT data, encouraging alternatives that fit within the existing framework.
- Provide feedback to the SAS group on what works and what is missing from the data formats and tools.
- Uncover systematic effects in reconstruction and analysis.

Support readiness by launch time to do first-year science!

Data Challenge Planning Approach

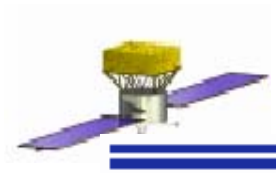
Walk before running: design a progression of studies

- DC1. Modest goals. Contains most essential features of a data challenge (see following slides).
- DC2. More ambitious science goals. Encourage further development, based on lessons from DC1.
- DC3. Support for flight science production.

Data Challenge Progression

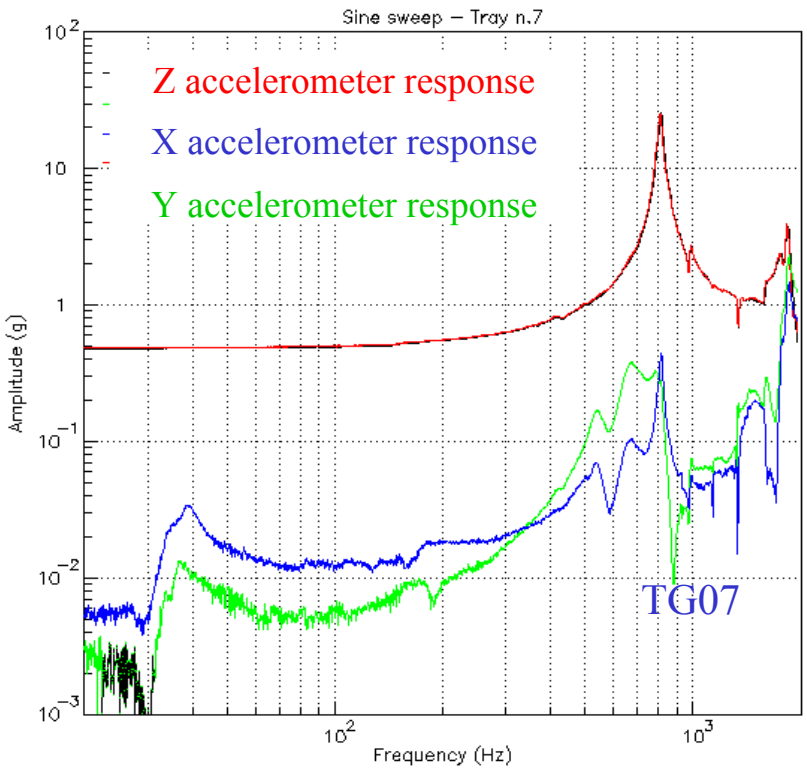
DC1:

- modest goals:
  - 1 simulated day all-sky survey simulation (3M bkgd+gamma events to ground, => 400M generated events)
  - find flaring AGN, a GRB
  - single-day point source sensitivity, daily quicklook analysis development
  - recognize simple hardware problem(s)
  - a few physics surprises
  - exercise:
    - exposure, orbit/attitude handling, data processing pipeline components, analysis tools
  - use existing recon, bkgd rejection and instrument response to show the problem areas that need improvement. Secondary goal (not required) is to prototype improvements.
- baseline schedule:
  - Sept-Oct startup problems resolution
  - Nov-Dec high-level tools beta testing. Finalize instrument response functions
  - Dec 15 high-level tools release, workshop
  - mid-January: interim reports (vrvs or face-to-face)
  - Feb 2004 closeout, and plan for DC2
  - Then, break for flight I&T start. Use the time for fixing problems learned in DC1, software advances, etc.

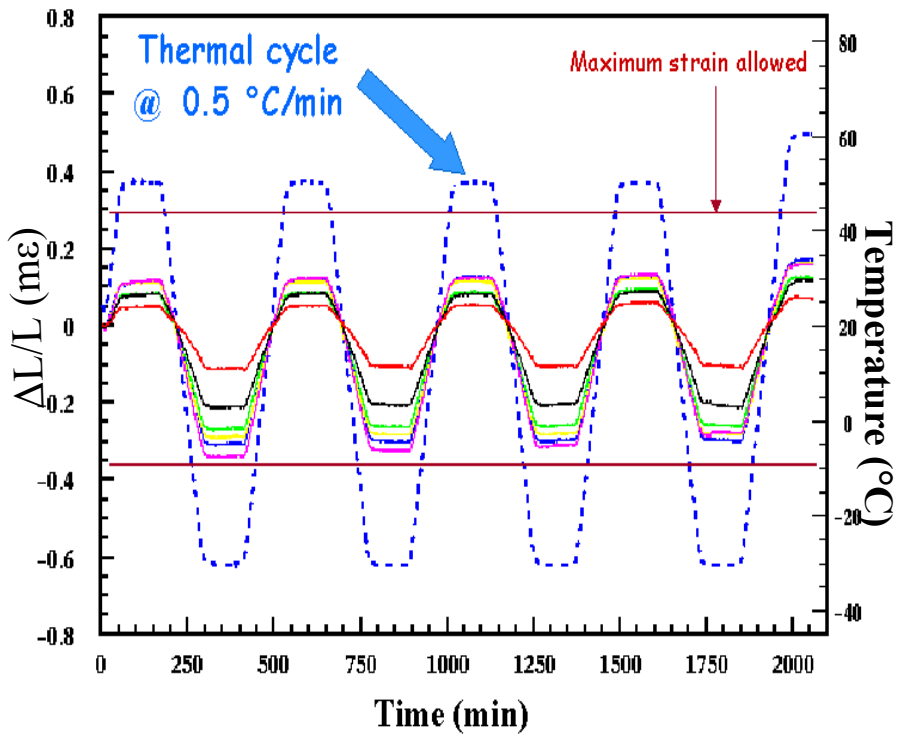


Environmental tests

Vibrational tests



Thermal cycles (-30°C - +50°C)



Resonance search:

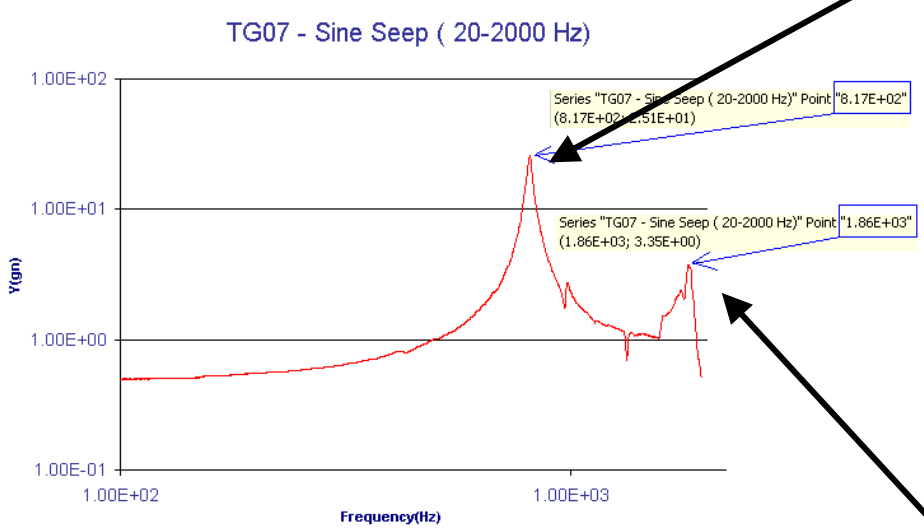
ν_0= 815 Hz, Q ≈ 51

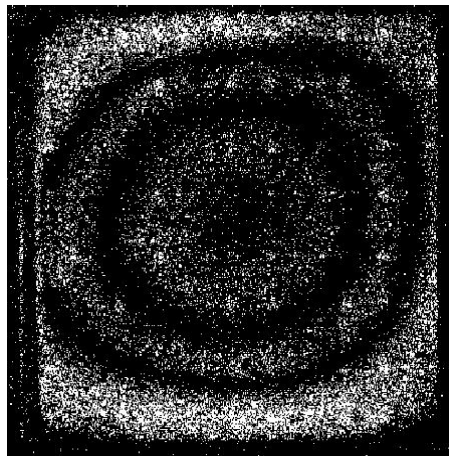
ΔT = 25 °C: ΔL/L ≈ 100 με

ΔT = -55 °C: ΔL/L ≈ -350 με

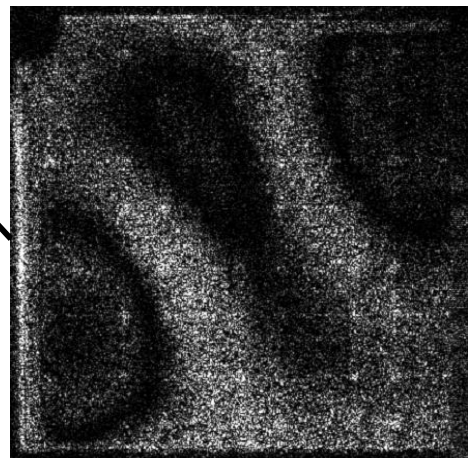
ESPI Vibrational Tests

TG07: Bare Panel + W + Bias Plane





817Hz first resonance mode



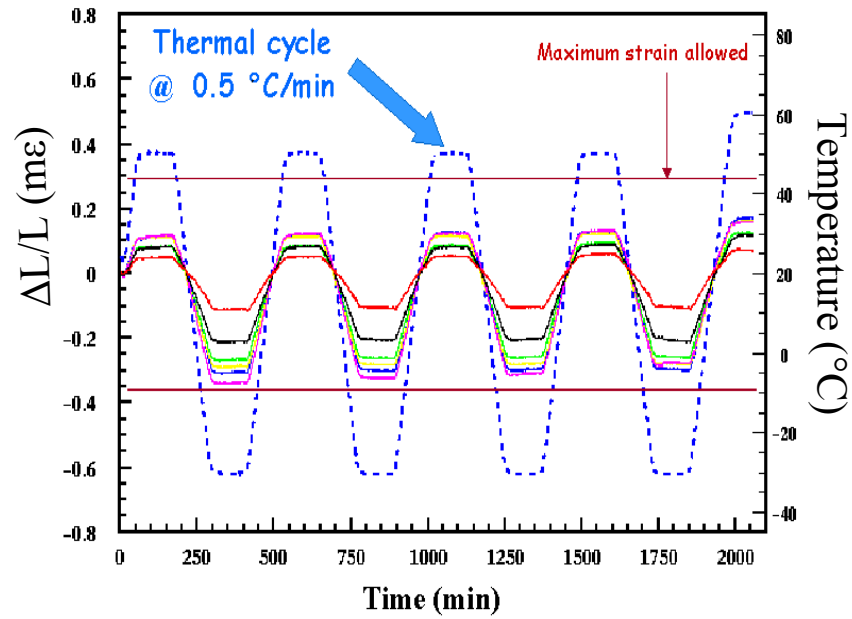
1860Hz second resonance mode

Trays Thermal Qualification Cycles

Qualification-like test:

- temperature range: -30°C ≈ +50°C
- T_0= 24°C
- number of cycles: 4
- 2 hr @ -30 °C, +50 °C
- (dT/dt) = 0.5 °C/min

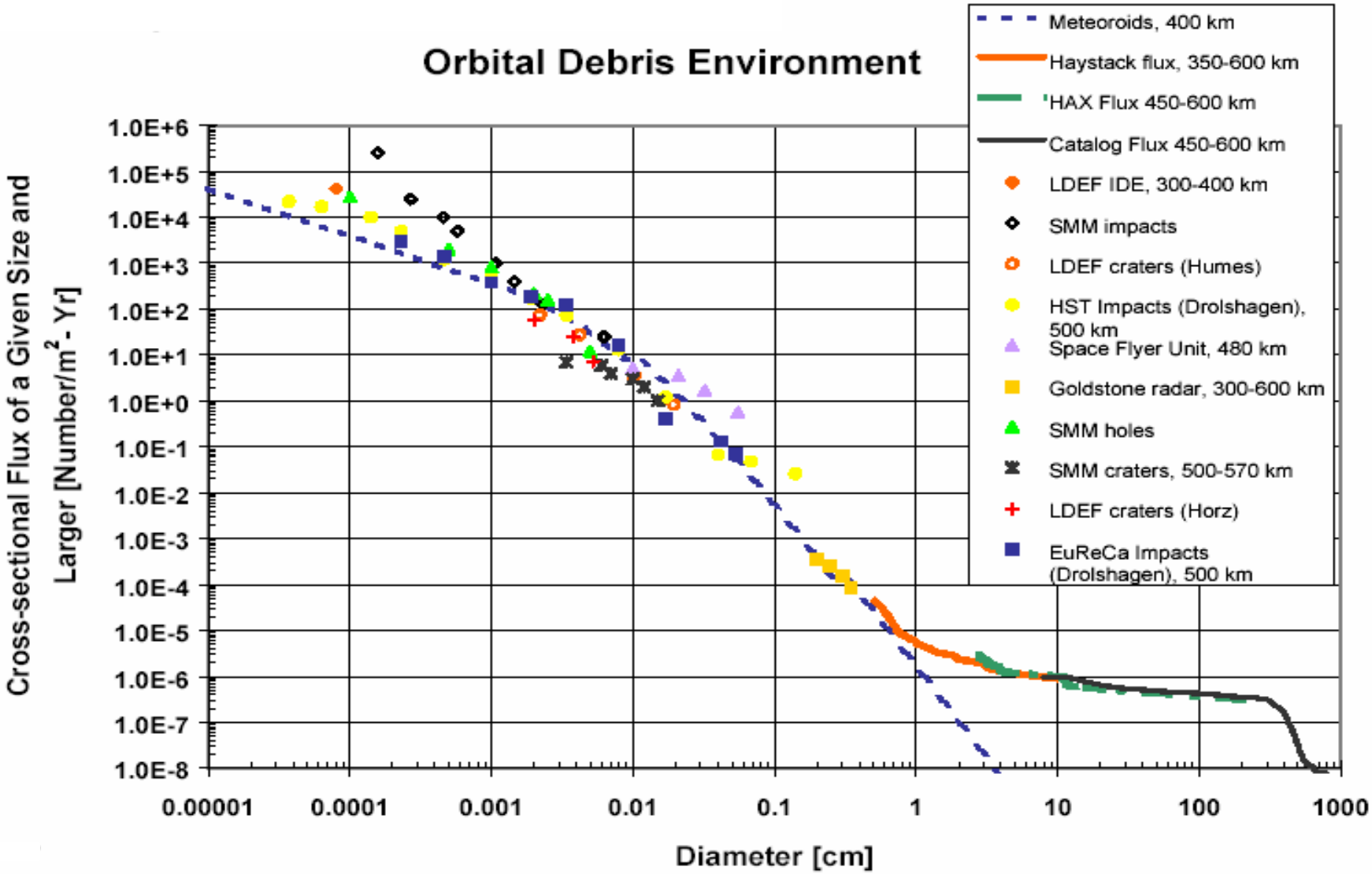
ΔT = 25 °C: ΔL/L ≈ 100 με
ΔT = -55 °C: ΔL/L ≈ -350 με

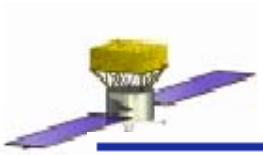


Thermal test lot ≥ 4 trays/cycle in 4 climatic chambers (2 ready by Pg in Terni, 1 foreseen in Pi, 1 foreseen in Ba)

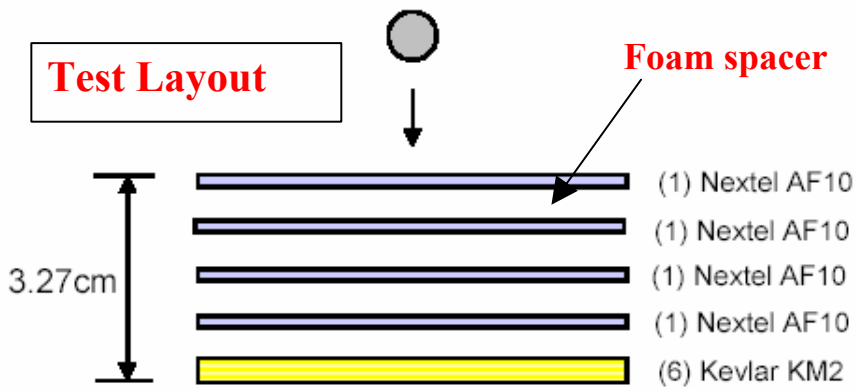
Test rate/climatic chamber ≈ 1 tower/month

Micro Meteoroid Distribution

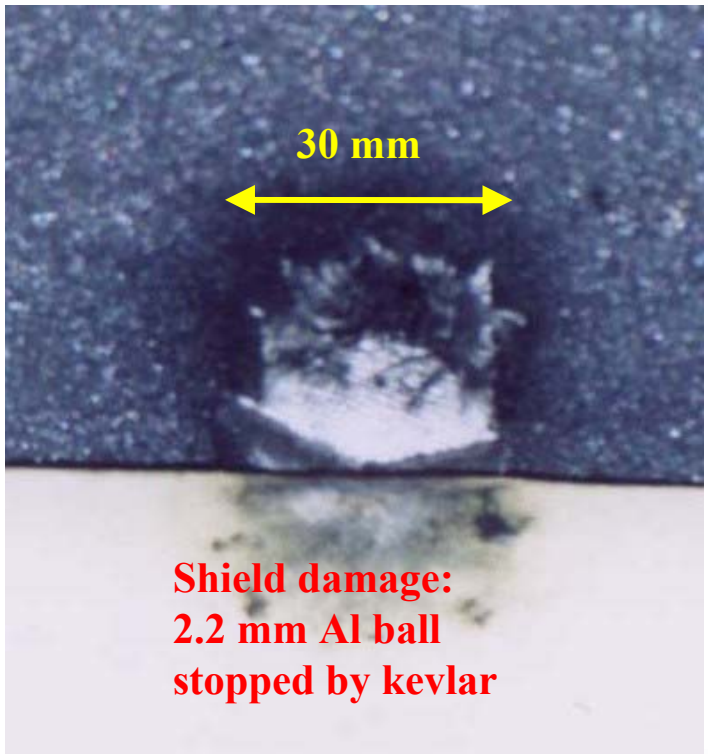


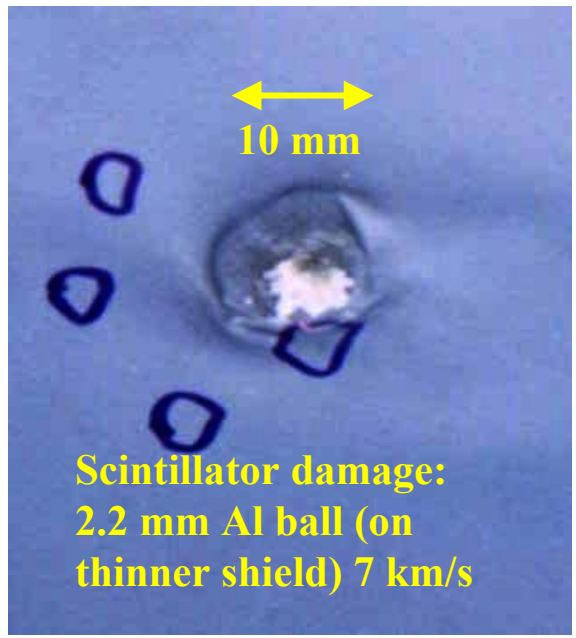


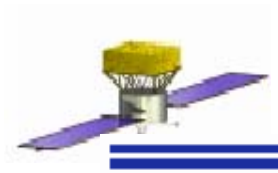
Micro Meteoroid Shield



Component	Number in Shield	Thickness each (cm)	Mass per Unit Area each (g/cm^2)	Total thickness (cm)	Total Mass per Unit Area (g/cm^2)
Nextel AF10	4	0.0254	0.025	0.102	0.100
Solimide Foam Spacer	4	0.66	0.0051	2.640	0.020
Thermal Blanket	1	0.32	0.0368	0.320	0.037
Kevlar KM2	6	0.0254	0.023	0.152	0.138
Overall Shield				3.21	0.295







Conclusions

- GLAST is a partnership of HEP and Astrophysics communities sharing scientific objectives and technology expertise
- GLAST is equipped with state-of-the-art particle detectors, resulting in an order of magnitude improvement in sensitivity and resolution with respect to previous missions
- GLAST-LAT construction has started with very promising results
- GLAST will therefore:
  - detect thousands of new and unknown γ-ray sources
  - identify the correct emission models for known classes of sources
  - probe the supersymmetric phase space in search for neutralino annihilation signals
  - provide significant data on the origin and evolution of GRB's
  - help building a new cosmological theory with key observation on the nature of dark matter, presence of an extra-galactic background light, quantum gravity effects, etc.

... much anticipation awaits GLAST on its way to discoveries that will change our knowledge of the Universe

Robotic Telescopes

an example: REM