FERMI: A NEW VIEW OF THE HIGH ENERGY UNIVERSE

LARGE AREA TELESCOPE: INTRODUCTION AND SCIENCE HIGHLIGHTS

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Stanford University

Principal Investigator, Large Area Telescope Collaboration

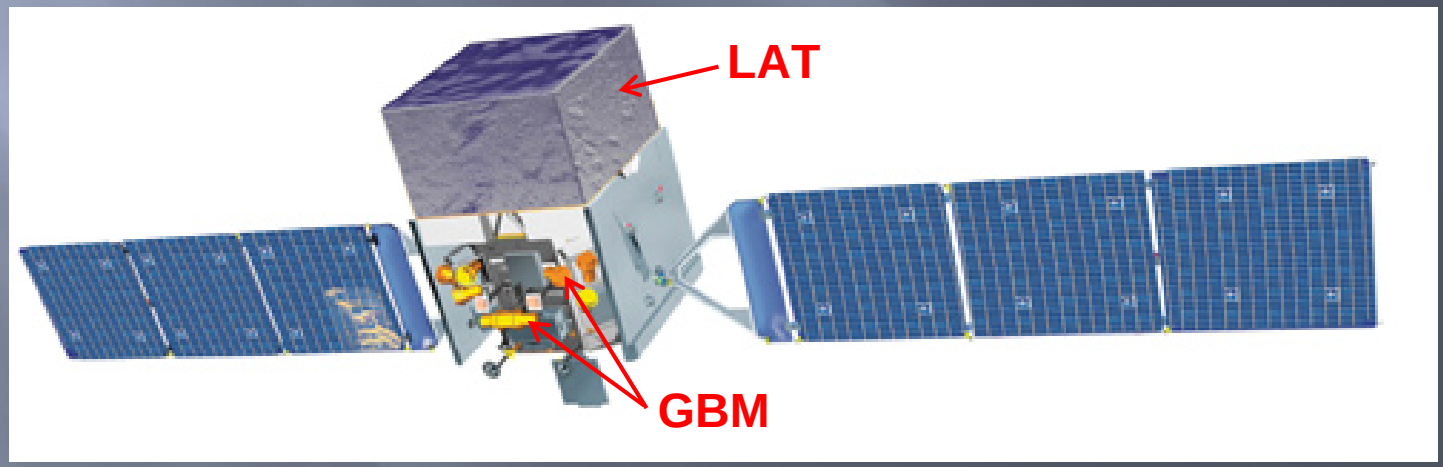
on behalf of the Fermi LAT Collaboration and the Fermi mission

Fermi Large Area Telescope

- Brief overview of Large Area Telescope (more in Bill Atwood's talk), including some history
- Science Objectives
- Summary of early results

Exploring the High-Energy Universe

- gamma rays provide a direct view into Nature's largest accelerators (neutron stars, black holes)
- gamma rays probe cosmological distances
  (e.g., $\gamma + \gamma_{EBL} \rightarrow e^+ + e^-$)
- huge leap in key capabilities, including a largely unexplored energy range; great potential for discovery: e.g. dark matter



Two instruments: Large Area Telescope (LAT), 20 MeV - >300 GeV
Gamma-ray Burst Monitor (GBM), 10 keV - 25 MeV

Fermi LAT science objectives

20 MeV - > 300 GeV

> 2000 AGNs
blazars and radiogal = f(θ,z)
evolution z < 5
Sag A*

10-50 GRB/year
GeV afterglow
spectra to high energy

γ-ray binaries
Pulsar winds
μ-quasar jets

Possibilities
starburst galaxies
galaxy clusters
measure EBL
unIDs

Dark Matter
neutralino lines
sub-halo clumps;
$e^+ + e^-$ spectrum

Cosmic rays and clouds
acceleration in Supernova remnants
OB associations
propagation (Milky Way, M31, LMC, SMC)
Interstellar mass tracers in galaxies

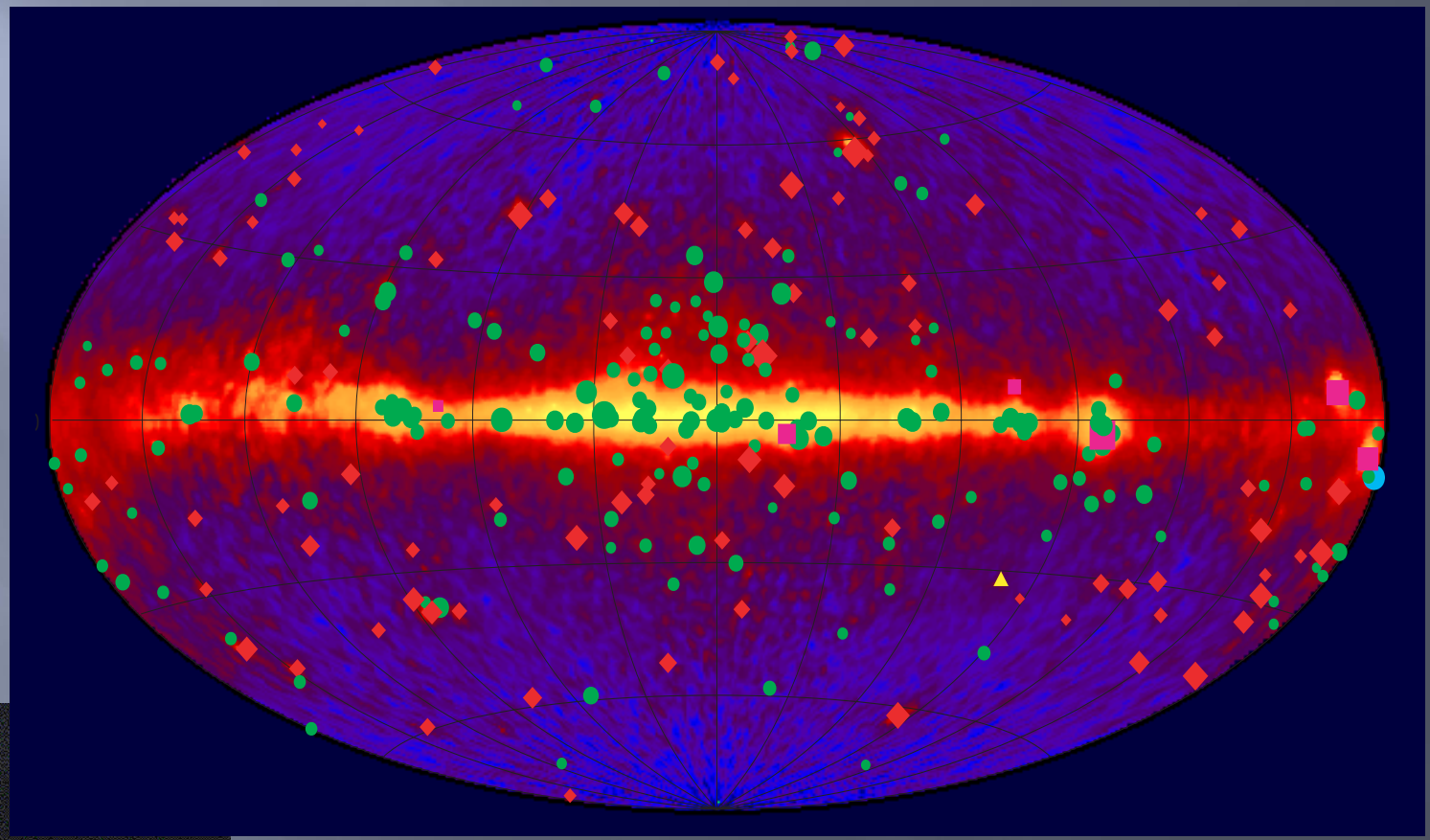
Pulsars
emission from radio and X-ray pulsars
blind searches for new Gemingas
magnetospheric physics
pulsar wind nebulae

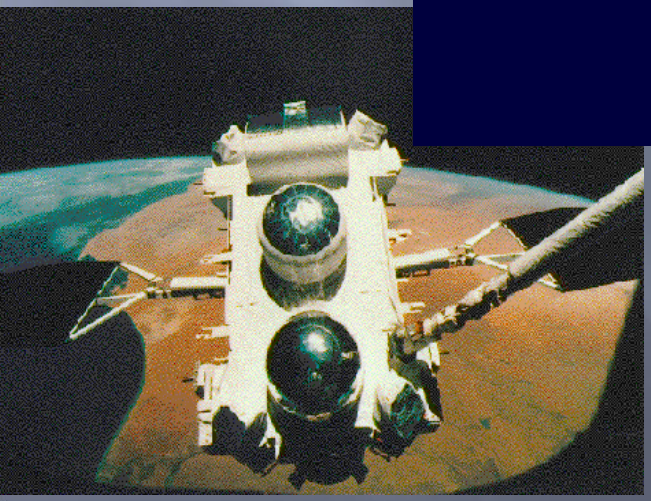
Compton Observatory / EGRET legacy

April 5, 1991 – June 4, 2000

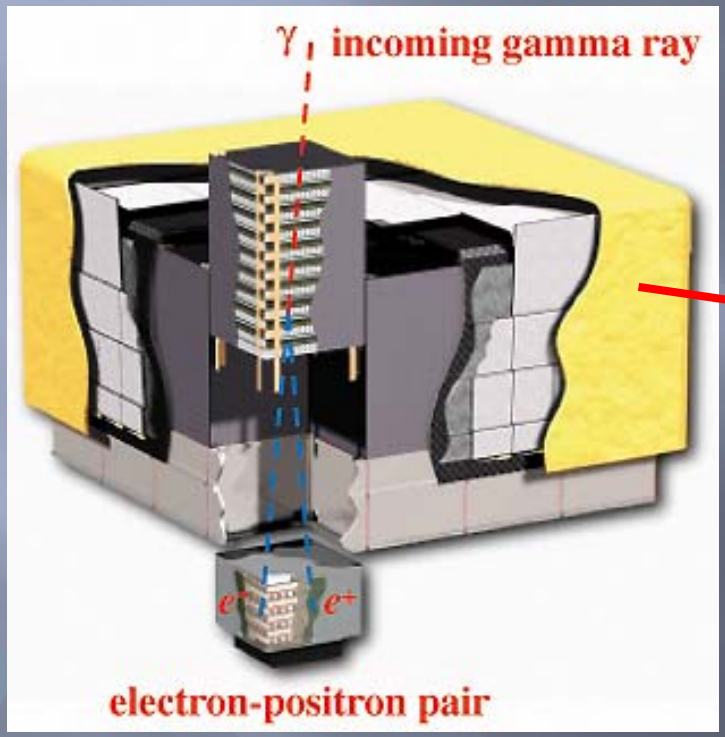
3rd EGRET catalog

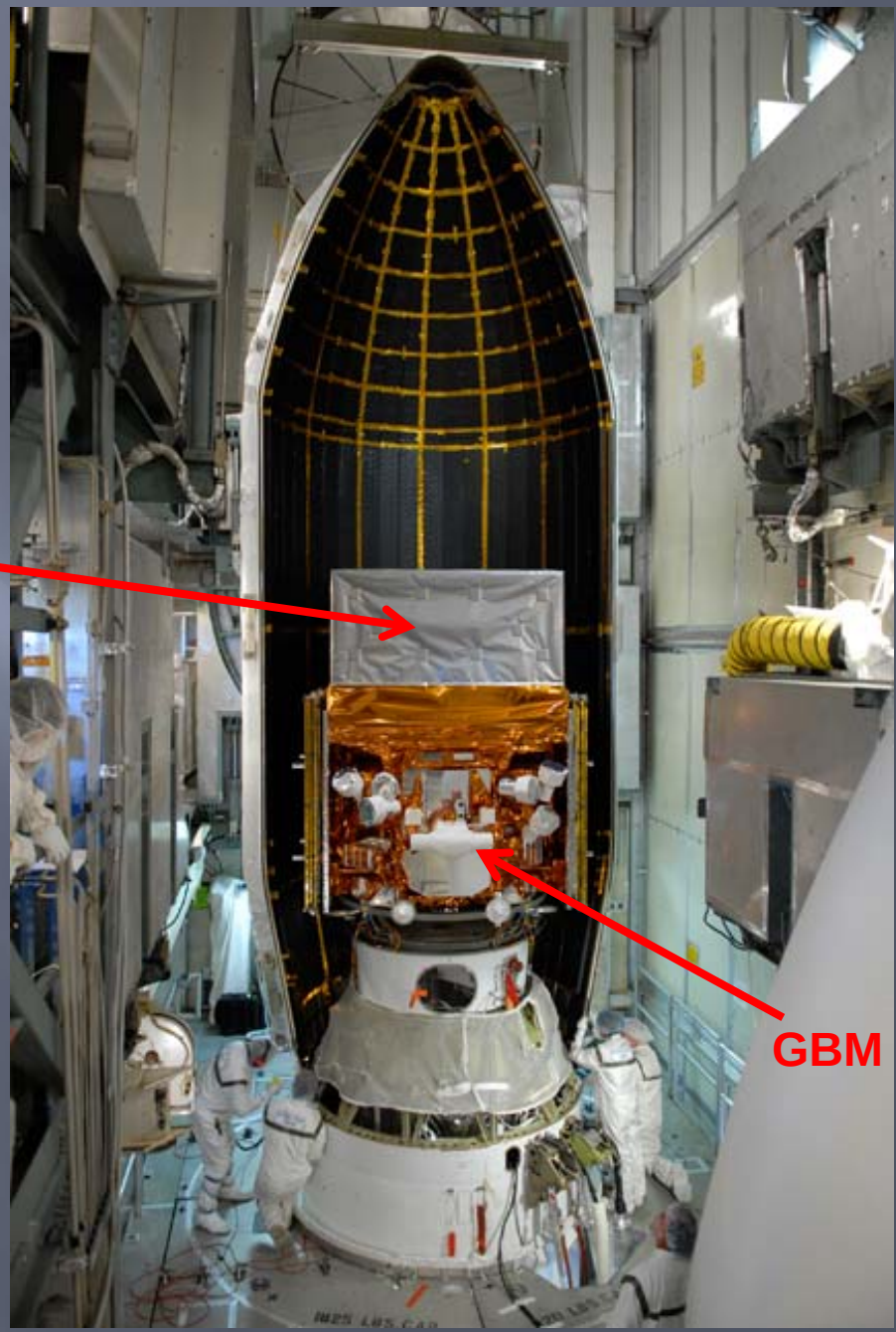
- AGN - blazars
- unidentified
- pulsars
- LMC





The Large Area Telescope (LAT)

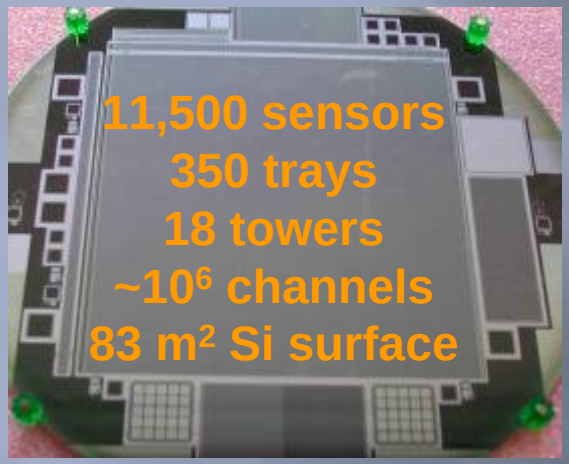


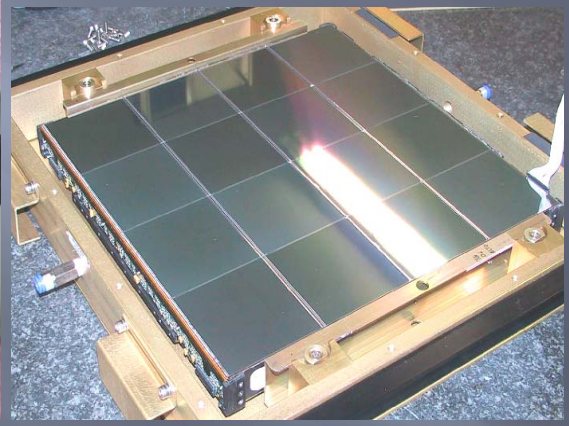


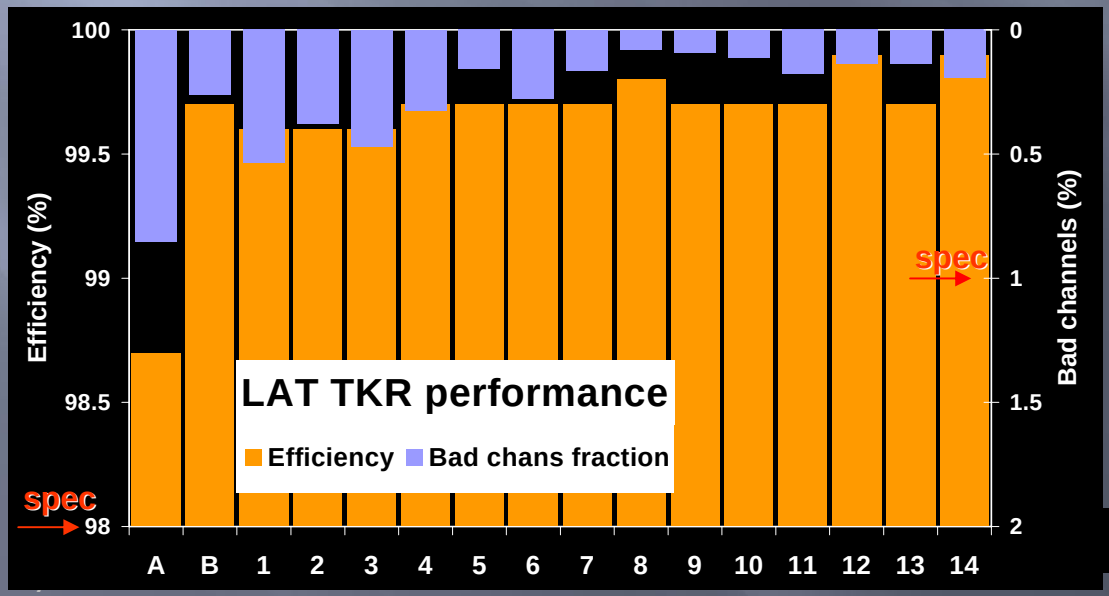
LAT images the sky one photon at a time: γ-ray converts in LAT to an electron and a positron ; direction and energy of these particles tell us the direction and energy of the photon

LAT Silicon Tracker

Silicon strip detectors from Hamamatsu Photonics and Japan GLAST Collaboration are a key part of LAT's success



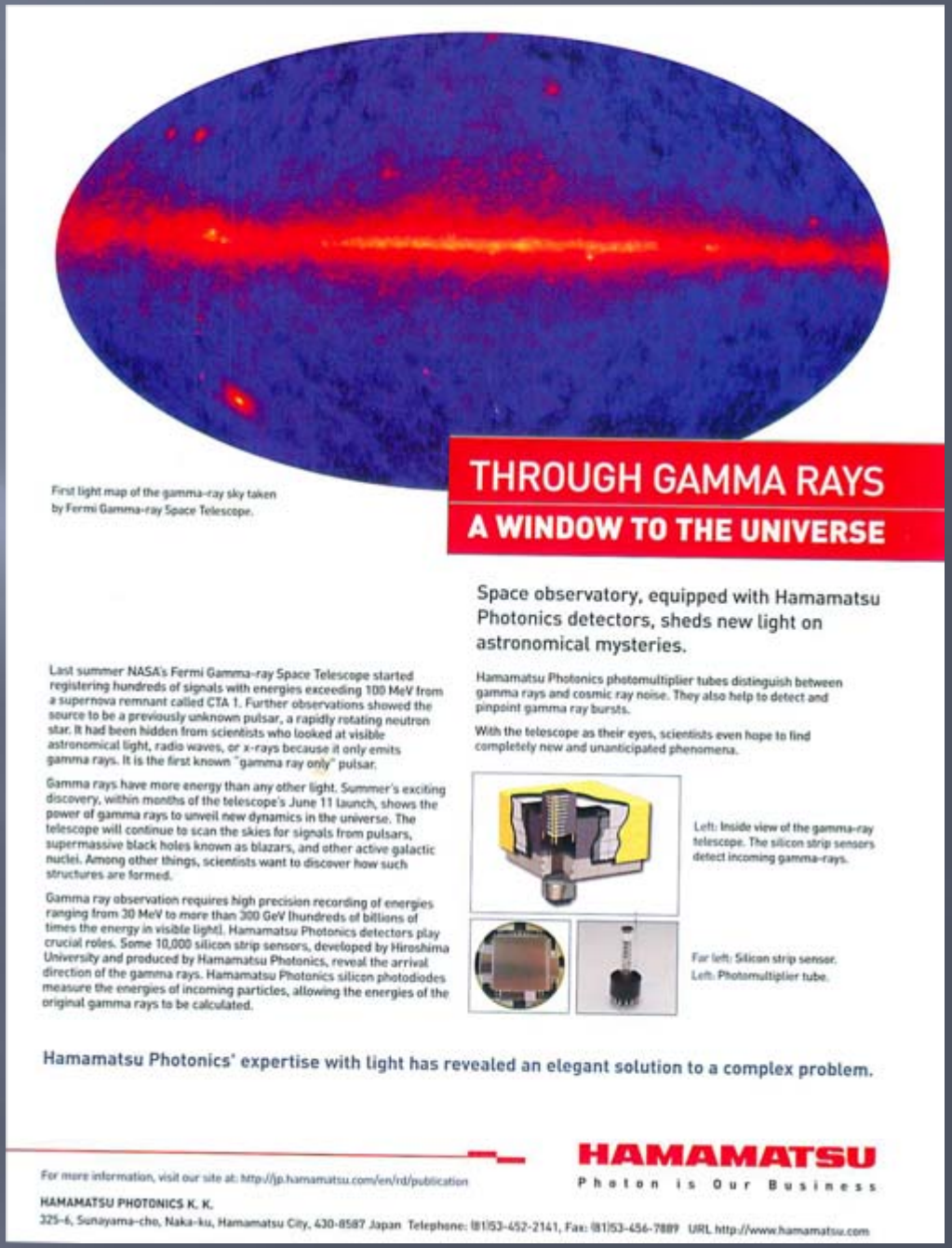




In addition to silicon-strip detectors for the tracker, Hamamatsu also supplied

Silicon photodiodes for the calorimeter,

Photomultiplier tubes for the anticoincidence detector readout



First light map of the gamma-ray sky taken by Fermi Gamma-ray Space Telescope.

THROUGH GAMMA RAYS

A WINDOW TO THE UNIVERSE

Space observatory, equipped with Hamamatsu Photonics detectors, sheds new light on astronomical mysteries.

Last summer NASA's Fermi Gamma-ray Space Telescope started registering hundreds of signals with energies exceeding 100 MeV from a supernova remnant called CTA 1. Further observations showed the source to be a previously unknown pulsar, a rapidly rotating neutron star. It had been hidden from scientists who looked at visible astronomical light, radio waves, or x-rays because it only emits gamma rays. It is the first known "gamma ray only" pulsar.

Gamma rays have more energy than any other light. Summer's exciting discovery, within months of the telescope's June 11 launch, shows the power of gamma rays to unveil new dynamics in the universe. The telescope will continue to scan the skies for signals from pulsars, supermassive black holes known as blazars, and other active galactic nuclei. Among other things, scientists want to discover how such structures are formed.

Gamma ray observation requires high precision recording of energies ranging from 30 MeV to more than 300 GeV (hundreds of billions of times the energy in visible light). Hamamatsu Photonics detectors play crucial roles. Some 10,000 silicon strip sensors, developed by Hiroshima University and produced by Hamamatsu Photonics, reveal the arrival direction of the gamma rays. Hamamatsu Photonics silicon photodiodes measure the energies of incoming particles, allowing the energies of the original gamma rays to be calculated.

Hamamatsu Photonics photomultiplier tubes distinguish between gamma rays and cosmic ray noise. They also help to detect and pinpoint gamma ray bursts.

With the telescope as their eyes, scientists even hope to find completely new and unanticipated phenomena.

Left: Inside view of the gamma-ray telescope. The silicon strip sensors detect incoming gamma-rays.

Far left: Silicon strip sensor.
Left: Photomultiplier tube.

Hamamatsu Photonics' expertise with light has revealed an elegant solution to a complex problem.

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Fermi LAT Collaboration

- **France**
  - IN2P3, CEA/Saclay
- **Italy**
  - INFN, ASI, INAF
- **Japan**
  - Hiroshima University
  - ISAS/JAXA
  - RIKEN
  - Tokyo Institute of Technology
- **Sweden**
  - Royal Institute of Technology (KTH)
  - Stockholm University
- **United States**
  - Stanford University (SLAC and HEPL/Physics)
  - University of California at Santa Cruz - Santa Cruz Institute for Particle Physics
  - Goddard Space Flight Center
  - Naval Research Laboratory
  - Sonoma State University
  - Ohio State University
  - University of Washington

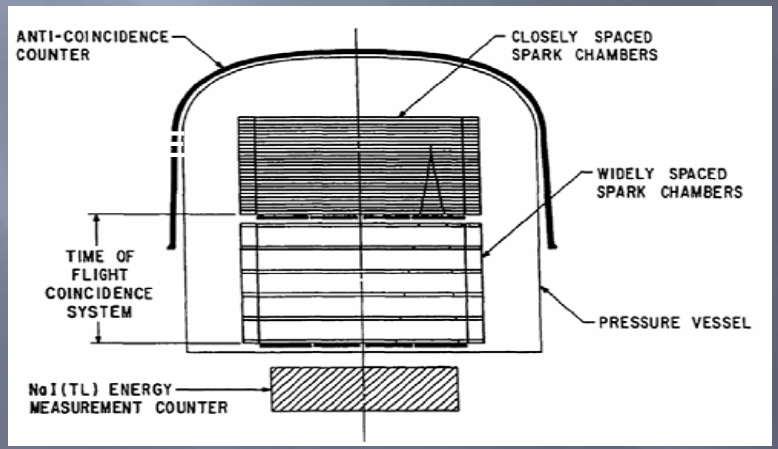
~390 Members
(~95 Affiliated Scientists, 68 Postdocs, and 105 Graduate Students)

construction managed by Stanford Linear Accelerator Center (SLAC), Stanford University

LAT as a Telescope

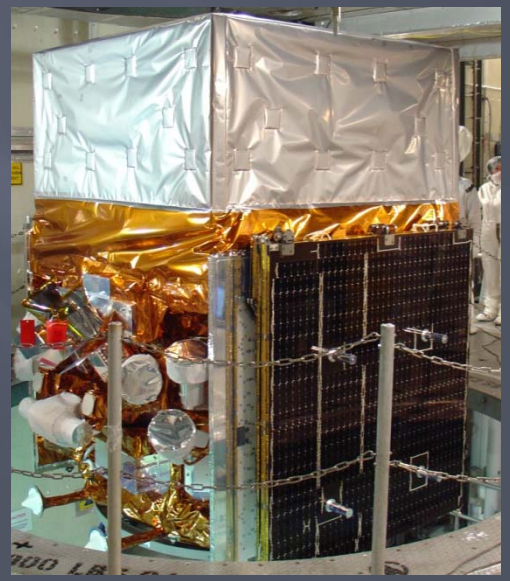
	Years	Ang. Res. (100 MeV)	Ang. Res. (10 GeV)	Eng. Rng. (GeV)	$A_{eff}\ \Omega$ (cm^2 sr)	# γ-rays
EGRET	**1991–00**	**5.8°**	**0.5°**	**0.03–10**	**750**	**1.4 × 10^6/yr**
AGILE	**2007–**	**4.7°**	**0.2°**	**0.03–50**	**1,500**	**4 × 10^6/yr**
***Fermi* LAT**	**2008–**	**3.5°**	**0.1°**	**0.02–300**	**25,000**	**1 × 10^8/yr**

- LAT has already surpassed EGRET and AGILE celestial gamma-ray totals
- Unlike EGRET and AGILE, LAT is an effective All-Sky Monitor
  whole sky every ~3 hours



CGRO EGRET

AGILE (ASI)



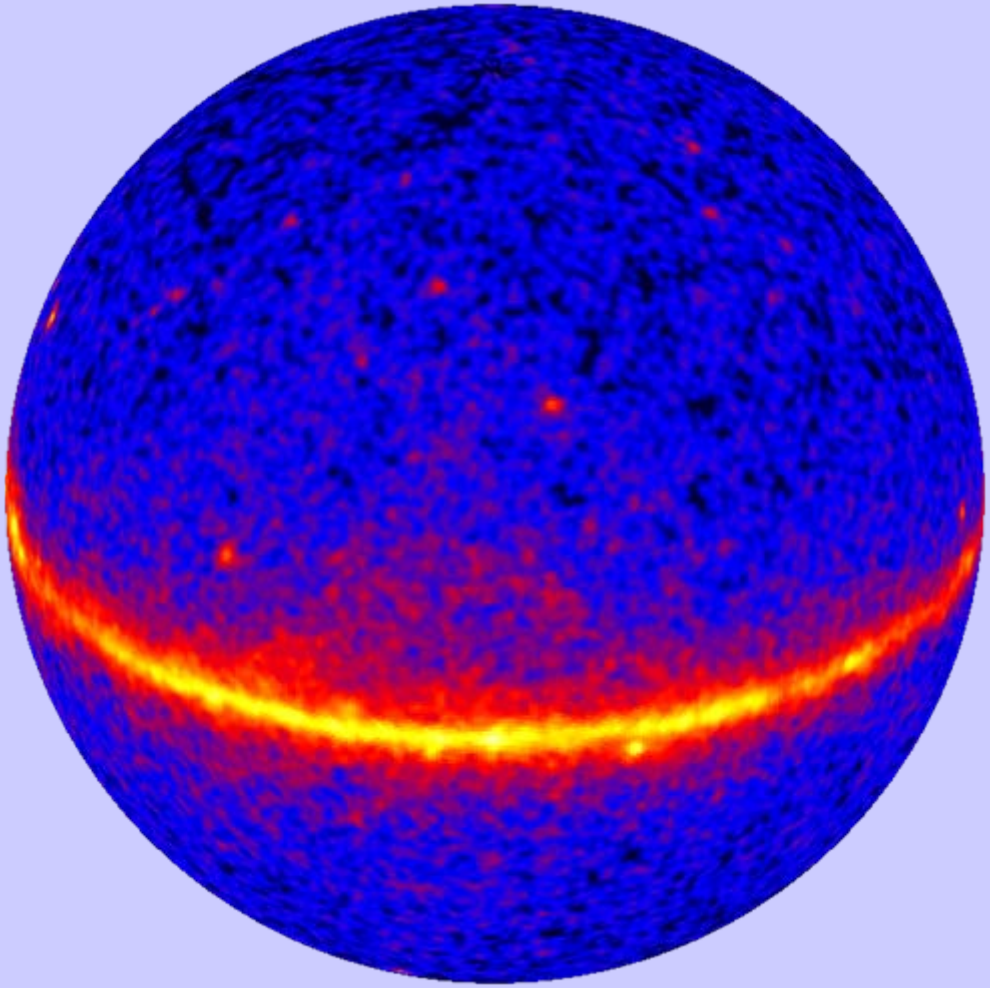
Fermi / LAT

June 11, 2008
11:30 am (EDT)

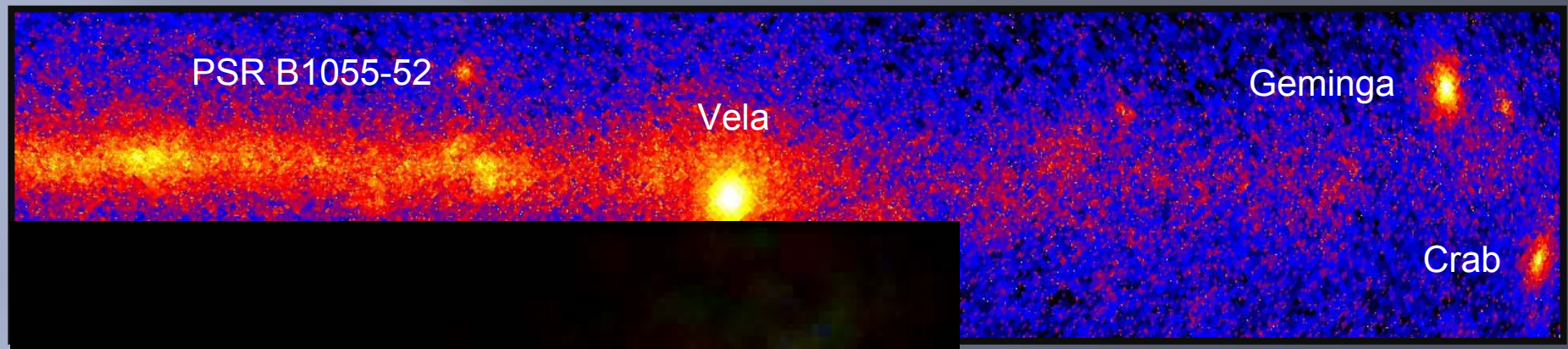

Pitch In!


June 11, 2008
12:05 pm (EDT)
USAF
ULA
DELTA
GLAST

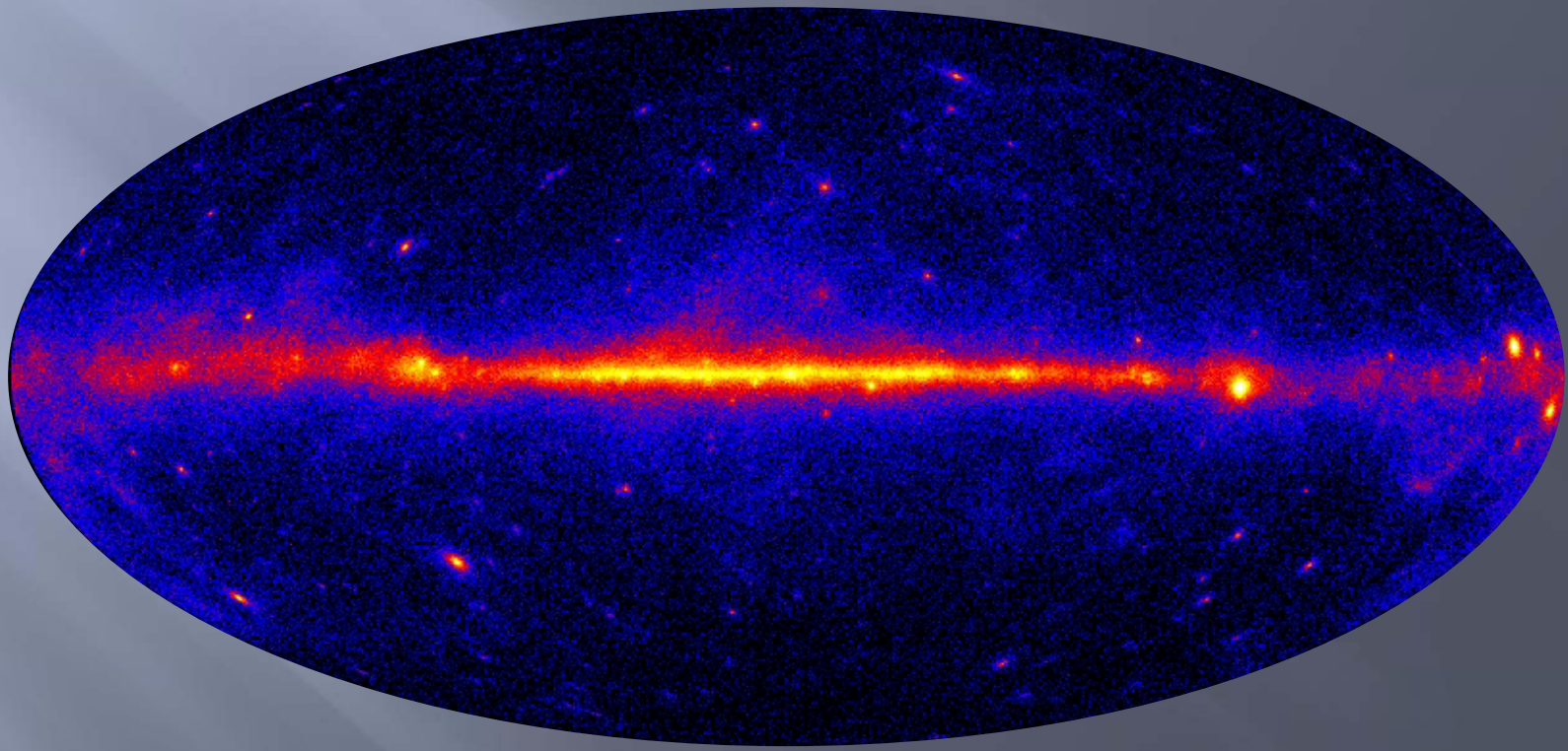
First Light



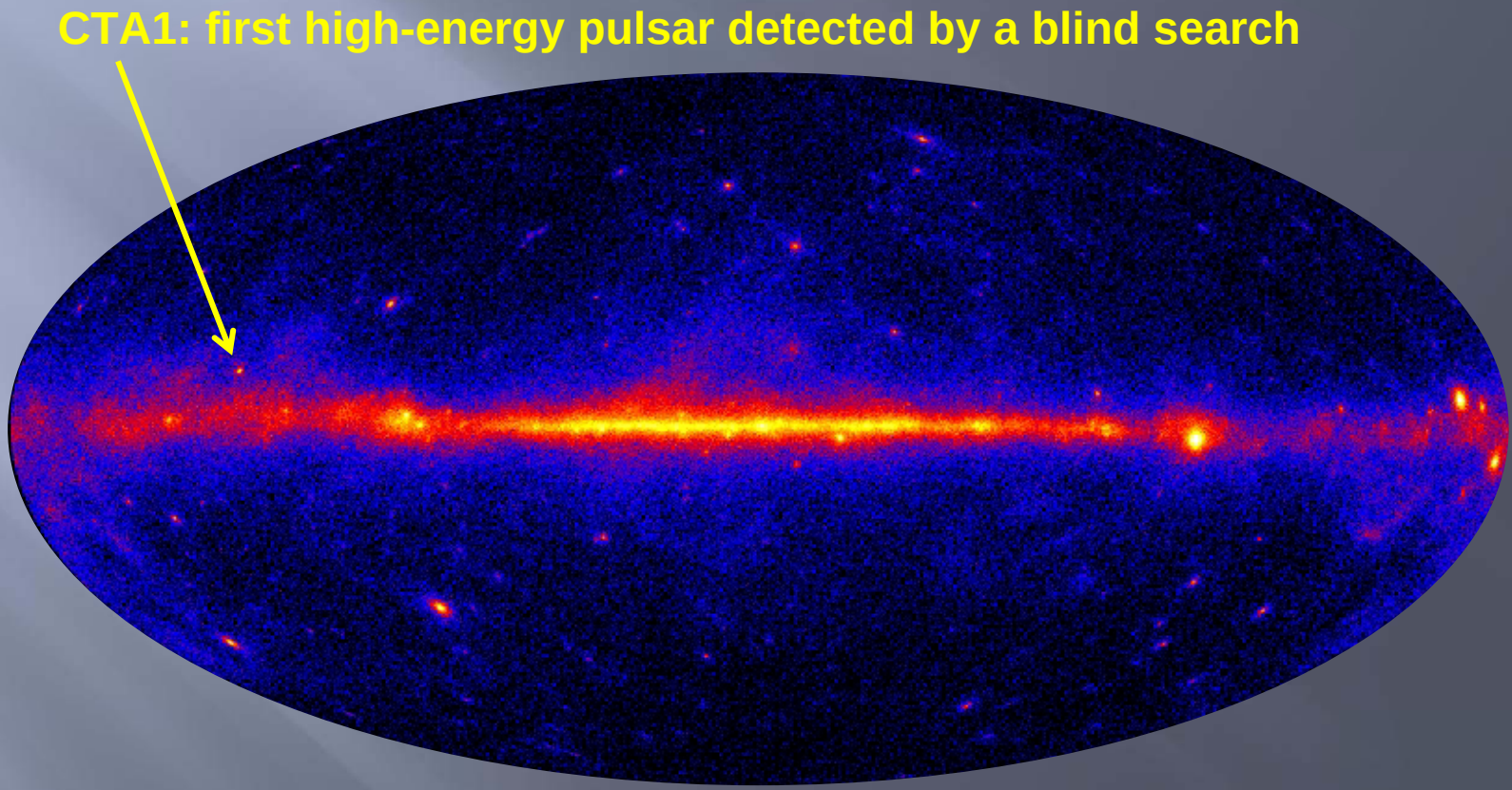
- ~4-day First Light exposure, June 30 – July 3, 2008
- Orthographic projection


PSR B1055-52
Vela
Geminga
Crab

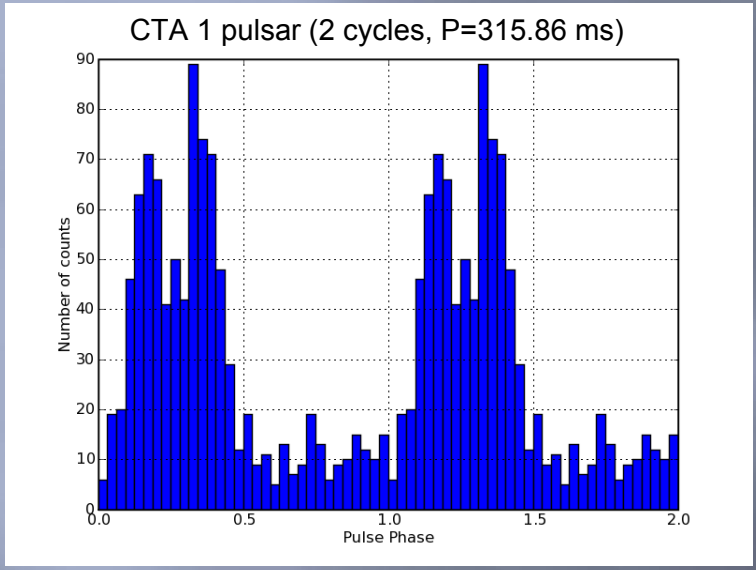
LAT 3 month sky map



LAT 3 month sky map

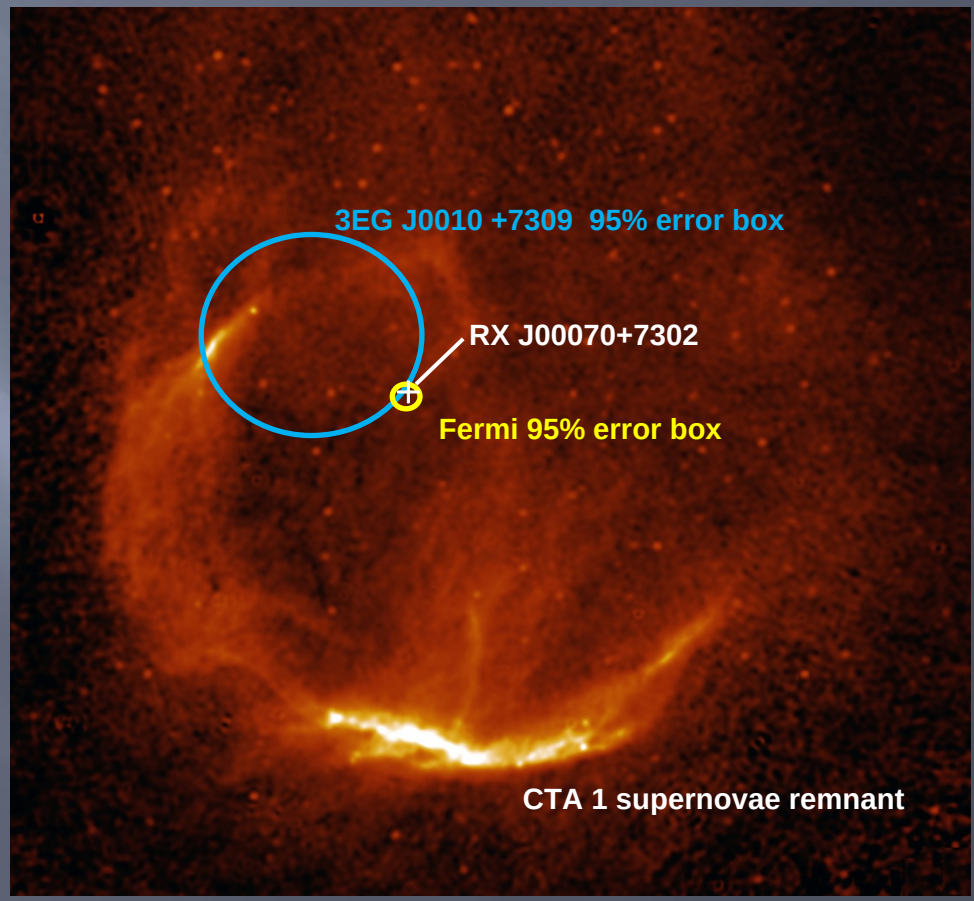


Pulsar in CTA 1



- exhibits all characteristics of a young high-energy pulsar (characteristic age ~1.4 x 10^4 yr), which powers a synchrotron pulsar wind nebula embedded in a larger SNR.

- spin-down luminosity ~10^{36} erg s^{-1}, sufficient to supply the PWN with magnetic fields and energetic electrons.

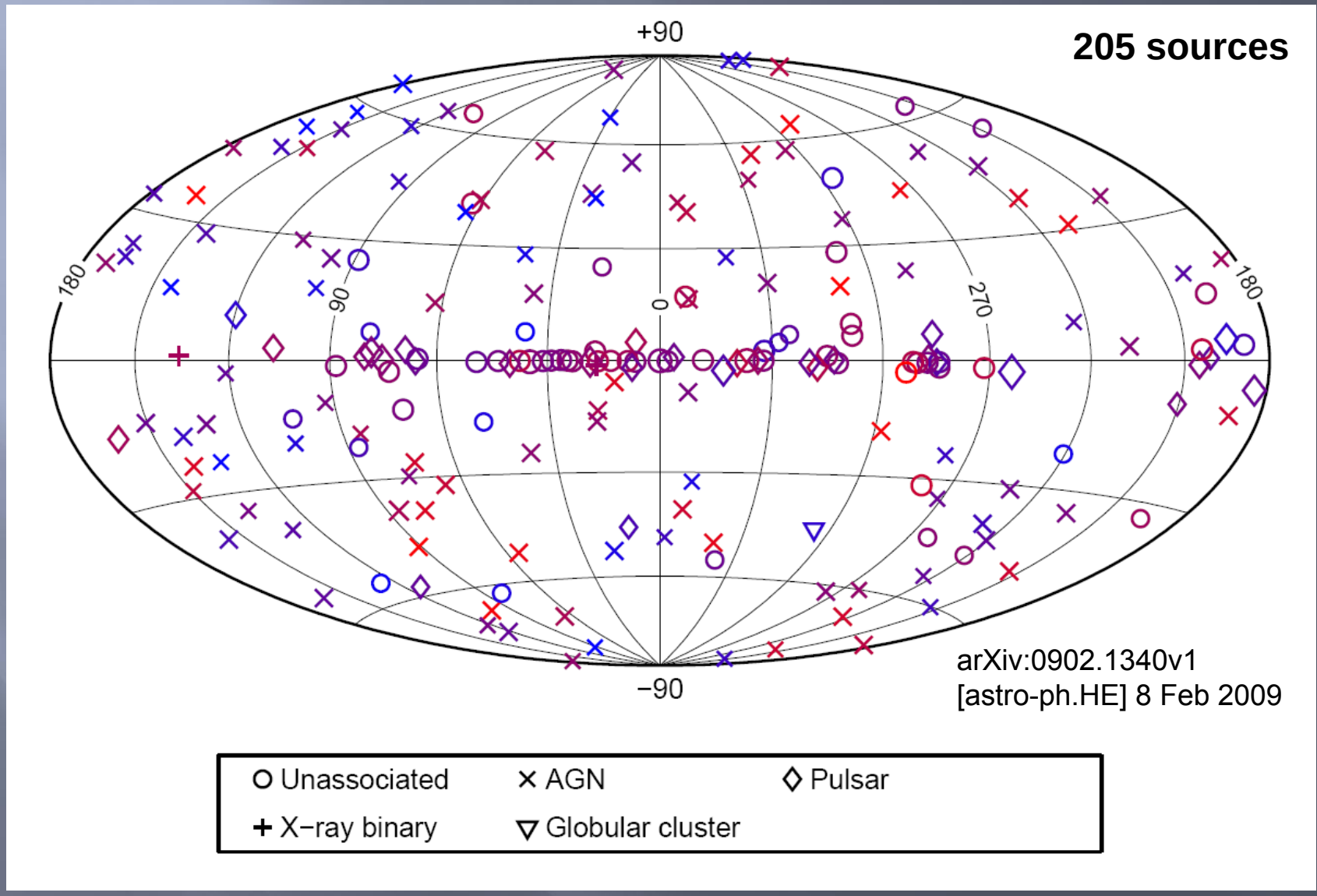


- γ-ray source at *l,b* = 119.652, 10.468; 95% error circle radius =0.038° contains the X-ray source RX J00070+7302, central to the PWN superimposed on the radio map at 1420 MHz.

- pulsar off-set from center of radio SNR; rough estimate of the lateral speed of the pulsar is ~450 km/s

LAT High-Confidence Bright Source List

- based on first 3 months of sky-survey

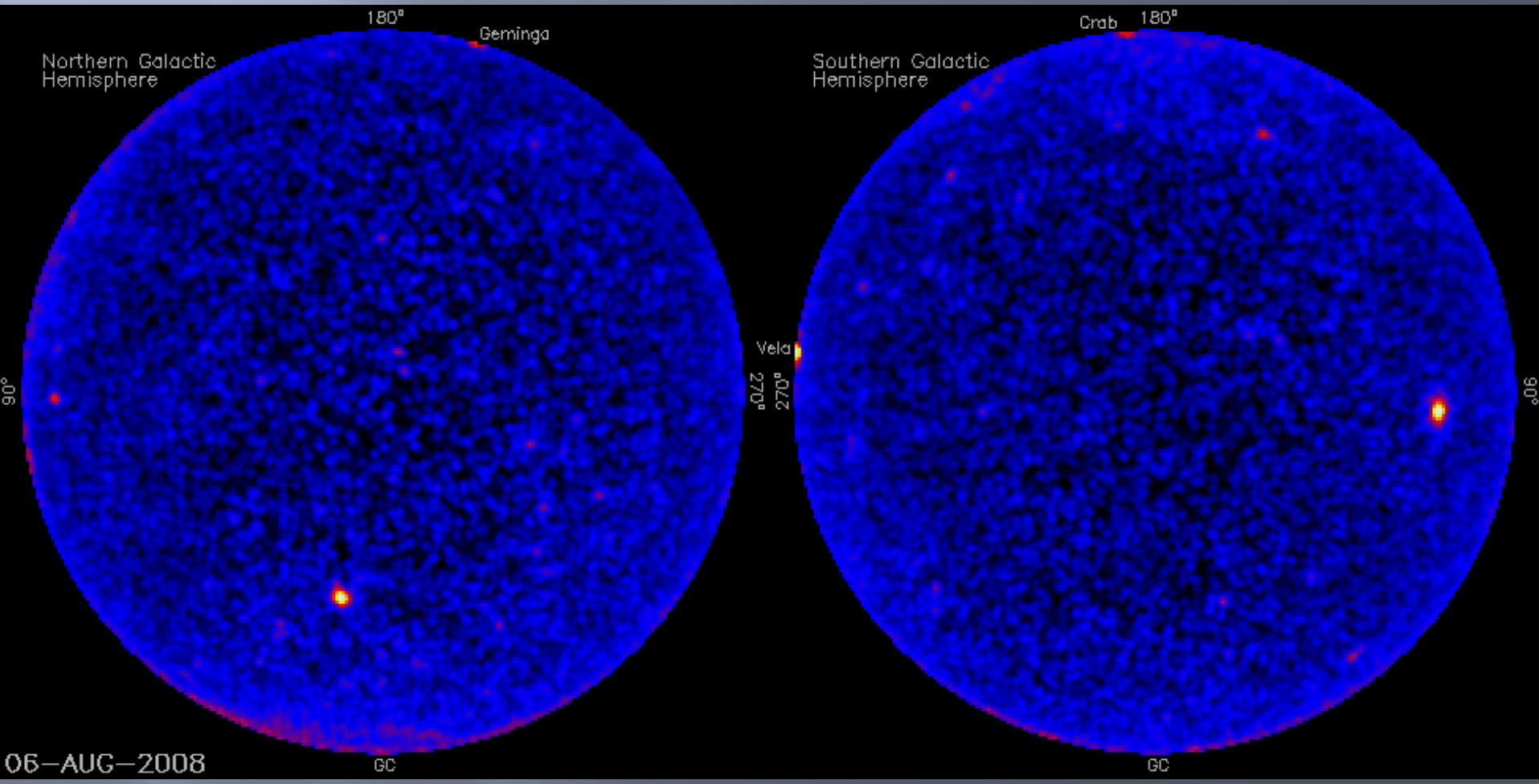


205 Preliminary LAT Bright Sources

Census of Associations (not Identifications)

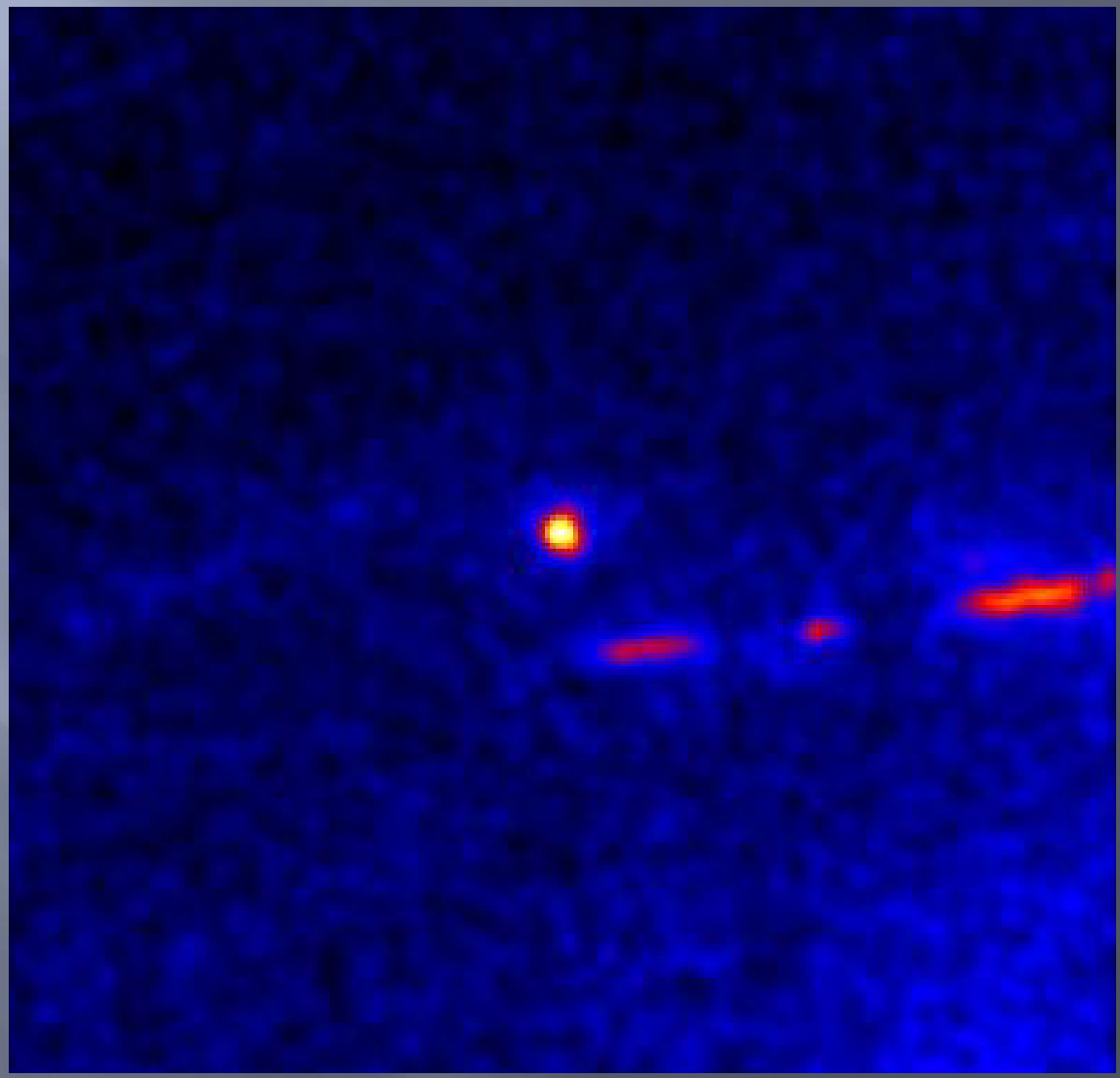
Class	Number
Radio/X-ray pulsar	15
LAT pulsar	14
Globular cluster (pulsars?)	1
HMXB	2
LMC	1
Flat Spectrum Radio Quasars	62
Bl Lac Objects	46
Blazar, uncertain type	11
Radio galaxies	2
Special cases (under study)	14
Unassociated	37

Three months of Fermi, the movie



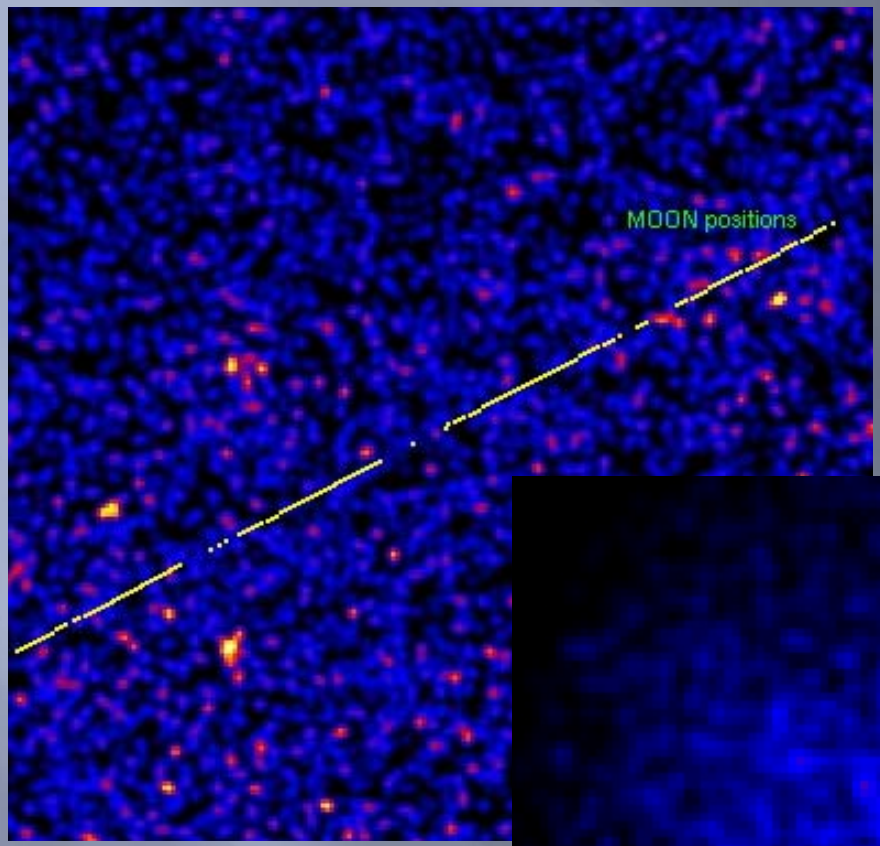
Fermi detects the Sun

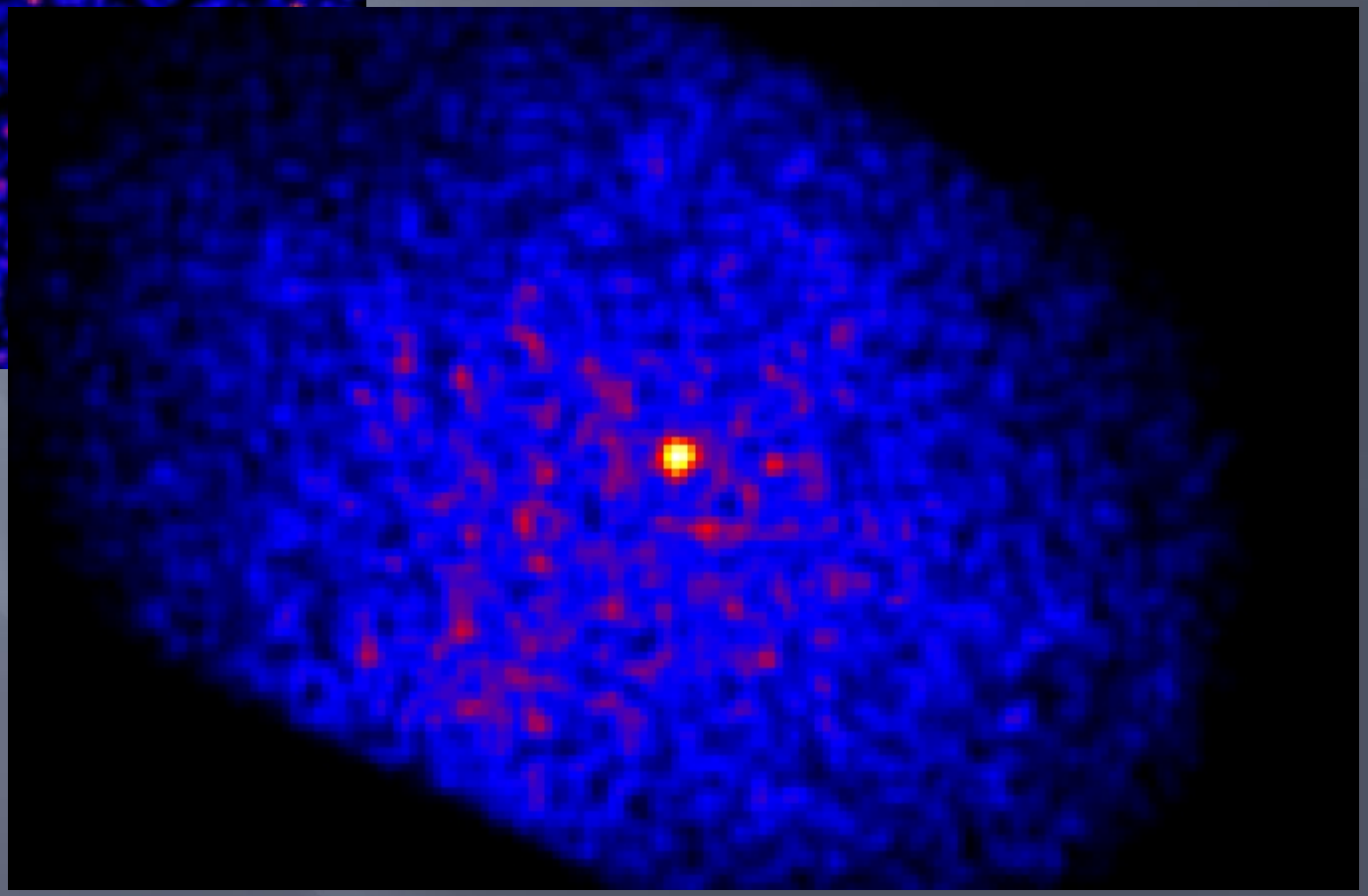
July 1 – Sept 24, 2008



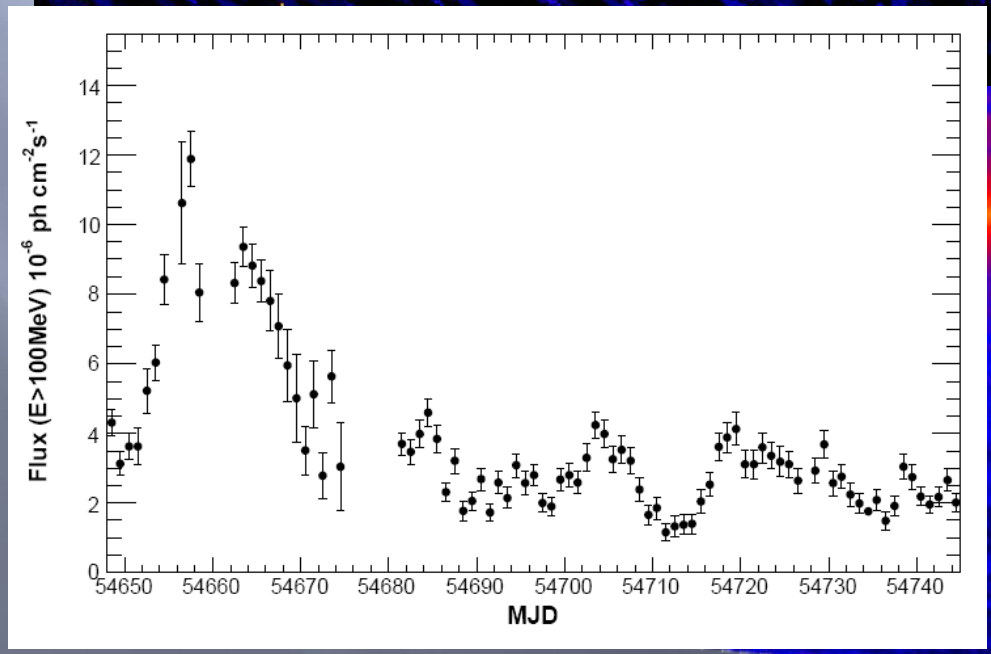
Fermi detects the Moon

August 3 – August 7, 2008





3C454.3
Supermassive black hole
8 billion light-years from us



GLAST-LAT detection of extraordinary gamma-ray activity in 3C 454.3

ATel #1628; *G. Tosti (Univ/INFN-Perugia) , J. Chiang (SLAC), B. Lott (CENBG/Bordeaux), E. do Couto e Silva (SLAC), J. E. Grove (NRL/Washington), J. G. Thayer (SLAC) on behalf of the GLAST Large Area Telescope Collaboration*
*on **24 Jul 2008; 14:25 UT***
Password Certification: Gino Tosti (tosti@pg.infn.it)

Subjects: Gamma Ray, >GeV, AGN, Quasars

The Large Area Telescope (LAT), one of two instruments on the Gamma-ray Large Area Space Telescope (GLAST) (launched June 11, 2008), which is still in its post-launch commissioning and checkout phase has been monitoring extraordinarily high flux from the gamma-ray blazar 3C 454.3 since June 28, 2008. This confirms the bright state of the source reported by AGILE (see ATel #1592) and by the optical-to-radio observers of the GASP-WEBT Project (ATel #1625).

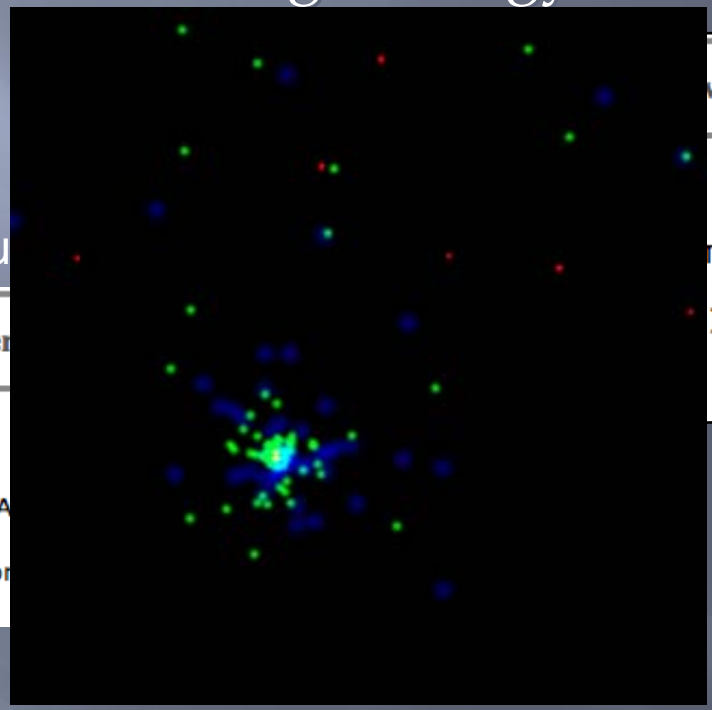
3C 454.3 has been detected on time scales of hours with high significance (> 5 sigma) by the LAT Automatic Science Processing (ASP) pipeline and the daily light curve (E>100 MeV) indicates that the source flux has increased from the initial measurements on June 28. Although in-flight calibration is still ongoing, preliminary analysis indicates that in the period July 10-21, 2008 the source has been in a very high state with a flux (E>100MeV) that is well above all previously published values reported by both EGRET (Hartman et al. 1999, ApJS, 123,79) and AGILE (see e.g. ATel #1592 and Vercellone et al. 2008, ApJ,676,L13).

Because GLAST will continue with calibration activities, regular monitoring of this source cannot be pursued. Monitoring by the LAT is expected to resume in early August. In consideration of the ongoing activity of this source we strongly encourage multiwavelength observations of 3C 454.3.

The GLAST LAT is a pair conversion telescope designed to cover the energy band from 20 MeV to greater than 300 GeV. It is the product of an international collaboration between NASA and DOE in the U.S. and many scientific institutions across France, Italy, Japan and Sweden.

Gamma-Ray Bursts observed by LAT

- LAT has reported 3 high-energy bursts since launch



long-duration bu

GRB 080825C: Fermi-LAT obser

SOURCE: GCN
TITLE: GCN CIRCULAR
NUMBER: 8183
SUBJECT: GRB 080825C: Fermi-LA
DATE: 08/09/05 17:45:46 GMT
FROM: Aurelien Bouvier at Stanfor

vation — Tajima et al. GCN 8246

T observation

)/GLAST

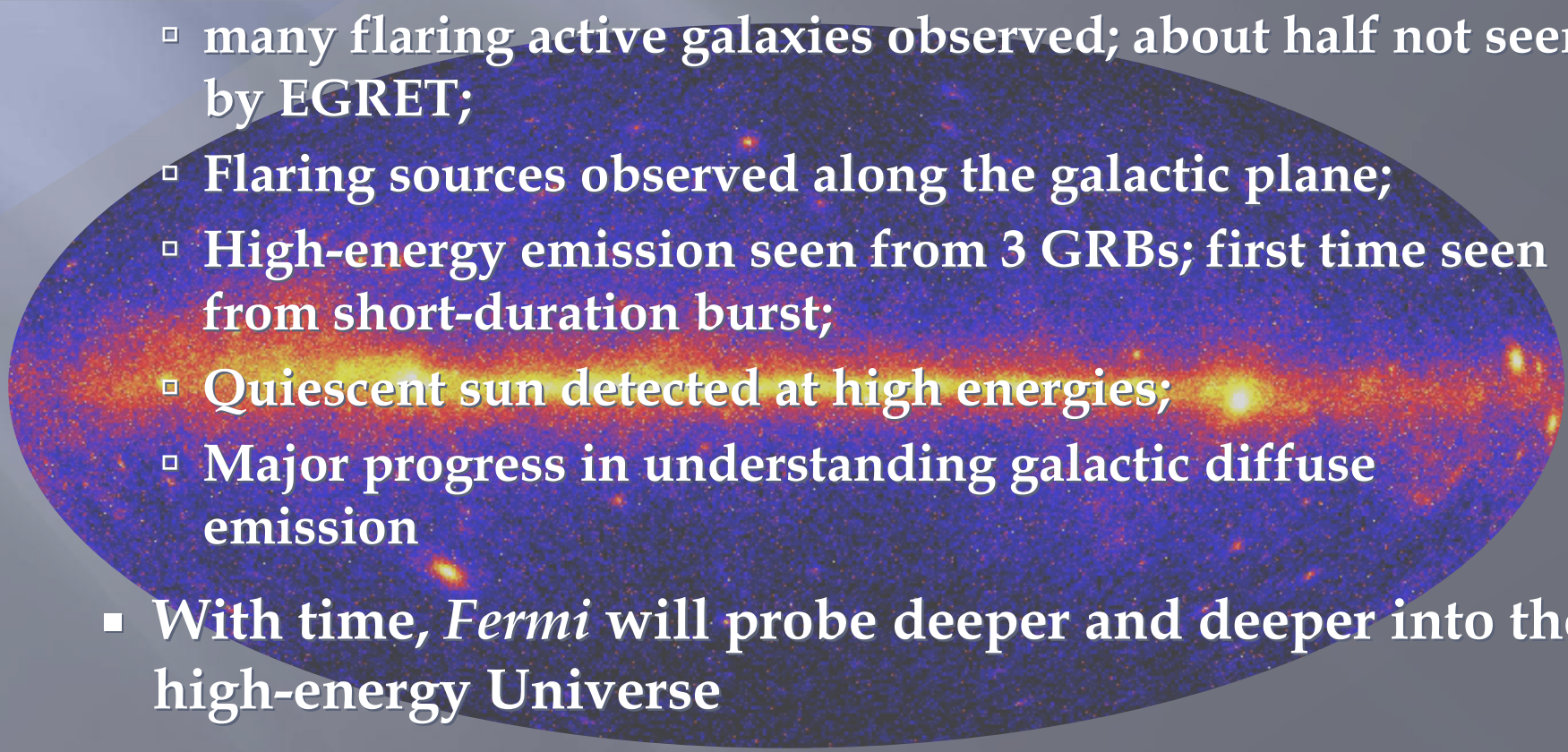
$Z = 4.35 \pm 0.15$

First detection of short-duration burst at high energy

Fermi-LAT observation of GRB 081024B — Omodei GCN 8407

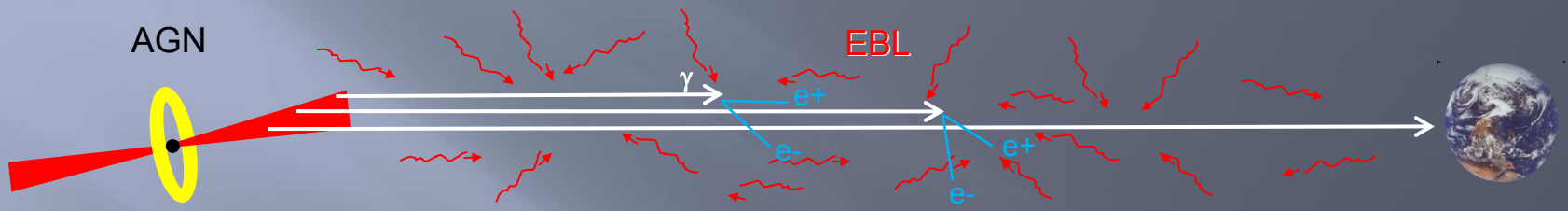
SOURCE: GCN
TITLE: GCN CIRCULAR
NUMBER: 8407
SUBJECT: Fermi-LAT observation of GRB 081024B
DATE: 08/10/25 14:07:58 GMT
FROM: Nicola Omodei at INFN(Pisa)/GLAST <nicola.omodei@pi.infn.it>

- *Fermi Gamma-ray Space Telescope* fully operational..
- In first few days of sky survey, the LAT corroborated many of the great discoveries of EGRET; now finding new sources as well;
- With 3 months of the 1st year all-sky survey phase;
  - large number of pulsars detected, some only in γ-rays;
  - many flaring active galaxies observed; about half not seen by EGRET;
  - Flaring sources observed along the galactic plane;
  - High-energy emission seen from 3 GRBs; first time seen from short-duration burst;
  - Quiescent sun detected at high energies;
  - Major progress in understanding galactic diffuse emission
- With time, *Fermi* will probe deeper and deeper into the high-energy Universe



Backup Slides

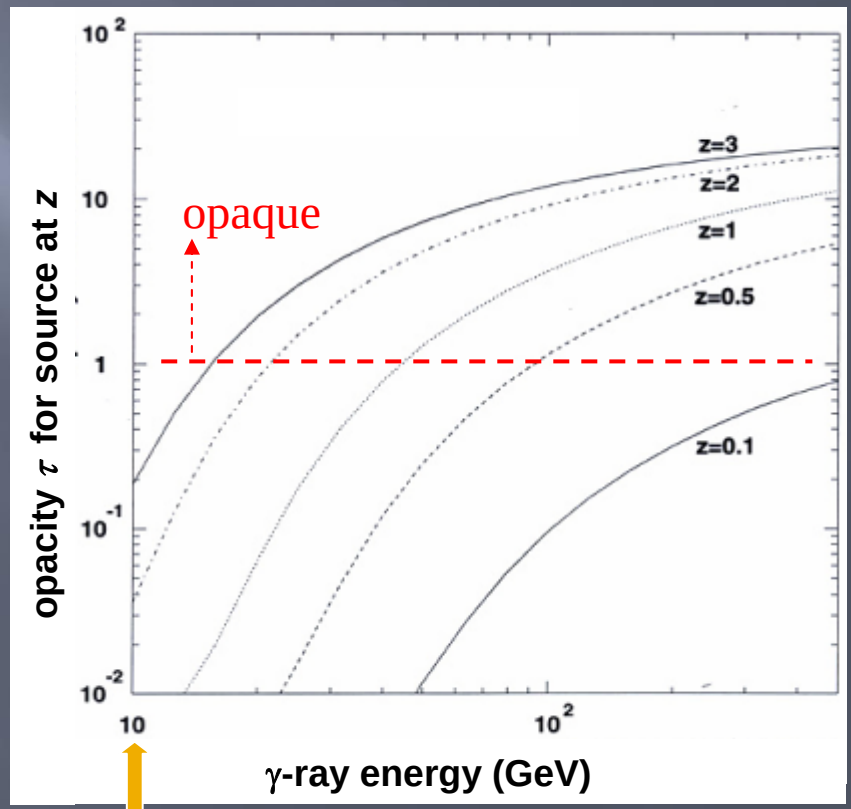
Probing Extragalactic Background StarLight with Blazars



- *diffuse EBL contains unique information about the epochs of formation and the evolution of galaxies and in what environments the stars of the universe formed*
- *direct EBL measurements require accurate model-based subtraction of bright foregrounds (e.g., zodiacal light)*
- *alternative approach: extract imprint of EBL absorption, as function of redshift, from high-energy spectra of extragalactic sources*

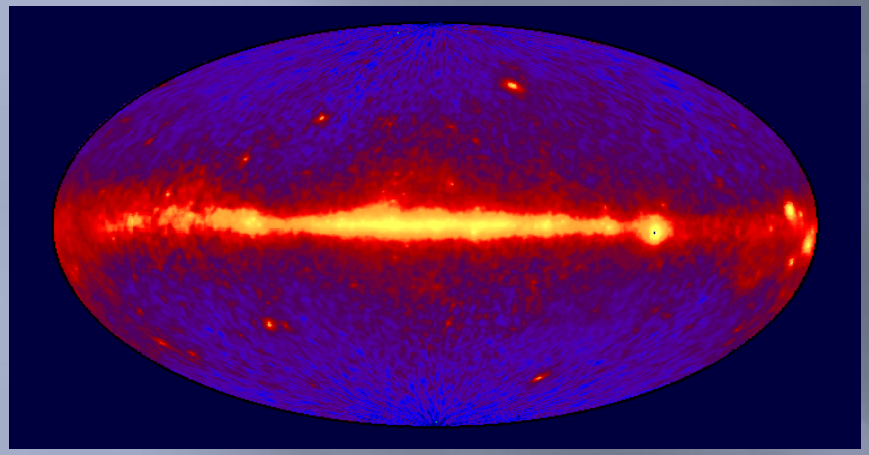
$\gamma\gamma \rightarrow e^+e^-$, *maximum when*

$\varepsilon_{EBL} \sim ½ \text{ (1000 GeV / } E_\gamma\text{) eV}$



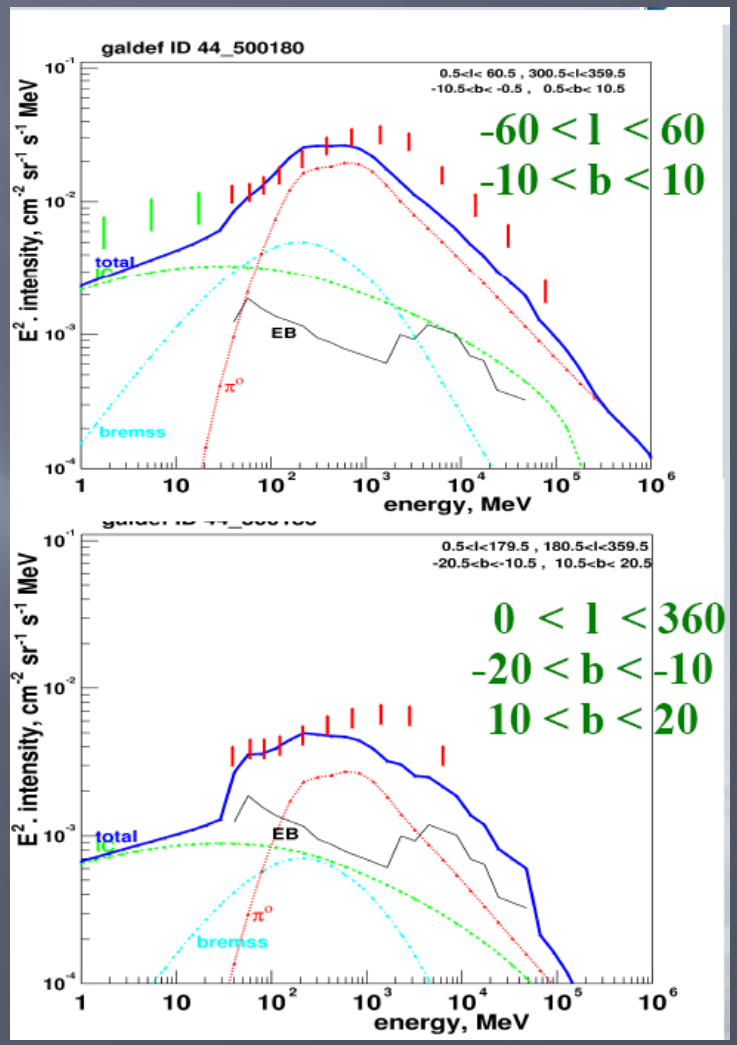
no significant attenuation below 10 GeV

EGRET "GeV excess"



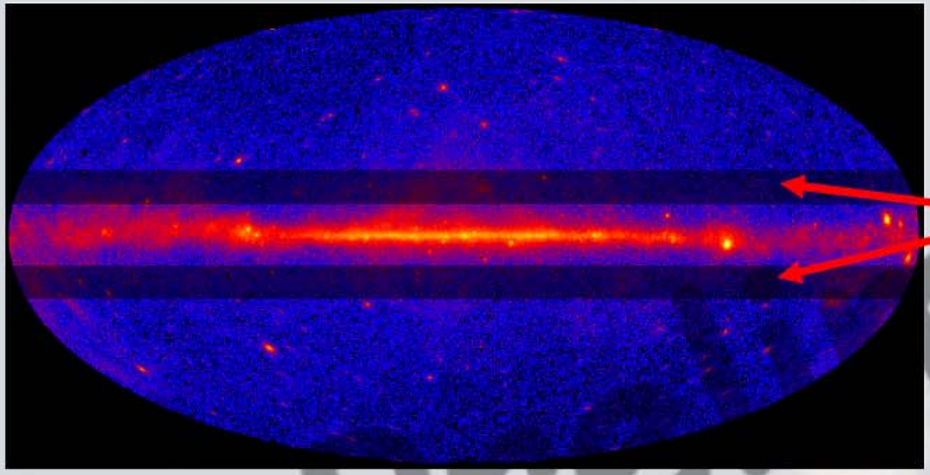
EGRET observations showed excess emission > 1 GeV when compared with conventional model tuned to reproduce local cosmic-ray nuclei and electron spectra

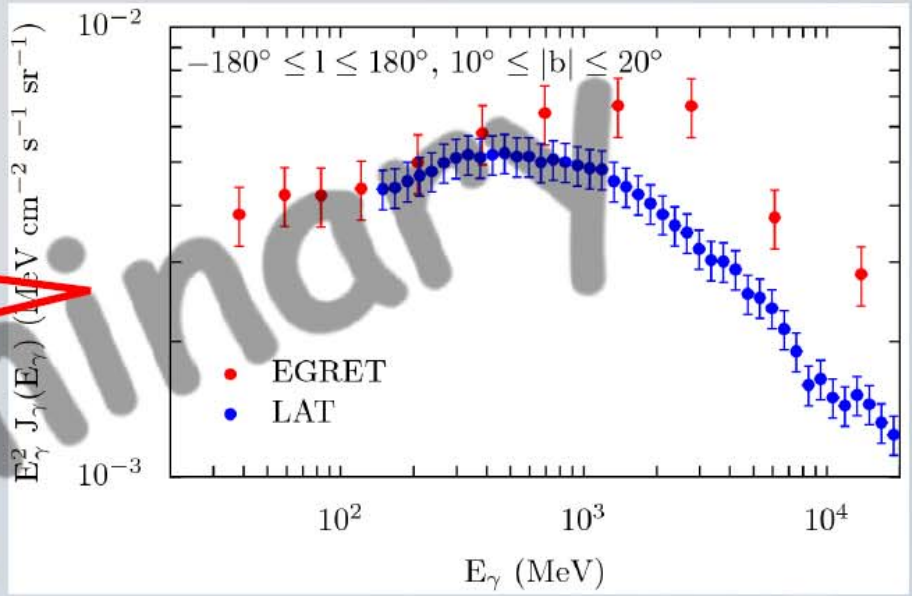
- Variety of explanations
  - Variations in cosmic-ray spectra over Galaxy
  - Unresolved sources (pulsars, SNRs, …)
  - Dark matter
  - Instrumental



~100% discrepancy > 1 GeV

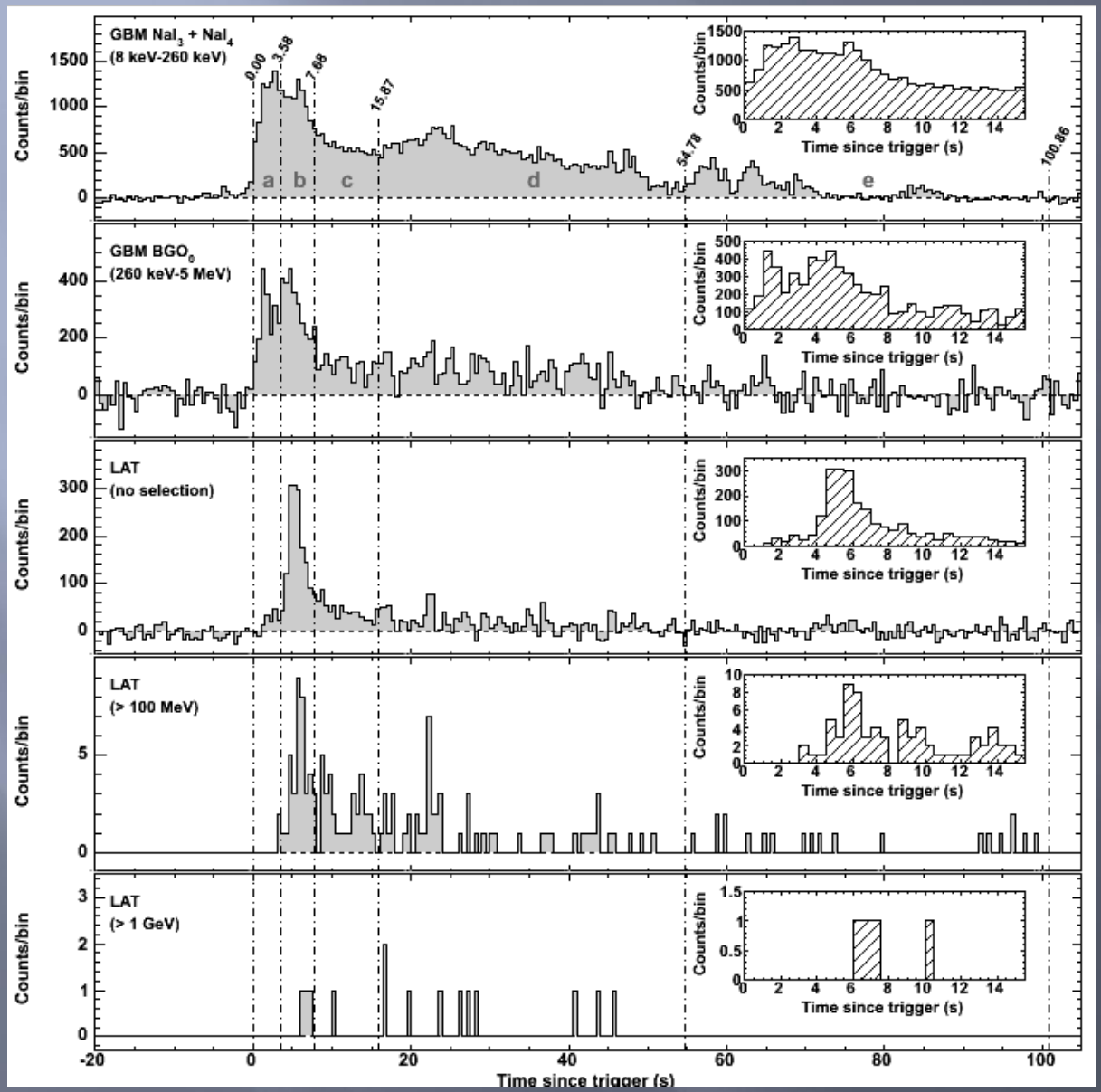
The Fermi LAT View





- Spectra shown for mid-latitude range → EGRET GeV excess in this region of the sky is <u>not</u> confirmed
- Sources are not subtracted but are a minor component
- LAT errors are systematics dominated and estimated ~10% → this is <u>preliminary</u>
- Work to analyse and understand diffuse emission over the entire sky is in progress

Energy-dependent Light Curve

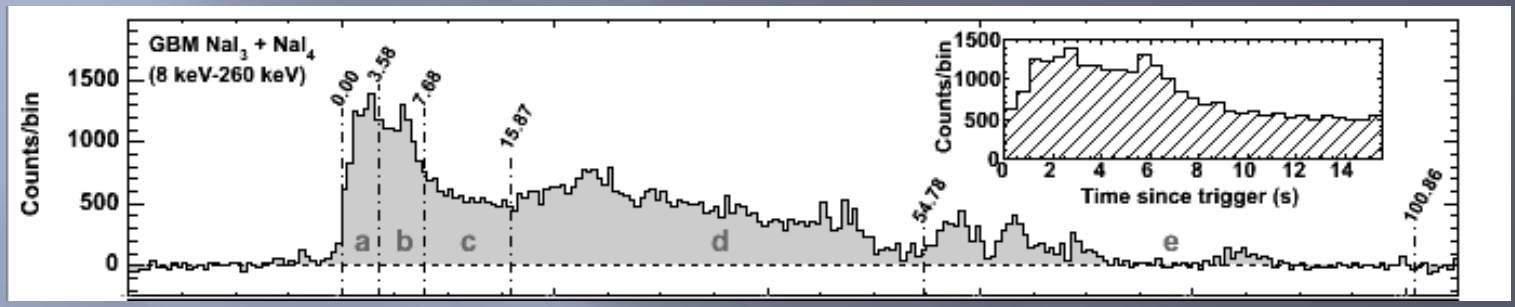


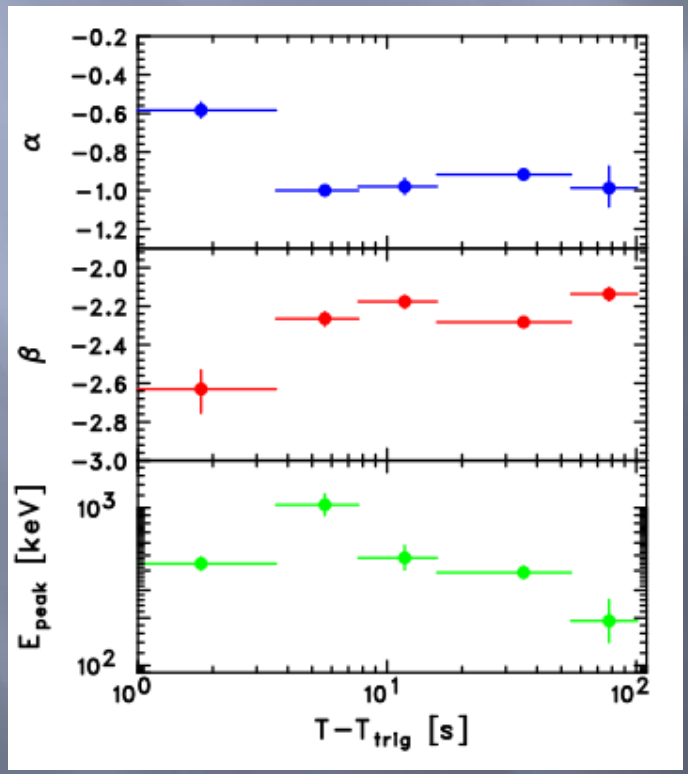
- For the first time, can study time structure > tens of MeV.
- Feature in the LC:
  - pulse in interval "a" disappears at LAT energies.

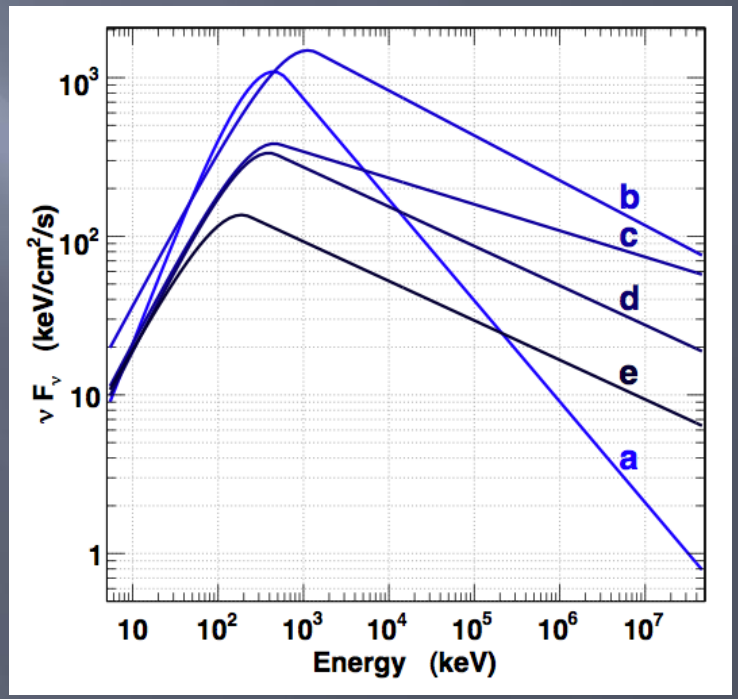
For this burst, $\gamma\gamma$ absorption arguments provide a stringent lower limit of $\Gamma_{min} = 860$

Science Express,
19 Feb 2009, pg 1

Spectral Evolution







Soft-to-hard spectral evolution followed by spectral softening