Gamma-ray Universe Revealed by Fermi Gamma-ray Space Telescope

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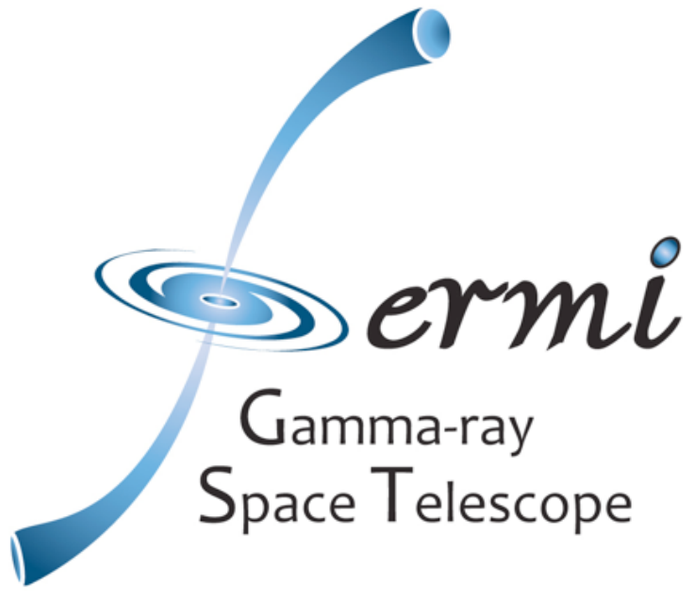
(Stanford Linear Accelerator Center)



ICRR Seminar
December 16, 2008
Kashiwa, Japan

Outline

- Overview of Fermi Large Area Telescope (LAT)
- Instrument Performance after Launch
- Science Results
  - Overview
  - Discovery Gamma-ray Pulsars
  - High-Energy Emission from Gamma-ray Bursts
- Future Prospects
  - Extended Sources
  - Cosmic-ray Electrons

Fermi/LAT Collaboration

Stanford University & SLAC
NASA Goddard Space Flight Center
Naval Research Laboratory
University of California at Santa Cruz
Sonoma State University
University of Washington
Purdue Univeristy-Calumet
Ohio State University
University of Denver

Commissariat a l'Energie Atomique, Saclay
CNRS/IN2P3 (CENBG-Bordeaux, LLR-Ecole polytechnique, LPTA-Montpellier)

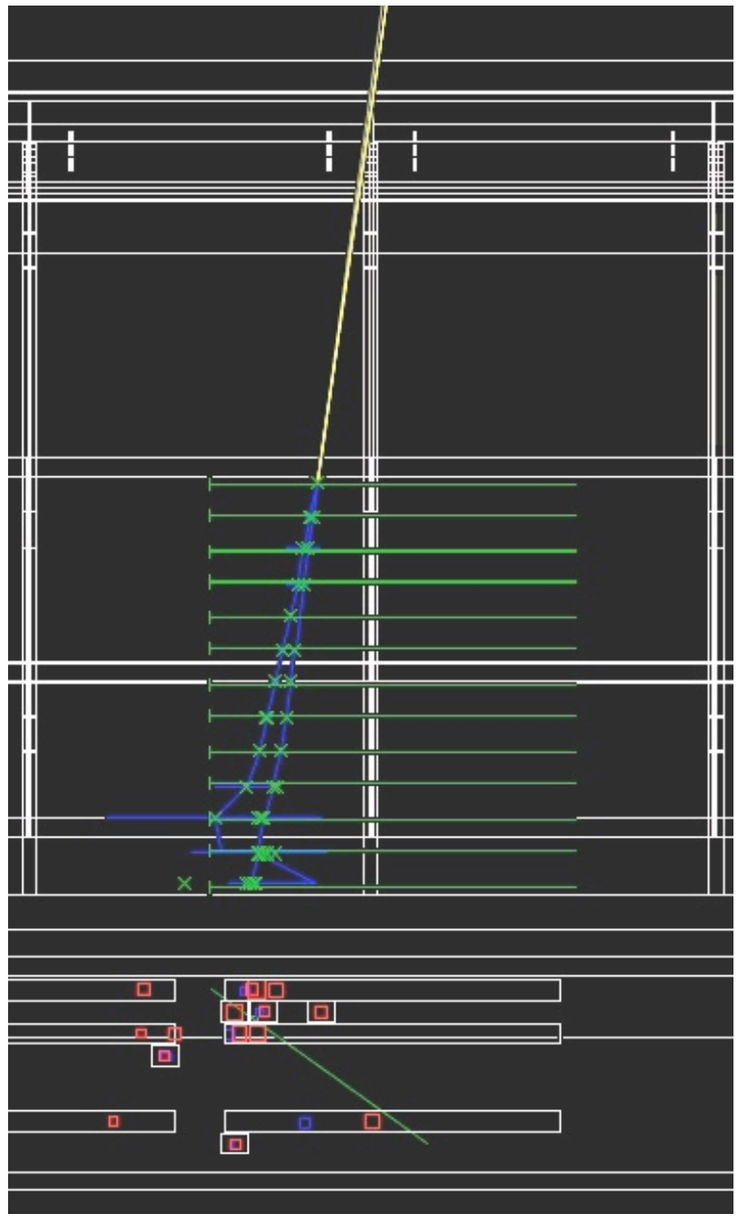
Hiroshima University
Institute of Space and Astronautical Science
Tokyo Institute of Technology
RIKEN

Instituto Nazionale di Fisica Nucleare
Agenzia Spaziale Italiana
Istituto di Astrofisica Spaziale e Fisica Cosmica

Royal Institute of Technology, Stockholm
Stockholms Universitet

Fermi/LAT Overview

- **Satellite experiment to observe gamma rays from Universe**
  - **Wide energy range: 20 MeV – 300 GeV**
  - **Large effective area: > 9000 cm² (~6xEGRET)**
  - **Wide field of view: > 2 sr (~6xEGRET)**
- **Scientific objectives**
  - **Dark matter**
    - Neutralino annihilation
  - **Particle acceleration**
    - Origin of cosmic rays
- **Pair-conversion telescope**
  - **“Clear” signature**
  - **Background rejection**



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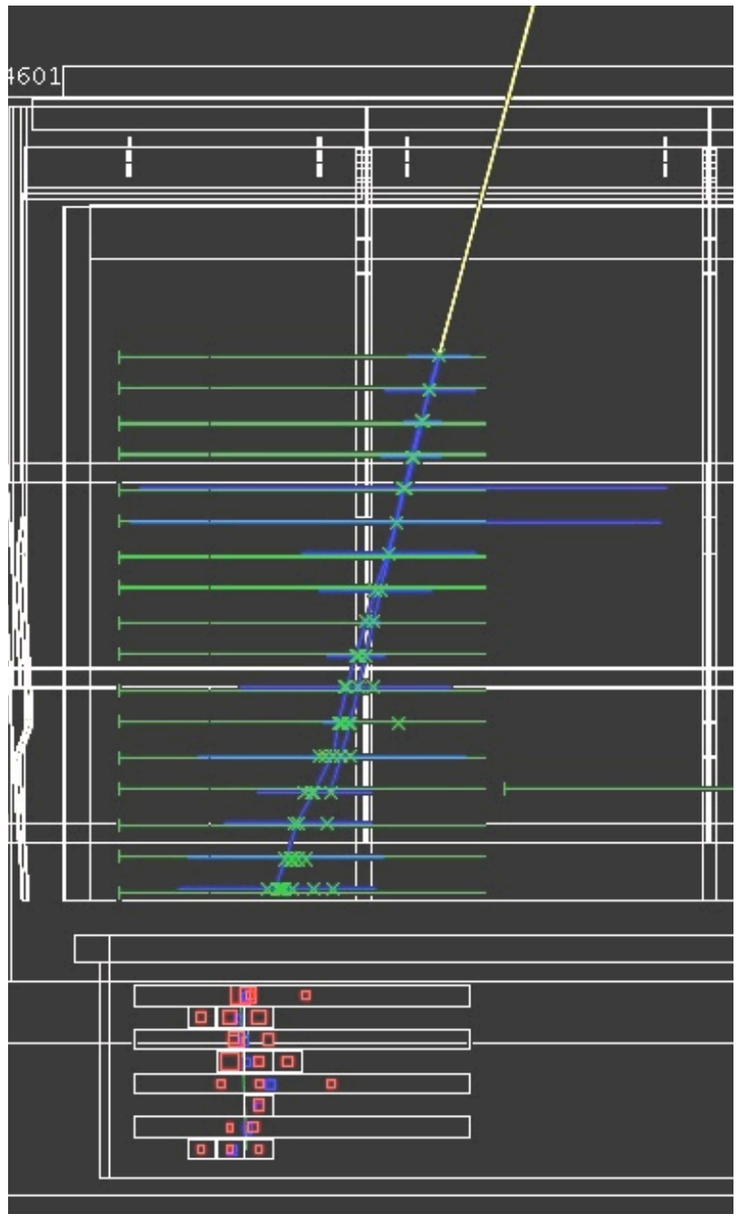

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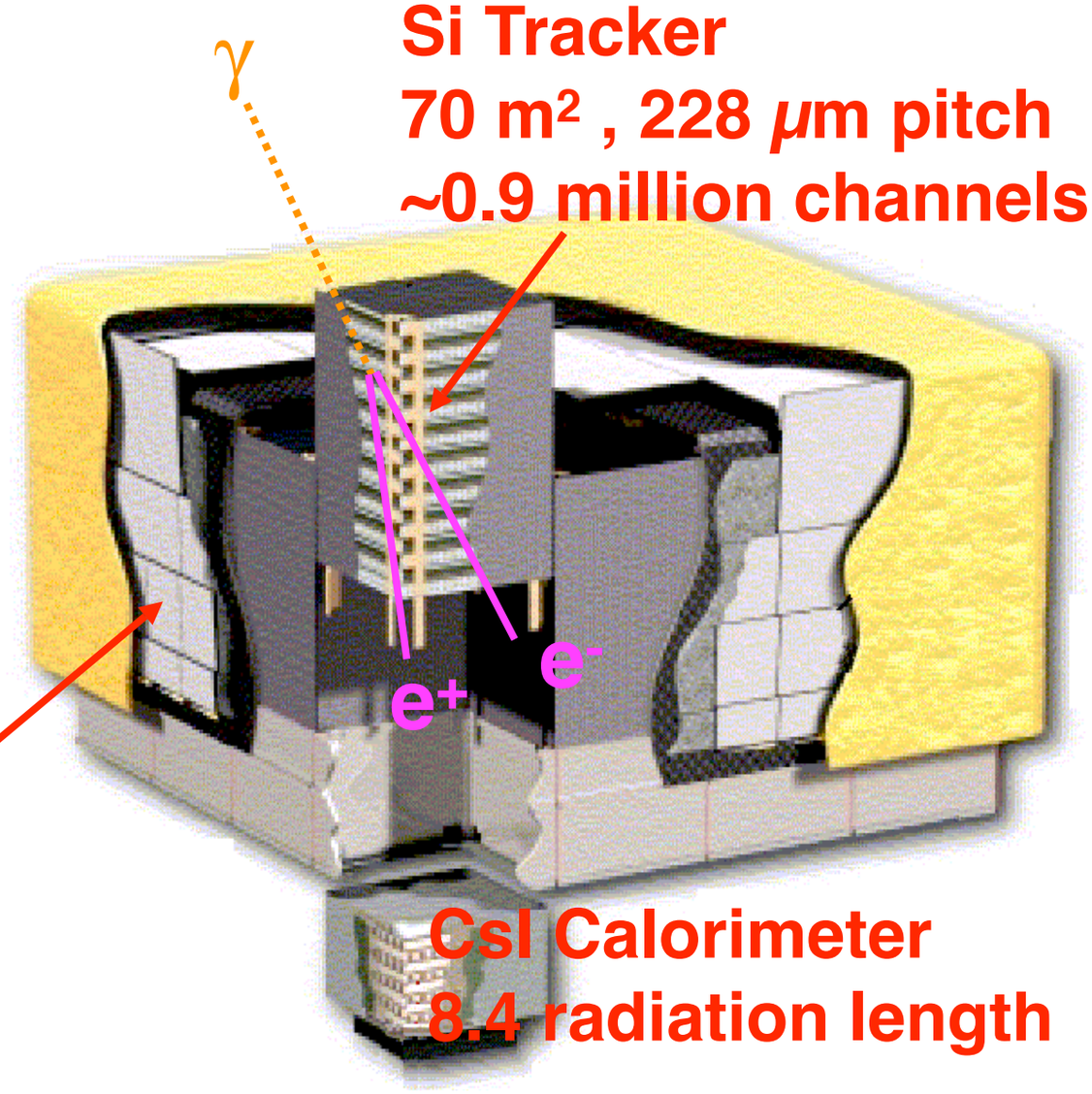
Instrument Configuration

- **Tracker (TKR): conversion, tracking**
  - **Angular resolution is dominated by scattering below ~GeV**
  - **Converter thickness optimization**
- **Calorimeter: energy measurement**
  - **8.4 radiation length**
  - **Use shower development to compensate for the leakage**
- **Anti-coincidence detector:**
  - **Efficiency > 99.97%**



Launch

- Milestones toward launch
  - 2005/10:
    Final Tracker module delivered
  - 2006/05:
    LAT integration complete
  - 2006/10:
    LAT environmental test finished
  - 2007/10:
    GLAST integration complete
  - 2008/02:
    GLAST environmental test finished
  - 2008/06/11: GLAST launch
  - 2008/06/24: LAT power on

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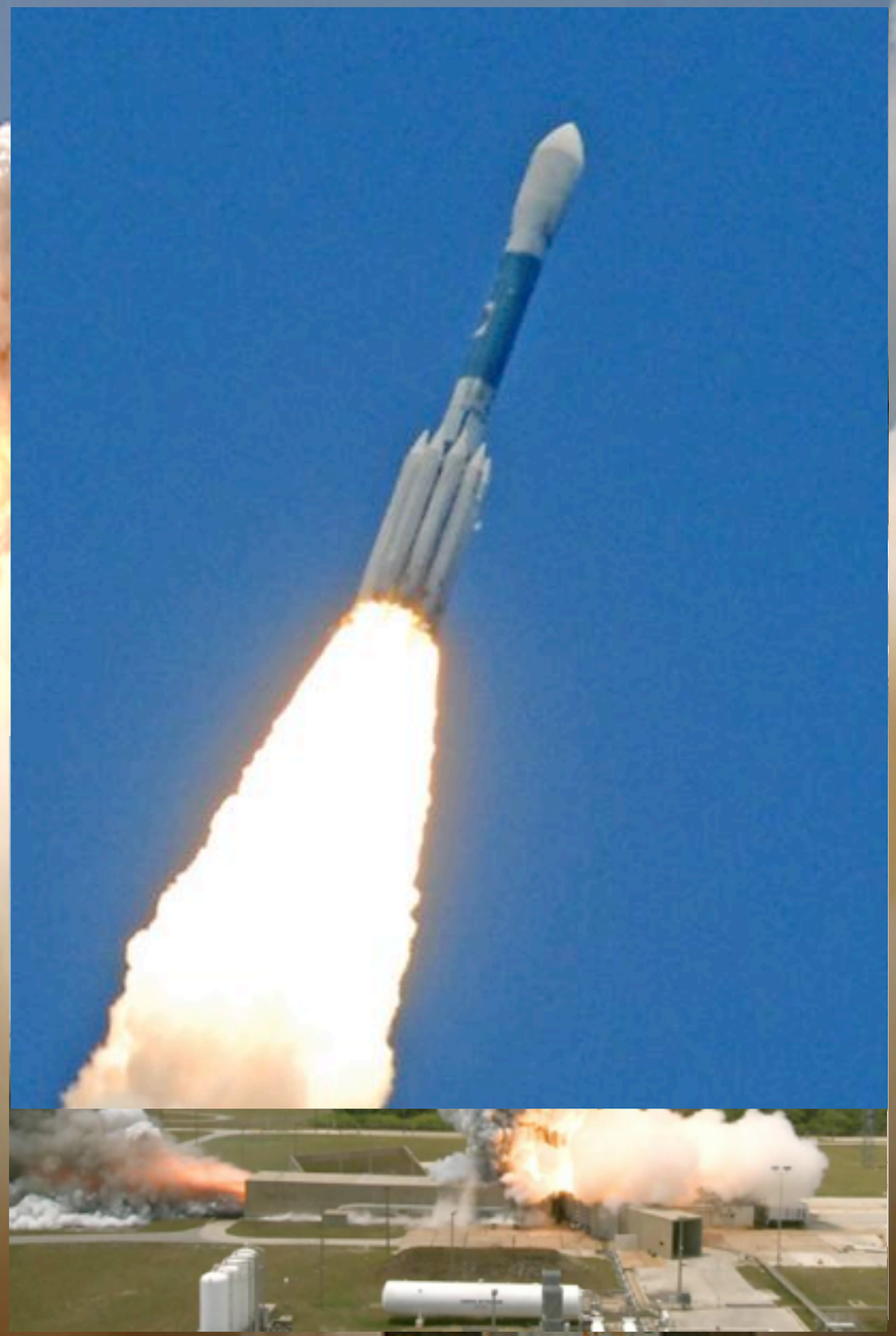
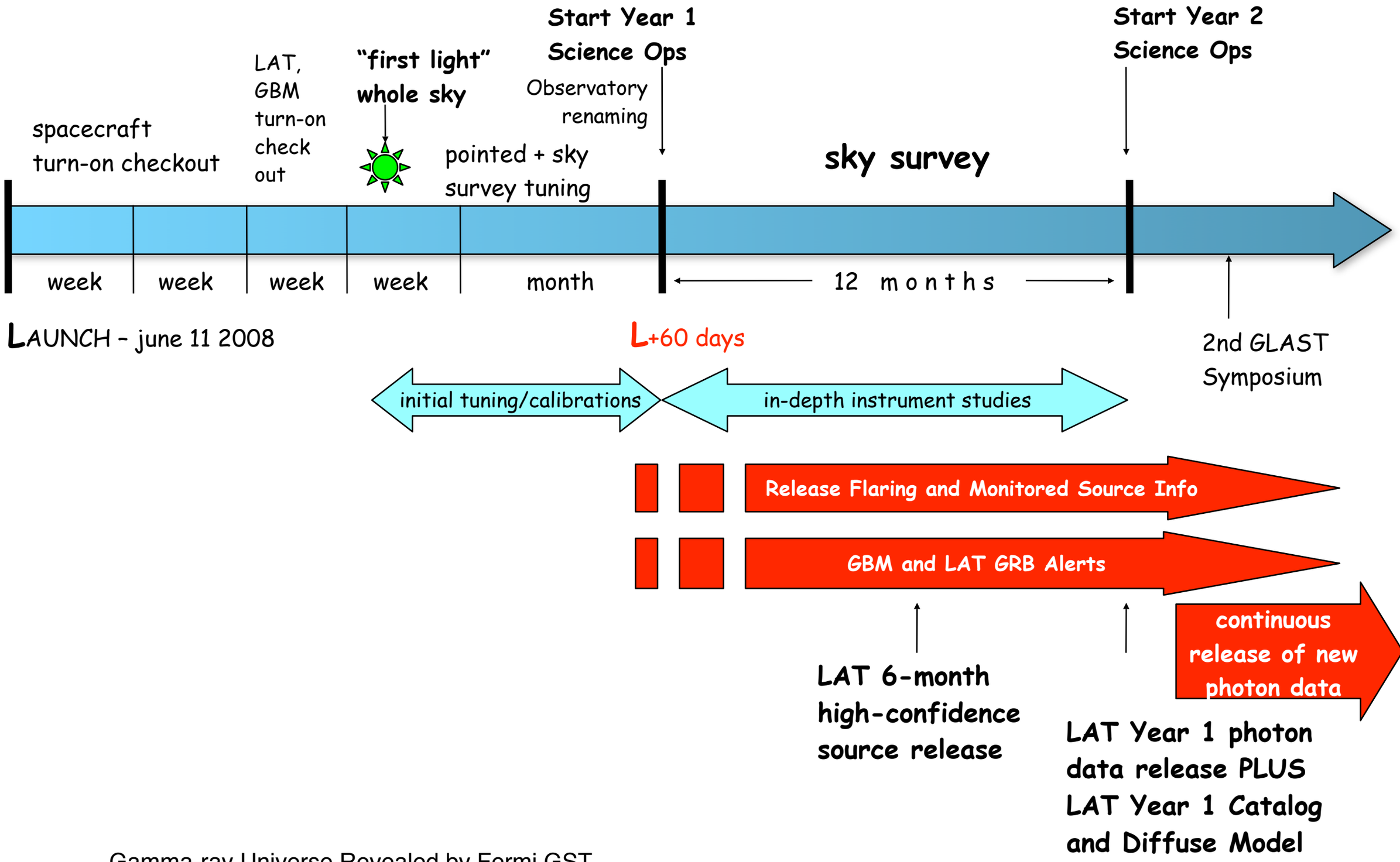
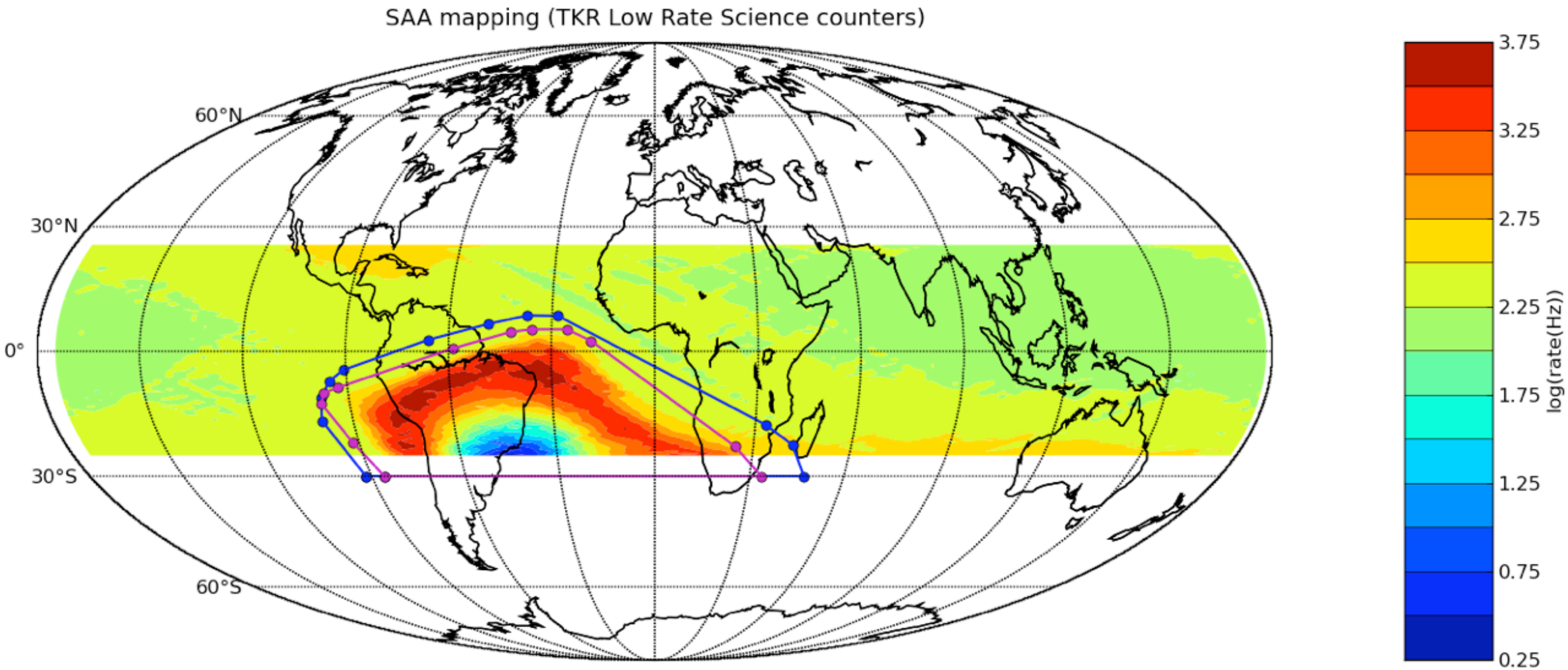


LAT Operations After Launch

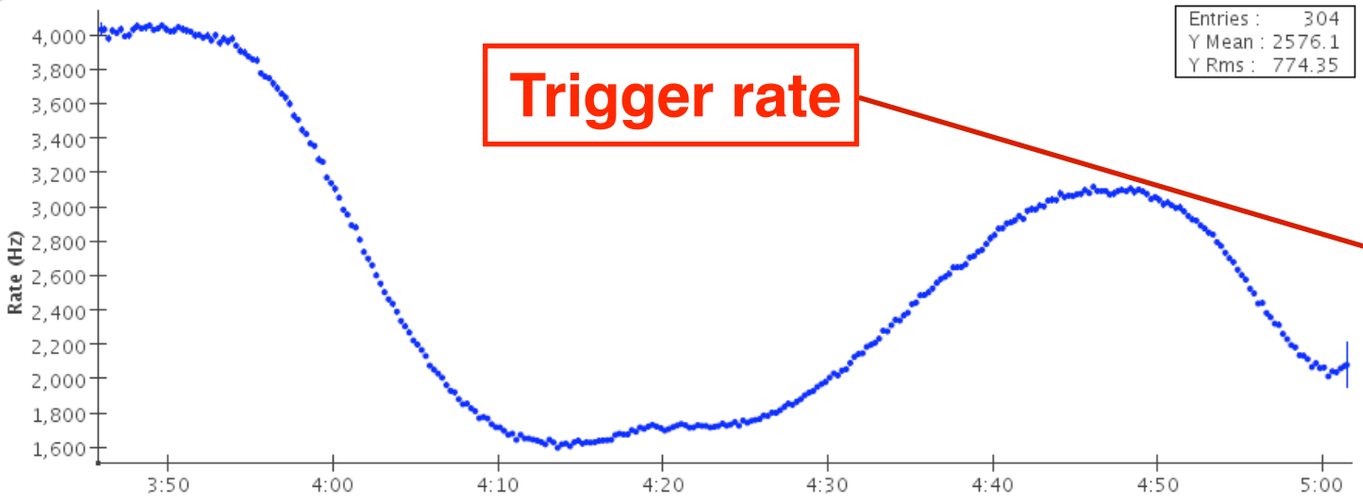


Particle Background Environment

- **TKR trigger rate is monitored throughout SAA**
  - **Trigger rate saturates above ~3.7 kHz/layer**

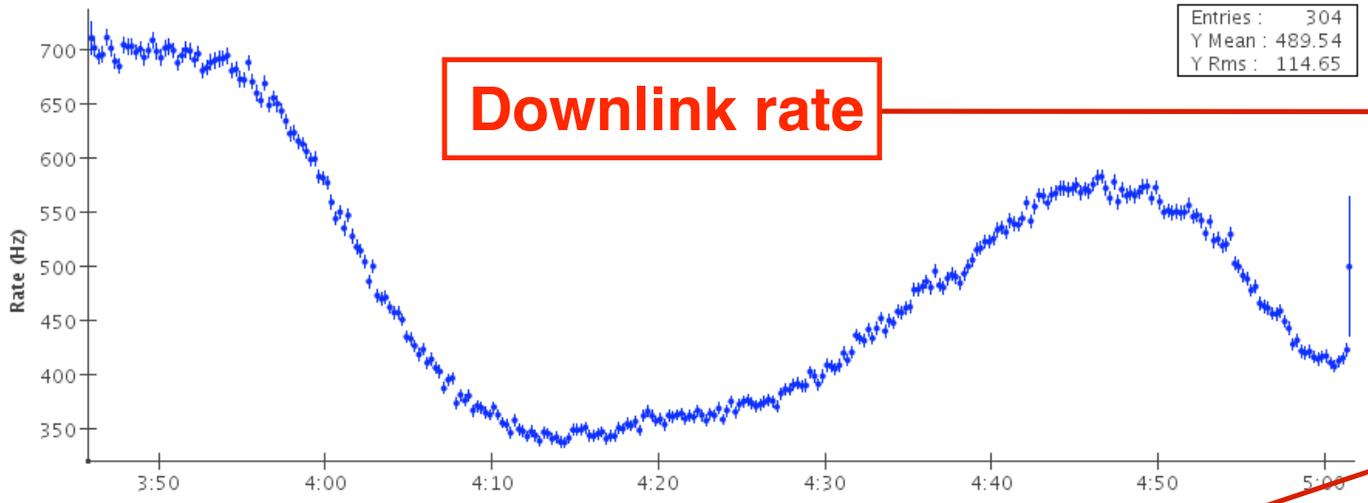


Event Rates



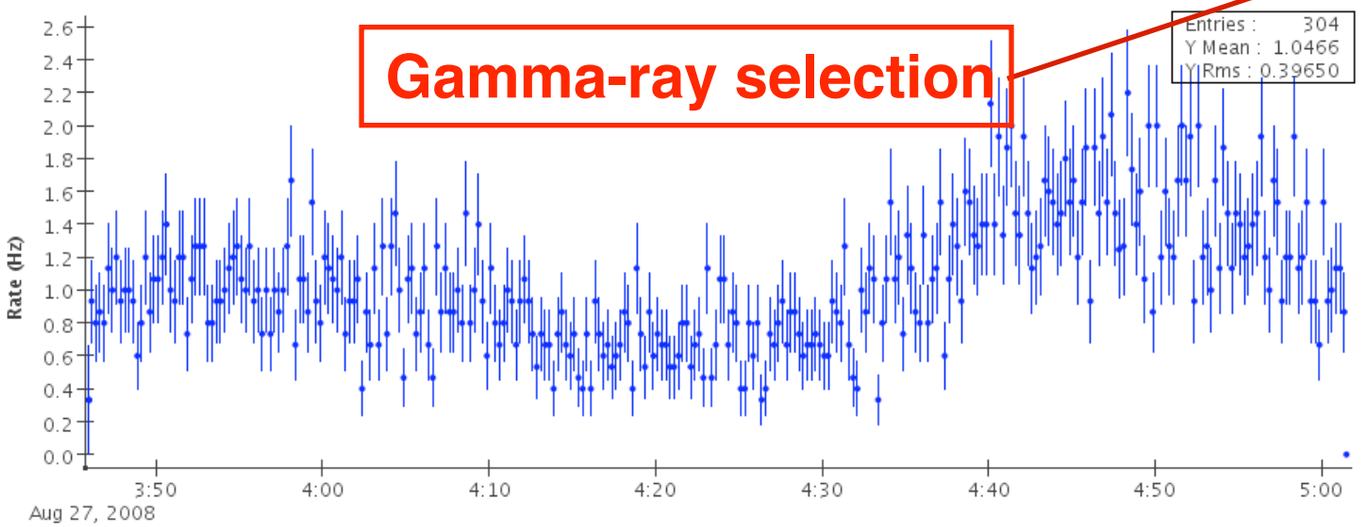
Trigger rate

- ✓ Overall trigger rate: ~1–4 kHz
  - ✓ Huge variations due to orbital effects.



Downlink rate

- ✓ Downlink rate: ~0.3–0.7 kHz
  - ✓ ~90% from GAMMA filter
  - ✓ ~30 Hz from minimum bias filter
  - ✓ ~5 Hz from heavy ion filter



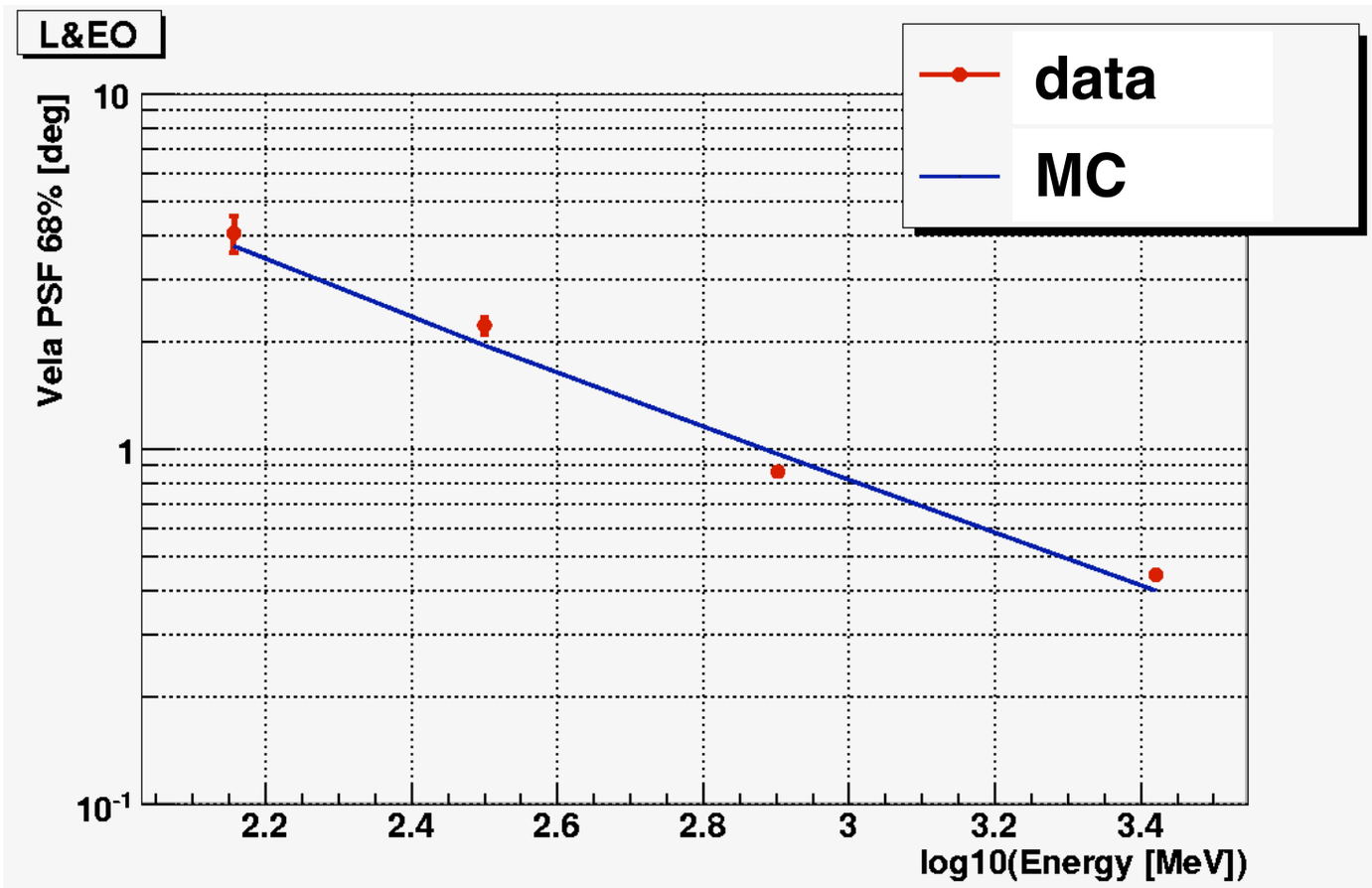
Gamma-ray selection

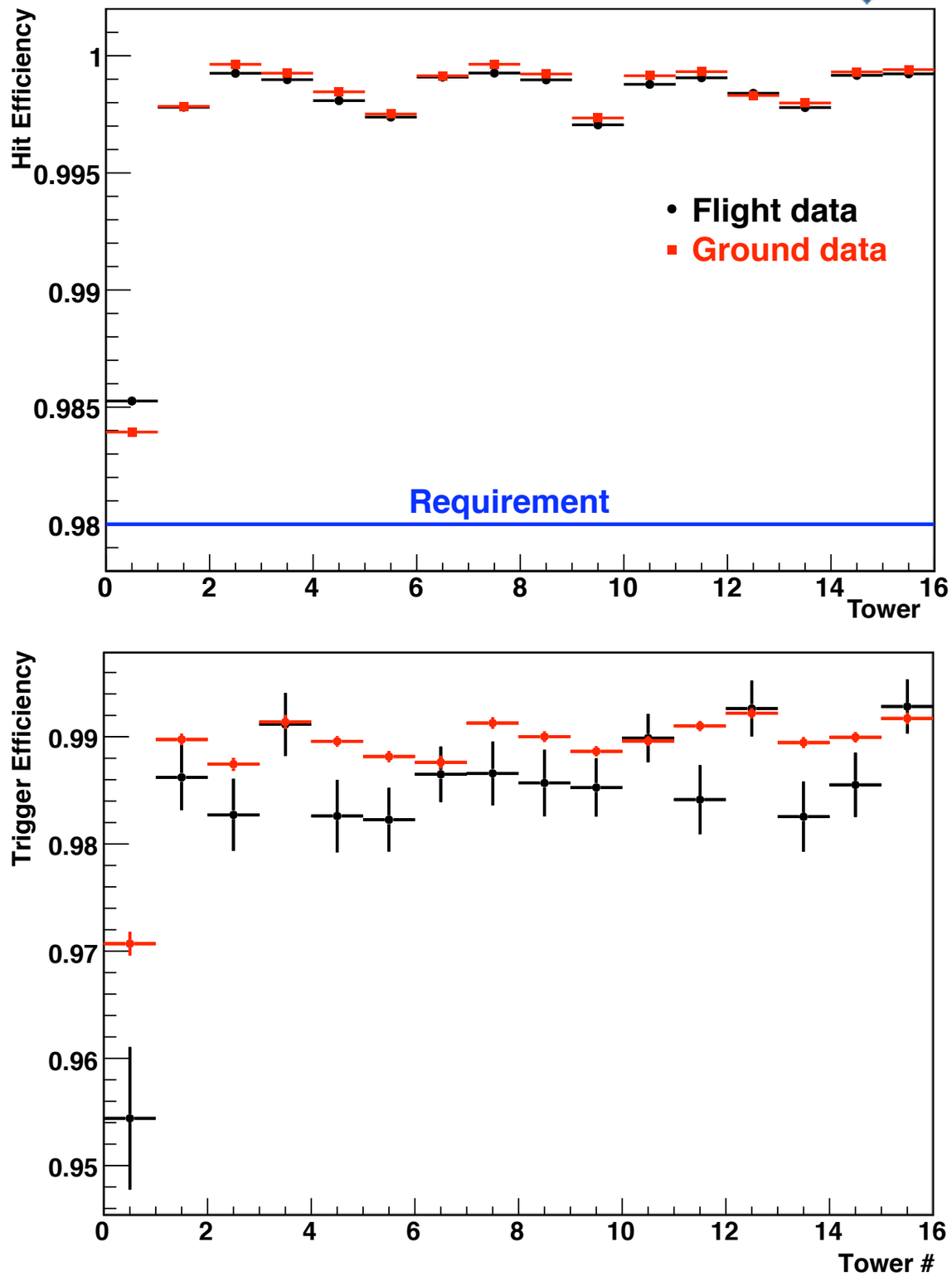
- ✓ Rate of photons after the standard background rejection cuts for source study: ~1 Hz

- ✓ Most of the downlinked events are in fact background, final ~ 1000:1 rejection is done in ground processing.

Performance After Launch

- Comparison before and after the launch
  - Apparent efficiencies slightly lower due to accidentals
- Point spread function (PSF) consistent between data and MC





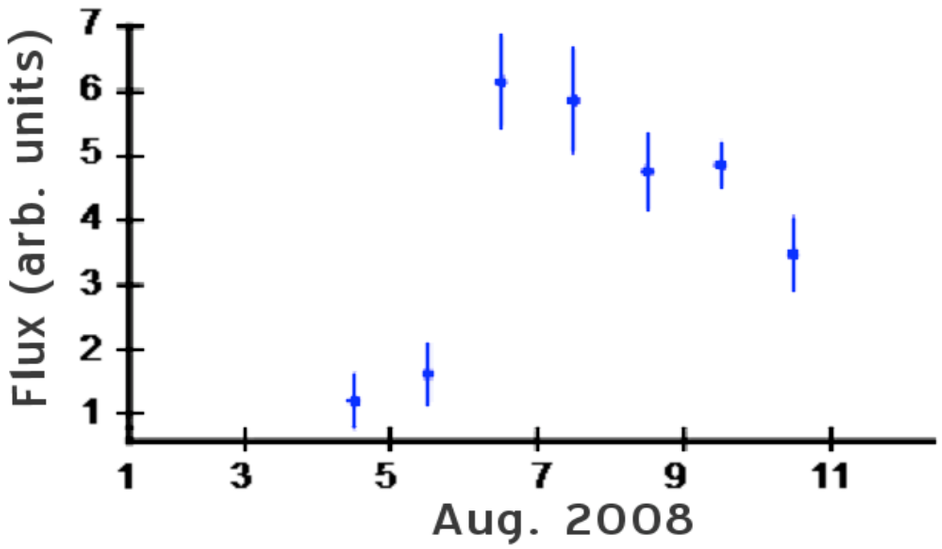
Early Science Results

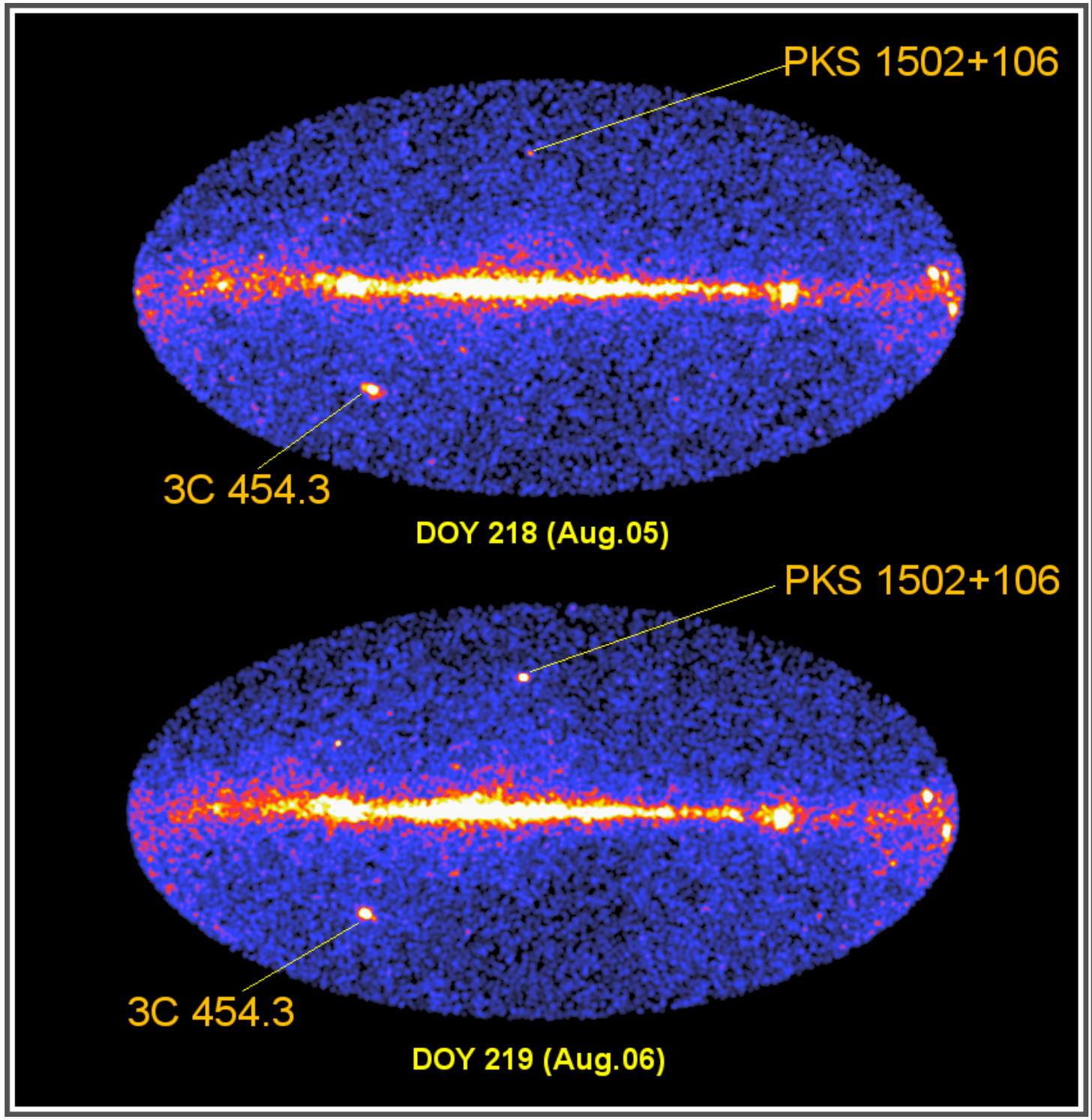
- Detection of transient sources
  - AGNs
  - Gamma-ray binaries
  - Gamma-ray bursts (GRBs)
- Gamma-ray pulsars
  - Discovery of new gamma-ray pulsars
  - Detection of radio pulsars
  - Energy cut-off for Vela pulsar

- Note: All results are preliminary except for CTA1 pulsar (published in Science)

Detection of Transient Sources

- **Fermi covers all sky in 3 hours**
  - **Detection of transients**
  - **Variability studies**
    - 3C 454.3
    - PKS 1502+106
    - Not seen by EGRET





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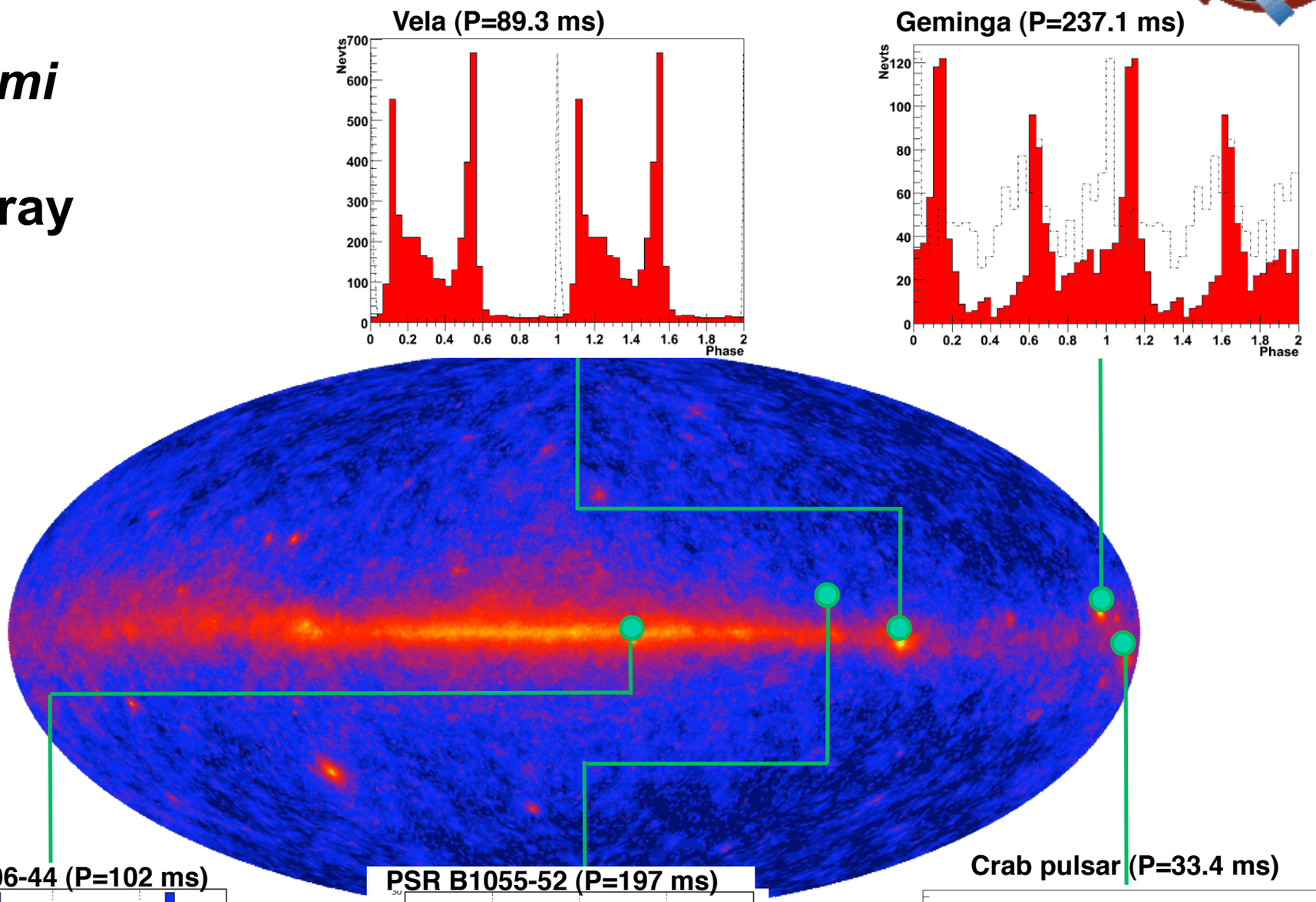
ATELs for Transient Sources

- **Extragalactic sources**
  - **1701: A possible new γ-ray flaring blazar: PKS 1454-354**
  - **1707: 3C 273 in flaring state**
  - **1743: PKS 1510-089 outburst**
  - **1744: Strong detection of blazar AO 0235+164**
  - **1759: Gamma ray activity in three blazars: 3C 66A, PKS 0208-512, PKS 0537-441**
  - **1784: Strong activity on short timescales of blazar AO 0235+164**
  - **1864: Increasing gamma ray activity of blazar 3C 279**
- **Galactic place sources**
  - **1771: Brightening of Galactic plane source 3EG J0903-3531**
  - **1788: New Gamma-ray transient in Galactic place: J0910-5041**
  - **1850: Fermi LAT Observations of the Cygnus Region**

EGRET Pulsars

In only a few days, *Fermi* confirmed the EGRET pulsars, finding new γ-ray pulsars as well



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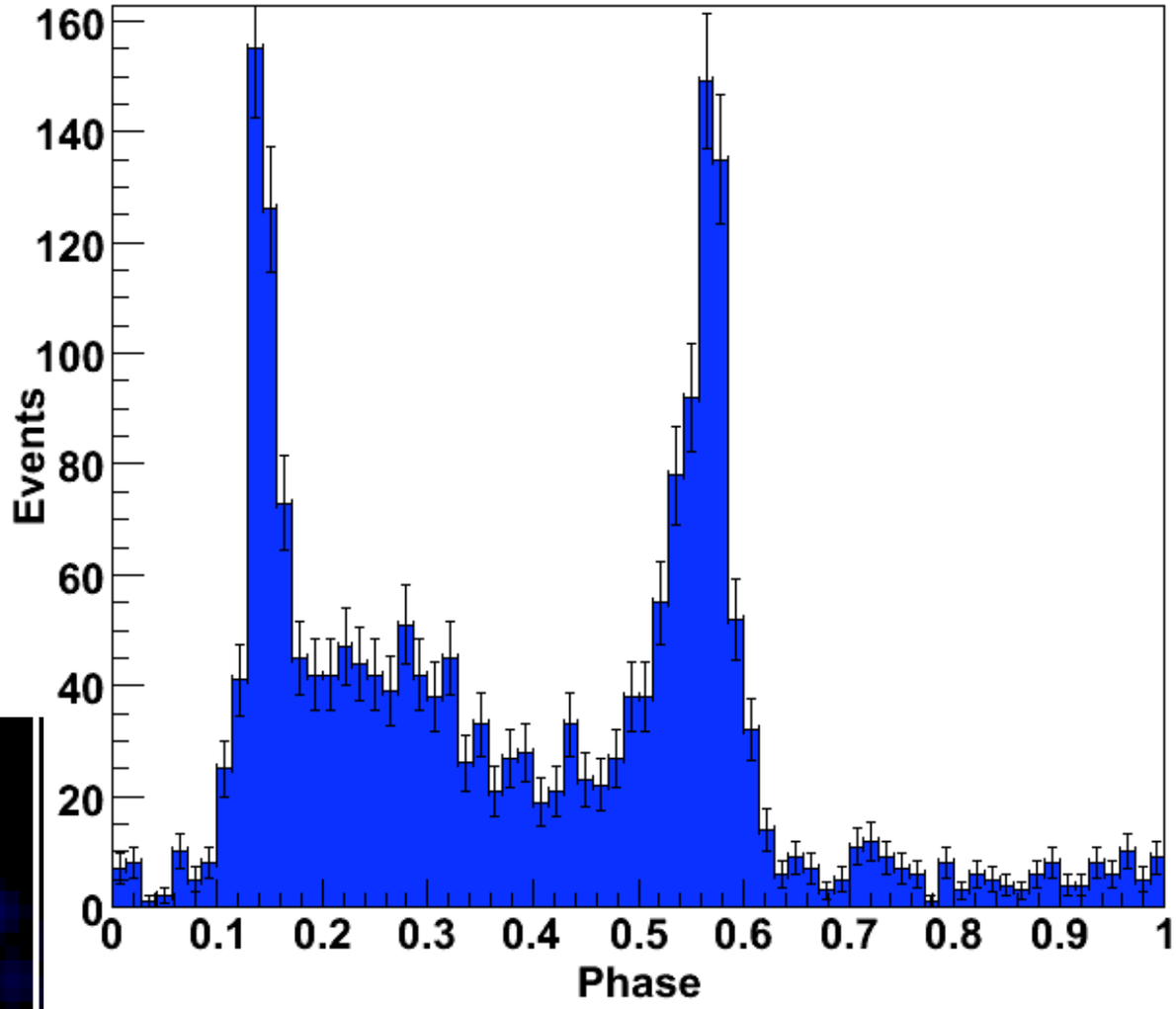
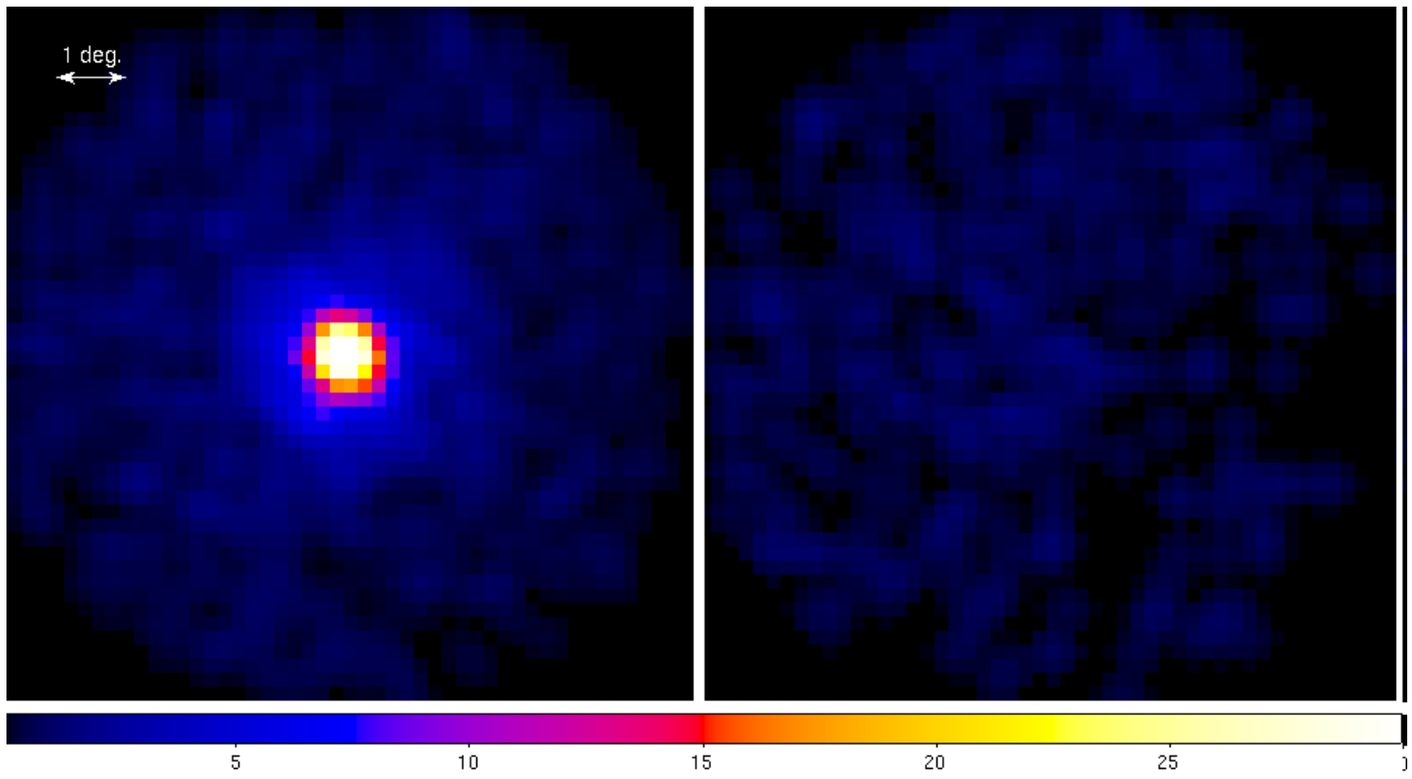
Studies of Vela Pulsar

- **Vela pulsar is brightest gamma-ray source**
  - **Used to evaluate instrument performance**
    - PSF
    - Timing



Preliminary
(publication in press)



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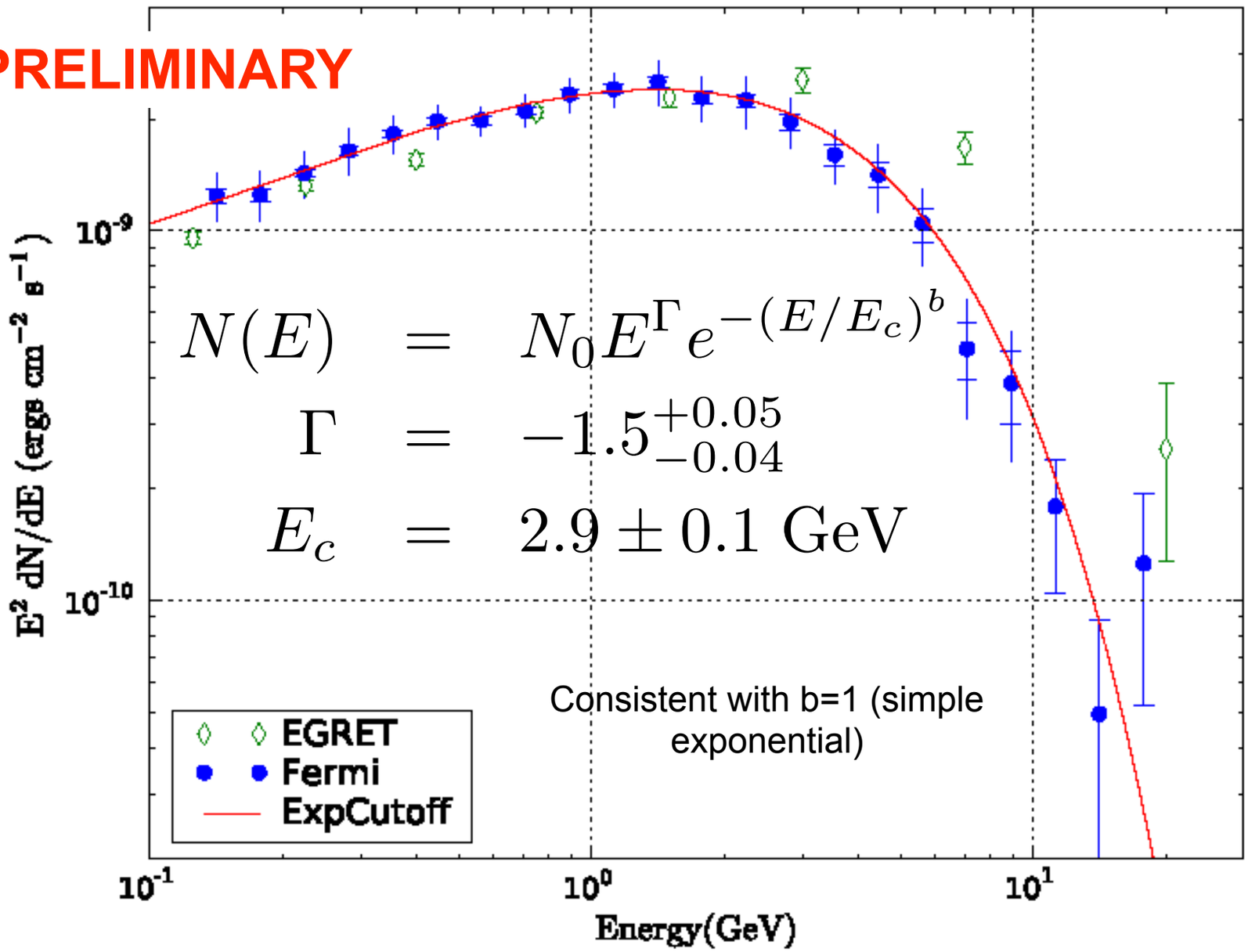
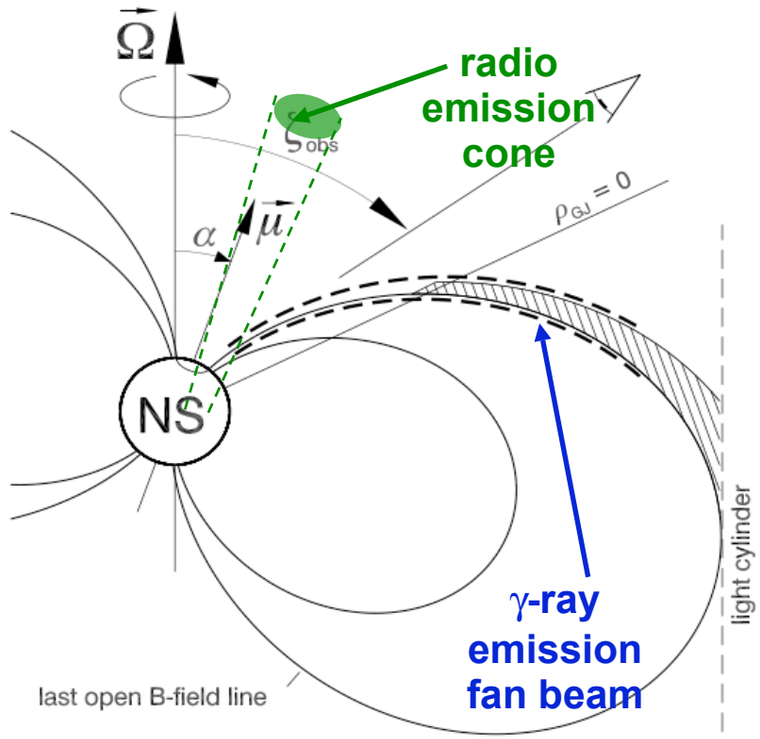
Gamma-ray Emission in Vela Pulsar

- **Acceleration in Magnetosphere**
  - **Outer magnetosphere** $\gamma\gamma \rightarrow e^+e^-$
  - **Near the NS surface** $\gamma + \vec{B} \rightarrow e^+ + e^-$

PRELIMINARY

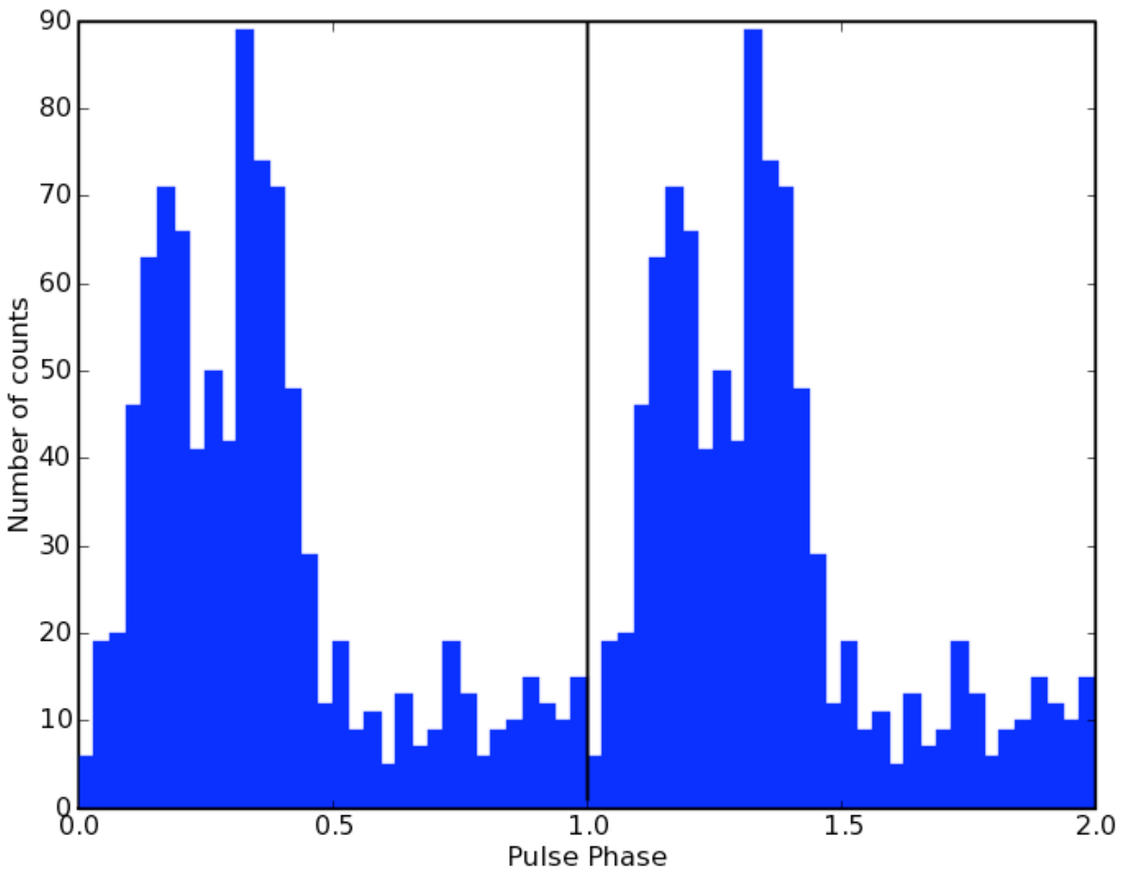




Near-surface emission ruled out

Discovery of Gamma-ray Pulsar

- Discovery of gamma-ray pulsar in CTA 1 after 20 days
  - 900 events with E>100 MeV
  - P=315.86 ms
  - Gamma-ray flux: 1–10% of E_{rot}



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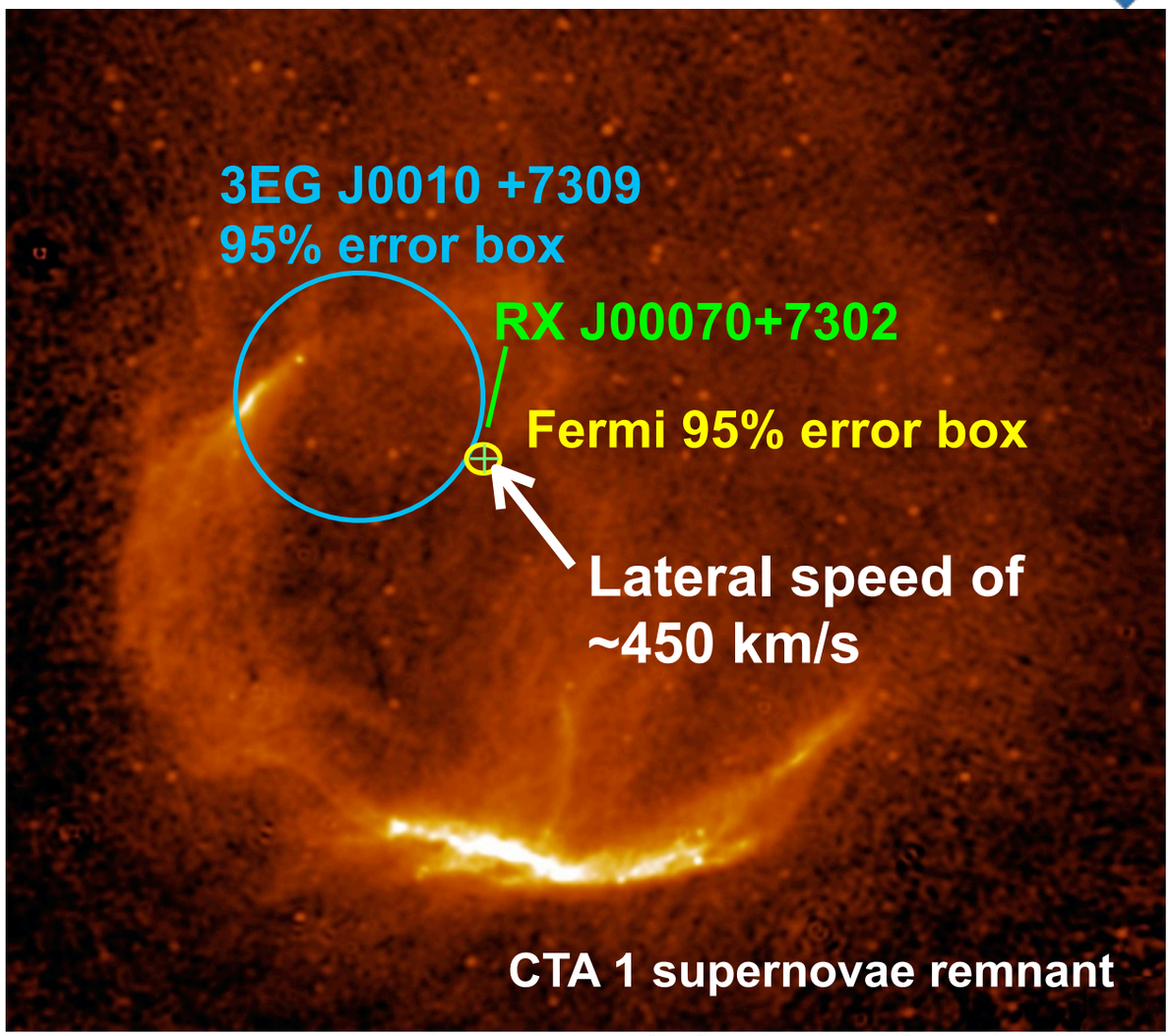
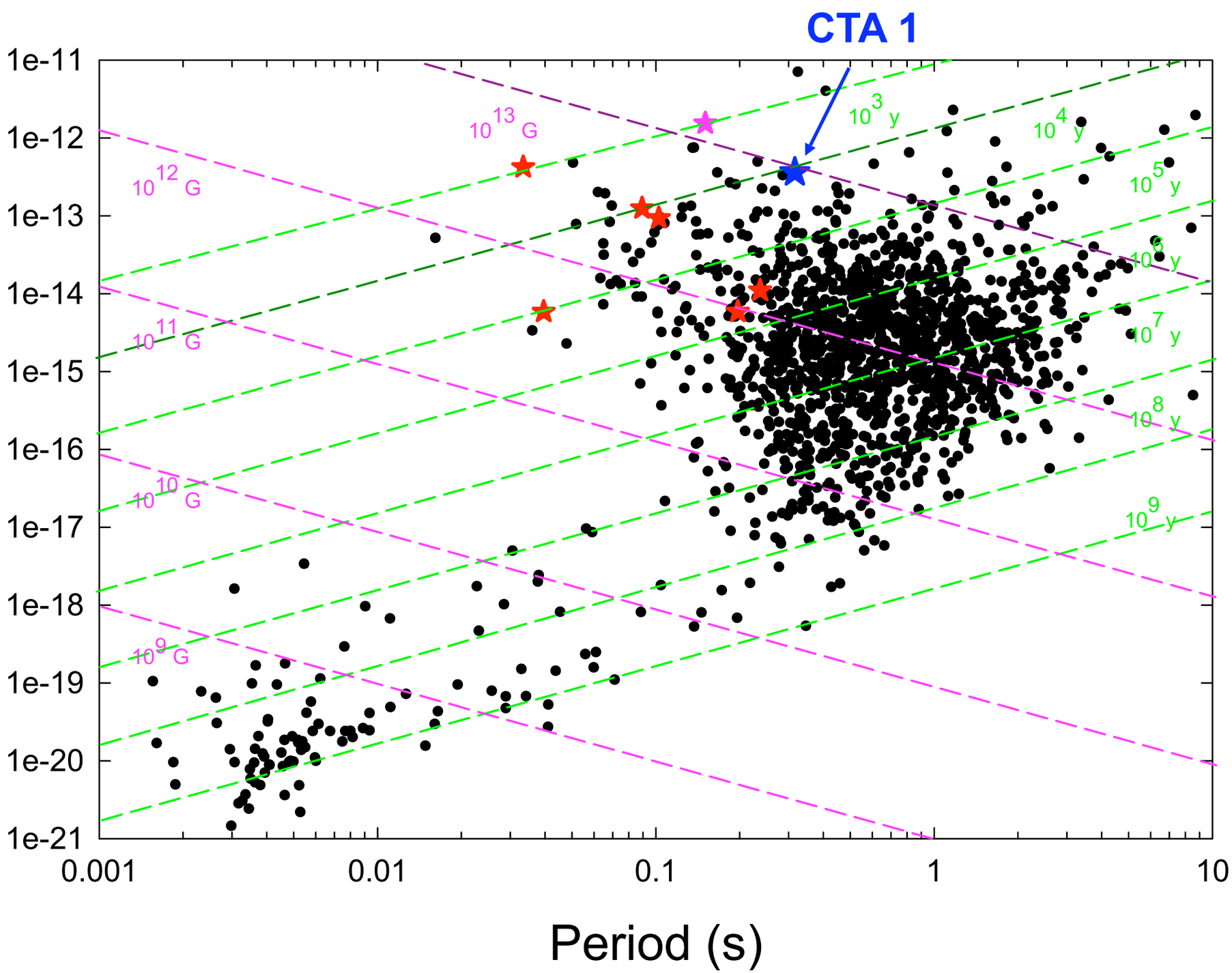
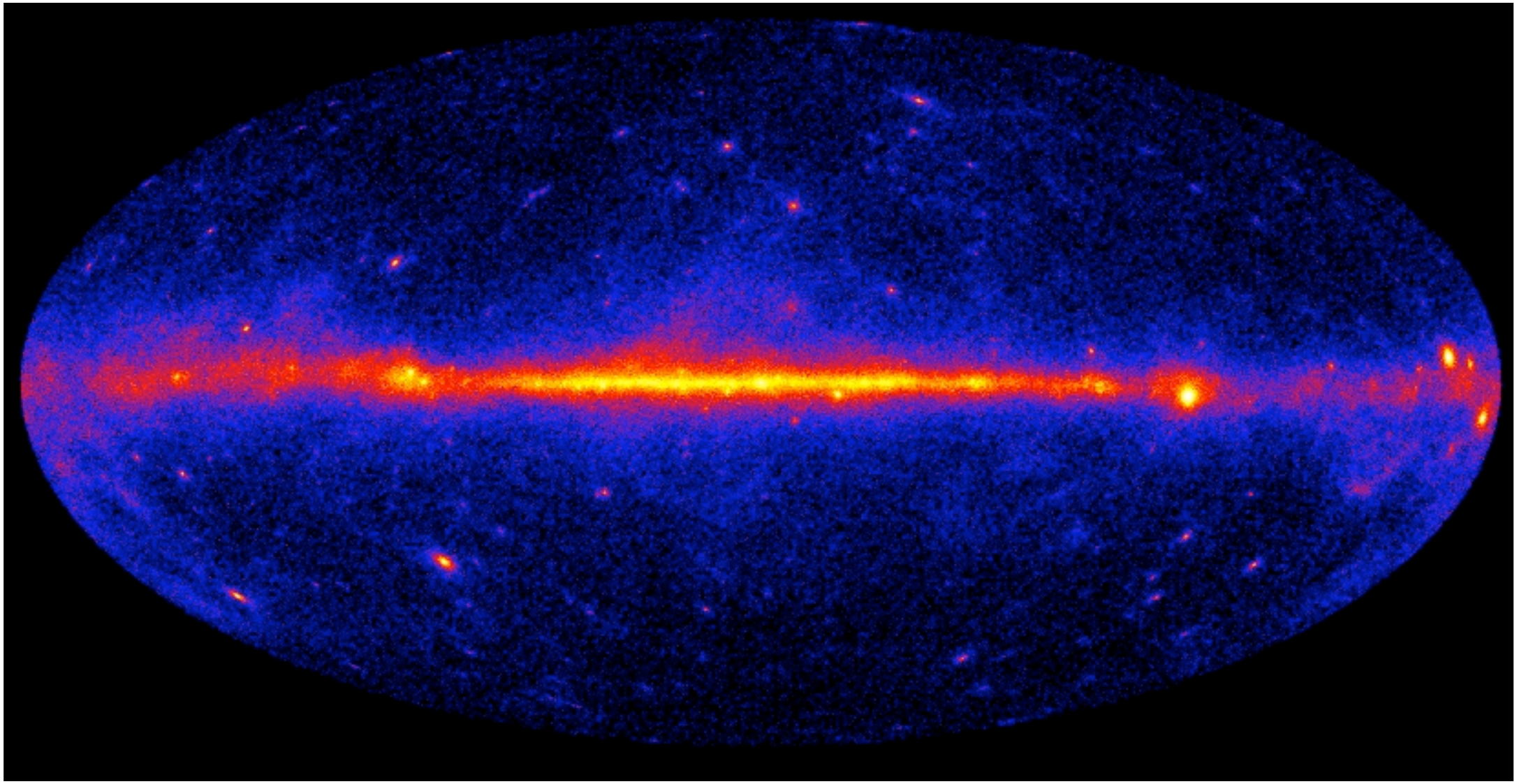


Abdo, A., et al Science, Oct 16, 2000

P-Pdot Diagram



Fermi Gamma-ray Pulsars



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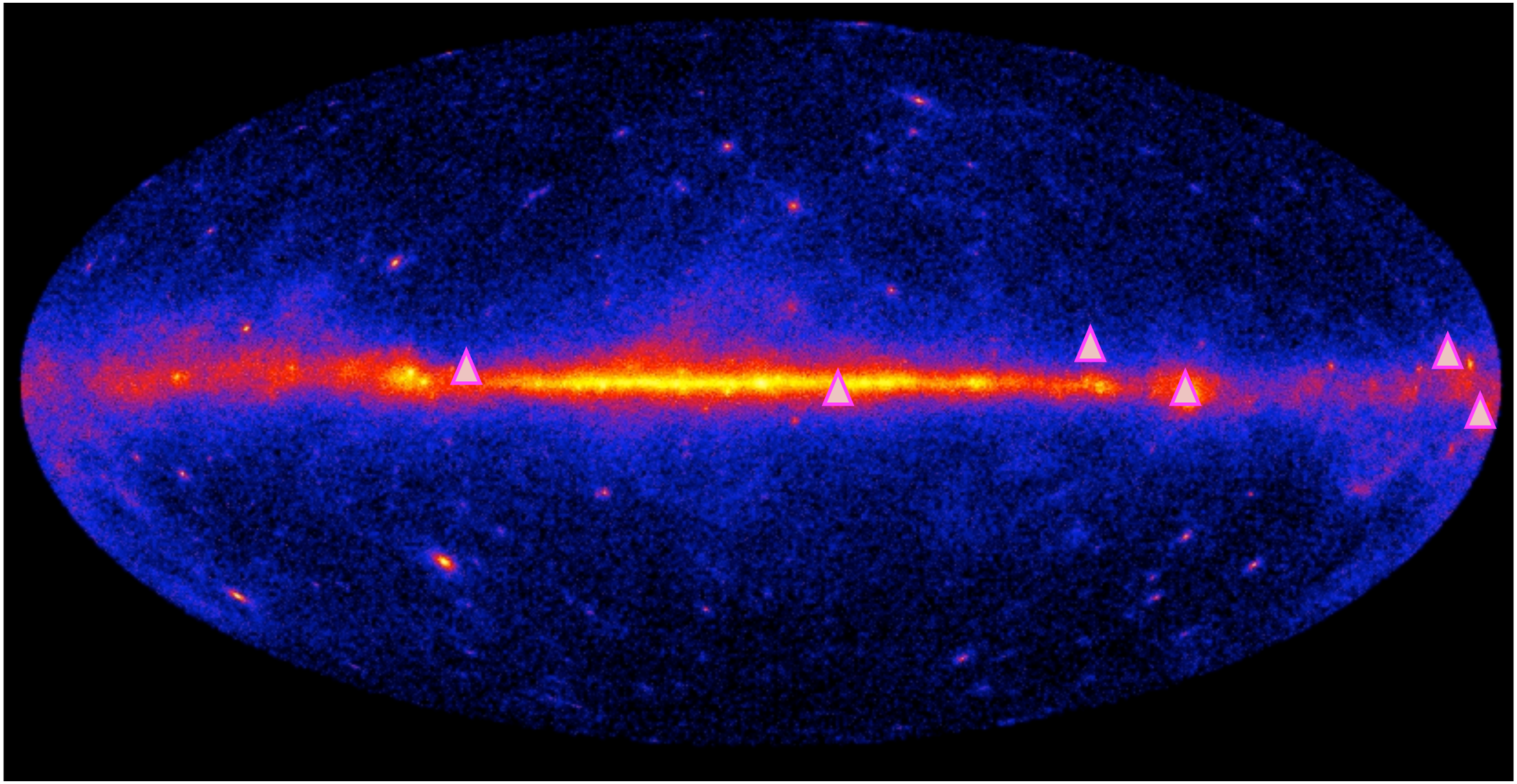
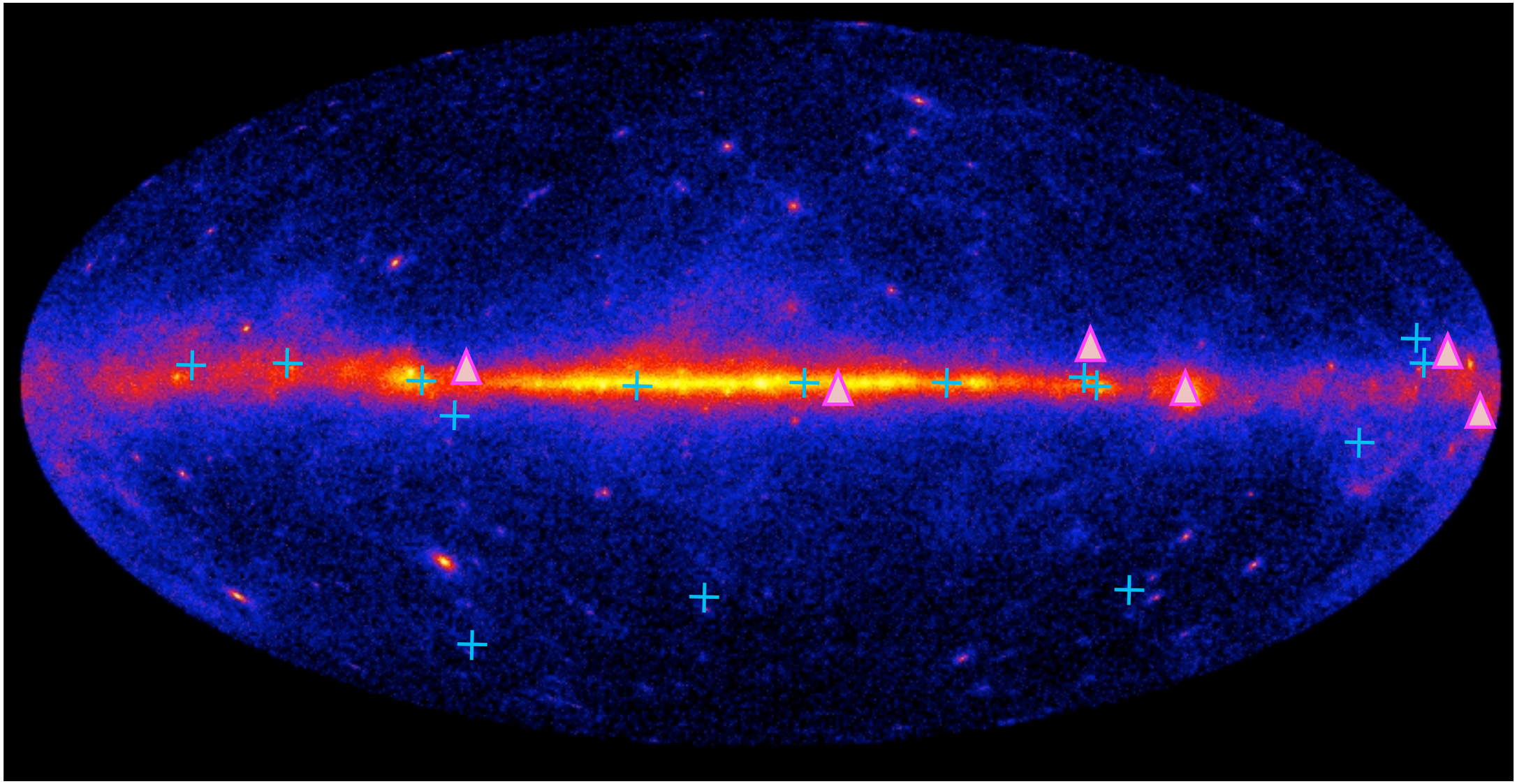


△ **EGRET pulsars**

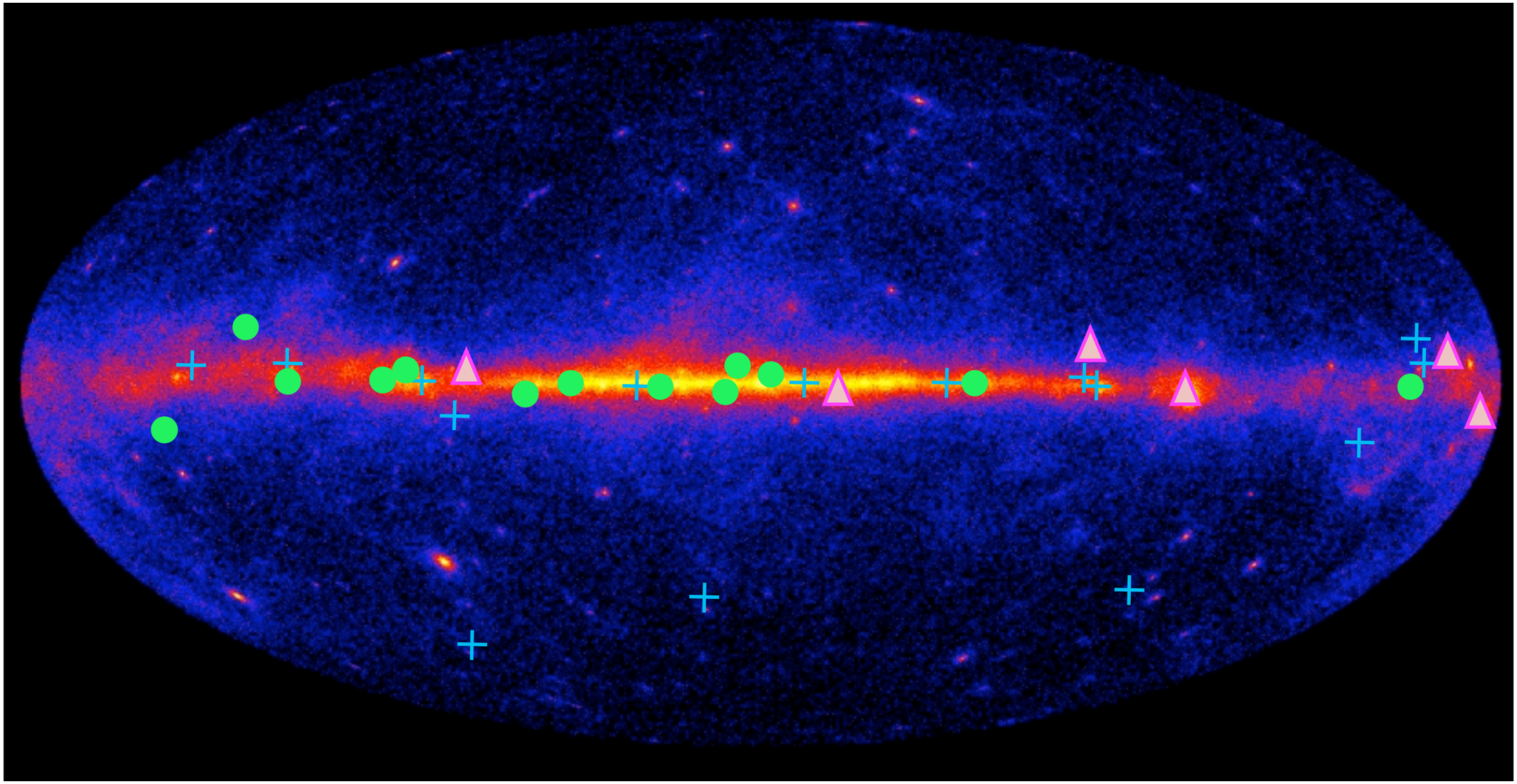
Fermi Gamma-ray Pulsars



△ EGRET pulsars

\+ Pulsars discovered using radio ephemeris

Fermi Gamma-ray Pulsars



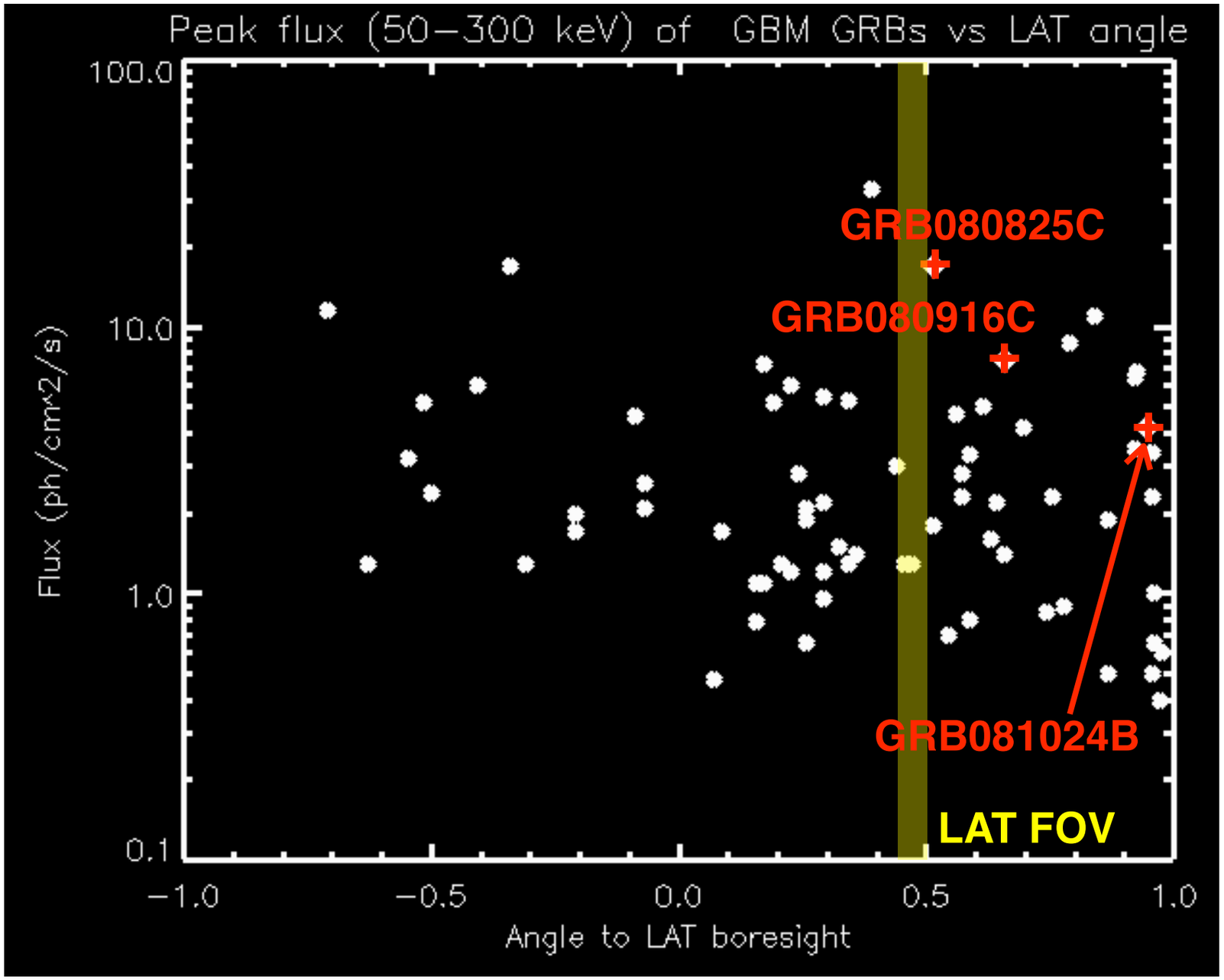
△ EGRET pulsars

\+ Pulsars discovered using radio ephemeris

● Pulsars discovered in blind search

Fermi Detection of GRBs

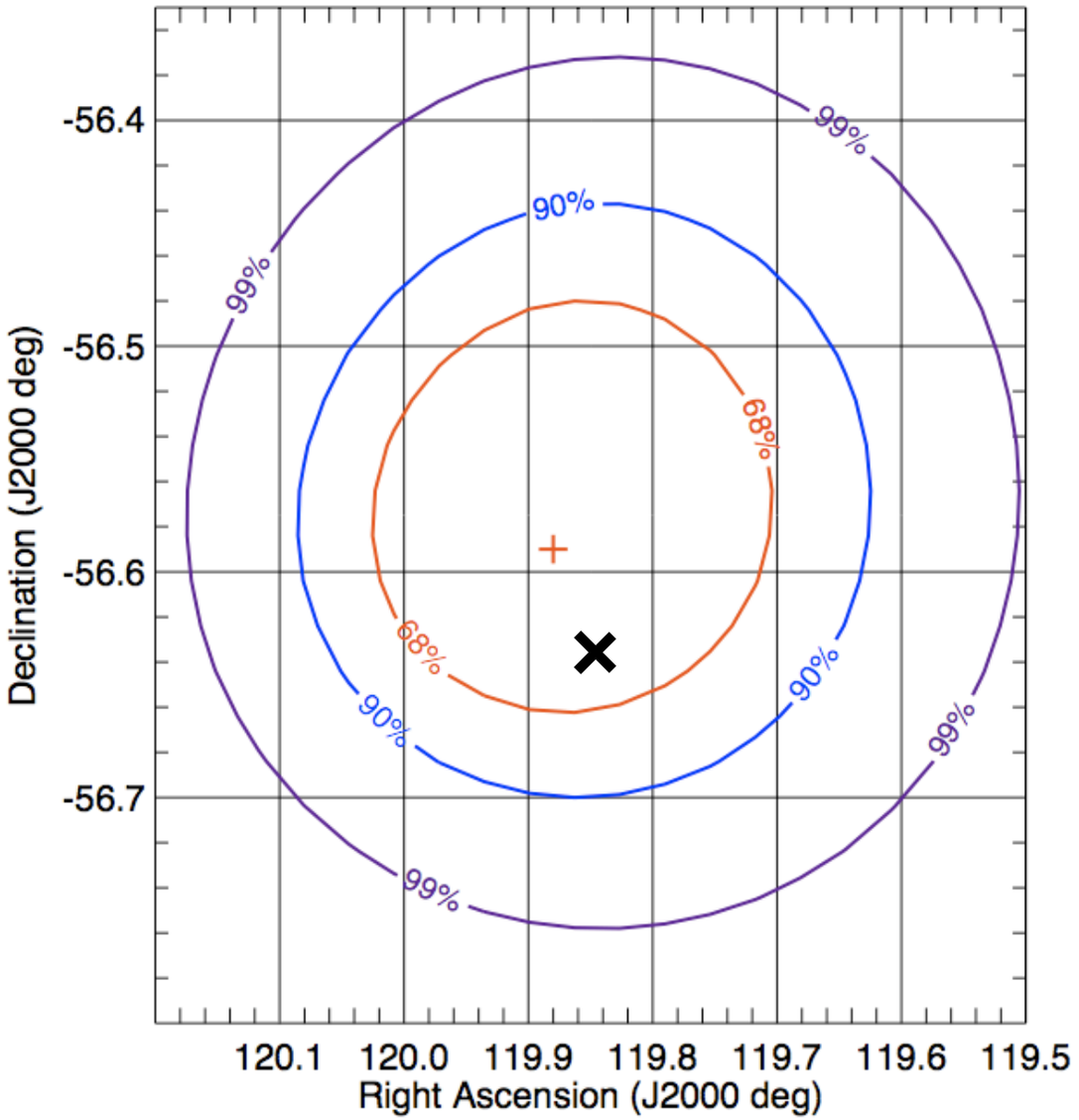
- GBM detections
  - 102 GRB since 7/14
- LAT detections
  - GRB080825C
    GCN8183
    Bouvier et al.
  - GRB080916C
    GCN8246
    Tajima et al.
  - GRB081024B
    GCN9407
    Omodei et al.



GRB080916C Detection

- GBM localization (GCN8245)
  - RA = 121.8°, Dec= -61.3°
    (±1° at 68% C.L., syst. 2°-3°)
- LAT localization (GCN8246)
  - RA = 119.88°, Dec = –56.59°
    (±0.09° @ 68%, ±0.13° @ 90% C.L.)
    systematic error<0.1° (preliminary)
- Swift/XRT follow-up (GCN8261)
  - RA = 119.8468°, Dec = –56.6380°
    (±1.9” at 90% C.L.)
- GROND follow-up (GCN8257)
  - RA = 119.8472°, Dec = –56.6383°
    (±0.5” at 68% C.L.)
  - z = 4.2±0.3 (Greiner et al. 08, submitted to Science)

T_0=00:12:45 September/16 2008

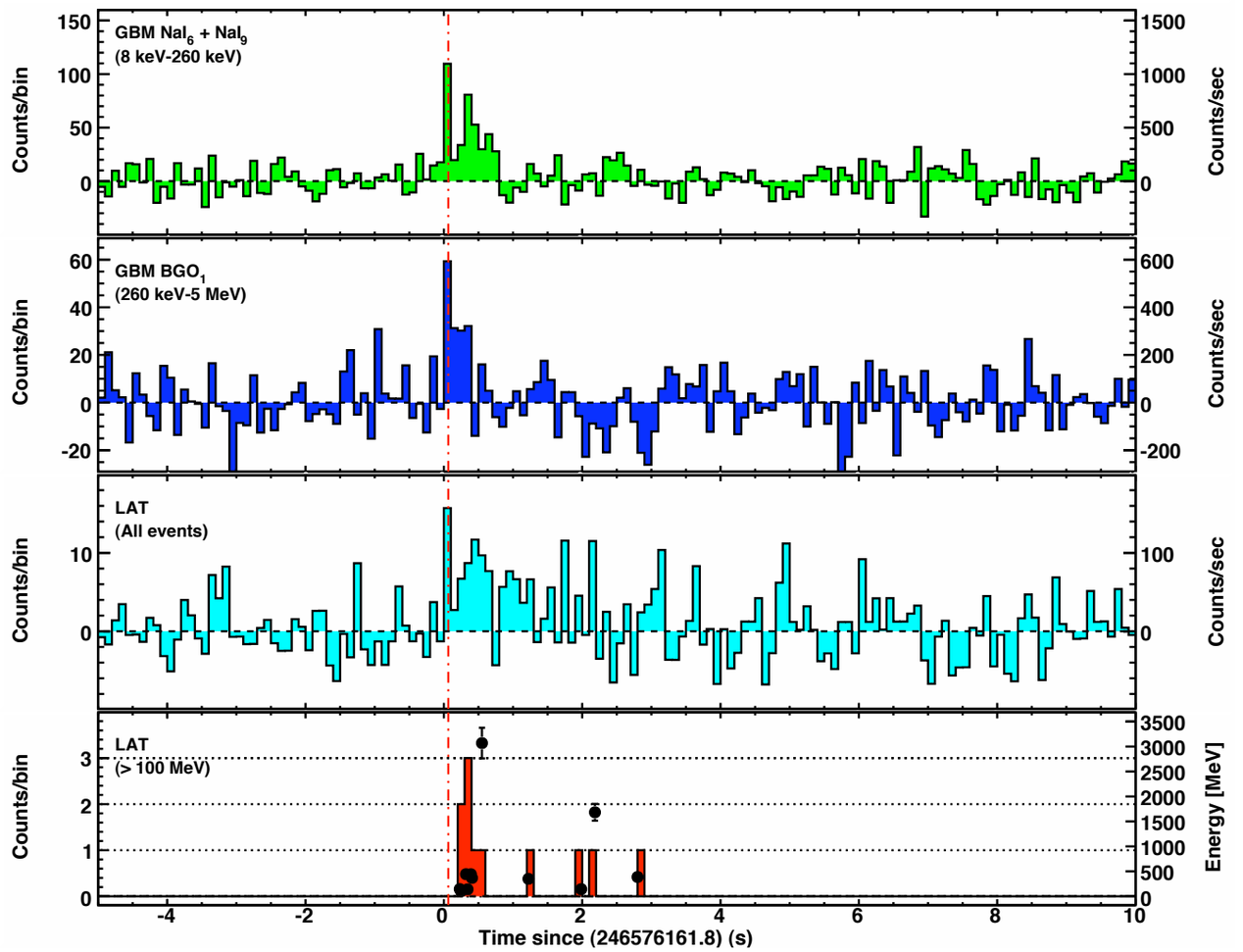


GRB080916C Lightcurves

- **Apparent delay of high-energy emission**

Lightcurves for Other LAT GRBs

- **Similar features**
  - **Apparent delay of high-energy emissions**
  - **Highest energy is very late (GRB080825C)**
    - No detectable low energy emissions



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Extra Component?

- **No conclusive evidence of extra component**
  - **Effect of EBL**
    - HE absorption
    - Transparency:
      0.03–1.0
      (model dependent)

Time bin ‘d’

Band + power law

Band function

Spectral Evolution

- **Soft to hard evolution**

Temporary Extended HE Emission

- HE (E>100 MeV) emission shows different temporal behavior

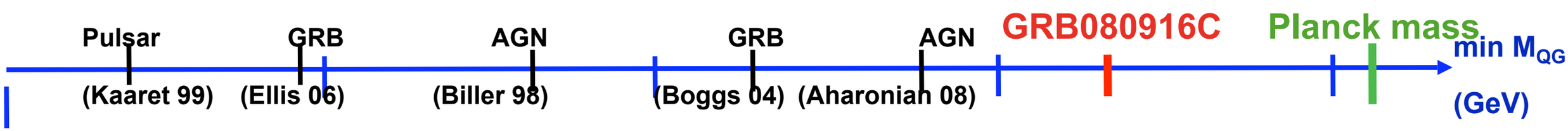
Implications from GR080916C

- Delayed HE emissions
- Extended HE emissions
- E_{iso} ~
- Minimum bulk Lorentz factor

  - EBL effect not included

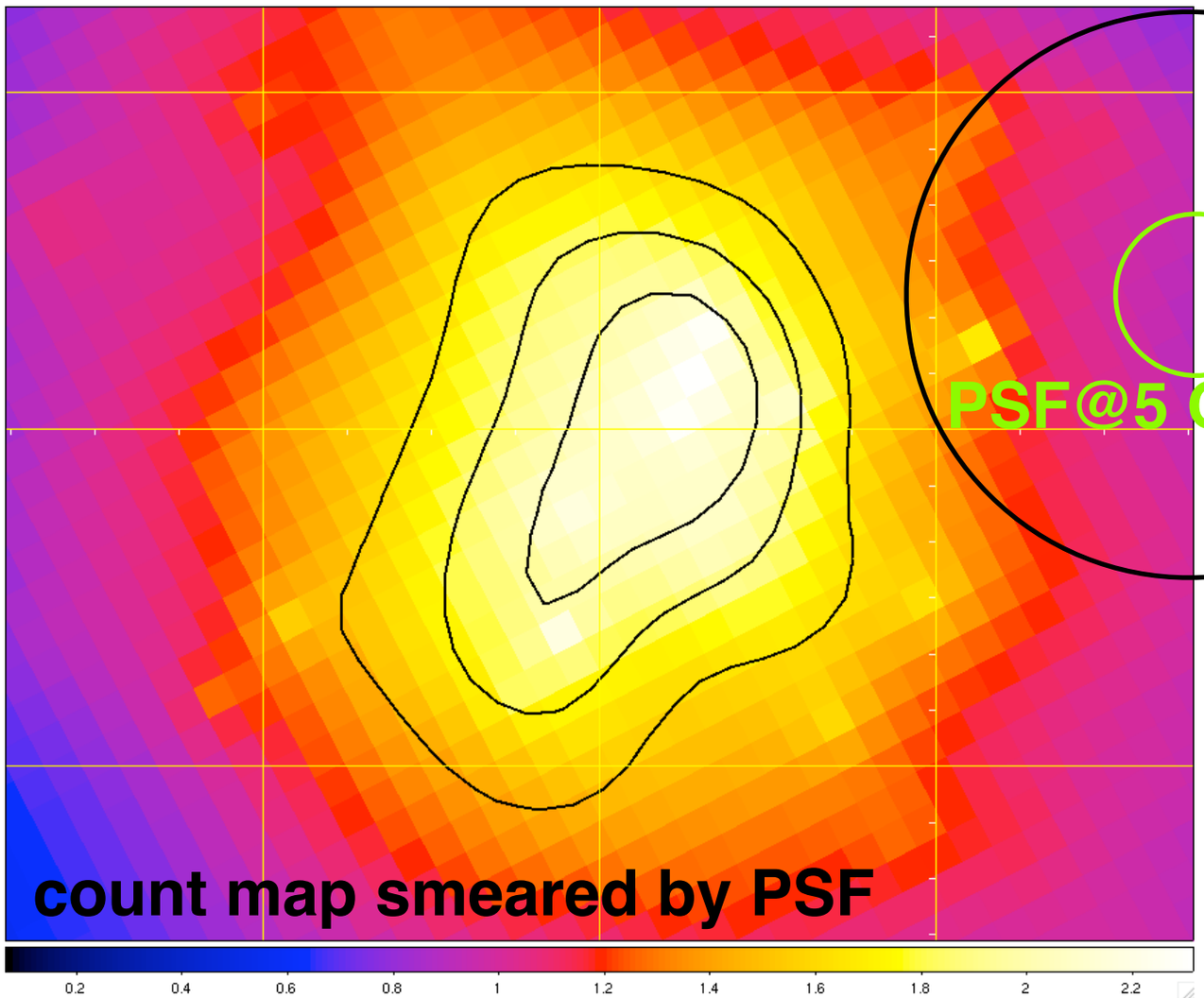
- Lorentz invariance violation

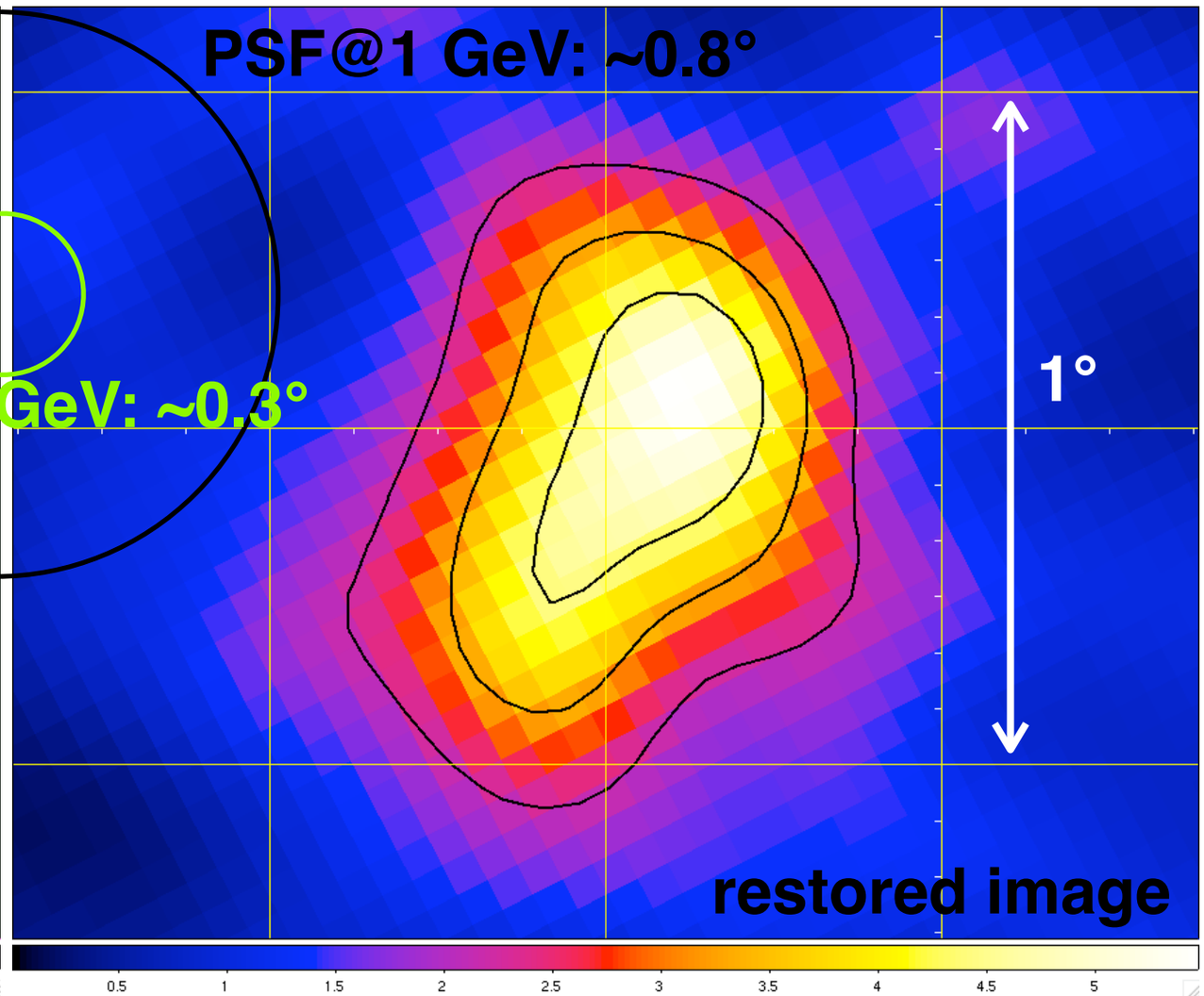
  -



Fermi Imaging Capability

- Extended source analysis with image restoration technique
  - Richardson-Lucy deconvolution with event by event PSF
  - Wavelet filtering to suppress spurious features
- Example with E>1 GeV (LAT data)

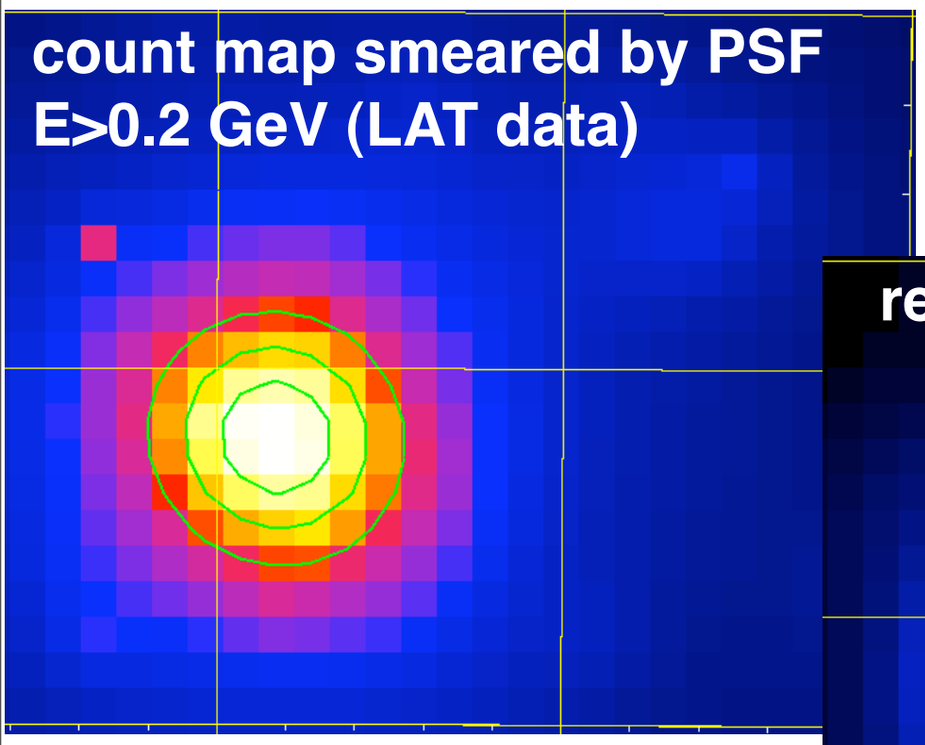


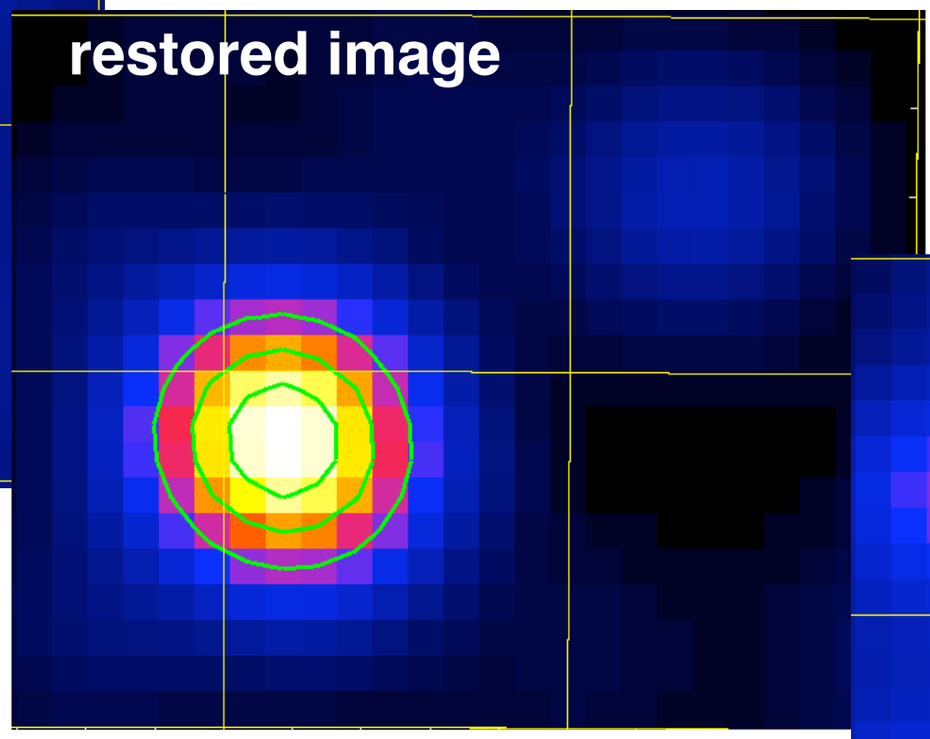


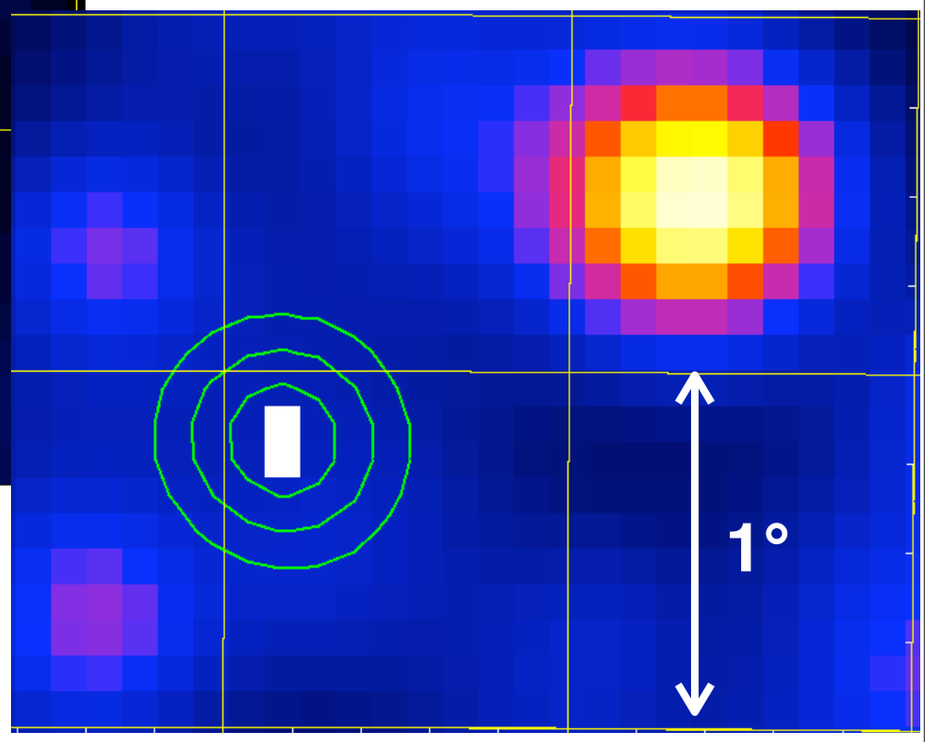
Tajima et al. arXiv:0705.1362v1

Demonstration with Point Source

- Demonstration of image restoration with point sources
  - Factor of ~3 improvement in peak intensity
  - Effective “removal” of point sources with little residual



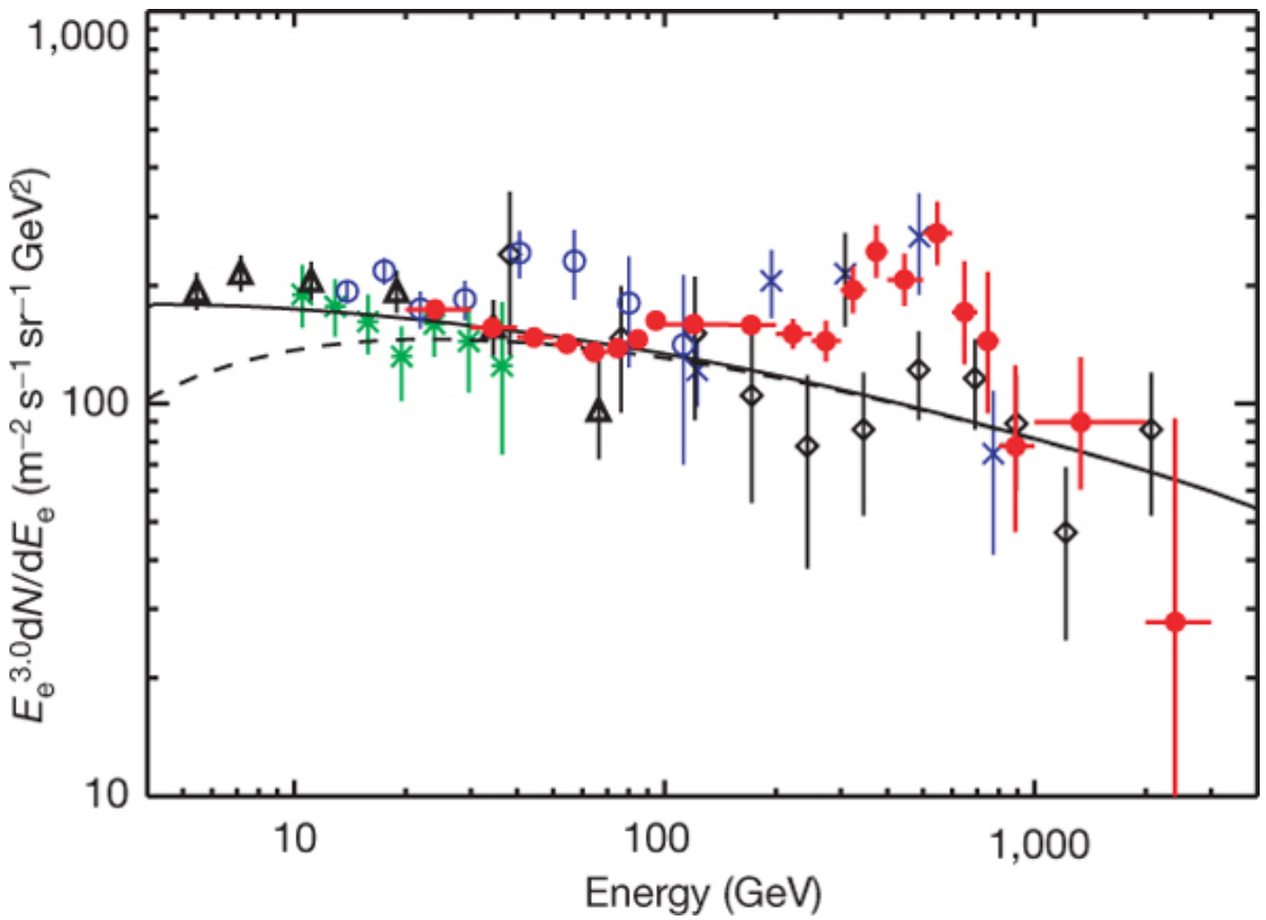




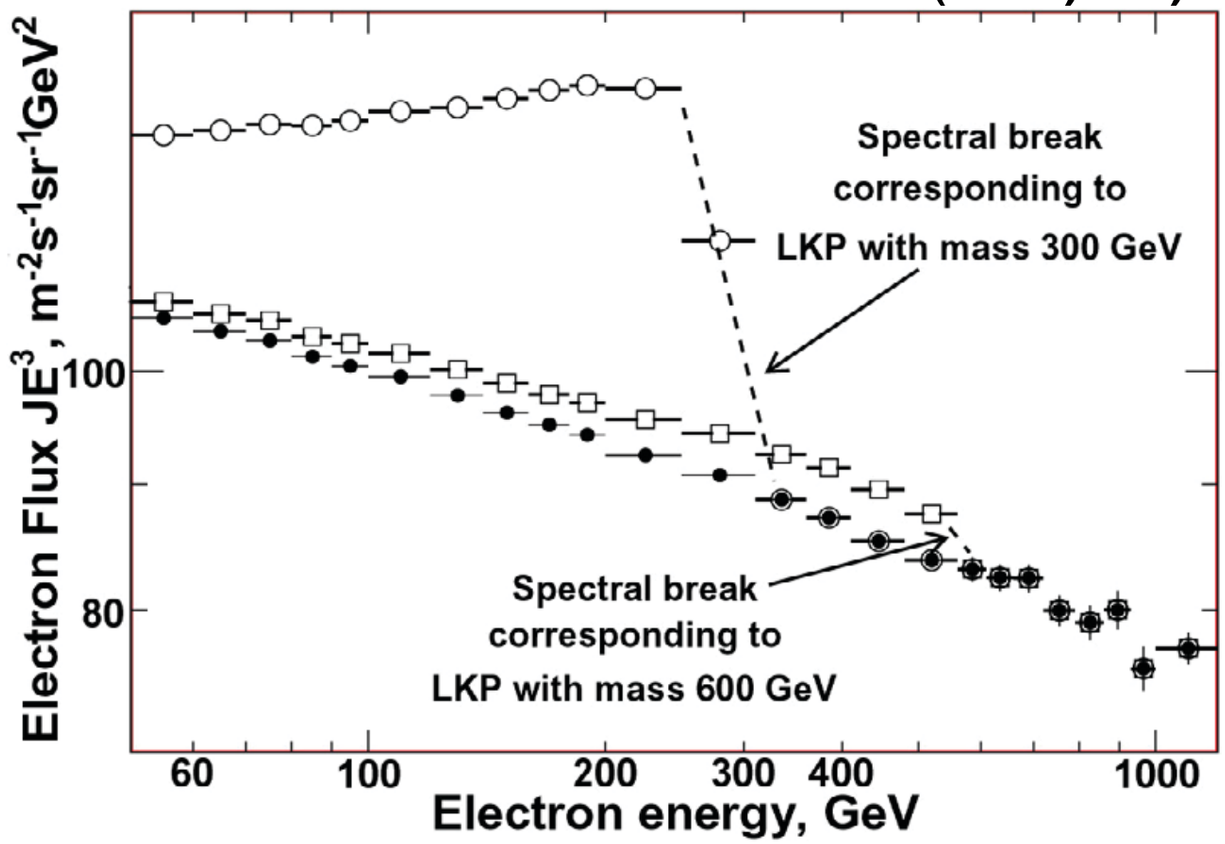
Cosmic-ray Electron?

- Recent report by ATIC indicates high energy excess
  - Could be interpreted as evidence of dark matter
- Fermi can measure CR electron spectrum with high statistics

J Chang *et al. Nature* **456**, 362-365 (2008)



Fermi MC
(E. A. Baltz, et al., JCAP07(2008)013)



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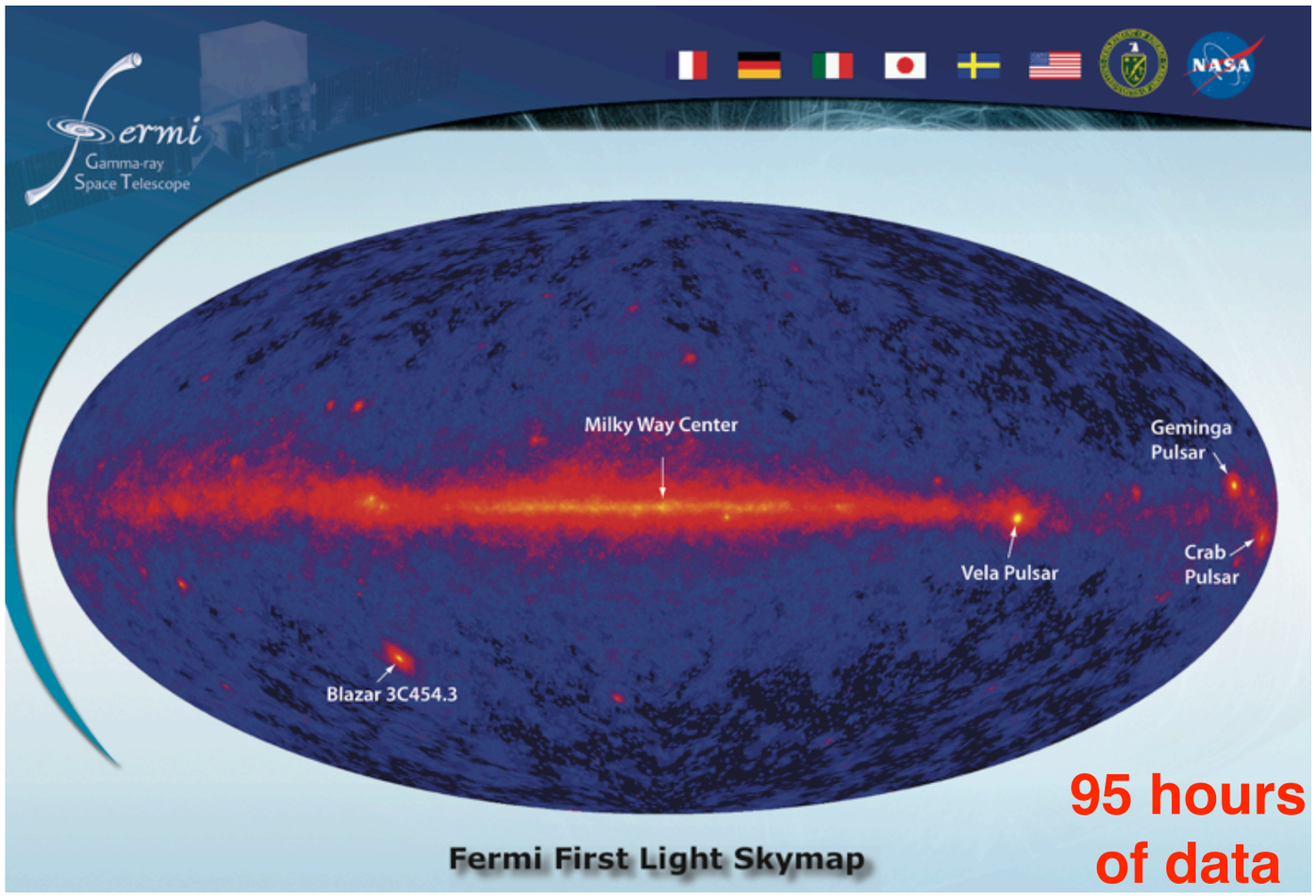
Summary

- Fermi was launched successfully on June/11 2008
- Fermi LAT has been working very stably in Space
- Fermi LAT demonstrating very exciting science in an early stage of its operations
- Very exciting science ahead of us



- Review talk for more Fermi science at JPS in March

Gamma-ray Universe Revealed by Fermi GST,
H. Tajima, ICRR Seminar, December 16, 2008

backup slides

Image Restoration

- **Image restoration with E>0.2 GeV gives similar image as E>1 GeV even though PSF@0.2 GeV is huge (~4°).**