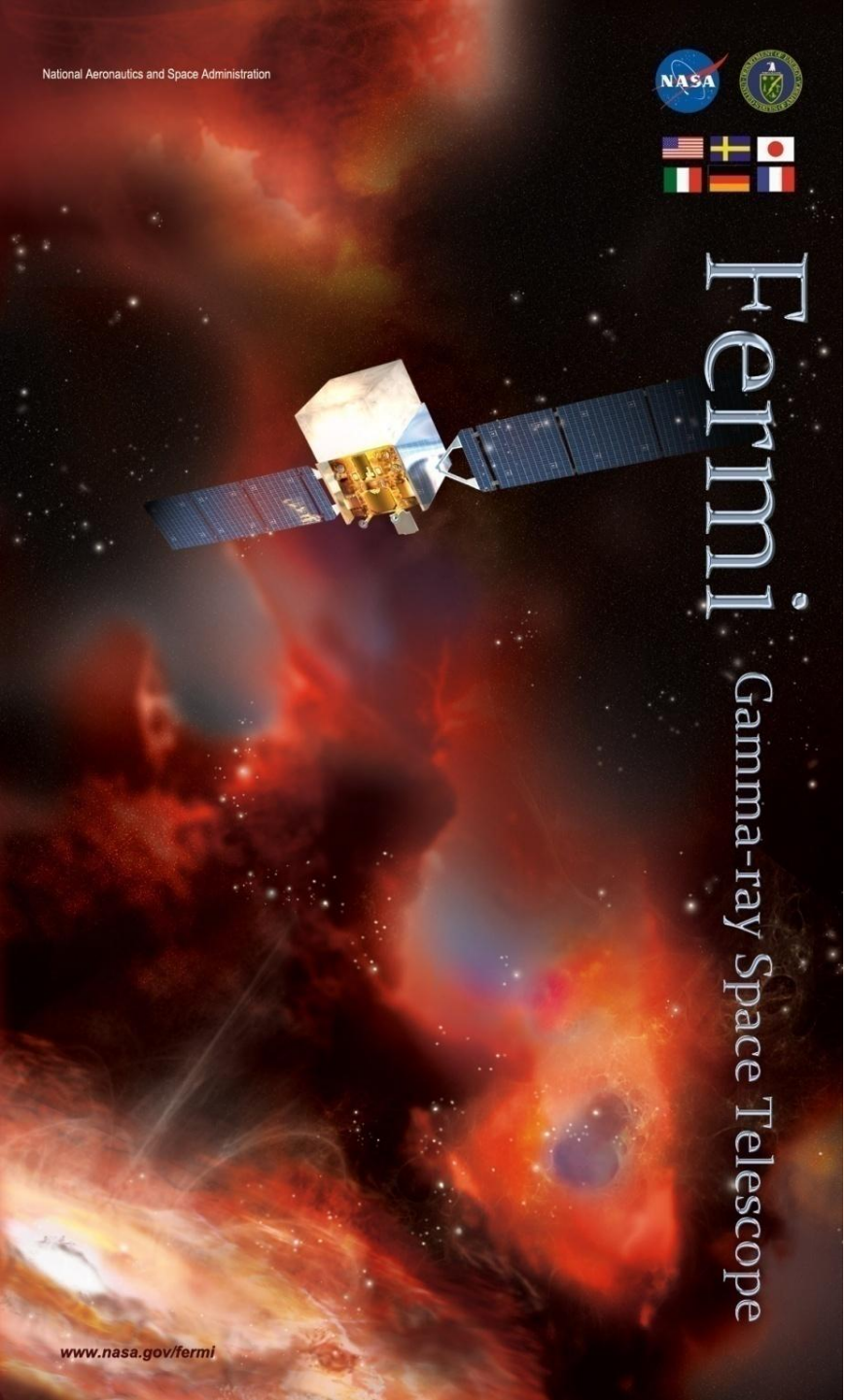


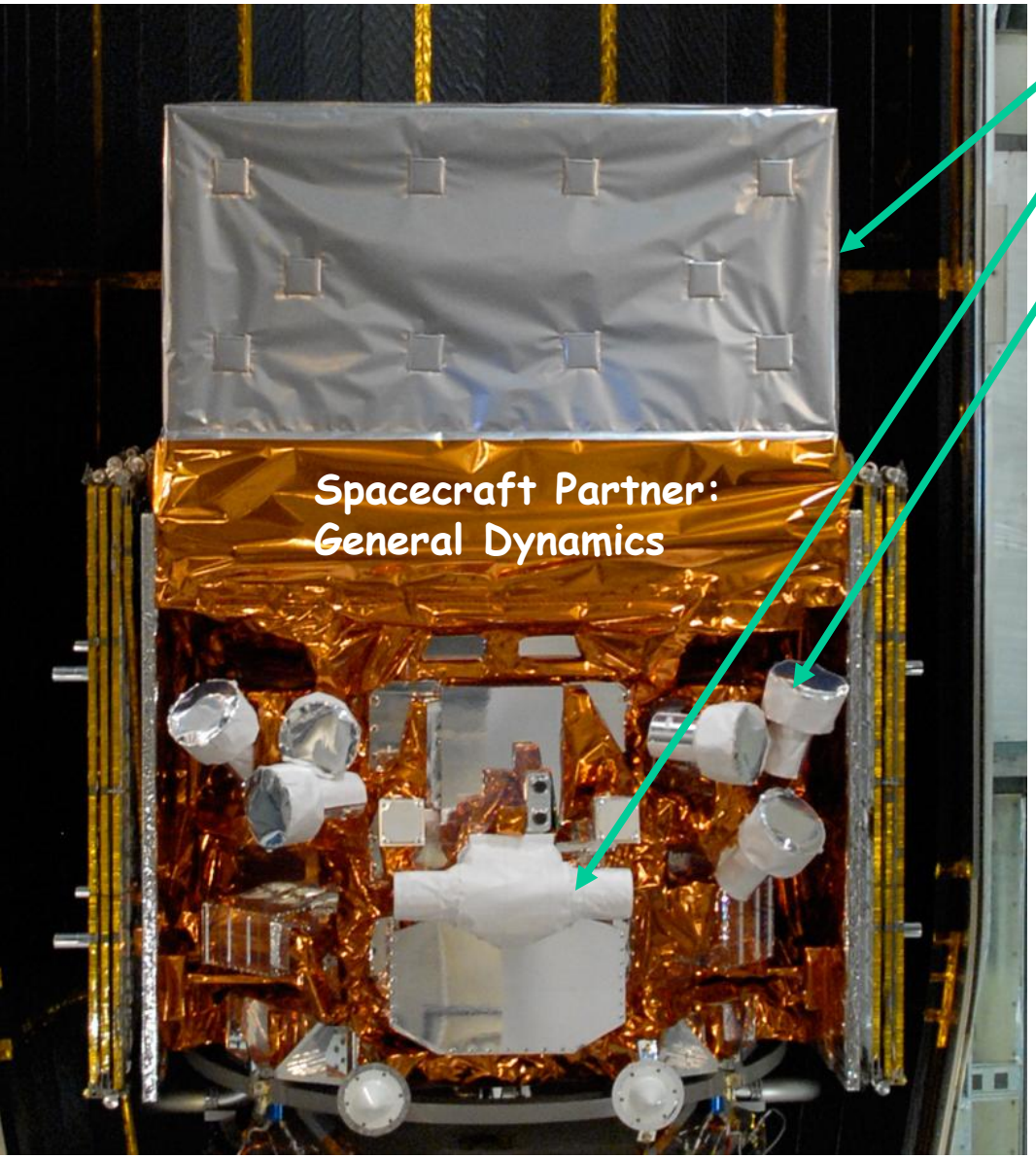
Sources detected by the *Fermi* Large Area Telescope

Jean Ballet (CEA/DSM/IRFU/SAp)

on behalf of the Fermi LAT Collaboration

The GeV and TeV sky
LLR, September 17, 2009

The Observatory



Large AreaTelescope (LAT)
20 MeV - >300 GeV

Gamma-ray Burst Monitor (GBM)
NaI and BGO Detectors
8 keV - 40 MeV

KEY FEATURES

- **Huge field of view**
  - –LAT: 19% of the sky at any instant; in sky survey mode, expose all parts of sky for ~30 minutes every 3 hours. GBM: whole unocculted sky at any time.
- **Huge energy range, including largely unexplored band 10 GeV - 100 GeV.**

  Total of >7 energy decades!
- **Large leap in all key capabilities. Great discovery potential.**

LAT Collaboration – an AP-HEP partnership

- **France**
  - CNRS/IN2P3 (LLR, CENBG, LPTA)
  - CEA/Saclay, CNRS/INSU (CESR)
- **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, Santa Cruz - Santa Cruz Inst. for Particle Physics
  - Goddard Space Flight Center
  - Naval Research Laboratory
  - Sonoma State University
  - The Ohio State University
  - University of Washington

PI: Peter Michelson
(Stanford)

~390 Scientific Members (including 96 Affiliated Scientists, plus 68 Postdocs and 105 Students)

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

Managed at SLAC.

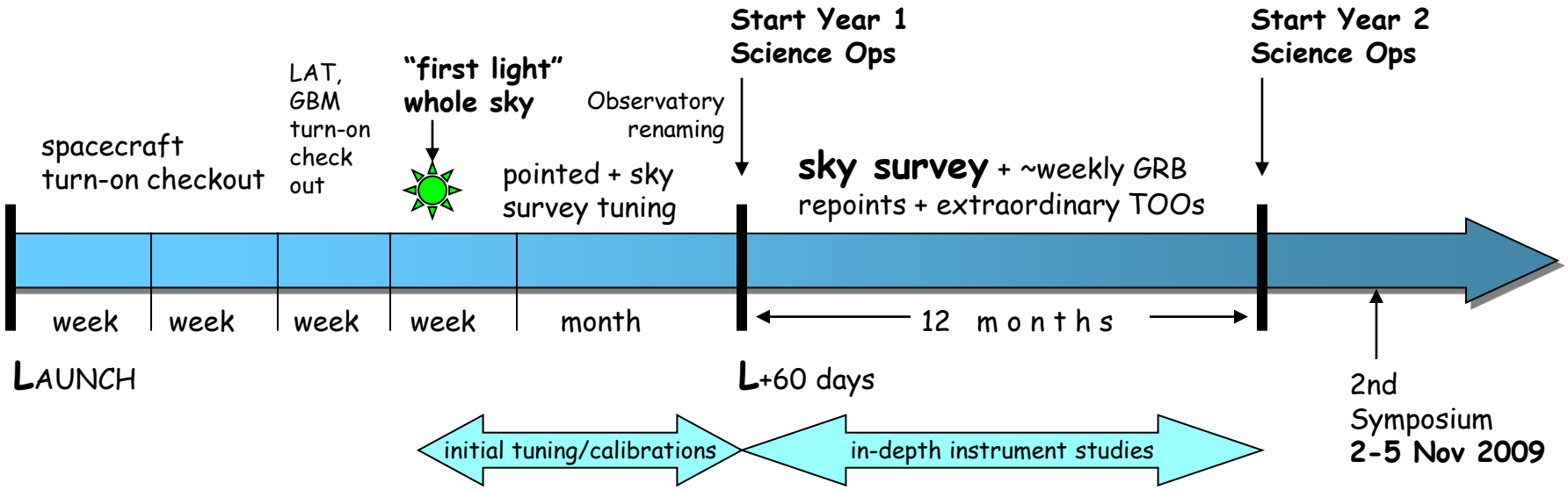
Launch!

Cape Canaveral

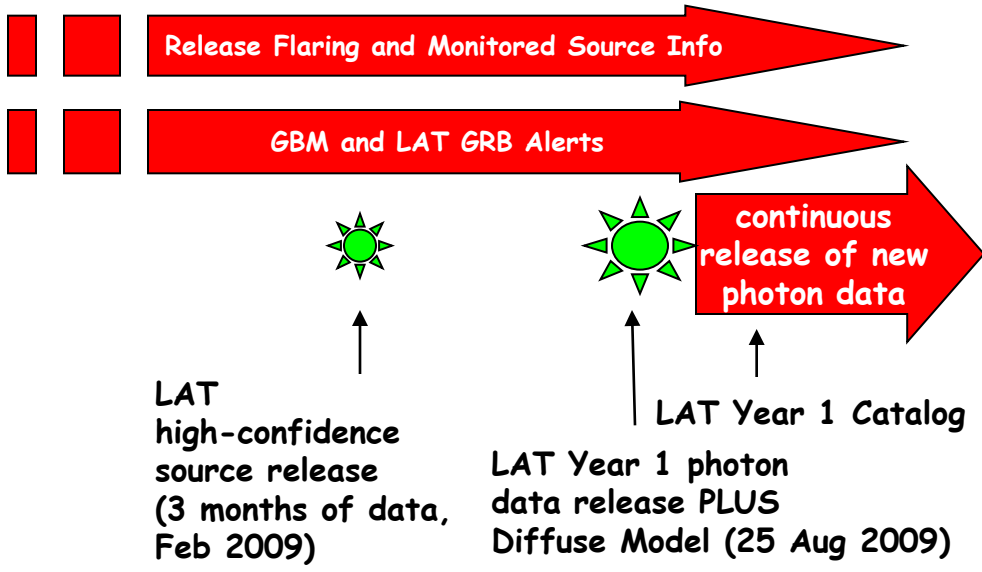
11 June 2008 at 12:05PM EDT

26 August 2008
NASA renames GLAST to Fermi

Year 1 Science Operations Timeline



Distributed by Fermi Science Support Center at Goddard
http://fermi.gsfc.nasa.gov/ssc/data/access/

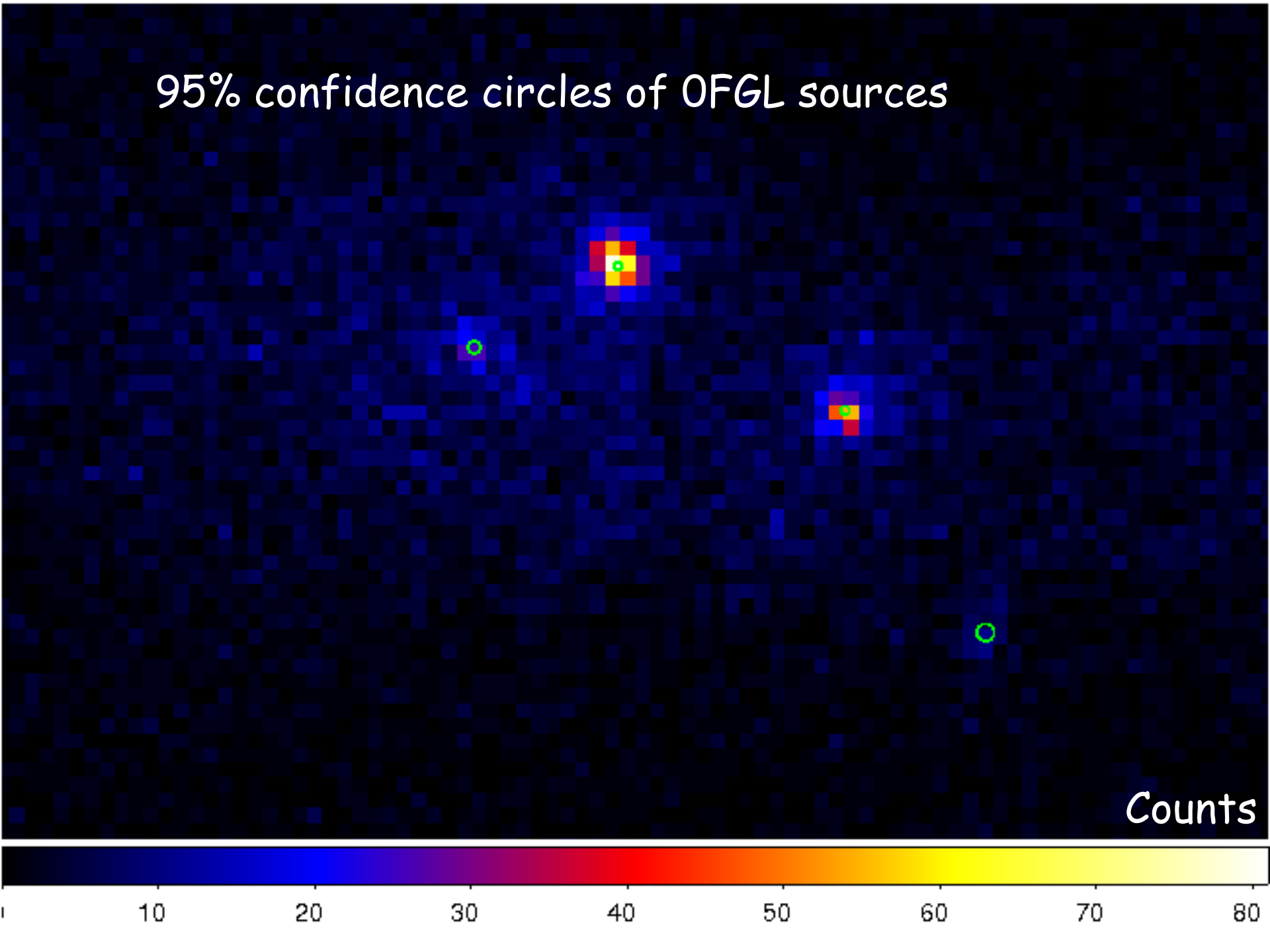


5 years operations (+ 5 years)

The LAT Bright Source List (0FGL)

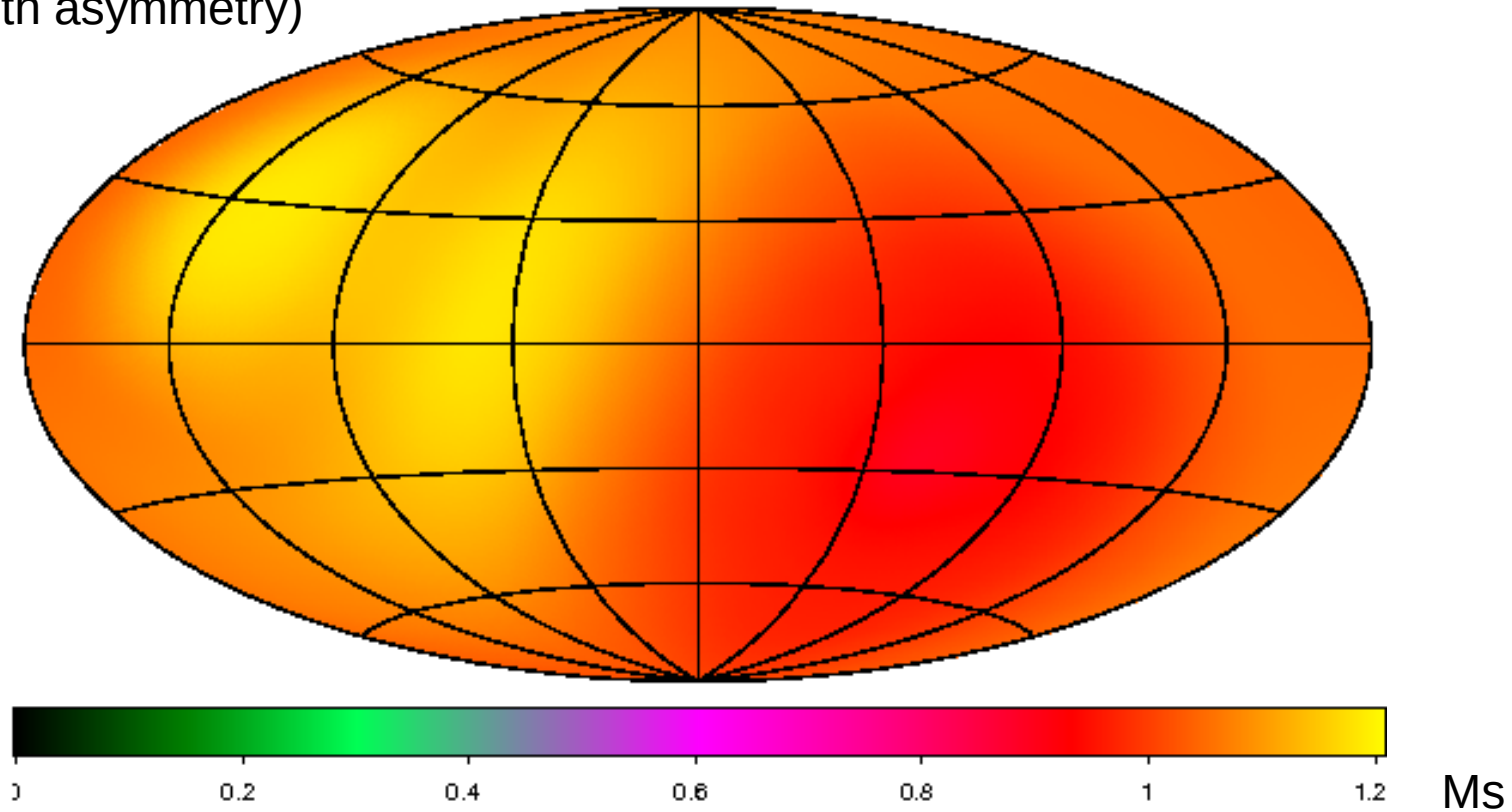
- 1.8 M events above 200 MeV with current cuts over 3 months
- Wavelet analysis (peak detection) for source detection
  1. Front events > 200 MeV + Back events > 400 MeV
  2. Front events > 1 GeV + Back events > 2 GeV
- Large overlap at low energy ➔ Maximum likelihood analysis for locations, source significance, fluxes below and above 1 GeV, and variability information.
- Confidence level greater than **10 σ** over 3 months. Not uniform - sources near the Galactic plane must be brighter because of the strong diffuse background
- Associations with known sources

The Point Spread Function is key to source detection and identification


95% confidence circles of 0FGL sources
Counts
10
20
30
40
50
60
70
80

Exposure map

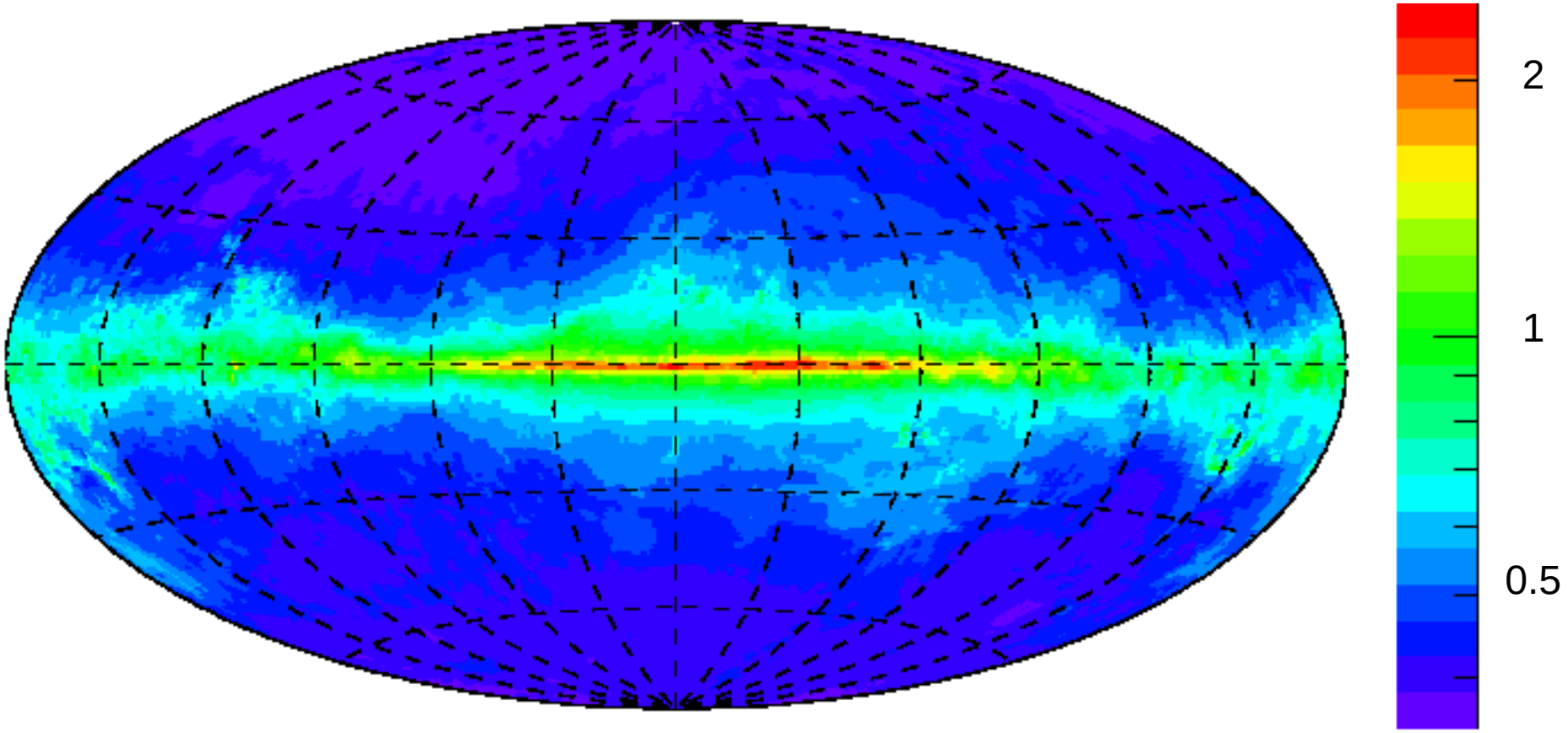
- Data used are the first three months of all-sky scanning data, Aug. - Oct. 2008. Total live time is 7.53 Ms
- Scanning scheme makes exposure map very uniform (SAA creates 25% North-South asymmetry)



Equivalent on-axis observing time, Galactic coordinates, Aitoff projection

Sensitivity map

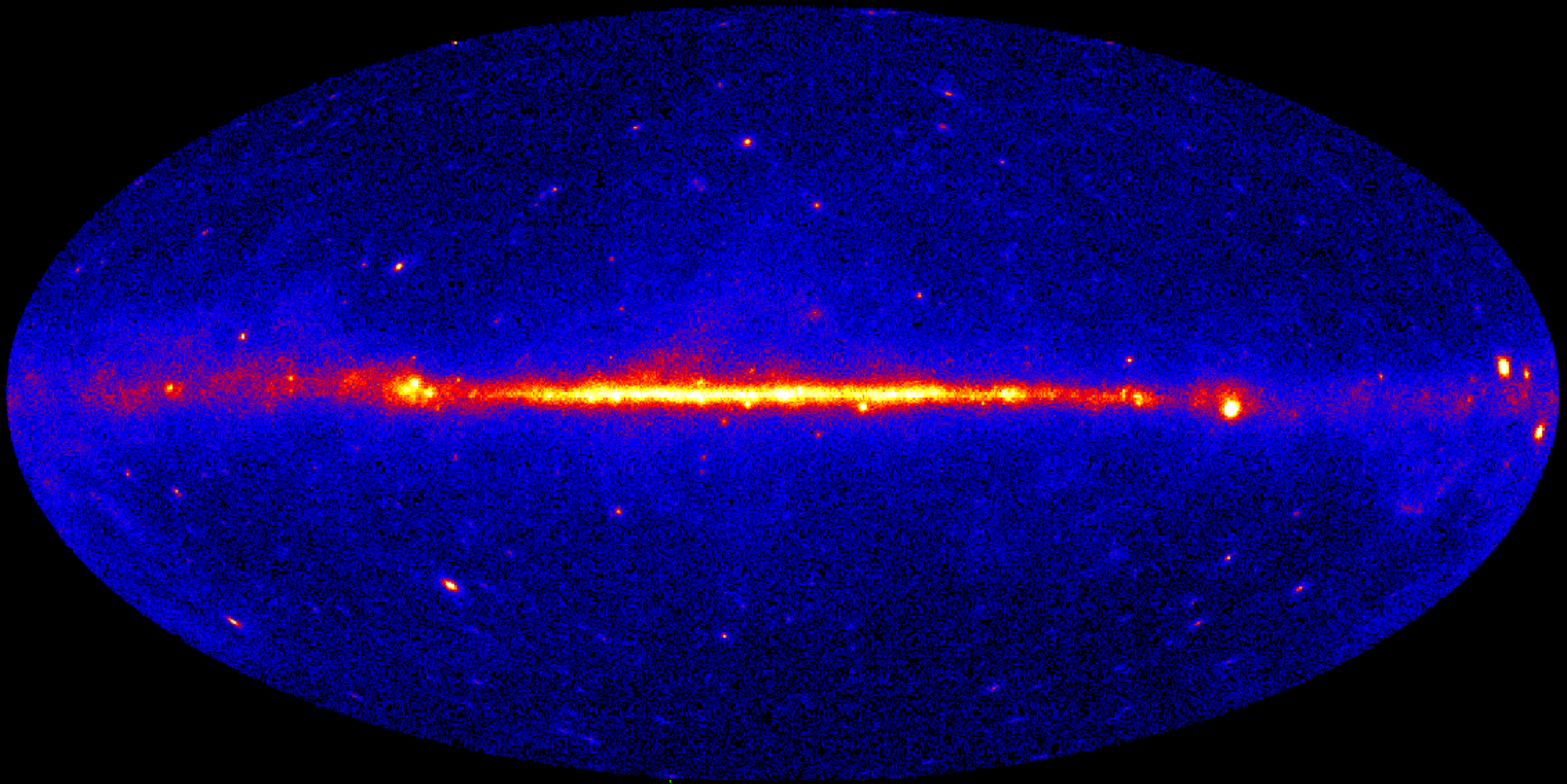
- Structure is mostly that of the interstellar medium
- Below 10^{-7} ph/cm^2/s outside the Galaxy (|b| > 10°)



Flux > 100 MeV required to reach 10 σ over 3 months for average $E^{-2.2}$ spectrum

Galactic coordinates, Aitoff projection

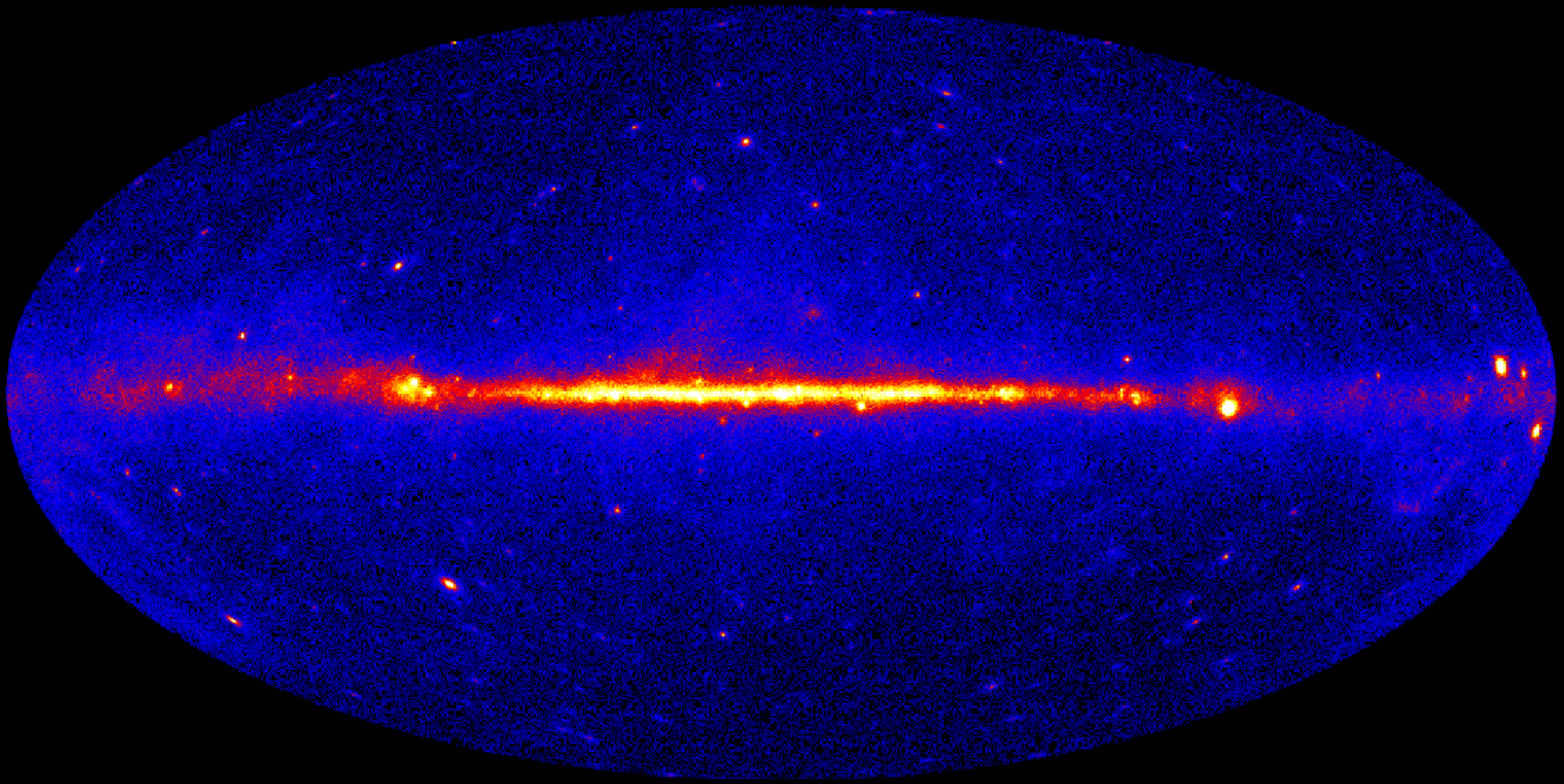
205 LAT Bright Sources



Front > 200 MeV, Back > 400 MeV

Crosses mark source locations, in Galactic coordinates. 1/3 at |b| < 10°.
Only 60 clearly associated with 3EG EGRET catalog. The sky changes!

9 months data

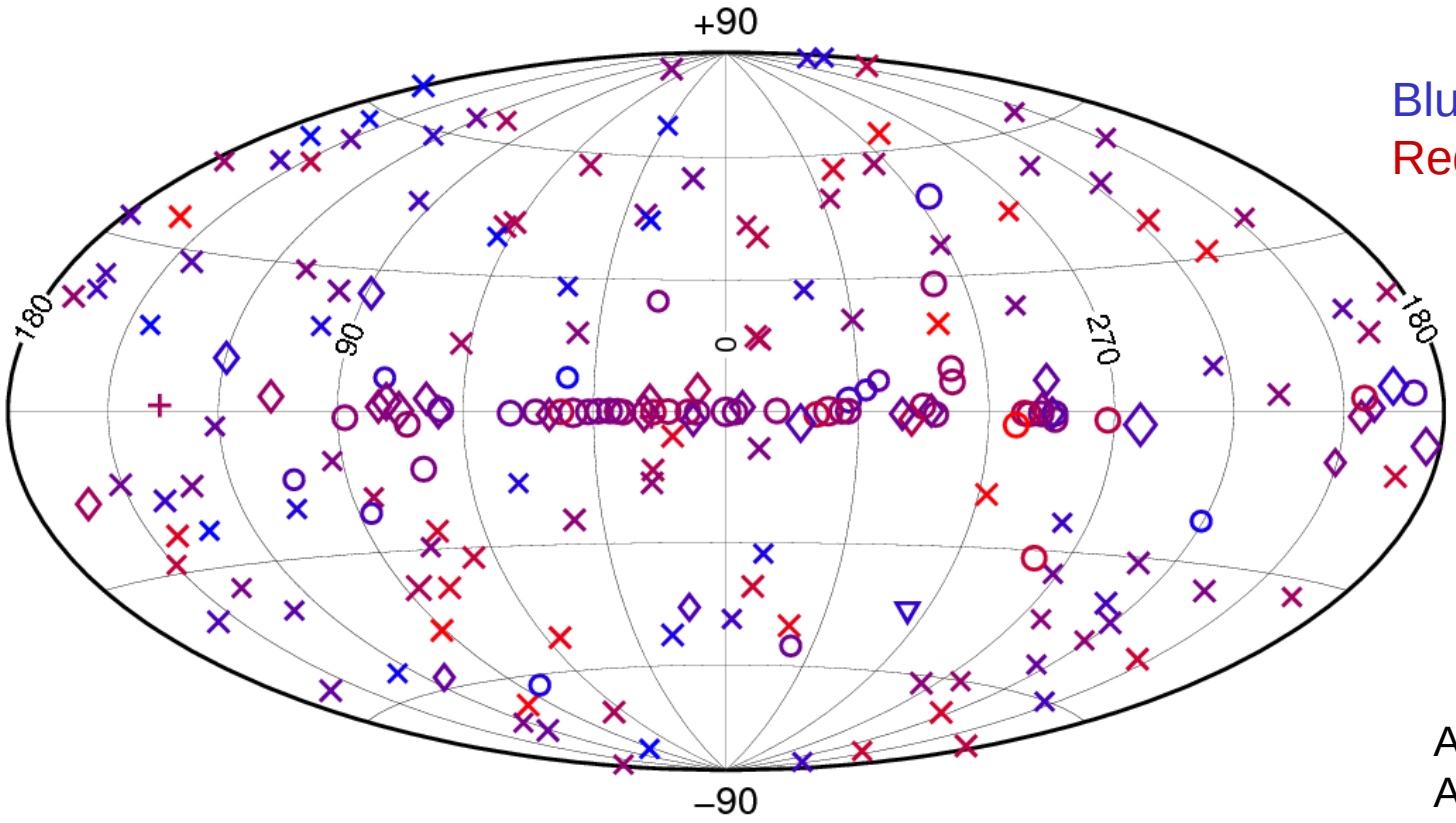


Front > 200 MeV, Back > 400 MeV

Galactic coordinates, Aitoff projection, SQRT color scale

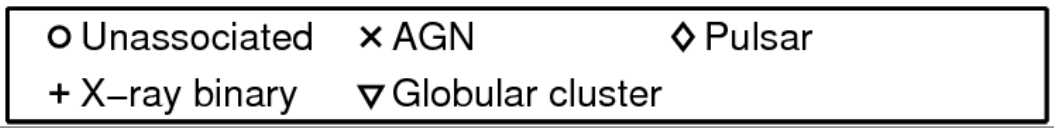
Source association

- 2/3 of the sources at |b|>10°, mostly AGN
- Only 9 unassociated outside the plane
- Globular cluster 47 Tuc (plenty of ms pulsars), LMC / 30 Dor (diffuse)



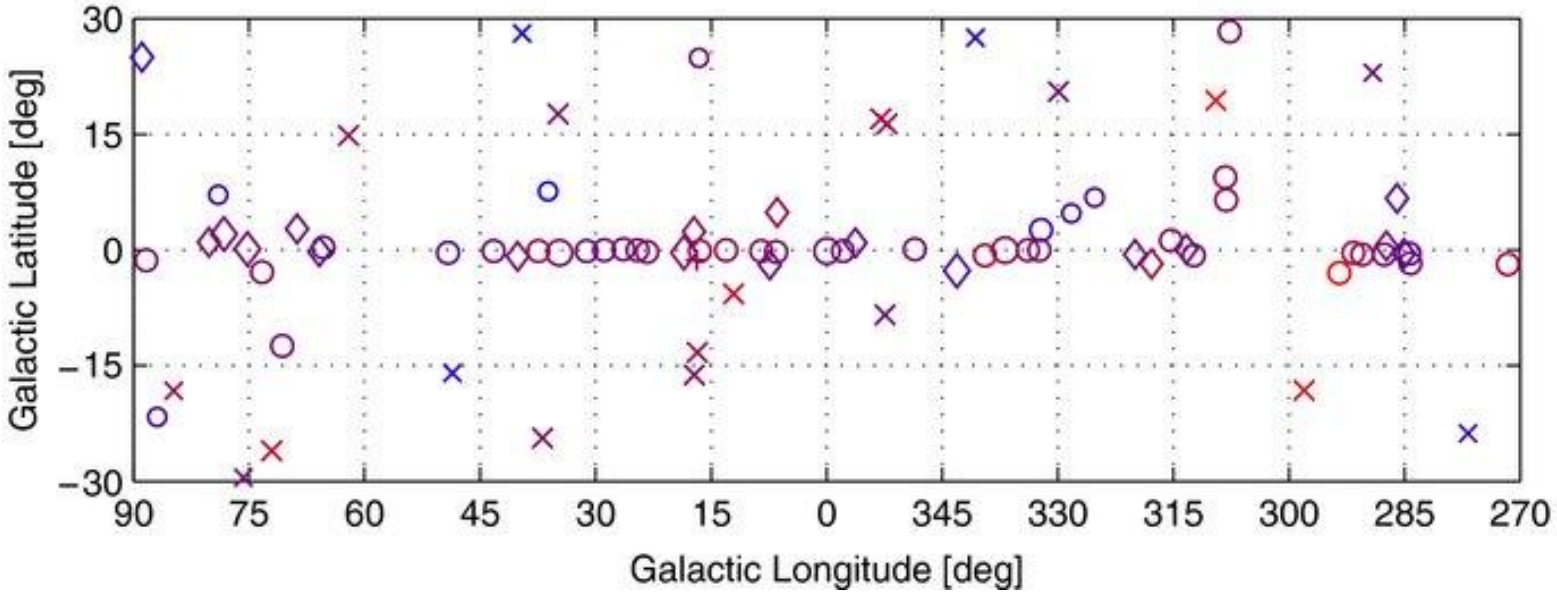
Blue is hard
Red is soft

Abdo et al. 2009
ApJS 183, 46



Source association 2

- Most associated sources in the Galaxy are pulsars
- Many unassociated sources in the inner regions of the Galaxy (circles)



Close-up on the Galactic ridge

The *Fermi* LAT First Source Catalog (1FGL)

Improvements over the Bright Source List (0FGL)

- Based on data accumulated over 11 months
- More accurate calibration
- More precise model for Galactic diffuse (public since August 25)
- Similar (but more inclusive) detection methods
- Similar maximum likelihood analysis, but more information (flux in five energy bands and per month, average spectral index)
- Minimum confidence level down to **5** σ. Will contain more than 1000 sources
- Similar association process, expect smaller association rate going to fainter sources

Expected in October 2009

Pulsars

Many categories of sources (blazars, GRBs, binaries, PWN, SNRs) will be covered in other talks

Pulsars are a major category of sources in the GeV band

Several EGRET unidentified sources turn out to be pulsars

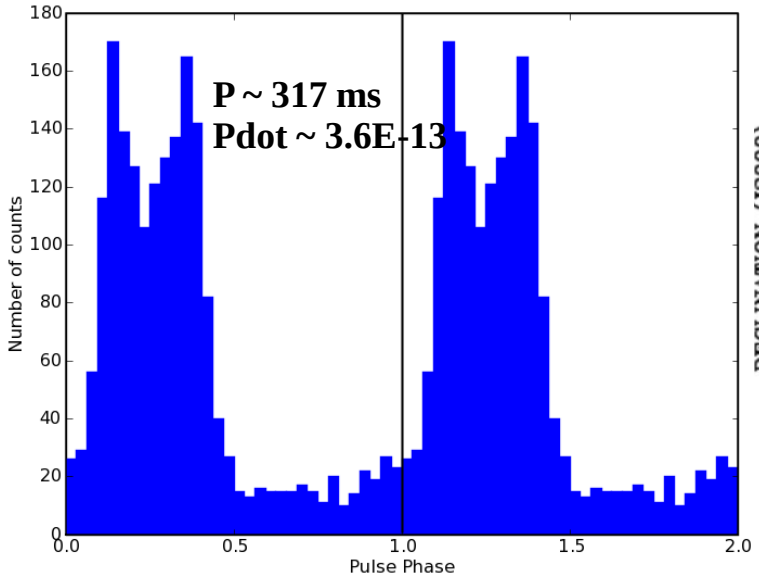
Not bright in TeV range

Discovery of First Gamma-ray-only Pulsar

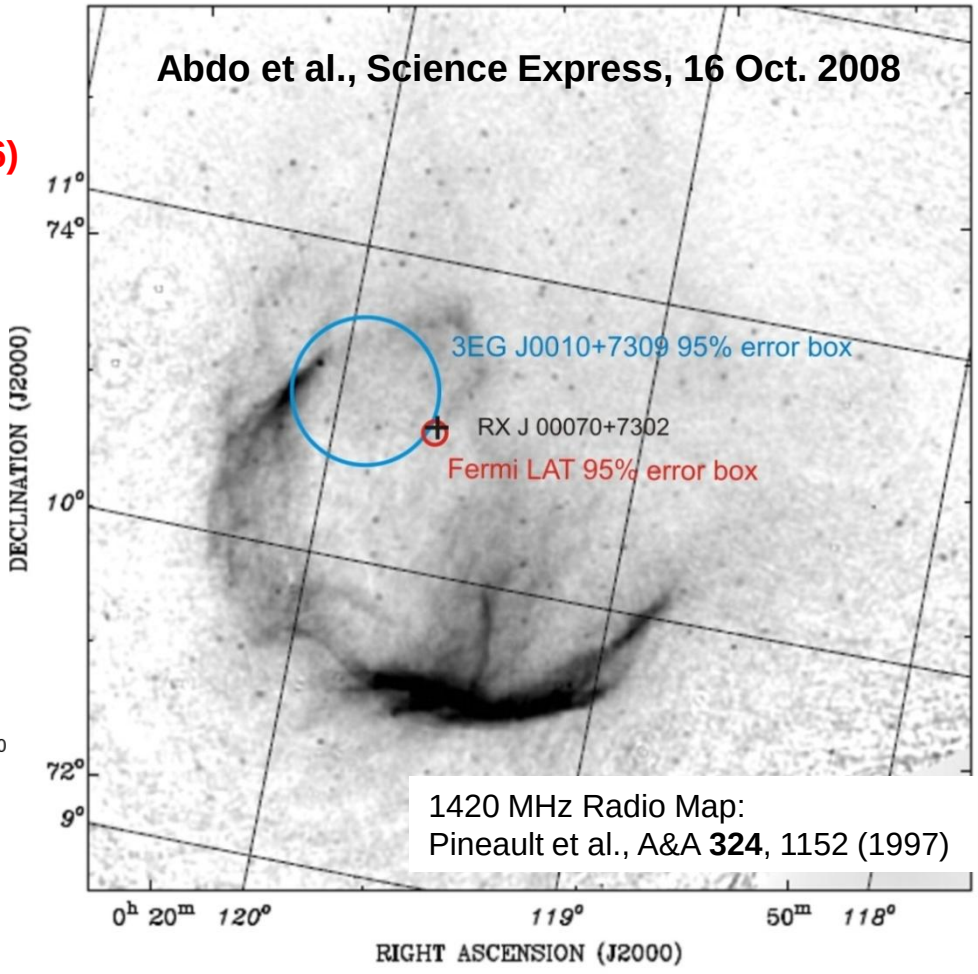
A radio-quiet, gamma-ray only pulsar, in Supernova Remnant CTA1

Quick discovery enabled by

- large leap in key capabilities
- new analysis technique (Atwood et al 2006)



- Spin-down luminosity ~10^{36} erg s^{-1}, sufficient to supply the PWN with magnetic fields and energetic electrons.
- The γ-ray flux from the CTA 1 pulsar corresponds to about 1-10% of E_{rot} (depending on beam geometry)



Age ~(0.5 – 1)x10^4 years
Distance ~ 1.4 kpc
Diameter ~ 1.5°

Pulsar emission model

In the simplest model, the emission should depend on 4 parameters: spin period, magnetic field, magnetic dipole inclination, and viewing angle

- luminosity derived from rotational energy

$E_{rot} = ½ I \Omega^2$

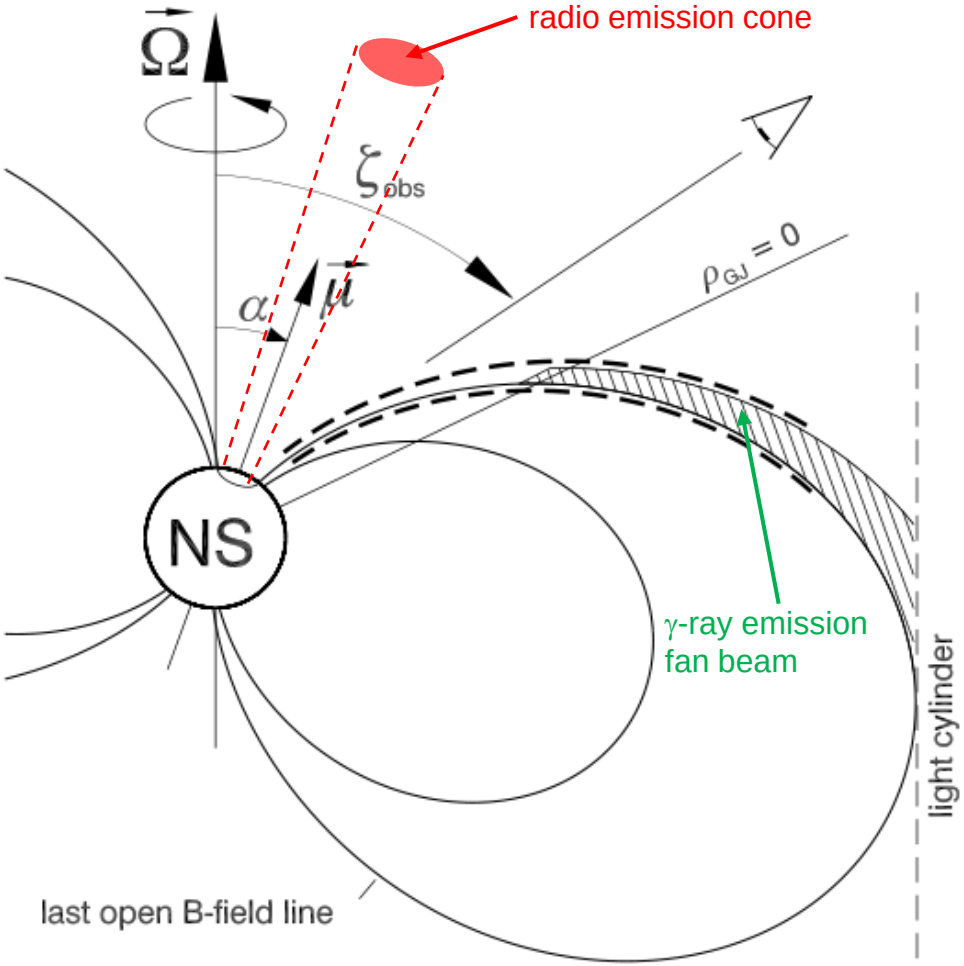
$\dot{E} = - B^2 R^6 \Omega^4 / c^3$

- derived parameters:

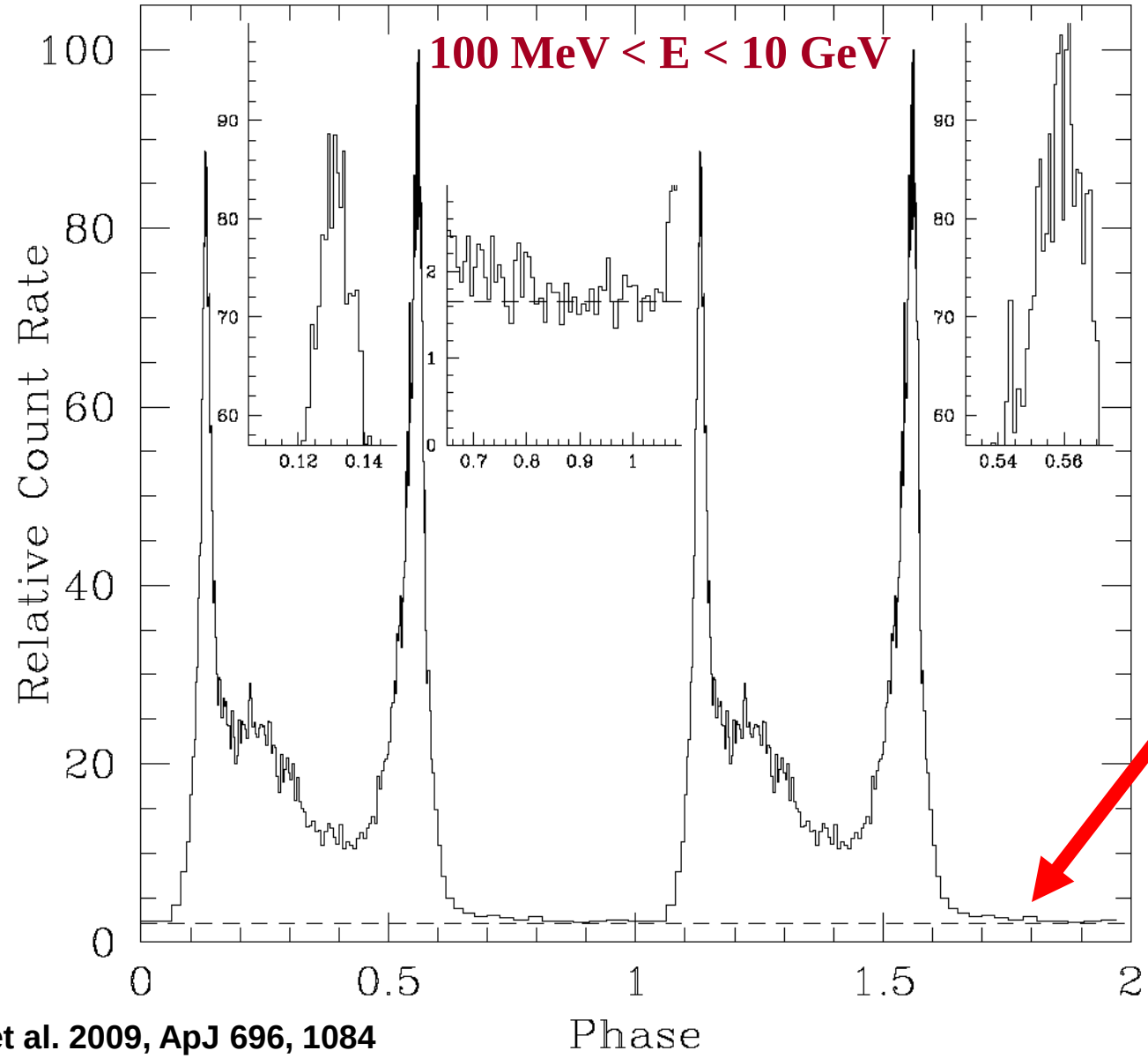
rotational age : $\tau = \Omega / 2\dot{\Omega}$

B field: $B = 3.2 \times 10^{19} (P\dot{P})^{1/2}$ G

spin-down power: $L = I\Omega\dot{\Omega}$



First *Fermi* view of the Vela Pulsar



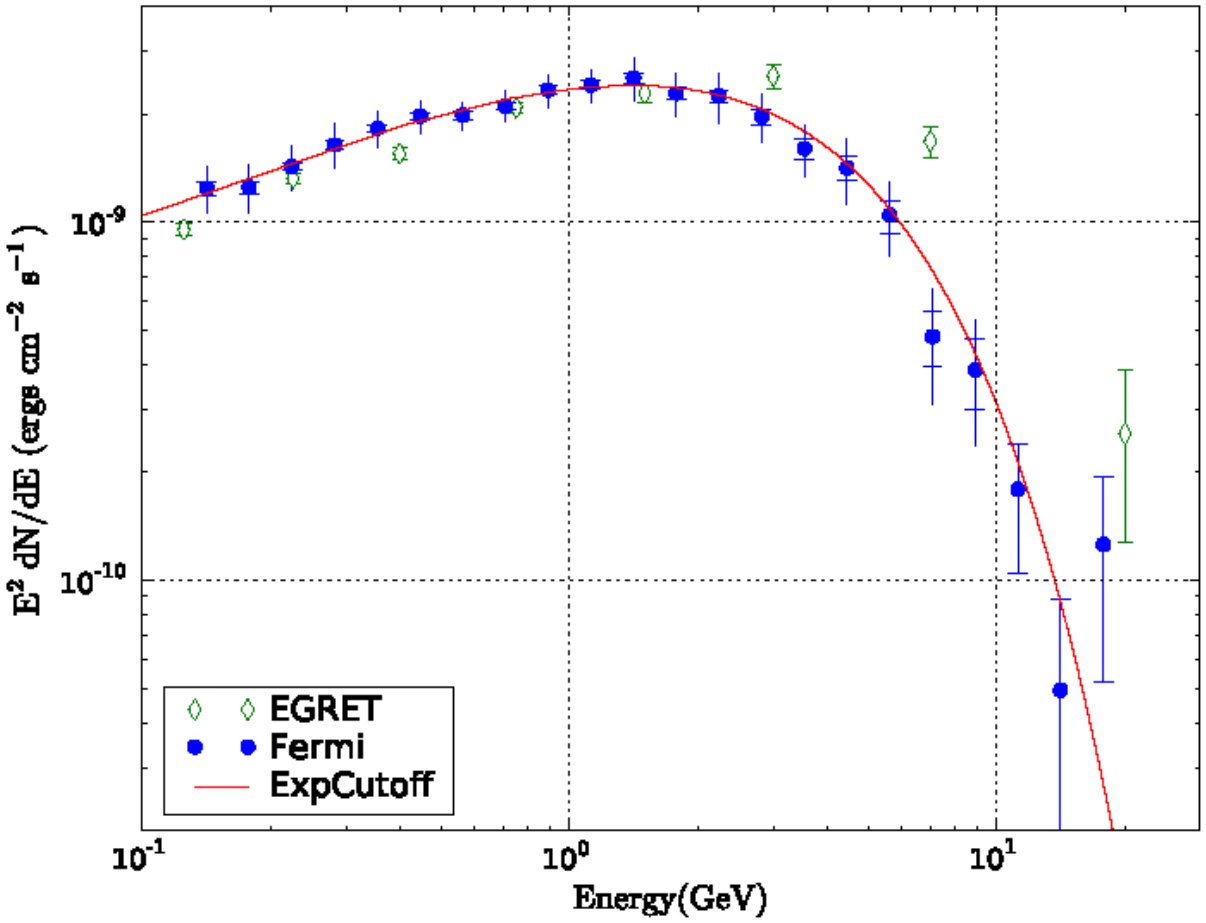
Remarkably sharp peaks; features to ~0.3ms.

Turns nearly completely off between the double pulses.

Abdo et al. 2009, ApJ 696, 1084

Vela Pulsar – Phase-averaged SED

$$N(E) = N_0 E^{\Gamma} e^{-(E/E_c)^b}$$



Consistent with b = 1 (simple exponential)

$$\Gamma = -1.51^{+0.05}_{-0.04}$$

$$E_c = 2.9 \pm 0.1 \text{ GeV}$$

b = 2 (super-exponential) rejected at 16.5 σ

No evidence for magnetic pair attenuation – Near-surface emission ruled out

Abdo et al. 2009, ApJ 696, 1084

Complication: the spectrum changes with phase

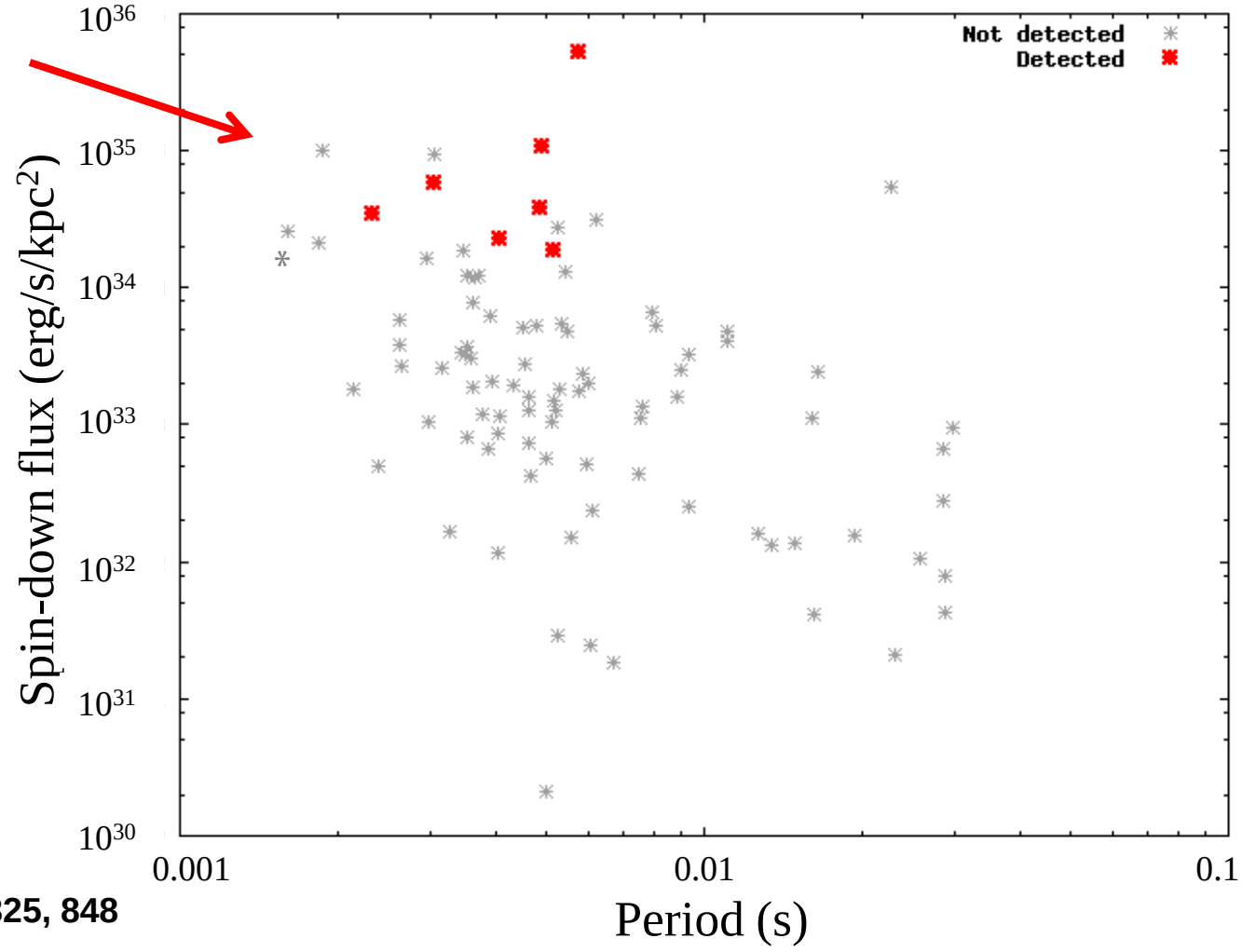
Millisecond pulsars

Old pulsars in a binary accelerated by accretion from the companion
Very fast rotators but low magnetic field

Fermi sees those with high 'spin-down flux'

$$\dot{E}_{sd} / d^2$$

The nearby population

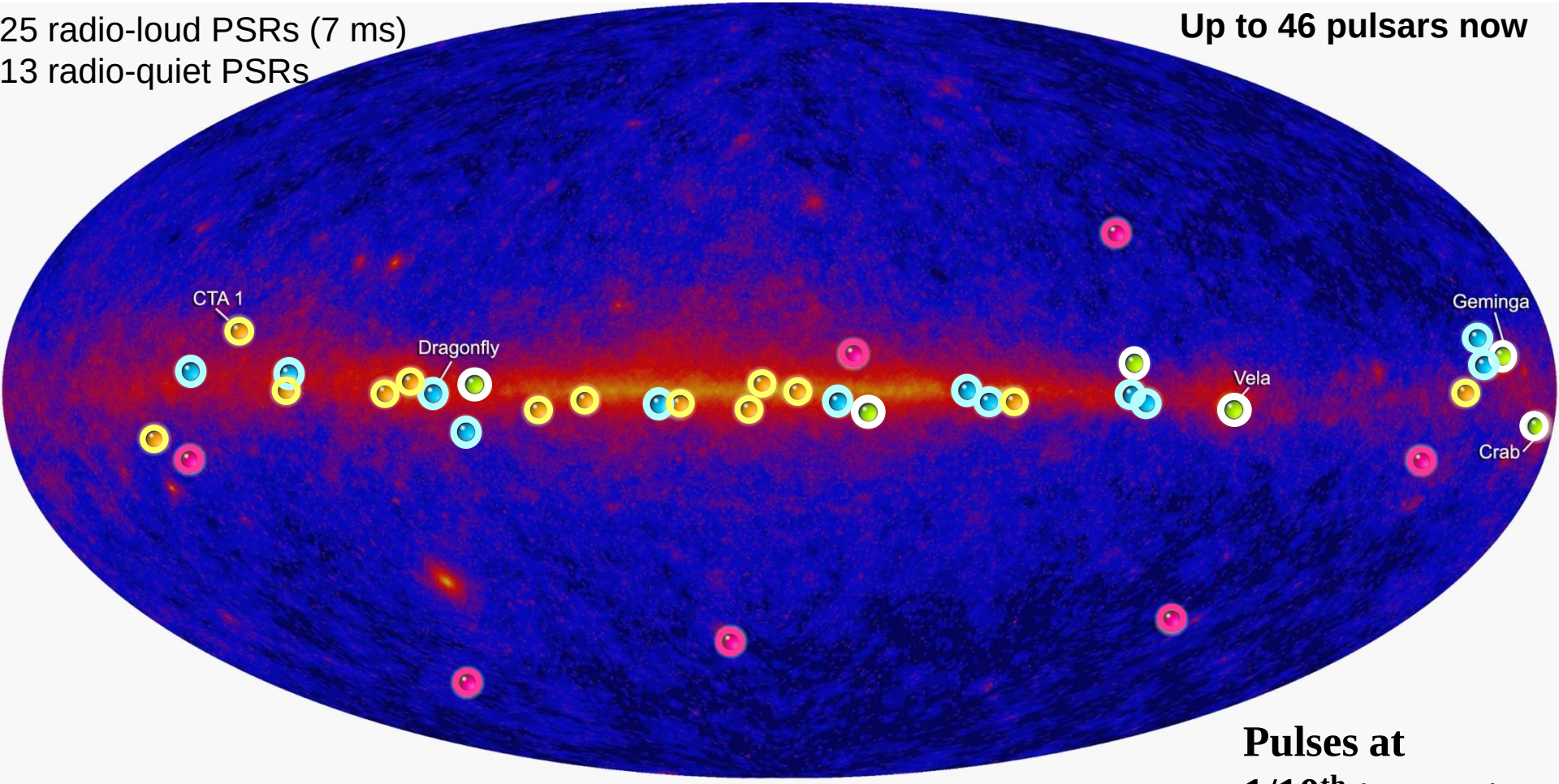


Abdo et al. 2009, Science 325, 848

The Pulsing Sky

25 radio-loud PSRs (7 ms)
13 radio-quiet PSRs

Up to 46 pulsars now



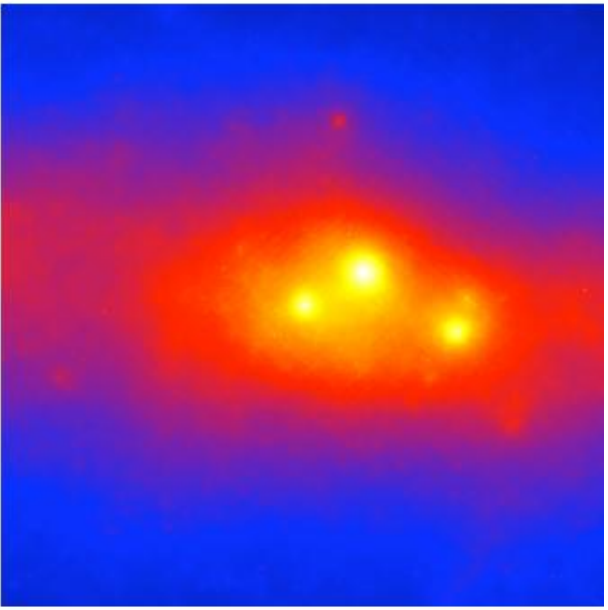
Pulses at 1/10th true rate

Fermi Pulsar Detections

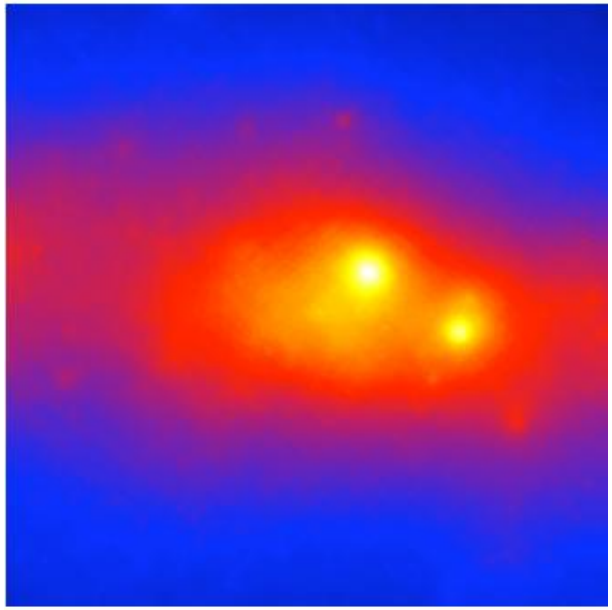
- New pulsars discovered in a blind search
- Millisecond radio pulsars
- Young radio pulsars
- Confirmed pulsars seen by Compton Observatory EGRET instrument

Radio follow-up

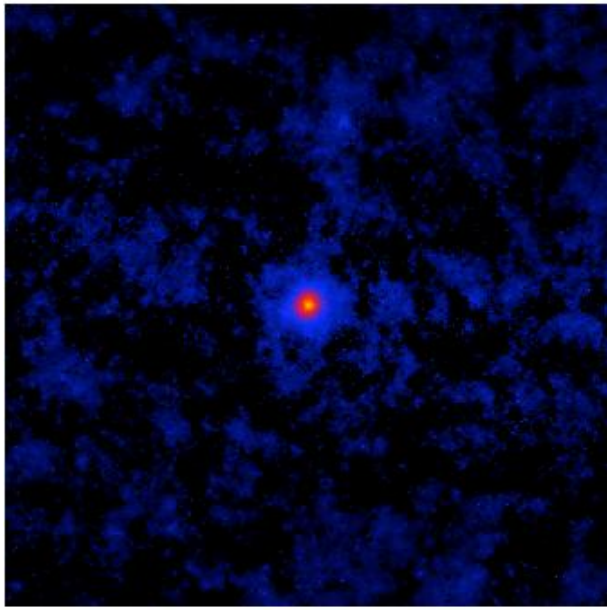
Radio detection of LAT PSRs J1741-2054 and J2032+4127:
no longer just gamma-ray pulsars (Camilo et al., accepted in ApJ)



All phases
Cygnus region



Off-pulse



On-pulse – Off-pulse

Publications

Published (20):

The Large Area Telescope on Fermi	Atwood, W. B. et al. 2009, ApJ, 697, 1071
NGC1275	Abdo, A. A. et al. 2009, ApJ, 699, 31
PKS 1454-354	Abdo, A. A. et al. 2009, ApJ, 697, 934
PKS 2155-304 with HESS & Fermi	Aharonian, F. et al. 2009, ApJL, 696, L150
3C 454.3	Abdo, A. A. et al. 2009, ApJ, 699, 817
PMN J0948+0022	Abdo, A. A. et al. 2009, ApJ, 699, 976
3-month bright AGN list	Abdo, A. A. et al. 2009, ApJ, 700, 597
Pulsar in CTA 1	Abdo, A. A. et al. 2008, Science, 322, 1218
Vela Pulsar	Abdo, A. A. et al. 2009, ApJ, 696, 1084
PSR J1028-5819	Abdo, A. A. et al. 2009, ApJL, 695, L72
PSR J0030+0451	Abdo, A. A. et al. 2009, ApJ, 699, 1171
PSR J0205+6449 in 3C 58	Abdo, A. A. et al. 2009, ApJ, 699, L102
PSR J2021+3651	Abdo, A. A. et al. 2009, ApJ, 700, L127
16 blind search pulsars	Abdo, A. A. et al. 2009, Science, 325, 840
Millisecond pulsars	Abdo, A. A. et al. 2009, Science, 325, 848
Globular cluster 47 Tuc	Abdo, A. A. et al. 2009, Science, 325, 845
3-month bright source list	Abdo, A. A. et al. 2009, ApJS, 183, 46
LS I +61 303	Abdo, A. A. et al. 2009, ApJ, 701, L123
Cosmic ray e+ + e- spectrum	Abdo, A. A. et al. 2009, PRL, 102, 181101
GRB 080916C	Abdo, A. A. et al. 2009, Science, 323, 1688

Conclusions

- CGRO/EGRET found only 31 sources above 10 σ in its lifetime, Fermi/LAT found 205 in the first 3 months
- Typical 95% error radius is less than 10 arcmin.
- About 1/3 of the sources show definite evidence of **variability**.
- Over half the sources are associated positionally with **blazars** (85% associations outside the plane, up from 60% with EGRET).
- 37 sources in 0FGL have no obvious associations with known gamma-ray emitting types of astrophysical objects.
- 46 **pulsars** are identified by gamma-ray pulsations (up from 6).
- 3 very bright **γ-ray bursts**, several fainter ones.
- 2 high-mass **X-ray binaries** (LSI +61 303 and LS 5039)
- Several **PWNe and SNRs** (W28, W44, W51C, IC443)