Fermi Gamma-ray Space Telescope

FERMI

Gamma-ray Space Telescope (GLAST)

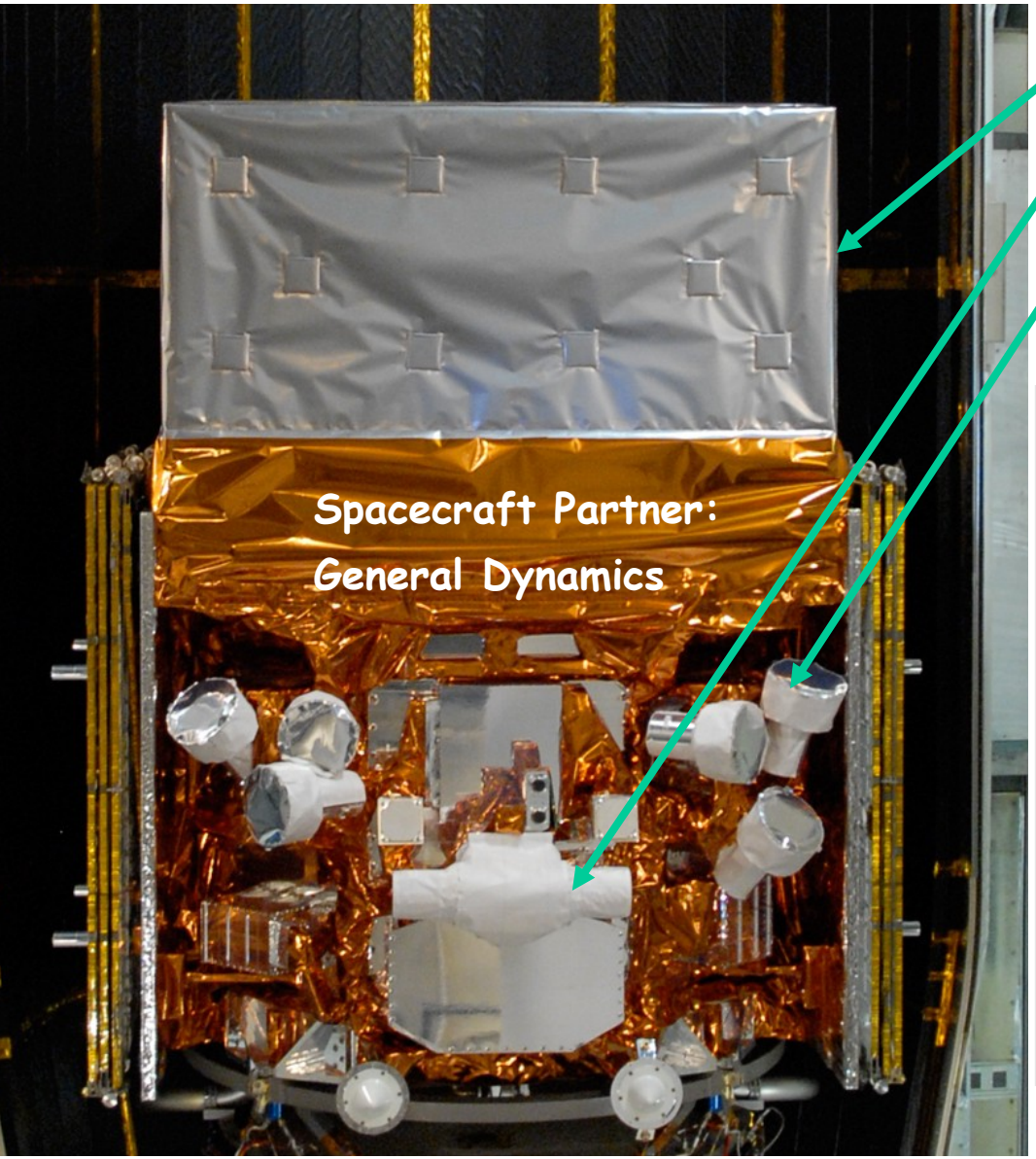
Observation of High Energy Gamma Rays with the Fermi Observatory

N.Giglietto

(INFN and Politecnico of Bari)

on behalf of the FERMI LAT Collaboration

The Observatory



Large AreaTelescope (LAT)
20 MeV - >300 GeV

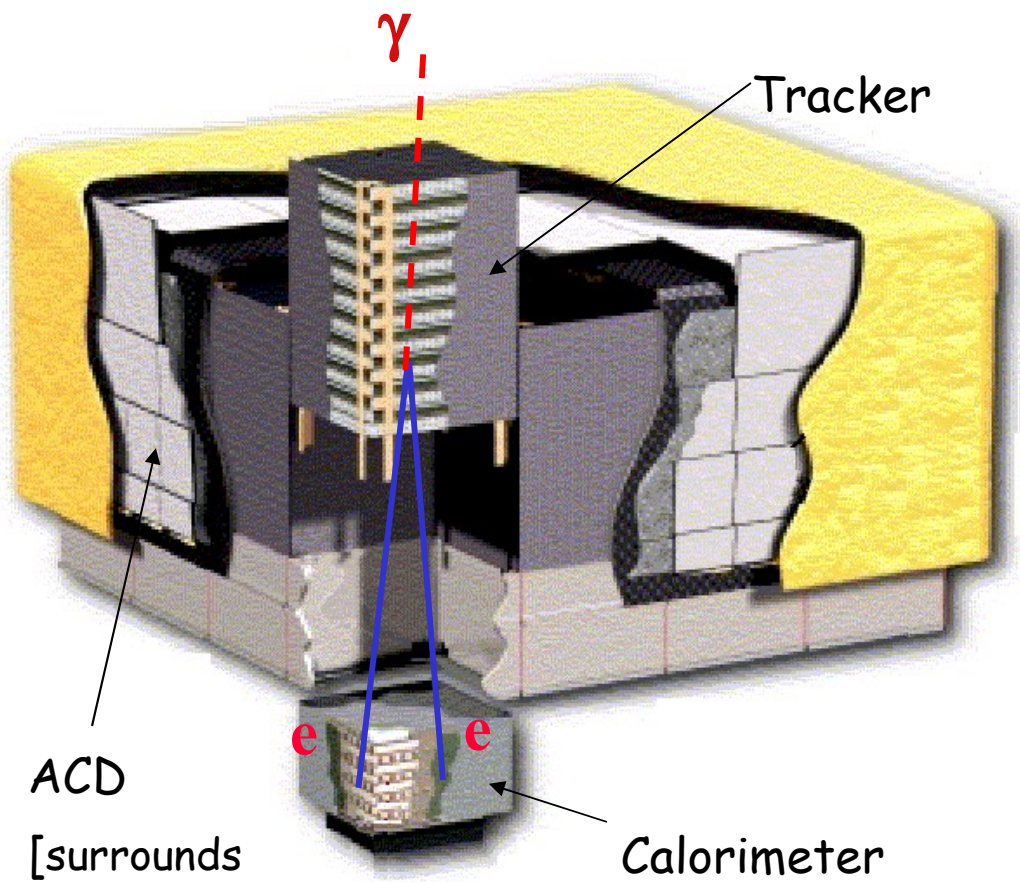
Gamma-ray Burst Monitor (GBM)
NaI and BGO Detectors
8 keV - 30 MeV

KEY FEATURES

- **Huge field of view**
  - LAT: 20% 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.**

Overview of LAT: How it works

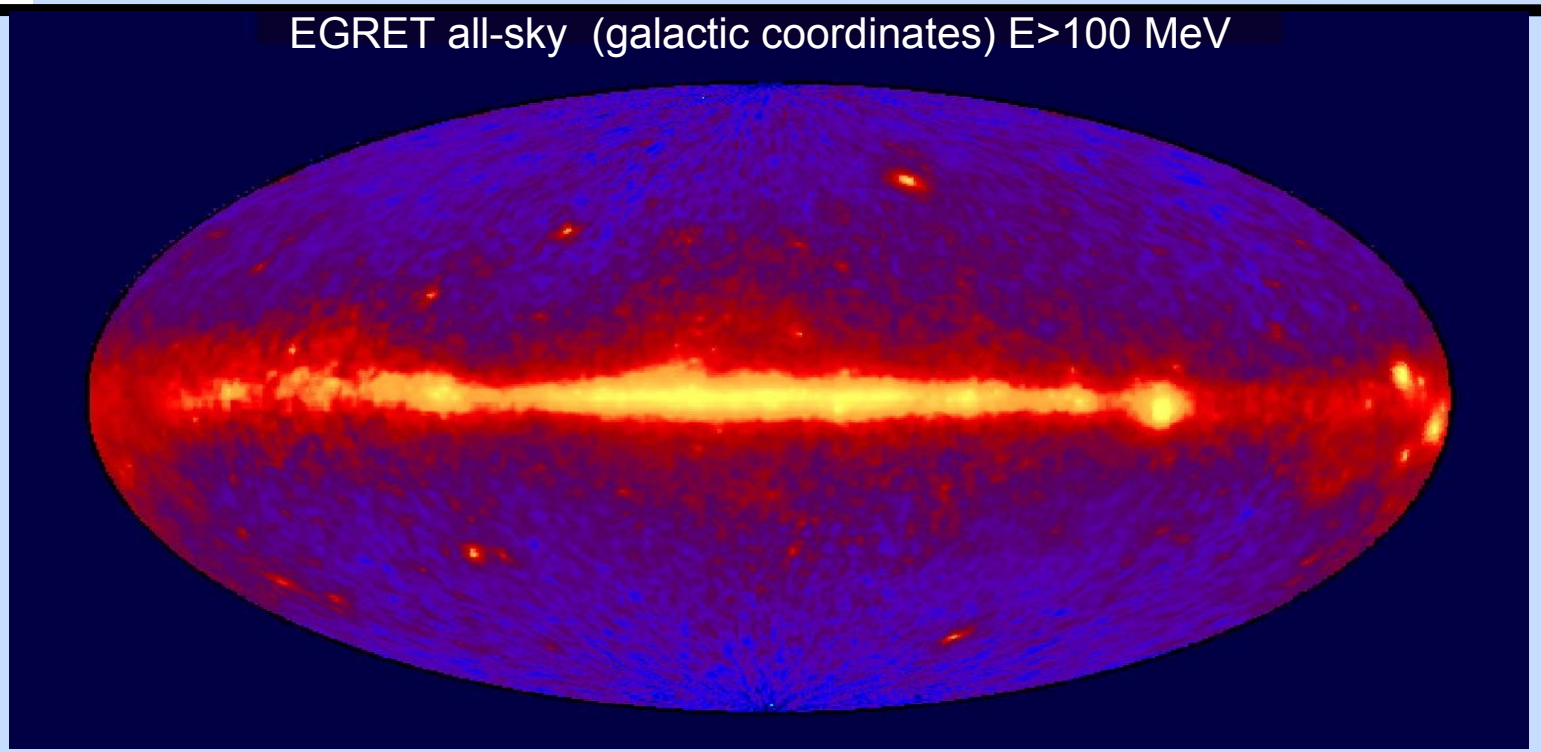
- Precision Si-strip Tracker (TKR) **228 μm pitch, 8.8 10 channels** Measure the photon direction; gamma ID.
- Hodoscopic CsI Calorimeter (CAL) Measure the photon energy; image the shower. (8.6X_0)
- Segmented Anticoincidence Detector (ACD) Reject background of charged cosmic rays; segmentation removes self-veto effects at high energy.
- Electronics System Includes flexible, robust hardware trigger and software filters.
- **3000 kg, 650 W**



Atwood et al, ApJ submitted

Systems work together to identify and measure the flux of cosmic gamma rays with energy 20 MeV - >300 GeV.

Features of the EGRET 5years gamma-ray sky

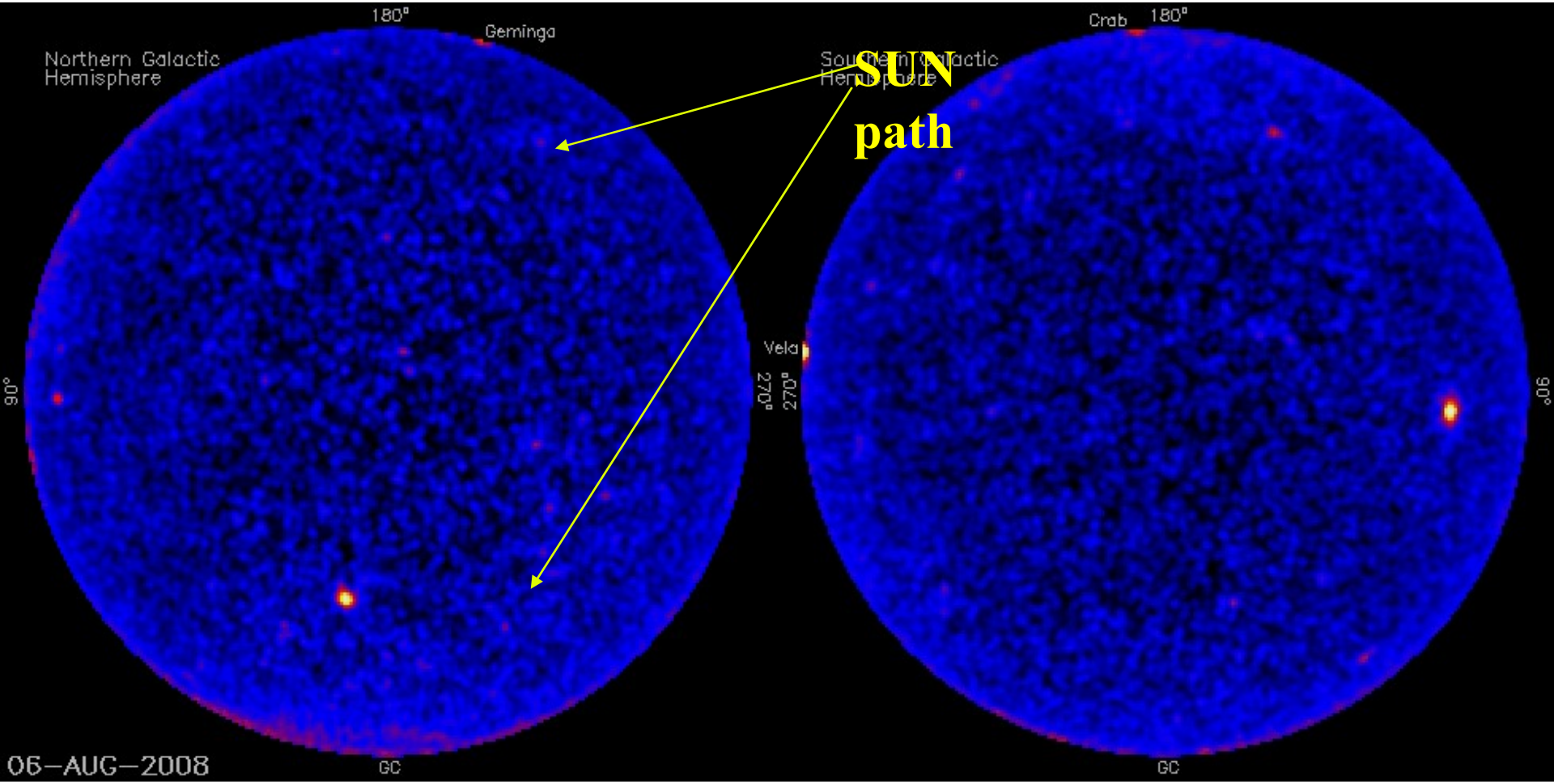


diffuse extra-galactic background (flux ~ 1.5x10 cm s sr)
galactic diffuse (flux ~30 times larger)
high latitude (extra-galactic) point sources
(typical flux from EGRET sources O(10 - 10) cm s)
galactic sources (pulsars, μ-IBH)

An essential new characteristic: VARIABILITY in time!

Field of view important for study of transients.

Variability a 3 months look (north-south galactic emisphere)



E>100MeV, poles view, 1day time interval,
extreme sensitivity to flux variations

Fermi Science

A very broad menu that includes:

- Systems with supermassive black holes (Active Galactic Nuclei)
- Gamma-ray bursts (GRBs)
- Pulsars
- Supernova remnants (SNRs), PWNe, Origin of Cosmic Rays
- Diffuse emissions
- Solar physics
- Probing the era of galaxy formation, optical-UV background light
- Solving the mystery of the high-energy unidentified sources
- Discovery! New source classes. Particle Dark Matter? Other relics from the Big Bang? Other fundamental physics checks.

Huge increment in capabilities.

Draws the interest of both the High Energy Particle Physics and High Energy Astrophysics communities.

The Accelerator

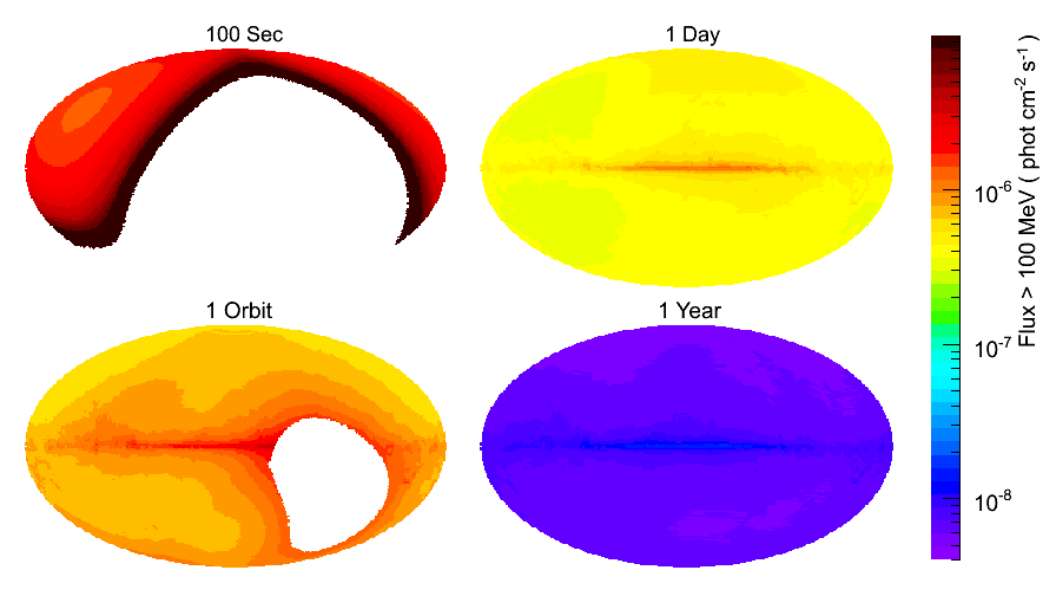
Launch!

- Launch from Cape Canaveral Air Station 11 June 2008 at 12:05PM EDT
- Circular orbit, 565 km altitude (96 min period), 25.6 deg inclination.

… and then …

Operating modes

- **Primary observing mode is Sky Survey**
  - Full sky every 2 orbits (3 hours)
  - Uniform exposure, with each region
  - viewed for ~30 minutes every 2 orbits
  - Best serves majority of science, facilitates
  - multiwavelength observation planning



- **Pointed observations when appropriate (selected by peer review in later years) with automatic earth avoidance selectable. Target of Opportunity pointing.**
  - Exposure intervals commensurate with
- **Autonomous repoints for onboard GRB detections in any mode.**
  - typical instrument integration times for

LAT Collaboration

- **France**
  - CNRS/IN2P3, CEA/Saclay
- **Italy**
  - INFN, ASI, INAF
- **Japan**
  - Hiroshima University
  - ISAS/JAXA
  - RIKEN
  - Tokyo Institute of Technology

PI: Peter Michelson
(Stanford)

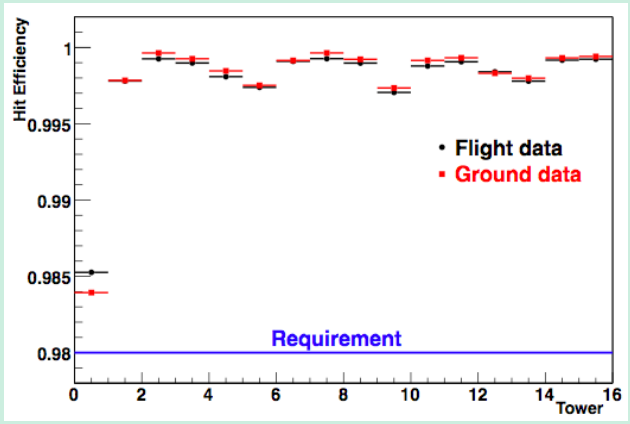
~390 Scientific Members (including 96 Affiliated Scientists, plus 68 Postdocs and 105 Students)

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

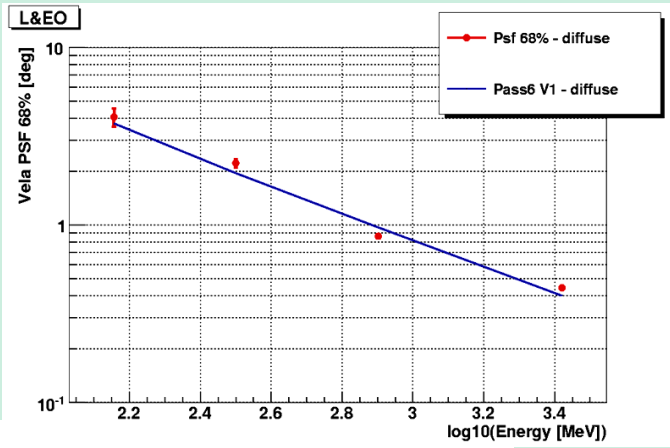
Managed at SLAC.

LAT Working Very Well On Orbit!

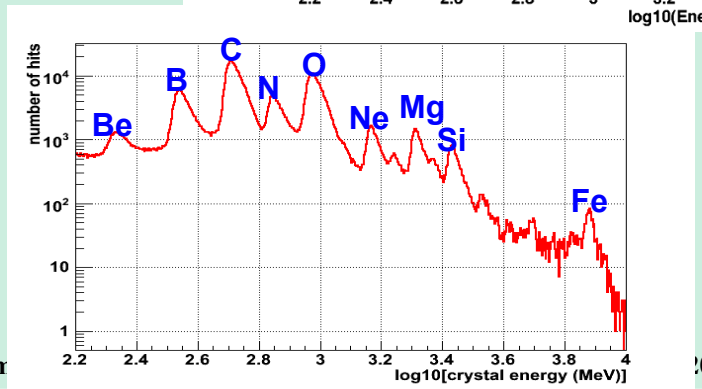
- **Total background rates very close to expectation (non-trivial!)**
- **Spectacular charged-particle hit efficiency:**



- **PSF on-orbit as expected (note intrinsic energy dependence => localization is source-dependent)**
  - verify using on-pulse photons from Vela, compare with
  - detailed MC simulation:



- **On-orbit calorimeter calibration stable**
  - use cosmic ray heavy ions:



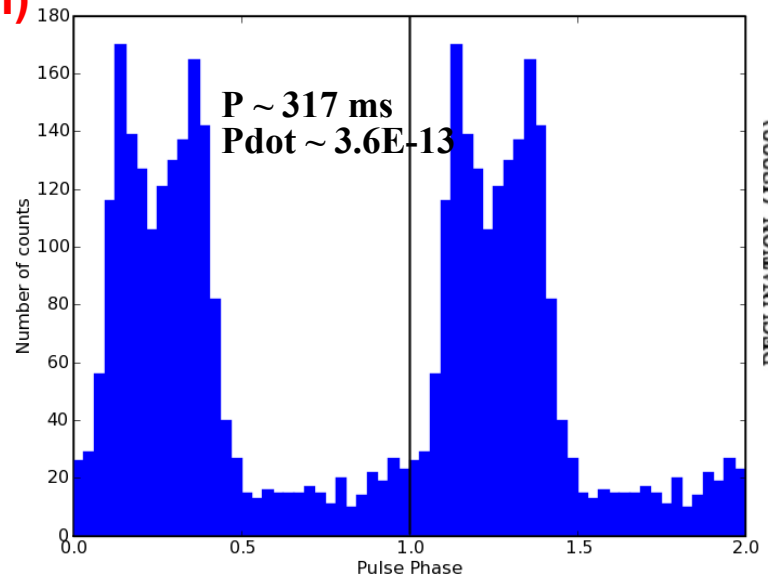
Big Questions From EGRET Era

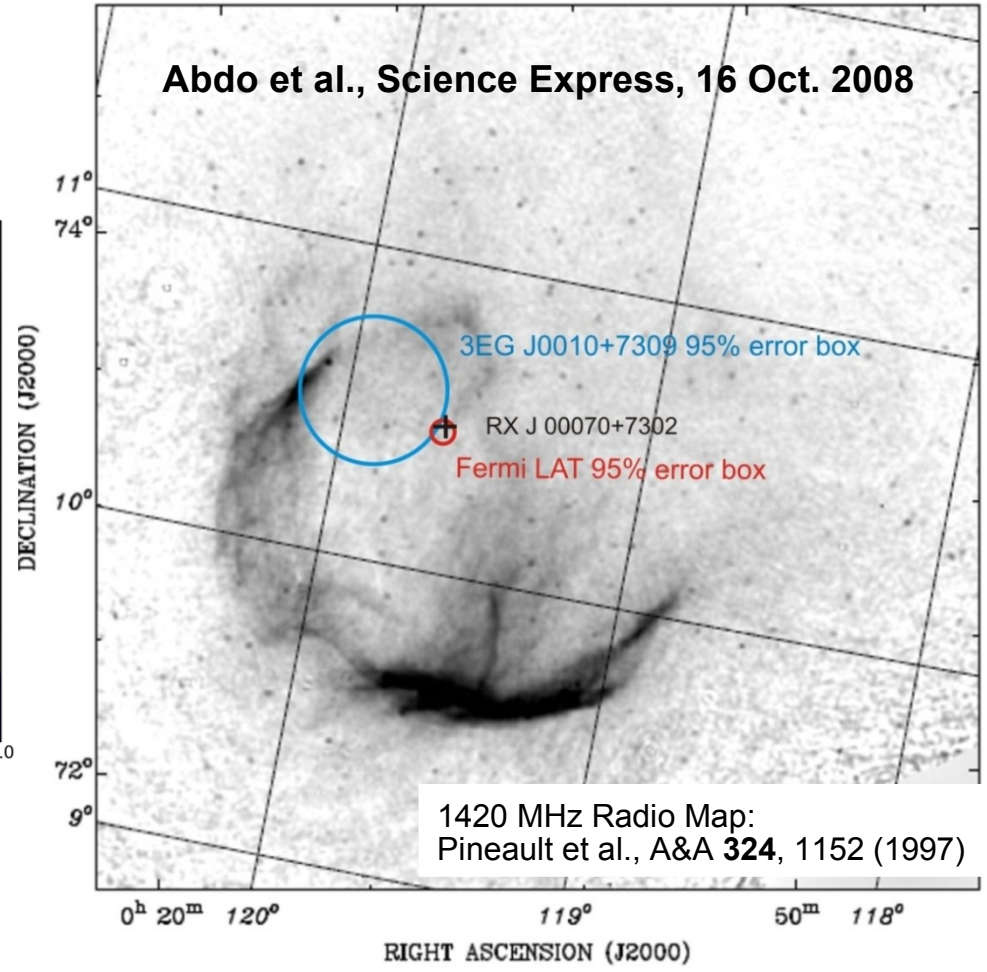
- How and where do pulsars emit gamma rays? How common are radio-quiet pulsars?
  - necessary clue to magnetic field configurations and dynamics
- What are the EGRET Unidentified Sources?
  - most of the EGRET source identifications are a mystery
- What are the energy budgets of gamma-ray bursts? What are the temporal characteristics of the high-energy emission?
  - not well characterized yet, key tests of models.
- What are the origins of the diffuse emissions?
  - galactic: cosmic-ray and matter distributions; sources
  - extragalactic: populations
  - new sources (Dark Matter annihilations, clusters, …)
- How do the supermassive black hole systems of AGN work? Why do the jets shine so brightly in gamma rays?
  - temporal and spectral variability over different timescales
- What remains to be discovered with great new capabilities??
  - EGRET showed us the tip of the iceberg. New sources and probes for new physics.

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)**



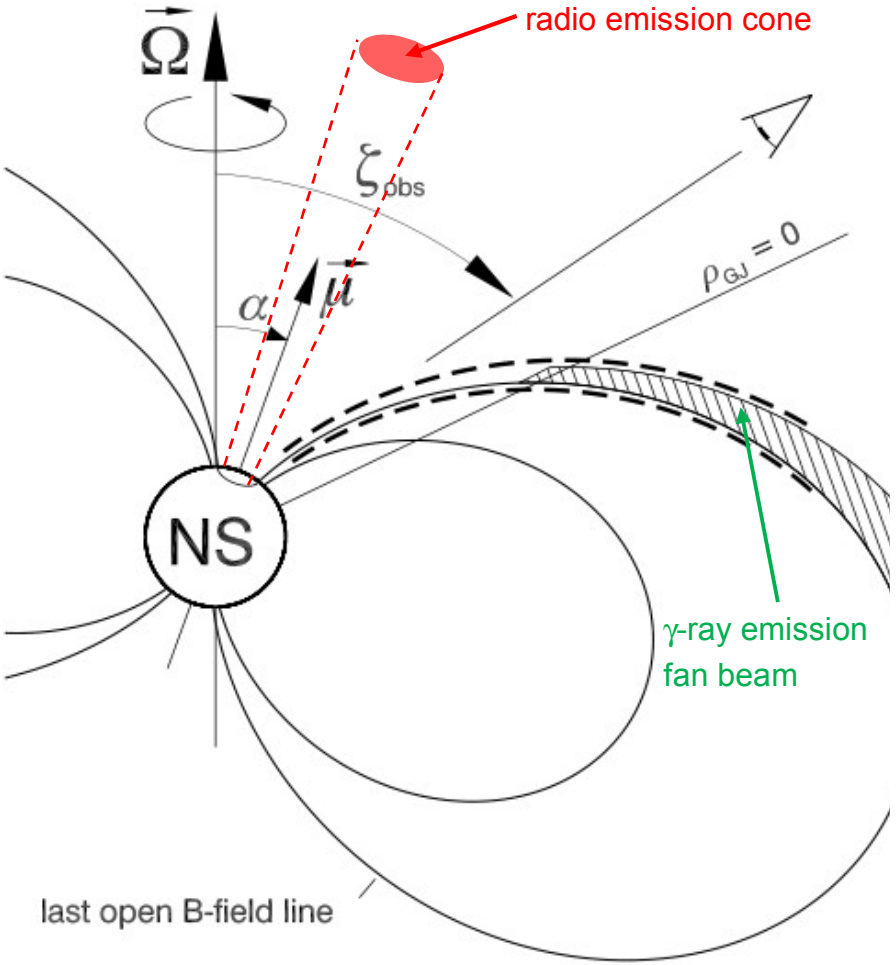


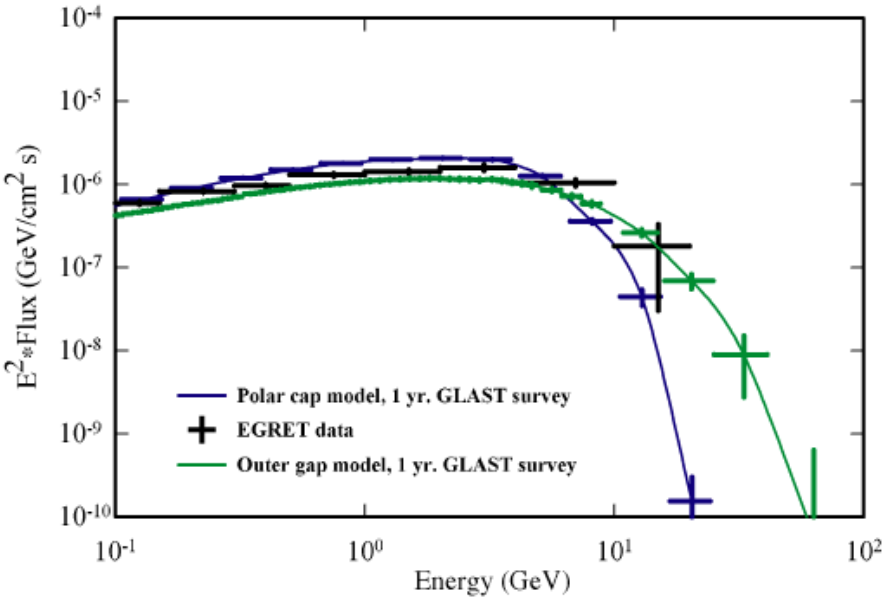
- Spin-down luminosity ~10^{36} erg s^{-1}, sufficient to supply the PWN with magnetic fields and energetic electrons.

- The γ-ray flux from the CTA 1 pulsar corresponds to about 1-10% of $\dot{E}_{rot}$ (depending

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

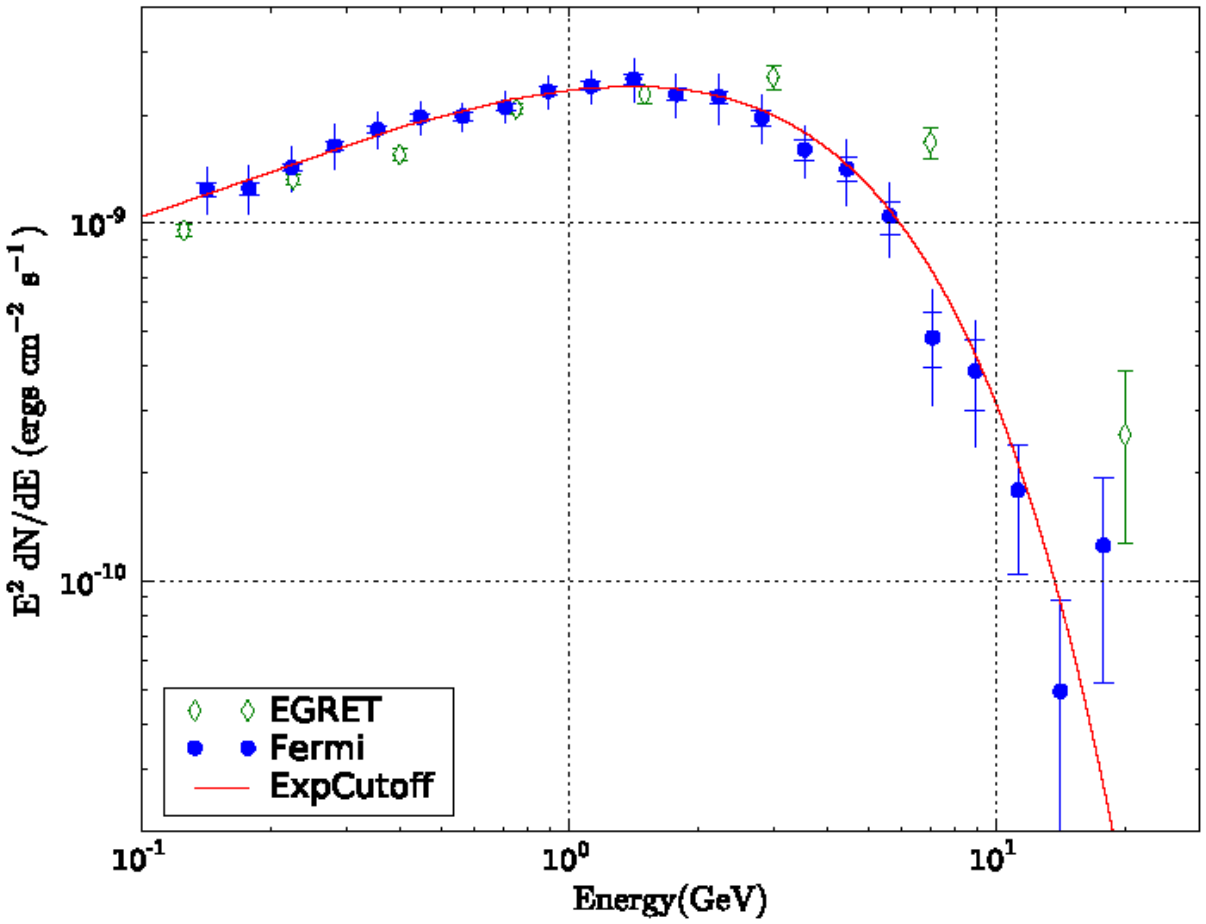
Pulsar Field Geometry Simplified





Vela Pulsar – Phase-averaged SED

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



Consistent with b=1 (simple exponential)

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

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

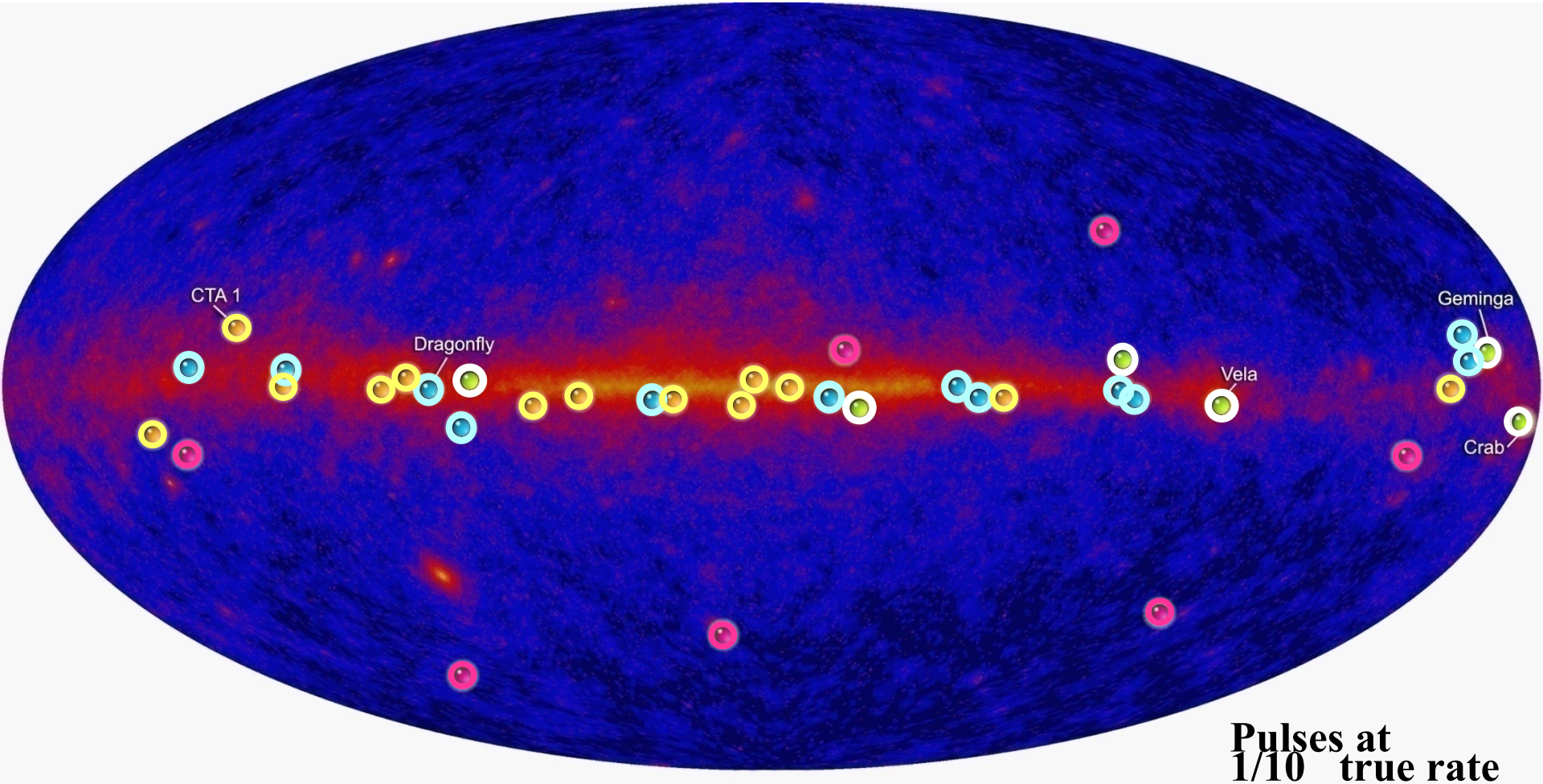
b=2 (super-exponential) rejected at 16.5σ

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

Summary: Fermi LAT Pulsar Discoveries

- **In the first 4 months of the mission, over 3 dozen pulsars detected!**

The Pulsing Sky



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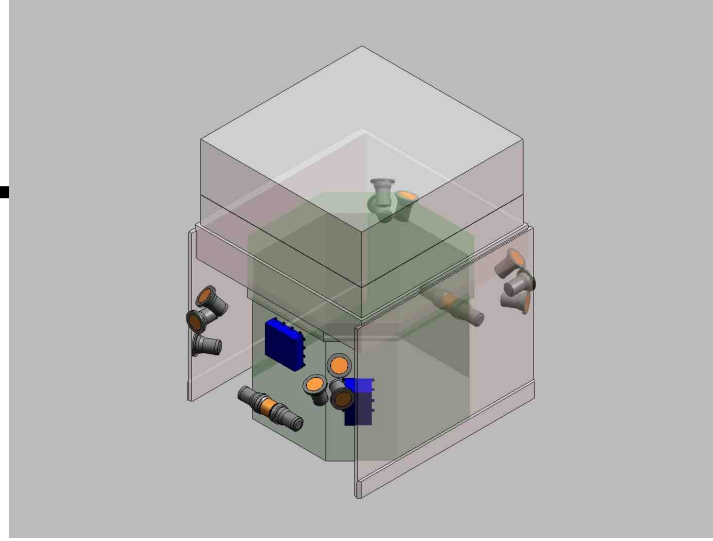
GBM Collaboration



National Space Science & Technology Center

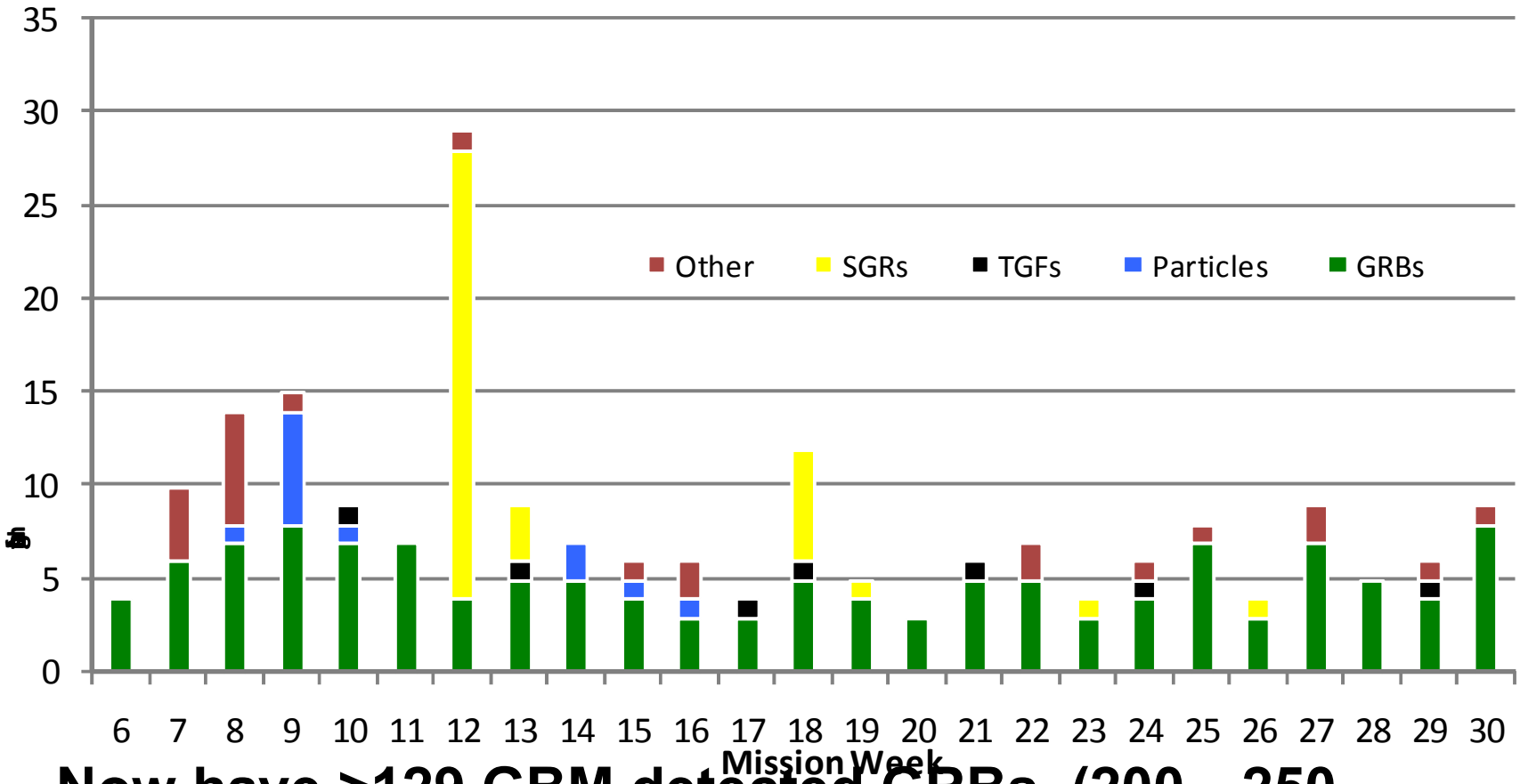
University of Alabama in Huntsville

NASA Marshall Space Flight Center

Max-Planck-Institut für extraterrestrische Physik

Charles Meegan (PI)
Jochen Greiner (Co-PI)

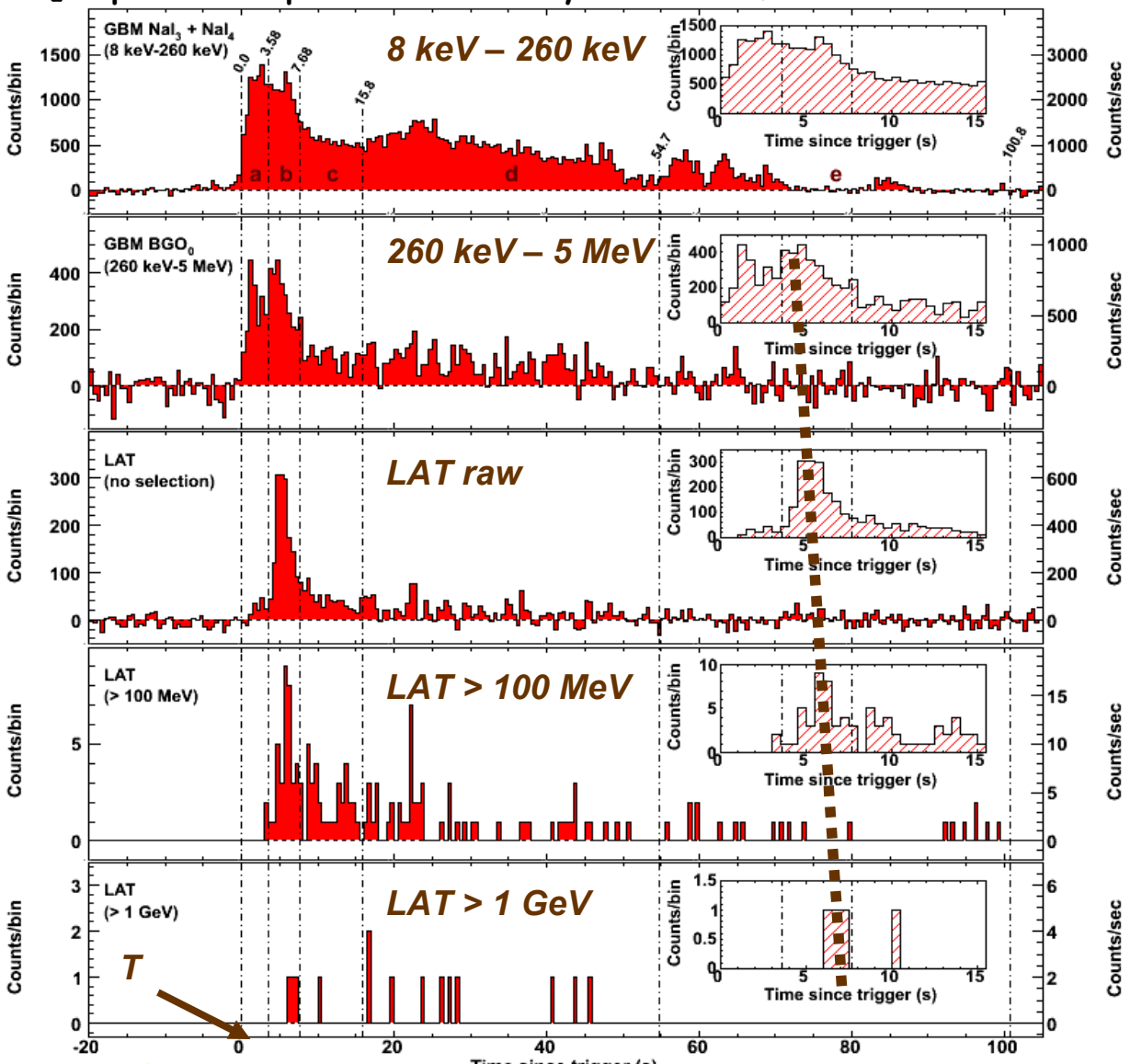
GBM Trigger Rate (weekly)



Now have >129 GBM detected GRBs (200—250 per year). 5 GRBs with LAT

GRB080916C

[Paper accepted 11 Feb by Science, online 19 Feb, Science DOI 10.1126/Science.1169101]



- The first low-energy peak is not observed at LAT energies
- 14 events above 1 GeV
- The bulk of the emission of
  nd
  the 2 peak is moving toward later times as the energy increases
  Clear signature of spectral evolution
- new era of GeV GRB lightcurves!

GROND optical follow up [GCN 8257, 8272]
Faint (21.7 mag at T +32h) and

fading (T +3.3d) source

RA = 119.8472°, Dec = −56.6383° (±0.5" at 68% C.L.)

GRB summary

Updated on feb,20,2009: 129 bursts detected by the GBM, including 5 LAT detections
Nice joint GBM+LAT analyses

High-energy GRB observations :
Evidences for a delay between keV-MeV emission and >100MeV emission
All spectra consistent with a Band function
081024B : First >GeV observation from a short burst

iso 54

080916C : Most energetic burst with a measured redshift E ~8.8x10 ergs
Evidence for a temporally extended GeV emission : up to 23min
090217: last GRB detected, again evidences for a delayed emission between kev-MeV emission (GCN circulars 8902-03)

Consequences :
Narrow collimated relativistic jet
keV-GeV spectrum and variability : unique mechanism, same emission region
Leptonic or hadronic origin?

QG 2 Planck

Best constraints ever on Γ (> 600 to 900) and M (> 1.50e18 GeV/c ~0.1 M)

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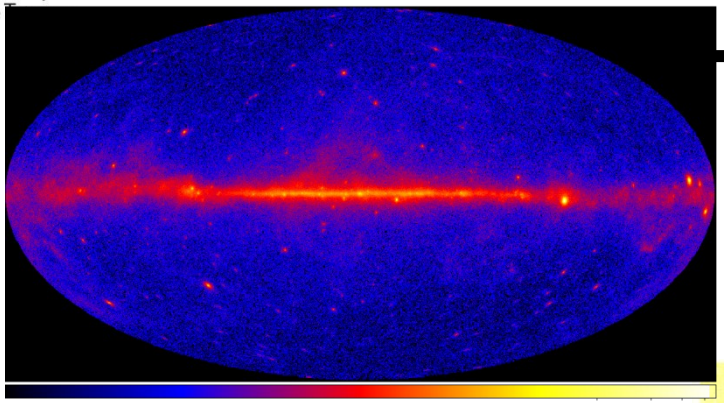
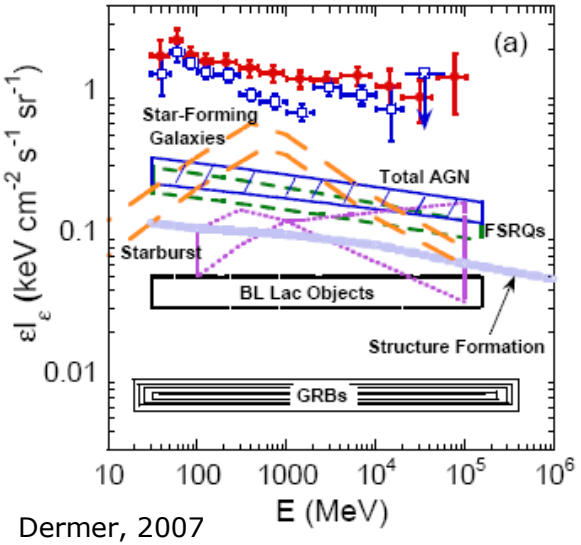
Introduction to the diffuse gamma-ray emission

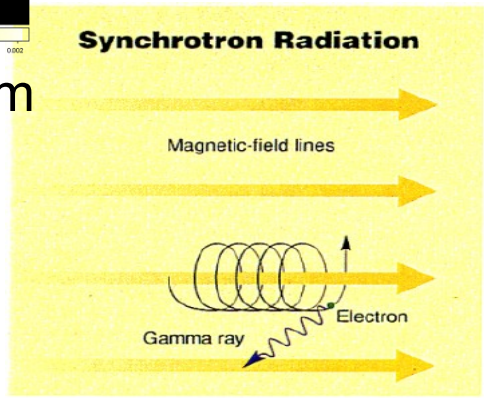


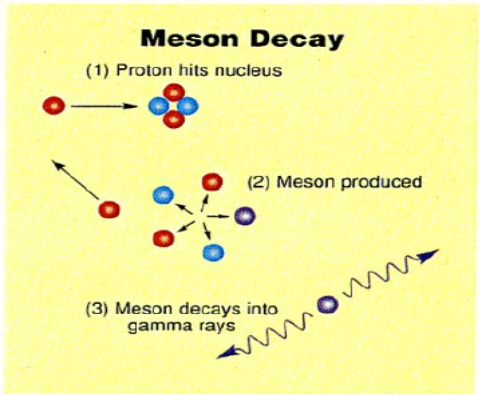
GeV Galactic diffuse emission is non-thermal emission from interaction of CR with the interstellar medium

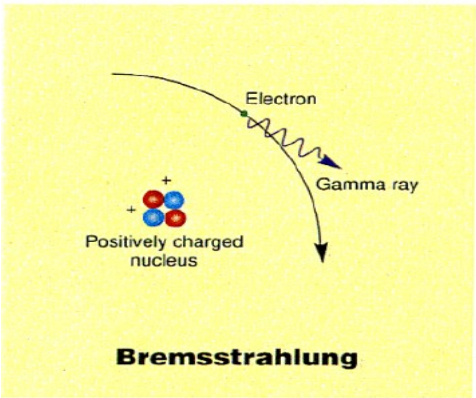
+ isotropic diffuse emission from unresolved AGN, star-forming galaxies, etc...

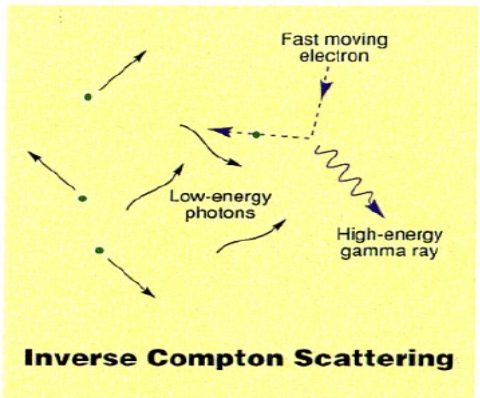


Dermer, 2007



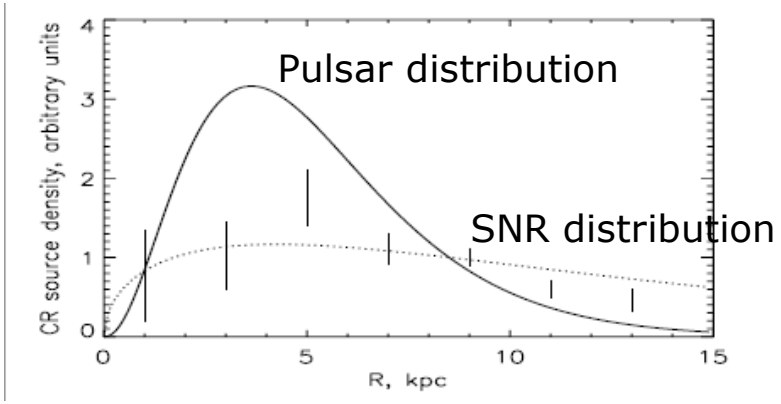






The challenge of modeling the galactic diffuse γ-ray emission

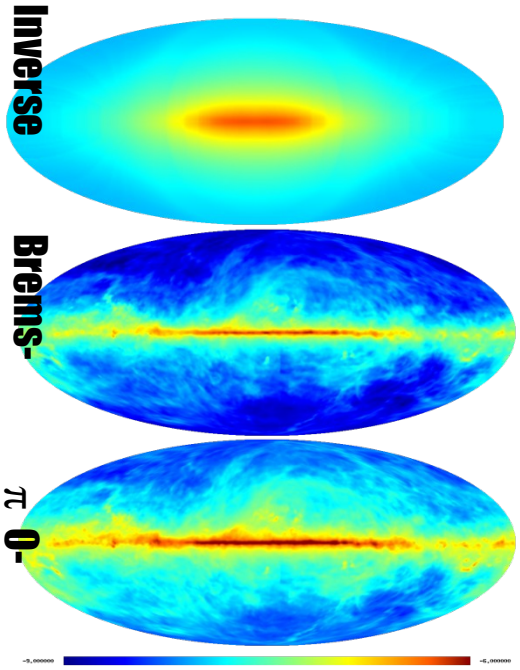
• **Cosmic-ray source distribution** • **Cosmic-ray propagation**

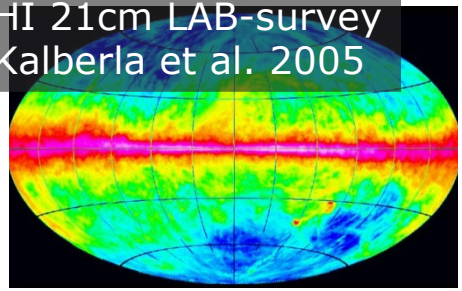


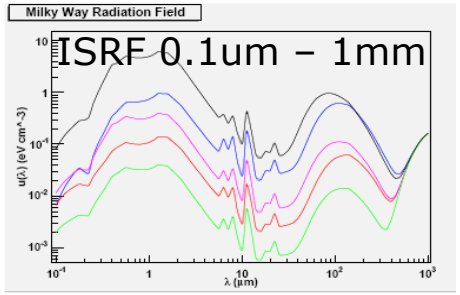
(numerical solution of the transport equation in 3 dimensions)

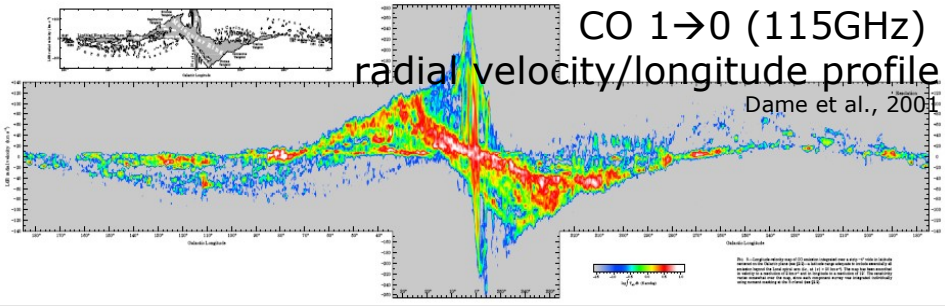
$$\frac{\partial \psi}{\partial t} = q(r, p) + \nabla \cdot (D_{xx} \nabla \psi - V\psi) + \frac{\partial}{\partial p} p^2 D_{pp} \frac{\partial}{\partial p} \frac{1}{p^2} \psi$$
$$- \frac{\partial}{\partial p} \left[\dot{p}\psi - \frac{p}{3} (\nabla \cdot V) \psi \right] - \frac{1}{\tau_f} \psi - \frac{1}{\tau_r} \psi ,$$

• **Interaction with interstellar medium**



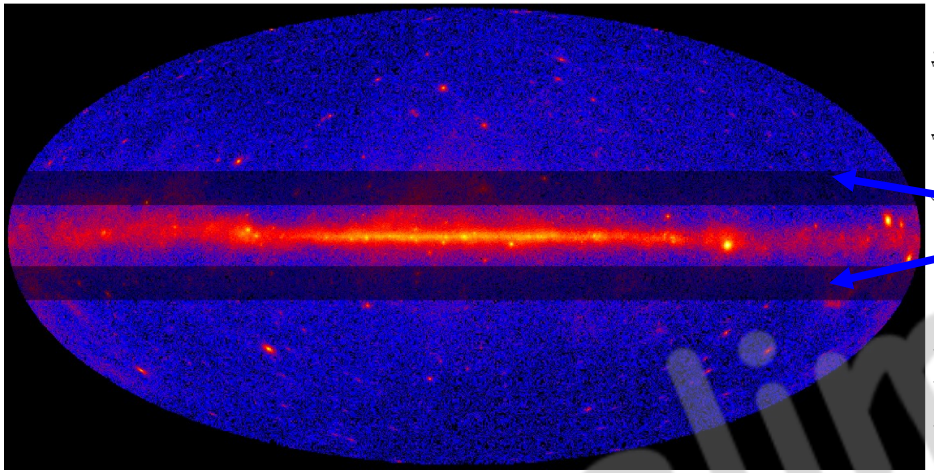


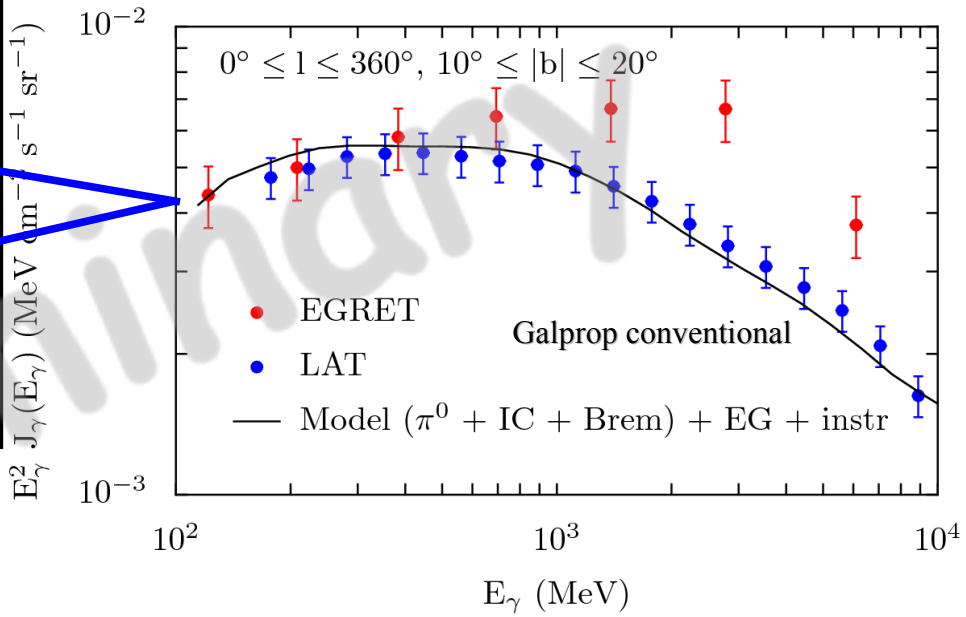




• **Line-of-sight integration of produced gamma-ray intensities**

Diffuse Emission, Nailing the EGRET "GeV Excess"

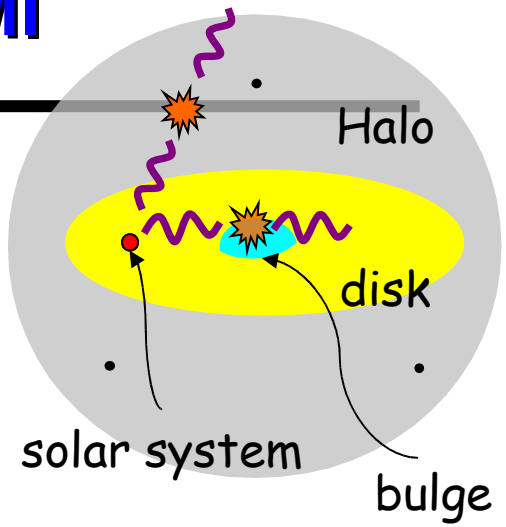


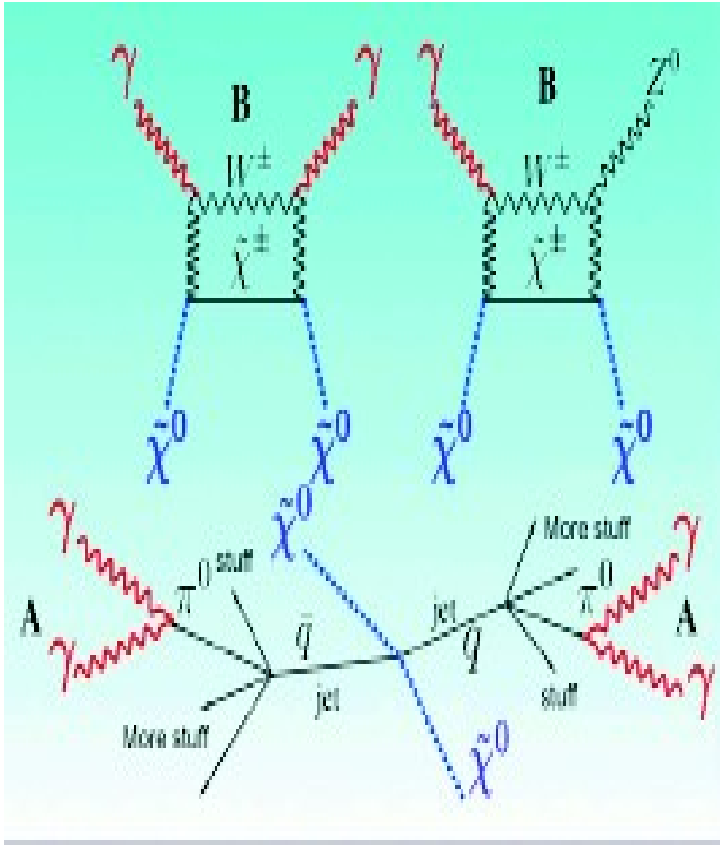


- Spectra shown for mid-latitude range → GeV excess in this region of the sky is not confirmed.
- Sources are not subtracted but are a minor component.
- LAT errors are dominated by systematic uncertainties and are currently estimated to be ~10% → this is preliminary.
- EGRET data is prepared as in Strong, et al. 2004 with a 15% systematic error assumed to dominate (Esposito, et al. 1999).
- EG + instrumental is assumed to be isotropic and determined from fitting the data at $|b| > 10°$.

Dark Matter searches with FERMI

$$\frac{d\Phi_\gamma}{dE_\gamma} = \frac{1}{4\pi} \underbrace{\frac{\langle\sigma v\rangle}{2m_\chi^2} \sum_f \frac{dn_\gamma^f}{dE_\gamma} B_f}_{\text{Particle Physics}} \underbrace{\int_{\Delta\Omega} \int_{l.o.s} \rho^2(l)\ dl(\psi)\ d\Omega}_{\text{Astrophysics } J(\psi)}$$



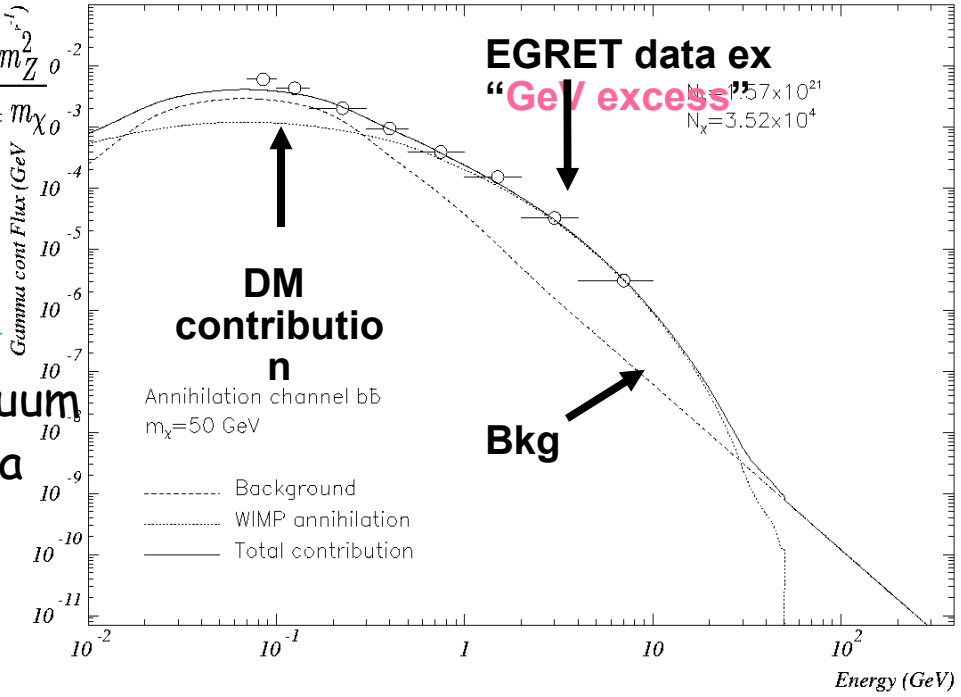


→ Gamma ray lines, the " smoking gun " signal of particle dark matter … but loop suppressed …

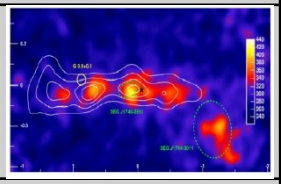
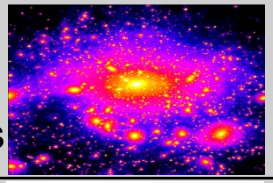
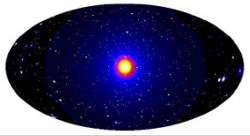
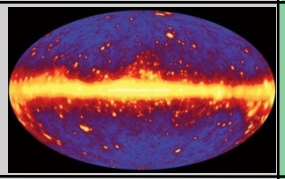
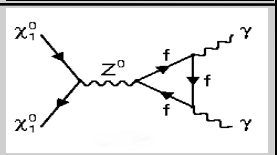
$$E_\gamma = m_\chi - \frac{m_Z^2}{4\, m_{\chi^0}}$$

$$E_\gamma = m_\chi$$

→ Continuum spectra

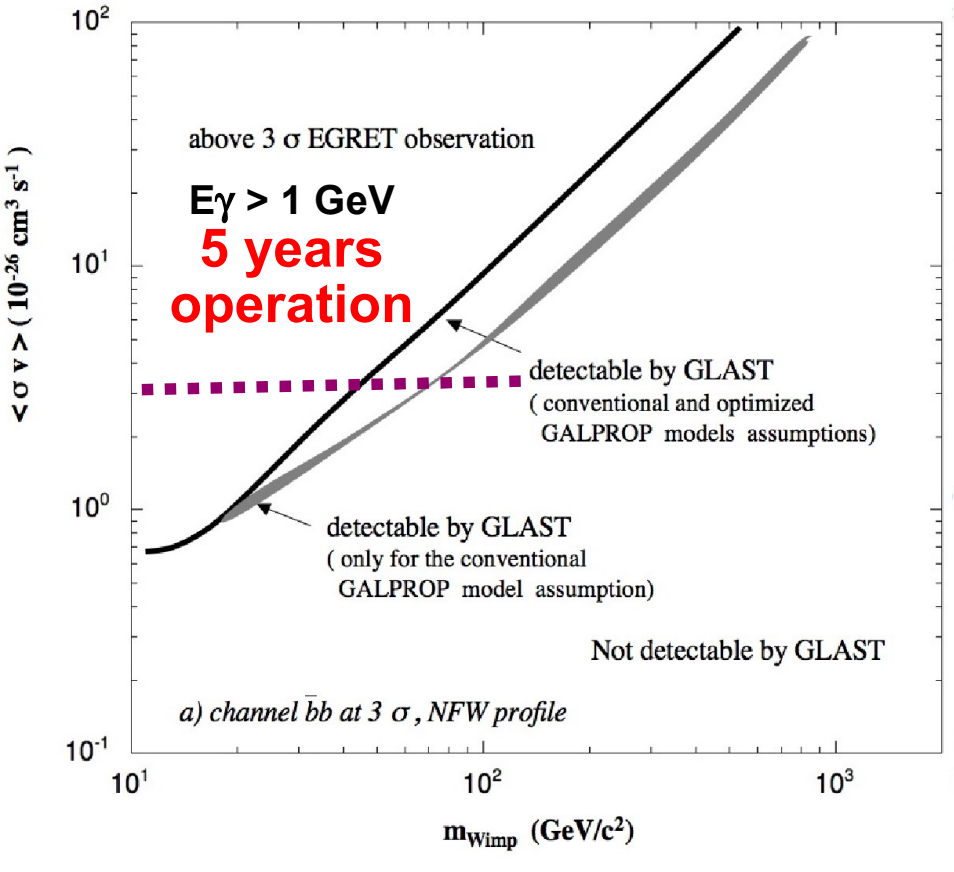


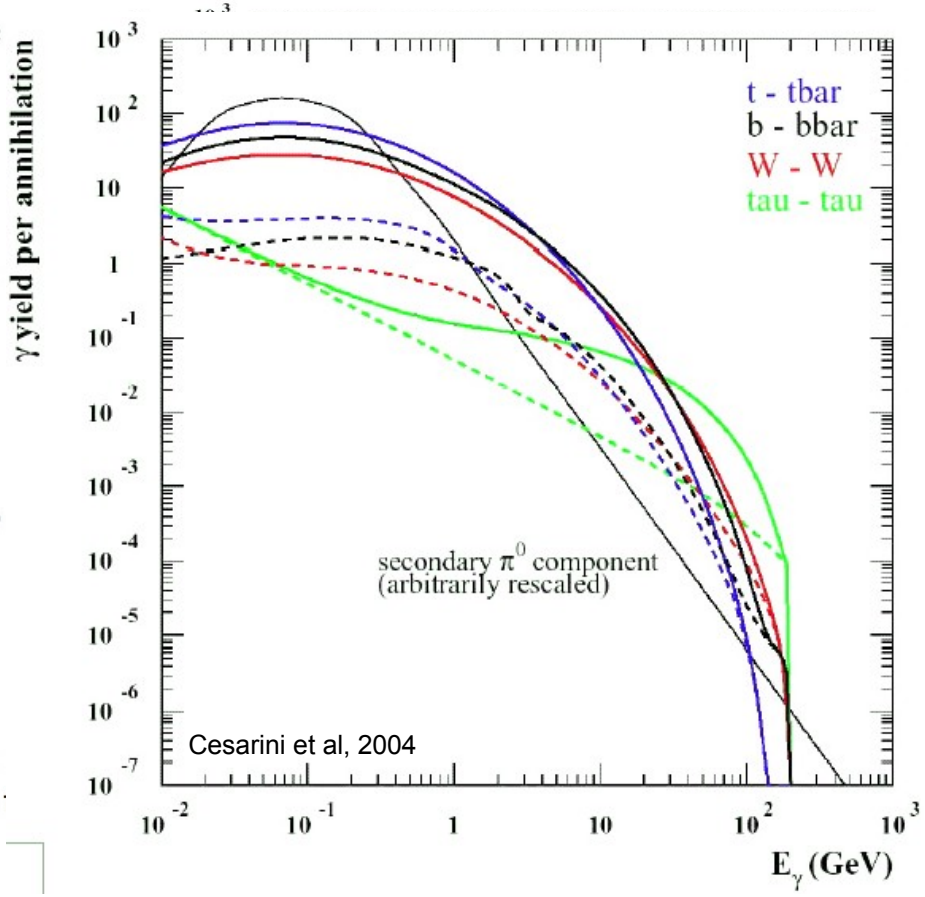
How the FERMI-LAT* telescope could help to disentangle the Dark Matter puzzle ?

Search Technique	advantages	challenges
Galactic center 	Good Statistics	Source confusion/ Diffuse background
Satellites, Subhalos, Point Sources 	Low background, Good source id	Low statistics
Milky Way halo 	Large statistics	Galactic diffuse background
Extra-galactic 	Large Statistics	Astrophysics, galactic diffuse background
Spectral lines 	No astrophysical uncertainties, good source id	Low statistics

E.A. Baltz et al. JCAP07 (2008) 013, arXiv:08062911

Sensitivity map for GC with FERMI

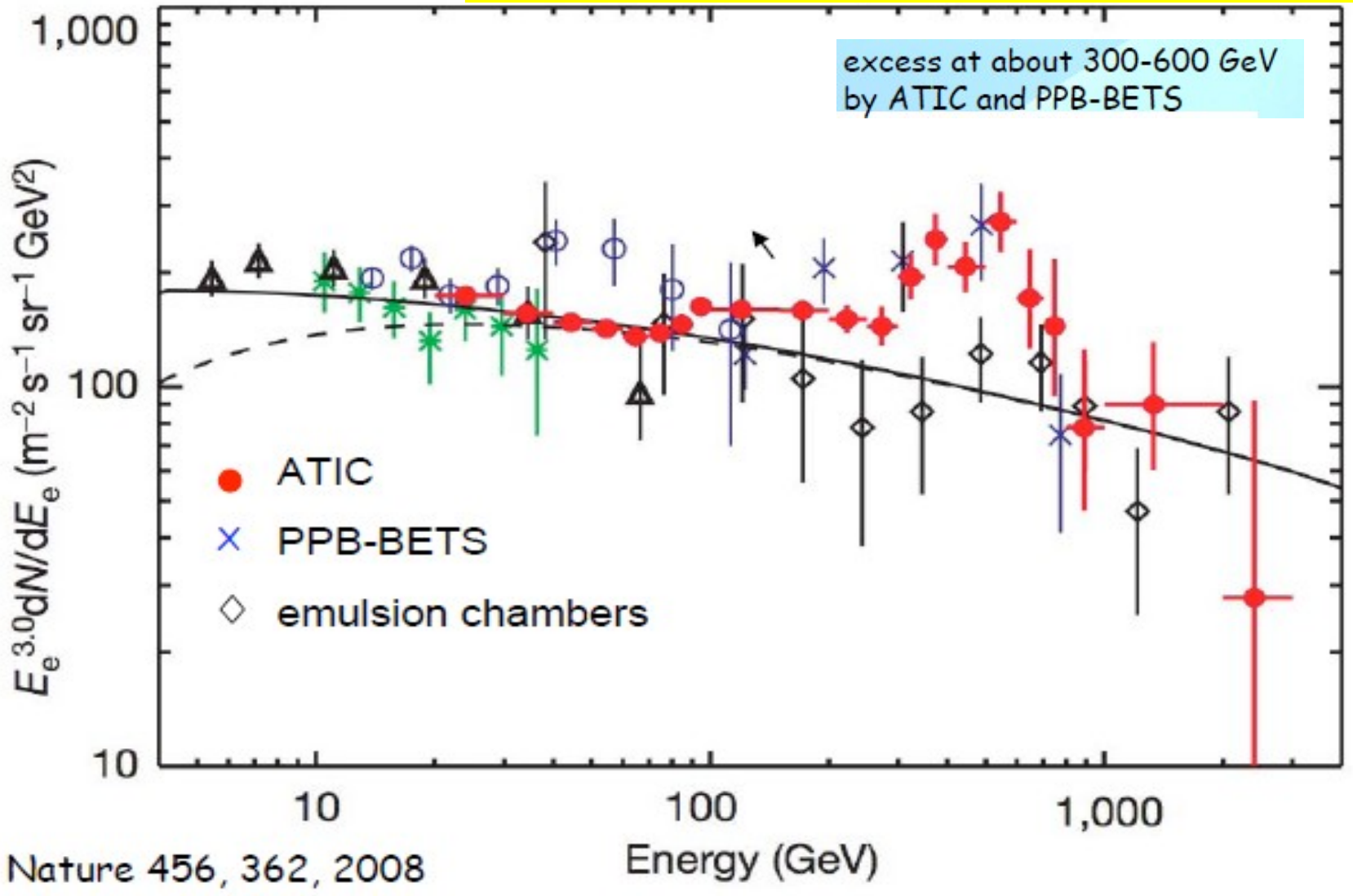




Others annihilating channels have been investigated : t-tbar, W W , τ τ , ...

electron + positron flux

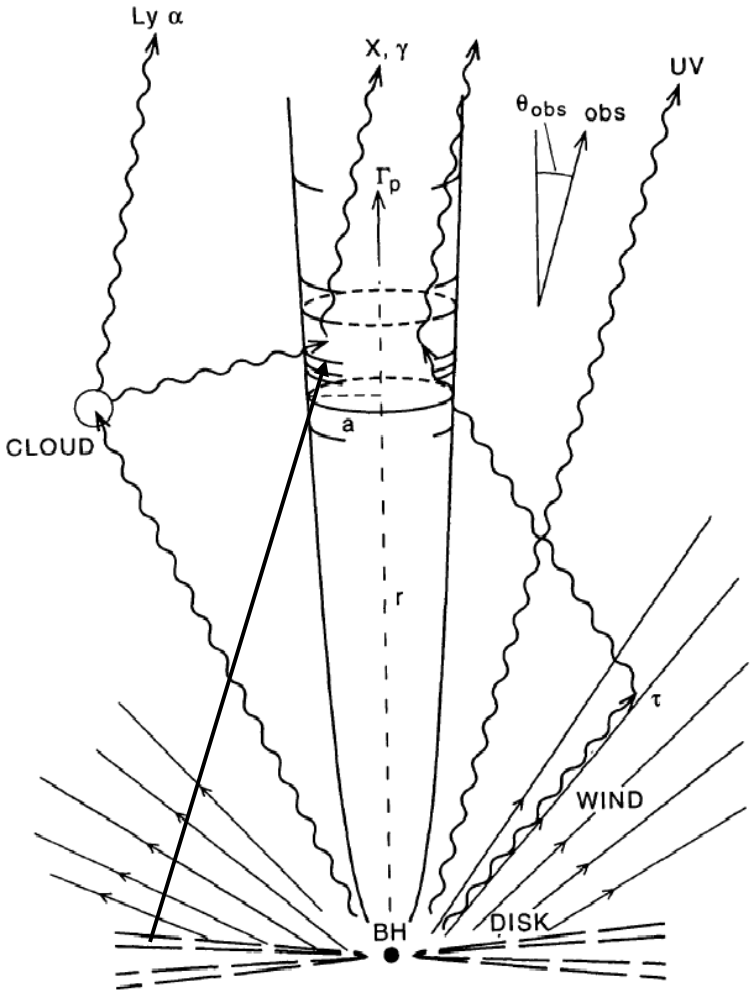
Fermi covers electrons energy measurements
20GeV-1000GeV



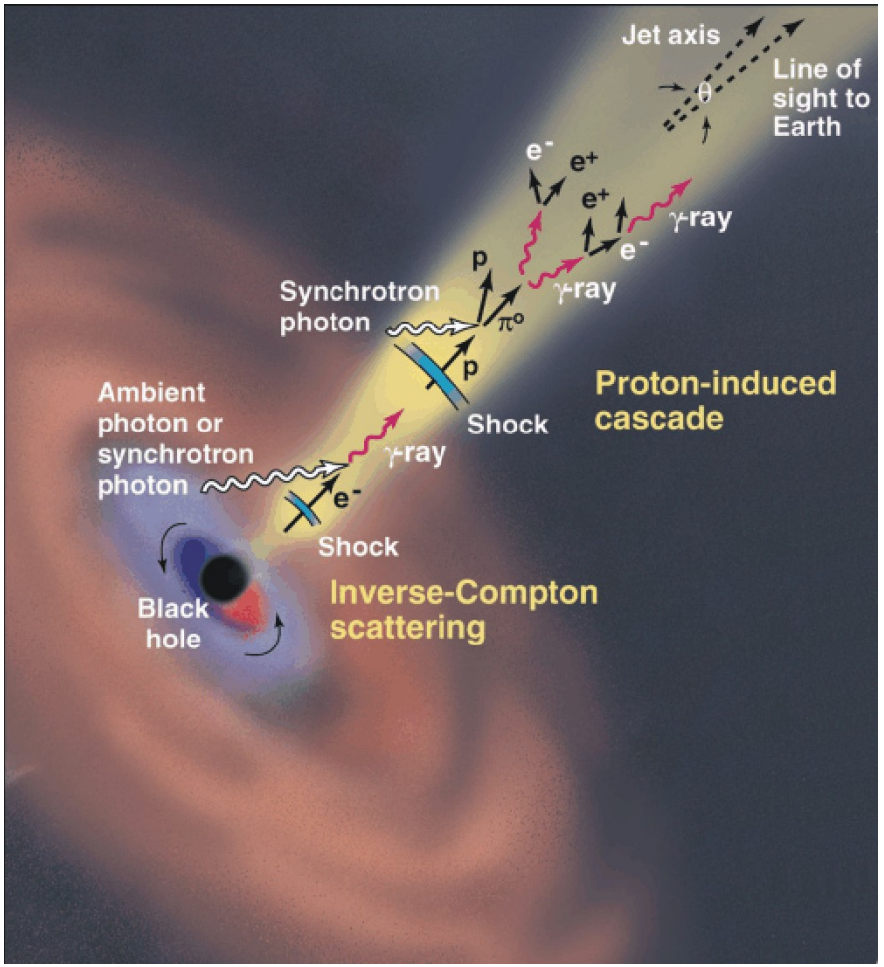
Big Questions From EGRET Era

- How and where do pulsars emit gamma rays? How common are radio-quiet pulsars?
  - necessary clue to magnetic field configurations and dynamics
- What are the EGRET Unidentified Sources?
  - most of the EGRET source identifications are a mystery
- What are the energy budgets of gamma-ray bursts? What are the temporal characteristics of the high-energy emission?
  - not well characterized yet, key tests of models.
- What are the origins of the diffuse emissions?
  - galactic: cosmic-ray and matter distributions; sources
  - extragalactic: populations
  - new sources (Dark Matter annihilations, clusters, …)
- How do the supermassive black hole systems of AGN work? Why do the jets shine so brightly in gamma rays?
  - temporal and spectral variability over different timescales
- What remains to be discovered with great new capabilities??
  - EGRET showed us the tip of the iceberg. New sources and probes for new physics.

Models of AGN Gamma-ray Production



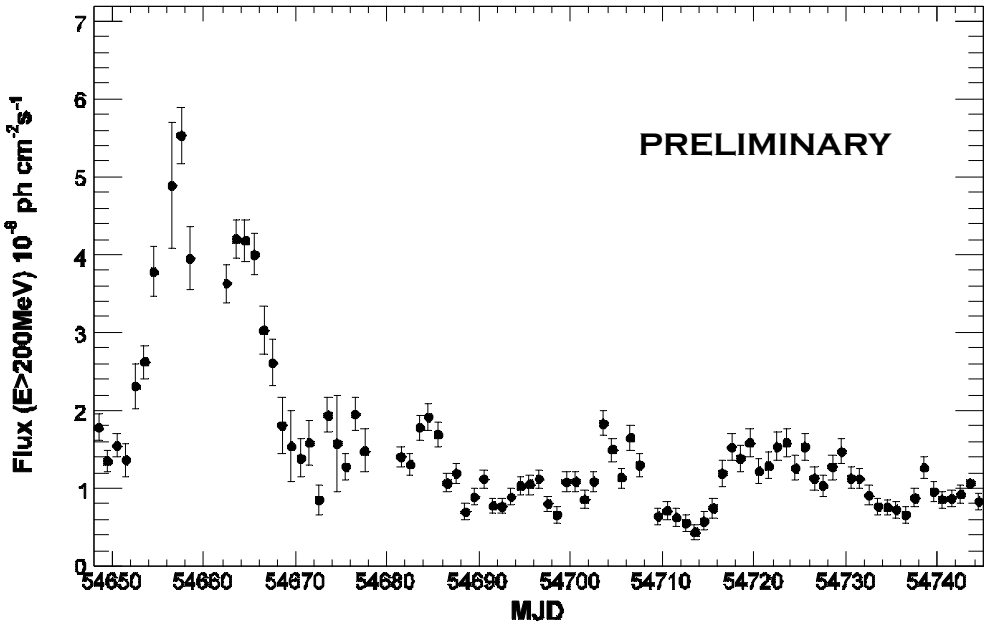
(from Sikora, Begelman, and Rees (1994))



(credit:J. Buckley)

3C454.3 with LAT

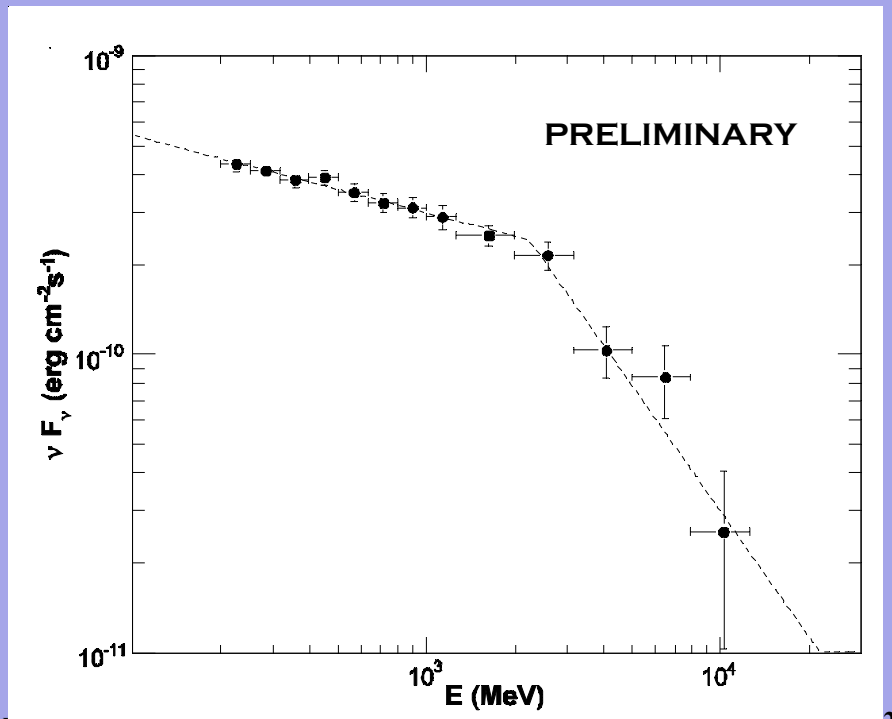
- Well-known radio source, identified with an OVV quasar at z = 0.859; also detected by EGRET, AGILE



- Not a simple power law

can describe as a broken power law with a

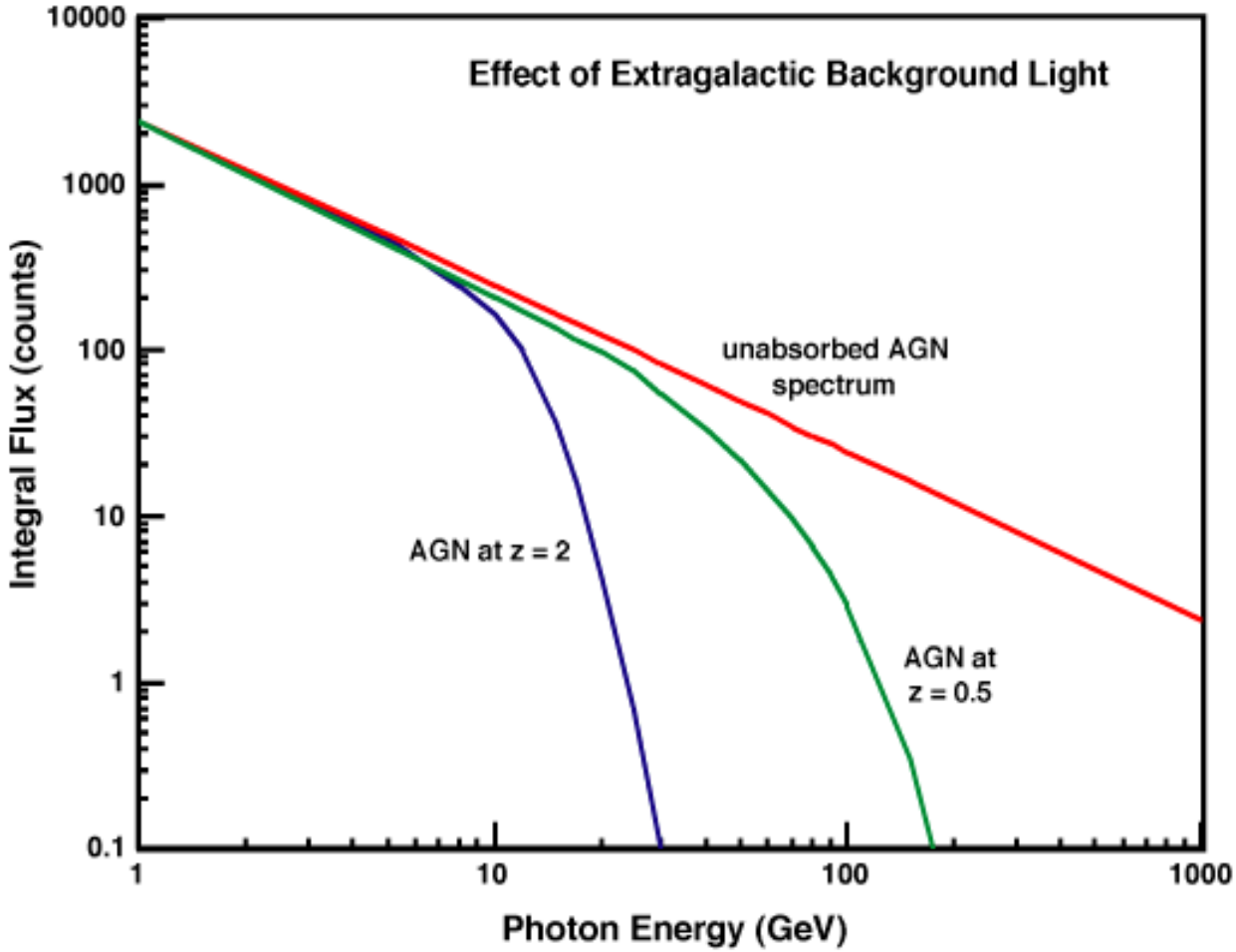
break, Γ1 ~ 2.3 to Γ2 ~3.5 at Ebr ~ 2 GeV



- Origin of the break?

LAT studies EBL cutoff

Probe history of star formation to z ~4 by determining spectral cutoff in AGN due to EBL



Summary

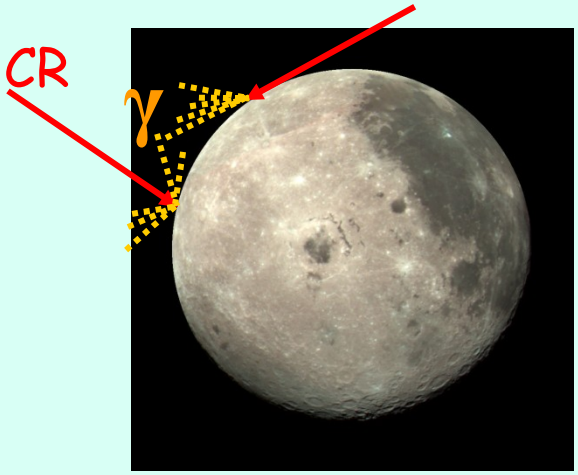
- **Fermi is off to a great start!**
  - Instruments are beautiful. The gamma-ray sky is keeping its promise. Great cooperation across the international team.
- **Already addressing many important questions from EGRET era**
  - new analysis techniques and approaches are essential -- new topics!
  - EGRET GeV excess excluded
  - Many variable sources discovered
  - Many pulsars discovered
  - the challenge of great discovery potential

Sign up for newsletters:
http://fermi.gsfc.nasa.gov/ssc/resources/newsletter/

Extra slides

Sources in Solar System

"γ-ray albedo" due to CR interactions with surface material



Moving sources:

The Moon (albedo)

The Sun (albedo + inverse Compton)

The Earth

Potential Sources:

Asteroids in different populations:

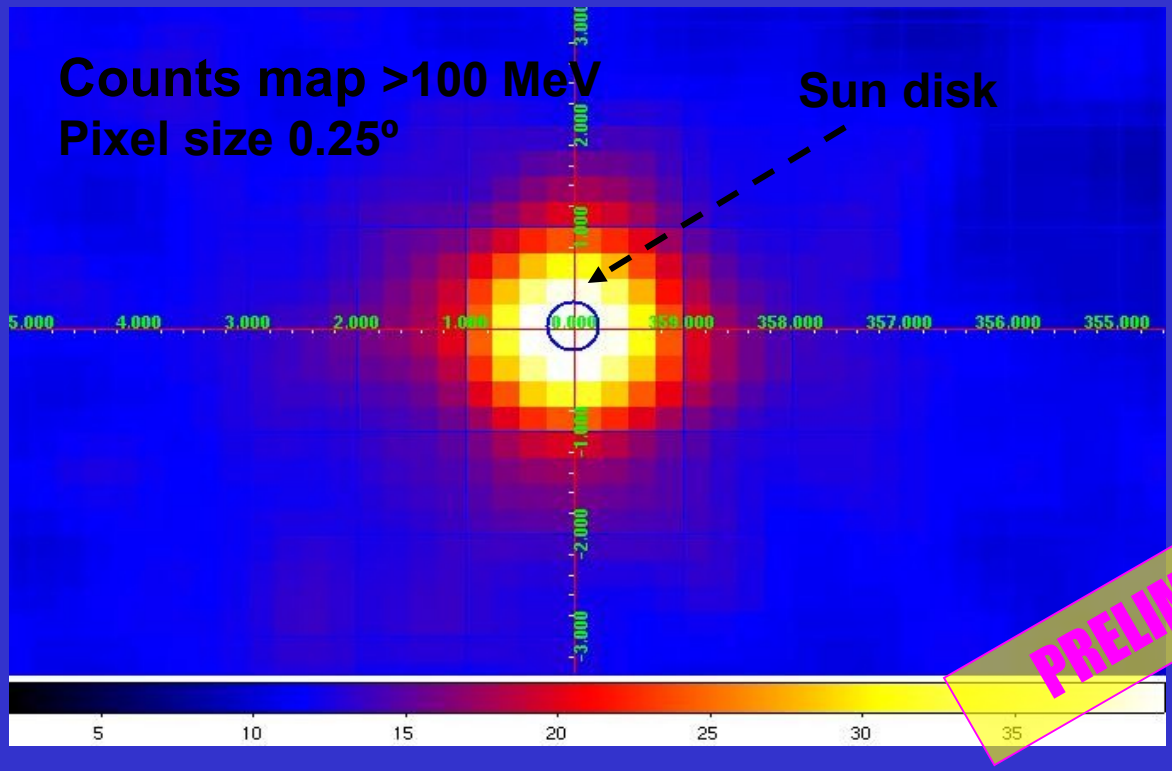
Main Asteroid Belt (MBAs)

Jovian and Neptunian Trojans (Trojans)

Kuiper Belt Objects (KBOs)

Other planets

The Quiet Sun: first 6 months of observation



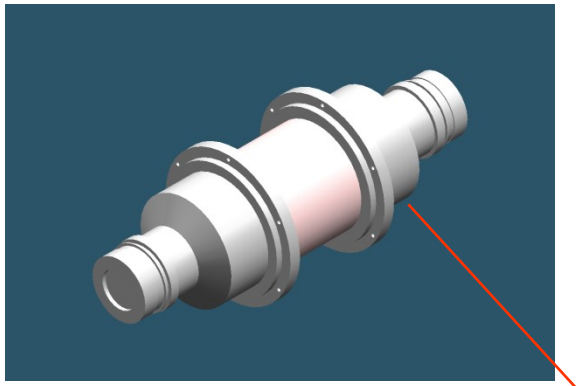
Source Flux (>100 MeV) ~ 4x10 cm s (albedo+IC, preliminary)

Expected IC Flux (>100 MeV) ~ 4.3x10 cm s (@ solar min, IM+'06)

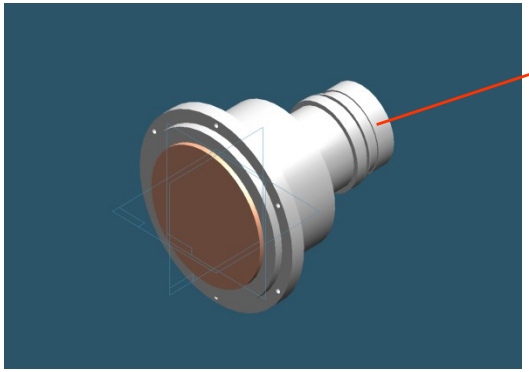
GBM Detector

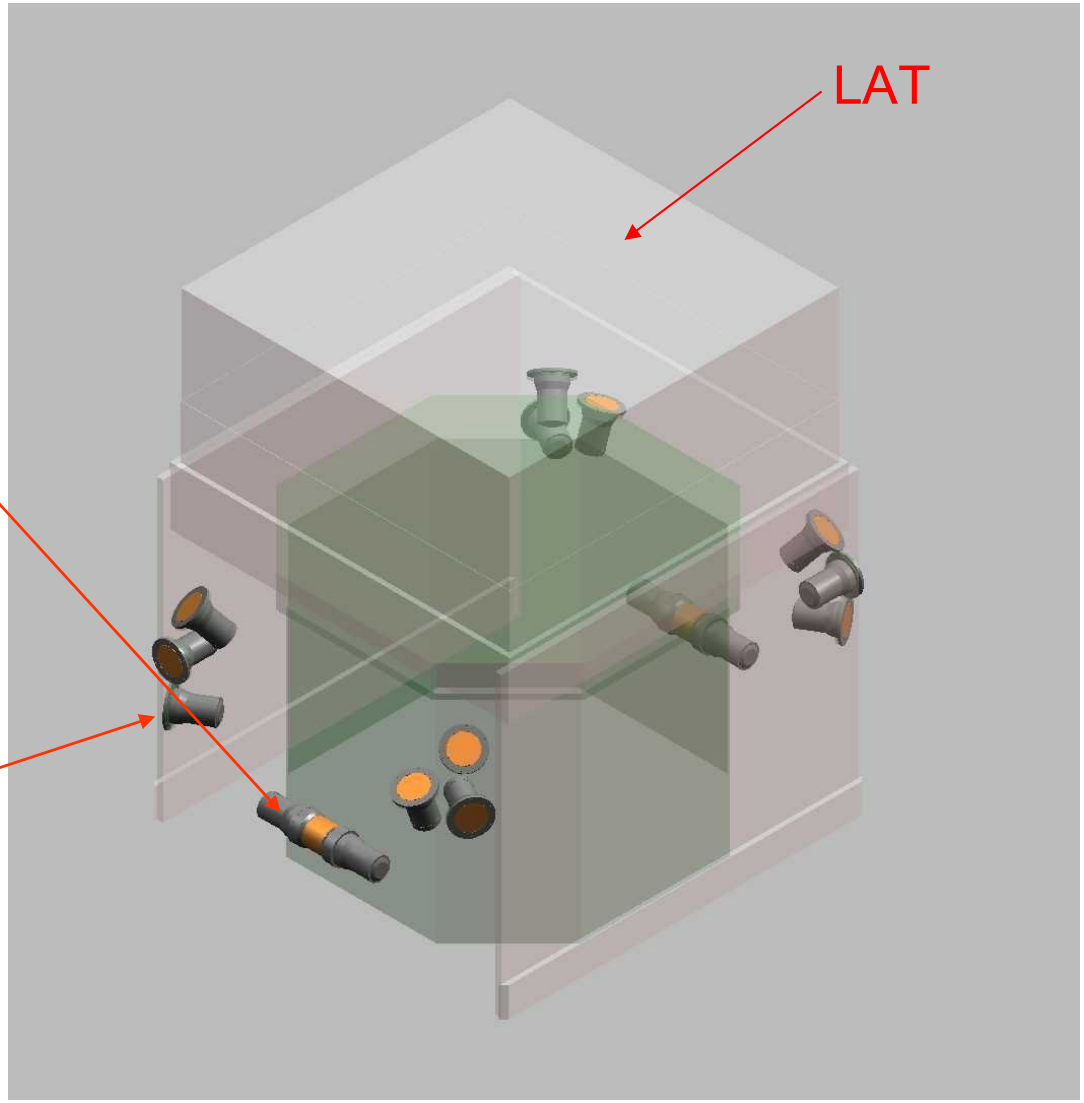
MSFC, MPE PI: Chip Meegan

Bismuth Germanate (BGO) Scintillation Detector

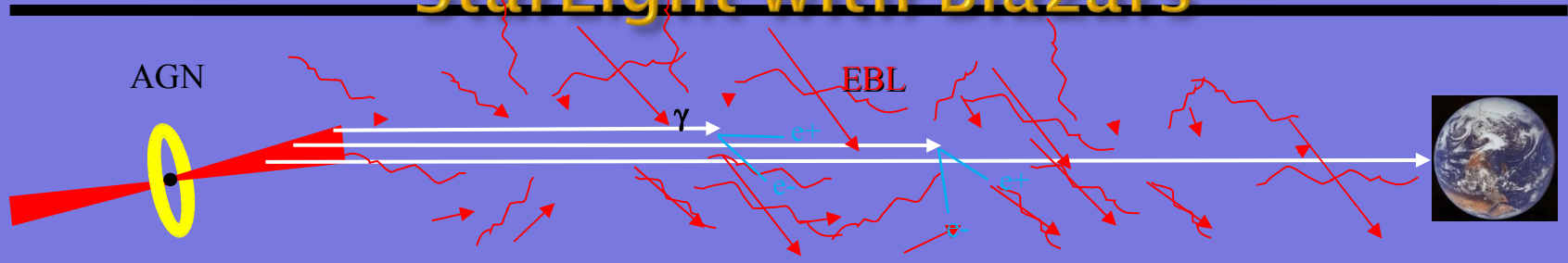


(12) Sodium Iodide (NaI) Scintillation Detectors

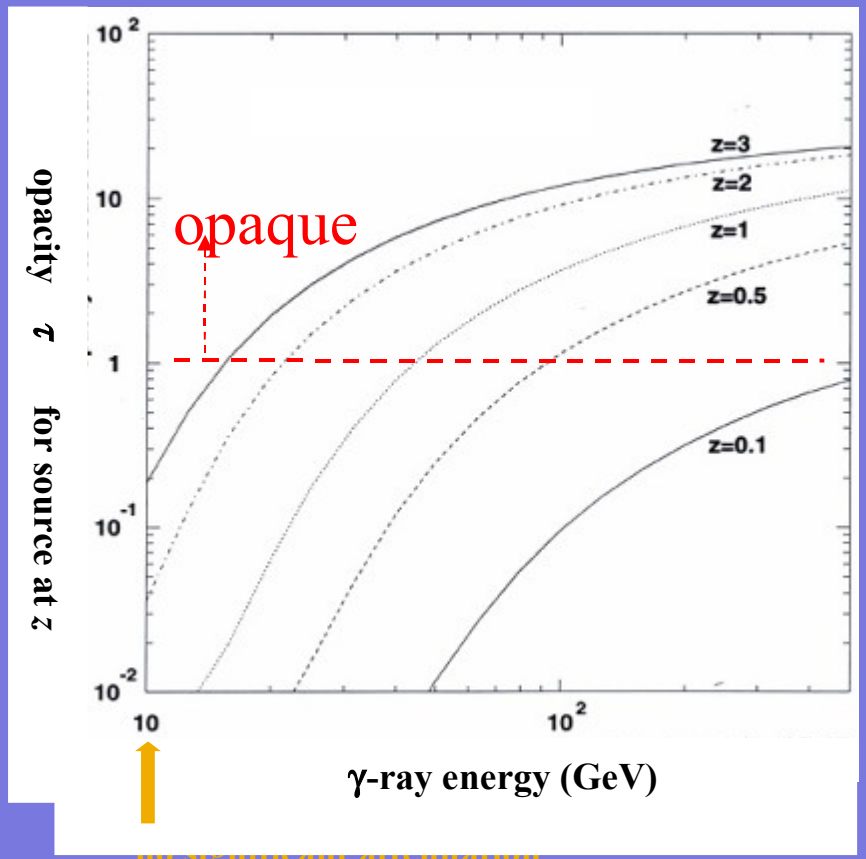




Probing Extragalactic Background StarLight with Blazars



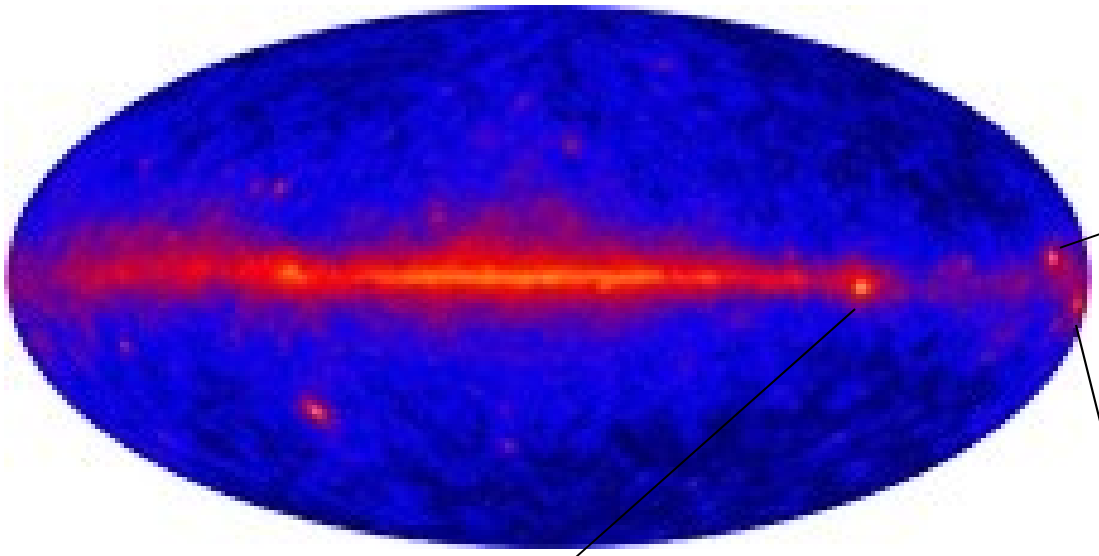
- *diffuse EBL contains unique information about the epochs of formation and the evolution of galaxies and in what environments the stars of the universe formed*
- *direct EBL measurements require accurate model-based subtraction of bright foregrounds (e.g., zodiacal light)*
- *alternative approach: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



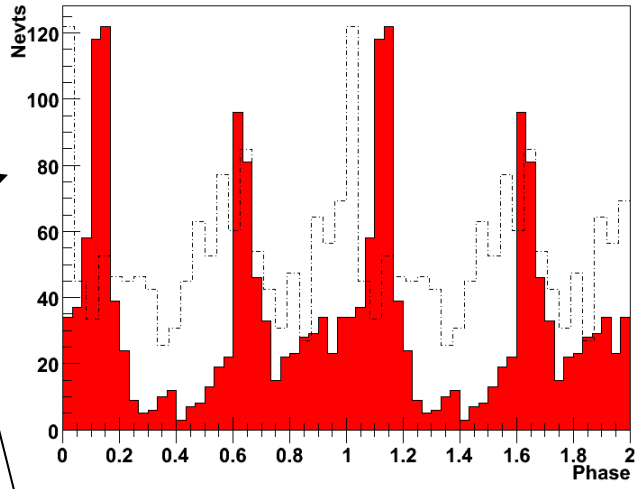
+ -

$\gamma\gamma \rightarrow e\ e$, *maximum when*
EBL

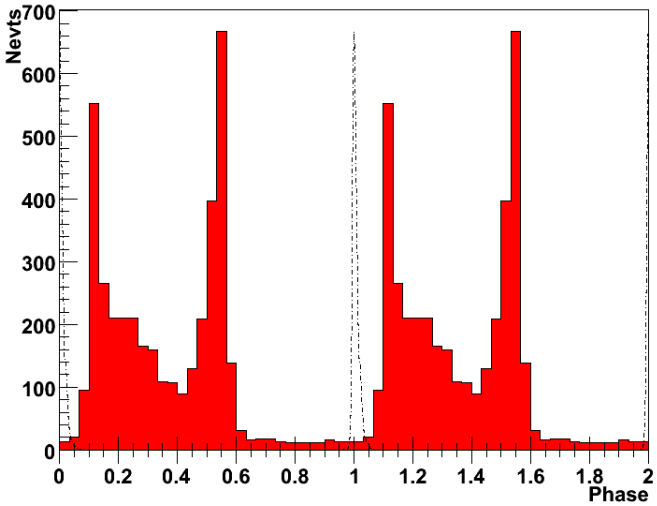
Pulsars (using early engineering data)



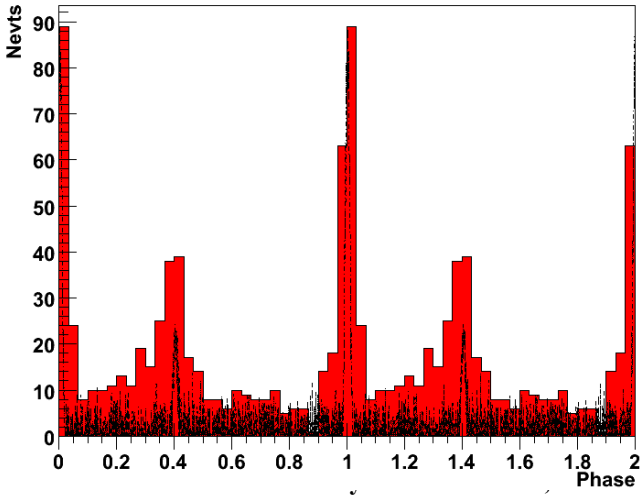
Geminga: P=237 ms



Vela: P=89.3 ms



Crab: P =33 ms



Solar system sources

- Quiet Sun and Moon contribute to the diffuse background
- Sun is now at the minimum solar activity but going to increase its activity: search for Solar flares, studies in connection with other observatories
- FERMI will operate during the entire 24 solar cycle

LAT First Year Source Monitoring List

http://fermi.gsfc.nasa.gov/ssc/data/policy/LAT_Monitored_Sources.html

Light curves (daily and weekly integrations) in energy bands.

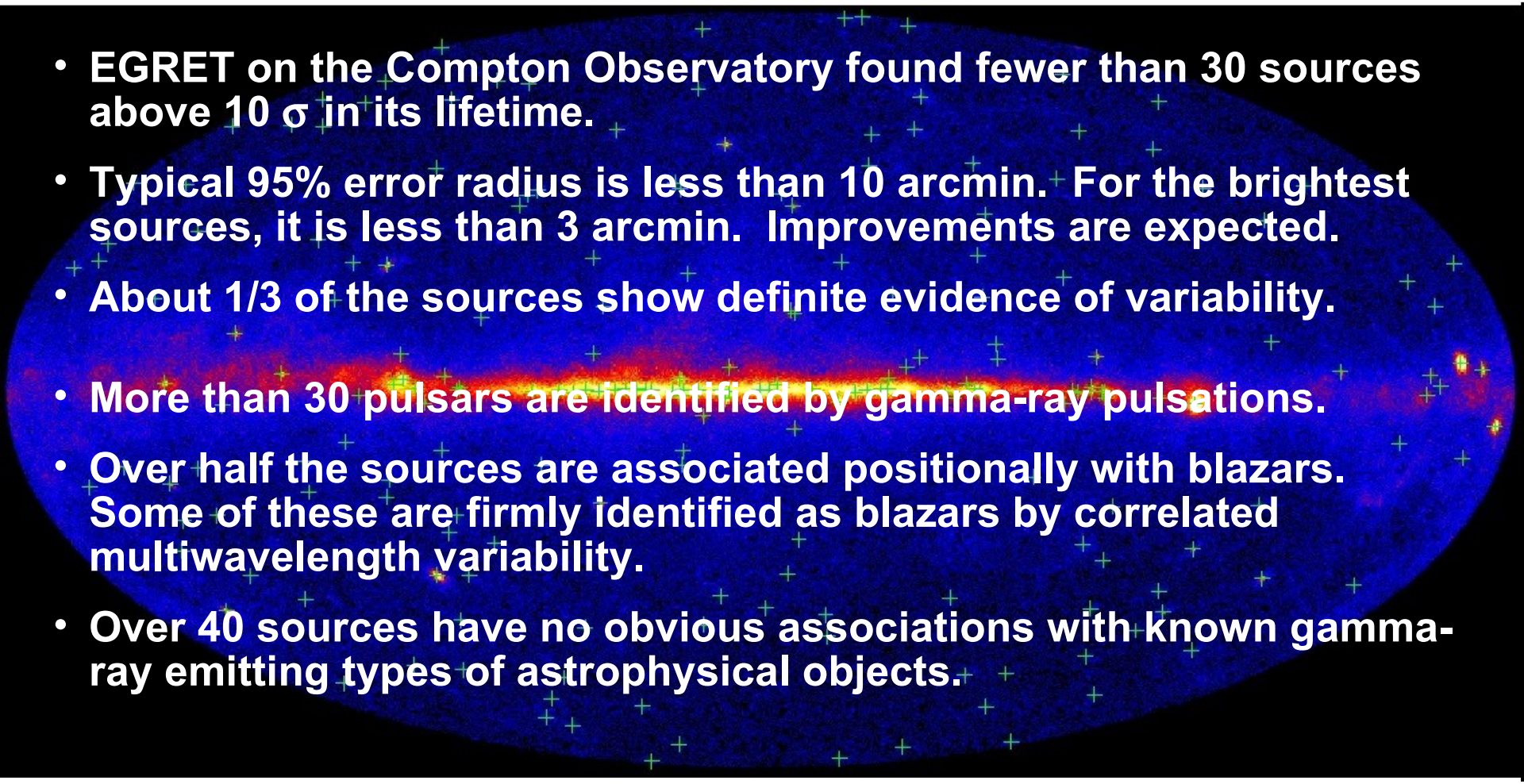
PLUS, same for any source flaring above 2e-6 ph/cm^2/s until the flux drops below 2e-7 ph/cm^2/s (two additional sources thus far: PKS 1454 and PKS 1502)

A "quicklook" analysis to get the results out as soon as possible. Tables may be updated as analysis and calibrations improve.

Source Type	Source Name	EGRET Name	Average or Min. Flux (10^{-8} γ $cm^{-2}s^{-1}$)	Galactic Lattitude	Redshift	TeV Source
Blazar	0208-512	3EGJ0210-5055	85.5 ± 4.5	-61.9	1.003	
	0235+164	3EGJ0237+1635	65.1 ± 8.8	-39.1	0.94	
	PKS 0528+134	3EGJ0530+1323	93.5 ± 3.6	-11.1	2.060	
	PKS 0716+714	3EGJ0721+7120	17.8 ± 2.0	28	0.3	
	0827+243	3EGJ0829+2413	24.9 ± 3.9	31.7	0.939	
	OJ 287	3EGJ0853+1941	10.6 ± 3.0	35.8	0.306	
	Mrk 421	3EGJ1104+3809	13.9 ± 1.8	65.0	0.031	Yes
	W Com 1219+285	3EGJ1222+2841	11.5 ± 1.8	83.5	0.102	
	3C 273	3EGJ1229+0210	15.4 ± 1.8	64.5	0.158	
	3C 279	3EGJ1255-0549	74.2 ± 2.8	57.0	0.538	
	1406-076	3EGJ1409-0745	27.4 ± 2.8	50.3	1.494	
	H 1426+428	NA		64.9	0.129	Yes
	1510-089	3EGJ1512-0849	18.0 ± 3.8	40.1	0.36	
	PKS 1622-297	3EGJ1625-2955	47.4 ± 3.7	13.4	0.815	
	1633+383	3EGJ1635+3813	58.4 ± 5.2	42.3	1.814	
	Mrk 501	NA		38.9	0.033	Yes
	1730-130 NRAO 530	3EGJ1733-1313	36.1 ± 3.4	10.6	0.902	
	1ES 1959+650	NA		17.7	0.048	Yes
	PKS 2155-304	3EG2158-3023	13.2 ± 3.2	-52.2	0.116	Yes
	BL_Lacertae (2200+420)	3EGJ2202+4217	39.9 ± 11.6	-10.4	0.069	Yes
	3C 454.3	3EGJ2254+1601	53.7 ± 4.0	-38.3	0.859	
	1ES 2344+514	NA		-9.9	0.044	Yes
HMXB	LSI+61 303 2CG135+01	3EGJ0241+6103	69.3 ± 6.1	1.0		Yes

205 Preliminary LAT Brightest Sources

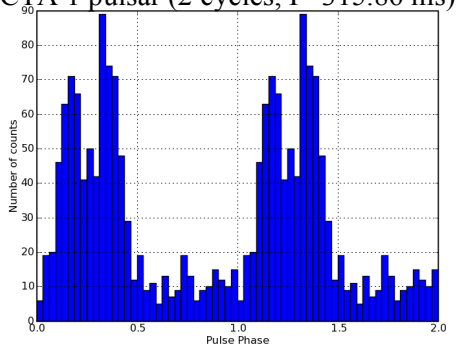
- EGRET on the Compton Observatory found fewer than 30 sources above 10 σ in its lifetime.
- Typical 95% error radius is less than 10 arcmin. For the brightest sources, it is less than 3 arcmin. Improvements are expected.
- About 1/3 of the sources show definite evidence of variability.
- More than 30 pulsars are identified by gamma-ray pulsations.
- Over half the sources are associated positionally with blazars. Some of these are firmly identified as blazars by correlated multiwavelength variability.
- Over 40 sources have no obvious associations with known gamma-ray emitting types of astrophysical objects.



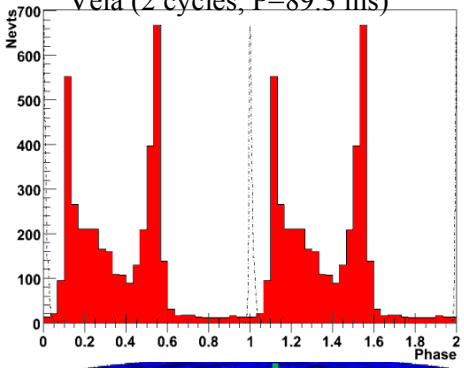
Crosses mark source locations, in Galactic coordinates.

A list, not a catalog!

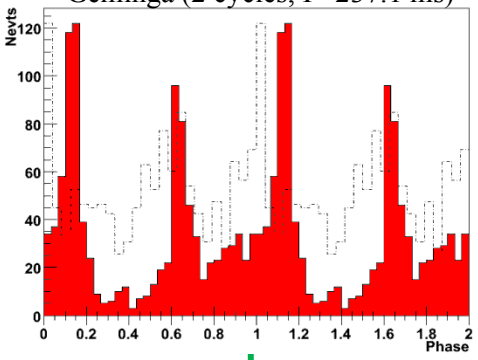
CTA 1 pulsar (2 cycles, P=315.86 ms)



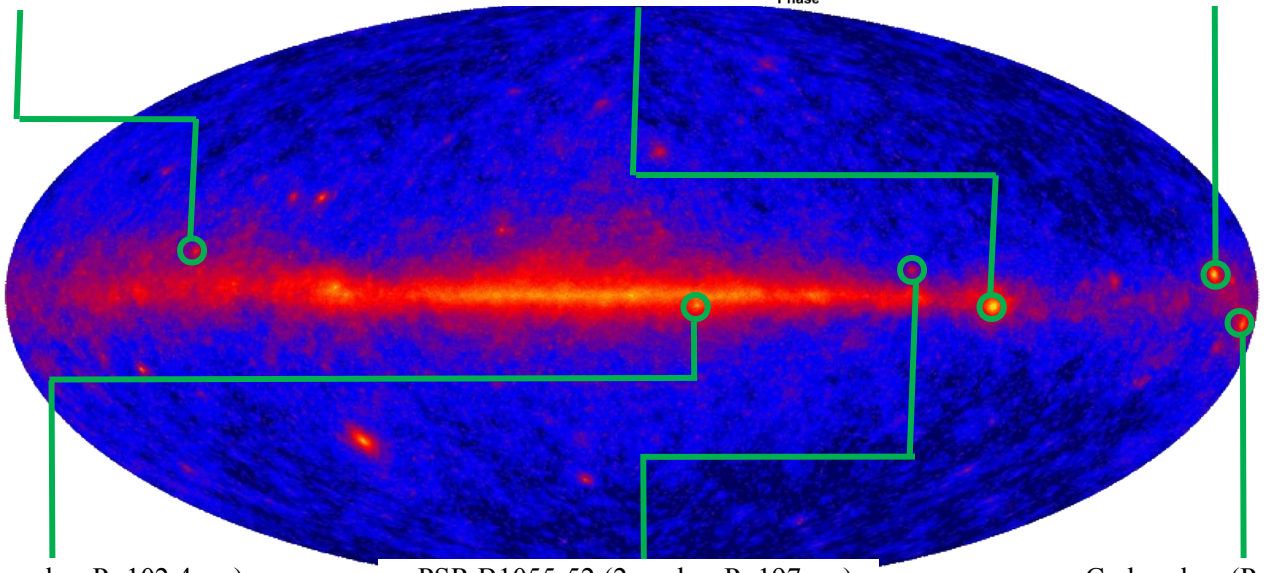
Vela (2 cycles, P=89.3 ms)



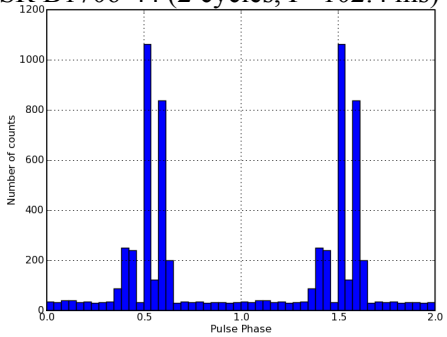
Geminga (2 cycles, P=237.1 ms)



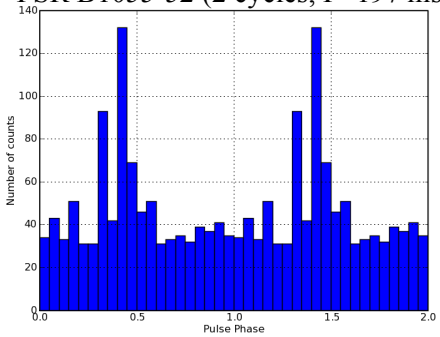
CTA 1:
Abdo, et al.,
Science Express,
Oct 2008



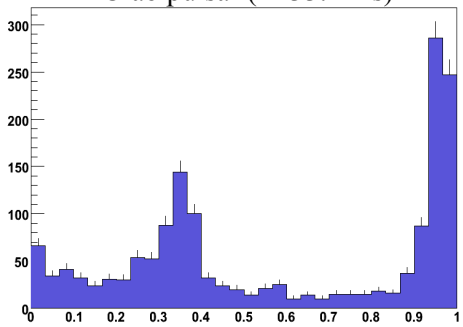
PSR B1706-44 (2 cycles, P=102.4 ms)



PSR B1055-52 (2 cycles, P=197 ms)



Crab pulsar (P=33.4 ms)



Gamma-Ray Bursts observed by LAT

LAT has reported 3 high-energy bursts since launch

long-duration bursts

GRB 080825C: Fermi-LAT observations

SOURCE: GCN
TITLE: GCN CIRCULAR
NUMBER: 8183
SUBJECT: GRB 080825C: Fermi-LAT observations
DATE: 08/09/05 17:45:46 GMT
FROM: Aurelien Bouvier at Stanford <bouvier@stanford.edu>

GRB 080916C: Fermi LAT observation — Tajima et al. GCN 8246

SOURCE: GCN
TITLE: GCN CIRCULAR
NUMBER: 8246
SUBJECT: GRB 080916C: Fermi LAT observation
DATE: 08/09/16 18:25:23 GMT
FROM: Nicola Omodei at INFN(Pisa)/GLAST
<nicola.omodei@pi.infn.it>

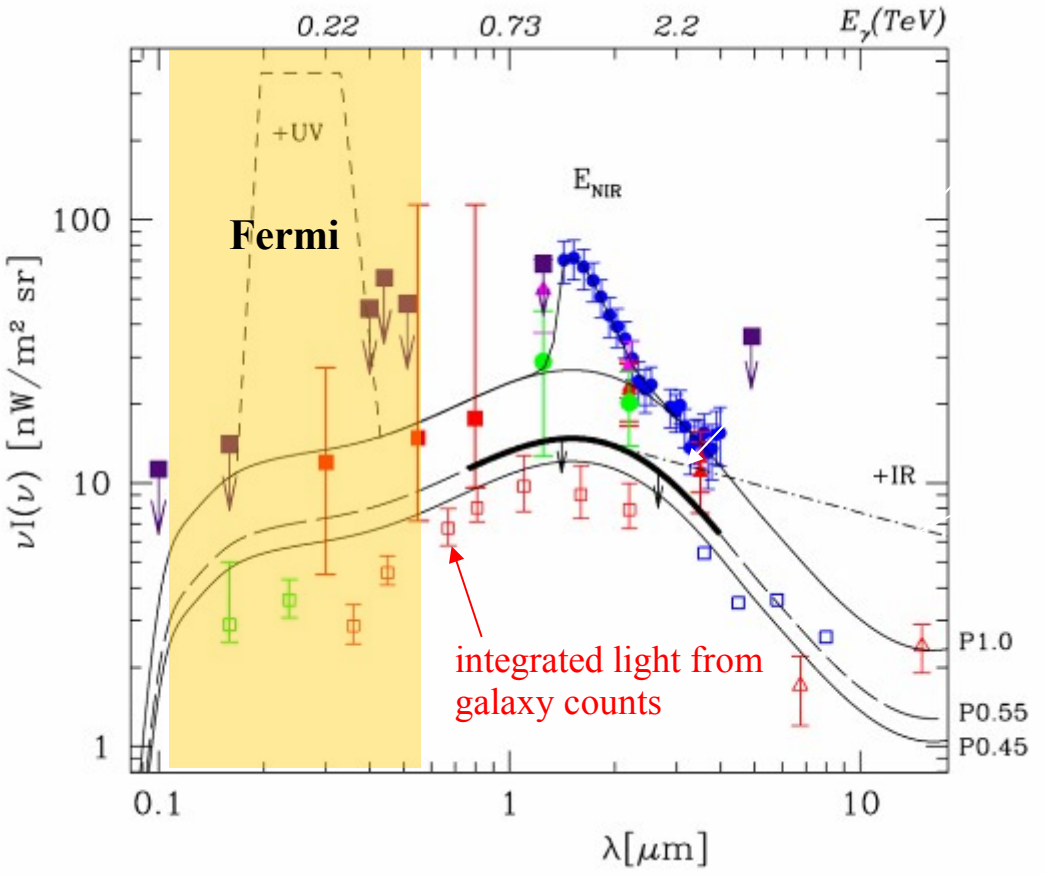
First detection of short-duration burst at high energy

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>

Blazar constraints on EBL

EBL spectral energy distribution



HESS upper limit derived from observed hard spectra of blazars at z = 0.165 and 0.186

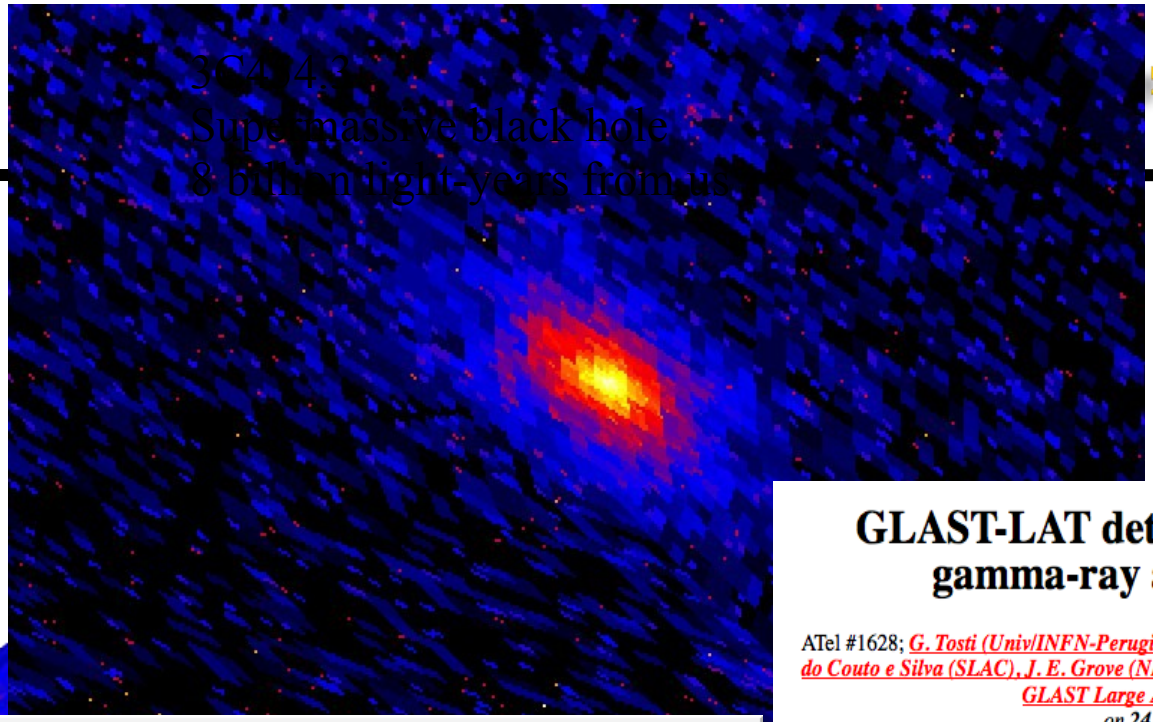
reference EBL SED, matches direct measurements at 2.2 and 3.5 μm.

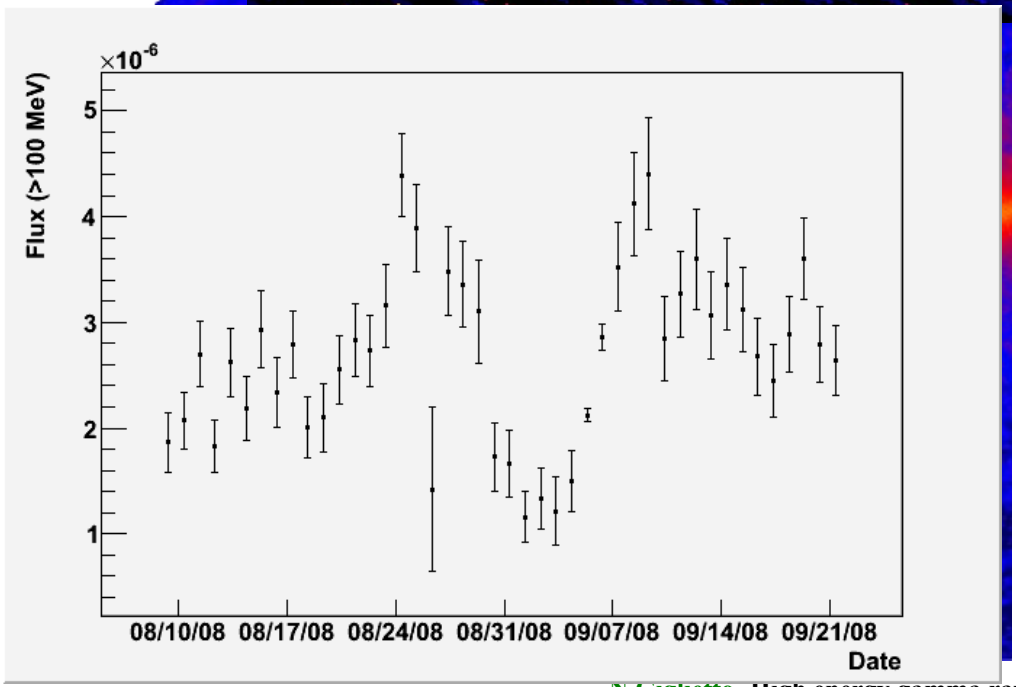
important science for VERITAS, HESS, Magic, and *Fermi*

- lower limits on HST galaxy counts combined with HESS upper limit on EBL imply that any unresolved component is no more than ~1/3 of the total.

Fermi Gamma-ray Space Telescope

' map





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.

Constructing the LAT Bright Source List

- First three months of all-sky scanning data, Aug. - Oct. 2008.
- Maximum likelihood analysis.

Pulsar emission

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

$E = \frac{1}{2} I \Omega$

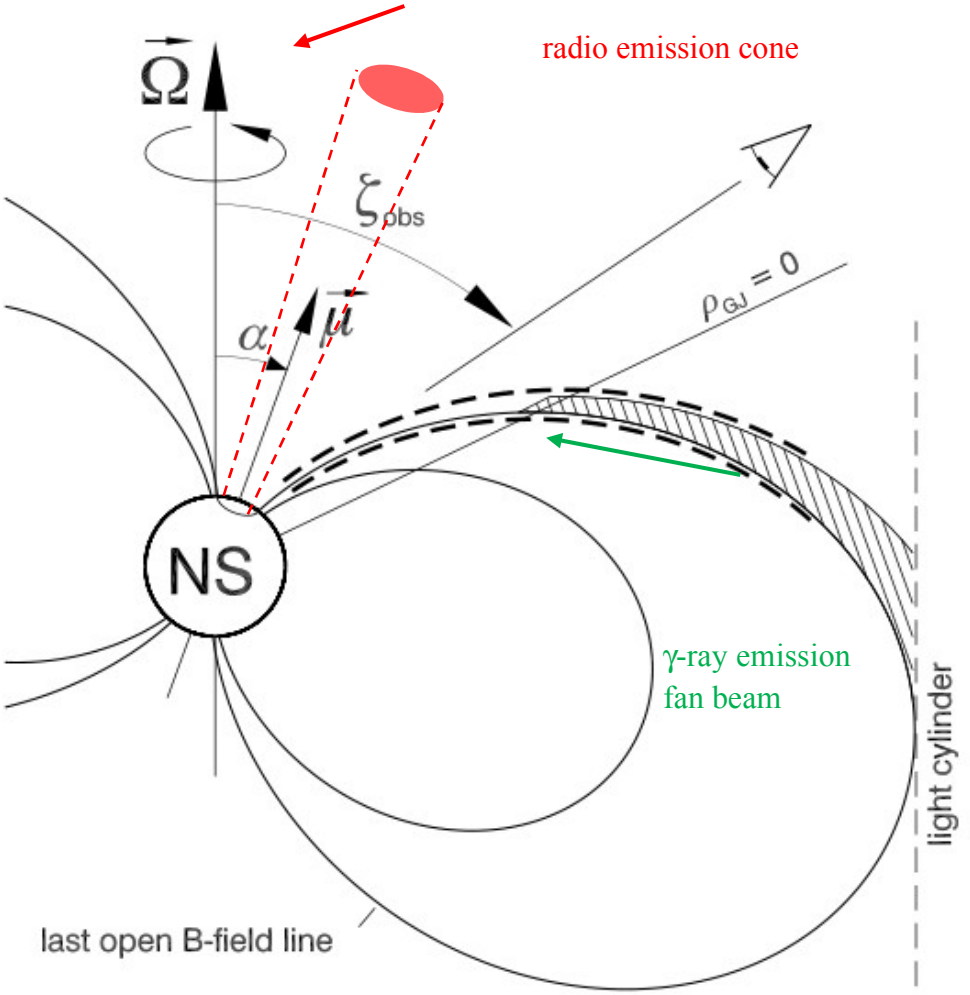
$\dot{E}_{rot} = -B R \Omega / c$

derived parameters:

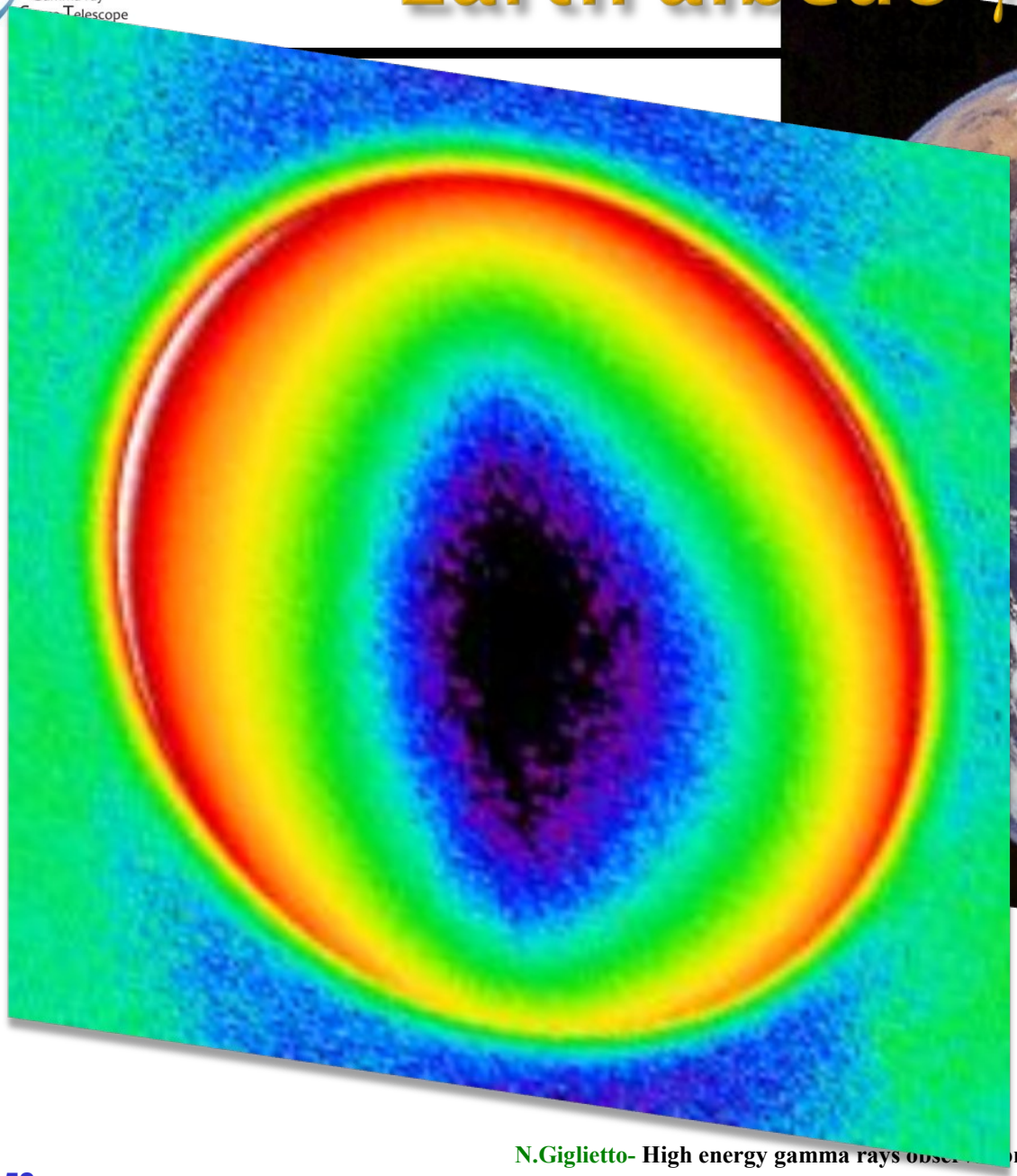
rotational age : $\tau = \Omega/2\dot{\Omega}$

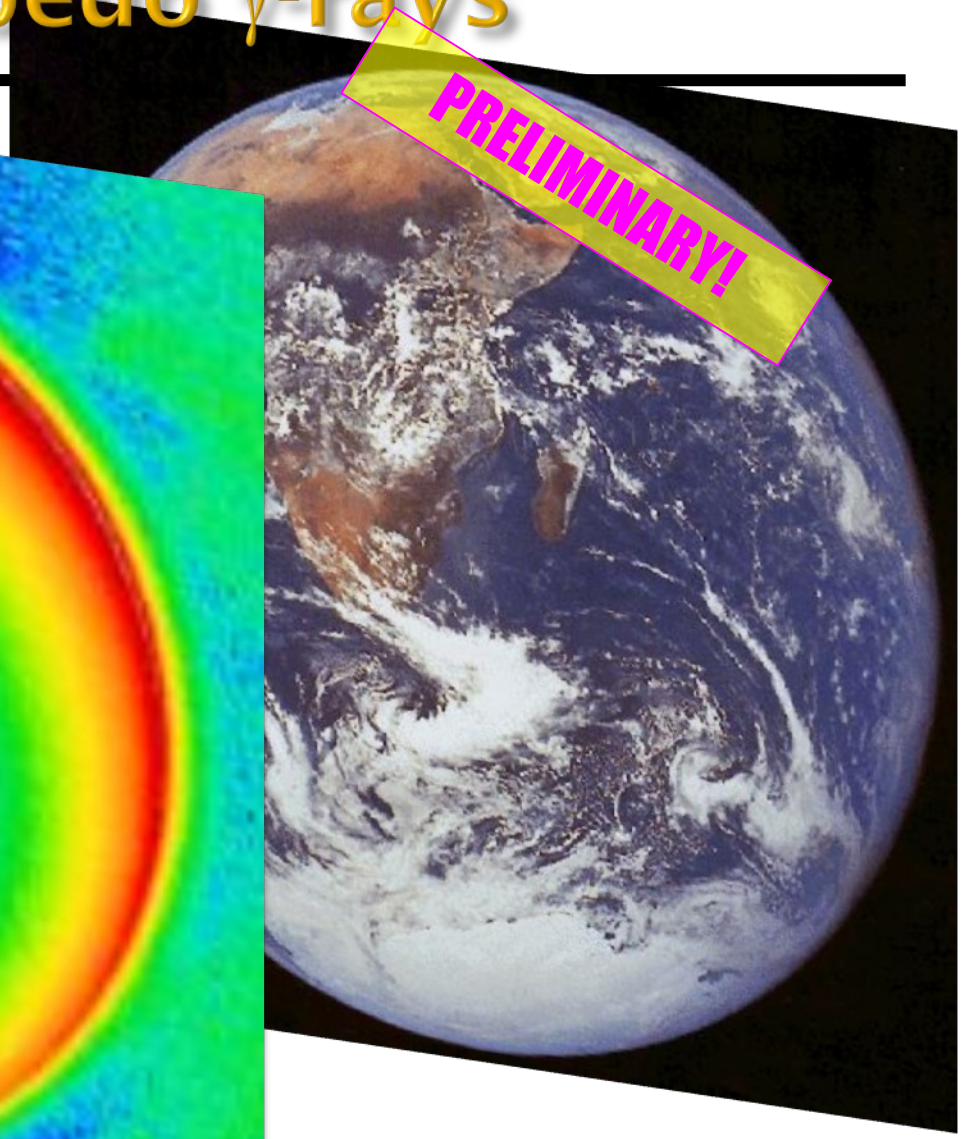
B field: $B = 3.2x10$

(PP) G



Earth albedo γ-rays





The interstellar medium

Interstellar gas

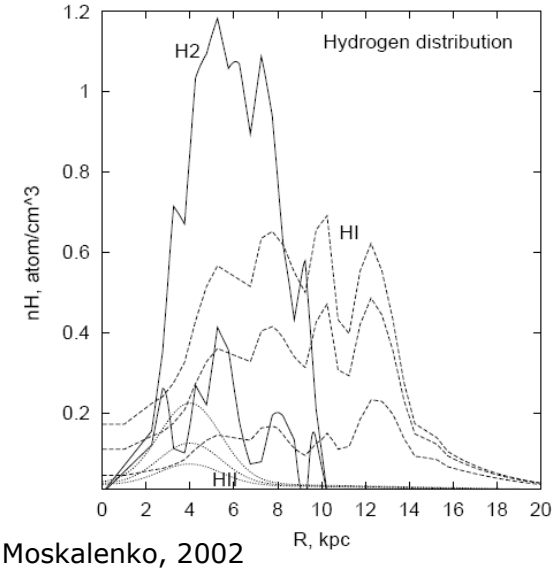
Atomic hydrogen (HI)

Column density and spatial distribution from 21cm line measurement

Molecular hydrogen (H_2)

Column density and spatial distribution from 2.6mm CO 1→0 transition measurement

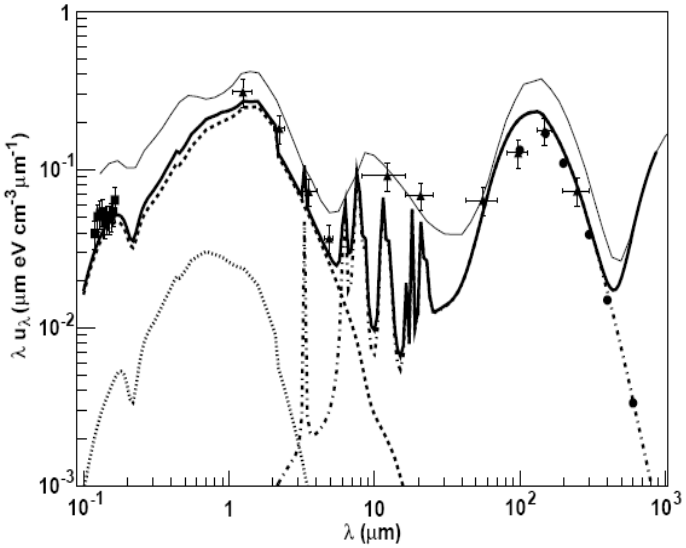
CO->H conversion via X factor



Moskalenko, 2002

Ionized hydrogen (HII)

Small contribution but scale height ~ 1 kpc → present at higher latitudes



Interstellar radiation field

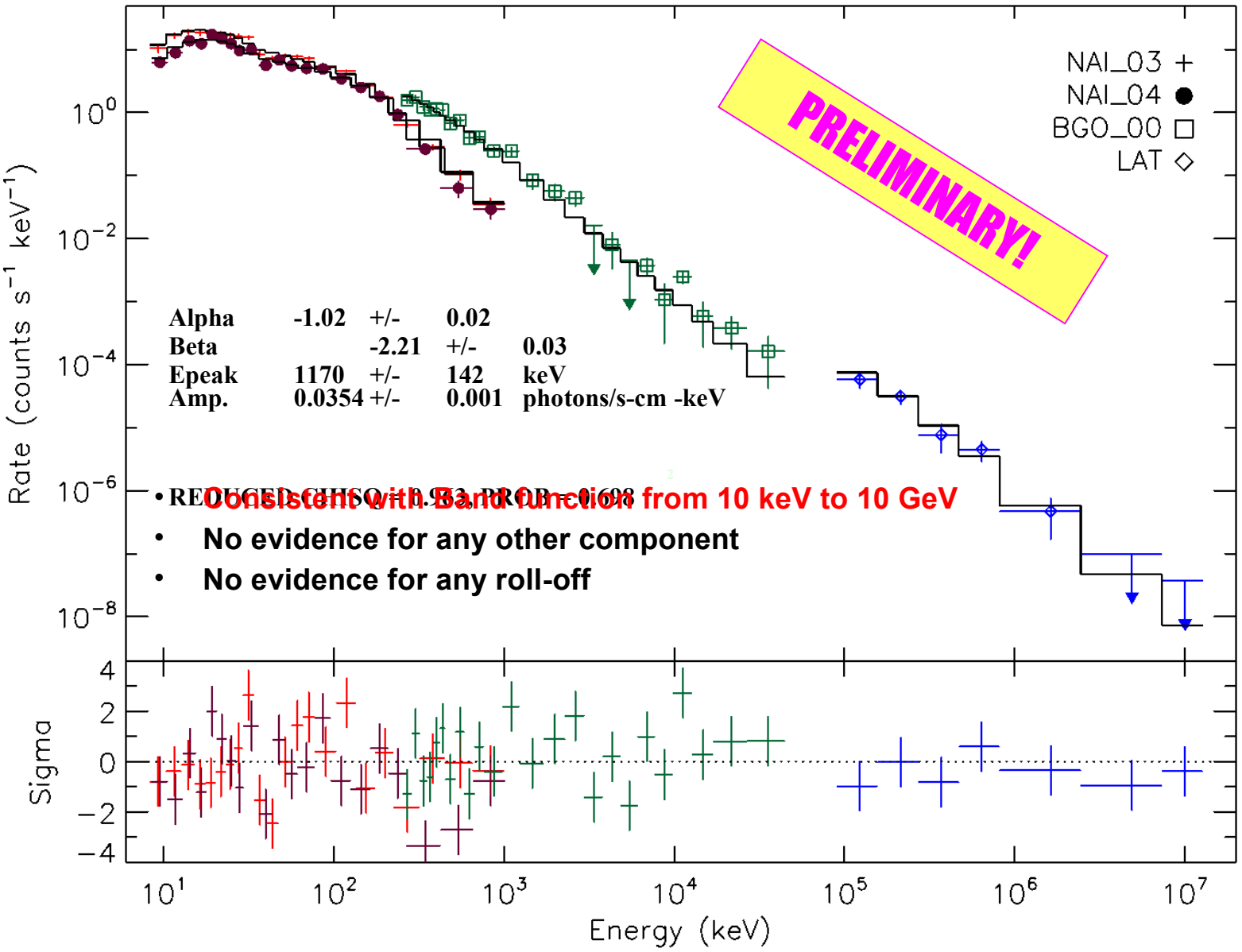
Starlight (~ 0.1 um – 10 um)

Dust (~ 10 um – 300 um)

Cosmic Microwave Background

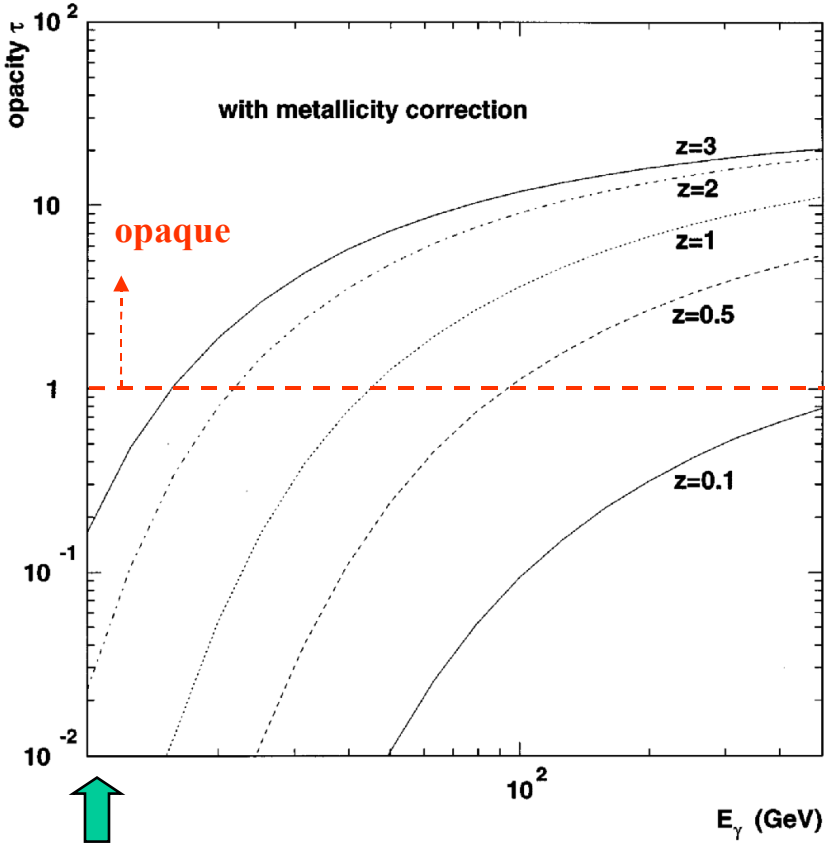
Moskalenko, Porter & Strong, 2006

GRB080916C Spectroscopy of the Main LAT peak



AGN &EBL Studies

Photons with E>10 GeV are attenuated by the diffuse field of UV-Optical-IR extragalactic background light (EBL)



EBL over cosmological distances is probed by gammas in the 10-100 GeV range. Important science for GLAST!

In contrast, the TeV-IR attenuation results in a flux that may be limited to more local (or much brighter) sources.

Millisecond pulsars detected by *Fermi*

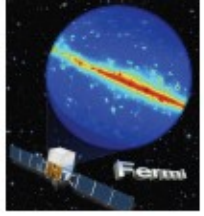
PULSAR	PERIOD (ms)	PERIOD DERIV. (10^{-20} s/s)	D (kpc)	Edot (erg/s)	# PHOTONS	H-TEST TS	CHANCE PROB
J0030+0451	4,86	1	0,32	3,44E+33	361	306,8	< 4e-08
J0218+4232	2,32	7,74	3,2	2,44E+35	455	12	0,01
J0437-4715	5,76	5,73	0,15	1,18E+34	166	89,1	< 4e-08
J0613-0200	3,06	0,96	0,48	1,32E+34	549	60	< 4e-08
J1024-0719	5,16	1,85	0,53	5,31E+33	135	14	0
J1744-1134	4,07	0,89	0,48	5,21E+33	1014	25,1	5,04E-05
J2124-3358	4,93	2,1	0,25	6,91E+33	277	57,7	< 4e-08

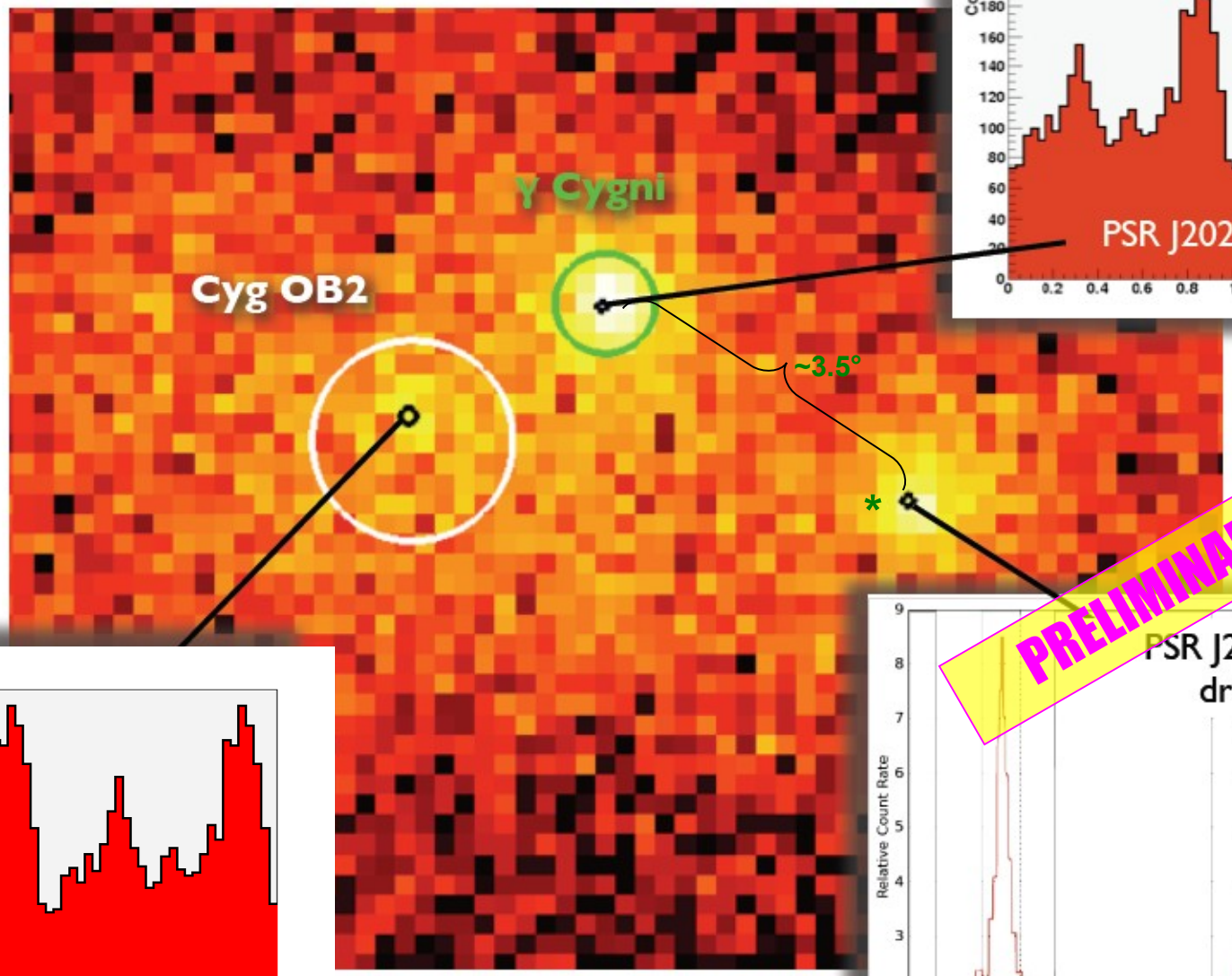
Which kind of MSP? The far, high Edot, and the close, intermediate Edot MSPs are detected.

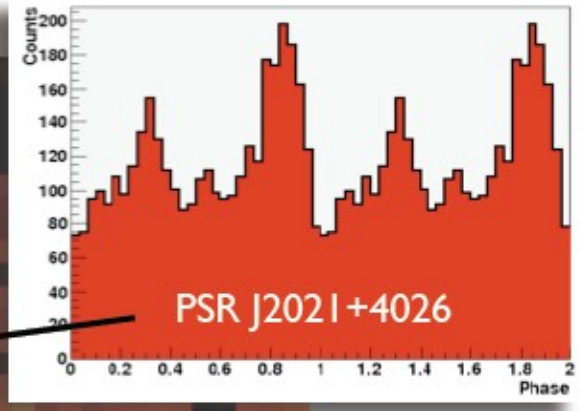
=> high spin-down flux MSPs (Edot / d)

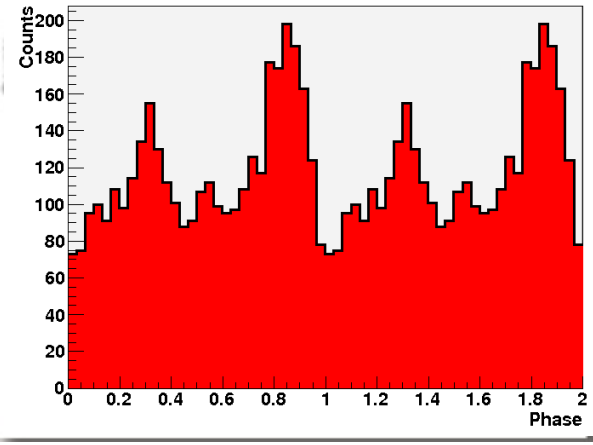
Many intermediate distance MSPs should be detected with time.

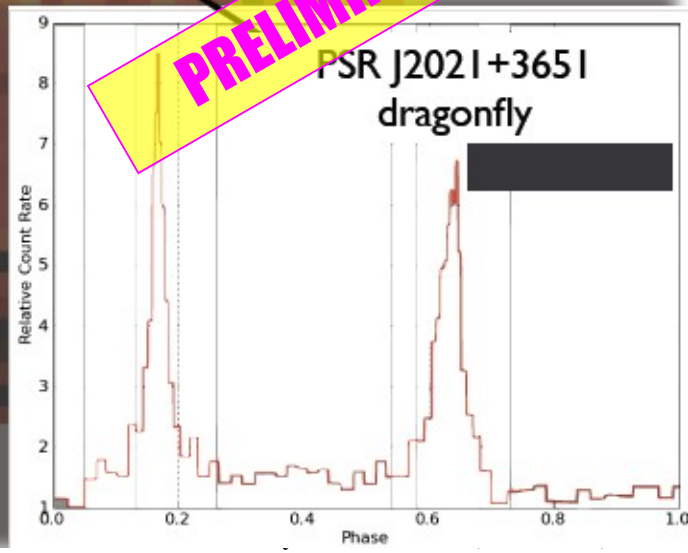
Cygnus region







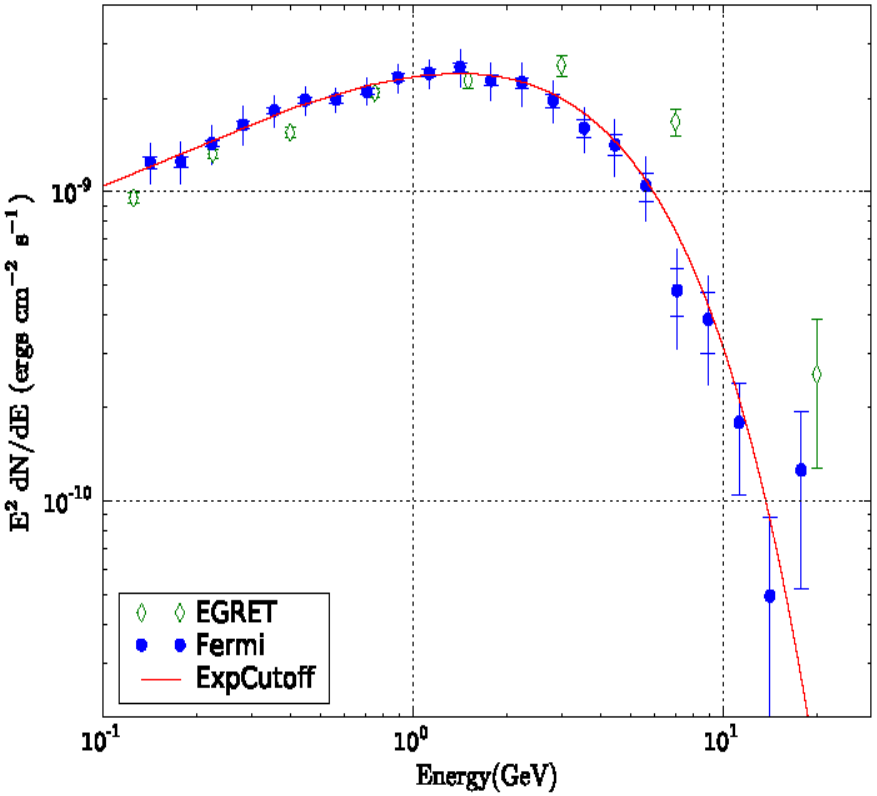




- **Intermediate latitude γ-ray spectra can be explained by cosmic-ray propagation models based on local cosmic-ray nuclei and electron spectra.**

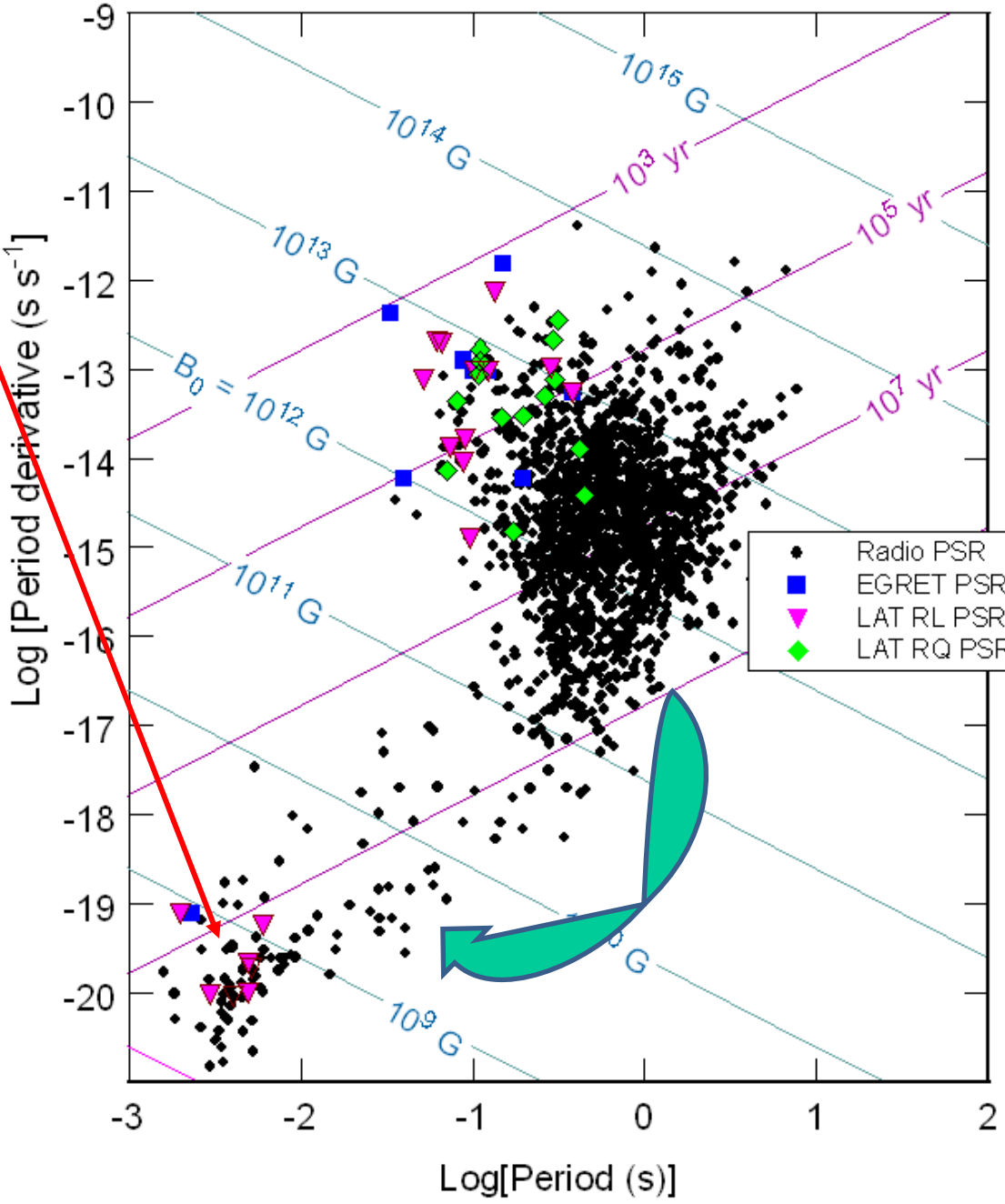
- **The Vela spectrum shows similar discrepancies, indicating that the GeV excess is instrumental.**

- **Work to analyse and understand diffuse emission over the entire sky is in progress**



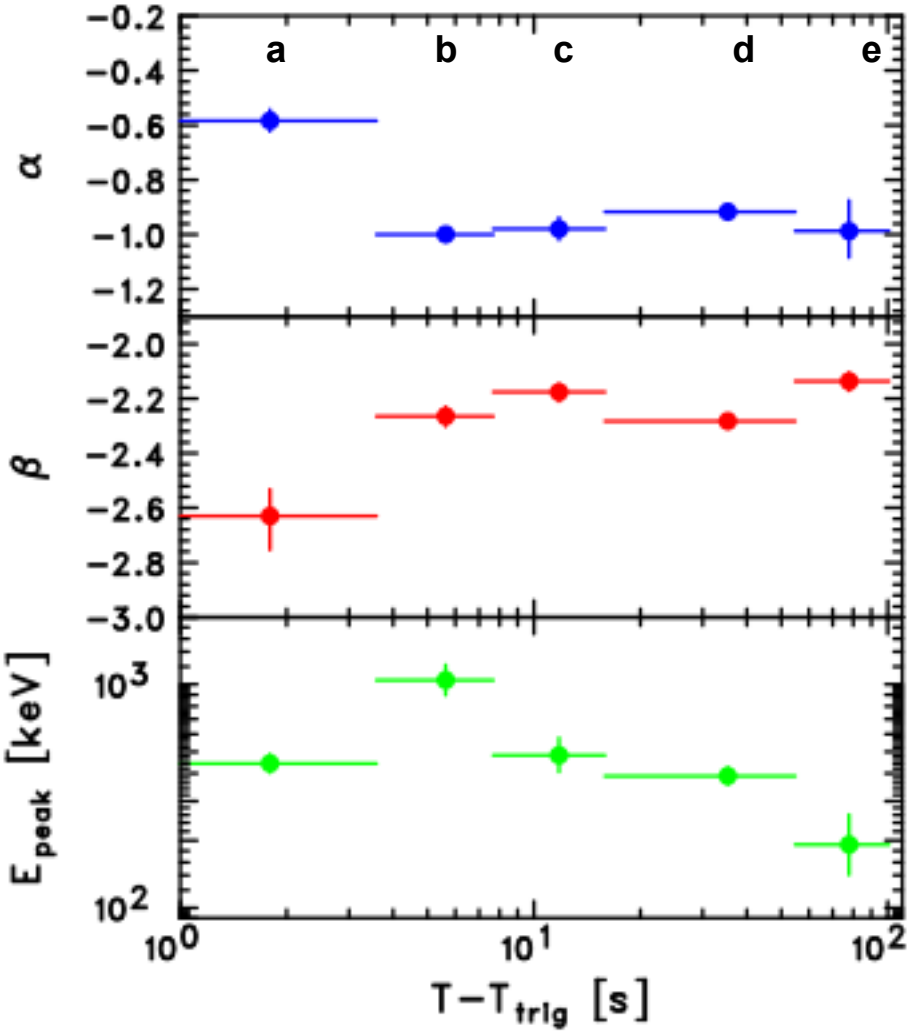
ms γ-ray pulsars

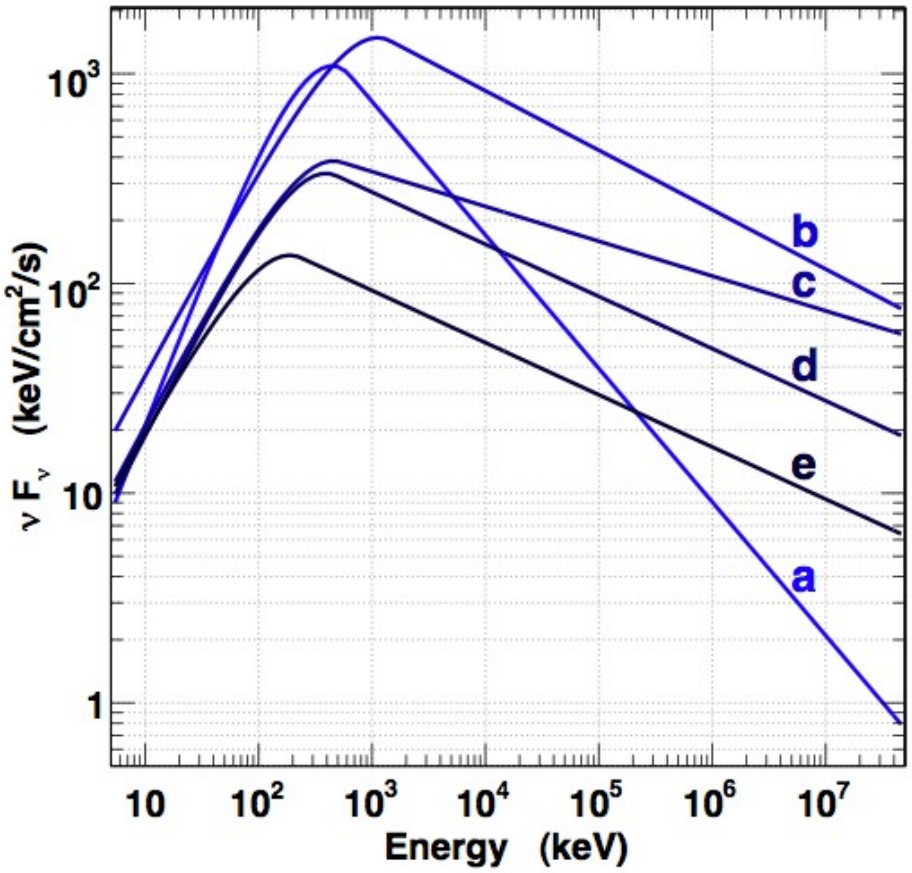
- Very different characteristics from the normal γ-ray pulsars:
  - Spinning 100 times faster
  - Magnetic fields ~10,000 times lower
  - ~10,000 times older
- "Recycled" pulsars spun-up by binary companion stars (movie)
  - Old recycled pulsars can accelerate particles to very high (TeV) energies
  - *Fermi* is seeing so far the nearby ms pulsar population
  - This may be the tip-of-the-iceberg



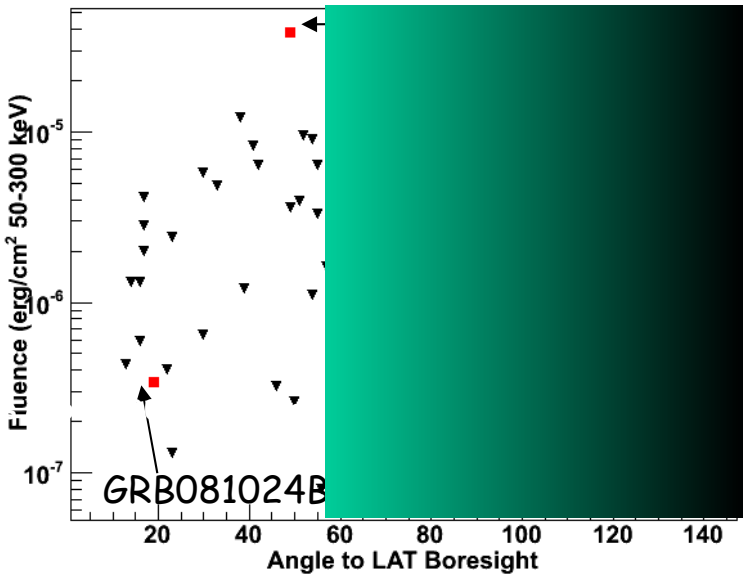
GRB080916C Spectral evolution

Soft-to-hard, then hard-to-soft evolution



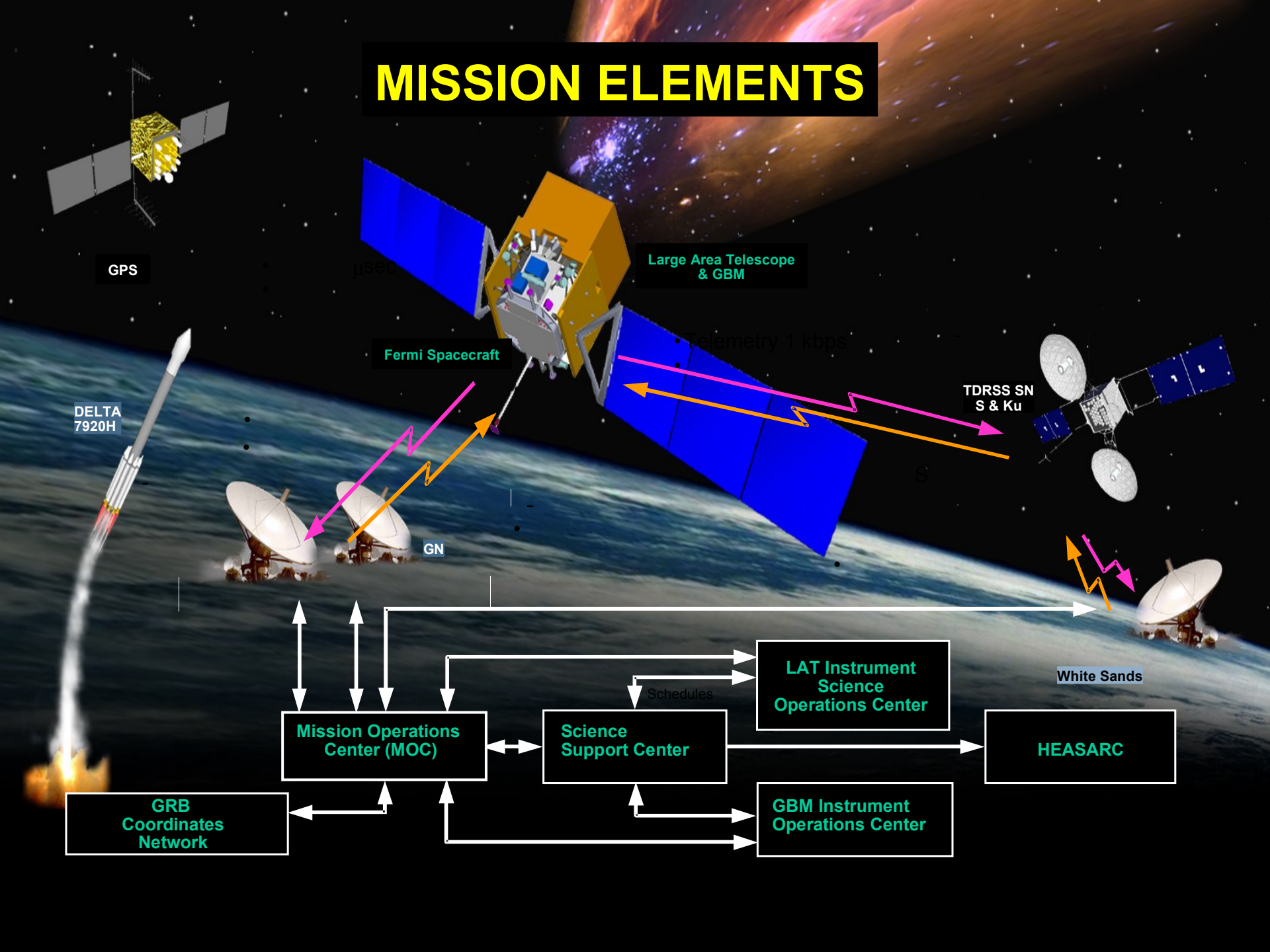


Summary: Gamma-ray Bursts Thus Far



- **LAT detections:**
  - **[GCN 8183 – Bouvier, A. et al., GCN 8141, 8184 – van der Horst, A. et al.]**
  -
  -
    - **[GCN 8246 – Tajima, H. et al., GCN 8245, 8278 – Goldstein, A. et al.]**

MISSION ELEMENTS



GRB080916C Interpretation

Redshift measurement :

- Fluence (10 keV - 10 GeV) ~ 2.4 x 10^{-4} ergs.cm^{-2} & z~4.35 => E_{iso} ~8.8x10^{54} ergs

strongly suggests narrow jet collimation

- highest energy photon in src frame : 13.2GeV x (1+z) = 70.6GeV
- delayed arrival (16.5s) of this photon

puts a constraint on Lorentz invariance violation:

M_{QG2} > 1.50e18 GeV/c ~0.1 M_{Planck}

No spectral cutoff :

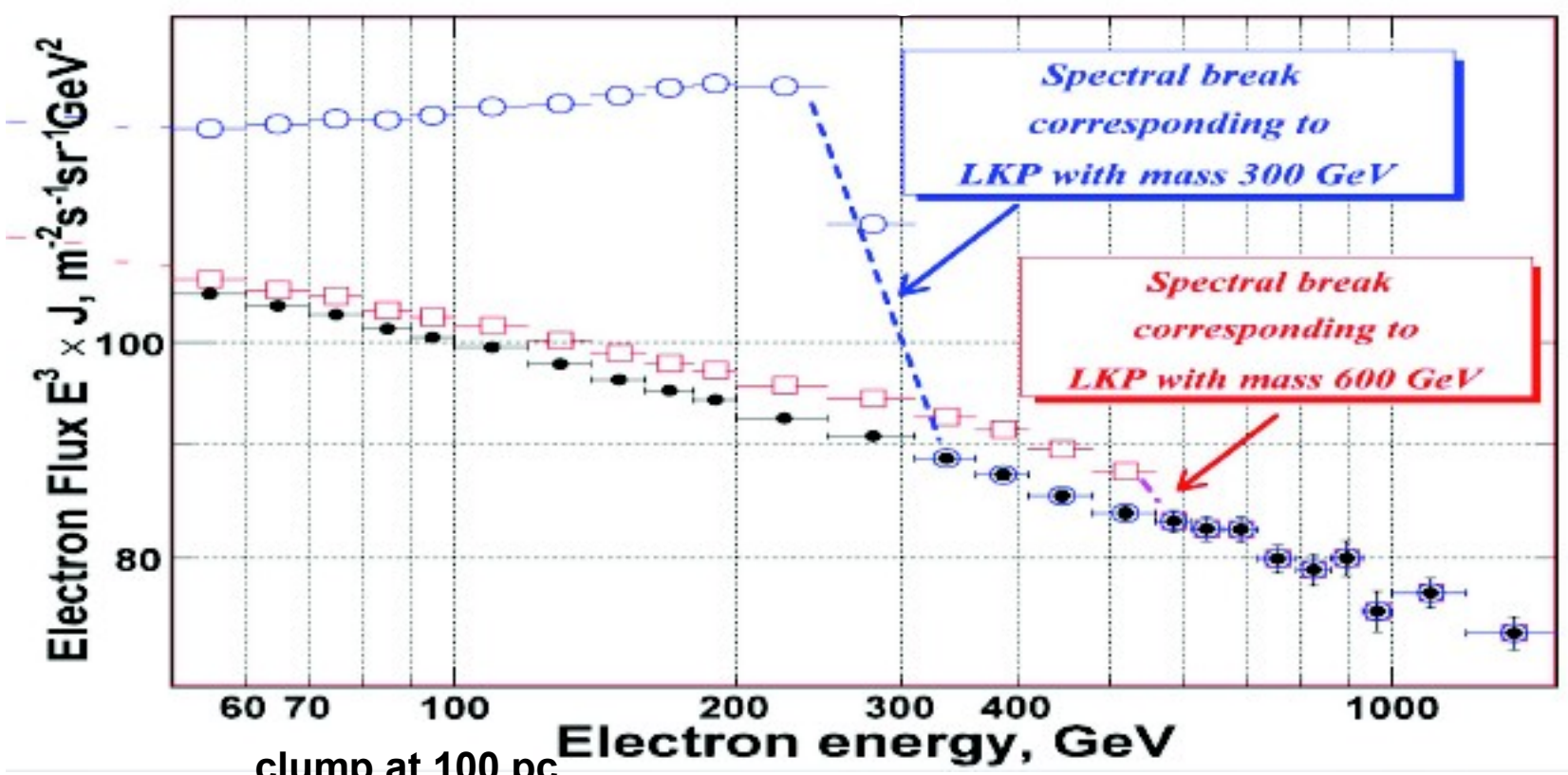
- high-energy delay a priori not due to pair-production opacity

- bulk Lorentz factor : Γ_{min} =600 (bin d), Γ_{min} =890 (bin b)

No extra spectral component (≠ Gonzalez et al., 03) :

- leptonic model : IC peak >> 10GeV

5 years of Fermi-LAT observations



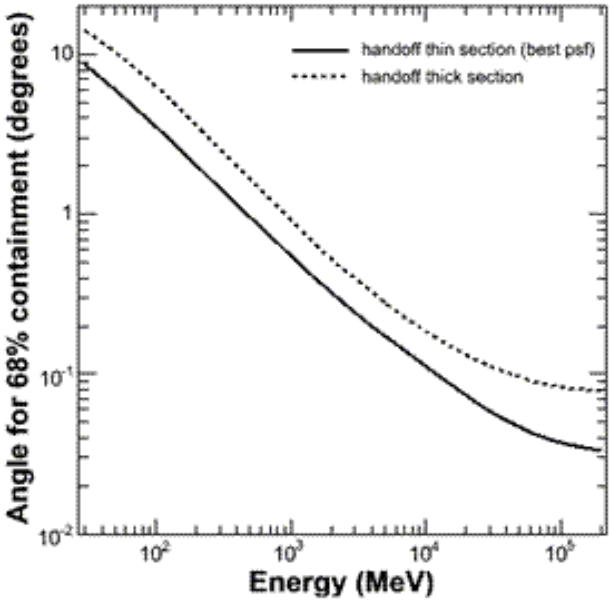
clump at 100 pc ,

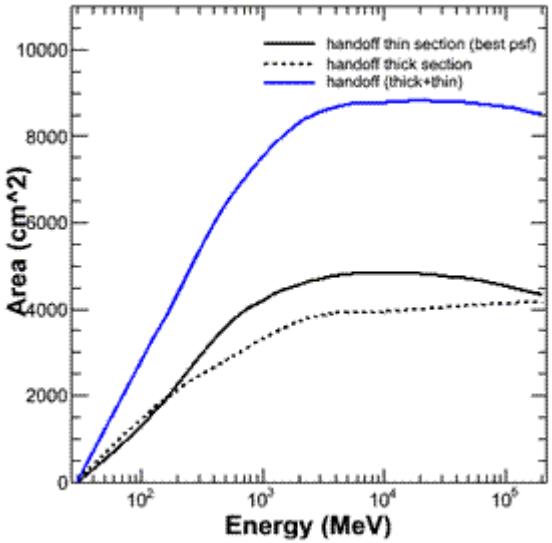
D0 = 1028 cm2 /s

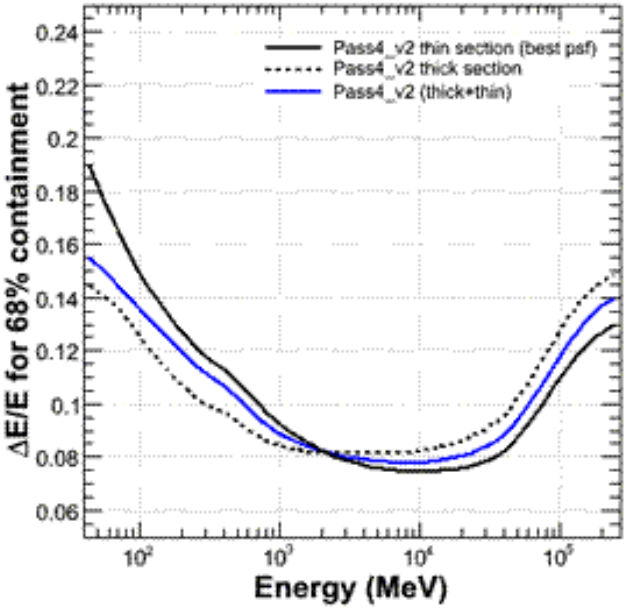
for a NFW DM distribution with boost factor of 5 and ρlocal = 0.4 GeV cm-3

Fermi measurements of the total lepton flux with large statistics will be able to explore this energy region and distinguish a slope change with a sharp cutoff with high confidence level

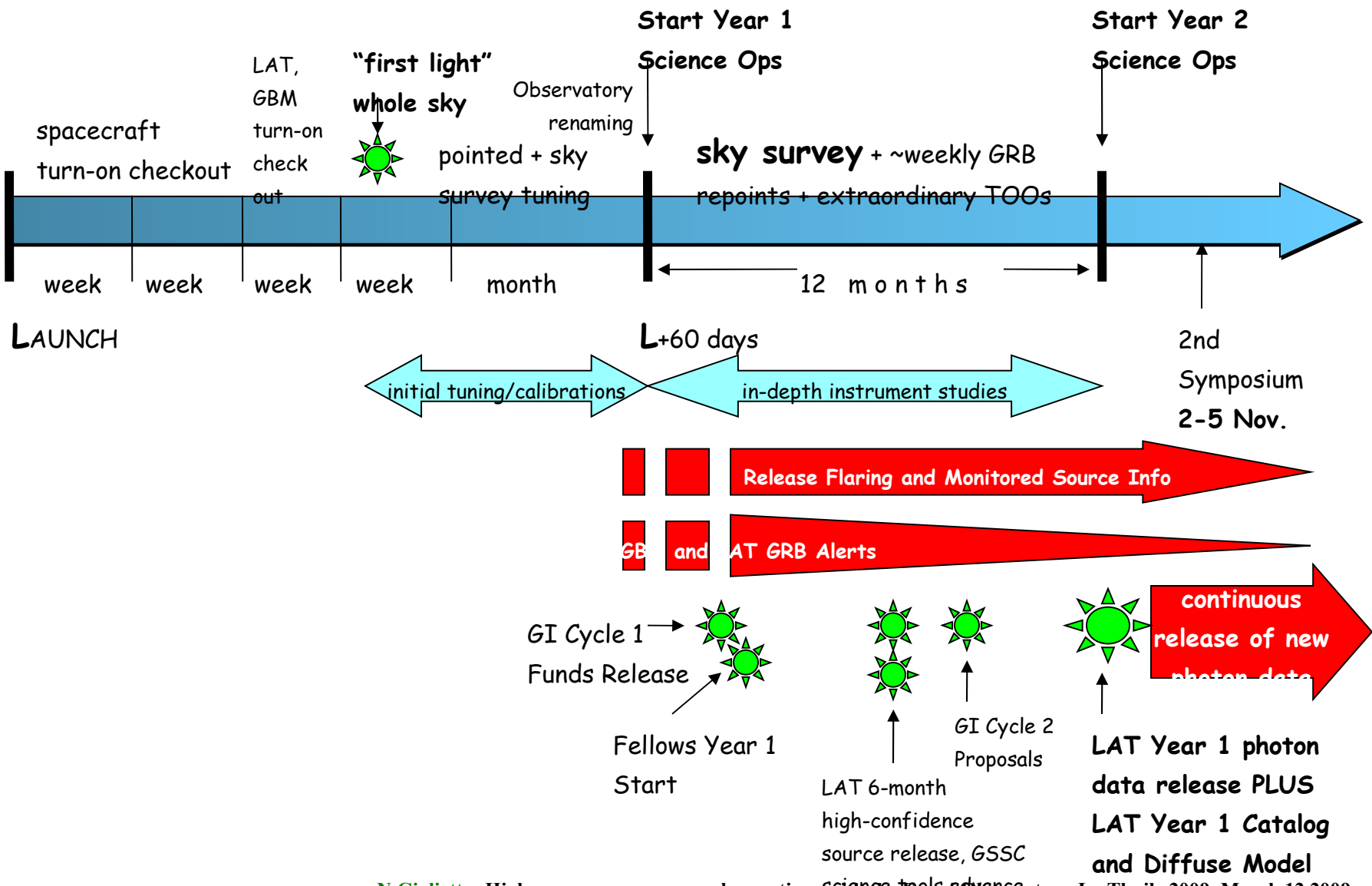
GLAST/LAT performance



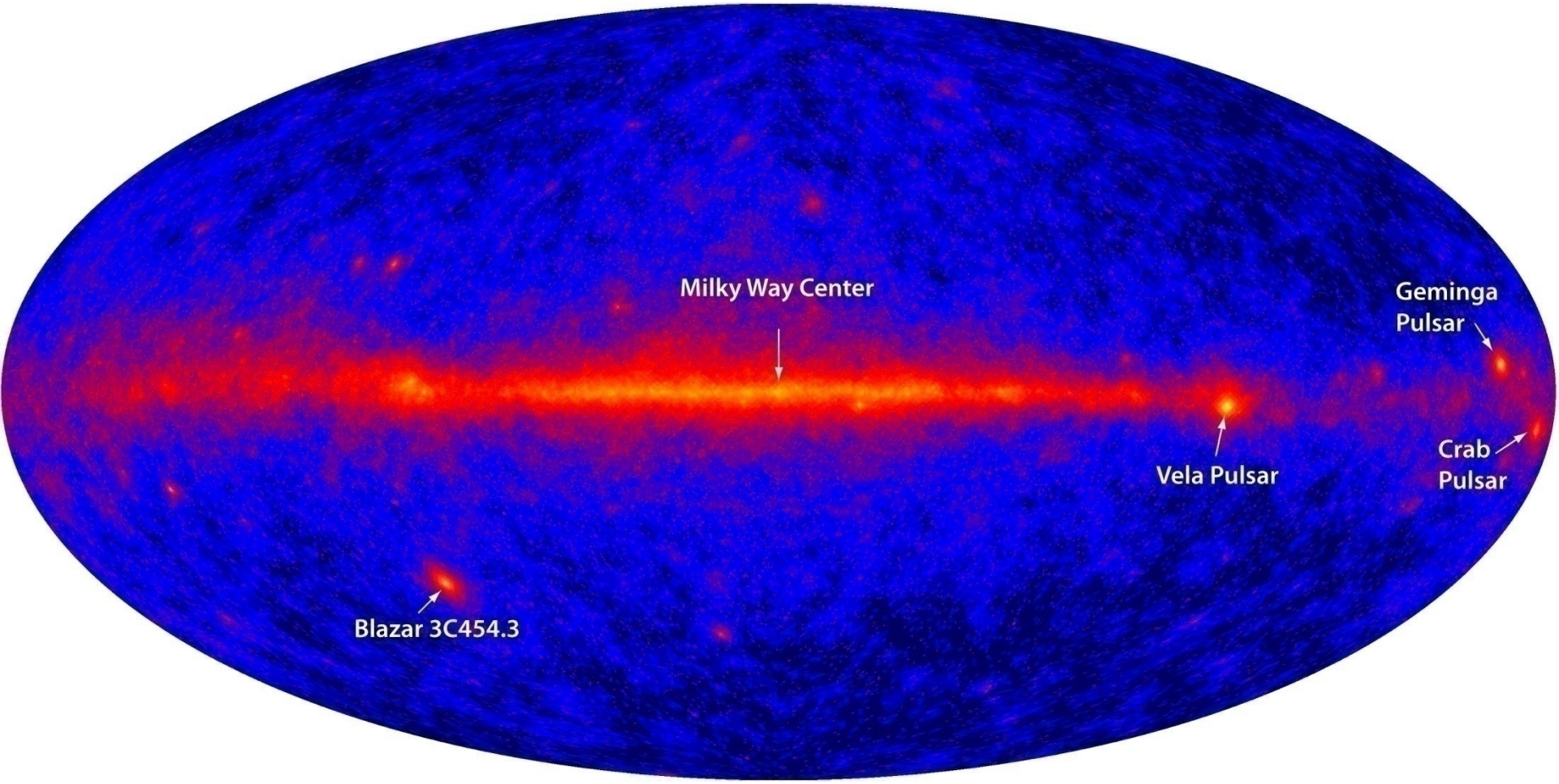




Year 1 Science Operations Timeline Plan



First Light!



Four days of all-sky survey engineering data.