The First Year of the Fermi LAT Mission

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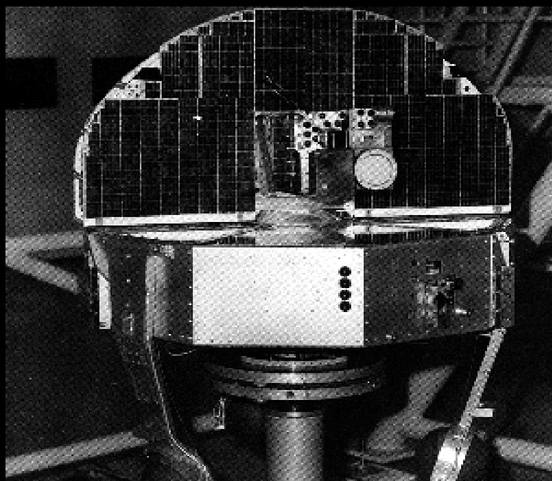
On behalf of the LAT collaboration

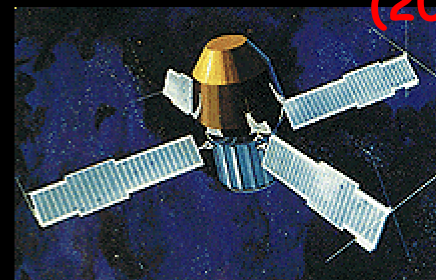
Brief History of Space-borne γ-ray Instruments

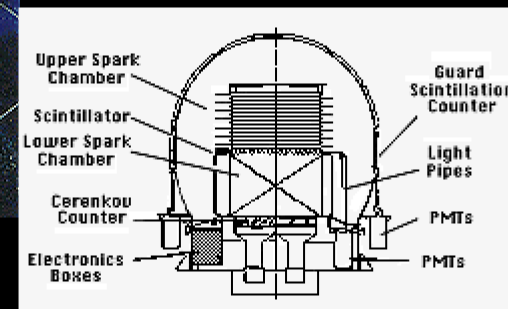
OSO-3 (NASA:'67-'69) (> 50 MeV)



SAS-2 (NASA:Nov '72-Jun '73

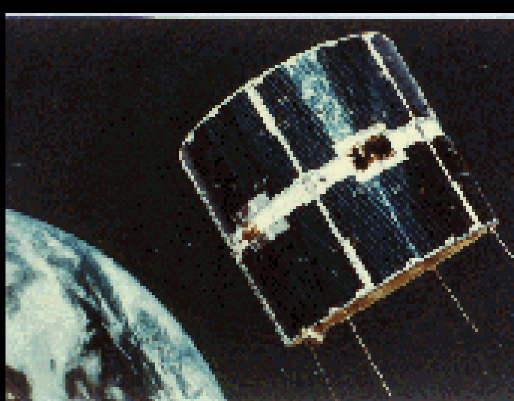
(20 MeV → 1 GeV)





COS-B (ESA:'75-'82)

(30 MeV → 5 GeV)



BATSE: 0.02-1 MeV

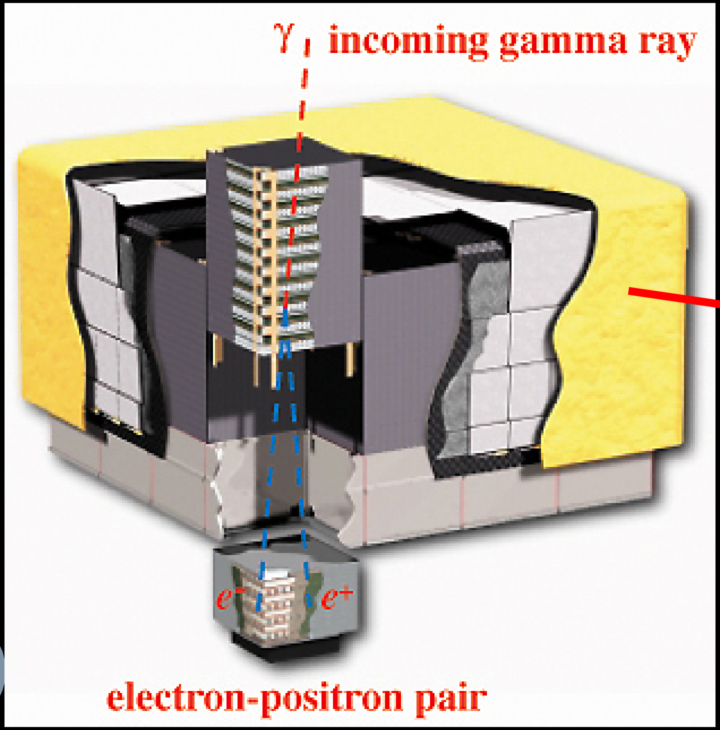
OSSE: 0.05-10 MeV

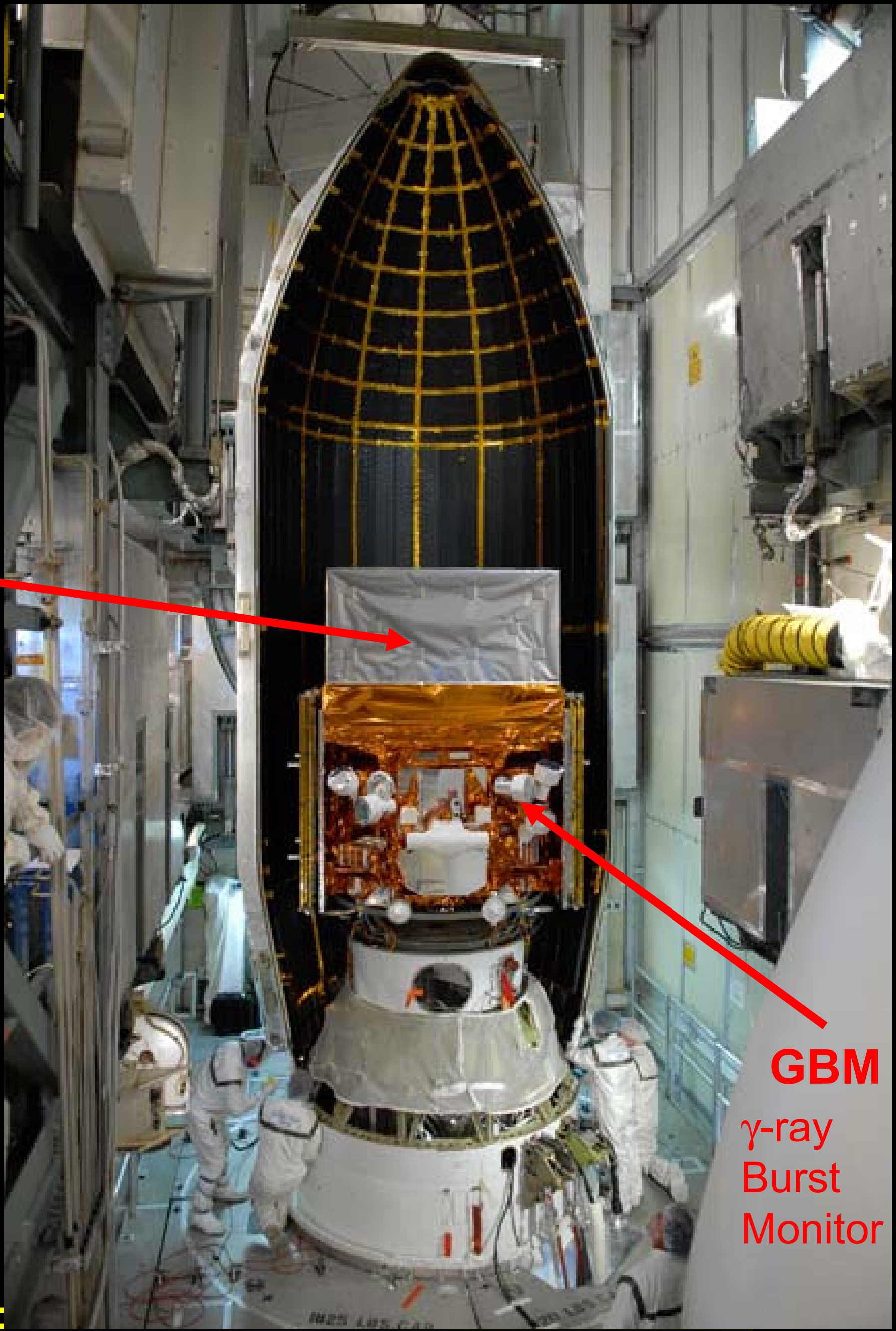
Comptel: 0.8-30 MeV

EGRET: 0.03-10 GeV

Two Fermi Instruments: GBM and LAT

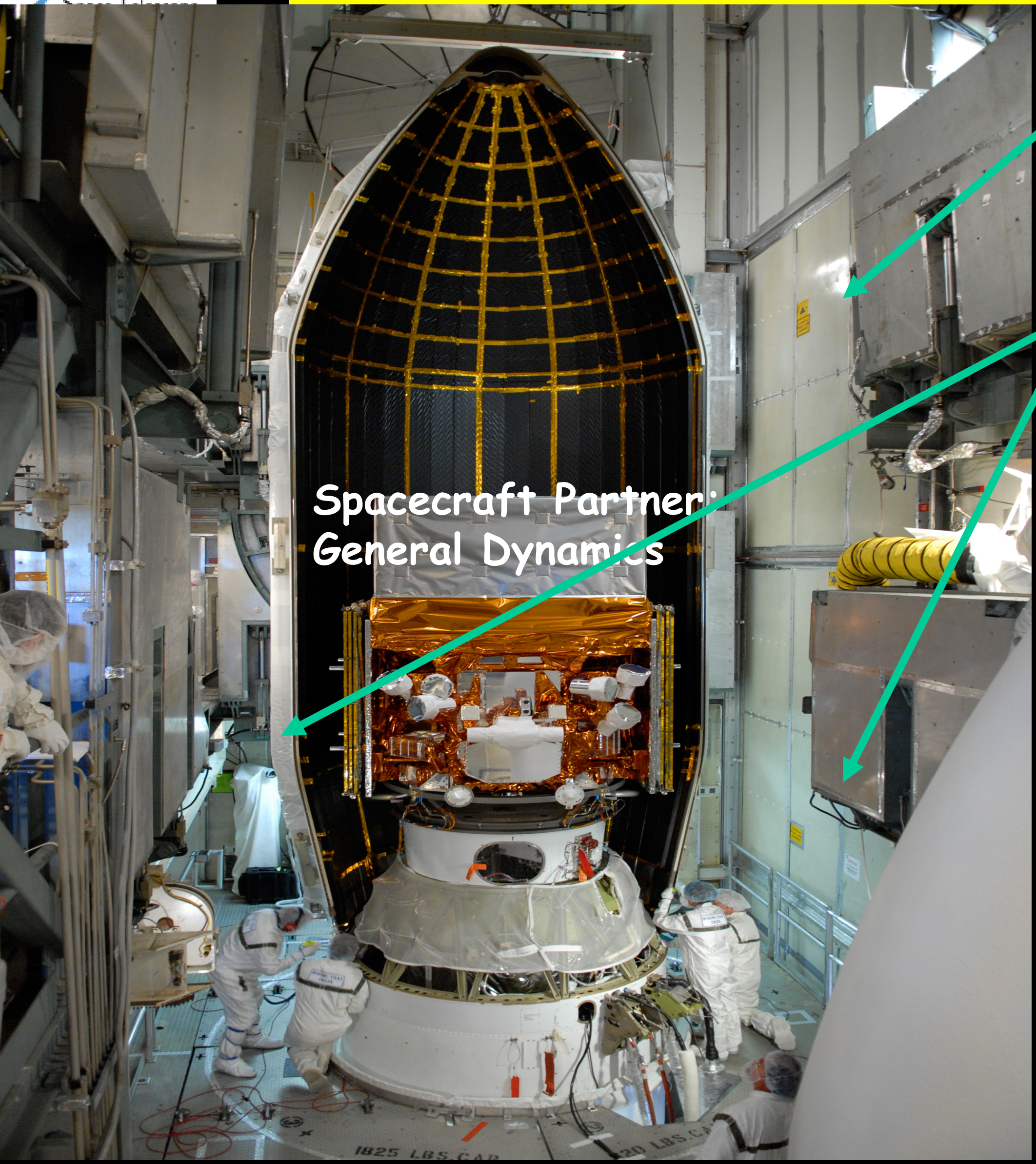
Large Area Telescope (LAT)





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

The Observatory



Large AreaTelescope (LAT)
20 MeV → >300 GeV

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

KEY FEATURES

Large field of view:

LAT → 20% of sky at any instant, in sky survey mode, expose all parts of sky for ~30 minutes/3 hours.

GBM → entire unocculted sky

Broad energy coverage, including unexplored 10-100 GeV range: > 7 decades in energy

LAT Collaboration

- France
  - CNRS/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, Santa Cruz - Santa Cruz Institute 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.

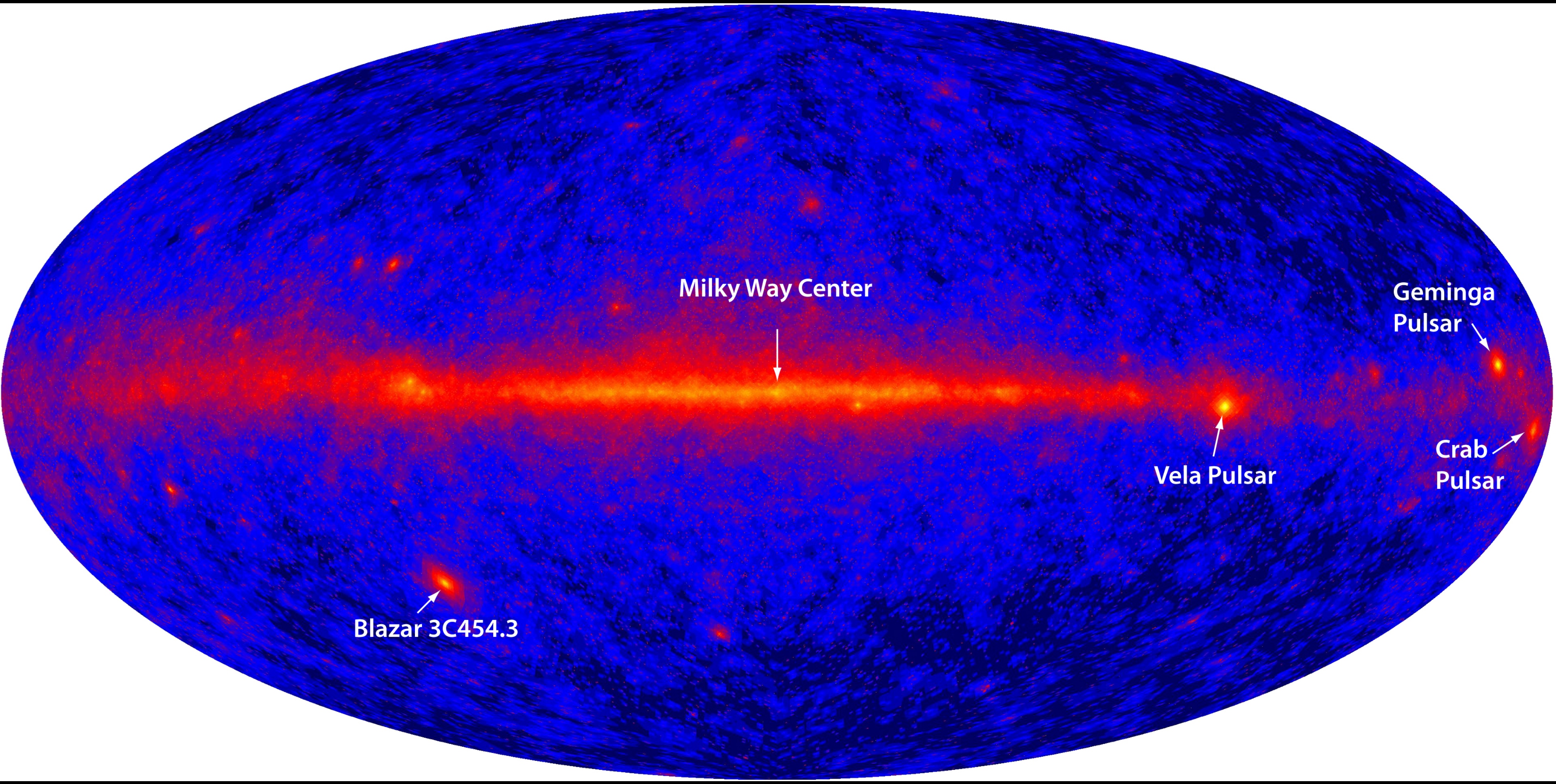
Managed at SLAC.

Launch!

Launch from Cape Canaveral Air Station 11 June 2008 at 12:05PM EDT

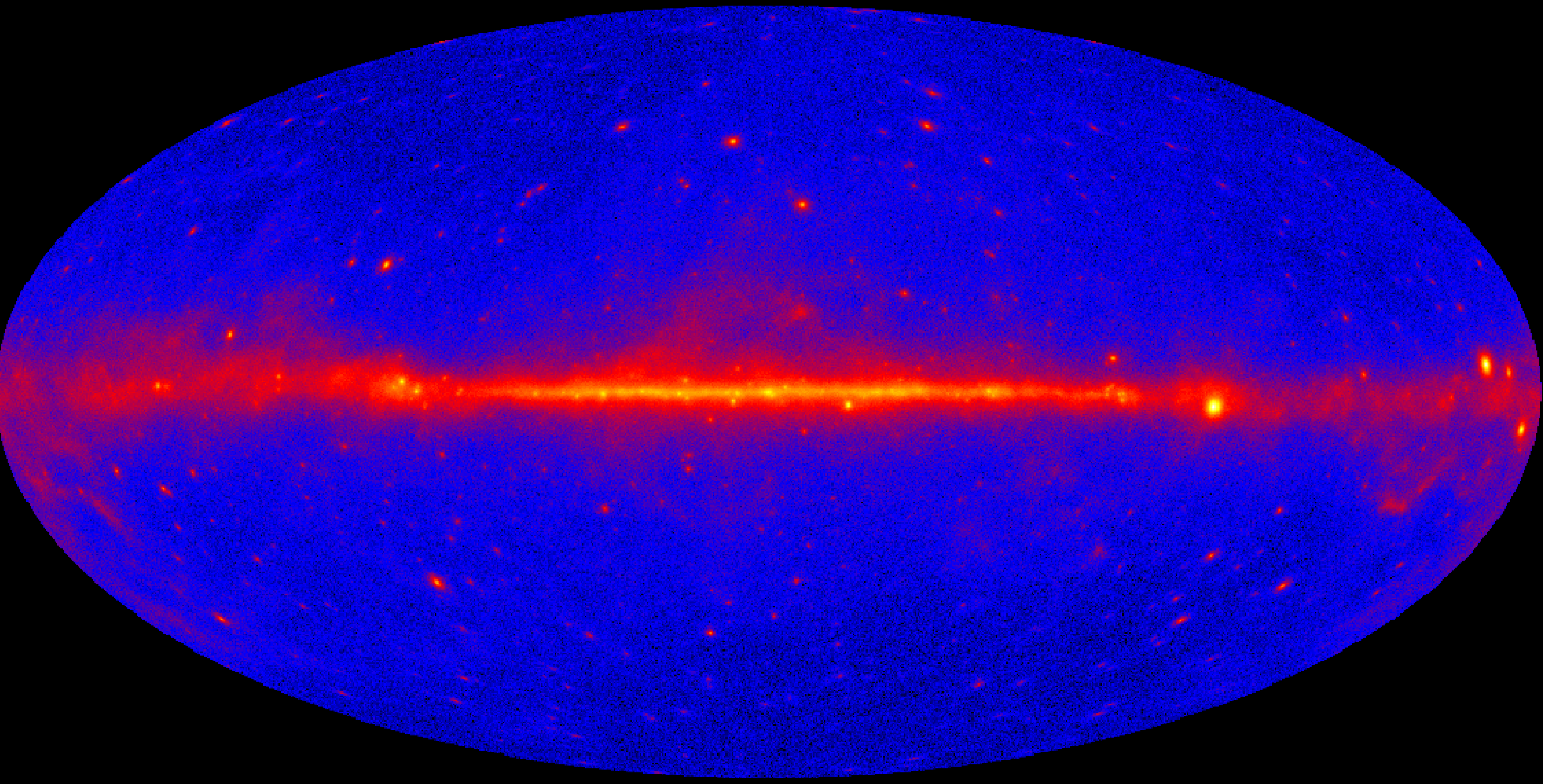
Circular orbit, 565 km altitude (96 min period), 25.6 deg inclination.

First Light!

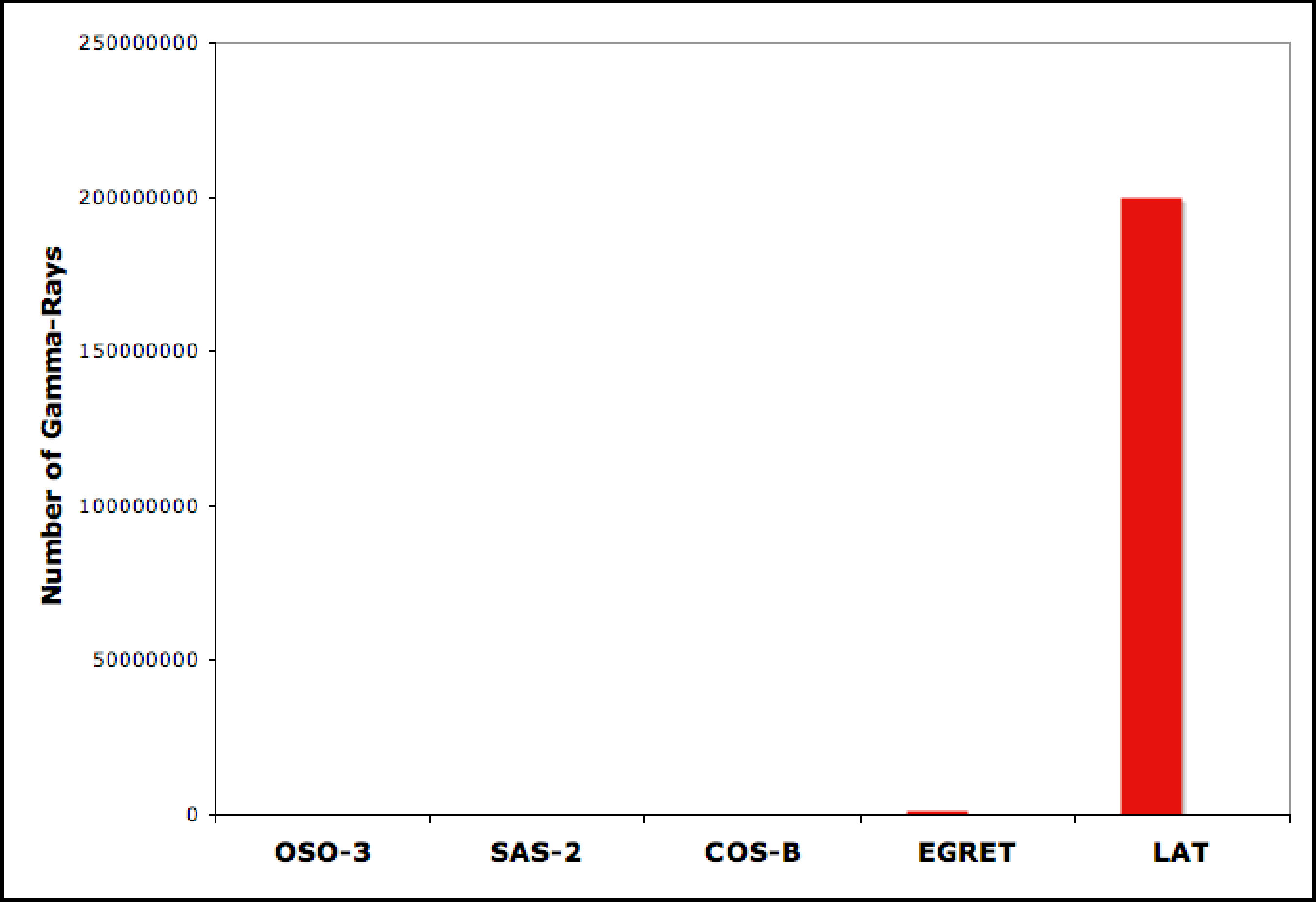


Milky Way Center
Geminga
Pulsar
Vela Pulsar
Crab
Pulsar
Blazar 3C454.3

The Fermi Sky at One Year

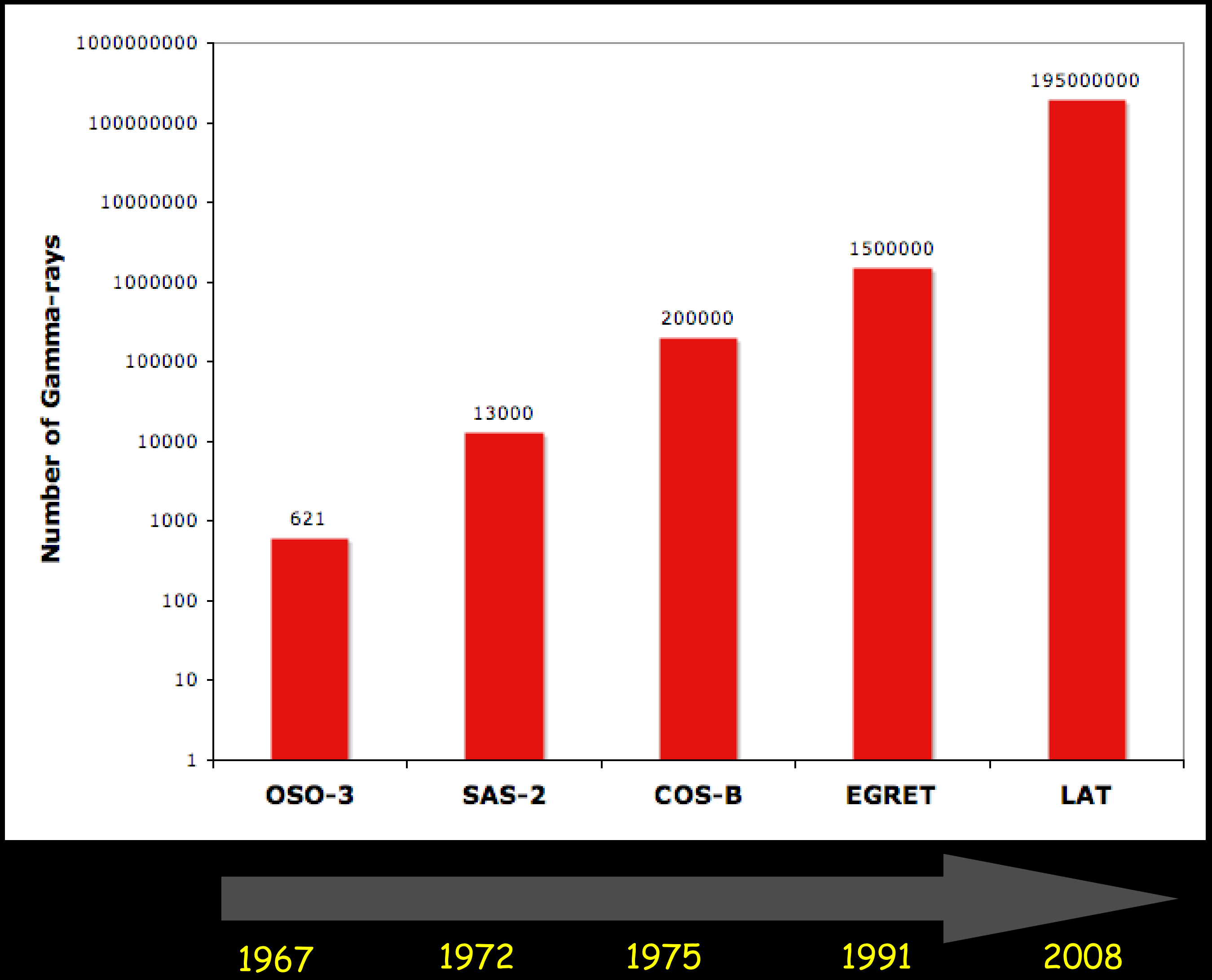


How many gamma rays?



1967 1972 1975 1991 2008

How many gamma rays?

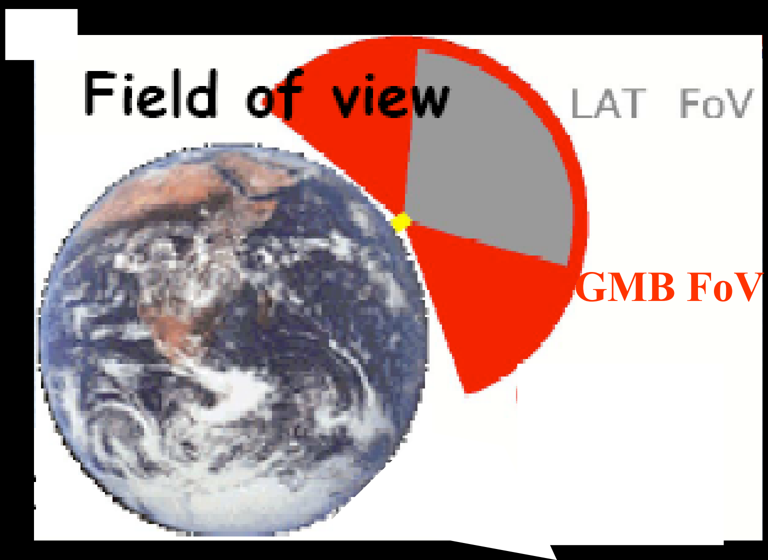


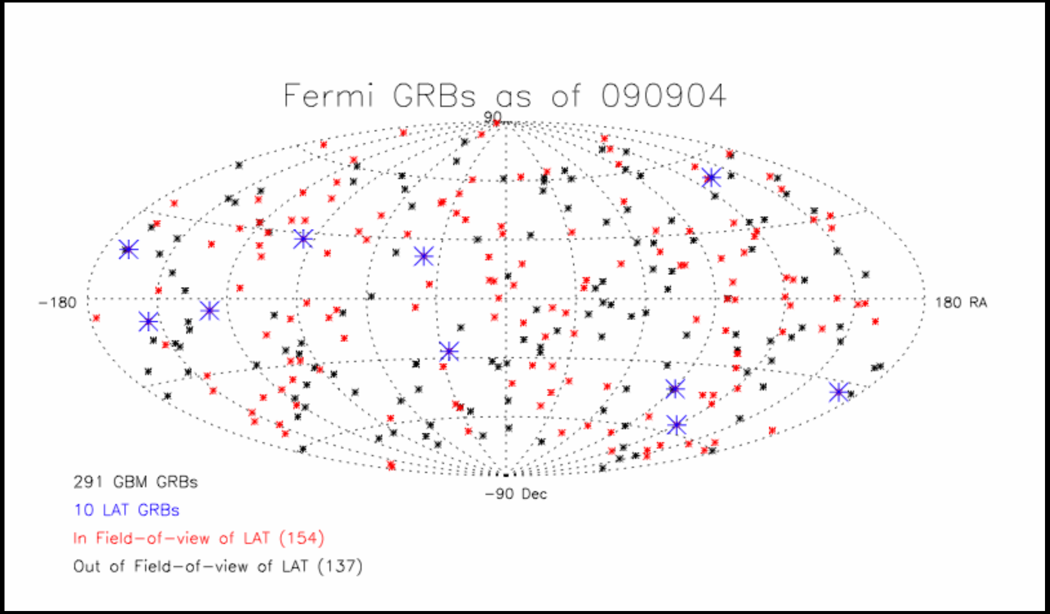
Some Highlights

- Discovery and study of >50 gamma-ray pulsars, 16 seen to pulse only in gamma rays
- Remarkable high-energy emission from GRBs
  - Era of GeV spectroscopy
  - Provides limits of photon velocity dispersion
- Very high statistics measurement of CR $e^{\pm}$ flux to 1 TeV
- First LAT determination of isotropic gamma-ray flux
- Early dark matter searches from different sources
- New results on supermassive black hole systems (AGN) → including sources not seen before in GeV range
- Cosmic-ray accelerators: X-ray binaries and supernova remnants
- Extensive bright source list
  - 3 months, 205 point sources ($>10\sigma$) → EGRET found < 30 sources > 10σ over mission lifetime
  - Catalogue coming soon

Fermi Gamma-ray Bursts

- GRB 080825C – long & weak
- GRB 080916C [z=0.90] – long & intense, very extended emission
- GRB 081024B – short & weak
- GRB 081215A – transverse to the LAT
- GRB 090217 – long & featureless
- GRB 090323 [z=3.6] – ARR, afterglow
- GRB 090328 [z=0.74] – ARR, afterglow
- GRB 090510 [z=0.90] – short & intense, ARR, afterglow, 1st LAT GCN alert notice
- GRB 090626 – long, no ARR, afterglow
- GRB 090902B [z=1.82] – long & intense, ARR, afterglow





About ½ of GBM Acceptance lies outside the LAT FoV
GRBs that have LAT Events are ~ 7% of GRBs within the FoV

LAT Burst Summary

GRB	duration	# of events > 100 MeV	# of events > 1 GeV	delayed HE onset	Long-lived HE emission	Highest Energy	Redshift
080825C	long	~10	0	✔	✔	~600 MeV	
080916C	long	**>100**	>10	✔	✔	~ 13.2 GeV	4.35
081024B	short	~10	2	✔	✔	3 GeV	
081215A	long	—	—	—	—	—	
090217	long	~10	0	x	—	~1 GeV	
090323	long	>10	>0	—	✔	—	3.57
090328	long	>10	—	—	✔	—	0.736
090510	short	>150	>20	✔	✔	~31 GeV	0.903
090626	long	—	—	—	✔	—	
090902B	long	>200	>30	✔	✔	~ 33 GeV	1.822

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QG-related Limits from GRB090510

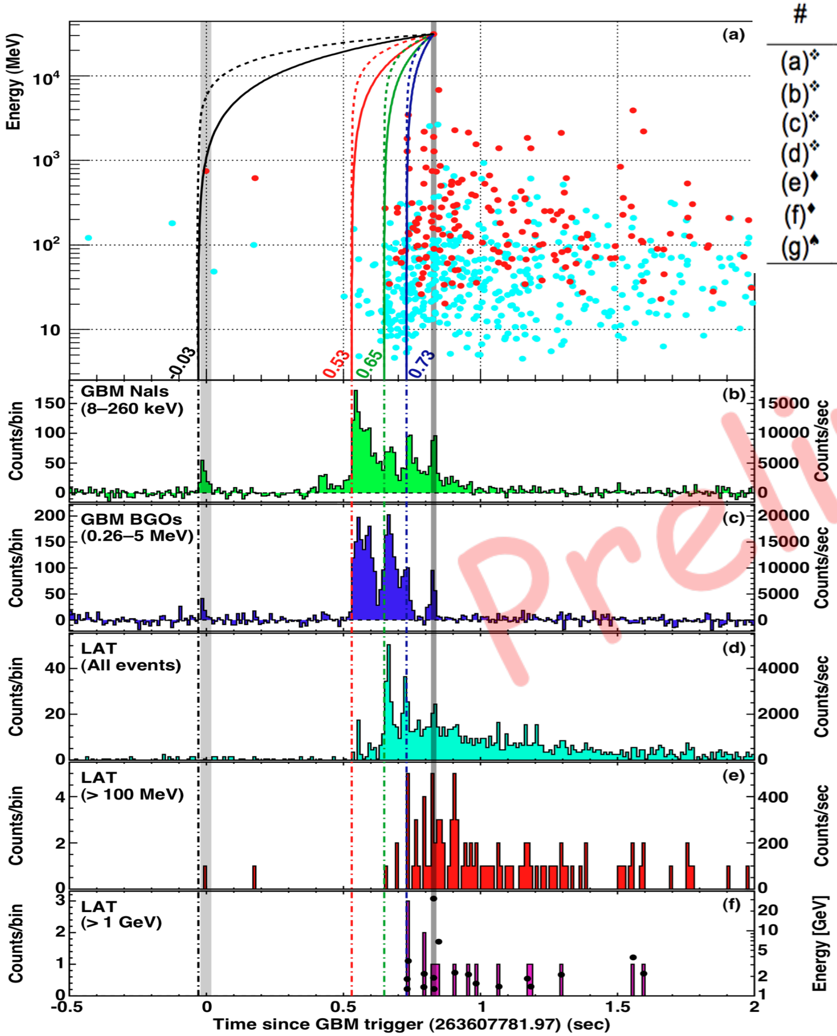


Table 2 | Limits on Lorentz Invariance Violation

#	$t_{start} - T_0$ (ms)	Limit on $\|\Delta t\|$ (ms)	Reasoning for choice of t_{start} or limit on Δt or $\|\Delta t/\Delta E\|$	E_l † (MeV)	Valid for s_n*	Lower limit on $M_{QG,1}/M_{Planck}$
(a)❖	−30	< 859	start of any < 1 MeV emission	0.1	1	> 1.19
(b)❖	530	< 299	start of main < 1 MeV emission	0.1	1	> 3.42
(c)❖	*648*	< 181	start of main > 0.1 GeV emission	100	1	> 5.63
(d)❖	730	< 99	start of > 1 GeV emission	1000	1	> 10.0
(e)♦	—	< 10	association with < 1 MeV spike	0.1	± 1	> 102
(f)♦	—	< 19	If 0.75 GeV‡ γ-ray from 1st spike	0.1	− 1	> 1.33
(g)♠	$\|\Delta t/\Delta E\|$ < 30 ms/GeV		lag analysis of > 1 GeV spikes	—	± 1	> 1.22

arXiv:0908.1832v1
Abdo et al. Nature, 2009

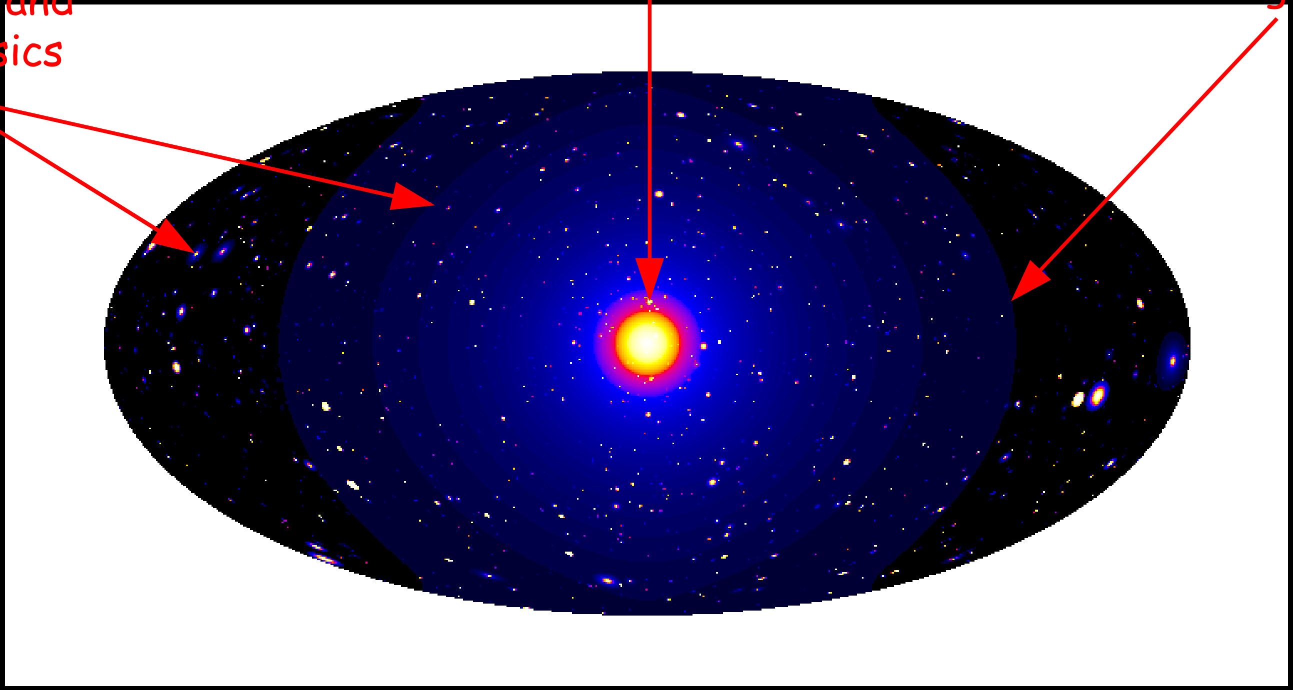
…with the assumption that the HE photons are not emitted *before* the LE photons.

Dark Matter Searches with Fermi-LAT

Satellites
Low background and good source id, but low statistics and astrophysics

Galactic Centre
Good statistics but diffuse background/source confusion

Milky Way Halo
Large statistics but diffuse background



All-sky map of simulated gamma-ray signal from dark matter annihilation (Baltz 2006)

Cosmic-ray electrons

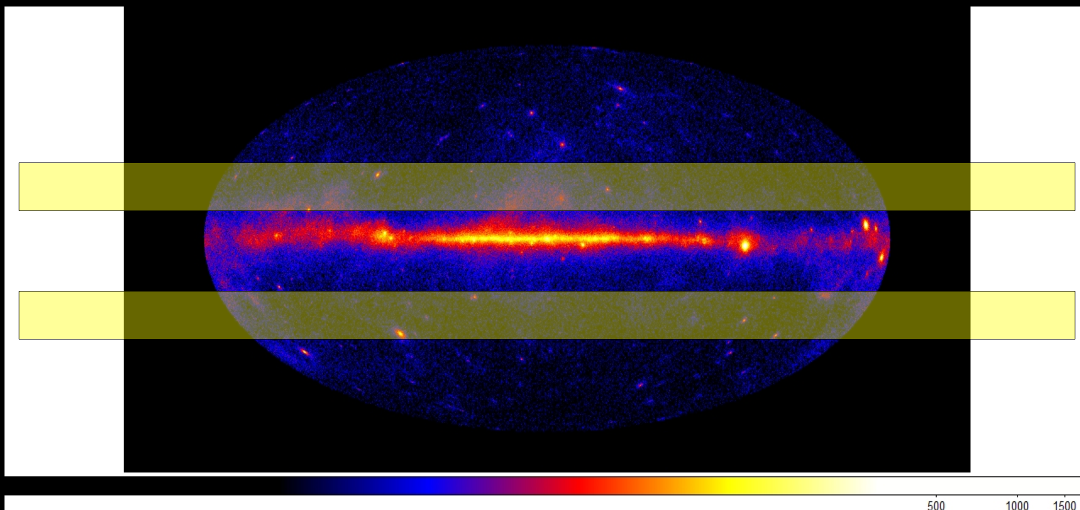
Spectral Lines
Good id but low sensitivity from small branching ratio

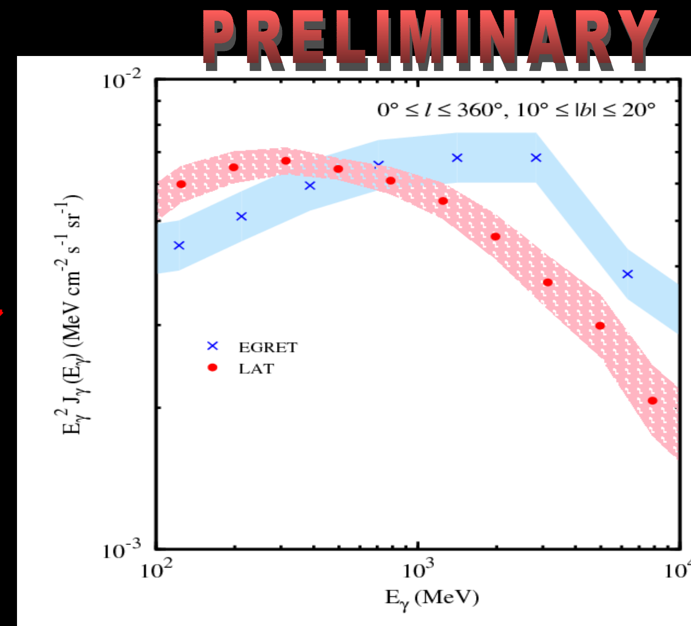
Galaxy Clusters
Low background but low statistics

Extragalactic
Large statistics but Galactic diffuse background and astrophysical sources

Pre-launch estimates of sensitivities published in Baltz et al., 2008, JCAP 0807:013 [astro-ph/0806.2911]

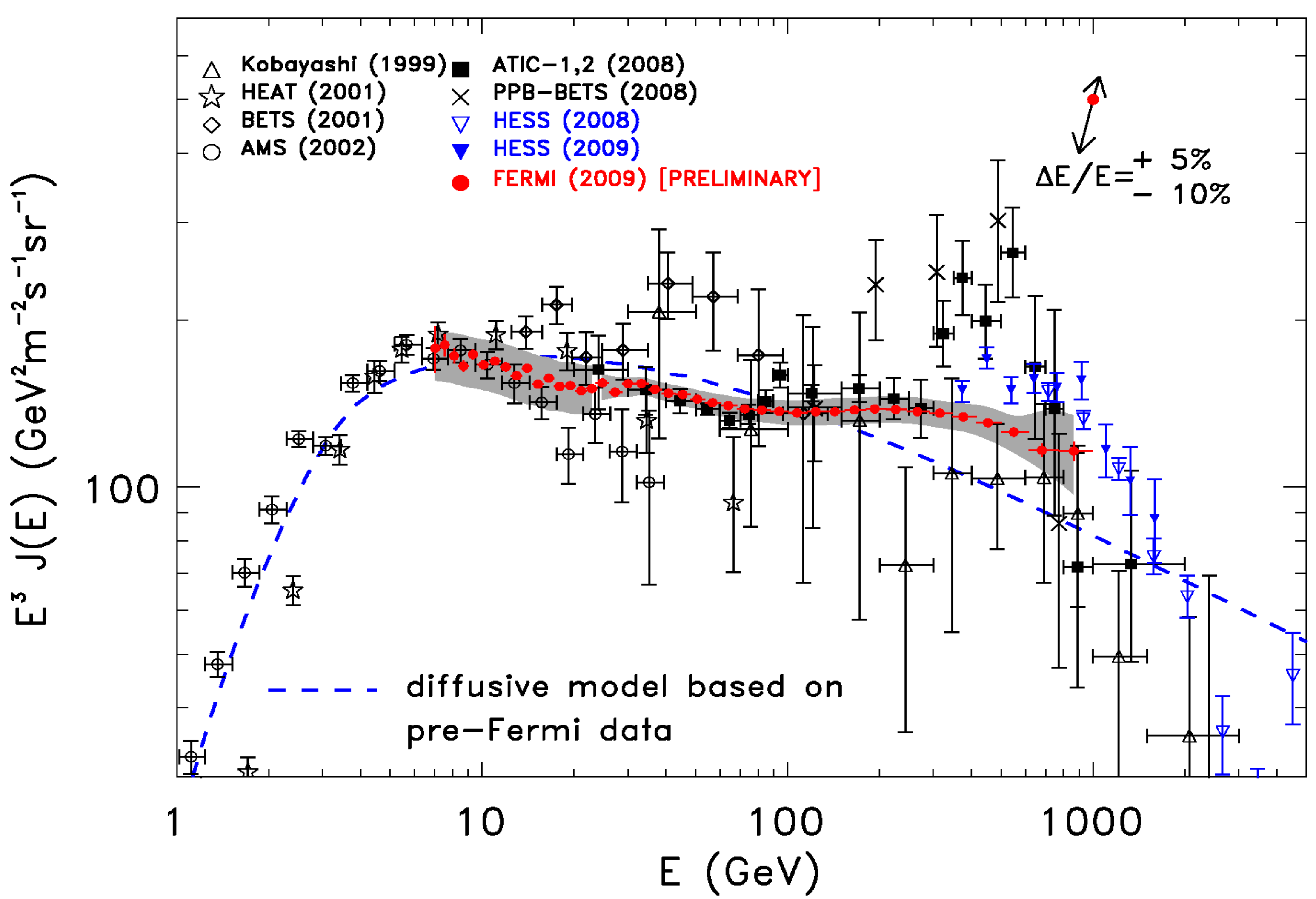
EGRET vs. LAT mid-latitude region





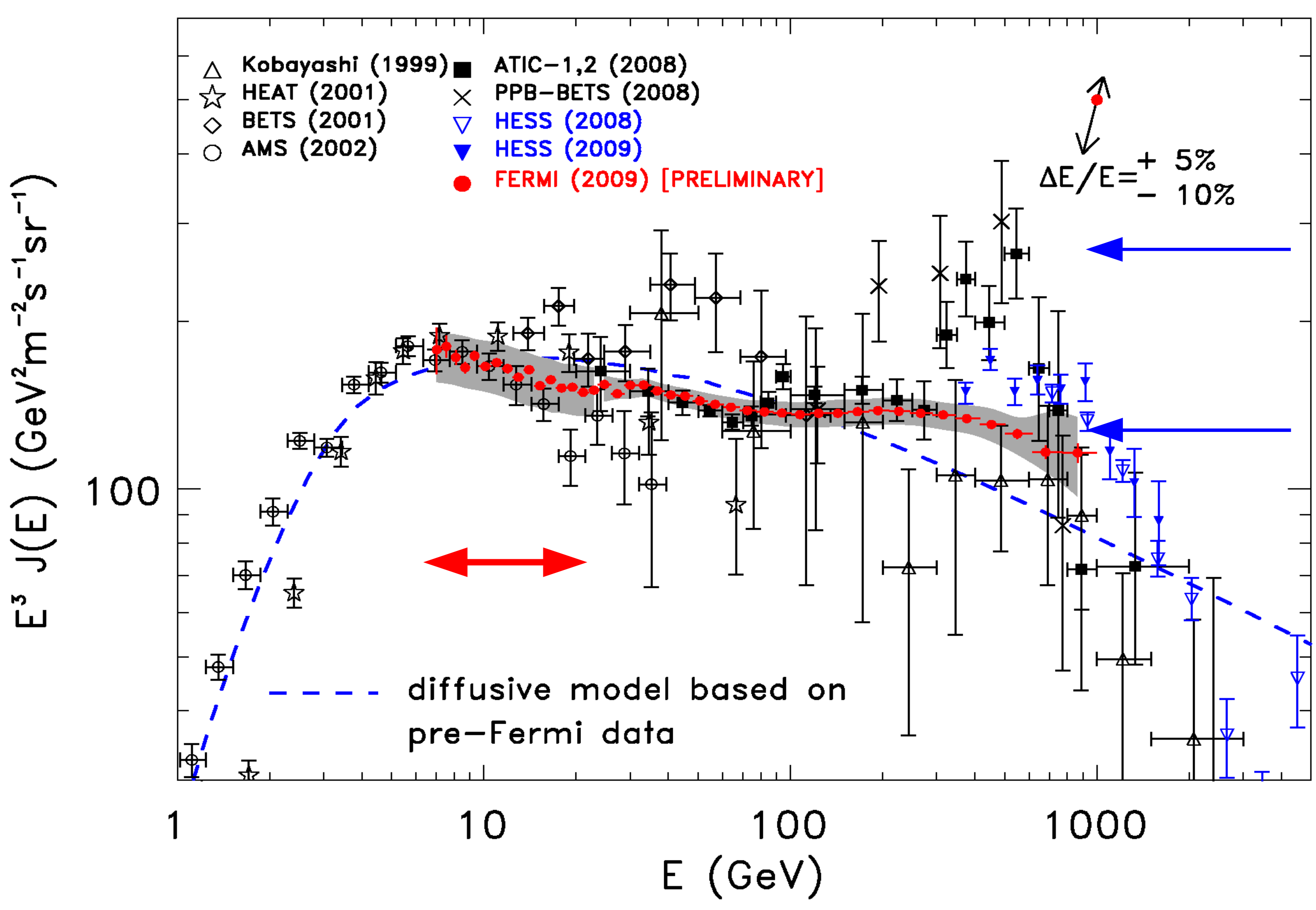
- Data from mid-August to end of December for 10°≤|*b*|≤20°
- EGRET data retrieved from GSSC (counts, exposure), processed, spectrum extracted for same region
- No source subtraction (minor component)
- LAT spectrum is significantly softer than EGRET → we do not confirm the EGRET GeV excess

Fermi Electron Spectrum (October 2009)



Extended Energy Range (7 GeV – 1 TeV) – One year statistics (8M evts)

Fermi Electron Spectrum (October 2009)

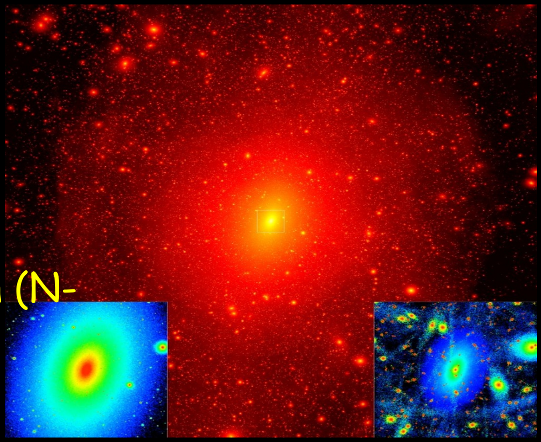


Extended Energy Range (7 GeV – 1 TeV) – One year statistics (8M evts)

Search for DM subhalos

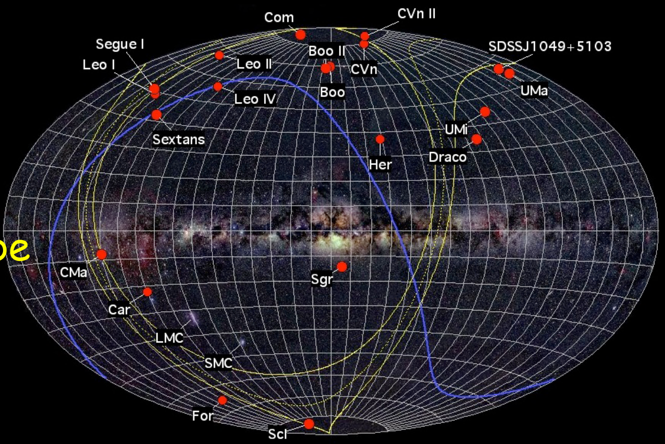
DM substructures: low background targets for DM searches

Never before observed DM substructures (DM Satellites)



- Would significantly shine only in radiation produced by DM annihilations or decays
- Blind search for promising candidates in the Fermi sky
- Some of these satellites could be within a few kpc from the Sun (N-body simulations). Their extension could be resolved by the LAT

Optically observed Dwarf Spheroidal Galaxies (dSph)

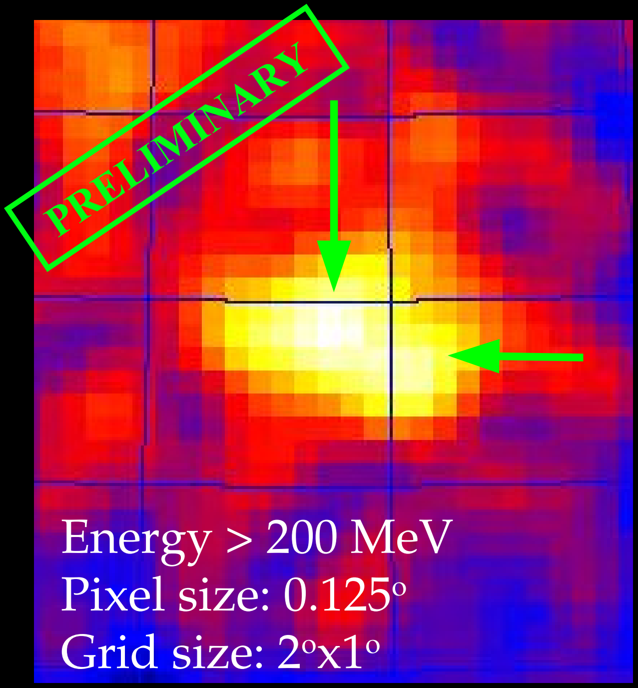


- Most are expected to be free from other astrophysical gamma ray sources and have low content in dust and gas as well as they have very few stars
- Select most promising candidates
- Given the distance and the LAT PSF, they are expected to be consistent with pointlike objects

DM Satellite Candidate

One source is found in the first 3 months of data!!

- Possibly extended (test NFW vs. point-like)
- Possibly non power law (test PL vs. WIMP b-bar spec)
- Not variable (based on 1-week lightcurve)
- No counterpart (dSph, molecular cloud)



A closer inspection with 10 months of data reveals two nearby sources…
Consistent with results of sensitivity study

So….

No DM satellites are detected with 3 months of data

Results with 1 year of data coming soon!

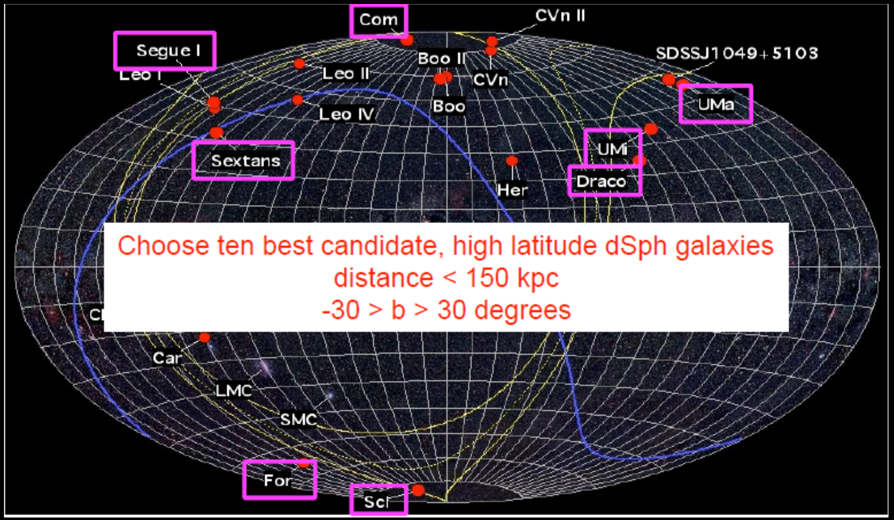
Dark Matter in Dwarf Spheroids

Select 10 most promising dSph based on proximity & stellar kinematic data:

- less that 150 kpc from the Sun
- more than 30° from the galactic plane

Not a final list! More promising targets could be discovered by current and upcoming experiments (SDSS, DES, PanSTARRS, ...)

Name	Distance (kpc)	year of discovery	M/L	l	b
Segue 1	23± 3	2007	1320 ± 2680	220.48	50.42
Ursa Major II	30± 5	2006	1722 ± 1226	152.46	37.44
Segue 2	35	2009	650^{+1300}_{-380}	149.4	-38.01
~~Willman 1~~	~~38± 7~~	~~2004~~	~~~ 500~~	~~158.57~~	~~56.78~~
Coma Berenices	44± 4	2006	448 ± 297	241.9	83.6
Usra Minor	66± 3	1954	275 ± 35	104.95	44.80
Sculptor	79± 4	1937	158 ± 33	287.15	-83.16
Draco	76± 5	1954	290 ± 60	86.37	34.72
Sextans	86± 4	1990	70 ± 10	243.4	42.2
Fornax	138± 8	1938	14.8 ± 8.3	237.1	-65.7



Most promising: Segue 1 is the closest and recent studies indicate a higher Mass/Luminosity Ratio with much smaller errors (found & counted more stars)

Willman 1 has subsequently been discredited as a dSph

Dark Matter in Dwarf Spheroids

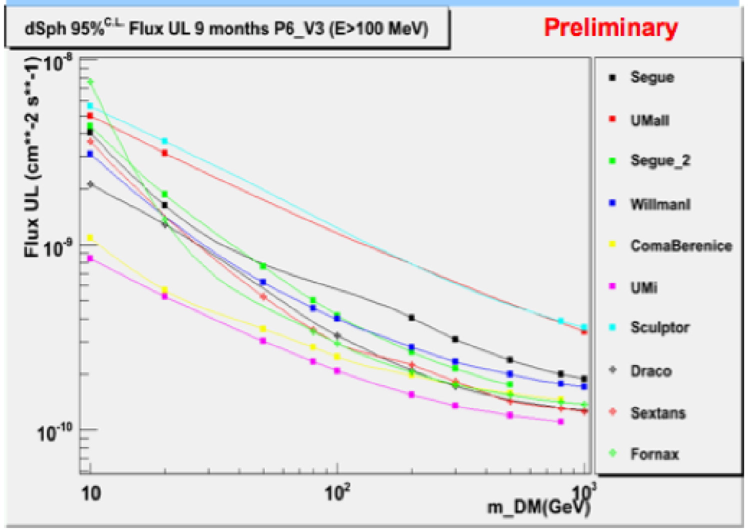
- **Search and analysis details:**
  - 100 MeV to 50 GeV
  - 10° region around dSph location
  - Background: point sources, Galactic diffuse, isotropic

Flux upper limits assuming a point-like source at the dwarf location

power-law with fixed spectral index of $\gamma = -2$

Name Preliminary	Flux UL (95%) $(E > 100\ MeV)$ $10^{-9}\ ph/cm^2/s$
Segue I	1.83
UMa II	4.60
Segue II	2.13
~~Willman I~~	~~2.12~~
Coma Berenice	0.97
UMi	0.72
Sculptor	4.79
Draco	1.16
Sextans	1.33
Fornax	1.67

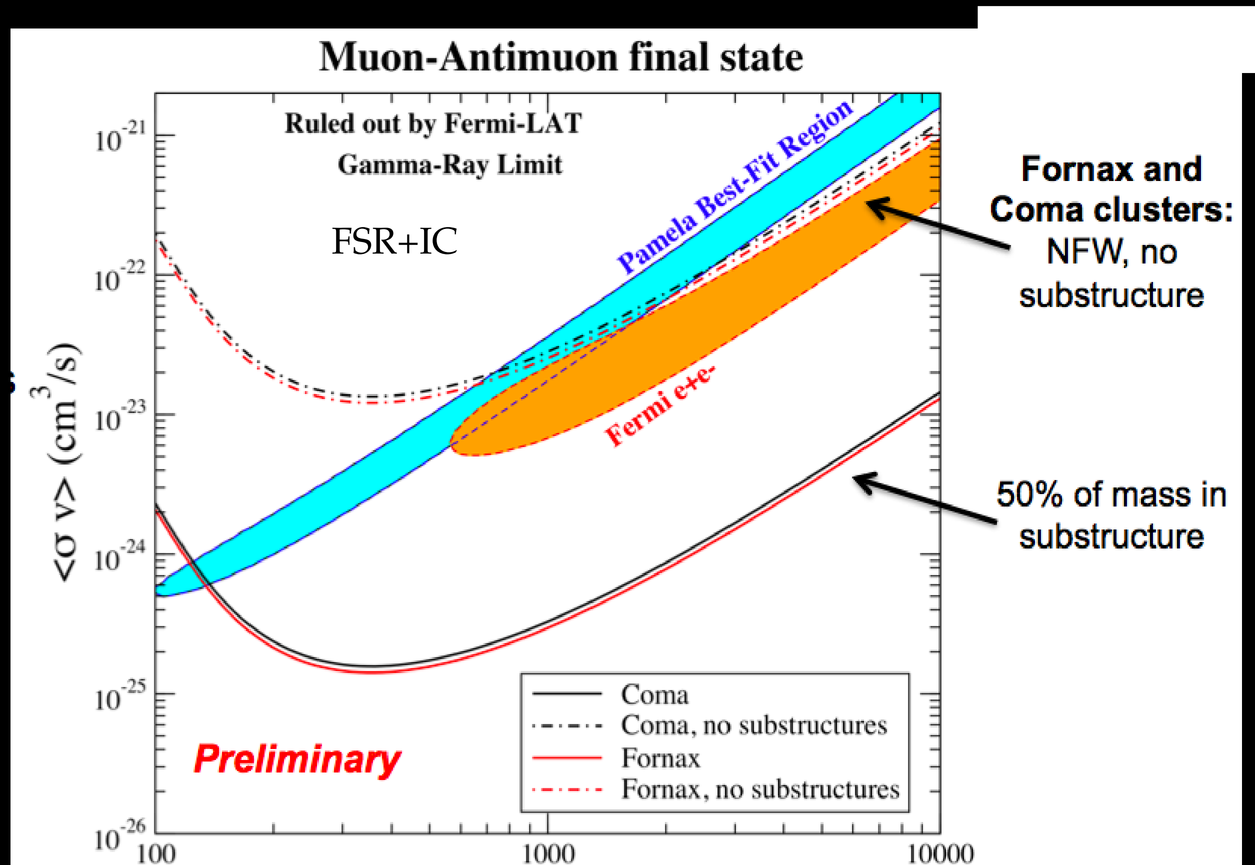
100% b-bbar DM annihilation



Using DMFIT package, Jeltema & Profumo 2008

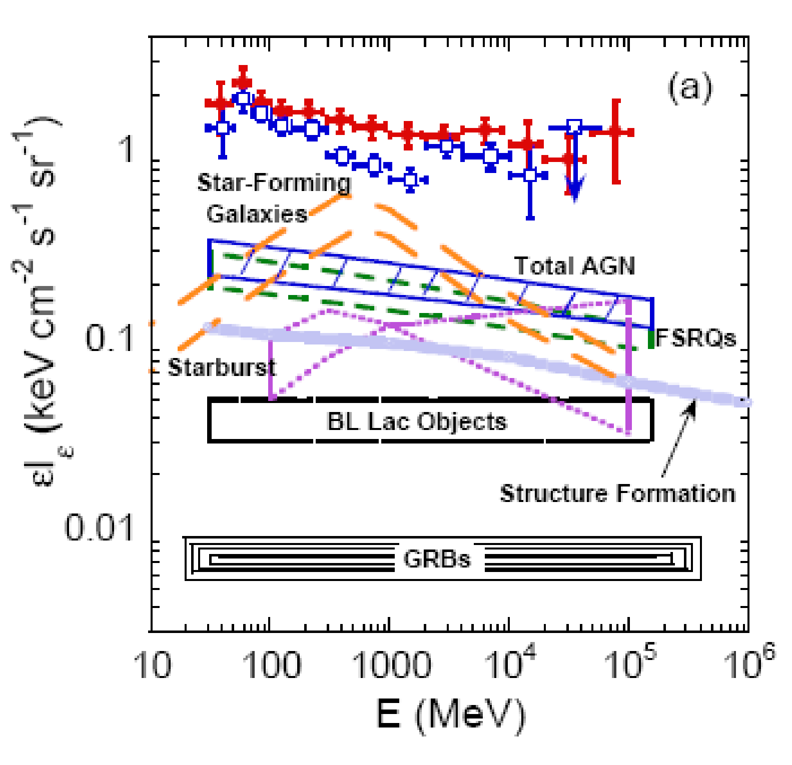
<u>**No detection of dSph by Fermi with 9 months of data**</u>

Constraints from Galaxy Clusters



Not detected by Fermi-LAT with 9 months of data

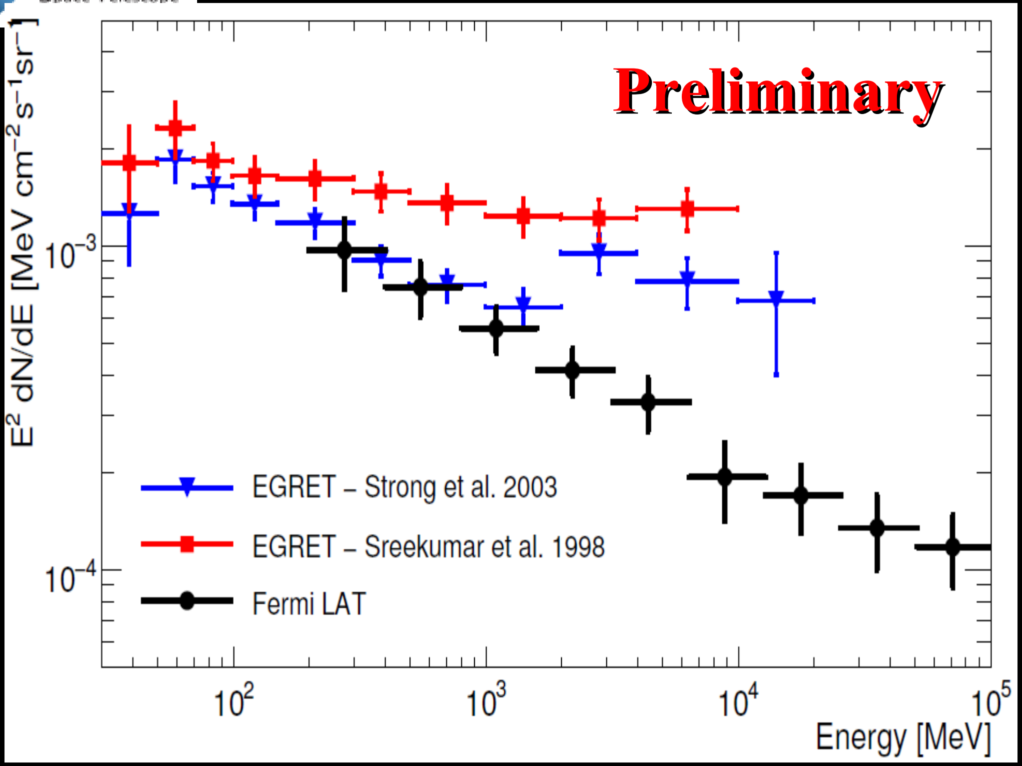
Isotropic Gamma-ray Background



- Potential contributions in LAT energy range (0.1 to >300 GeV)
  - Unresolved point sources
    - AGN
    - Star-forming galaxies
    - GRBS
  - Diffuse processes
  - UHE CR interactions with CMB
  - Structure formation
  - Large (Galactic) CRE halo
  - Dark matter

- Isotropic diffuse flux unresolved point source contribution depends on LAT point source sensitivity
- Contribution by unresolved sources expected to decrease with LAT observation time

Fermi LAT isotropic gamma-ray background



- Steeper spectrum than EGRET-team analysis
- No spectral feature above few GeV seen in Strong et al analysis
- Isotropic level expected to diminish with increased observation time

	Intensity > 100 MeV ($x10^{-5}$ cm^{-2} s^{-1} sr^{-1})	Spectral Index
LAT (this analysis)	1.03 ± 0.17	2.41 ± 0.05
EGRET (Sreekumar et al '98)	1.45 ± 0.05	2.13 ± 0.03
EGRET (Strong et al '04)	1.11 ± 0.10	
LAT + resolved sources	1.19 ± 0.18	2.37 ± 0.05

Summary

- Fermi observatory operating for > 14 months
  - Total `up' time for nominal science mode data taking ~98%
  - Both GBM and LAT operating according to design specifications
- Already addressing questions from the EGRET era
- Breaking new ground in the `LAT era'
- Photon data are public as soon as pass through pipeline at SLAC
  - Science tools also public
  - Anyone can download, analyse, …
  - See post CoSPA workshop next week (Galloway)
- At least 4 more years

Summary cont.

http://fermi.gsfc.nasa.gov/science/symposium/2009/
2-5 November, Washington D.C.

- Results for the 1st year highlighted at 2nd Fermi Symposium → presentations available at: http://fermi.gsfc.nasa.gov/science/symposium/2009/program.html

Supplementary Slides

Overview of LAT: How it works

Precision Si-strip Tracker (TKR) 18 xy
Measure the photon direction; gamma ID.

8x12 layers

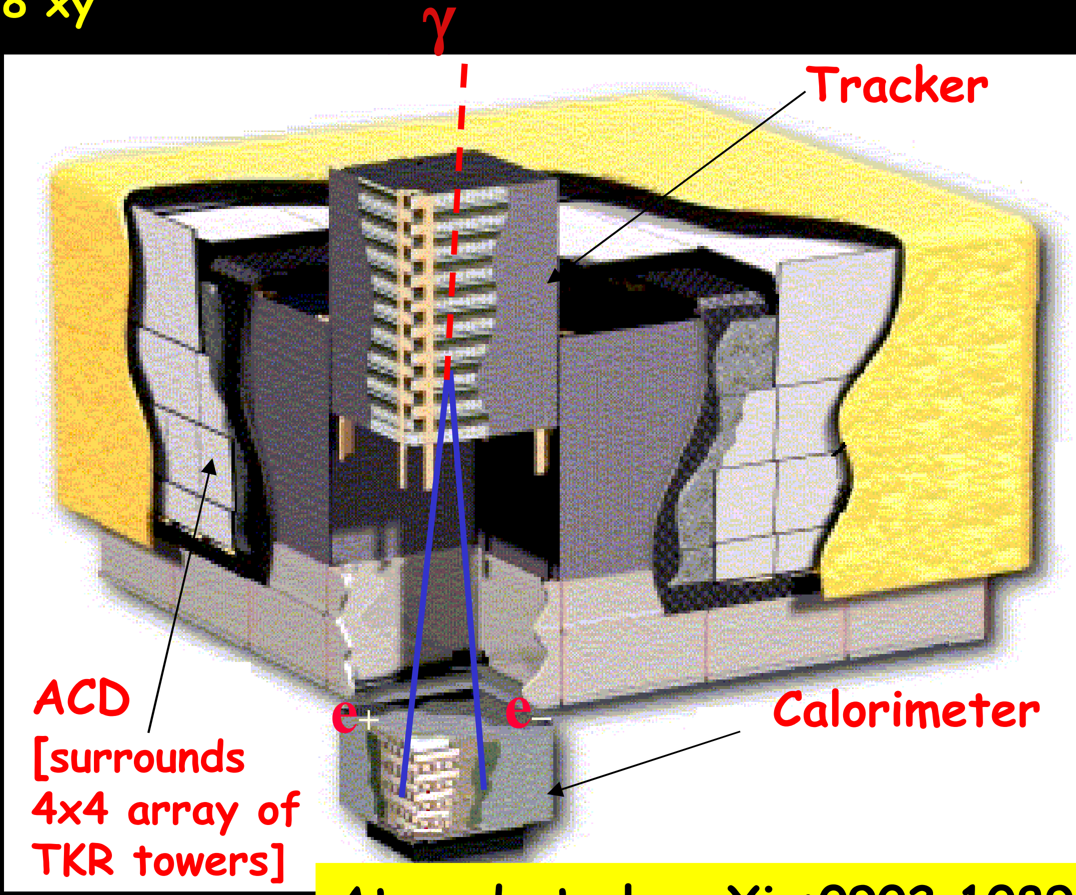
Hodoscopic CsI Calorimeter (CAL) Measure the photon energy; image the shower.

Segmented Anticoincidence Detector (ACD)

Reject background of charged cosmic rays; segmentation removes self-veto effects at high energy.

Electronics System

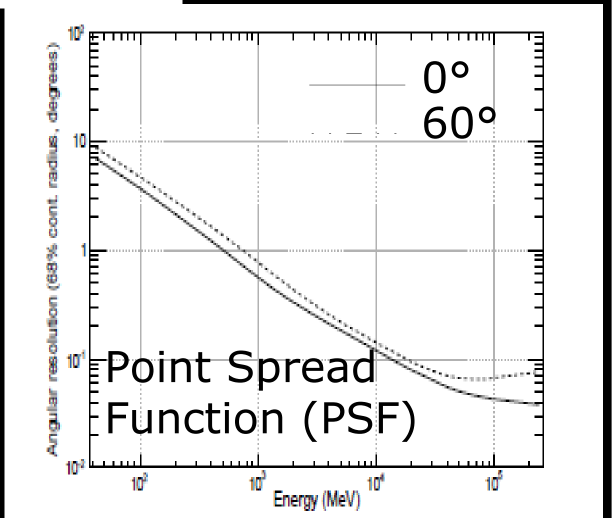
Includes flexible, robust hardware trigger and software filters.

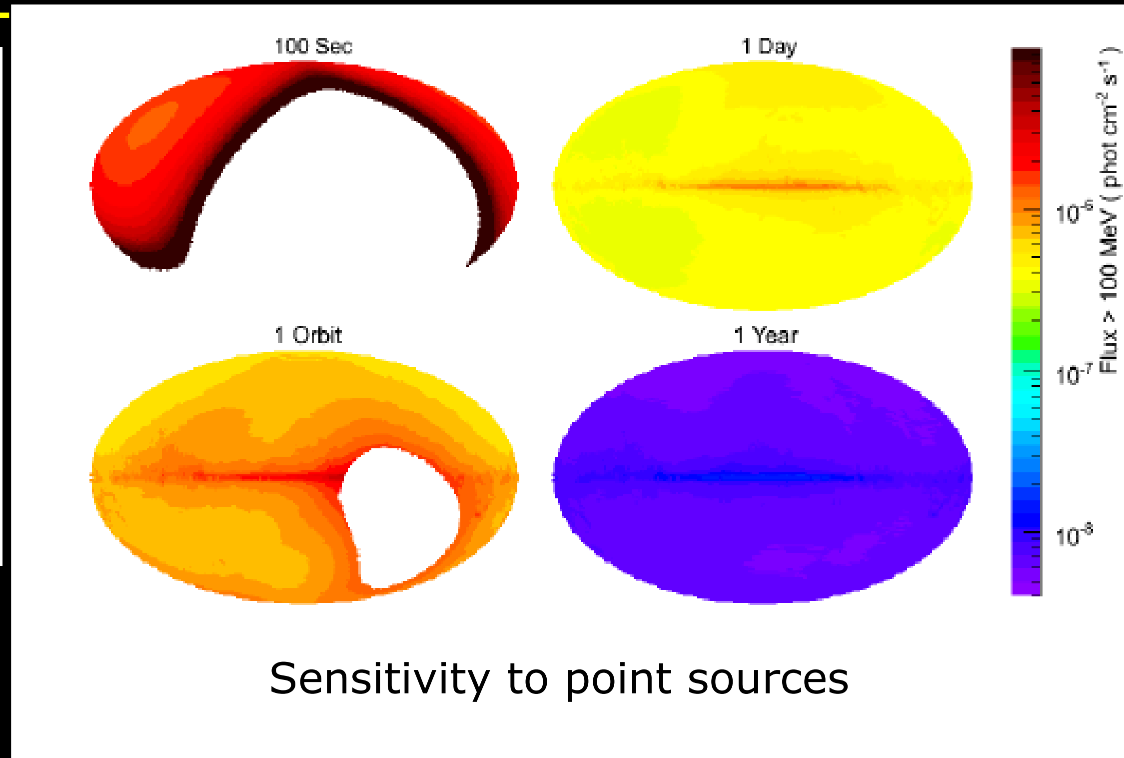


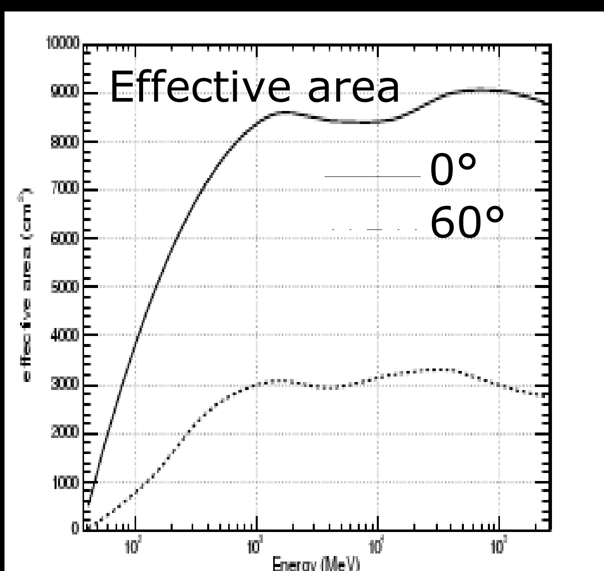
Atwood et al, arXiv:0902.1089 and ApJ 697, 1071 (2009)

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

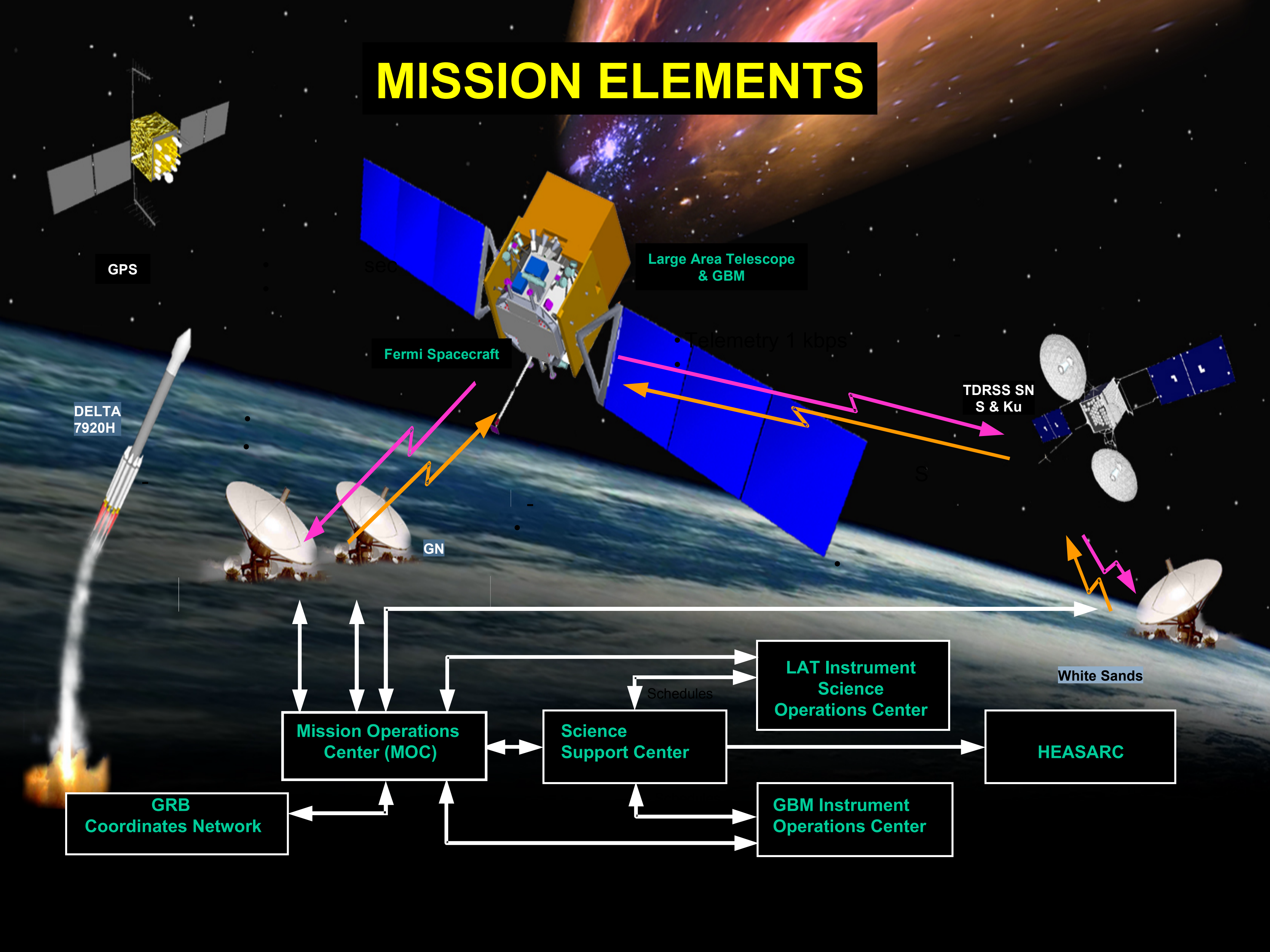
Instrument Performance







- Energy Resolution: ~10%
- PSF (68%) at 100 MeV: ~ 3.5° (front)
- PSF (68%) at 10 GeV: ~ 0.1°
- Field Of View: 2.4 sr
- Point Source sens(>100 MeV): 3×10^{-9} cm^{-2}s^{-1} (1-year survey, assuming $dN/dE \sim E^{-2}$)



MISSION ELEMENTS
GPS
Large Area Telescope
& GBM
Fermi Spacecraft
Telemetry 1 kbps
DELTA
7920H
TDRSS SN
S & Ku
GN
White Sands
LAT Instrument
Science
Operations Center
Schedules
Mission Operations
Center (MOC)
Science
Support Center
HEASARC
GRB
Coordinates Network
GBM Instrument
Operations Center

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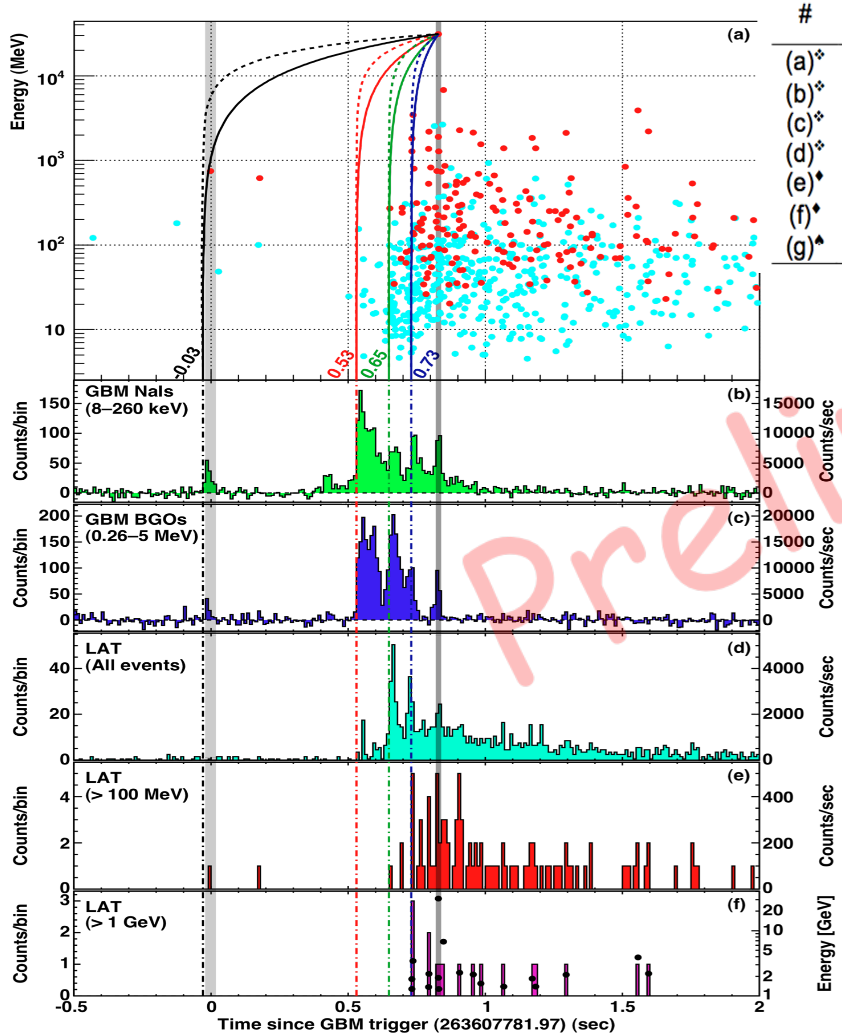


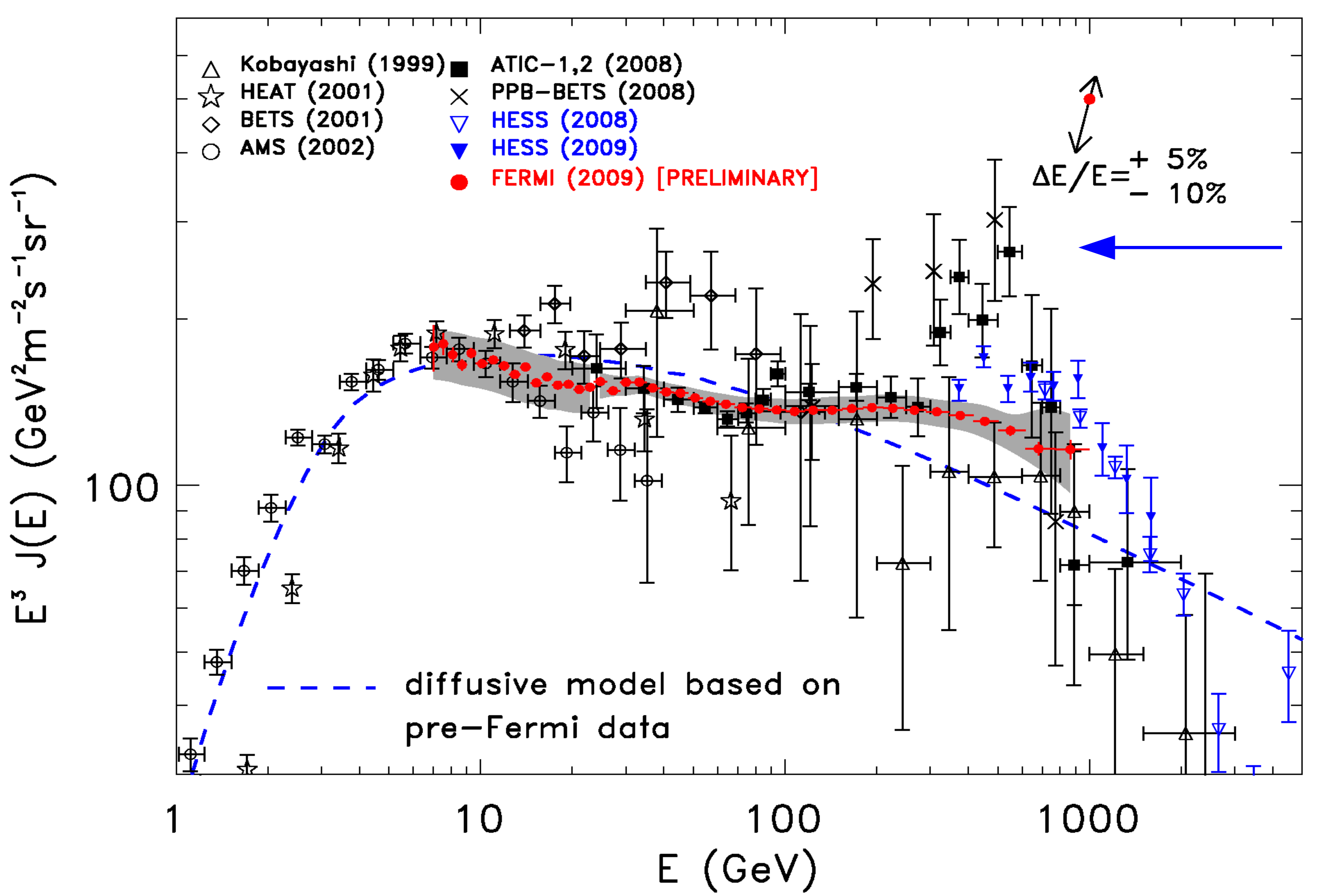
Table 2 | Limits on Lorentz Invariance Violation

#	$t_{start} - T_0$ (ms)	Limit on $\lvert\Delta t\rvert$ (ms)	Reasoning for choice of t_{start} or limit on Δt or $\lvert\Delta t/\Delta E\rvert$	E_l † (MeV)	Valid for s_n*	Lower limit on $M_{QG,1}/M_{Planck}$
(a)✧	−30	< 859	start of any < 1 MeV emission	0.1	1	> 1.19
(b)✧	530	< 299	start of main < 1 MeV emission	0.1	1	> 3.42
(c)✧	*648*	< 181	start of main > 0.1 GeV emission	100	1	> 5.63
(d)✧	730	< 99	start of > 1 GeV emission	1000	1	> 10.0
(e)♦	—	< 10	association with < 1 MeV spike	0.1	±1	> 102
(f)♦	—	< 19	If 0.75 GeV‡ γ-ray from 1st spike	0.1	−1	> 1.33
(g)♠	$\lvert\Delta t/\Delta E\rvert$ < 30 ms/GeV		lag analysis of > 1 GeV spikes	—	±1	> 1.22

arXiv:0908.1832v1
Abdo et al. Nature, 2009

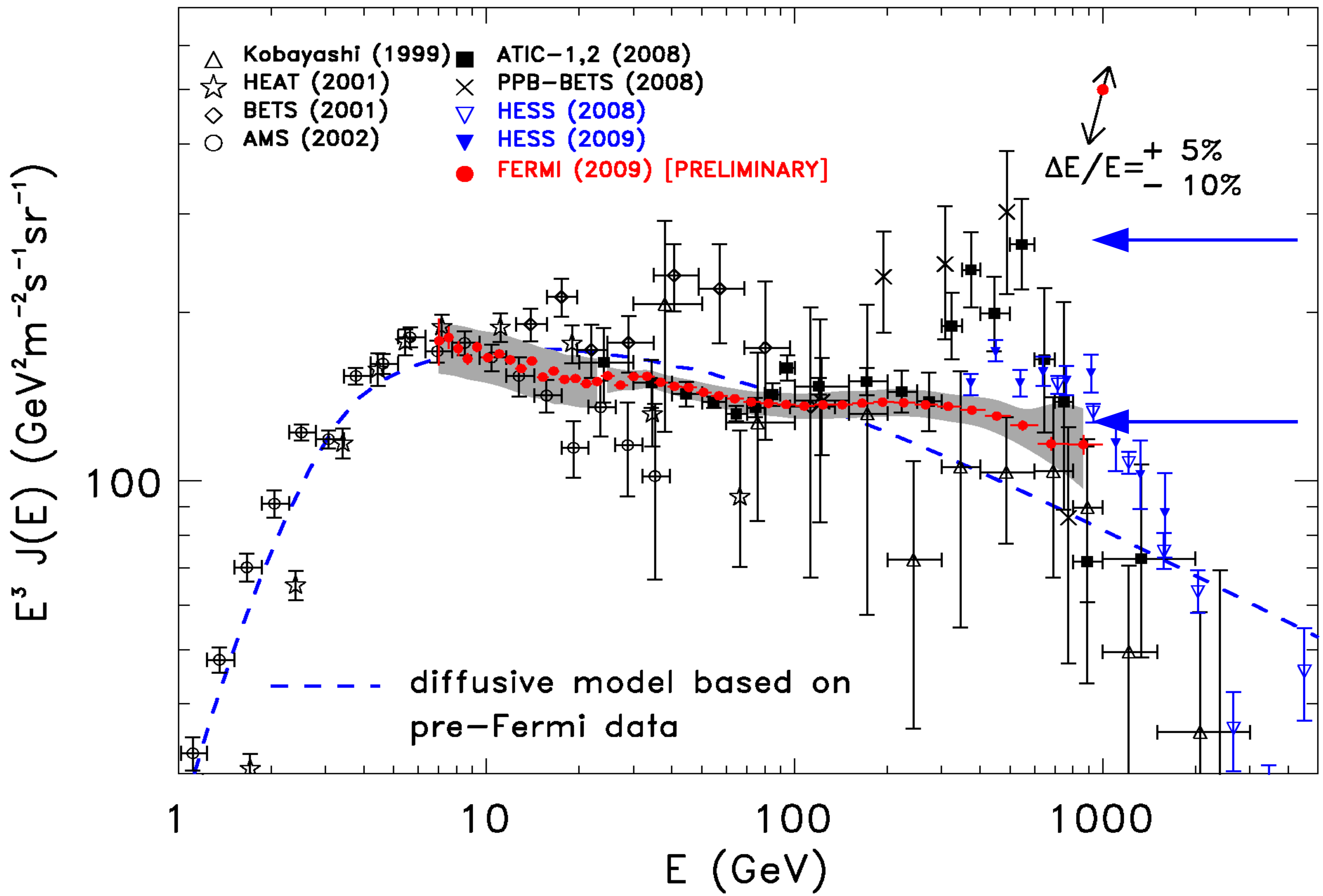
…with the assumption that the HE photons are not emitted *before* the LE photons.

Fermi Electron Spectrum (October 2009)



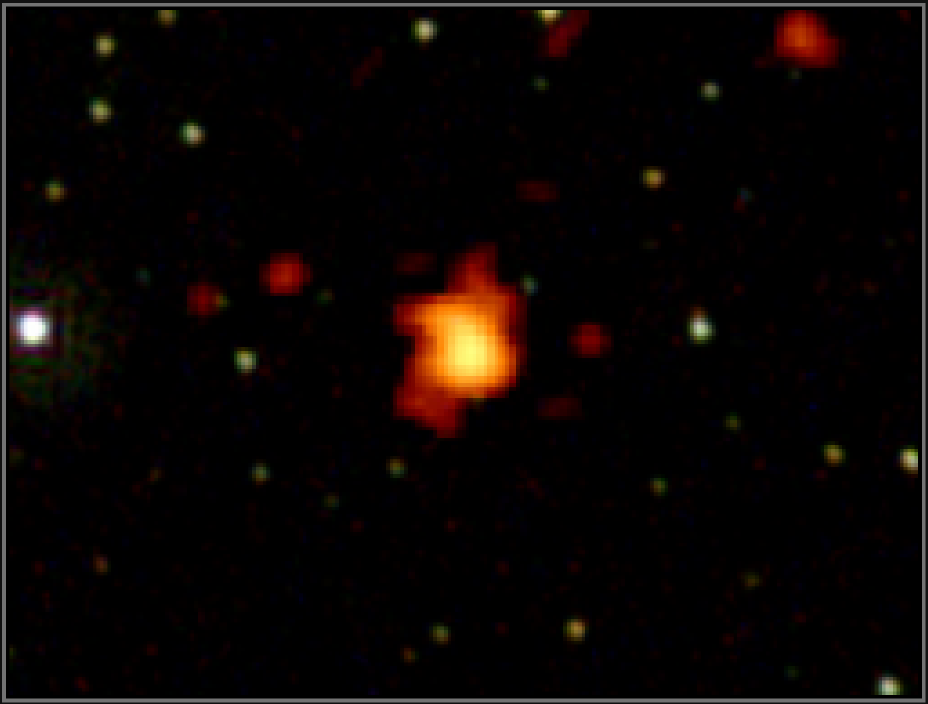
Extended Energy Range (7 GeV – 1 TeV) – One year statistics (8M evts)

Fermi Electron Spectrum (October 2009)



Extended Energy Range (7 GeV – 1 TeV) – One year statistics (8M evts)

Fermi Sees Most Extreme Gamma-ray Blast Yet



The first burst to be seen in high-res by the Fermi telescope had the greatest total energy, the fastest motions and the highest-energy initial emissions ever seen.

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19-2-2009

located at 12B light years from us using observations of radio afterglow by the GROND observatory

Large fluence (2.4×10^{-4} erg/cm^2)

& redshift ($z = 4.35 \pm 0.15$)

⇒ record breaking

- **$E_{\gamma,iso} \approx 8.8\times10^{54}$ erg $\approx 4.9\ M_{\odot}c^2$**
- $\Gamma_{min} \approx 890 \pm 20$
- **$M_{QG} > 1.5 \times 10^{18}$ (GeV)**