Highlights from the Fermi Large Area Telescope

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on behalf of
the Fermi-LAT Collaboration

IFAE2017, Trieste

Outline

- The Fermi Observatory
  - Mission status and prospects
- Science highlights
  - The γ-ray sky
  - Probing Dark Matter
  - GW follow-up
  - Not only γ-rays: CR electrons

The Fermi Observatory

Large Area Telescope [LAT]
- pair conversion
- 20 MeV - >300 GeV

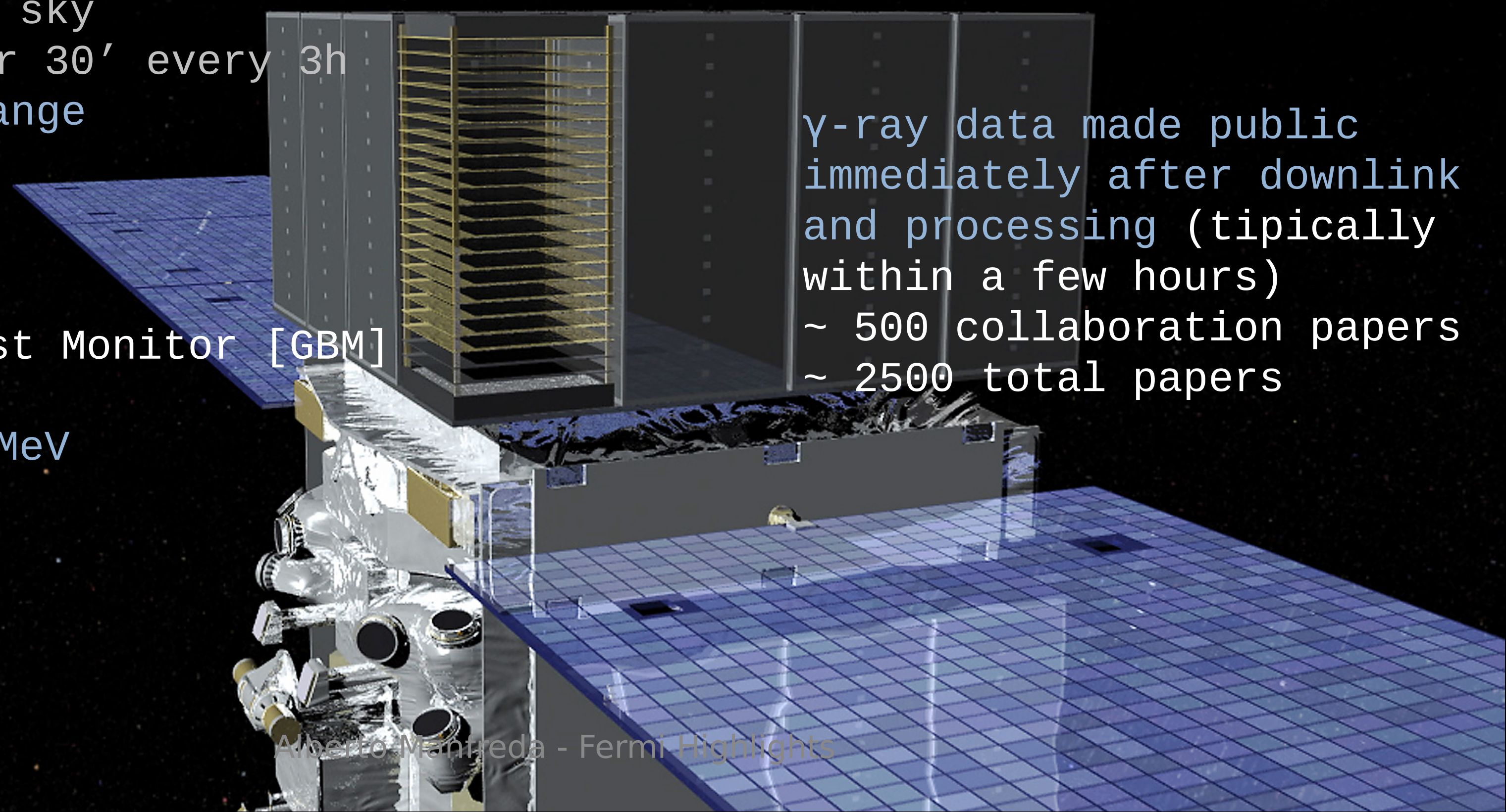
Huge FoV (2.4 sr)
- instant 20% sky
- full sky for 30’ every 3h

Wide energy range

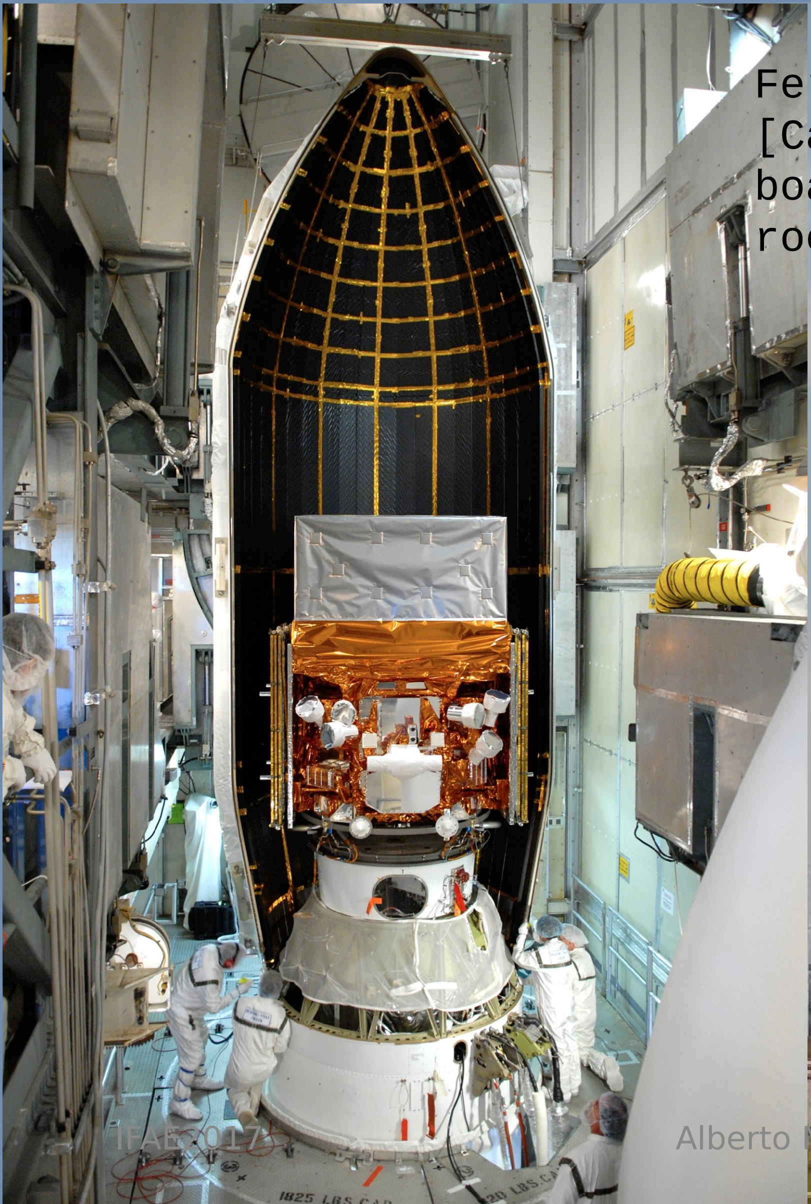
Gamma-ray burst Monitor [GBM]
- counters
- 8 keV – 40 MeV

An International Collaboration
~ 400 Scientific Members
- NASA/DOE
- International contributors

γ-ray data made public immediately after downlink and processing (tipically within a few hours)
~ 500 collaboration papers
~ 2500 total papers



The Fermi Observatory

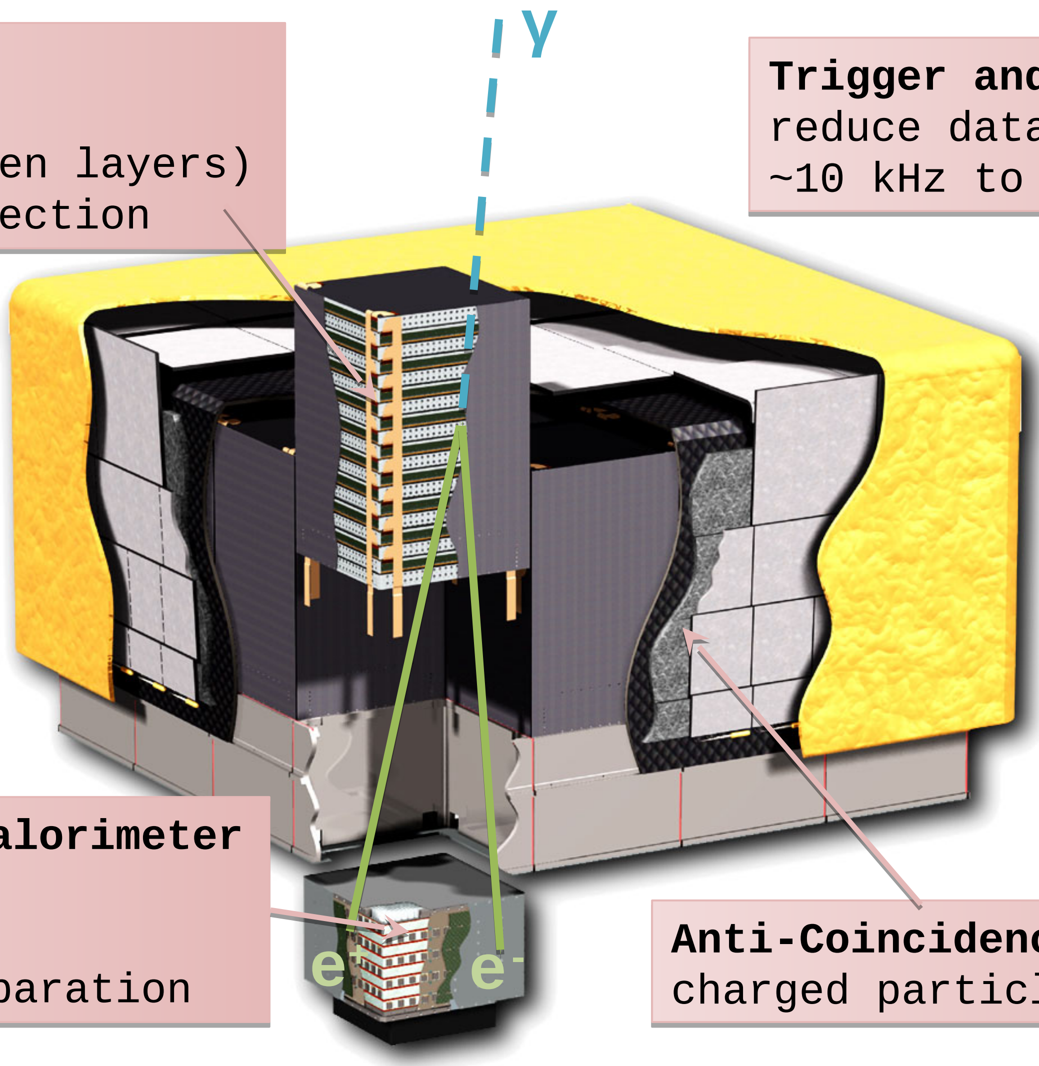


Fermi was launched from [Cape Canaveral] on board a Delta II 7920-H rocket on July 11, 2008

The Fermi-LAT

Si-strip Tracker
convert γ → e^+e^-
(mostly in tungsten layers)
reconstruct γ direction

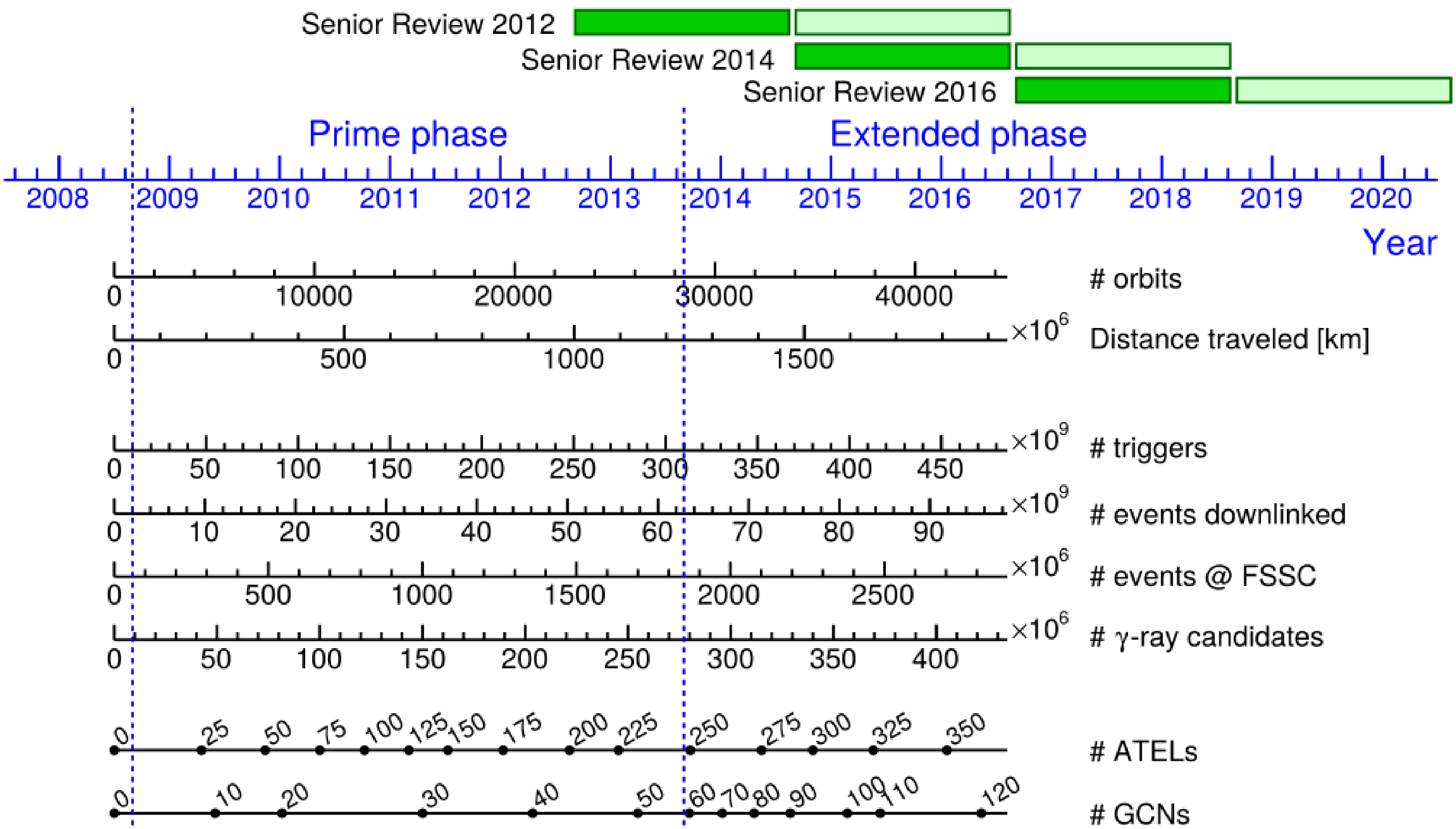
Trigger and Filter
reduce data rate from
~10 kHz to 300-500 Hz



Hodoscopic CsI Calorimeter
measure γ energy
image EM shower
EM vs. hadron separation

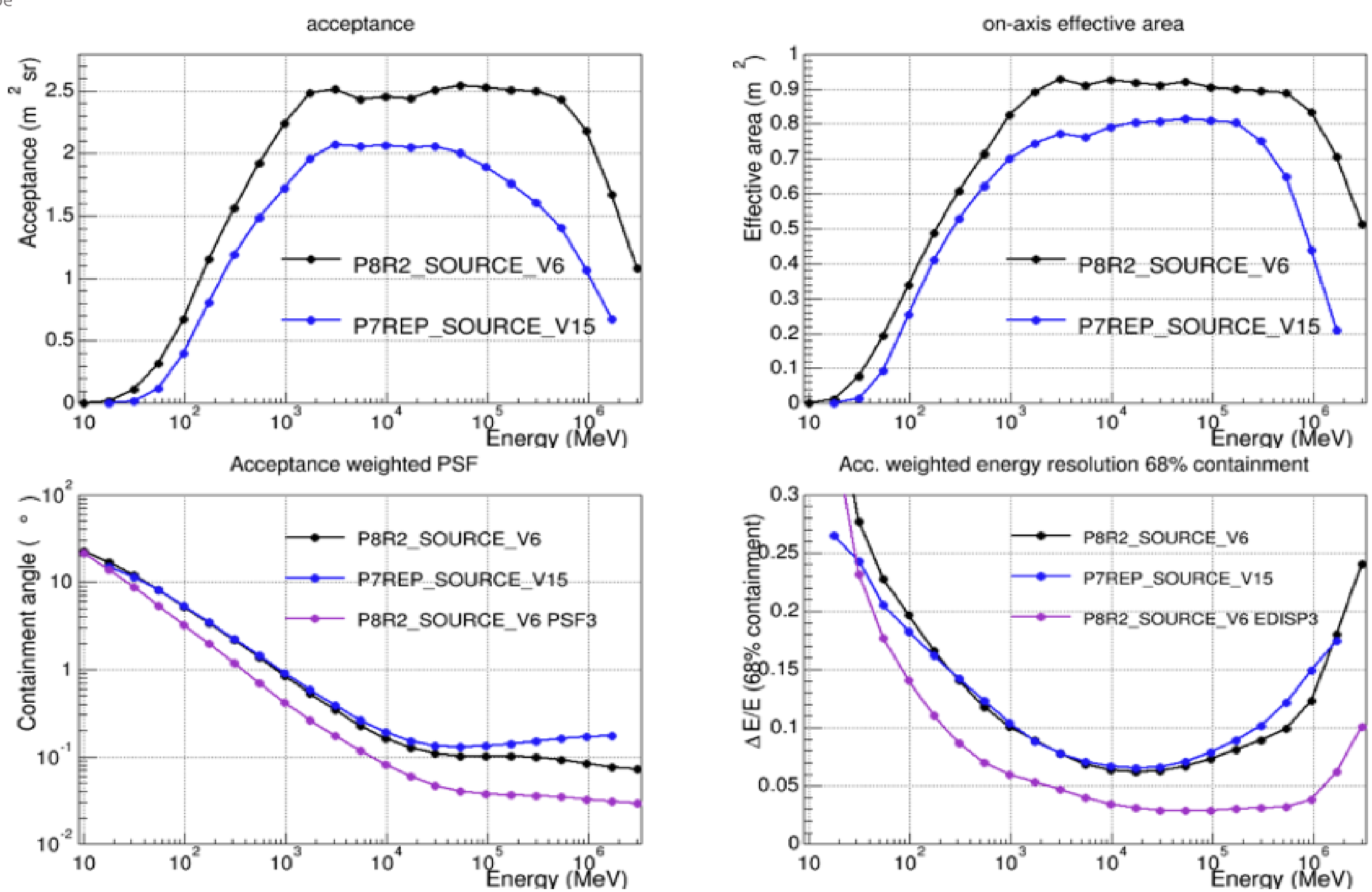
Anti-Coincidence Detector
charged particle separation

Mission Timeline



NASA Spring 2016 Senior Review confirm operations through 2018 and recommend through 2020
http://science.nasa.gov/astrophysics/documents

Pass-8 Event Reconstruction



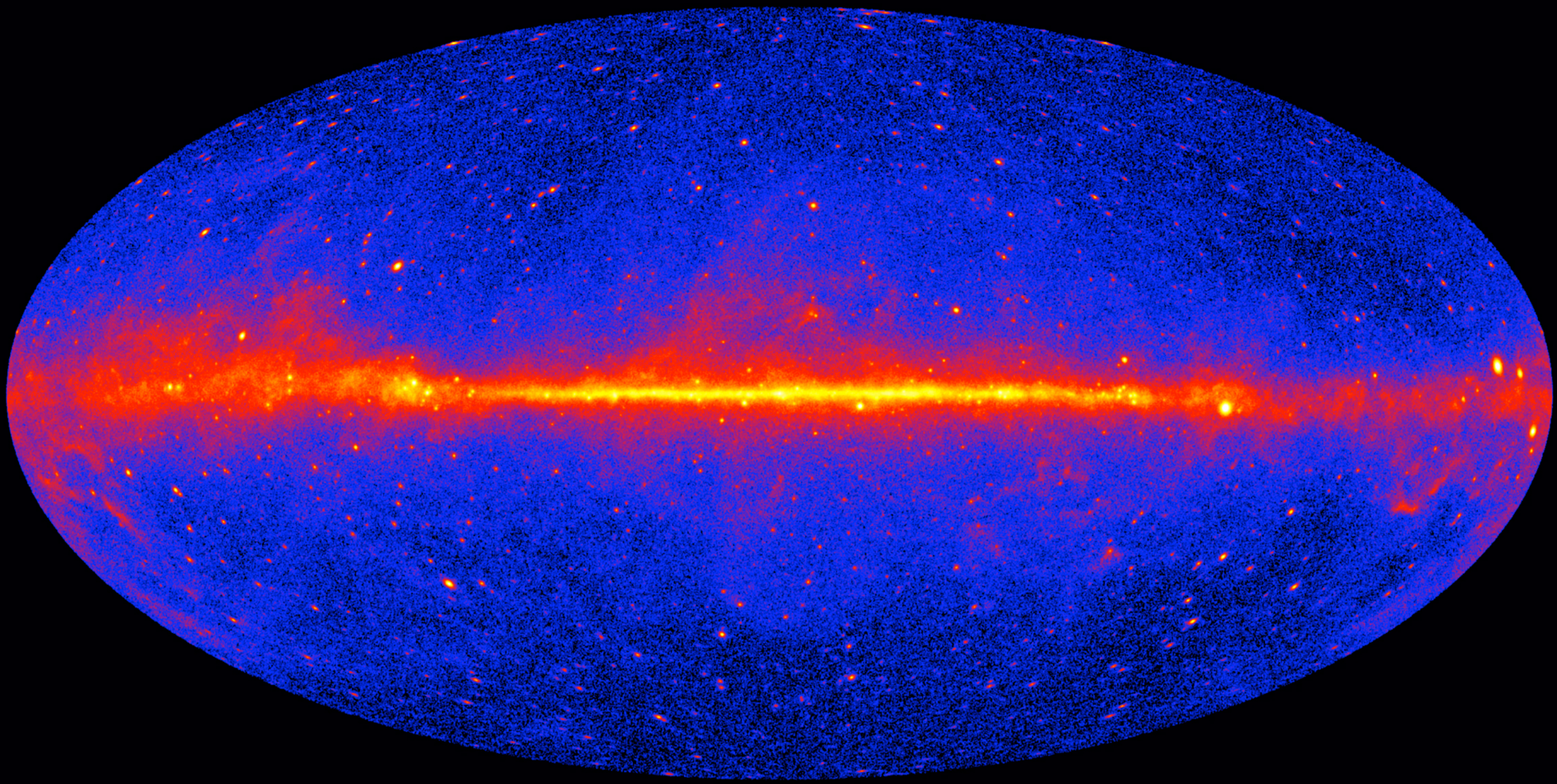
Public release in June 2015

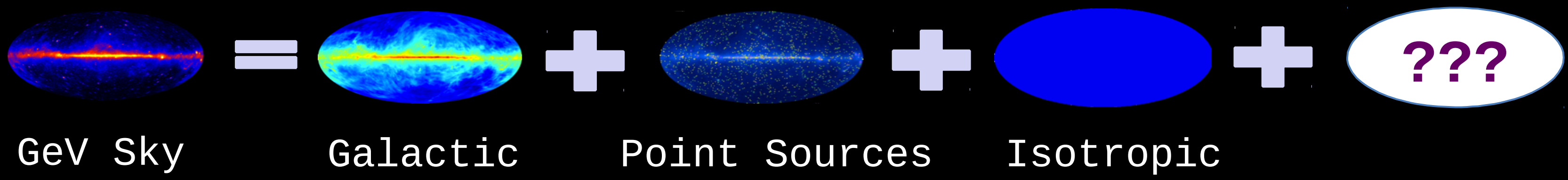
Higher acceptance – wider energy range – better resolution

A new, improved LAT: Pass-8 was worth the huge effort!

https://www.slac.stanford.edu/exp/glast/groups/canda/lat_Performance.htm

The γ-ray sky





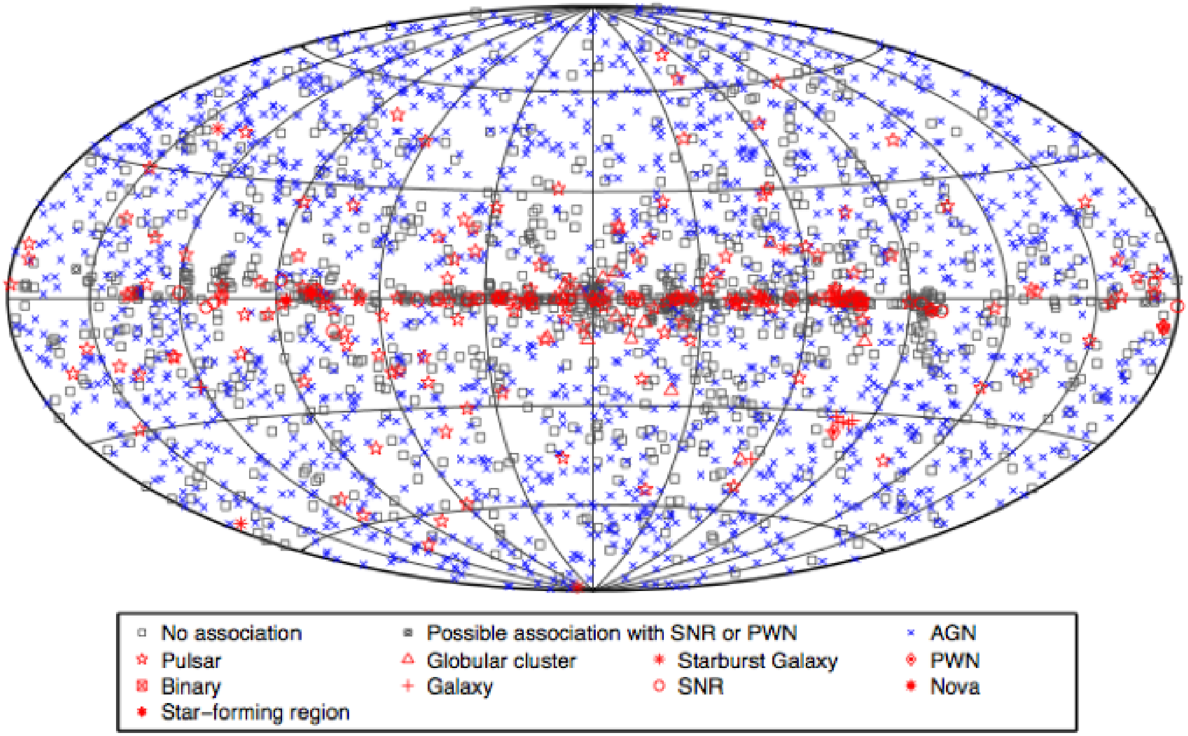
Identifying sources: Catalogs

The third Fermi-LAT catalog [3FGL]
4 years - 3000+ sources

2015, ApJS, 218, 23

Galactic sources:
Pulsars, SNRs

Extragalactic sources:
AGNs

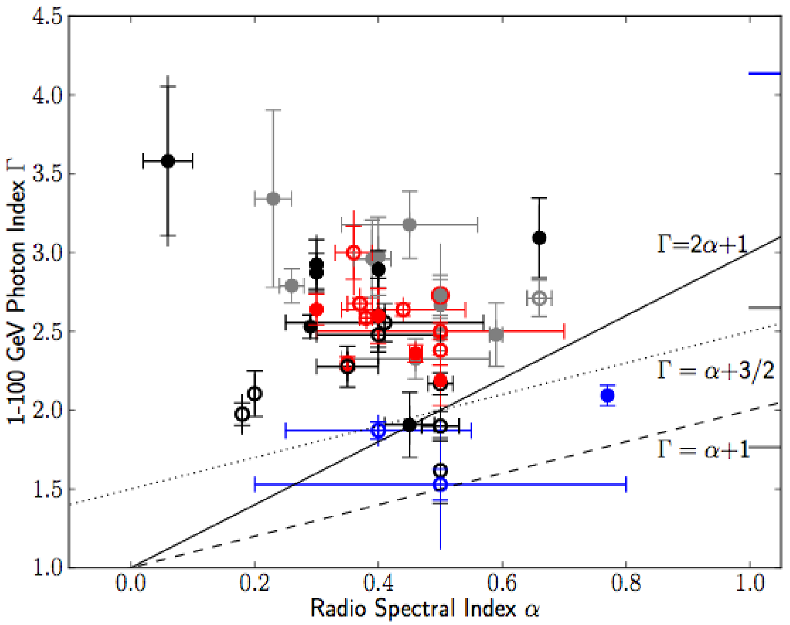


Includes source not seen before in gamma-rays:
non-AGN galaxies,
globular clusters,
high-mass binaries,
novae

30% of sources still unassociated:
new type of gamma-ray emitters?

Class-specific Catalogs

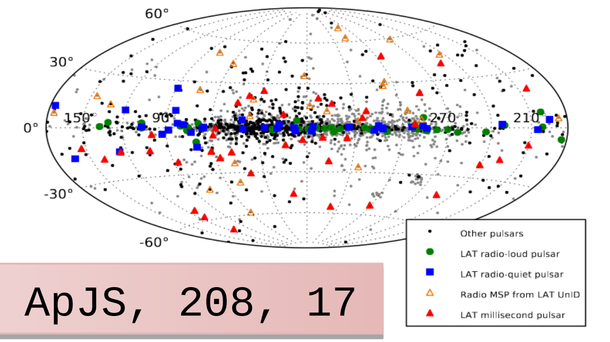
SN Remnants: 1 to 100 GeV



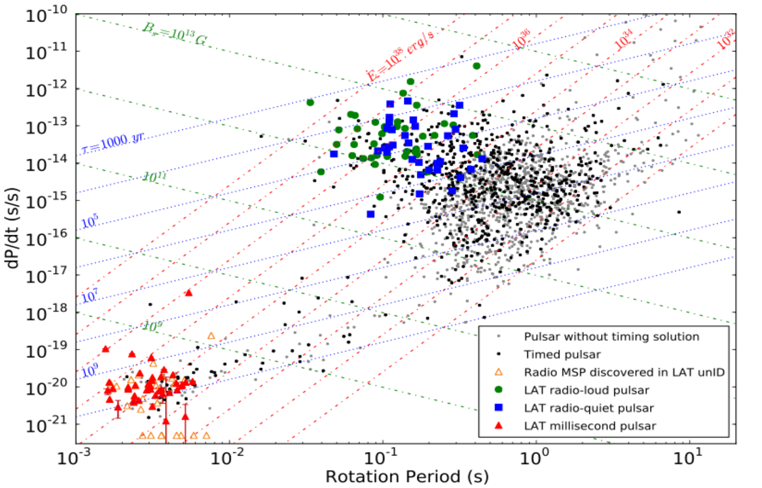
30 sources identified as GeV counterparts to radio SNRs + 14 candidates probably related to SNRs

2016, ApJS, 224, 8

γ-ray Pulsars: 147 sources



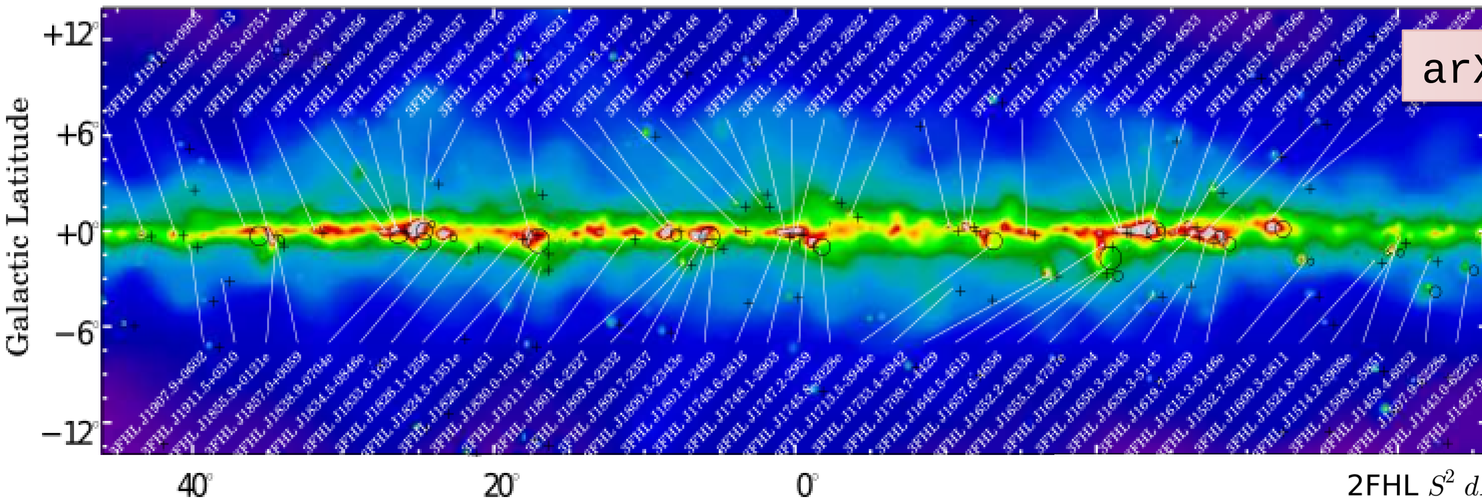
2013, ApJS, 208, 17



PSR J2021+4026 in Gamma-Cyg was the first variable γ-ray pulsar

Hard sources and EBG

Hard sources Catalogs [2FHL, 3FHL]:
1558 sources > 10 GeV, 360 sources > 50 GeV

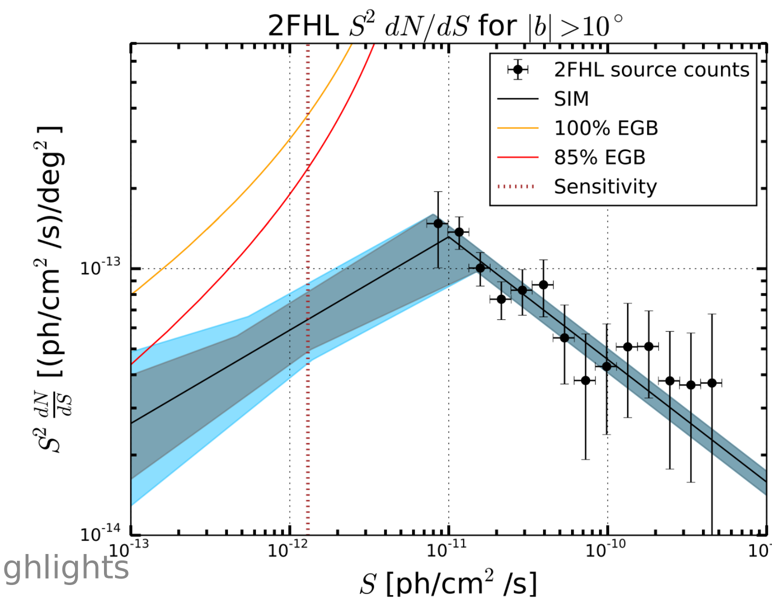


arXiv:1702.00664

Closes the energy gap between the LAT and Cherenkov telescopes

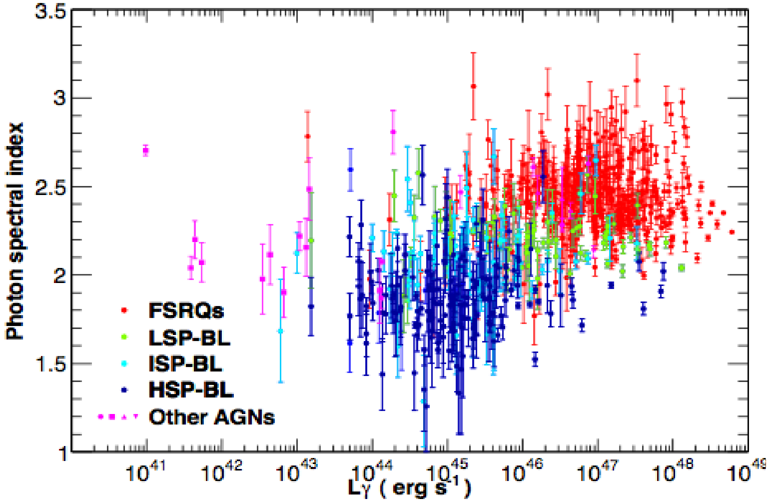
Hard sources contribute for ~85% to the isotropic flux
→ other [exotic] contributions must be small

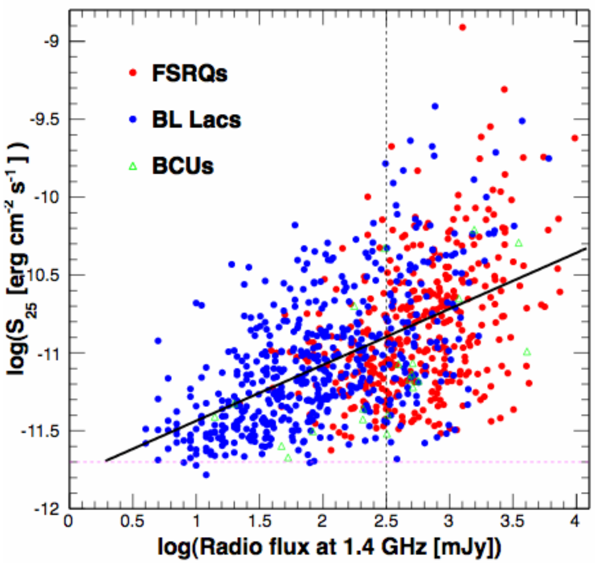
SUGGESTION 2016, PRL, 116, 151105

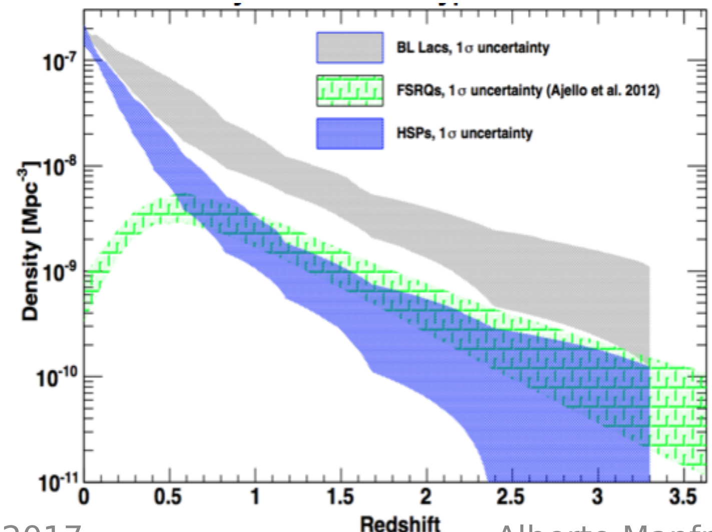


Extragalactic sources: Active Galactic Nuclei

AGN Catalog [3LAC]: 1591 sources







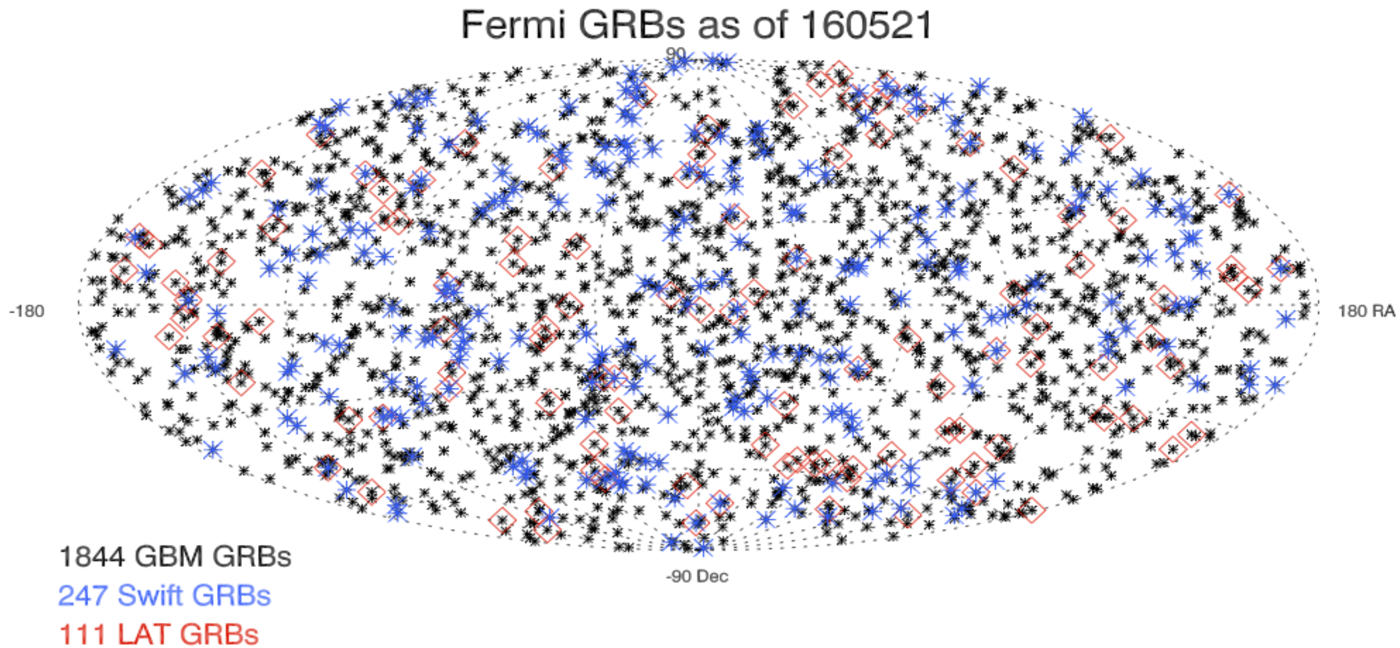
98% of the sources are **blazars**:
BL Lacs + FSRQ

AGN unified model: different view of the same phenomeon

2015, ApJ, 810, 1, 14

Extragalactic sources: GRB

GBM → full unocculted sky / sensitive to impulsive flares
LAT → full sky every 3 hs / sensitive to transients from ms to yr



GBM has detected over 1800 GRBs so far, with over 100 detected by the LAT above 40 MeV

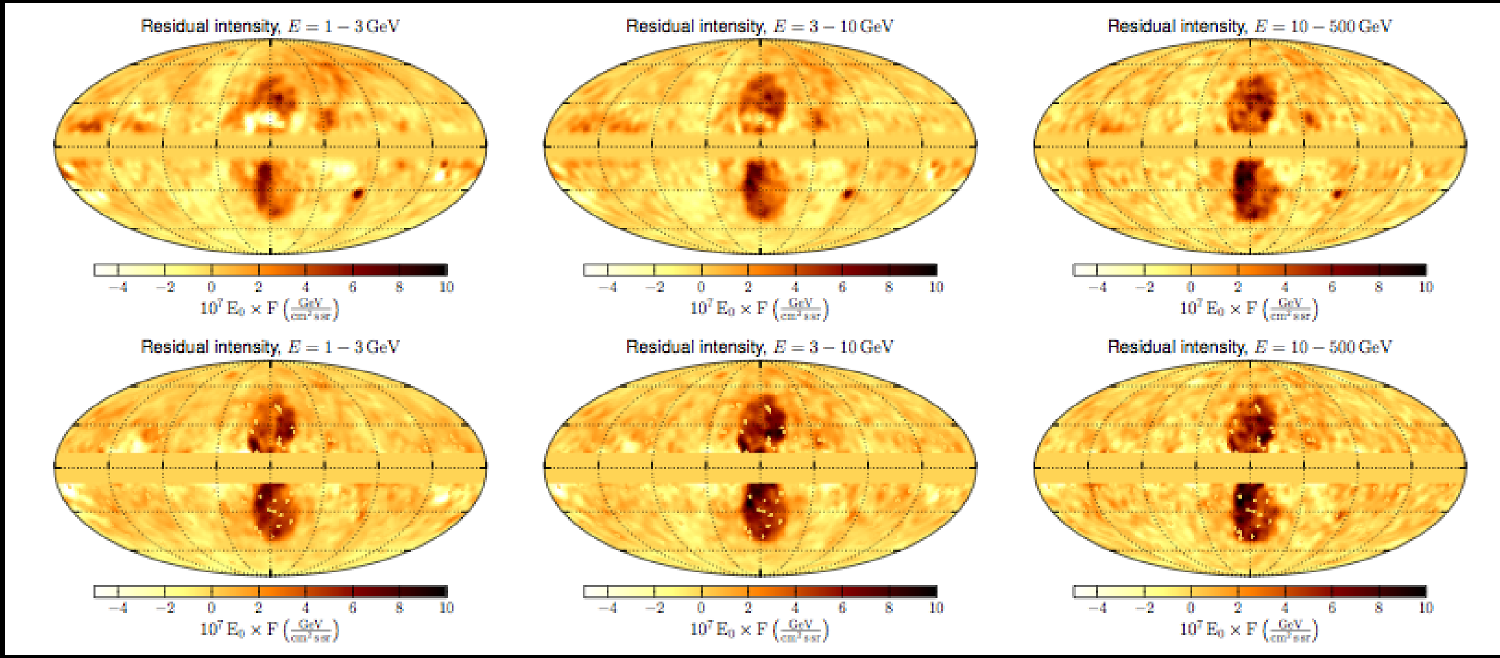
→ **study for the first time the high energy emission tail**

Second LAT GRB catalog (pass-8) in preparation

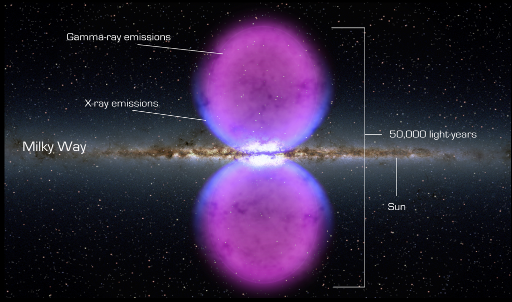
Back to the Milky Way: Bubbles

Is the Milky way an active Galaxy?

2014, ApJ, 793, 64



No, it is currently quiet.
The structures were created by some large energy injection in the GC, maybe a past accretion event onto the central MBH, or a nuclear starburst in the last ~10 Myr.

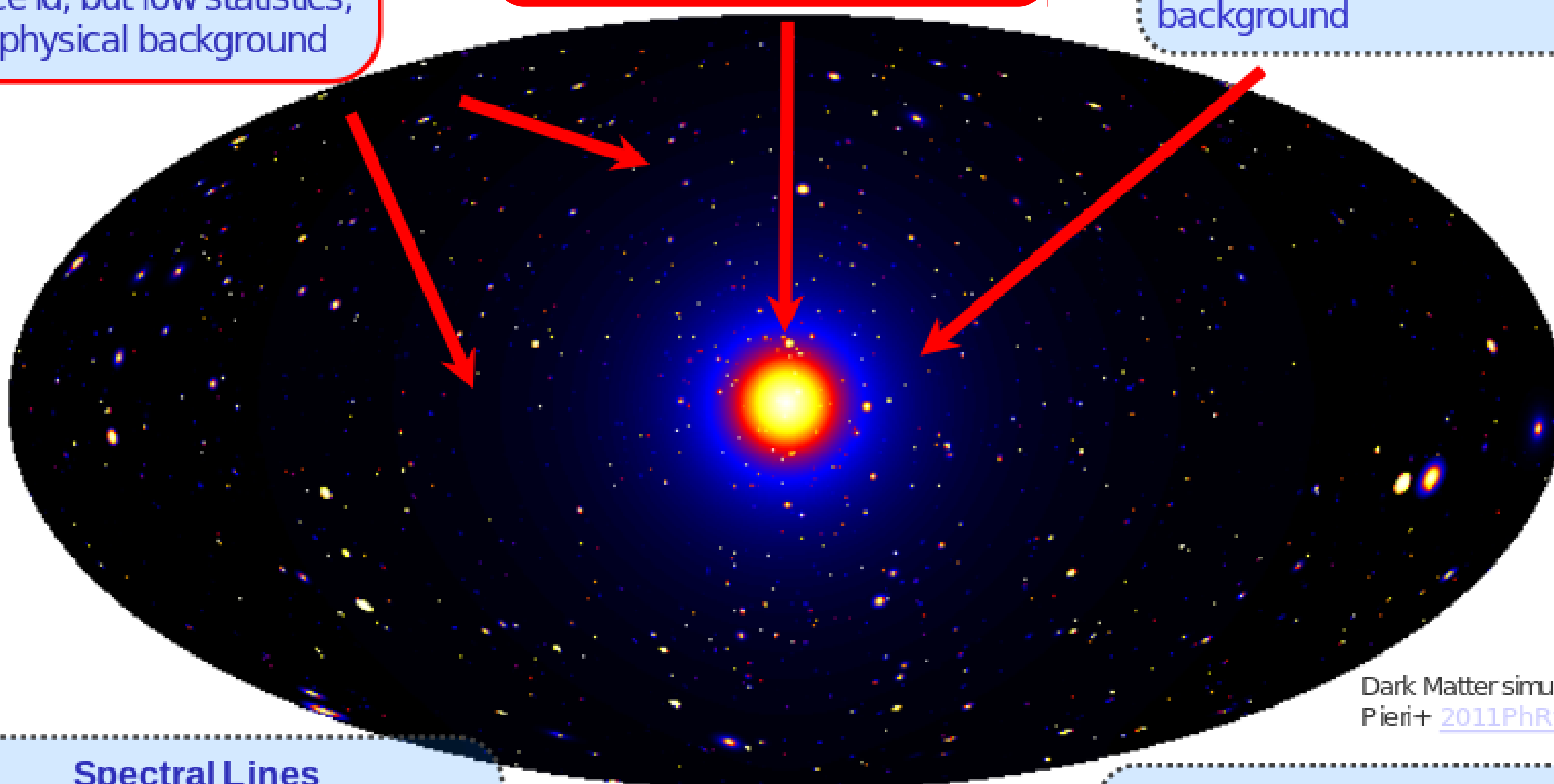


Probing DM: Fermi-LAT DM search targets

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

Galactic Center
Good Statistics but source confusion/diffuse background

Milky Way Halo
Large statistics but diffuse background



Dark Matter simulation:
Pieri+ 2011PhRvD..83b3518P

Spectral Lines
No astrophysical uncertainties, good source id, but low sensitivity because of expected small BR

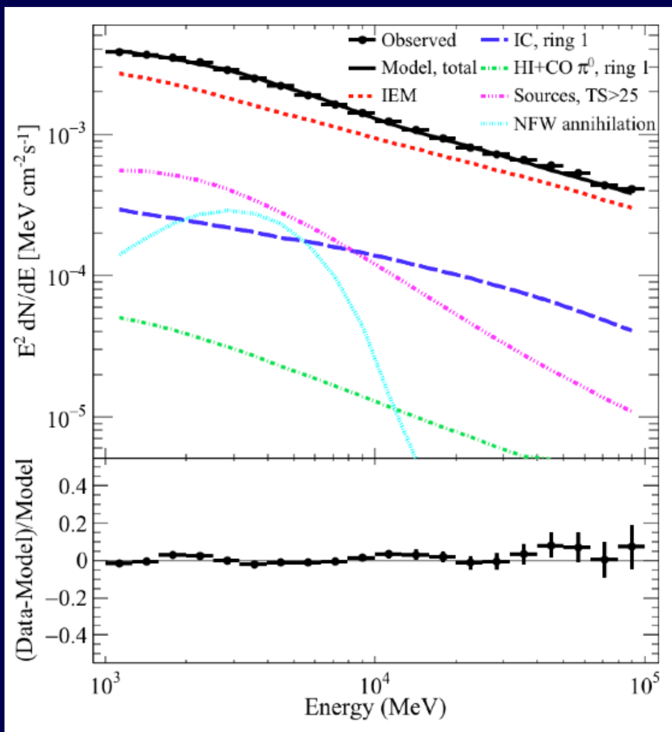
Galaxy Clusters
Low background, but low statistics

Extragalactic
Large statistics, but astrophysics, galactic diffuse background

Probing DM: Diffuse emission from the Inner Galaxy

Independent analyses report a spatially extended excess

- Spherically symmetric, spectrum **consistent with DM**



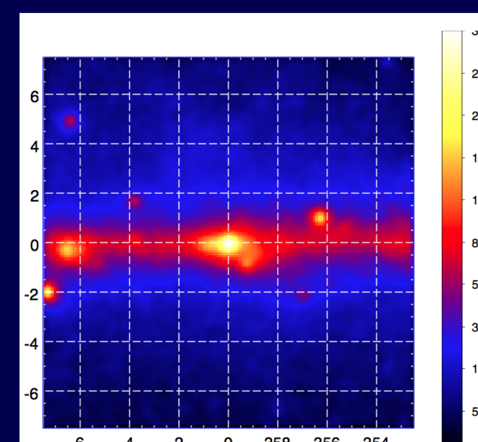
Included in the model:

- Galactic diffuse emission (sum of many processes)
- isotropic gamma-ray background (measured)
- detected gamma-ray sources

What's not in the model:

- unresolved gamma-ray sources
- dark matter

2016, ApJ, 819, 44

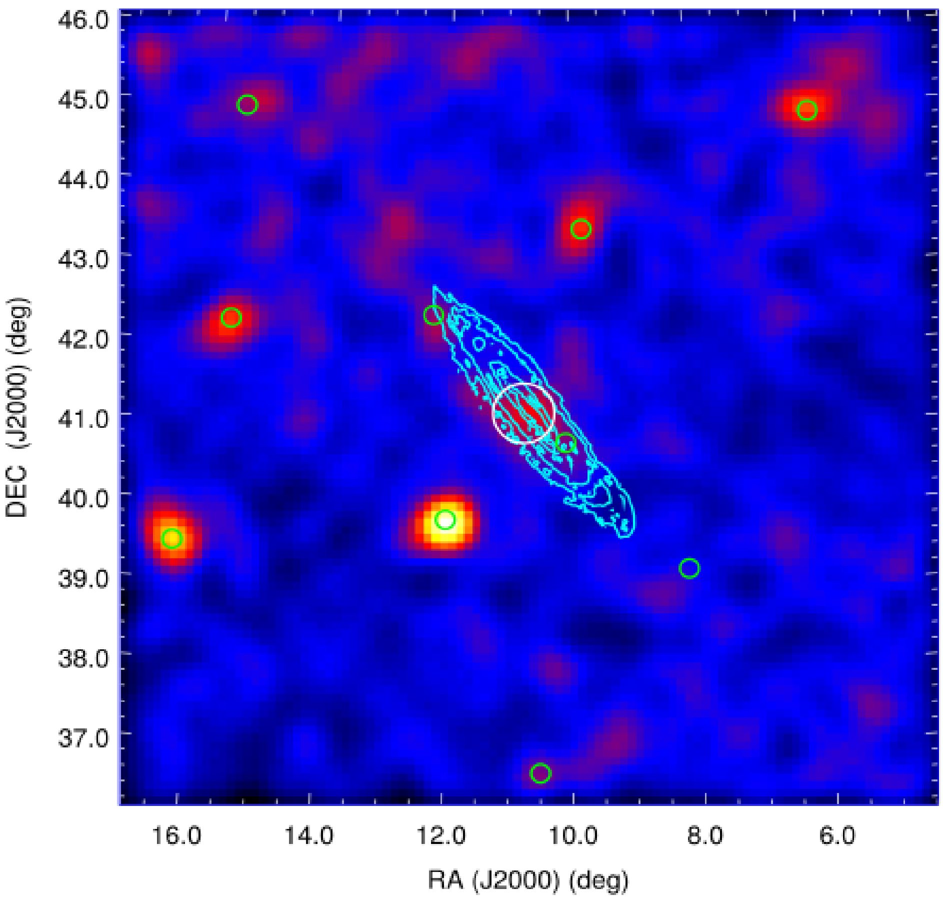


- Degenerate with potential **astrophysical contributions**
  - diffuse from CR inhomogeneity, MSP

Probing DM: M31

2017, Apj, 836, 2

No disk emission detected!



Probing MW emission models

How to explain the the emission?

Cosmic-rays…
… but apparently not correlated with gas distribution or star-formation activity

DM…
… but in tension with excess from our Galactic Center
(~5x too high)

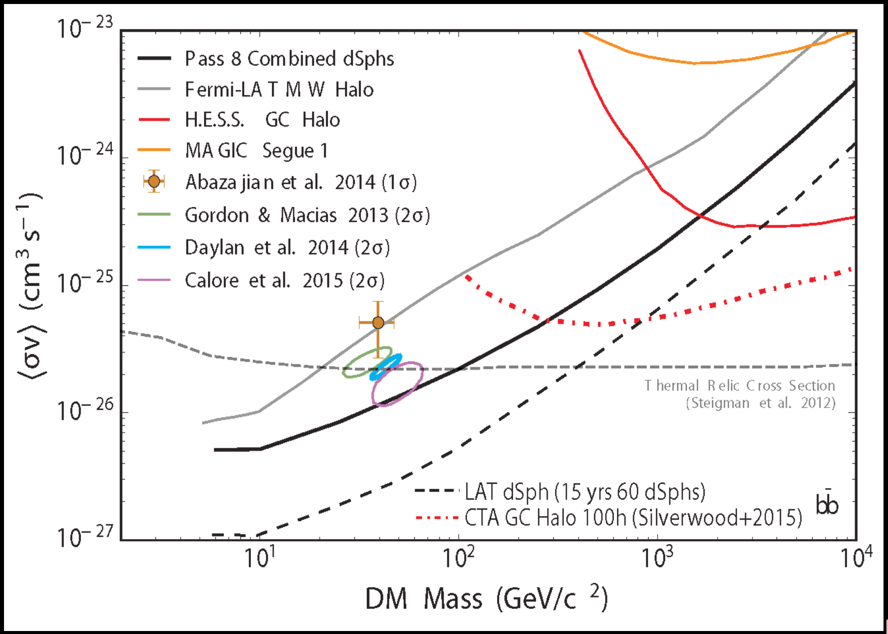
MSP…
… can explain GCE too?

Probing DM: the Dwarf Spheroidal Satellite Galaxies

- Kinematics → dSphs of the Milky way contain a large DM component
- Optical surveys are significantly increasing the number of known dSphs [DES: arXiv:1508.03622,1503.02584,1503.02079]

Signal = particle physics x astrophysics

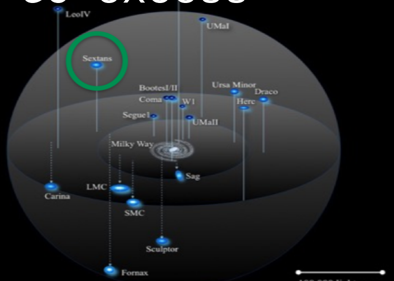
$$\phi_\gamma(E,\Delta\Omega) = \frac{1}{4\pi}\frac{\langle\sigma_\chi v\rangle}{2m_\chi^2} N_\gamma(E) \times J(\Delta\Omega)$$



Joint analysis of 15 dSphs: exclude thermal relic annihilation cross section for m_χ<100 GeV through the quark b and τ channel

Non observation of γ-rays from dSphs in the next 4 years → exclude WIMP mass below ~400 GeV and rule out the DM GC excess

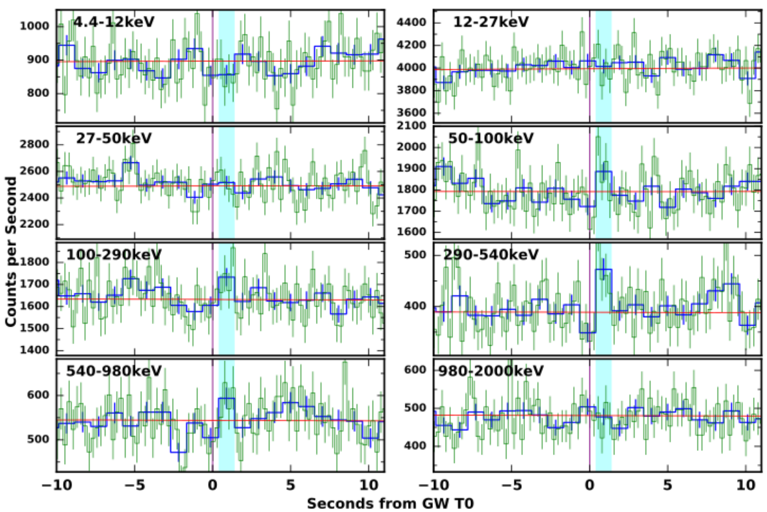
2015, PRL, 115, 23



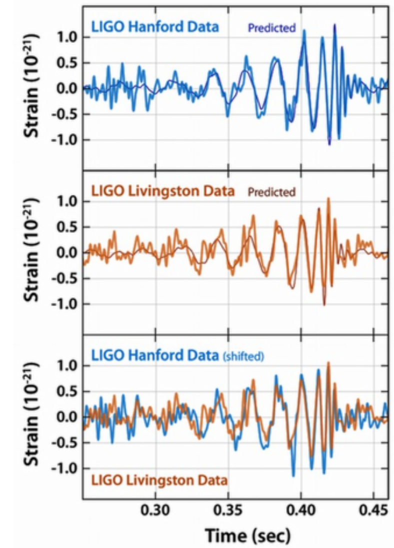
Multimessenger: Follow-up of GWs

A needle in a haystack…

GBM:
No triggers from standard onboad or offline pipelines
→ **candidate from specific "subthreshold" pipeline**
Estimated FAR: 0.002 / Close to Earth limb

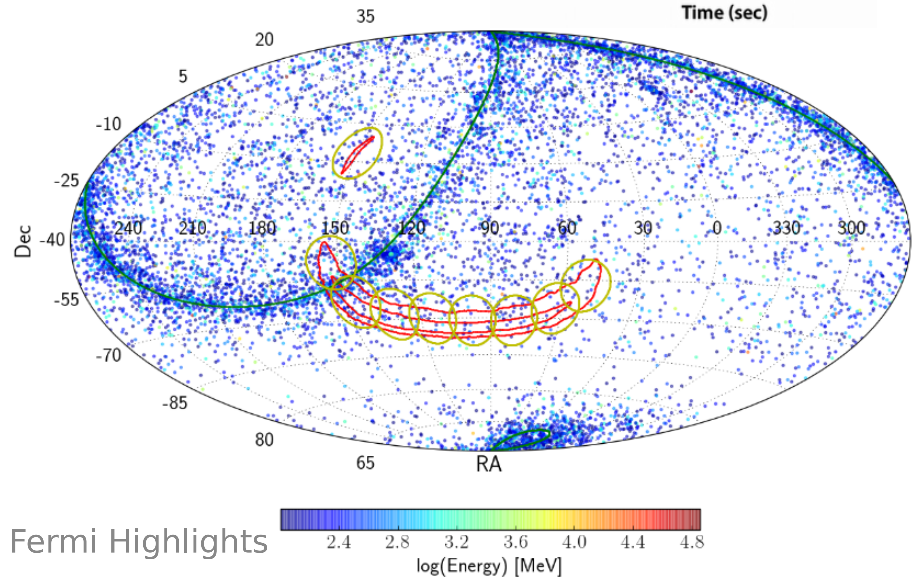


GW150914



2016, ApJ, 823, 1, L2

LAT:
Coverage started from t+70 m
No triggers on automatic pipeline
No significant excesses on short and long-based ad hoc pipelines

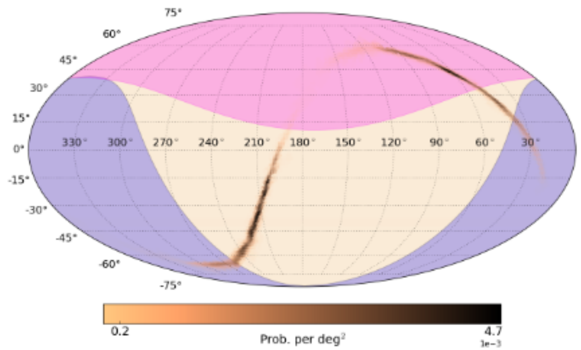


Multimessenger: Follow-up of GWs

GW151226

GBM-Occulted
Loc. Prob. = 83%

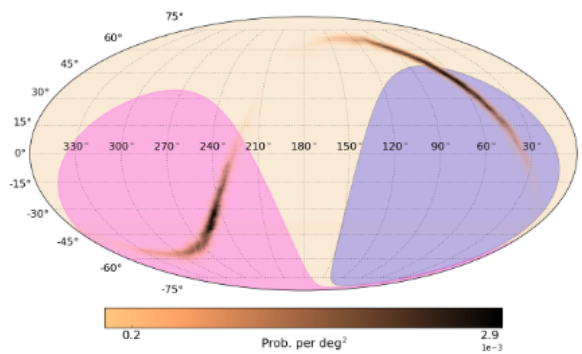
LAT FoV
Loc. Prob. = 32%

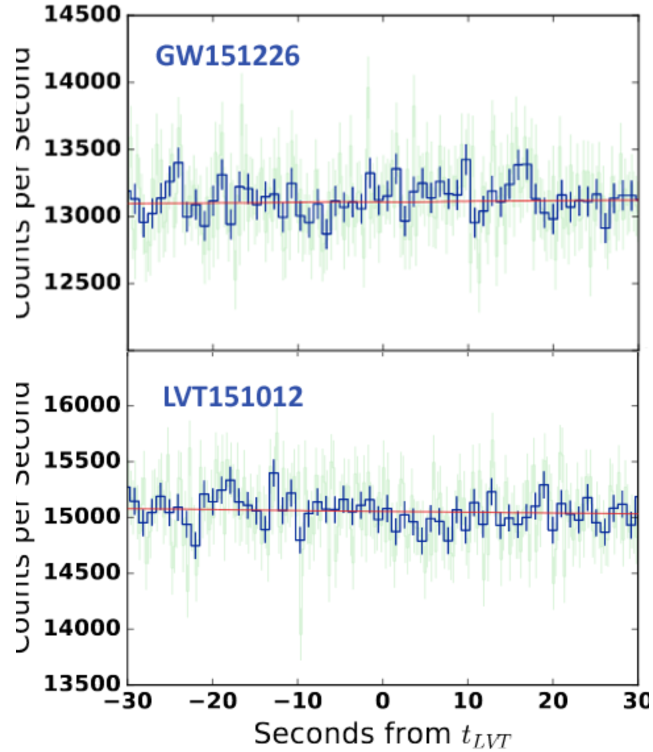


LVT15101

GBM-Occulted
Loc. Prob. = 68%

LAT FoV
Loc. Prob. = 47%





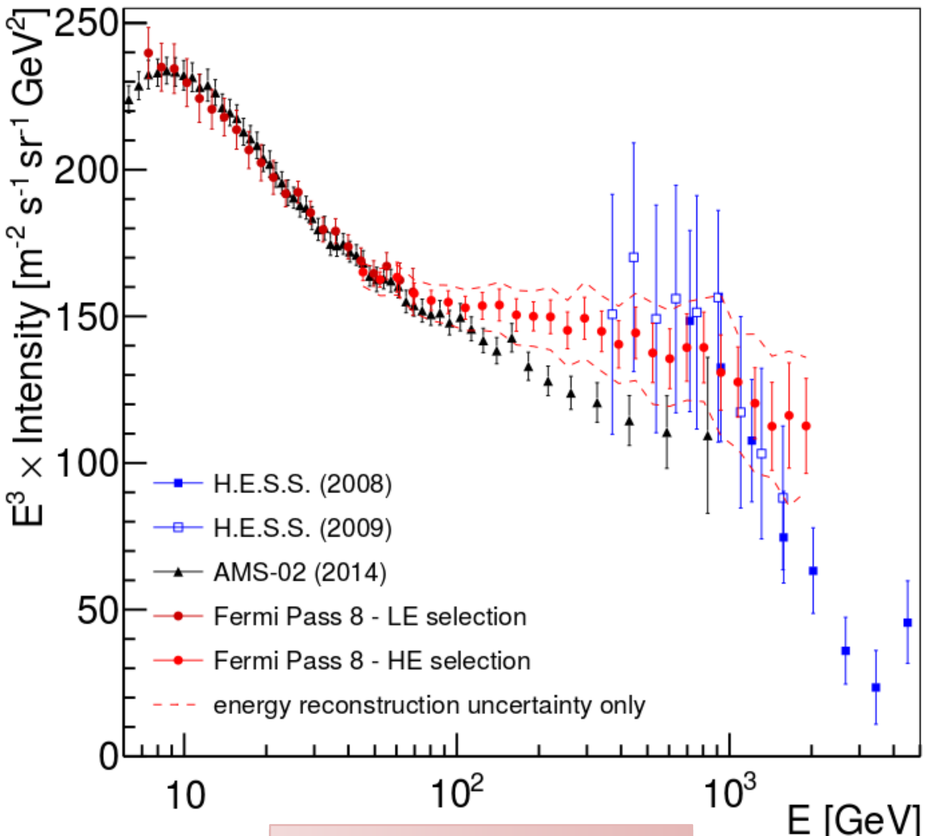
No candidate EM counterparts were detected by either the GBM or LAT.

arXiv:1606.04901

However…
Black hole mergers are not expected to emit significant X-ray or γ-ray signals because any gas around binary BHs should be swept up long before the final merging

Comsic-ray Electrons

Spectrum from 7 GeV to 2 TeV



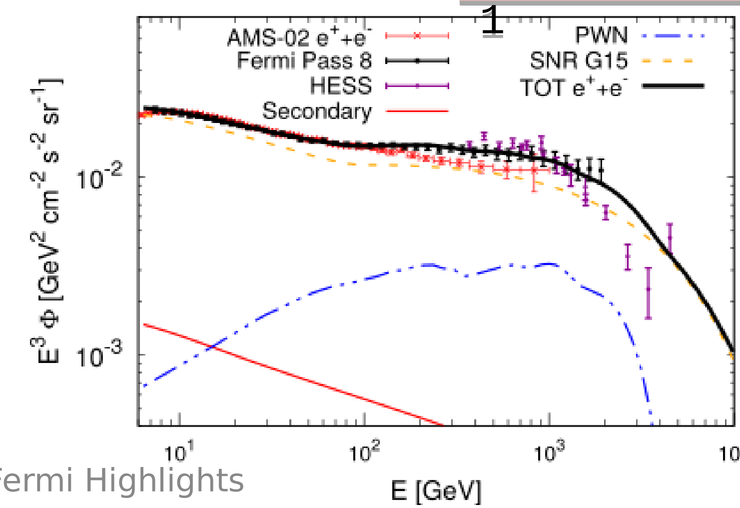
accepted by PRD

Best fit: Broken PL
Break at ~50 GeV
Index 1: 3.21 ± 0.02
Index 2: 3.07 ± 0.02 ± 0.04

Cutoff < 1.8 TeV excluded
@ 95% CL

Possible interpretation:
Break from injection spectrum, not from diffusion

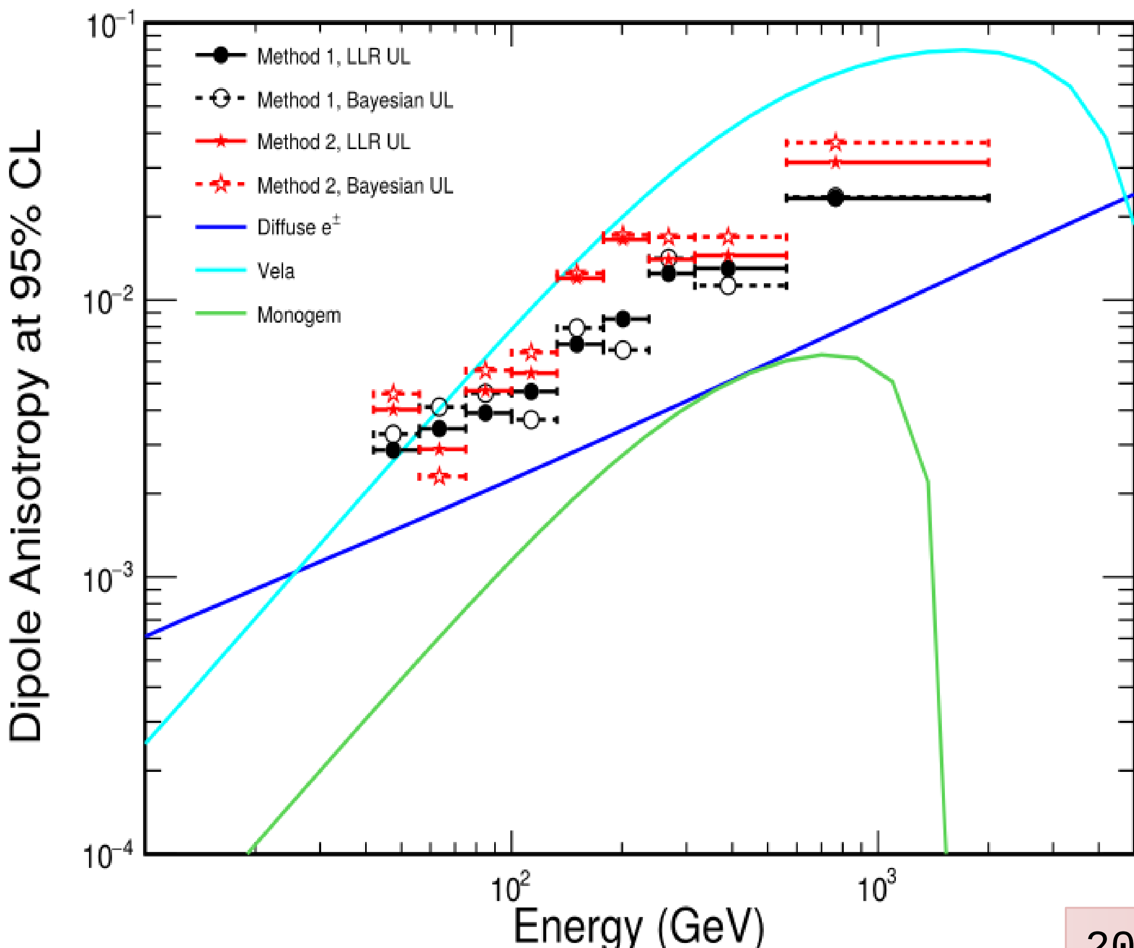
arXiv:1606.04901



First space experiment to probe region > 1TeV

Comsic-ray Electrons

Search for anisotropies



Best electron sample available @ 1 TeV

Probing anisotropies down to 10^{-3} level

No significant anisotropy observed

Limit on dipole anisotropy, starting to rule out individual sources

Still limited by statistics: will improve with time!

2017, PRL, 118, 091103

Not covered in this talk:

- CR physics with the Sun and the Moon 2016, Phys. Rev. D, 93, 082001
- Solar Flares 2015, ApJL, 805, L15
- Novae 2014, Science, 345, 554
- DM lines 2015, Phys. Rev. D, D91, 122002
- Gamma-ray anisotropies and x-correlations 2015, PRL 114, 241301
- Constraints on ALPs 2016, PRL arxiv:1603.06978
-

And others…

Conclusion

- At 9 years from the launch Fermi continue to produce first class science
- Hopefully operations will continue up to 2020 (and after)

From 2016 Senior Review:

"Fermi, the only space born GeV gamma-ray astrophysics observatory world wide, has exciting potential for multi-messenger astrophysics and provides unmatched capabilities for time domain astronomy and astroparticle physics.

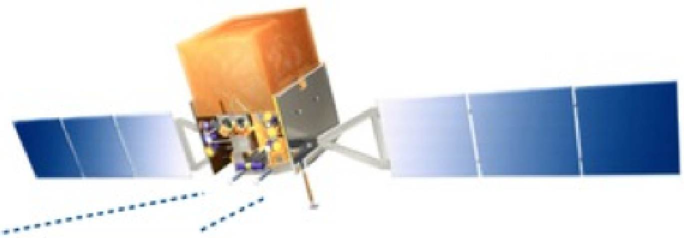
Fermi represents the only significant access to three decades of the GeV gamma-ray sky for many years to come."

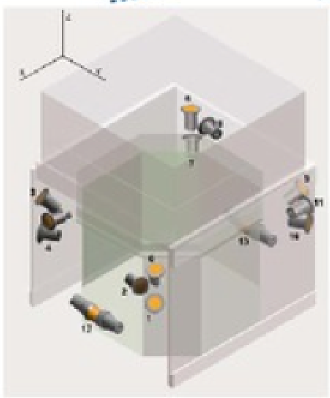
Fermi-LAT Highlights

BACKUP

GBM

Fermi Gamma-ray Burst Monitor





GBM consists of an array of:

- *12 NaI scintillation detectors < 1 MeV*
- *2 BGO detectors < 40 MeV*

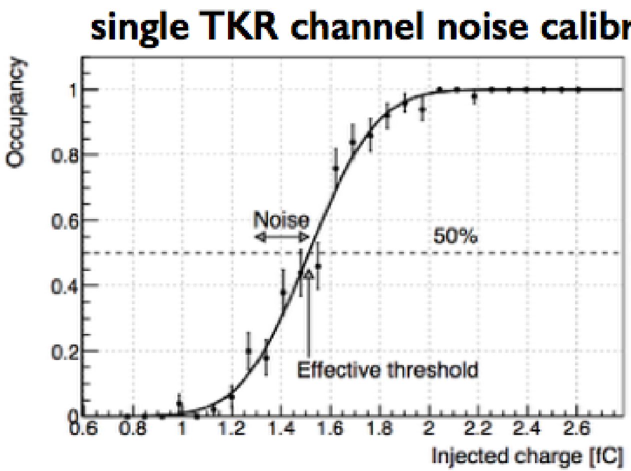
Bursts are seen as coincident excess over background in multiple detectors

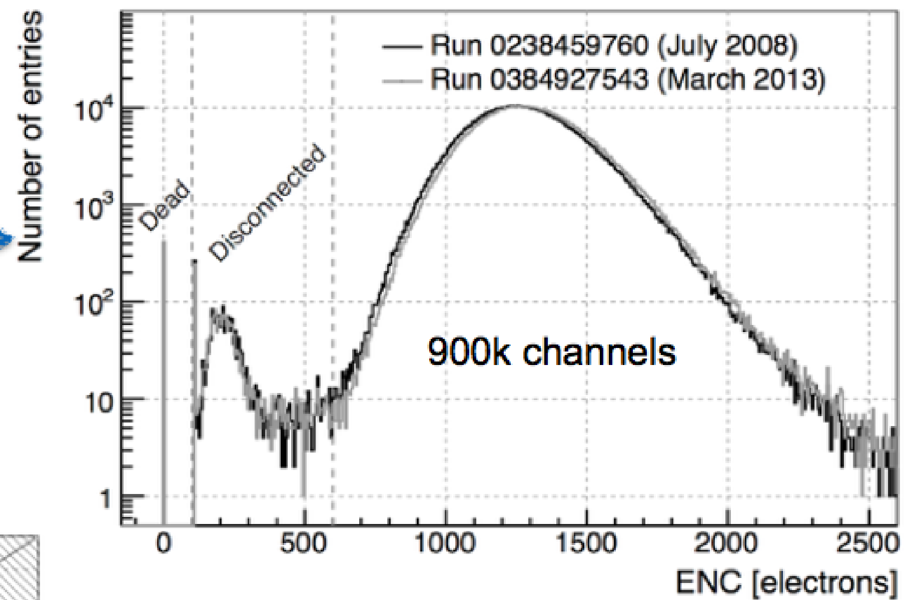
- *smooth background fit*
- *coincidence rejects noise*
- *relative rates determine source location*

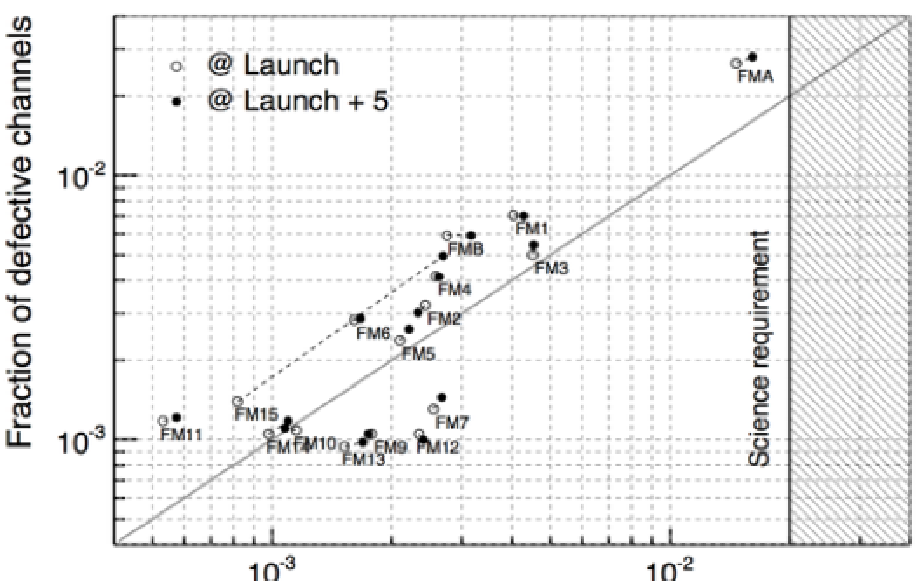
Continuous production of offline (daily) data products

- *CTIME: (0.256s, 8 channels) for high time resolution*
- *CSPEC: (4s, 128 channels) for high spectral resolution*
- *TTE: (2µs, 128 channels) for detailed time and spectral resolution*
  continuous archiving of TTE data starting end of 2012

Detector Status

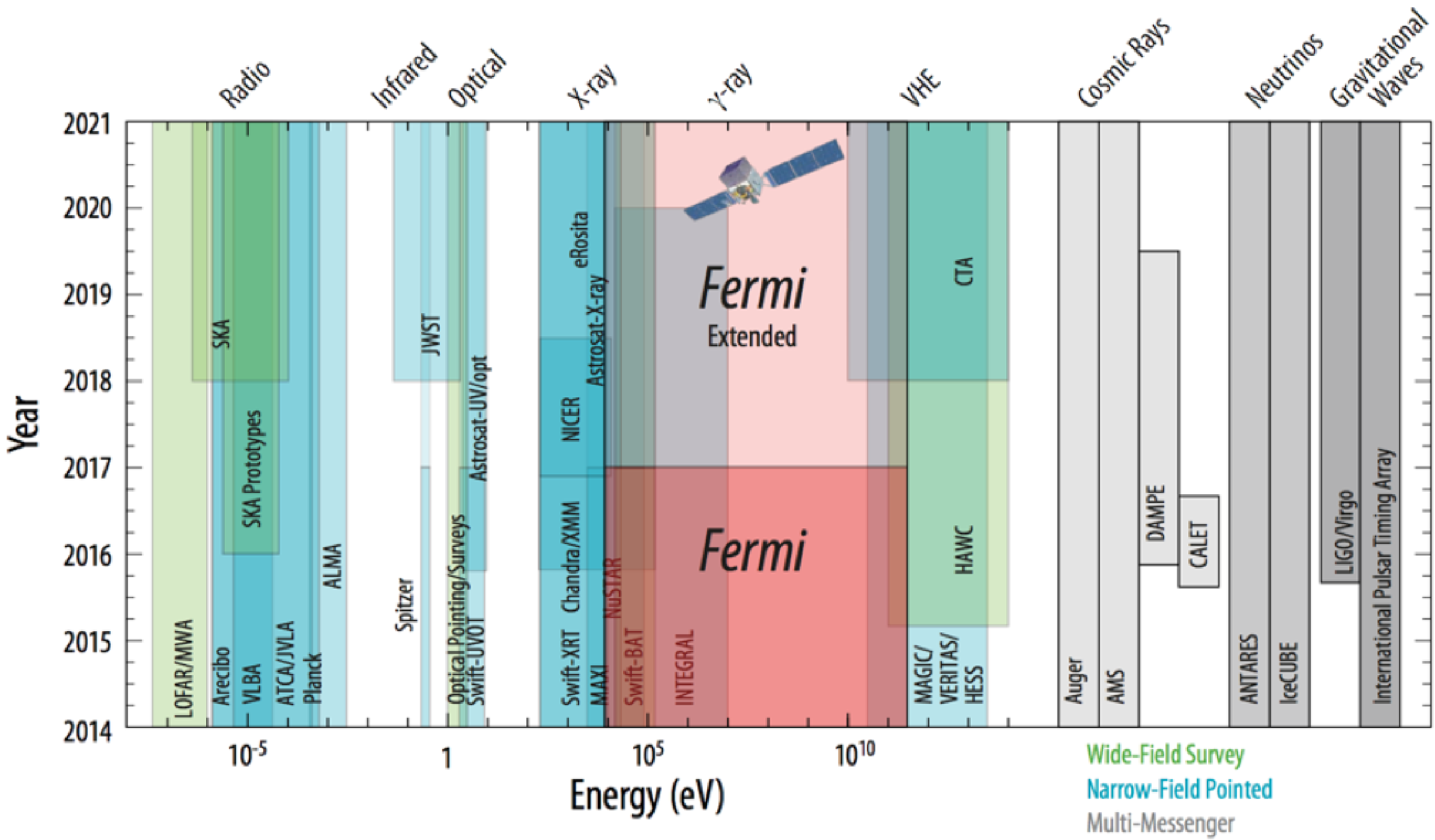






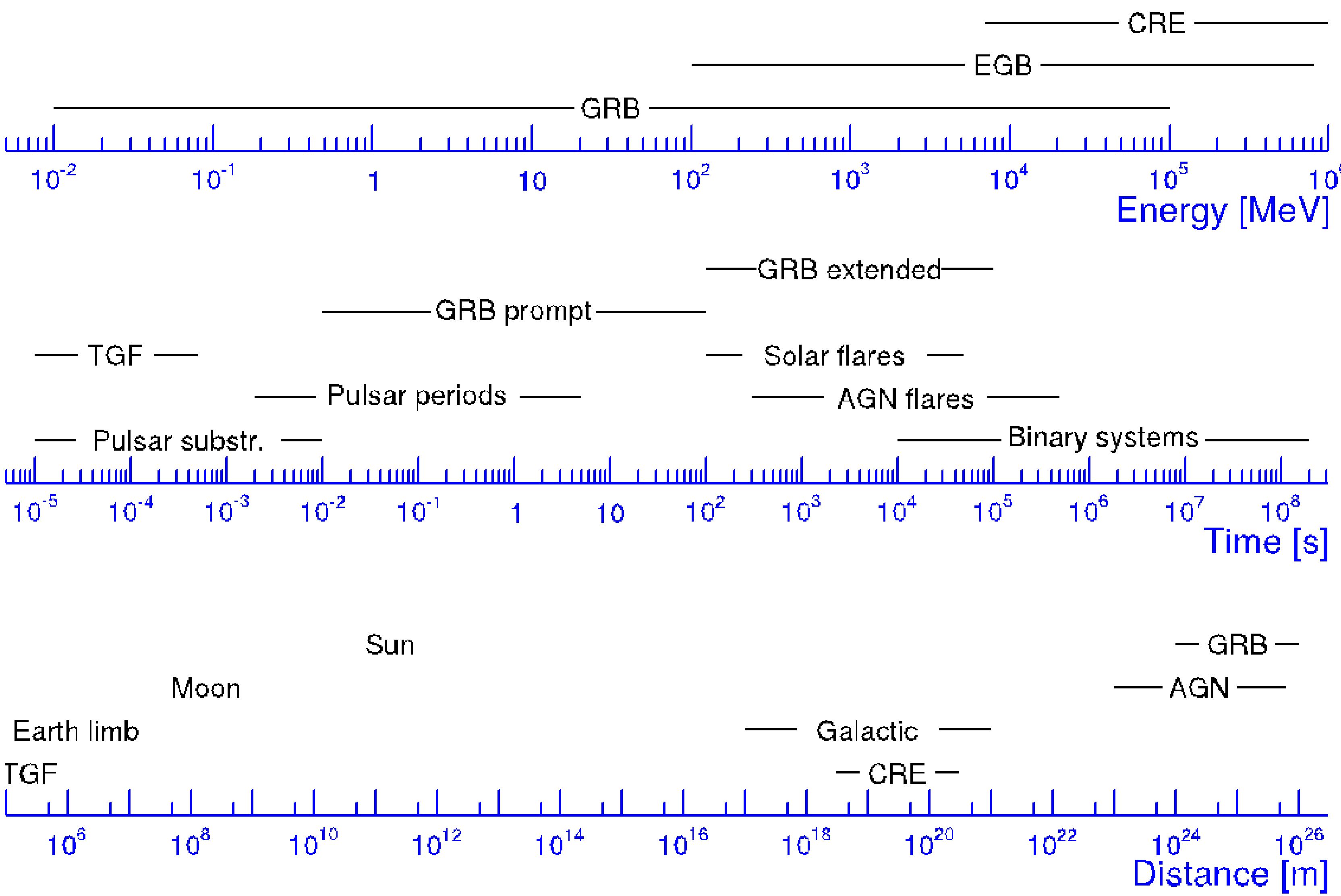
- $73m^2$ active silicon, 900k chans
  - ~ATLAS Silicon tracker
- stable performance
  - +~2% noisy chans in 5 yrs
- similar stability in ACD and CAL
  - ~1% CAL aging in 2 yrs
- ~hrs/year spent in calibrations

Context

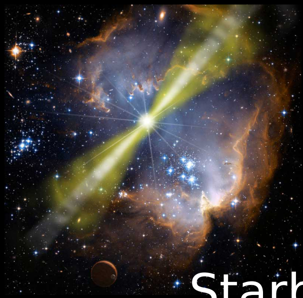


Fermi: all-sky monitor in a wide energy range + multimessenger

Fermi science



Gamma-Ray Sources



Gamma-Ray Bursts

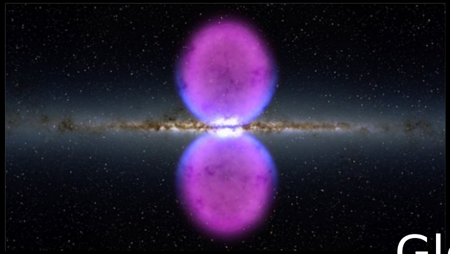
Blazars

Radio Galaxies

Starburst Galaxies

Large & Small Magellanic Clouds

Extragalactic



Fermi Bubbles

Globular Clusters

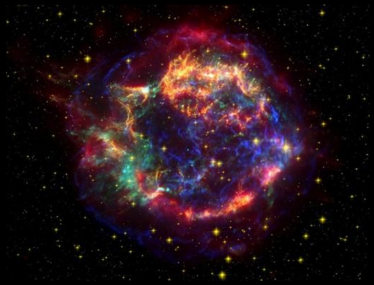
Novae

Galactic

Supernova Remnants

Gamma-ray binaries

Pulsars

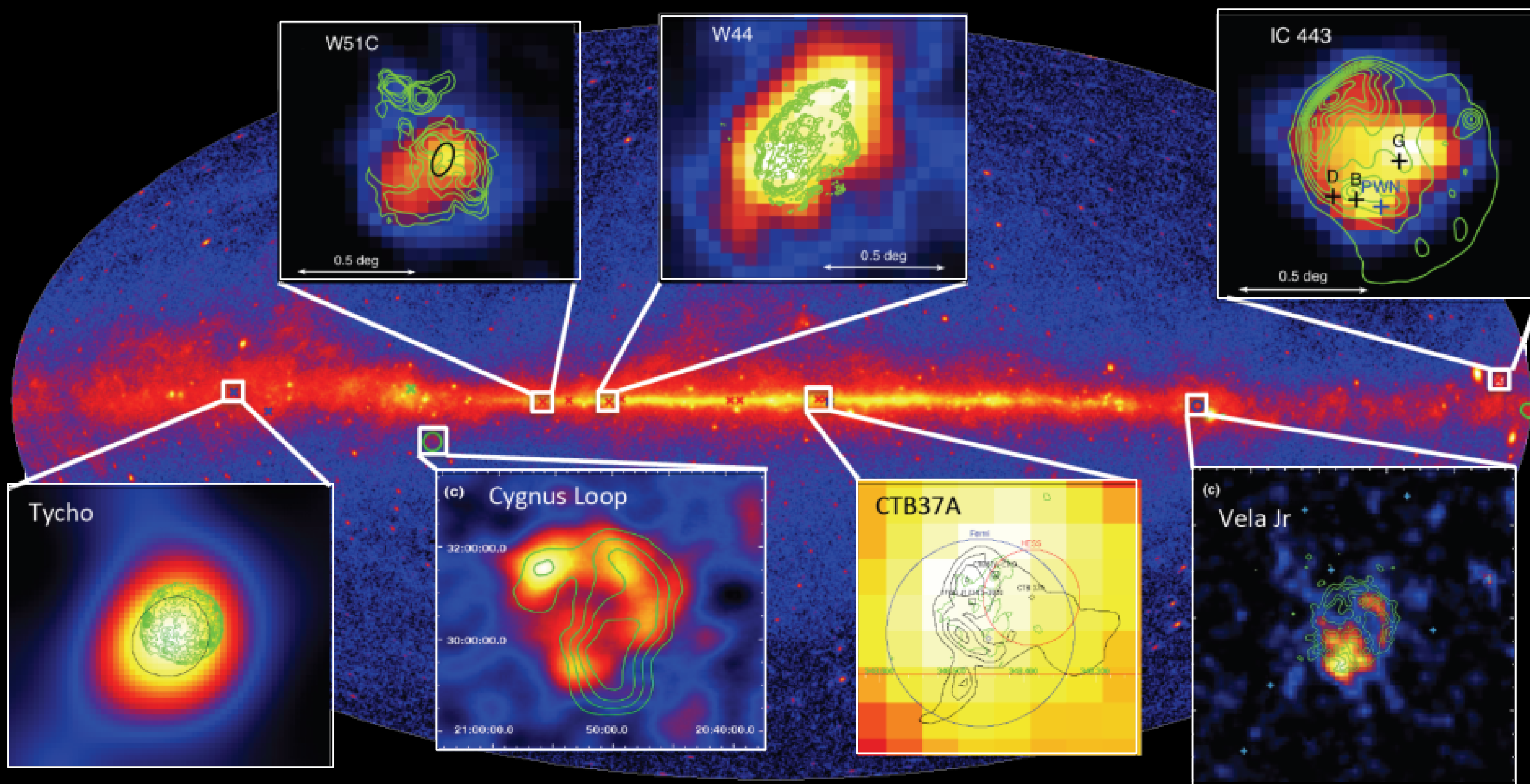


Local

Sun & Moon

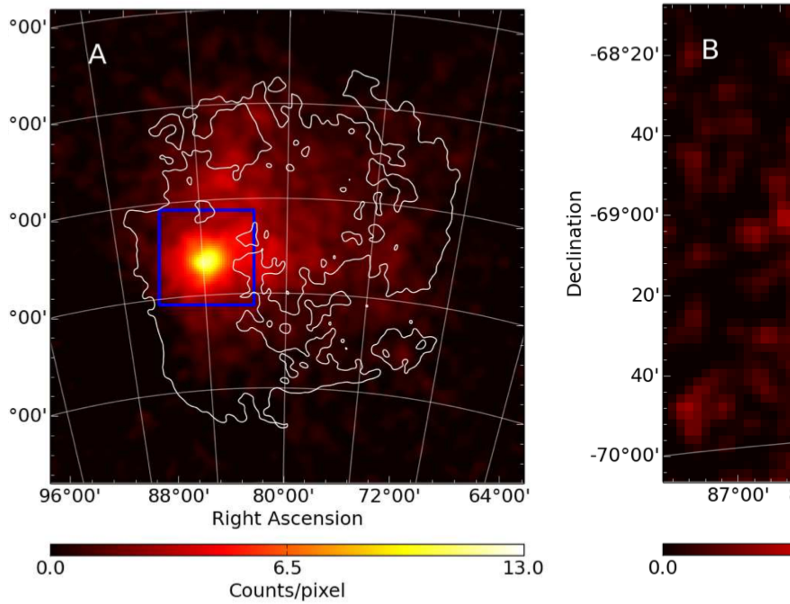
Terrestrial gamma-ray flashes

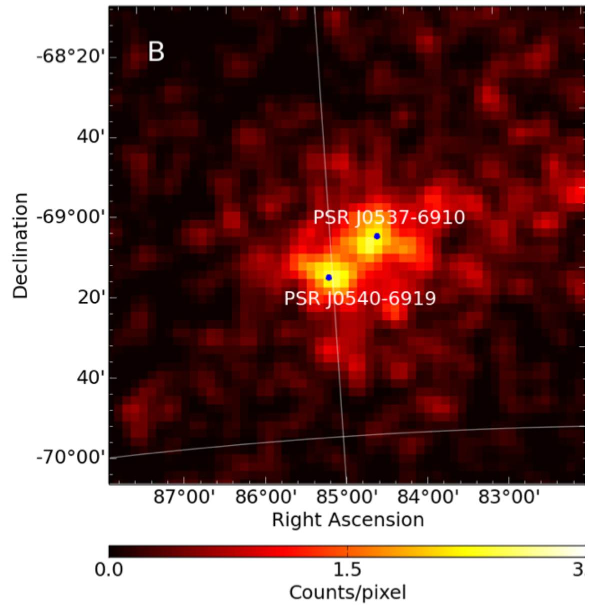
Resolving complex regions: SNRs

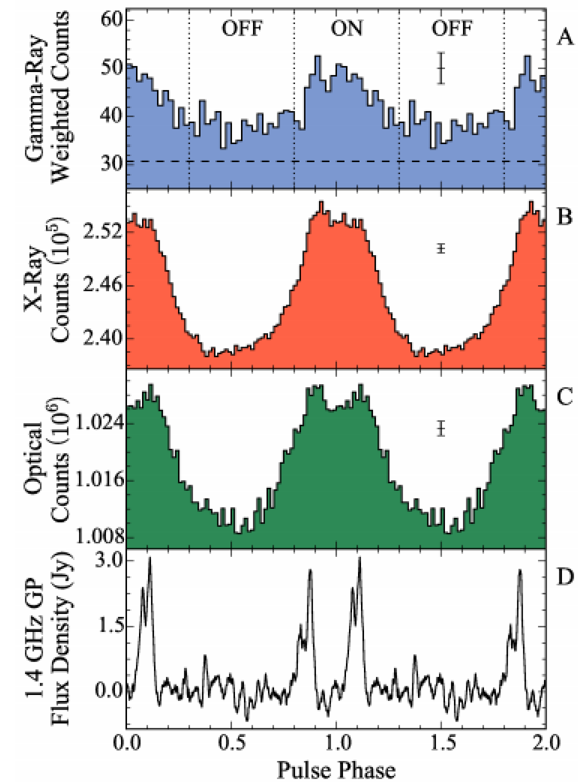


Fundamental in understaing galactic CR acceleration mechanisms

Resolving complex regions: an extragalctic Pulsar







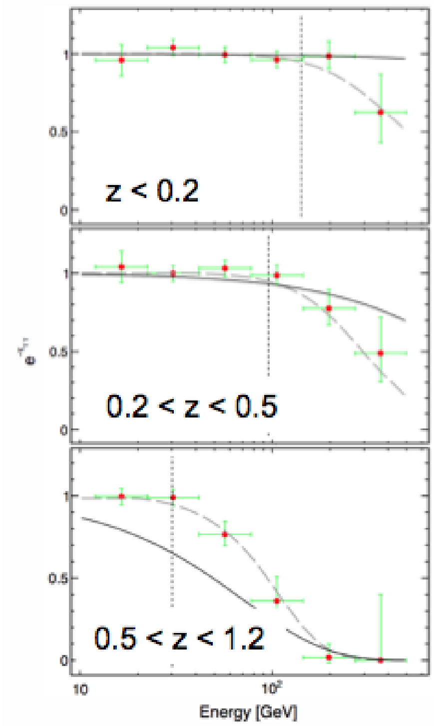
1st ever detected extra-galactic pulsar, in the 30Doradus region in the Large Magellanic Cloud

2015, Science, 350, 801

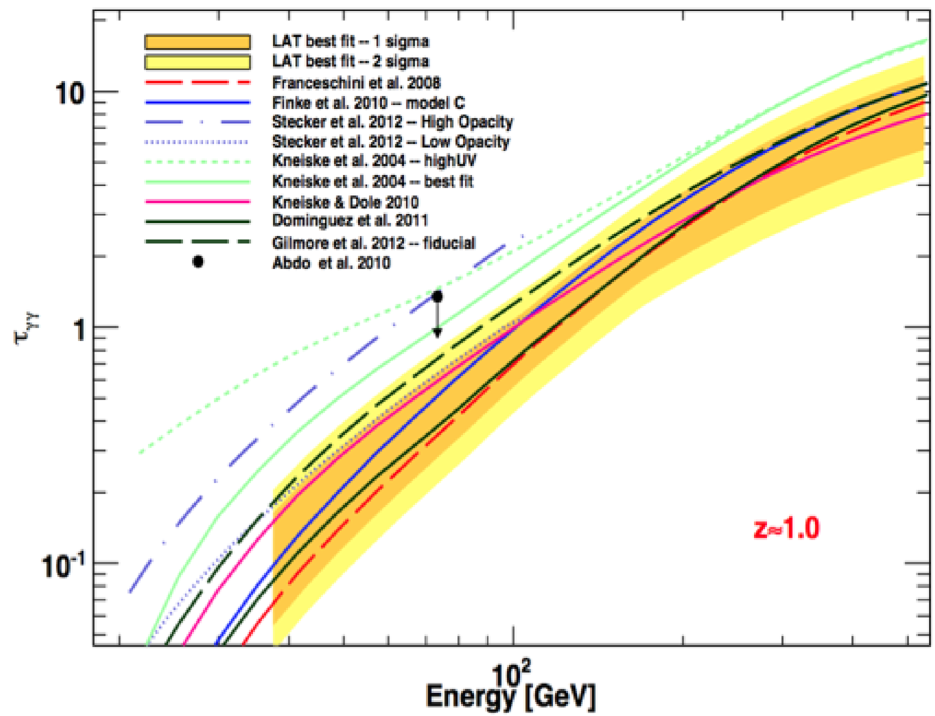
Fermi Gamma-ray Space Telescope

Extragalctic Background Light

Attenuation v. Redshift[1]



Opacity at z = 1 as a Function of Energy[1]



Knowledge of EBL is important to understand the star formation and galaxy evolution

Measure redshift-dependent high-energy spectral cutoffs in AGN (and GRB) population to determine γ-ray opacity due to pair production from starlight.

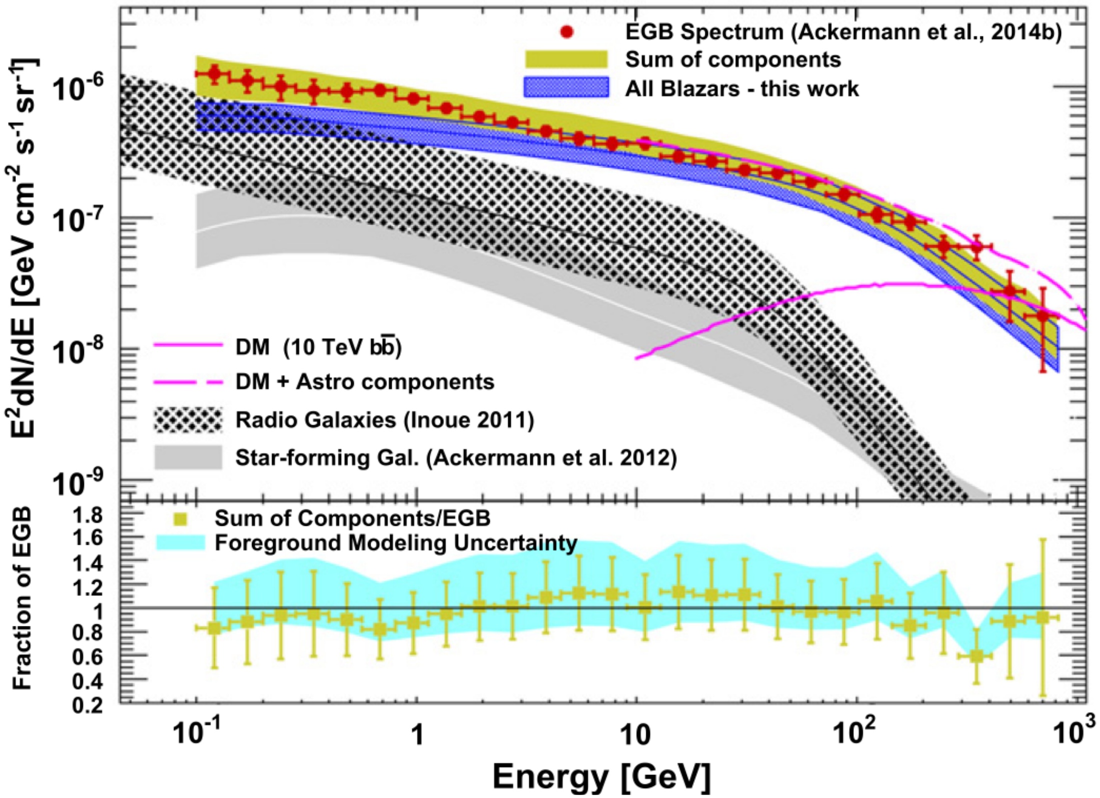
Results favor lower-opacity models

[1] Ackermann et al. 2012Sci...338.1190A. [2] Furniss et al 2013ApJ...768L..31F Also, Dominguez et al 2013ApJ...770...77D, Abdo et al. 2010ApJ...723.1082A, Stecker & Scully 2010ApJ...709L.124S, Venters et al. 2009ApJ...703.1939V, Meyer et al. 2012A&A...542A..59M, Vovk et al. 2012ApJ...747L..14V ...

Probing DM: the isotropic Gamma-Rays

DM contribution to the EGB?

2015, ApJL, 800, L27



Blazars: ~ 50% of EGB
Cut-off in the EGB spectrum is well explained by EBL absorption of the high-energy emission

Radio Galaxies: 10-30% of EGB
Star-forming Galaxies: 10-30% of EGB

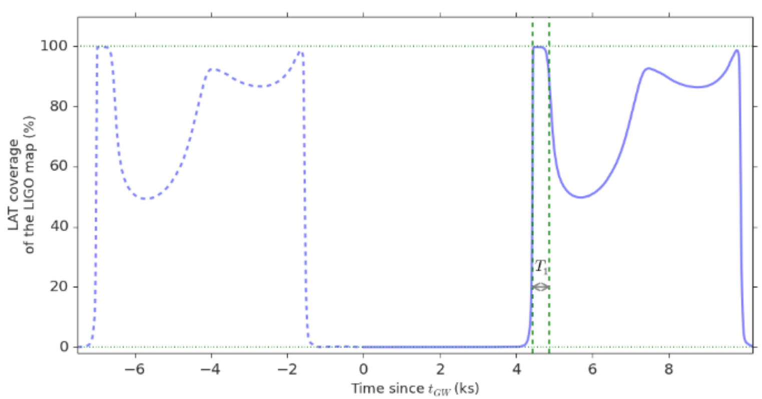
→ Constraint on the Cosmological Dark Matter

GW150914 The view of the LAT

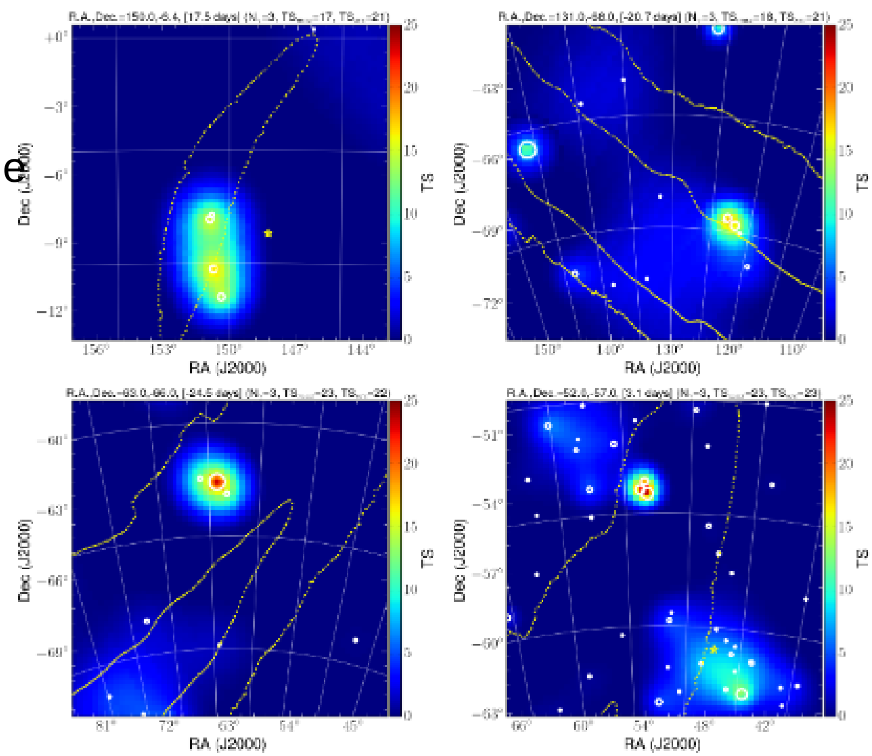
- Other analysis by high-energy facilities to confirm/disprove GBM transient
- Large fov (2.4 sr), survey mode (t=95 m)
- High-energy (>100 MeV) gamma rays

Results:

- Coverage started from t+70 m
- No triggers on automatic pipeline
- No significant excesses on short and long-based ad hoc pipelines



LAT coverage



Top sources in 60-day window