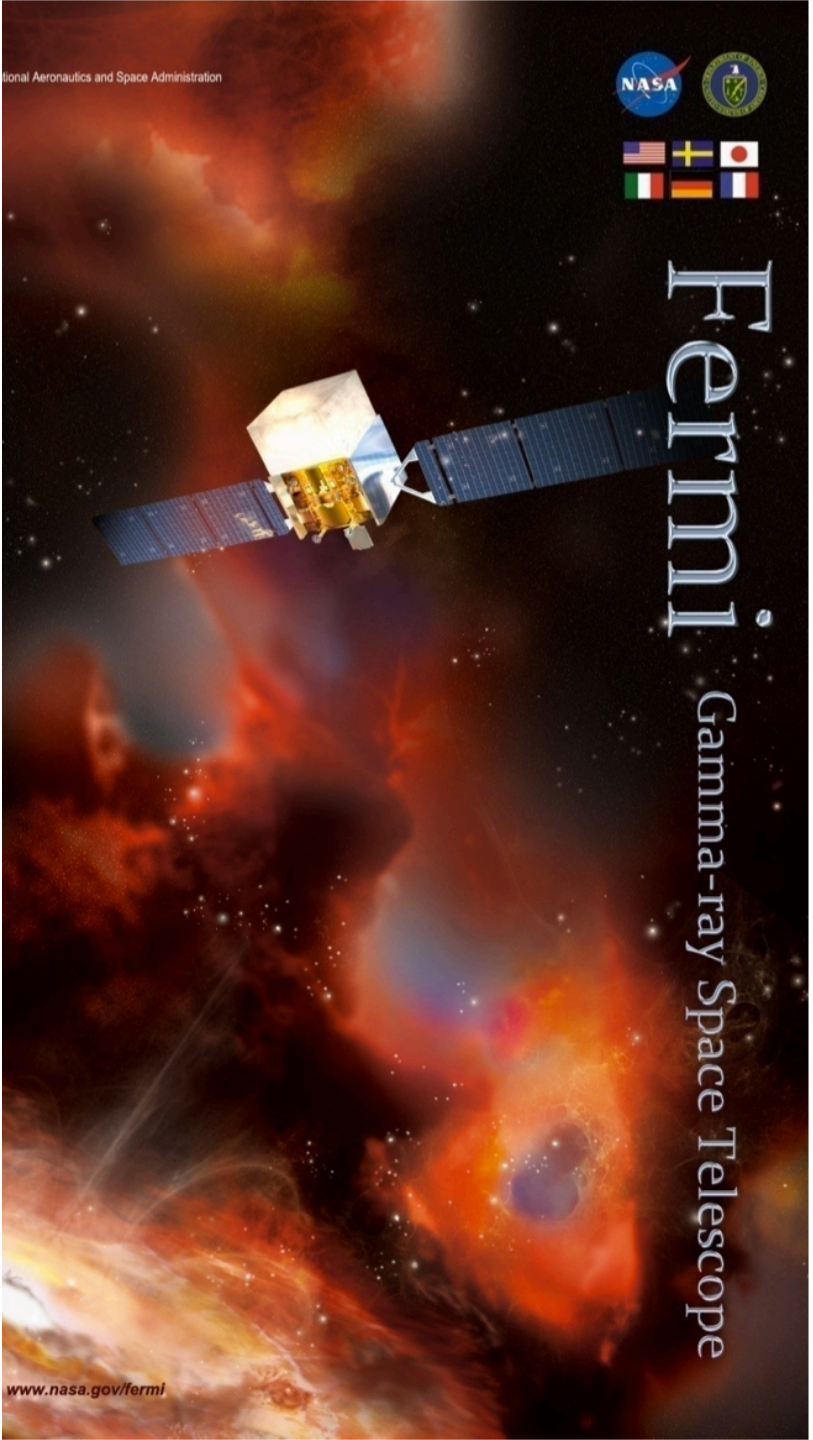

Highlights from the Fermi Large Area Telescope

Francesca Spada
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on behalf of
the Fermi-LAT Collaboration

CRIS2016, Ischia

Outline

- The Fermi Observatory
  - Mission status and prospects
- Science highlights
  - The γ-ray sky
  - Probing Dark Matter
  - Signals from the far-away Universe
  - 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

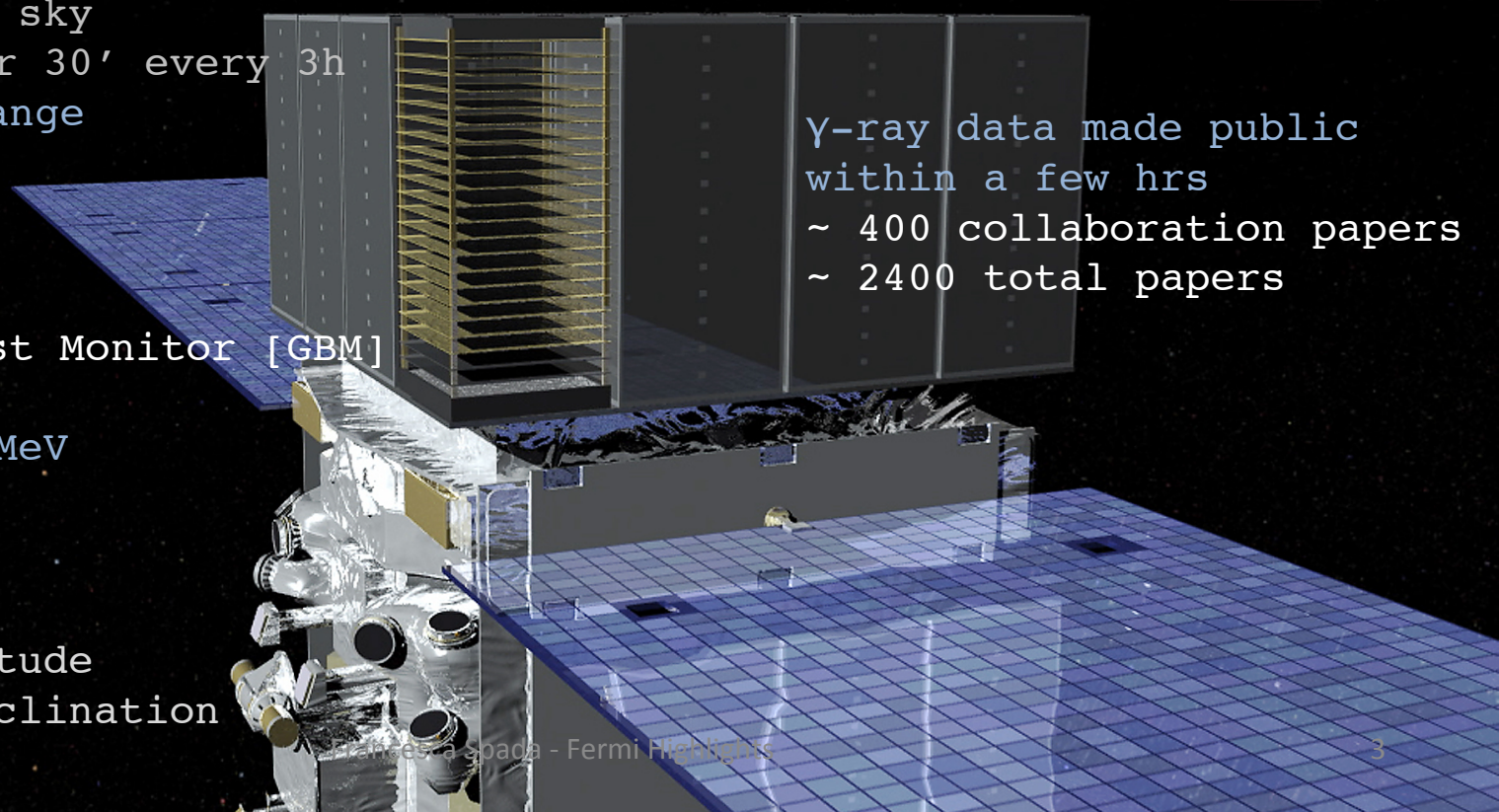
Wide energy range

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

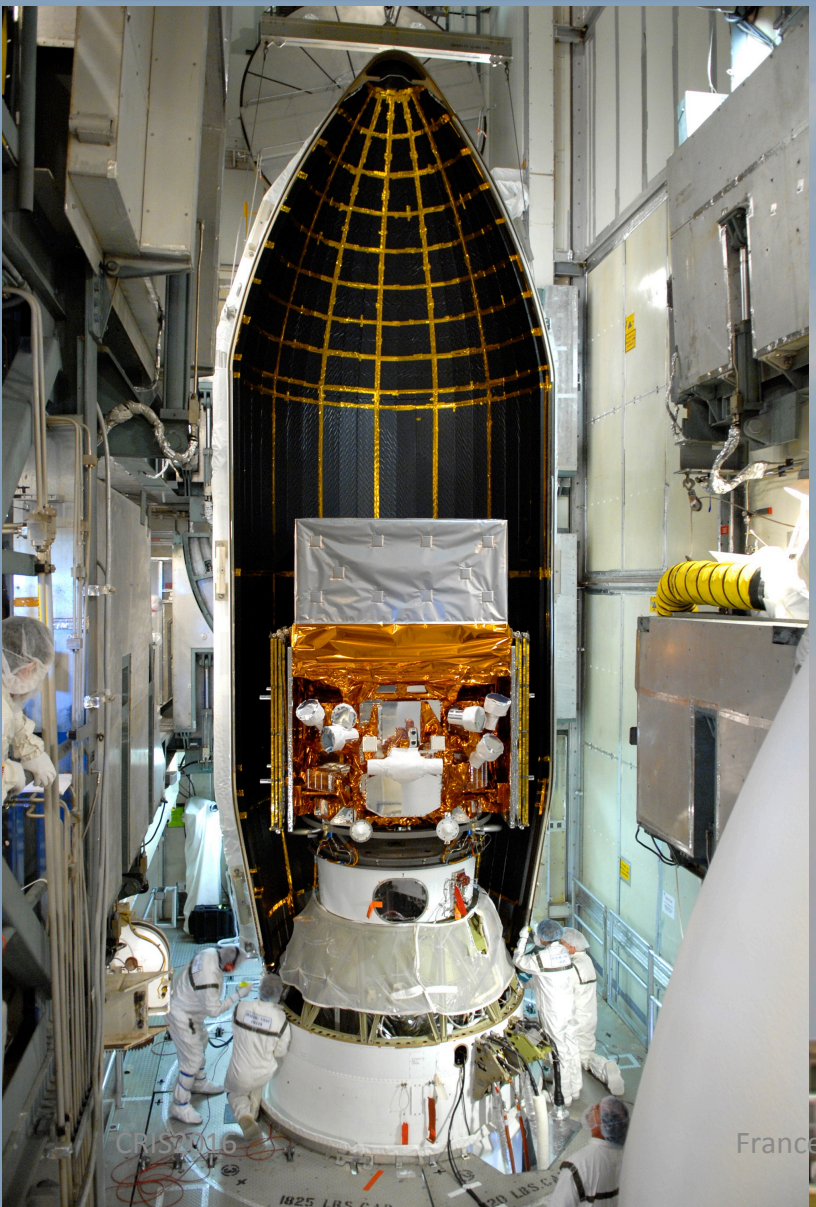
Orbit
- 565 km altitude
- 25.6 deg inclination

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

γ-ray data made public within a few hrs
~ 400 collaboration papers
~ 2400 total papers



The Fermi Observatory

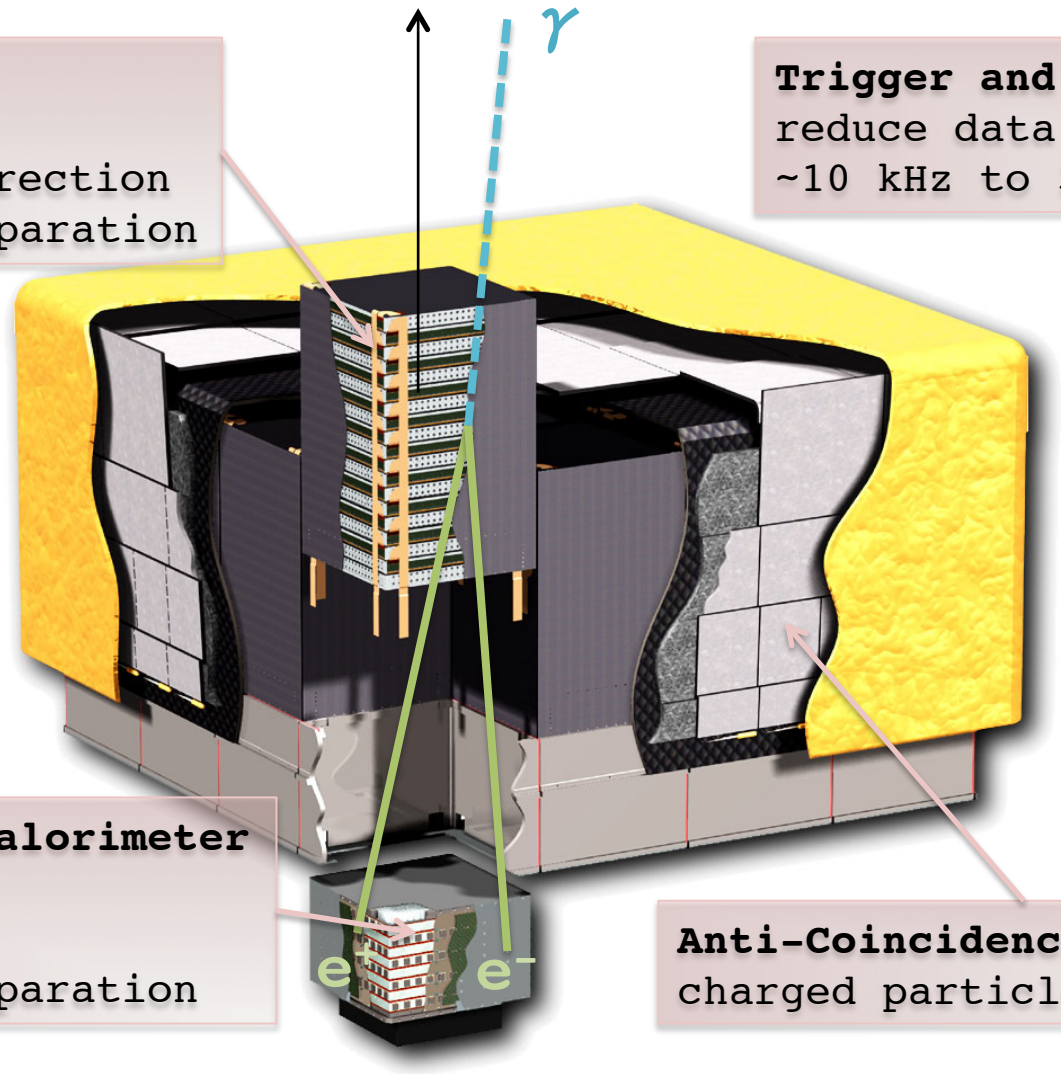


GLAST was launched from Kennedy Space Center [Cape Canaveral] on board a Delta II 7920-H rocket on July 11, 2008.
Nominal science operation since 4 August 2008

The Fermi-LAT

Si-strip Tracker
convert γ → e^+e^-
reconstruct γ direction
EM vs. hadron separation

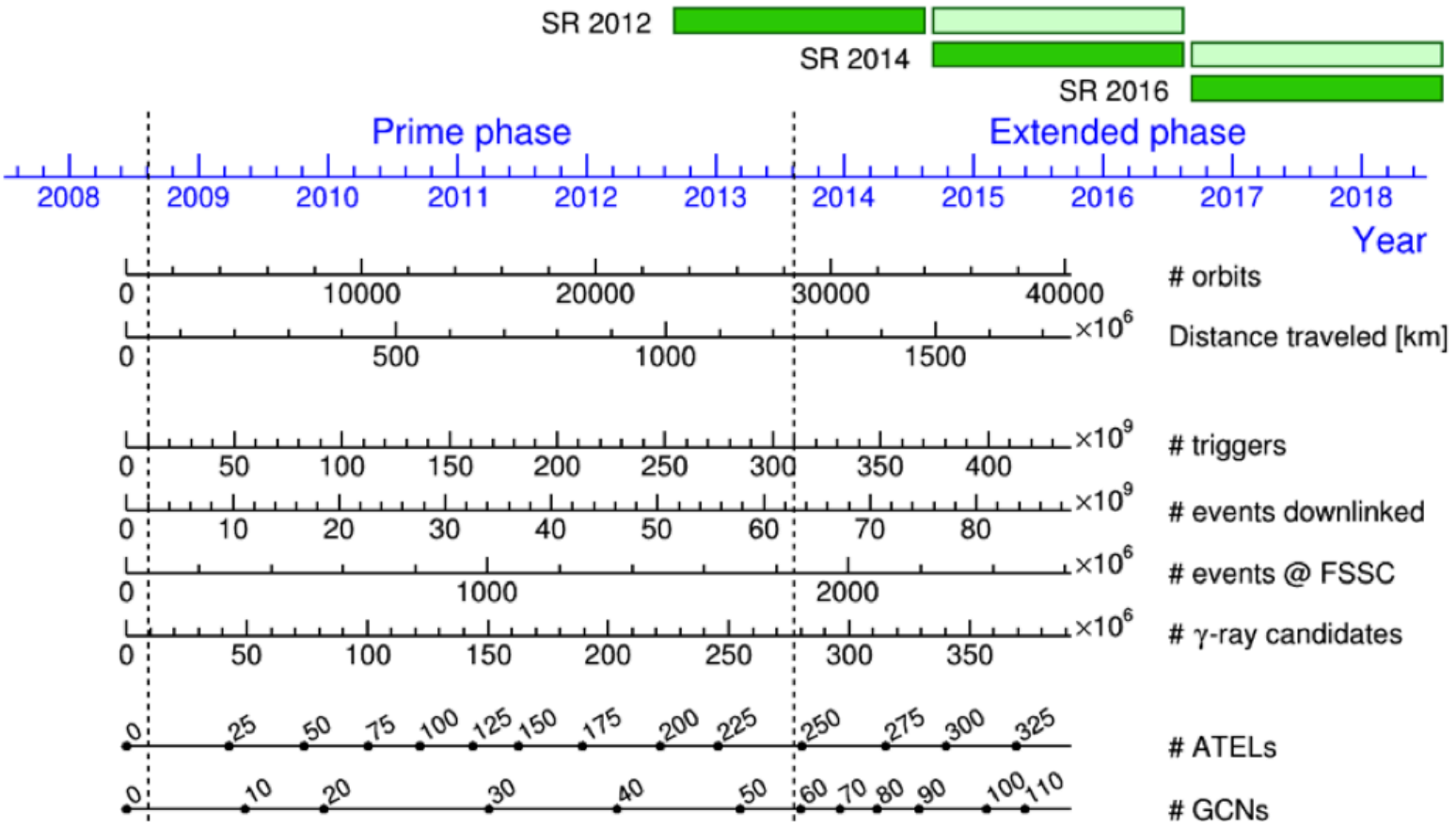
Trigger and Filter
reduce data rate from
~10 kHz to 300-500 Hz



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

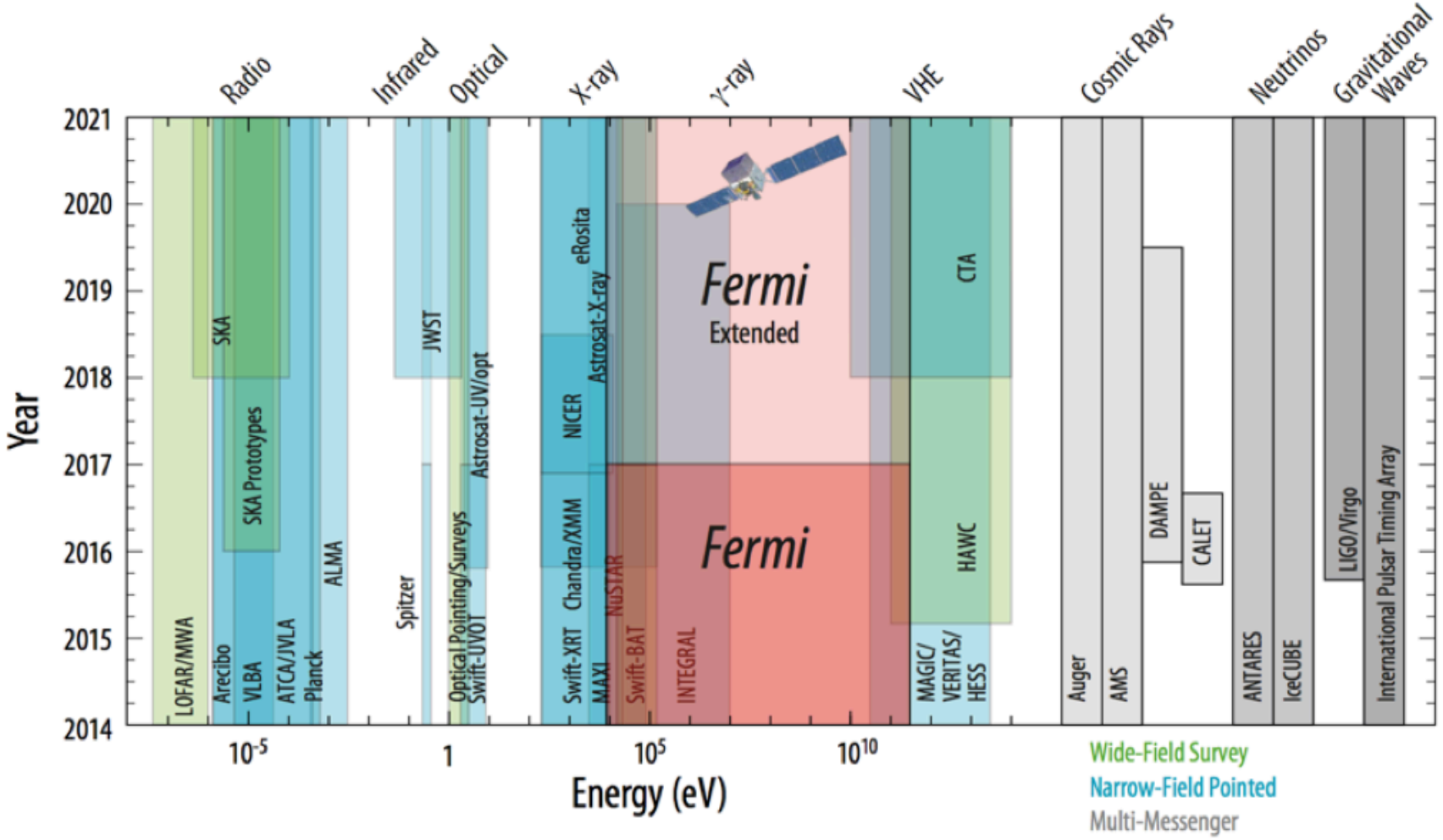
Anti-Coincidence Detector
charged particle separation

Mission Timeline



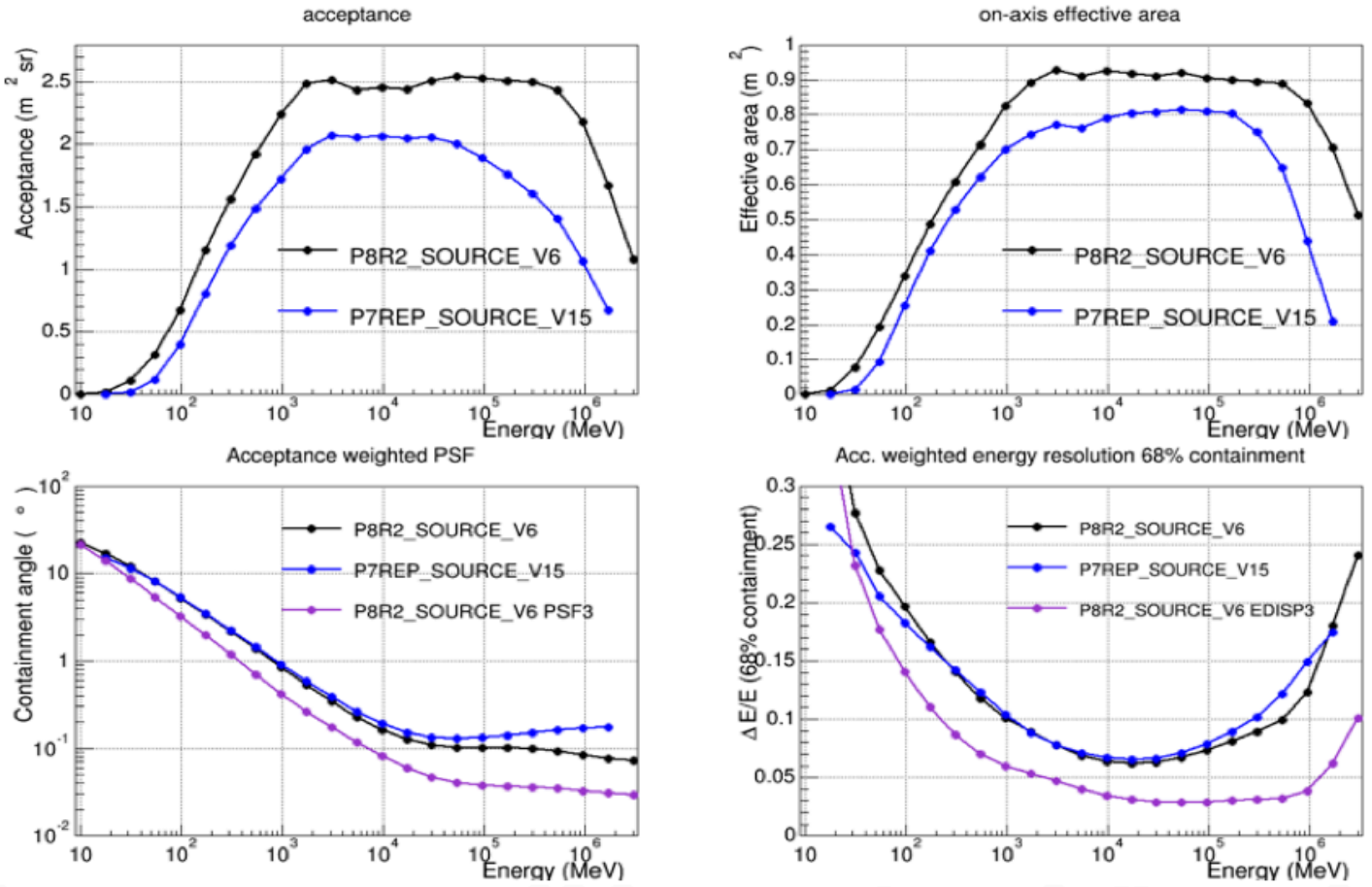
NASA Spring 2016 Senior Review confirm operations through 2018 and recommend through 2020
http://science.nasa.gov/astrophysics/documents

Context



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

Pass-8 Event Reconstruction

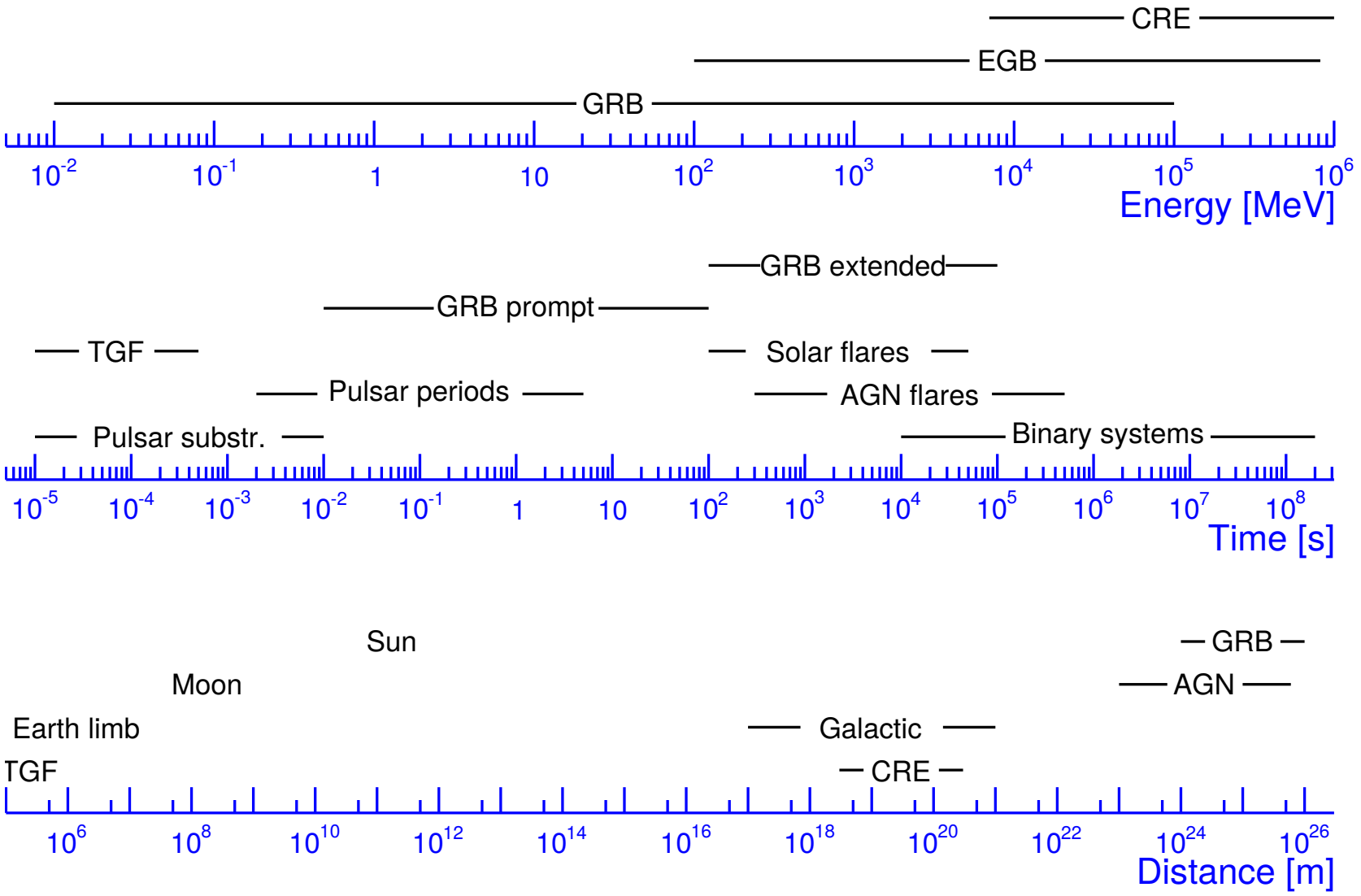


Public release in June 2015

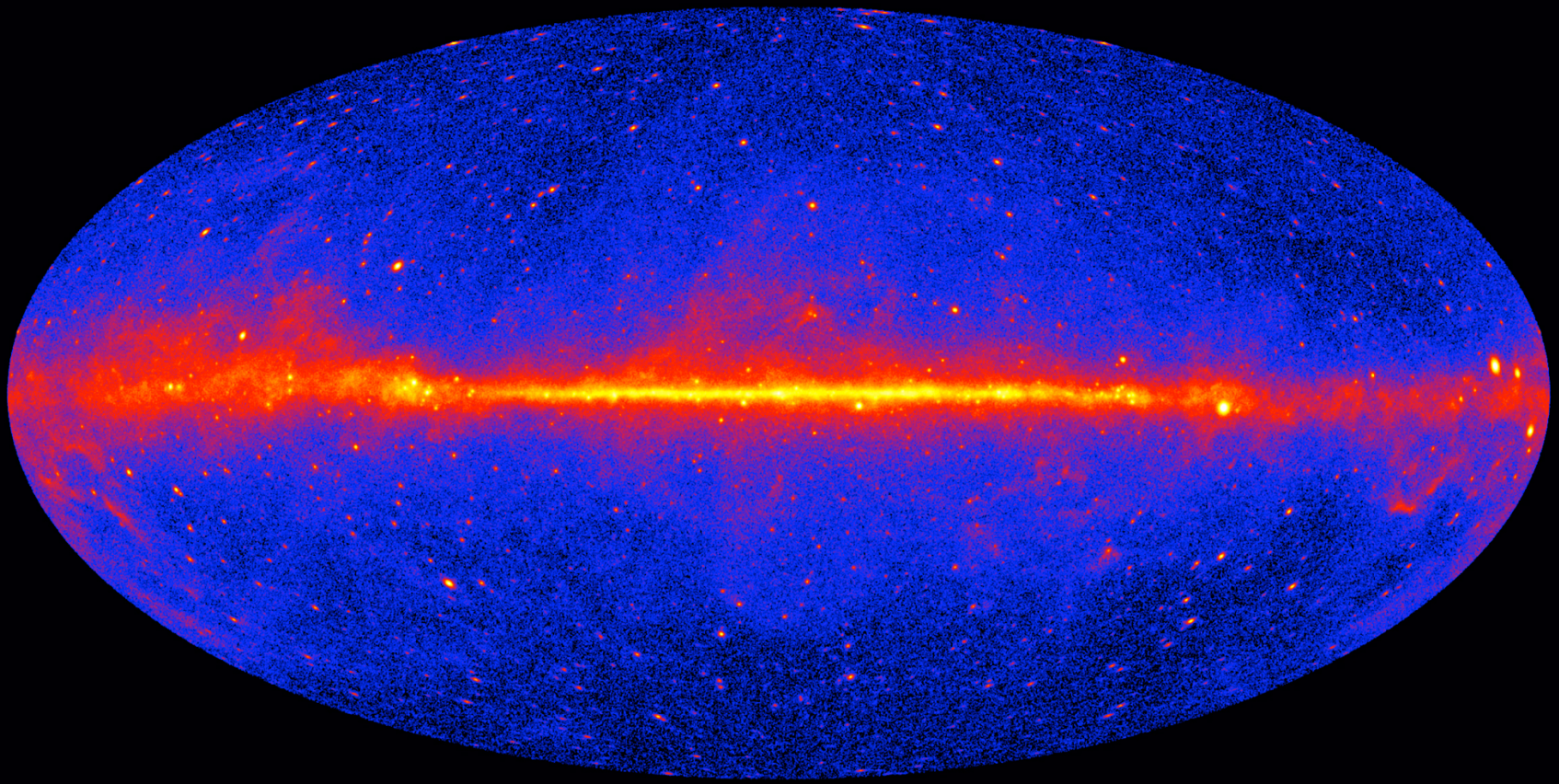
Higher acceptance – wider energy range – better resolution

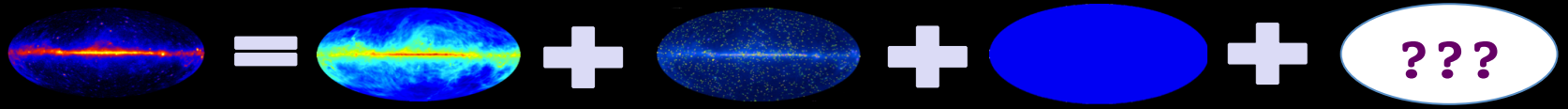
A new, improved LAT: Pass-8 was worth the huge effort!

Fermi science



The γ-ray sky





GeV Sky = Galactic + Point Sources + Isotropic

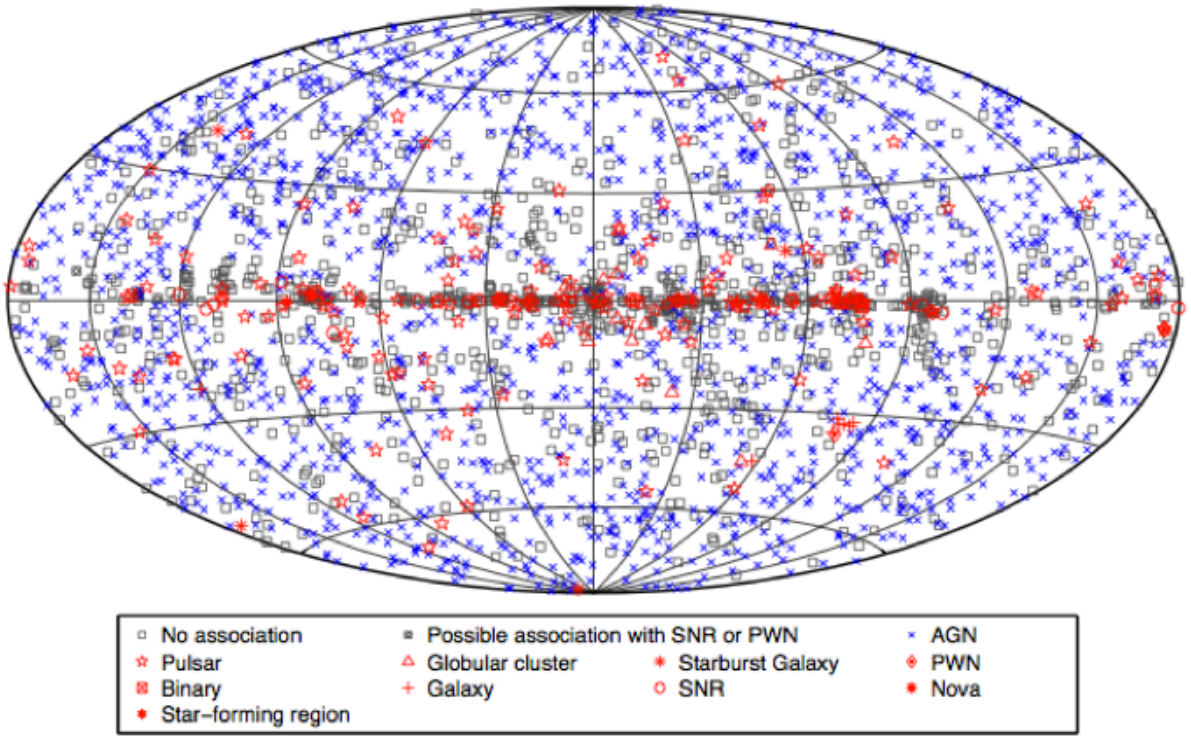
Identifying sources: Catalogs

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

2015, ApJS, 218, 23

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

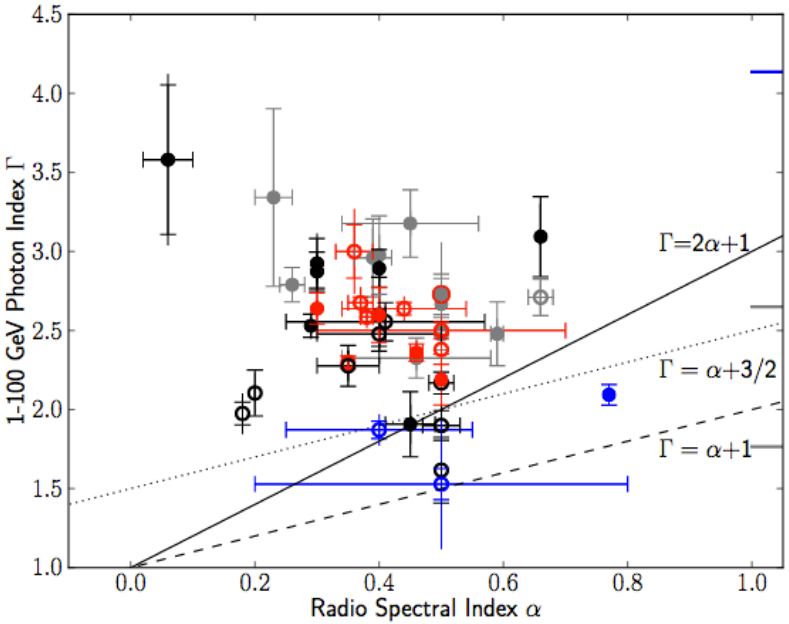
Some source classes more populated than expected:
millisecond pulsars,
radio-quiet pulsars,
high-redshift AGNs



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

Class-specific Catalogs

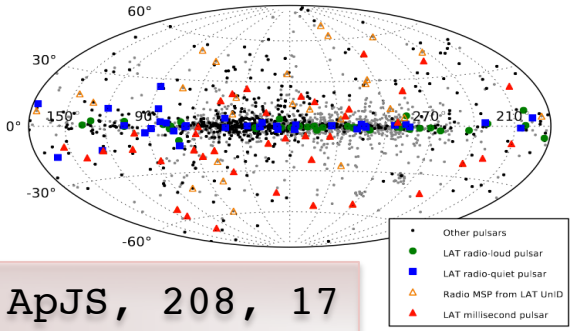
SN Remnants: 1 to 100 GeV



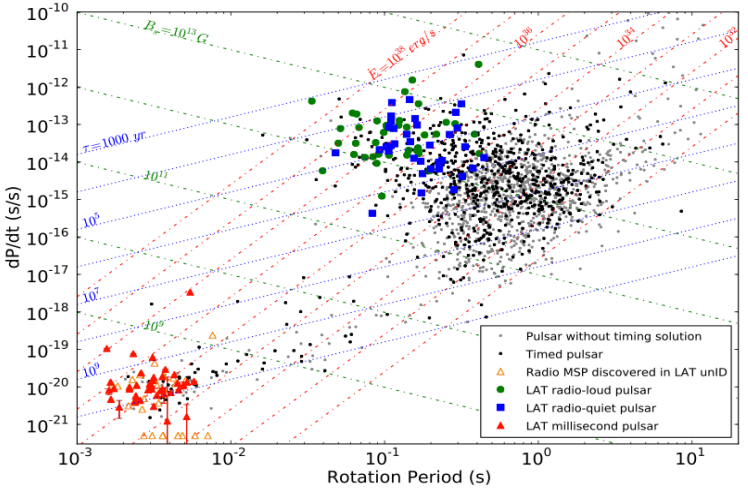
30 sources identified as GeV counterparts to radio SNRs + 14 candidates probably related to SNRs

2016, ApJS, 224, 8

γ-ray Pulsars: 117 sources

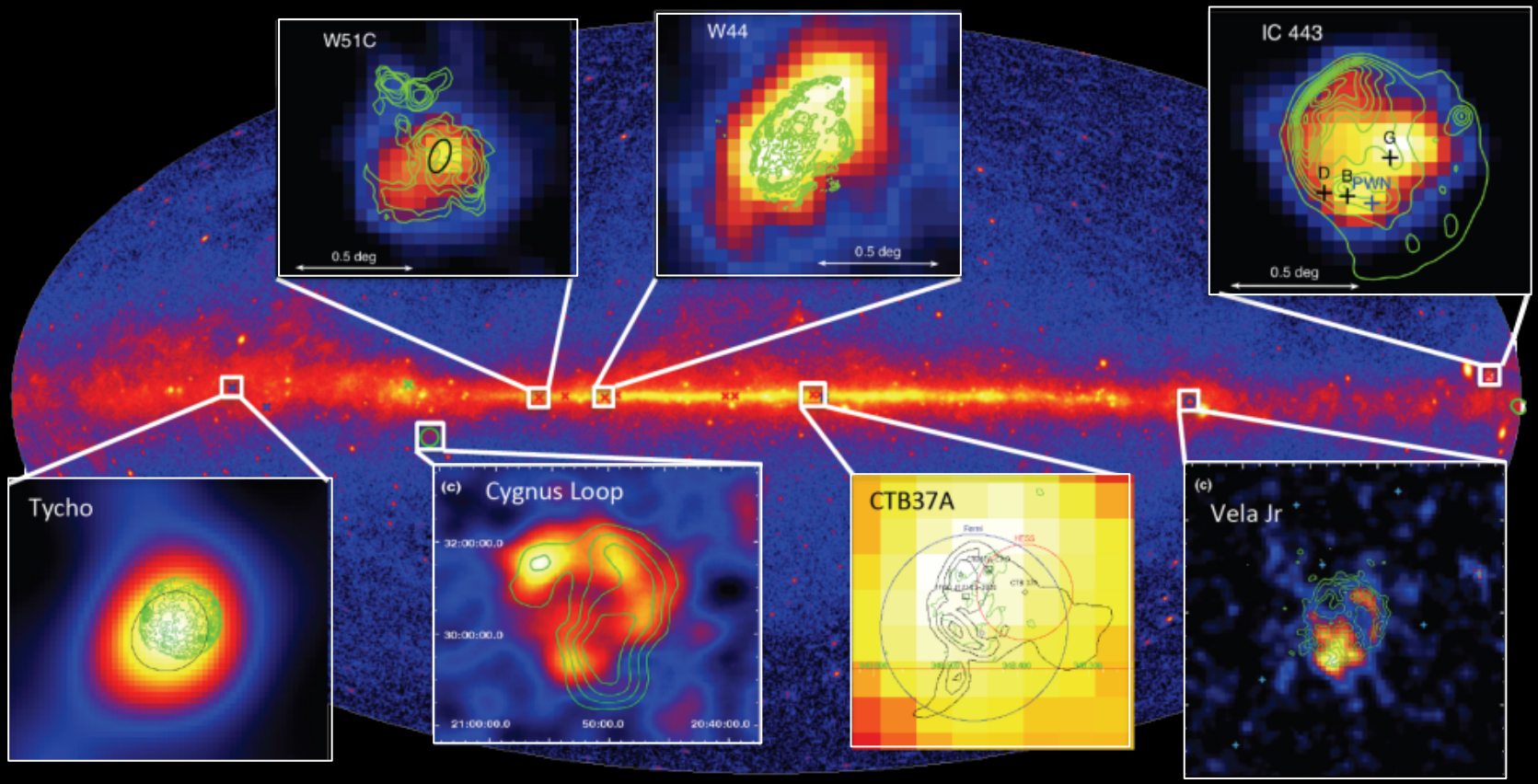


2013, ApJS, 208, 17



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

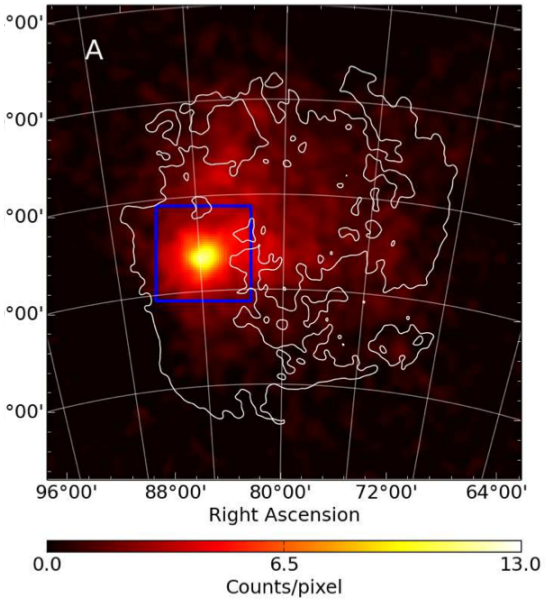
Resolving complex regions: SNRs

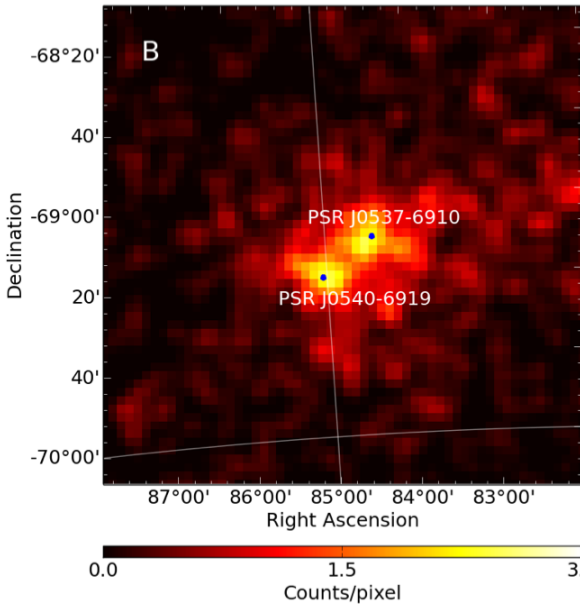


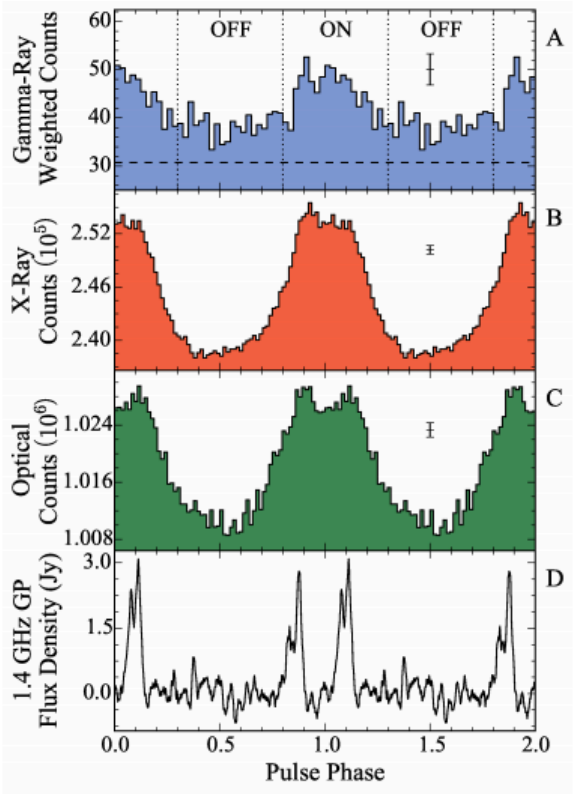
Fundamental in understaing galactic CR acceleration mechanisms

See talk by L. Di Venere

Resolving complex regions: an extragalctic Pulsar







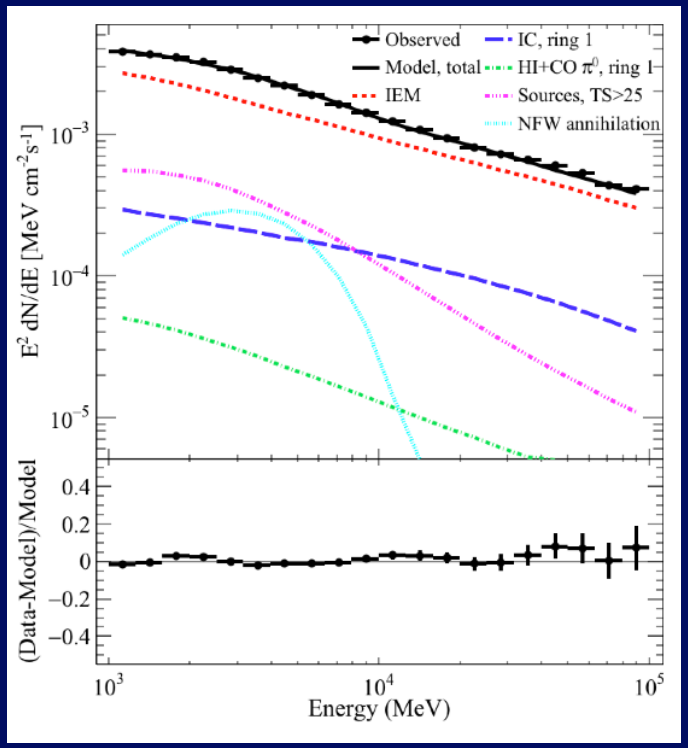
1st ever detected γ-ray extra-galactic pulsar, in the 30Doradus region in the Large Magellanic Cloud.
The most luminous pulsed gamma-ray emission yet observed.

2015, Science, 350, 801

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)

See talk by D. Grasso

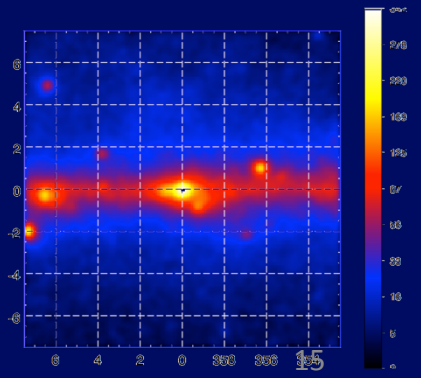
- isotropic gamma-ray background (measured)
- detected gamma-ray sources

What's not in the model:

- unresolved gamma-ray sources
- dark matter

2016, ApJ, 819, 44

- Degenerate with potential **astrophysical contributions**

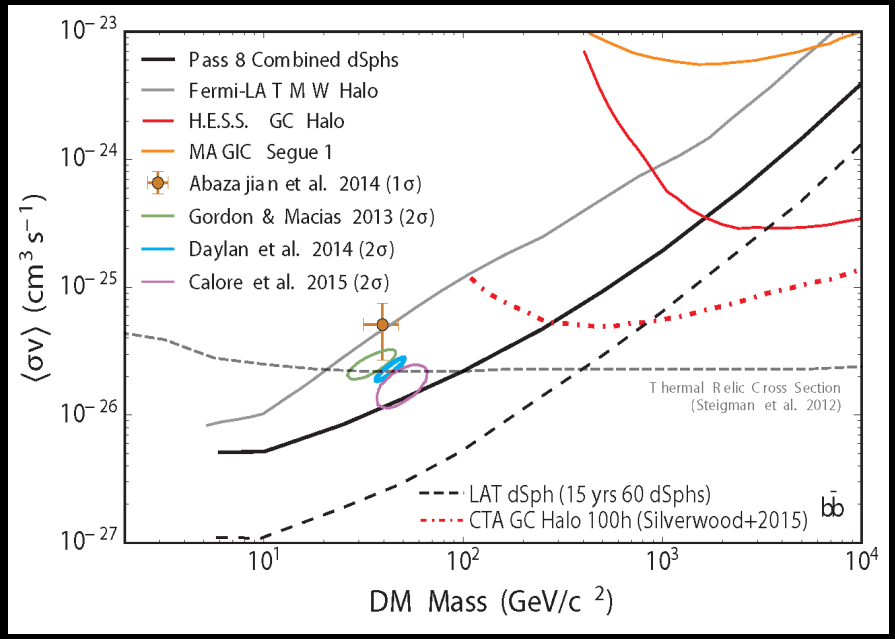


Probing DM: the Dwarf Spheroidal Satellite Galaxies

- 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

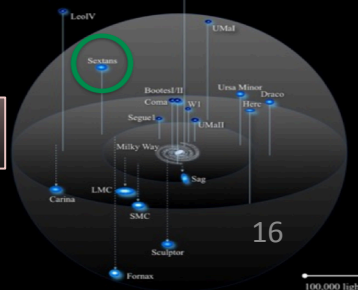
$$\phi_\gamma(E,\Delta\Omega) = \frac{1}{4\pi}\frac{\langle\sigma_\chi v\rangle}{2m_\chi^2} N_\gamma(E) \times J(\Delta\Omega)$$



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

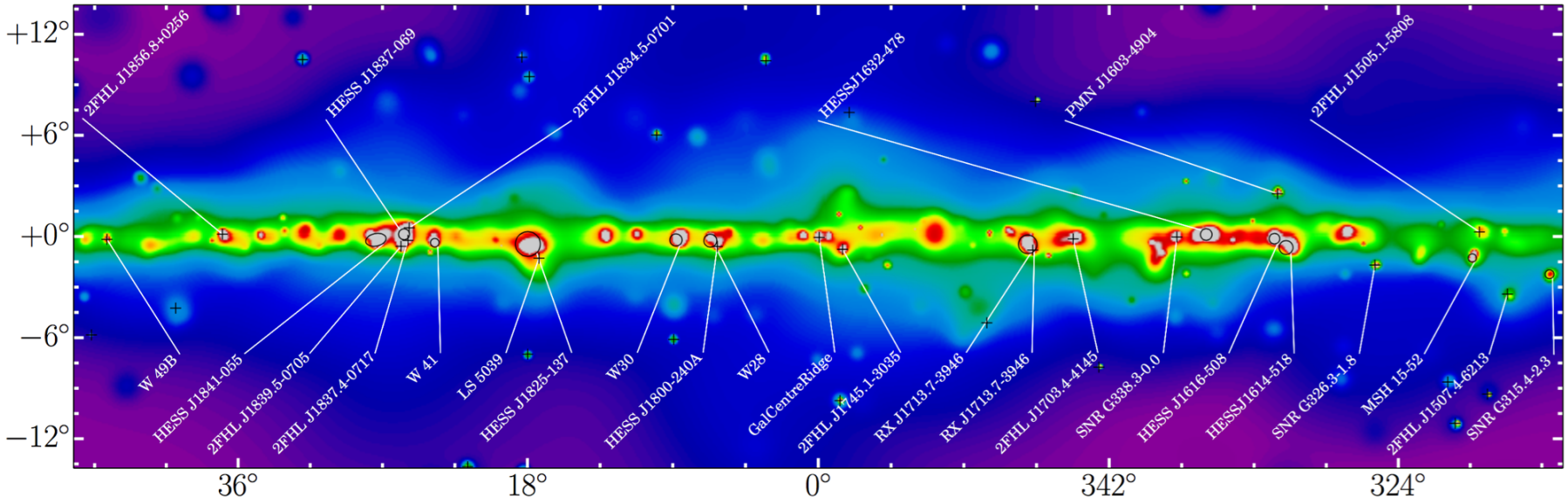
2015, PRL, 115, 23



See talk by A. Morselli

Hard sources and EBG

Hard sources Catalog [2FHL]: 253 sources > 50 GeV



Closes the energy gap between the LAT and Cherenkov telescopes

2016, ApJS, 222, 55

Hard sources contribute for ~85% to the isotropic flux

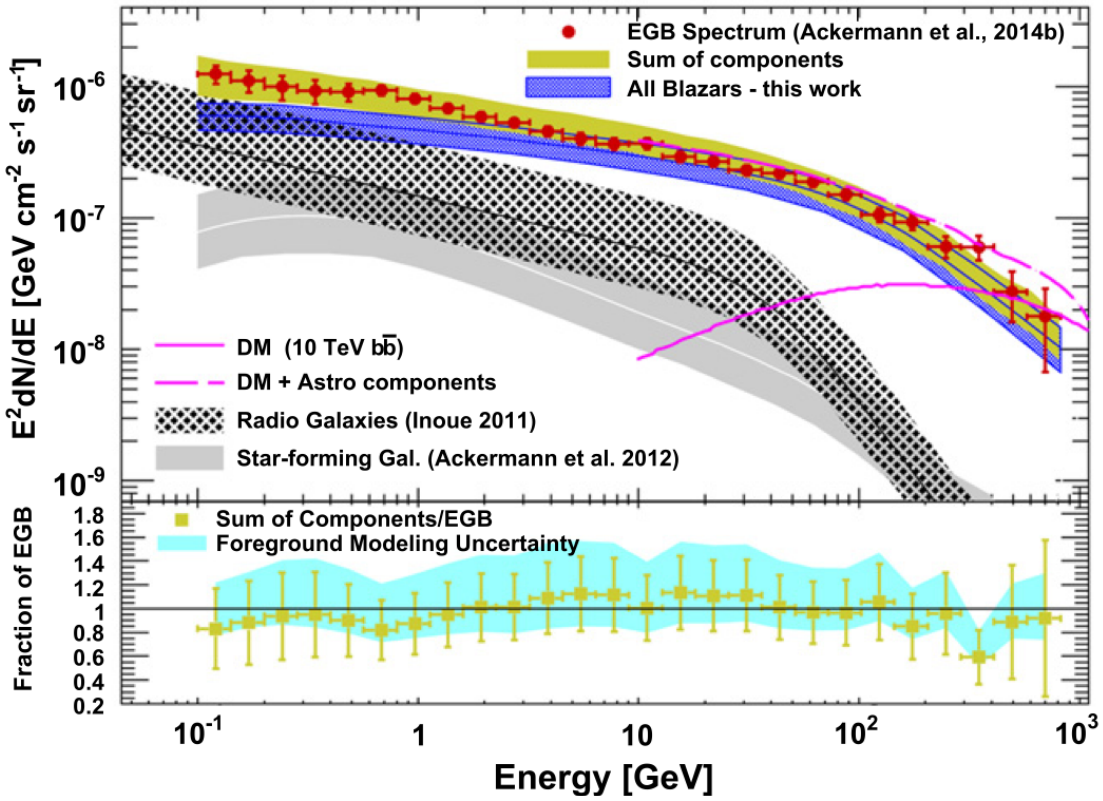
→ other [exotic] contributions must be small

SUGGESTION 2016, PRL, 116, 151105

Probing DM: the isotropic Gamma-Rays

DM contribution to the EGB?

2015, ApJL, 800, L27



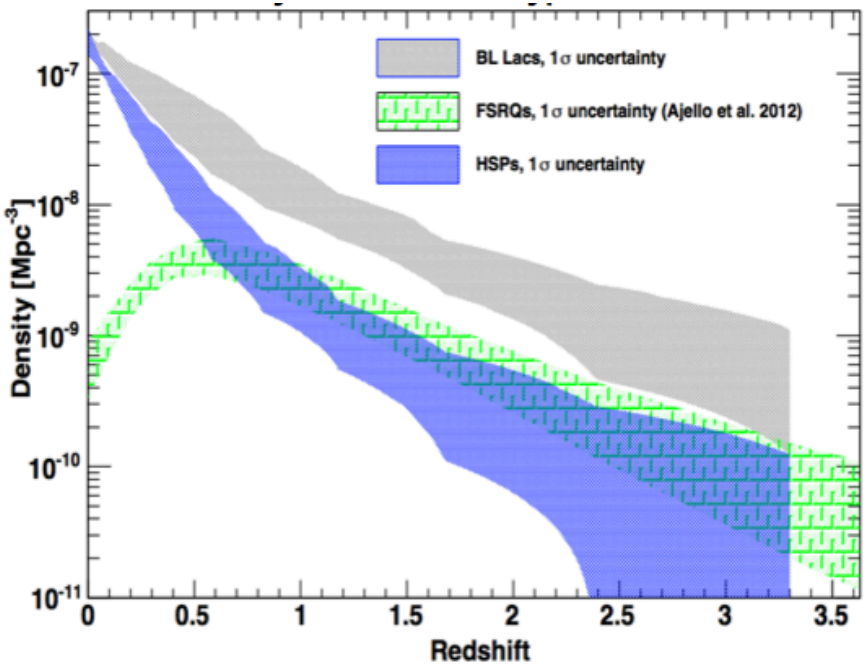
Blazars: ~ 50% of EGB
Cut-off in the EGB spectrum is well explained by EBL absorption of the high-energy emission

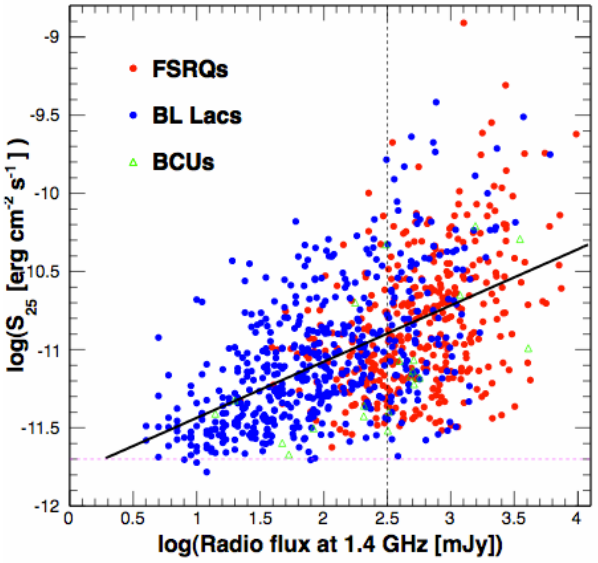
Radio Galaxies: 10-30% of EGB
Star-forming Galaxies: 10-30% of EGB

→ **Constraint on the Cosmological Dark Matter**

Extragalactic sources: Active Galactic Nuclei

AGN Catalog [3LAC]: 2591 sources





75% of the sources are **aligned AGN:** blazars (BL Lacs + FSRQ)

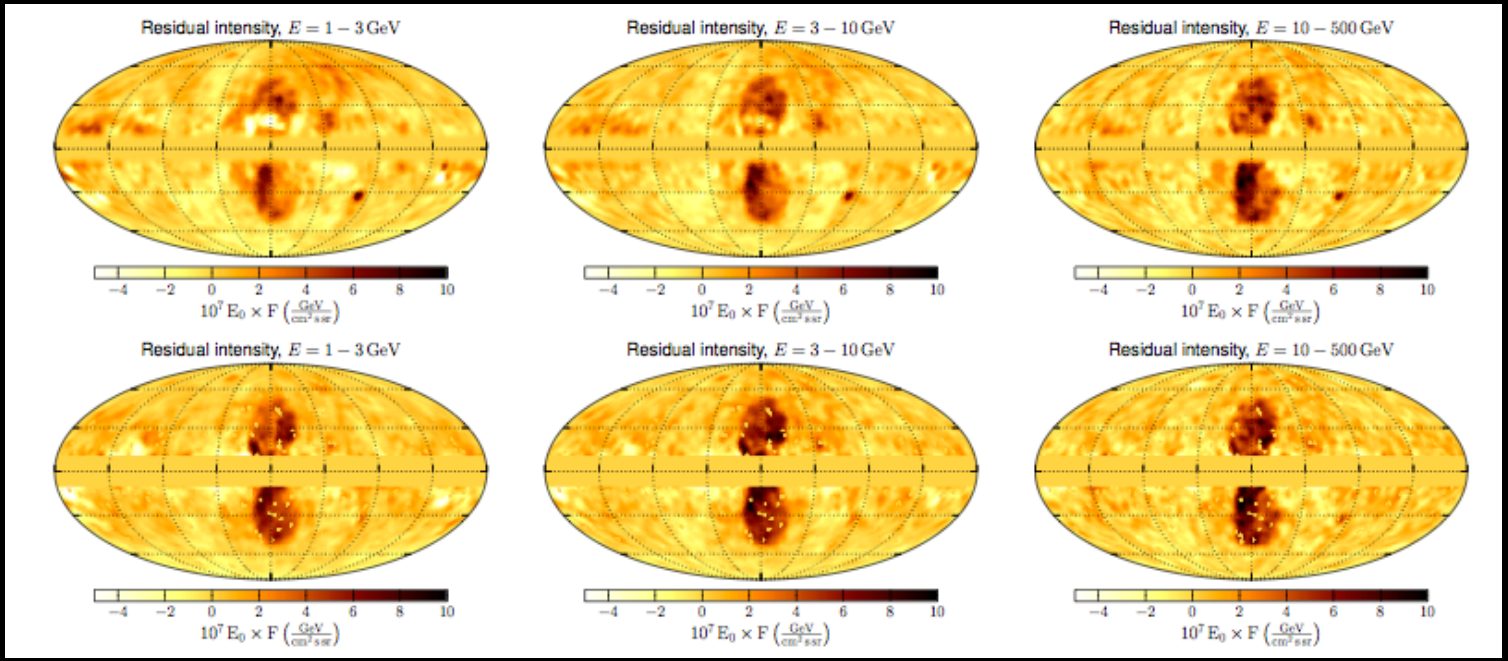
A population of **high-redshift BL Lacs** was found with MW follow-ups that provide *z*

2015, ApJ, 810, 1, 14

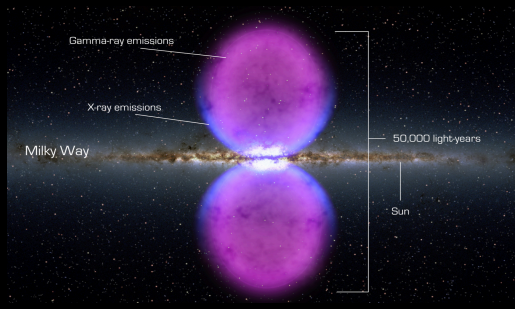
Back to the Milky Way: Bubbles

Is the Milky way an active Galaxy?

2014, ApJ, 793, 64

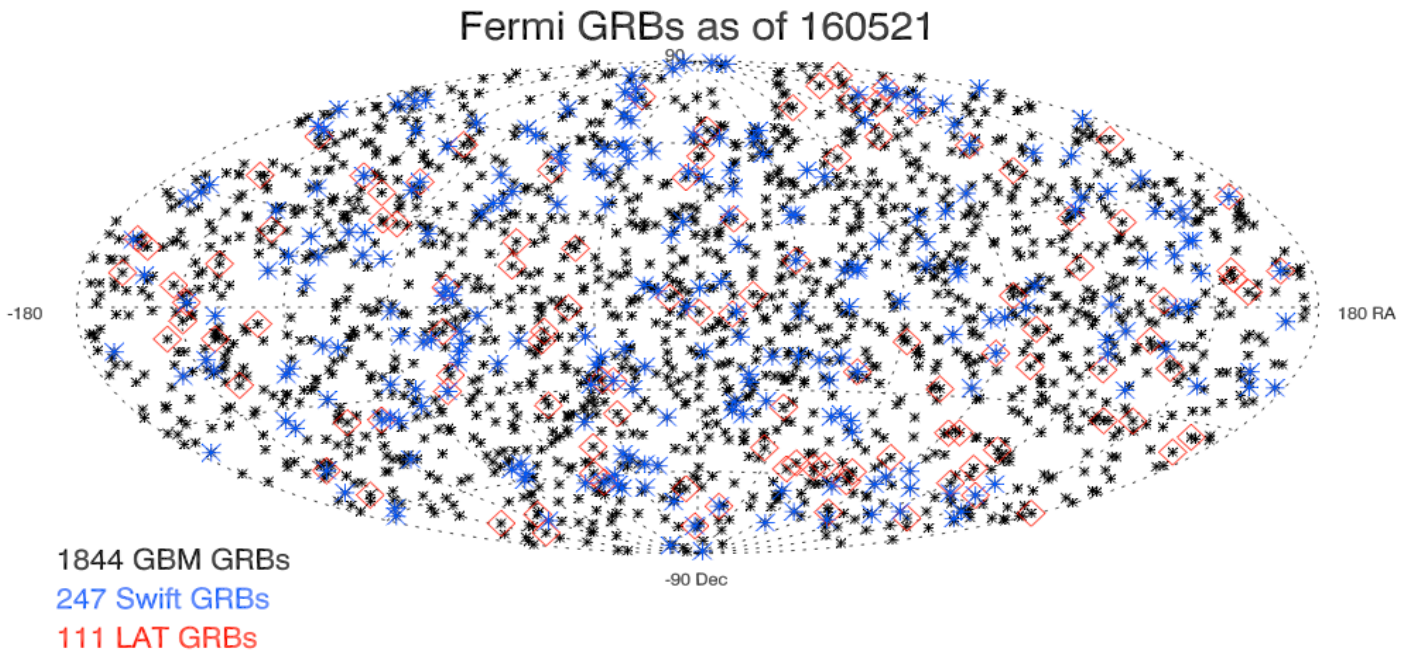


No, it is currently quiet.
The structures were created by some large energy injection in the GC, maybe a past accretion event onto the central MBH, or a nuclear starburst in the last ~10 Myr.
Substructures, but no evidence of a jet



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

Multimessenger: Follow-up of GWs

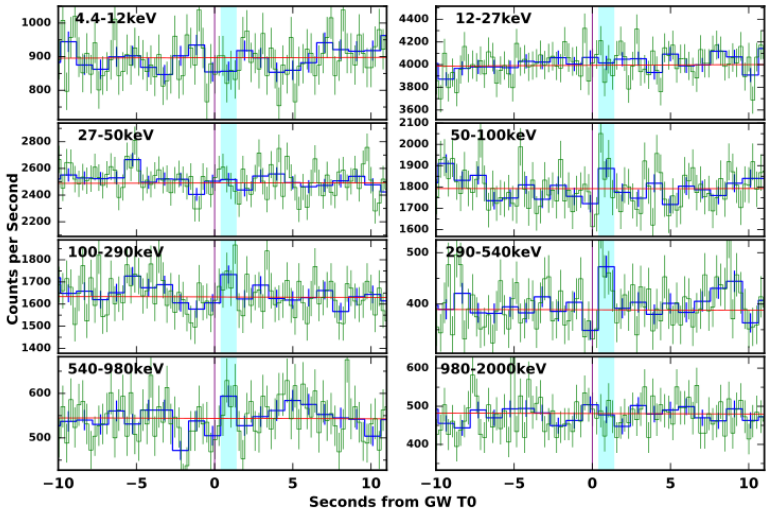
A needle in a haystack…

GBM:

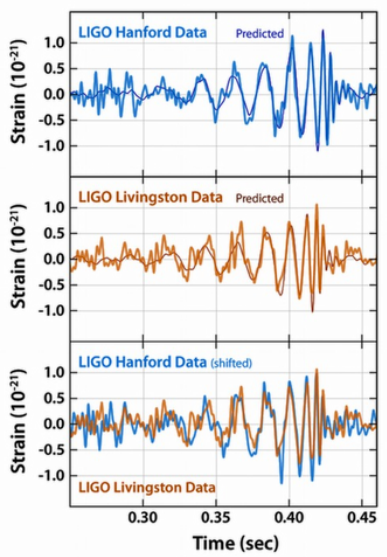
No triggers from standard onboad or offline pipelines

→ **candidate from specific "subthreshold" pipeline**

Estimated FAR: 0.002 / Close to Earth limb



GW150914



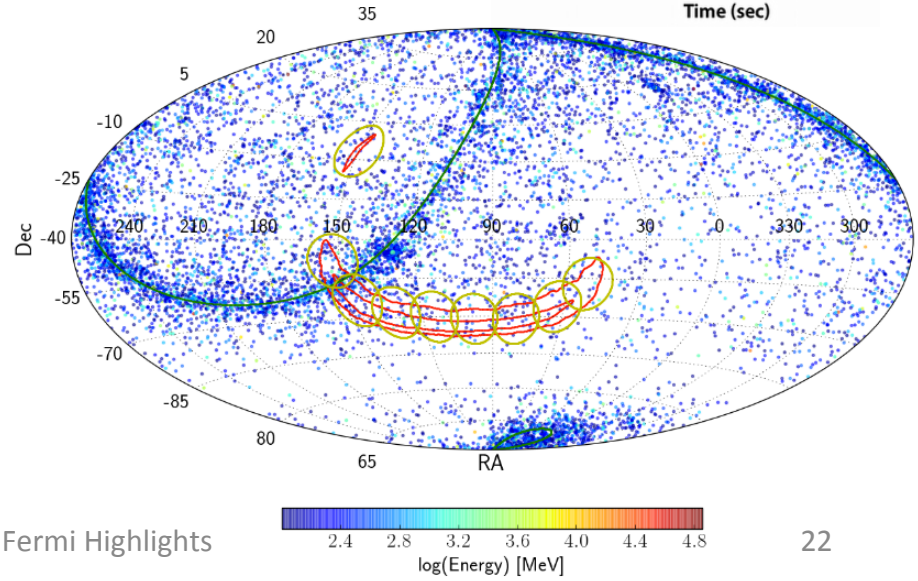
2016, ApJ, 823, 1, L2

LAT:

Coverage started from t+70 min

No triggers on automatic pipeline

No significant excesses on short- and long-based ad hoc pipelines



Multimessenger: Follow-up of GWs

GW151226

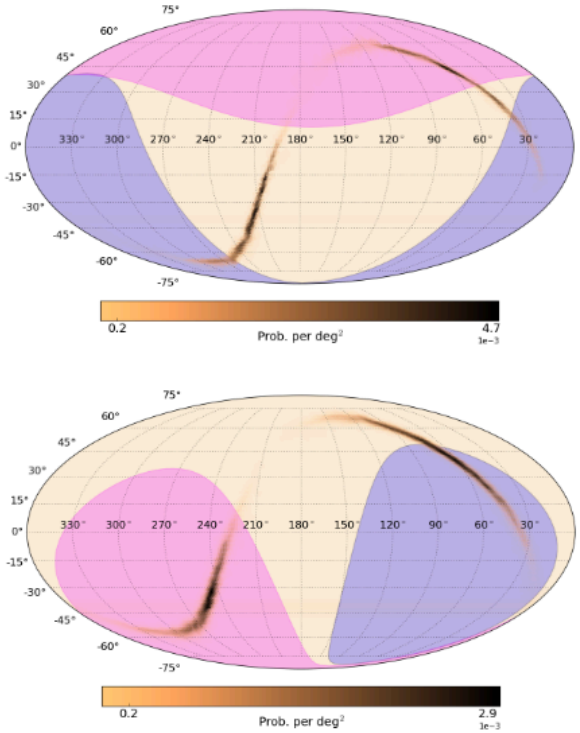
GBM-Occulted
Loc. Prob. = 83%

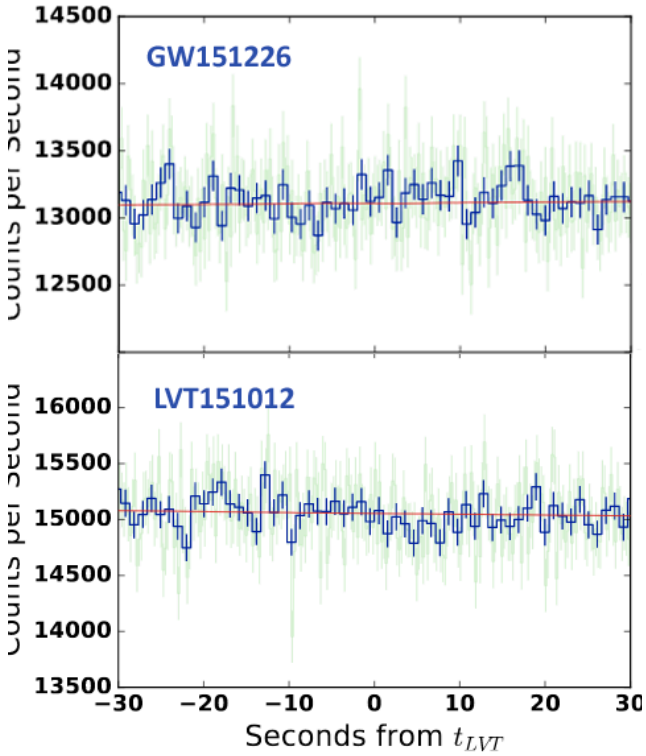
LAT FoV
Loc. Prob. = 32%

LVT151012

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

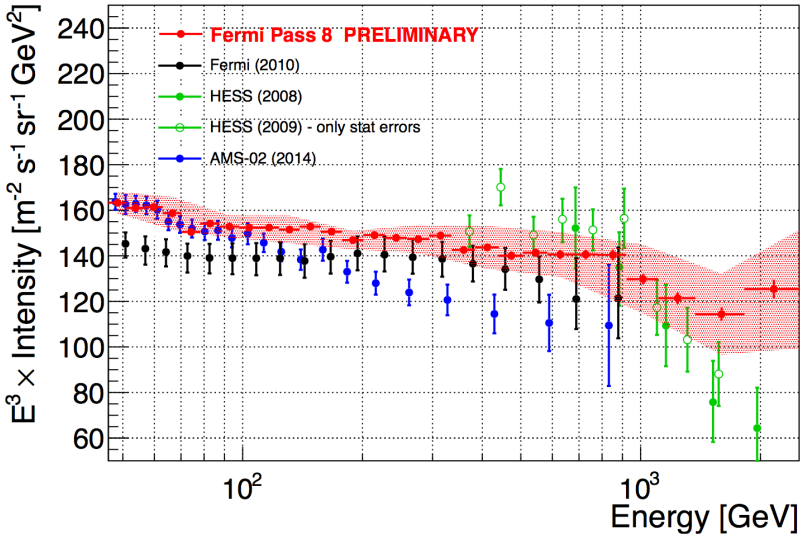
However…
Black hole mergers are not expected to emit significant X-ray or γ-ray signals because any gas around binary BHs should be swept up long before the final merging

See talk by M. Razzano

Multimessenger: CR Electrons

- The detector is designed for imaging the development of EM showers → naturally suitable to measure electrons

CRE spectrum



Now probing the ~TeV cutoff

CRE (pass-8) paper in preparation

- The LAT on-board gamma filter is designed to reject charged particles but it accepts all events with a deposited energy in the CAL >20 GeV

  → **CRE are there!**

  ~10K events above 1 TeV

- Shape of the spectrum above ~100 GeV can give information about the sources of CRE and their propagation

LAT Collaboration, 2015 Fermi Symposium

Not covered in this talk:

- CR physics with the Sun and the Moon 2016, Phys. Rev. D, 93, 082001

See talk by S. Rainò

- 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
- CRE anisotropies in preparation

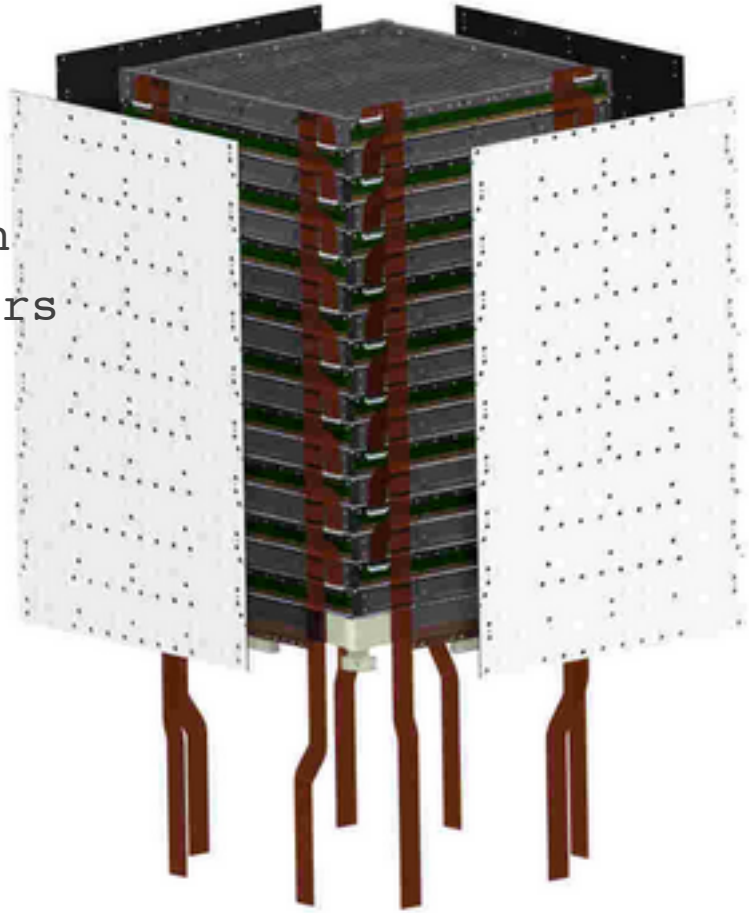
A lot of great science… don't miss next talks and stay tuned for upcoming new results!

Fermi-LAT Highlights

BACKUP

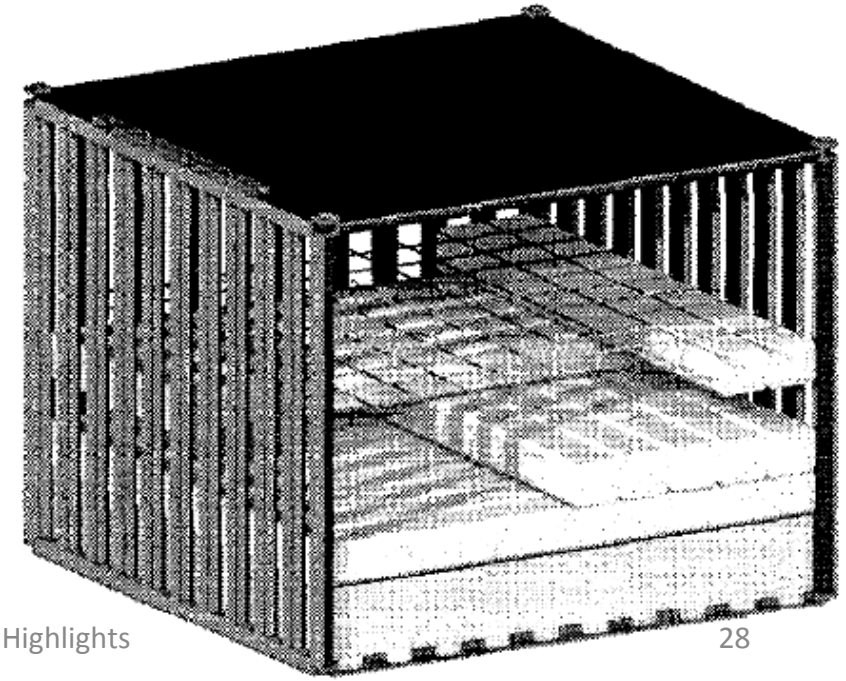
Tracker

- 18 x,y tracking planes Si-strip detectors
  - pitch 200 μm
- 16 converter planes of tungsten
  - "FRONT" → first 12 "thin" layers of 3% radiation length
  - "BACK" → next 4 "thick" layers of 18% radiation length



Calorimeter

- made in a hodoscopic fashion from CsI(Tl)
- position-sensitive crystal rods measuring 333.0 × 26.7 × 19.9 mm^3
- Each calorimeter tower contains 8 layers of crystals with 12 crystals in each layer
- approximately 8.6 radiation lengths deep



ACD

- Charged-particle bkg rejection
- Plastic scintillator, Wavelength Shifting (WLS) fiber readout
- Segmented tiles
  - control backsplash
  - reduce self-veto

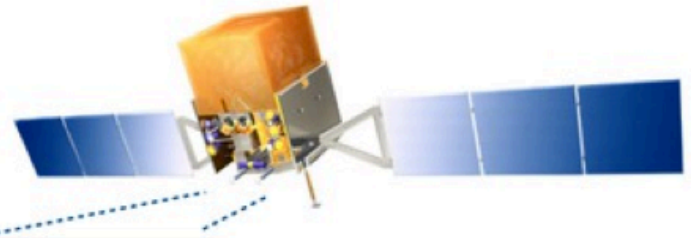
pass-8

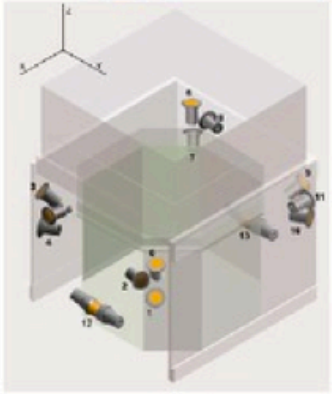
One of the the primary motivations for Pass 8 was to mitigate the effect of 'ghost' events, instrumental pile-up away from the gamma-ray shower that introduced errors in the measurement of the energy, and shower center and direction. Although originally motivated by the issue of ghost events, the new event reconstruction features improvements in many key areas beyond that. These include:

- A new pattern recognition algorithm in the Tracker reconstruction that does not depend on Calorimeter information and is less sensitive to track confusion induced by the backsplash.
- A clustering stage in the Calorimeter reconstruction aimed at finding and discarding the charge deposition due to ghost events.
- A better energy reconstruction that improves the handling of energy leakage and crystal saturation.
- A better algorithm for the association between tracks and ACD tiles for the rejection of charged particles.
- A new event classification analysis based on boosted decision trees that improves the separation power between photon and cosmic-ray background events.

GBM

Fermi Gamma-ray Burst Monitor



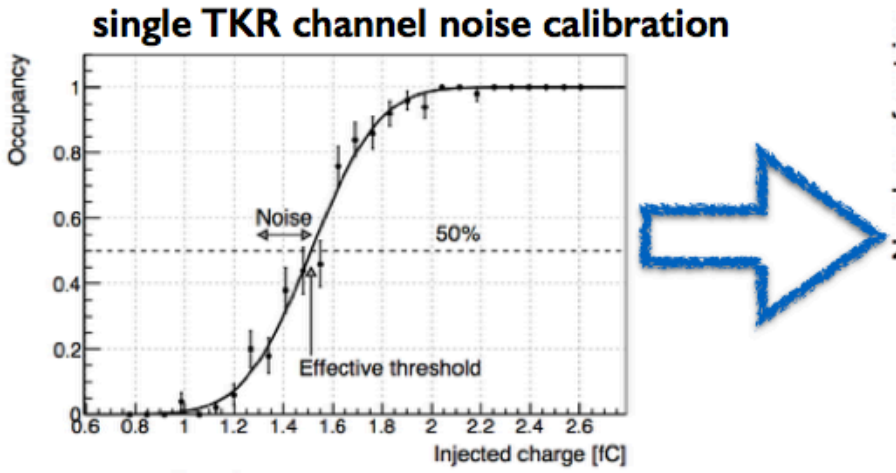


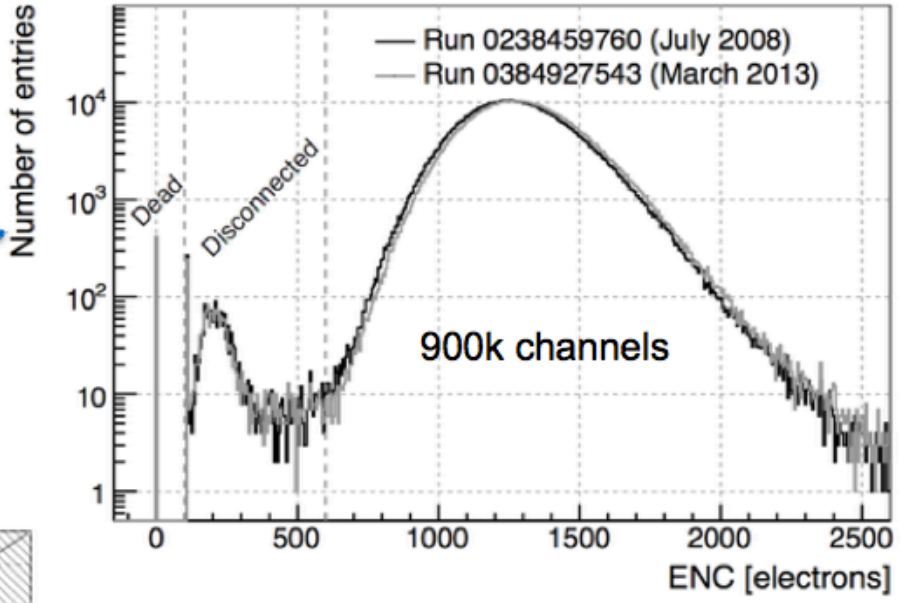
GBM consists of an array of:
- *12 NaI scintillation detectors < 1 MeV*
- *2 BGO detectors < 40 MeV*

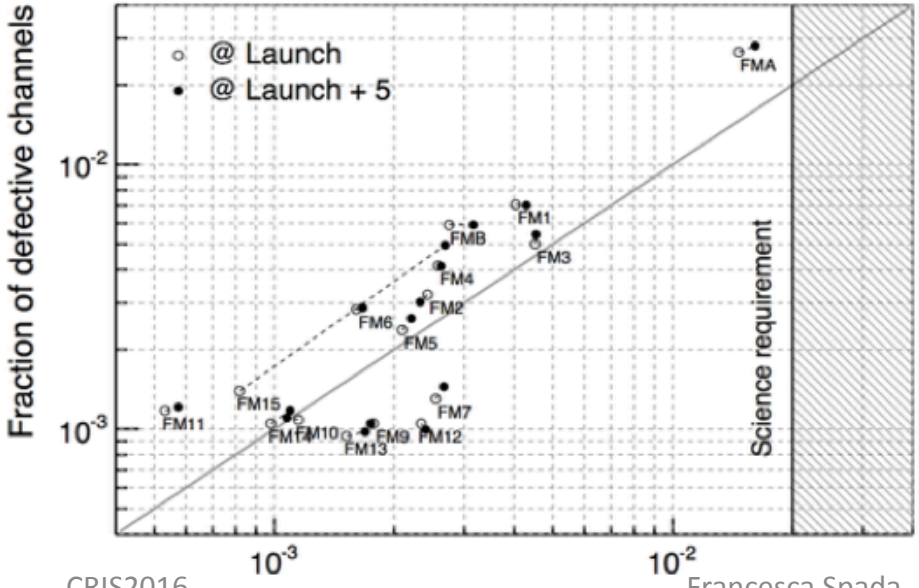
Bursts are seen as coincident excess over background in multiple detectors
- *smooth background fit*
- *coincidence rejects noise*
- *relative rates determine source location*

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







- **73m² 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**

Gamma-Ray Sources

Gamma-Ray Bursts

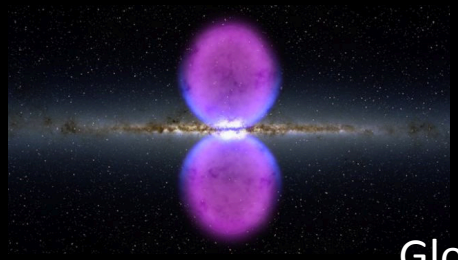
Blazars

Radio Galaxies

Starburst Galaxies

Extragalactic

Large & Small Magellanic Clouds



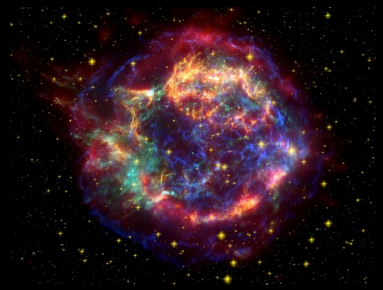
Fermi Bubbles

Globular Clusters

Novae

Galactic

Supernova Remnants



Gamma-ray binaries

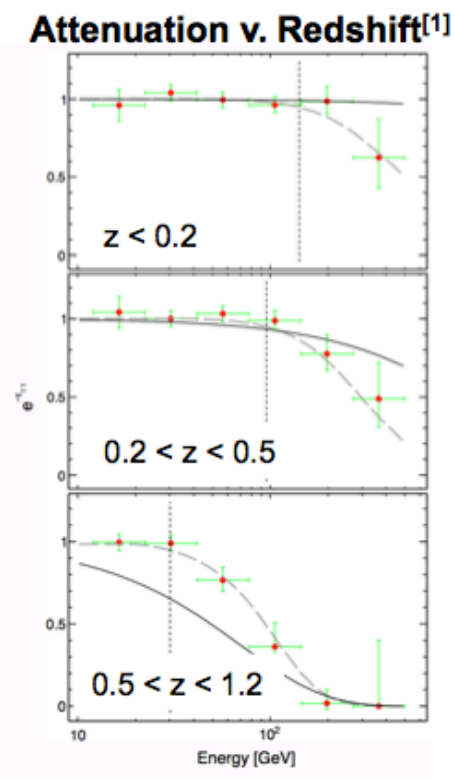
Pulsars

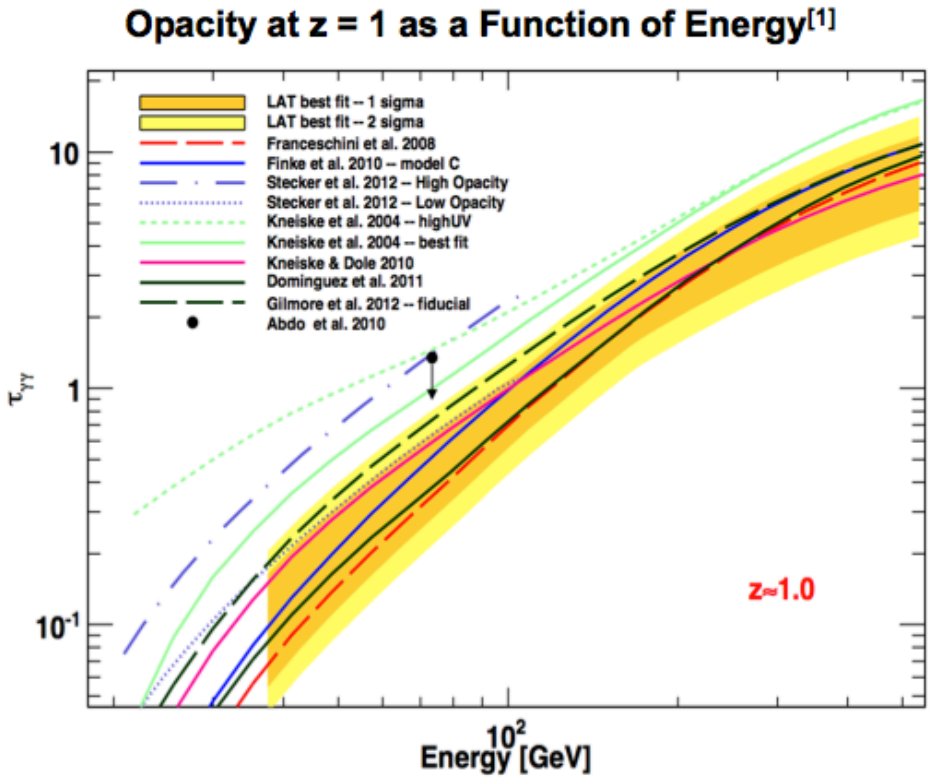
Local

Sun & Moon

Terrestrial gamma-ray flashes

Extragalctic Background Light





[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 ...

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.

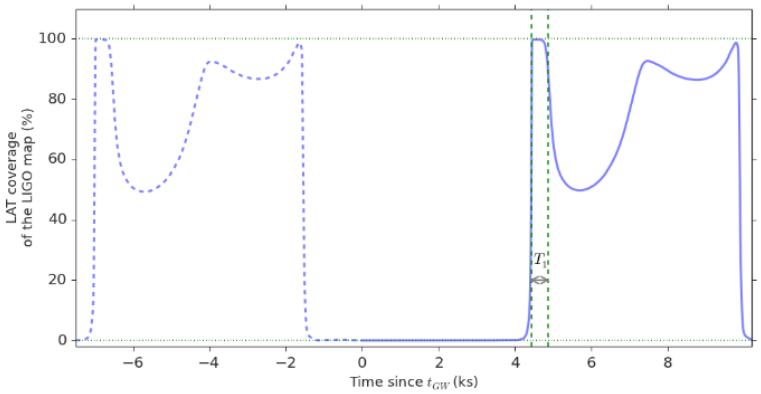
Results favor lower-opacity models

GW150914 The view of the LAT

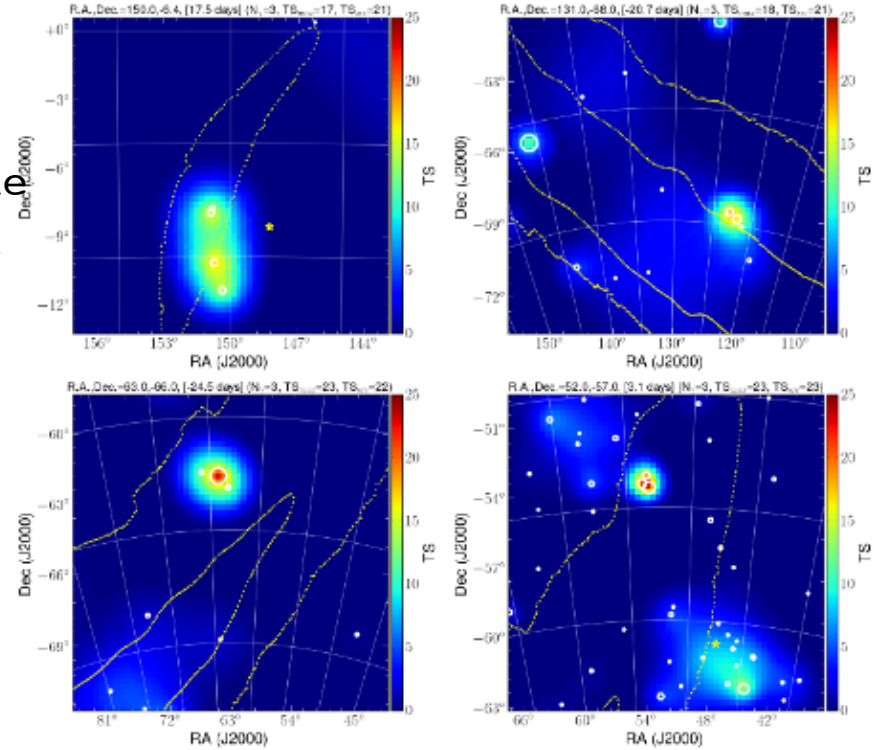
- Other analysis by high-energy facilities to confirm/disprove GBM transient
- Large fov (2.4 sr), survey mode (t=95 m)
- High-energy (>100 MeV) gamma rays

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

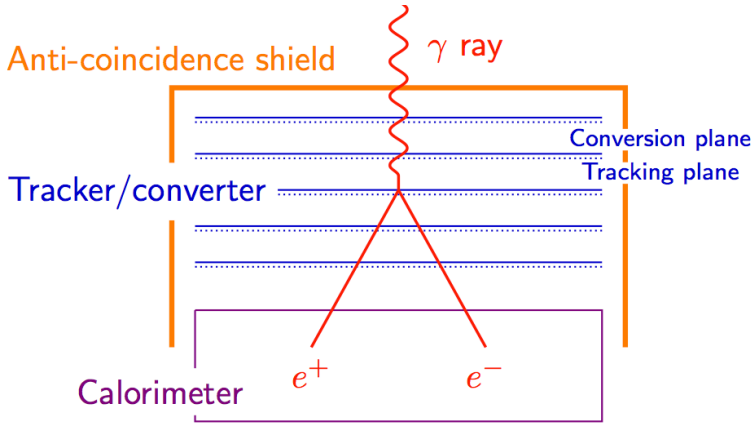


Top sources in 60-day window

CR Electrons and the LAT

- The detector is designed for imaging the development of EM showers → naturally suitable to measure electrons
- The LAT on-board gamma filter is designed to reject charged particles but it accepts all events with a deposited energy in the CAL >20 GeV

  → **CRE are there!**
- A "trick" is needed to go to lower energies… We get down to 7 GeV



- Extending the measurement beyond 1 TeV is challenging
  - Almost 10^4 events above 1 TeV: **statistics is not an issue!** But…
  - at such high energy only ~ 35% of the shower is typically contained in the CAL
  - a significant fraction of the CAL crystals along the shower axis are saturated