The first 10 years of the Fermi Large Area Telescope

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on behalf of
the Fermi-LAT Collaboration

WASHDA 2018, Moscow

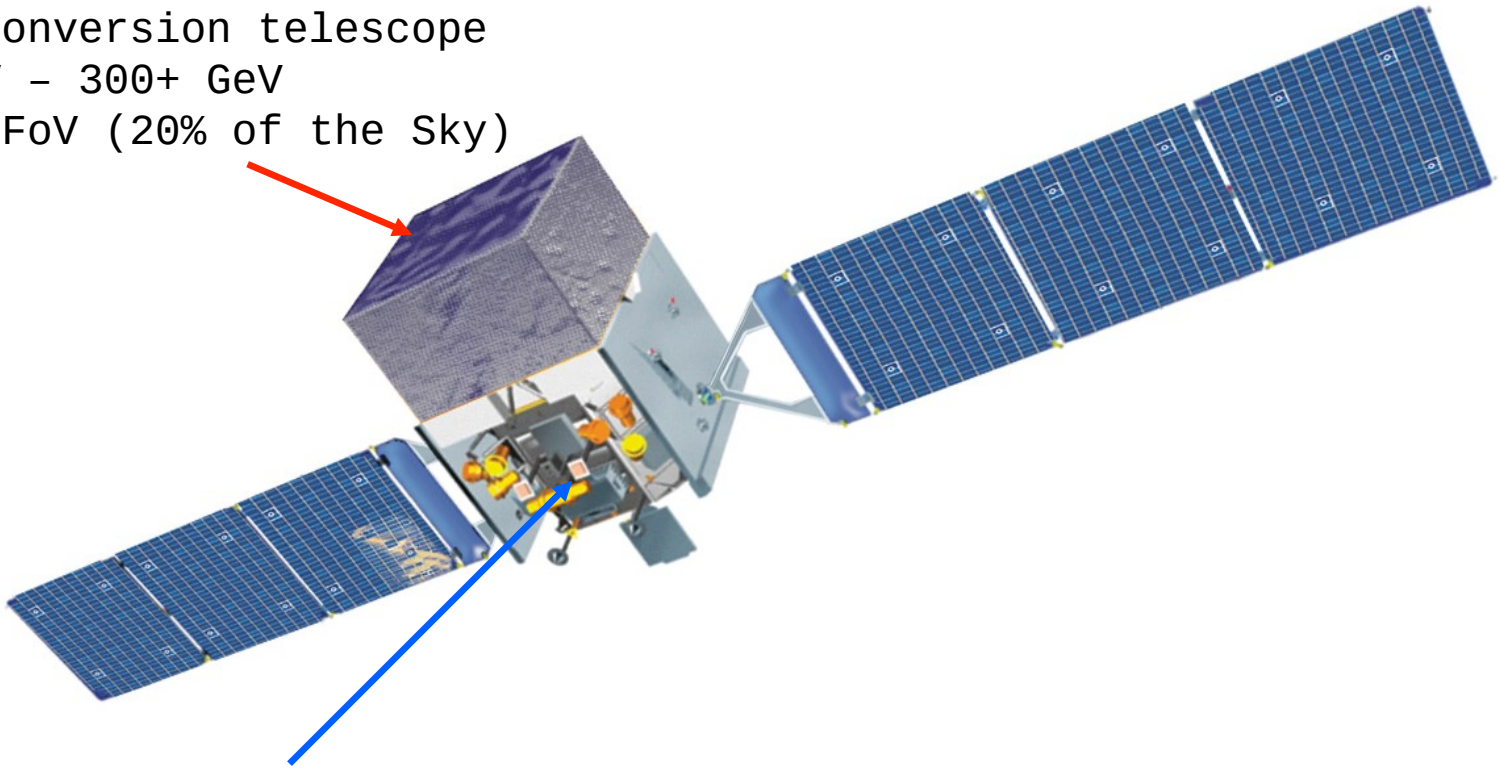
10 years of Fermi!

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

The Fermi-LAT collaboration, March 2018

The Fermi Observatory

Large Area Telescope
- Pair conversion telescope
- 20 MeV – 300+ GeV
- Large FoV (20% of the Sky)

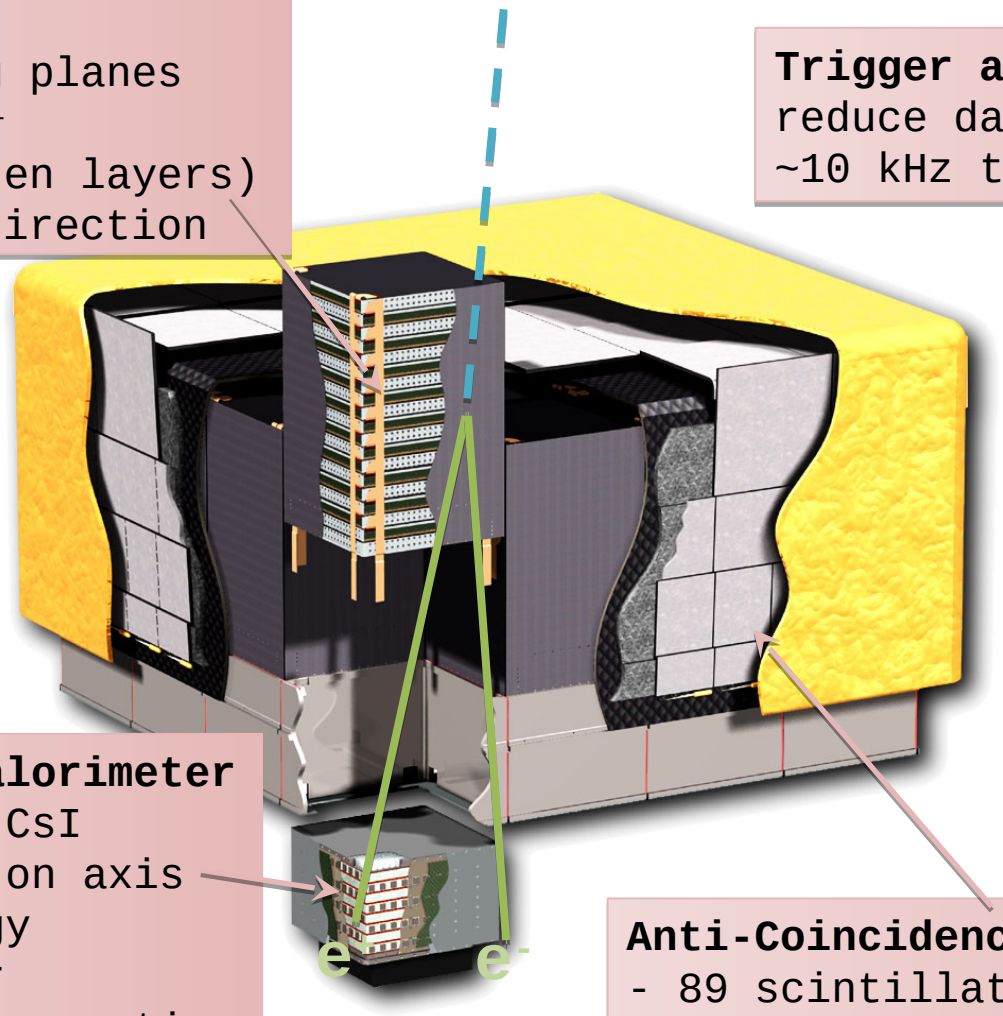


Gamma Burst Monitor
- 12 NaI scintillators and two cylindrical BGO scintillators
- 8 KeV to 40 MeV
- Observes entire unocculted sky

The Large Area Telescope

Si-strip Tracker
- 18 x-y tracking planes
- 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
- 8 layers, 1536 CsI crystals, 8.6 X0 on axis
- Measure γ energy
- Image EM shower
- EM vs. hadron separation

Anti-Coincidence Detector
- 89 scintillation tiles
- charged particle separation

Mission status

10 years of operations on orbit:
- 99% uptime, ~15% inside SAA
- ~600 billion triggers, >1 billion photons of the Source class
- data publicly available immediately after being processed (usually in a few hours)

All LAT sub-systems are still up and running:
- 596/884736 (0.07%) noisy TRK strips masked
- 1 of the 6144 CAL pre-amplifiers failed. No measurable scientific impact thanks to redundancy.
- Light yeld decrease (~0.3%/year) corrected by periodic calibration

One relevant spacecraft issue:
- On March 16, 2018 one solar panel got stuck, observatory went in safe mode for a couple of weeks.
- LAT currently fully operational with modified observing profile: rocking angle is switched only when appropriate (instead of every orbit).

Mission status

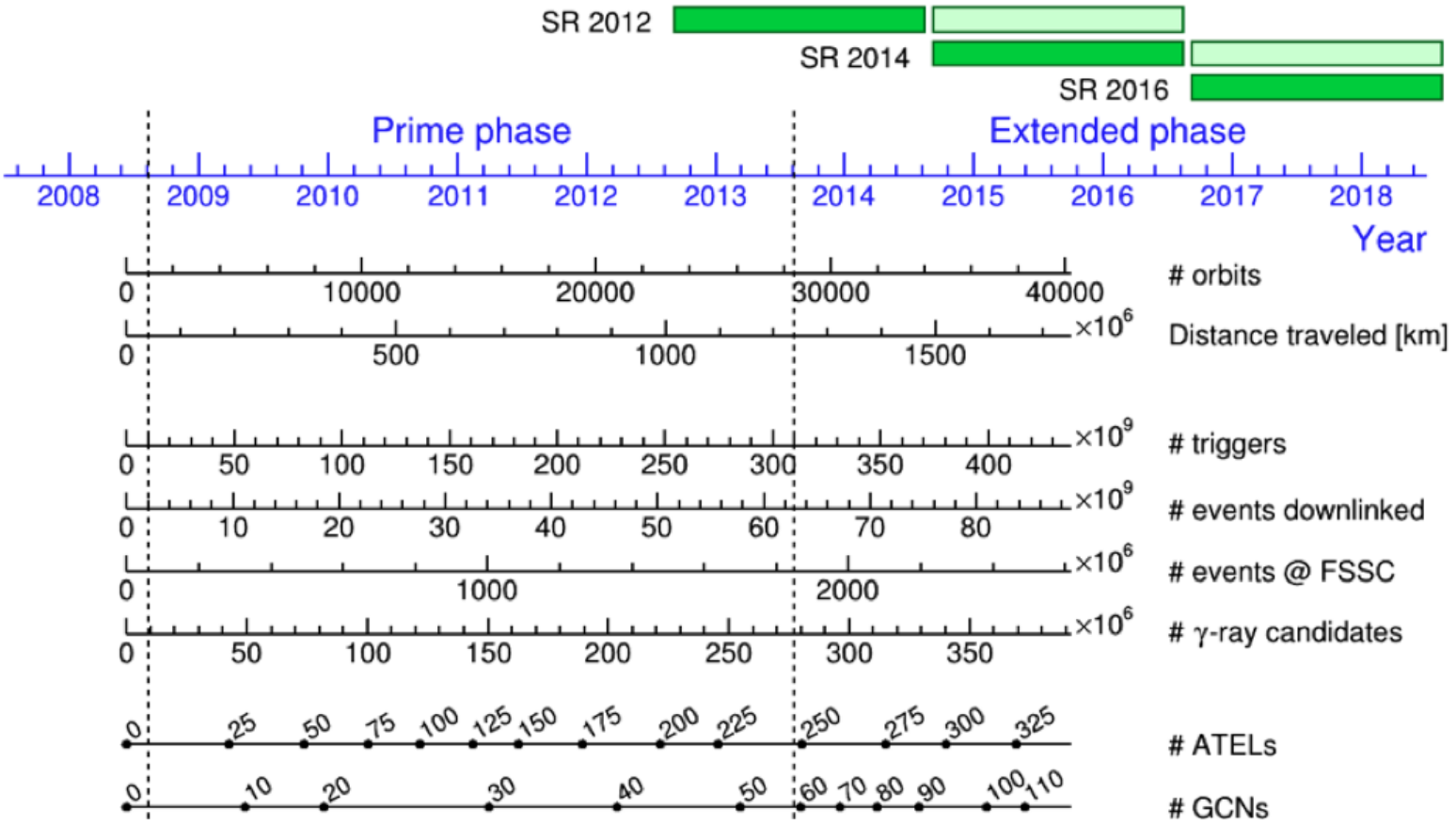
Understanding of the instrument improved with time:

- Reconstruction, selection and calibration of the LAT have all been refined through the years
- Reconstruction algorithms updated in passes (Pass 6, Pass 7, Pass 8)
- Pass 8 was released to public in 2015
- No further major update anticipated. Will (likely) be the one used for LAT legacy data

Mission is still actively supported:

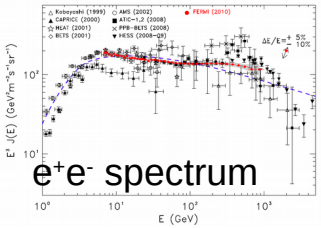
- Fermi-LAT collaboration committed to maintain analysis tools and transient monitoring
- New photon classes (P305) recently developed, will be released soon. The selection strategy allows for reduced contamination (compared to the Source class) without acceptance loss.

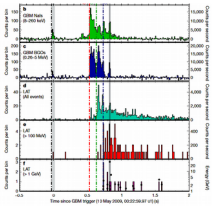
Mission Status



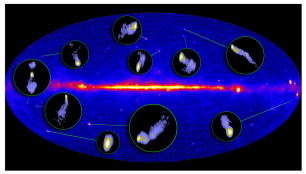
NASA Spring 2016 Senior Review confirm operations through 2018 and recommend through 2020.
Next Senior review will be in 2019

Fermi-LAT targets

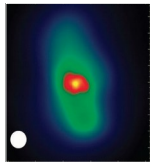




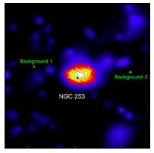
GRBs



Blazars

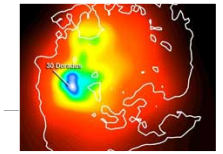


Radio Galaxies

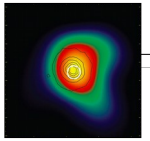


Starburst Galaxies

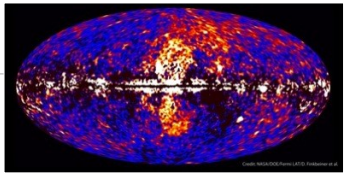
LMC & SMC

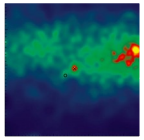


Globular Clusters



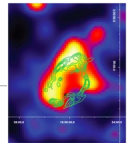
Fermi Bubbles

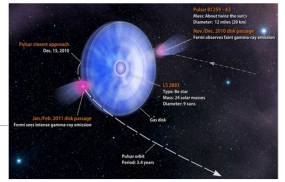




Nova (1)

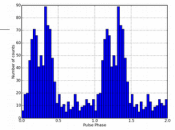
SNRs & PWN





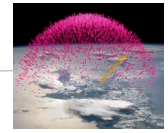
γ-ray binaries

Pulsars: isolated, binaries, & MSPs



Sun: flares & CR interactions

TGFs

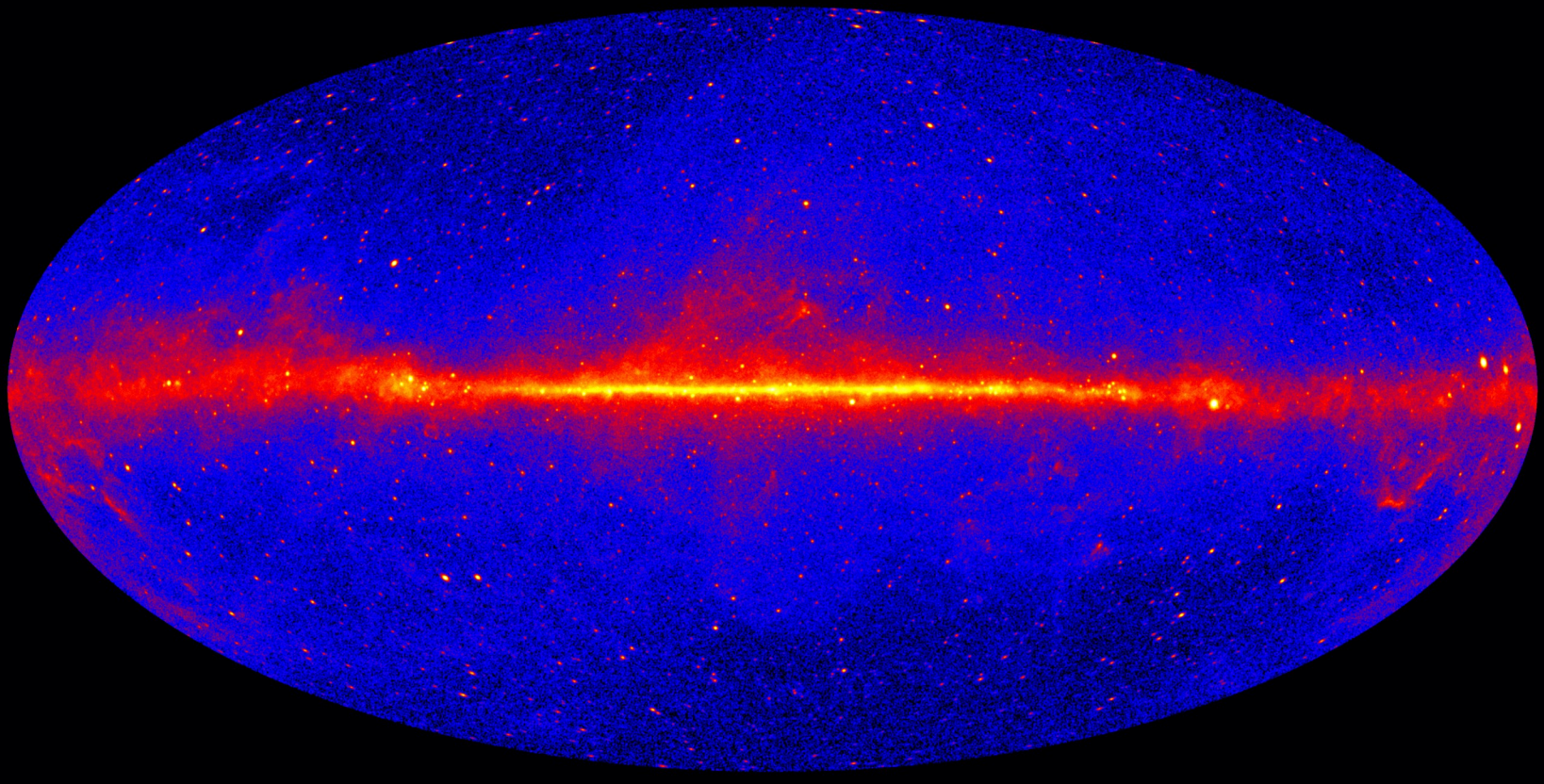


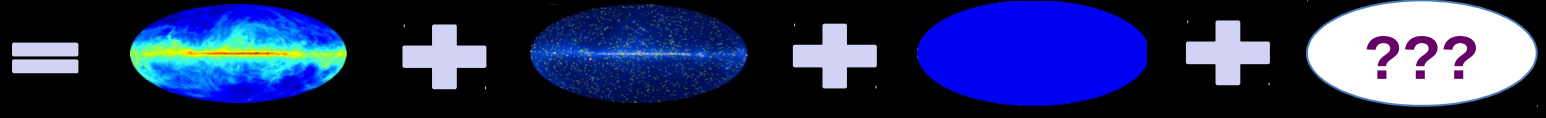
Unidentified Sources

Galactic

Extragalactic

The γ-ray sky





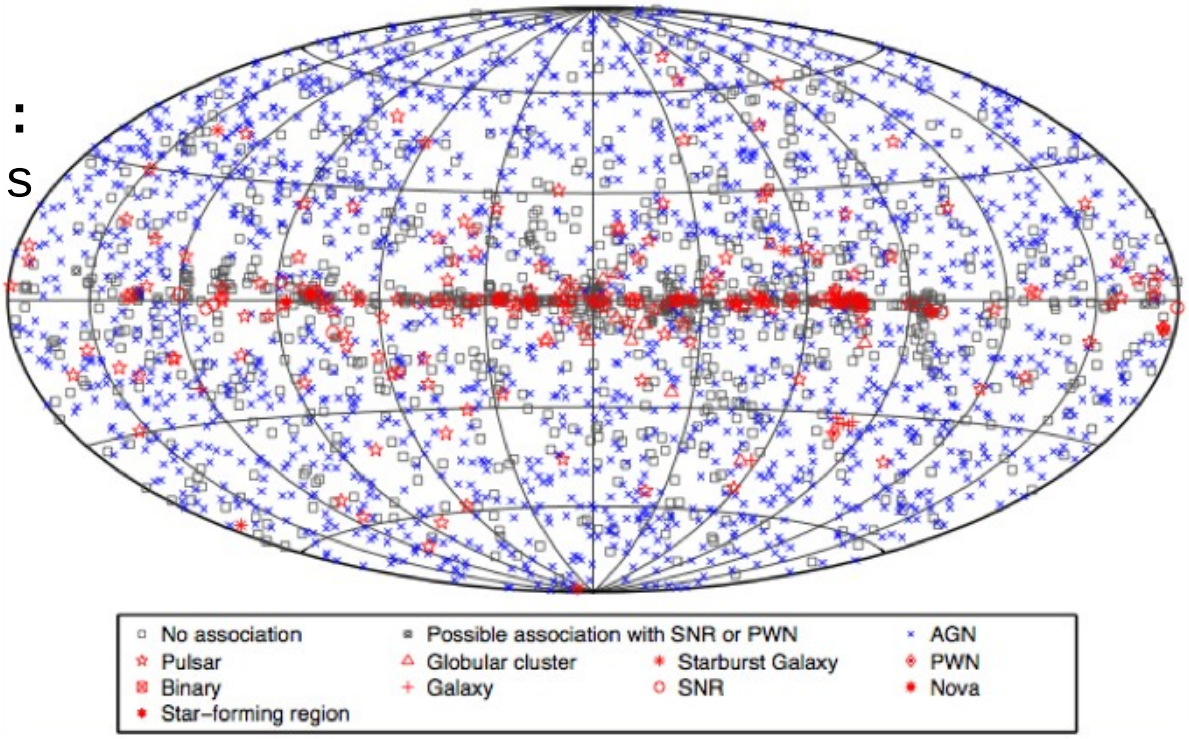
Diffuse Point Sources Isotropic

Identifying sources: Catalog

The third Fermi-LAT catalog [3FGL]
4 years, 3000+ sources (E > 100MeV)

2015, ApJS, 218, 23

4FGL (in preparation):
8 years, ~5500 sources
Pass 8 data

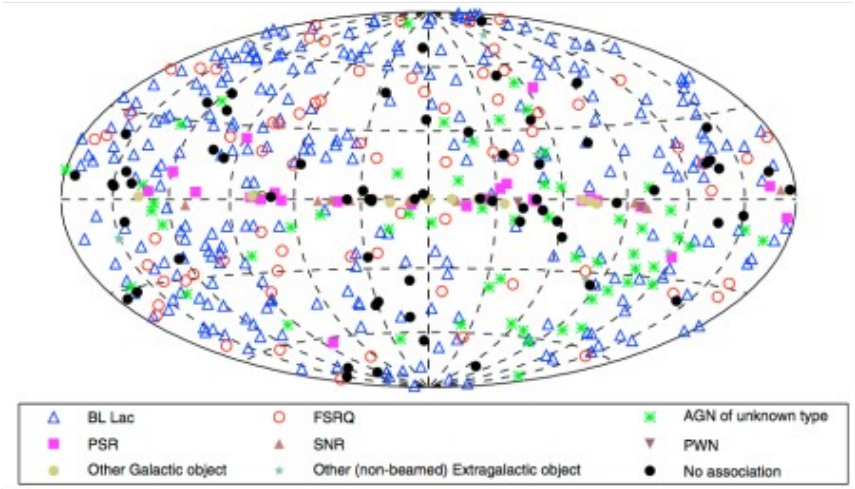


LAT discovered new class of gamma-ray emitters:
non-AGN galaxies,
globular clusters,
high-mass binaries,
galactic novae

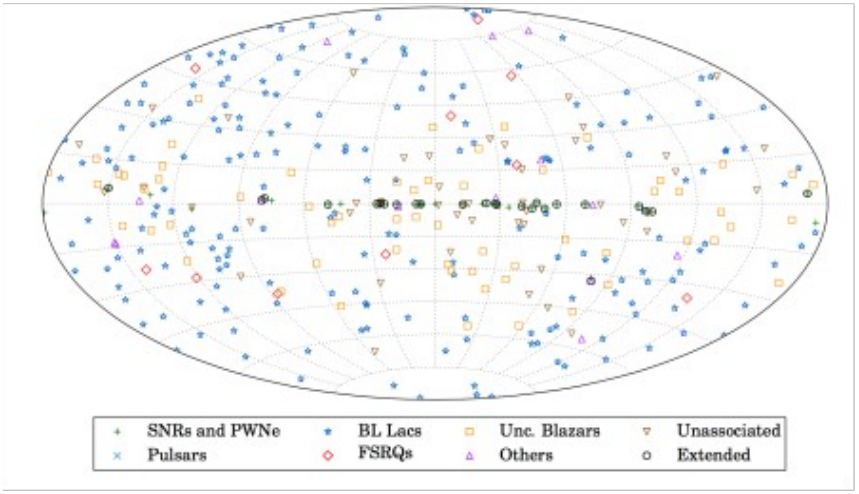
30% of sources still unassociated:
Fraction ~constant after each catalog iteration!

High Energy Source Catalogs

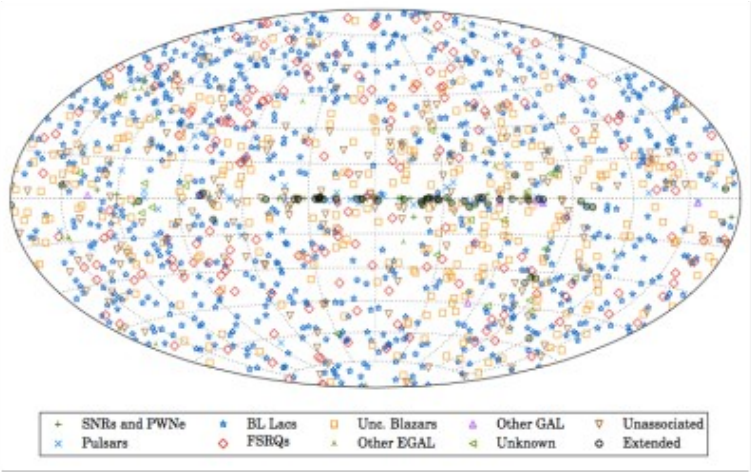
1FHL > 10 GeV, 3 years



2FHL > 50 GeV – 2 TeV, 6.7 years



3FHL: 10 GeV – 2 TeV, 7 years



Closes the energy gap between the LAT and Cherenkov telescopes

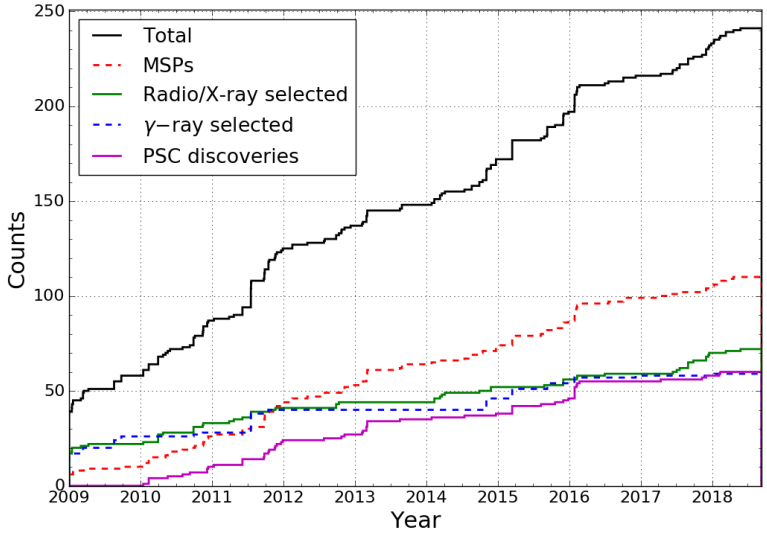
Galactic sources: Pulsars

Before the launch: 7 γ-ray Pulsars known.
After 10 years: **200+**

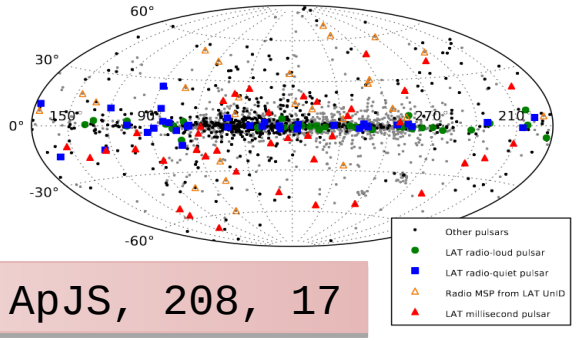
First extragalactic pulsar PSR J0540-6919 observed in the LMC

2015, Science, 350, 6262

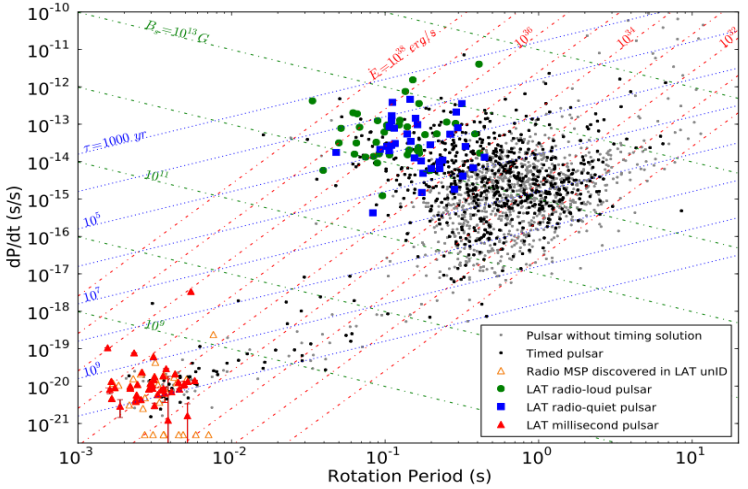
Rate of discoveries stable: 2/month



γ-ray Pulsars: 147 sources

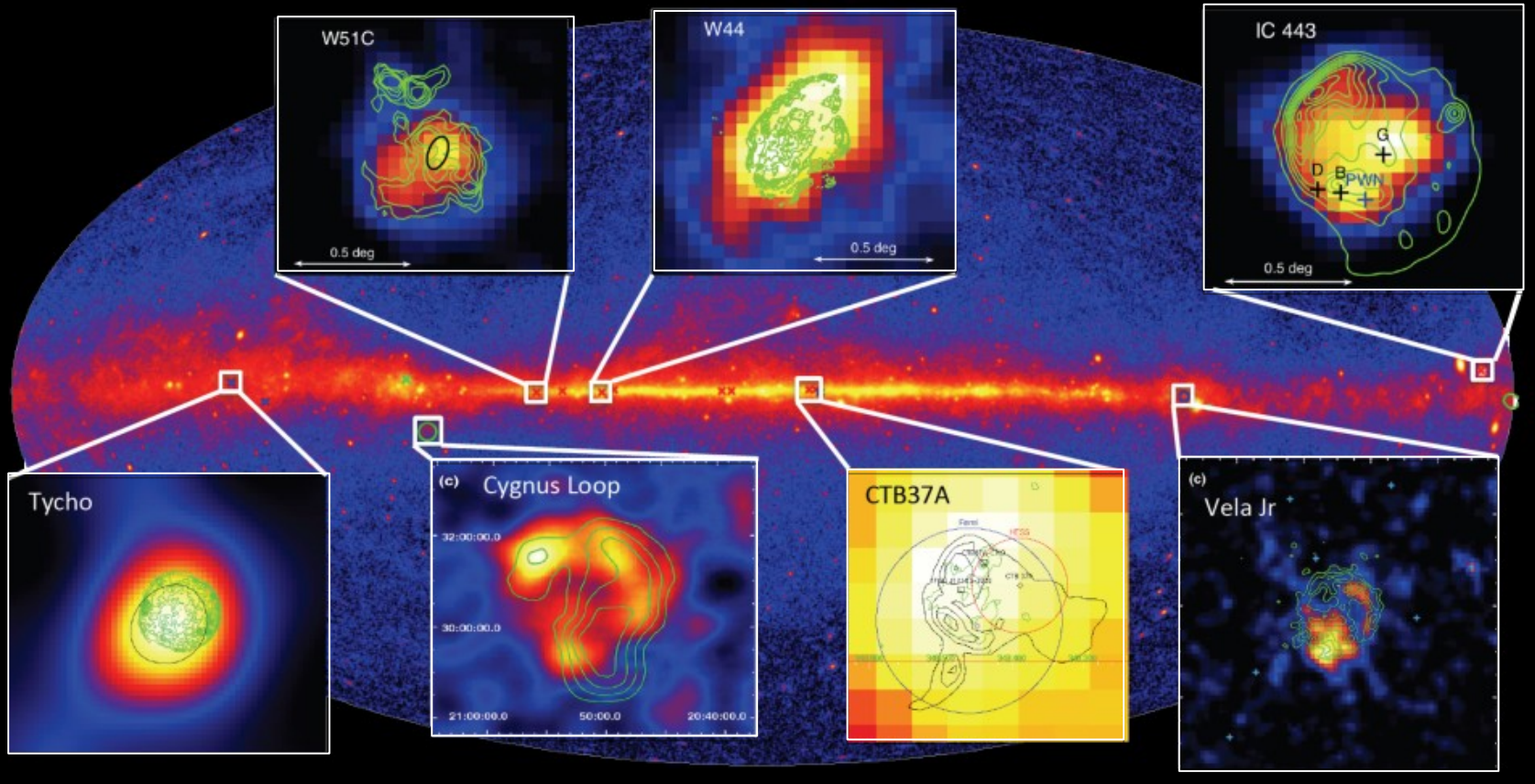


2013, ApJS, 208, 17



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

Galactic sources: SNRs

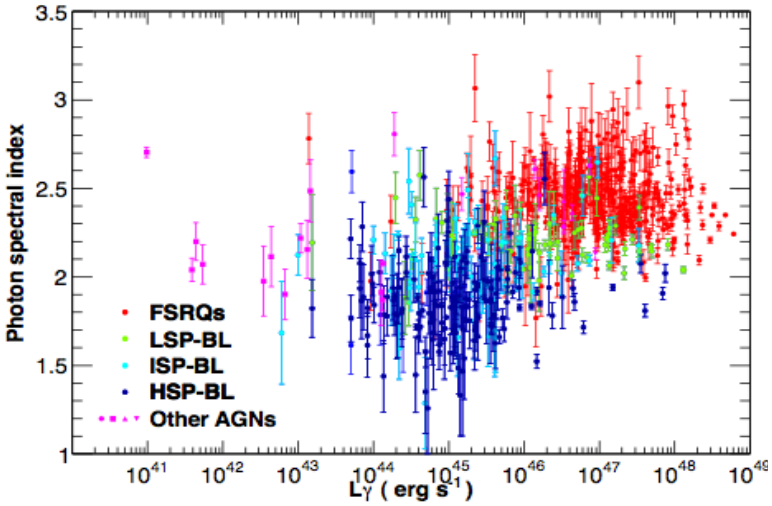


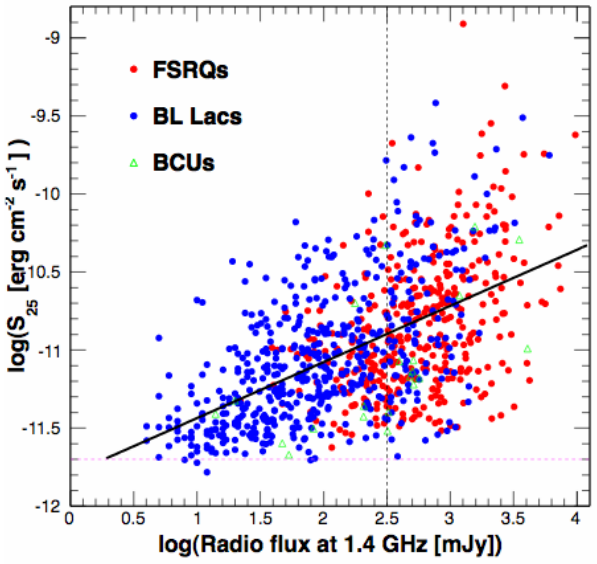
SNRs cataloog: 30 (+14) sources.
Two populations: young and old+cloud.

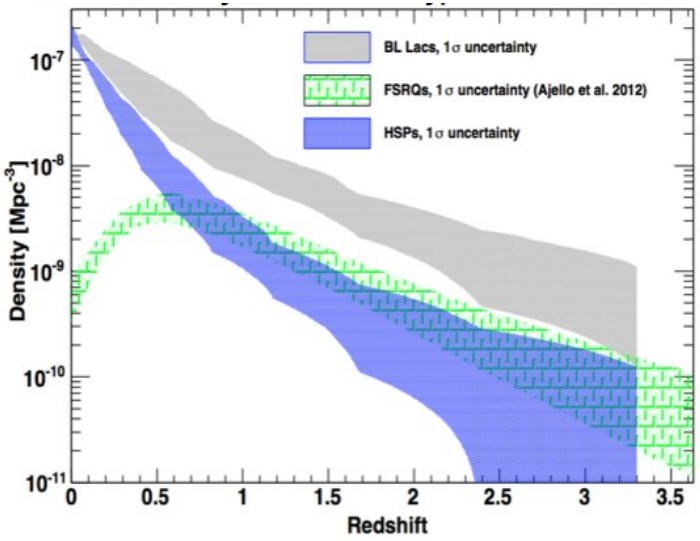
2016, ApJS, 224, 8

Extragalactic sources: Active Galactic Nuclei

AGN Catalog [3LAC]: 1591 sources







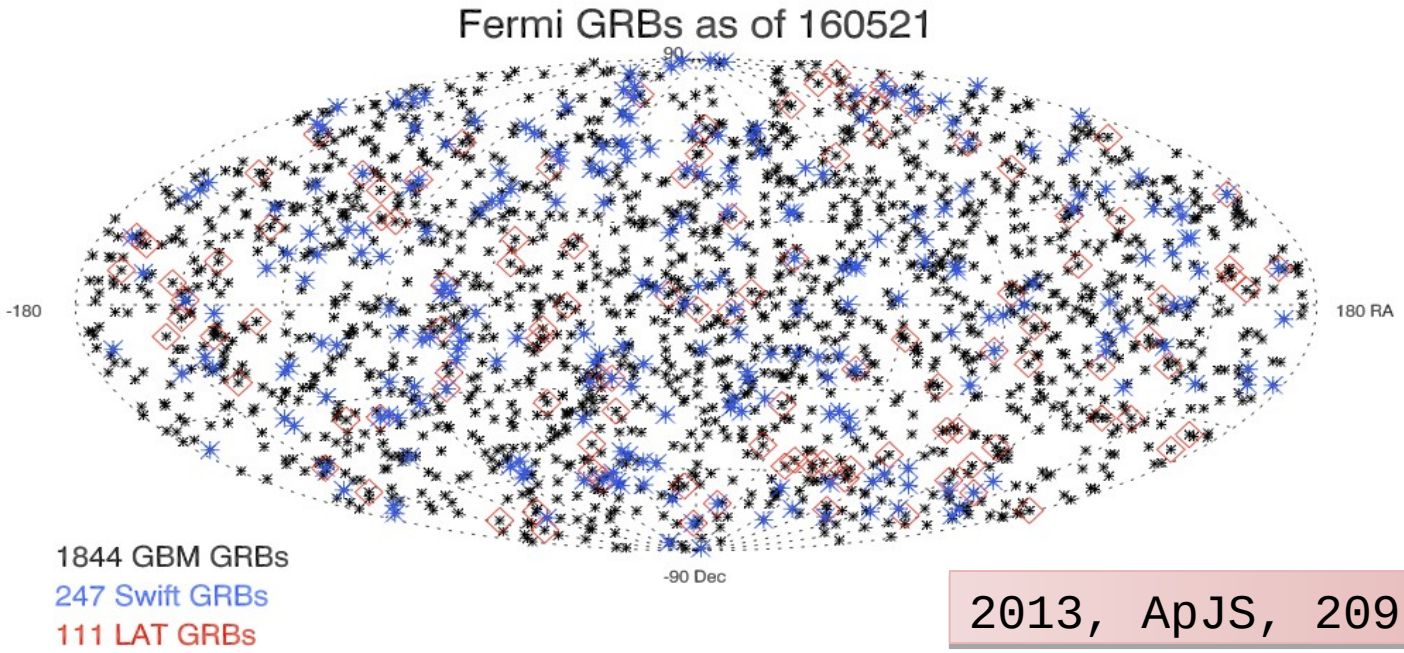
98% of the sources are **blazars**: BL Lacs + FSRQ

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



2013, ApJS, 209, 11

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

Cosmic-rays and diffuse emission

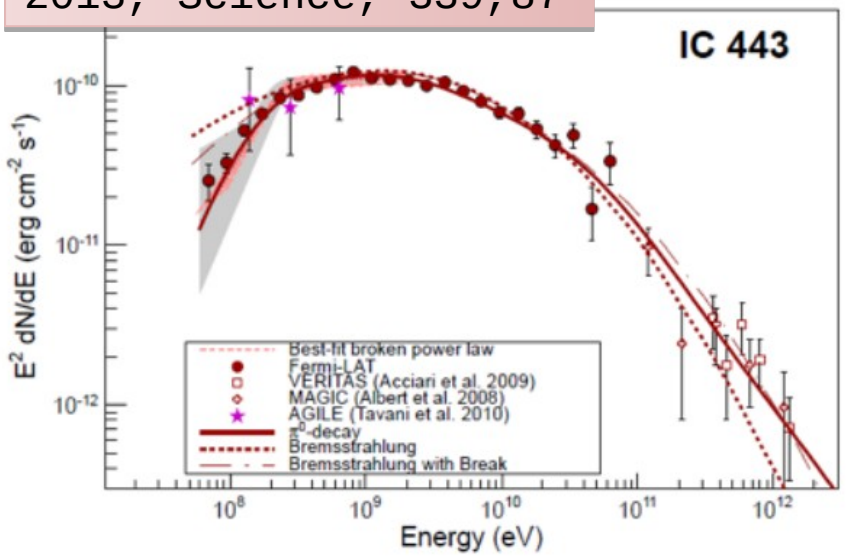
Study CR acceleration sites
- 39 SNRs detected (27 extended)
- Evidence of pion decay signature in two SNRs

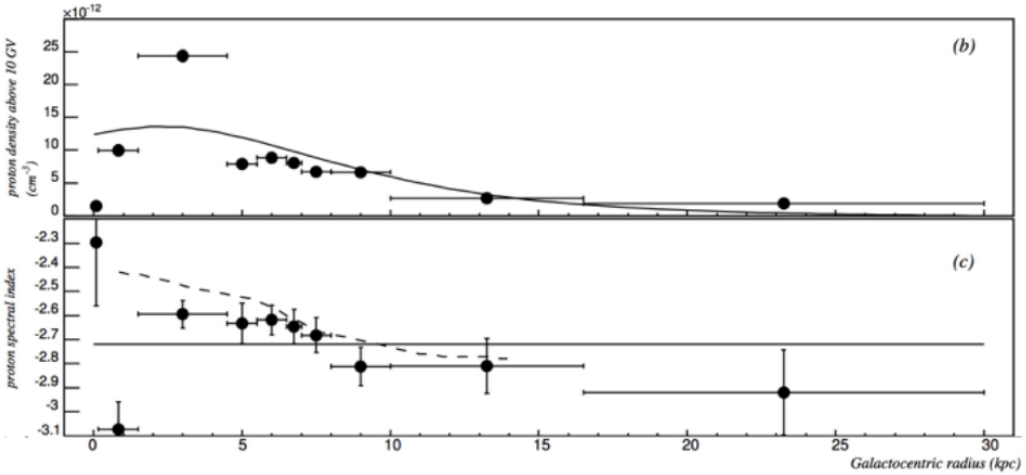
Model diffuse emission:
Fitting emission template to Fermi data (both for source detection and for studying CR and ISM)

Proton density and slope decrease with Galactocentric distance

2016, ApJS 223, 2,26

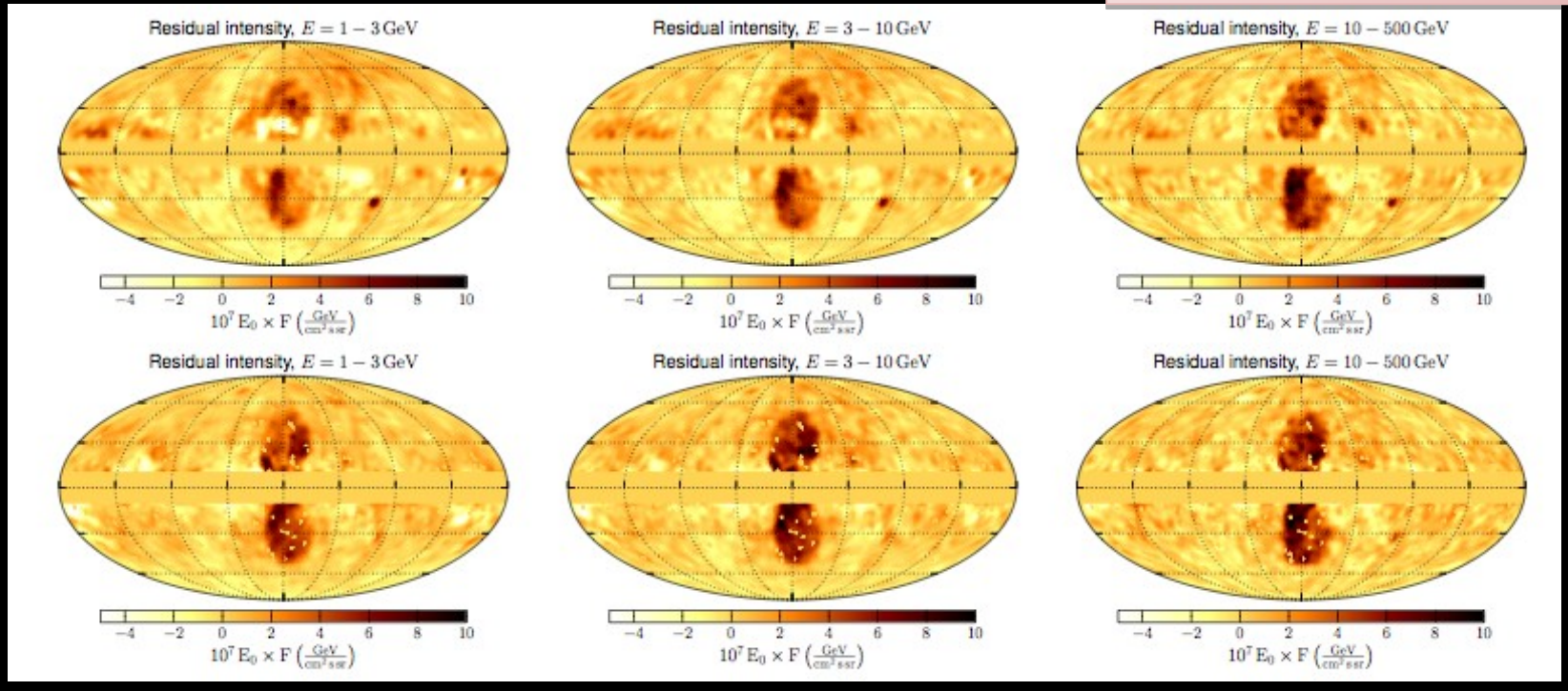
2013, Science, 339,87





A surprise: the Fermi Bubbles

2014, ApJ, 793, 64

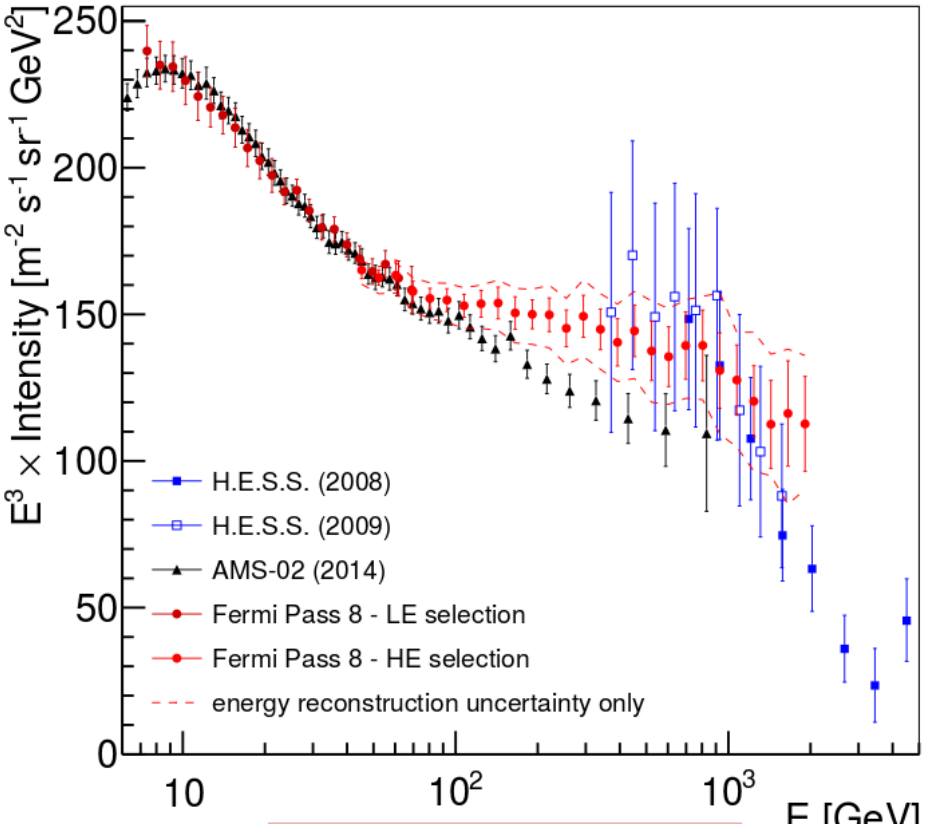


Was the Milky way an active Galaxy?

The structures may have been 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.

Comsic-ray Electrons

Spectrum from 7 GeV to 2 TeV



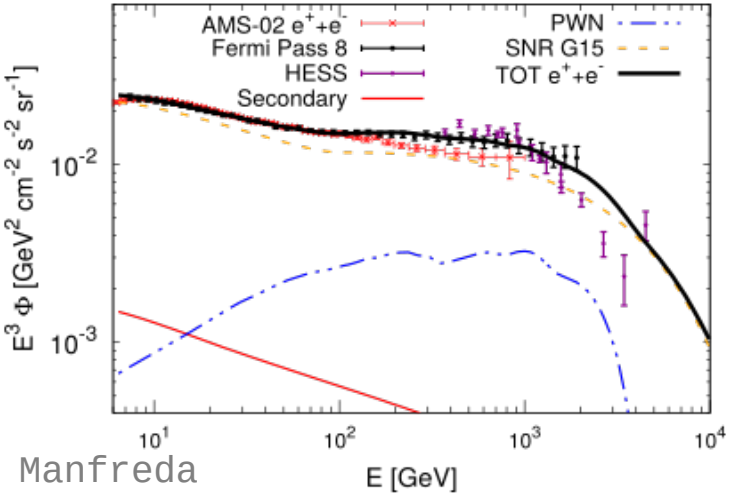
2017, PRD, 95, 8

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

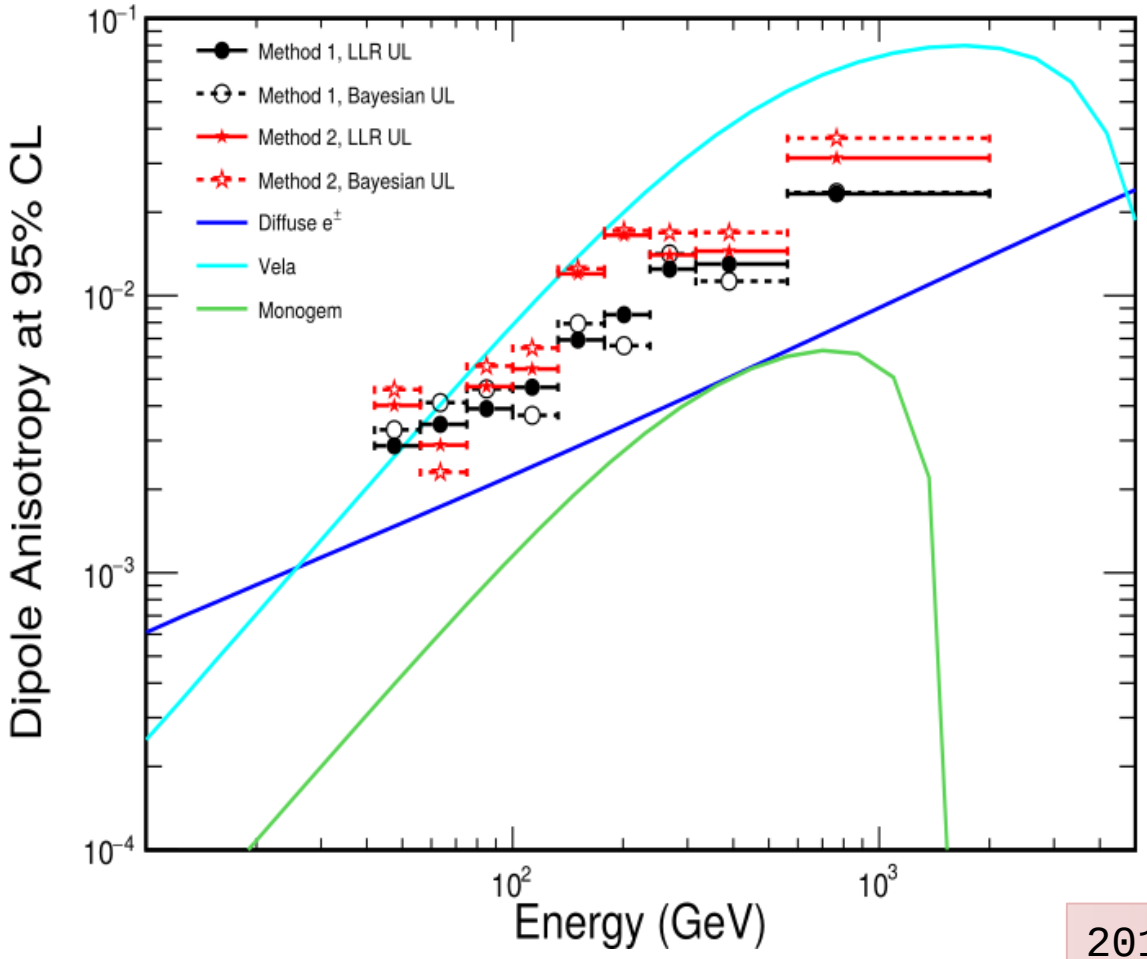
2017, ApJ, 845, 2



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!

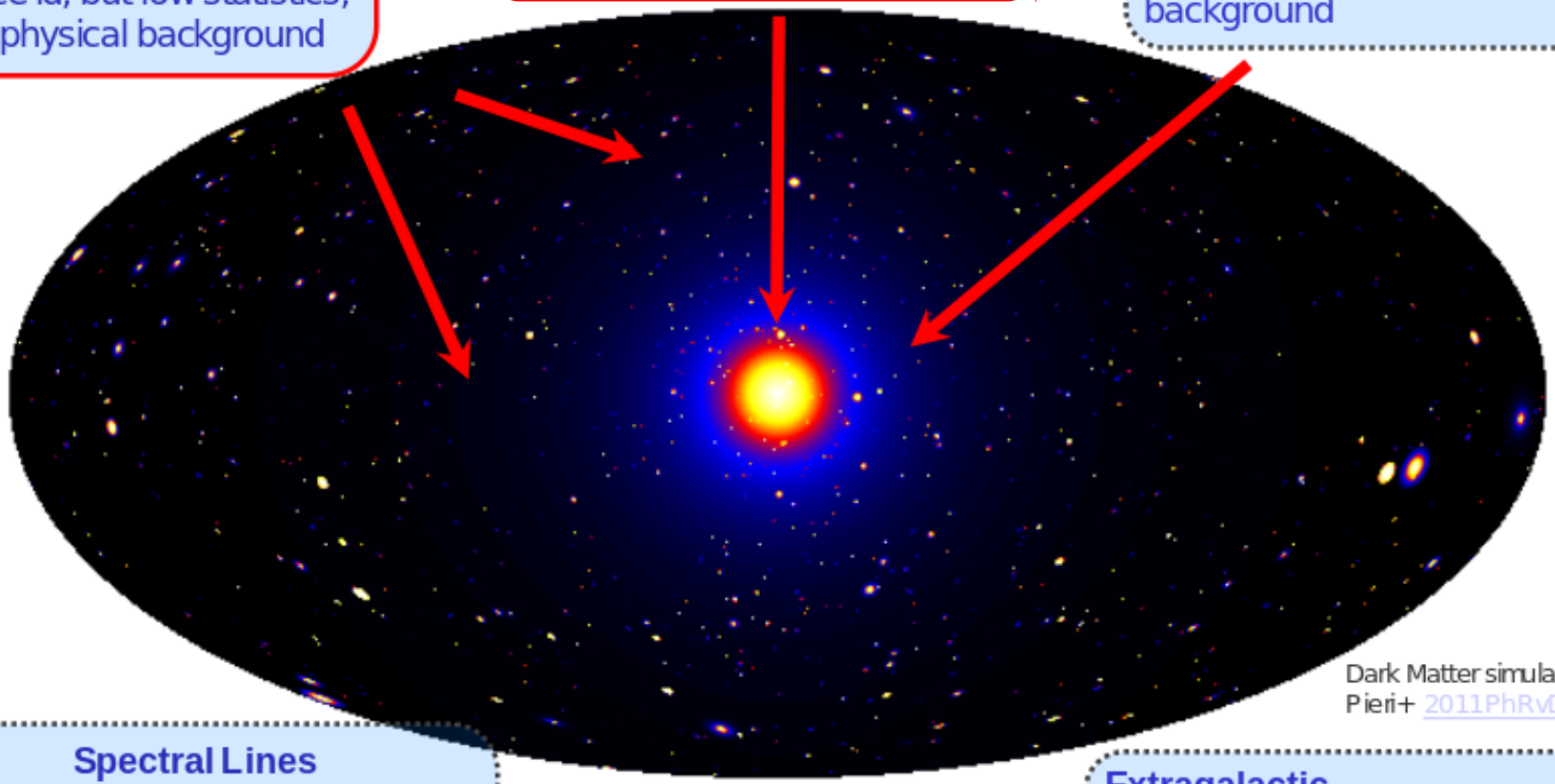
2017, PRL, 118, 091103

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

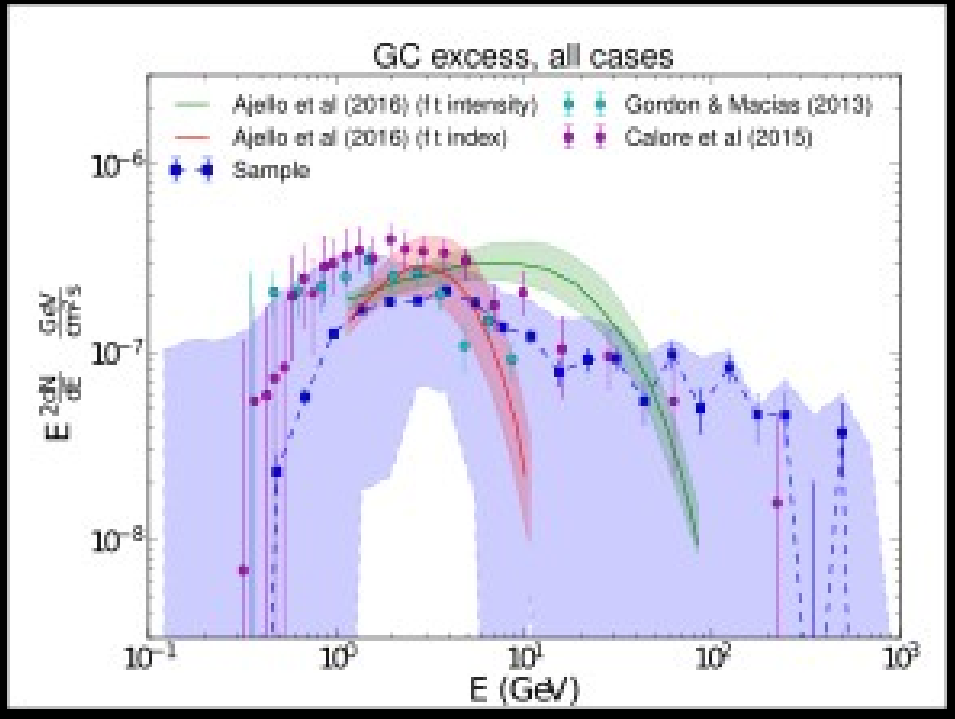
Galaxy Clusters
Low background, but low statistics

Extragalactic
Large statistics, but astrophysics, galactic diffuse background

Probing DM: GC excess

Independent analyses report a spatially extended excess

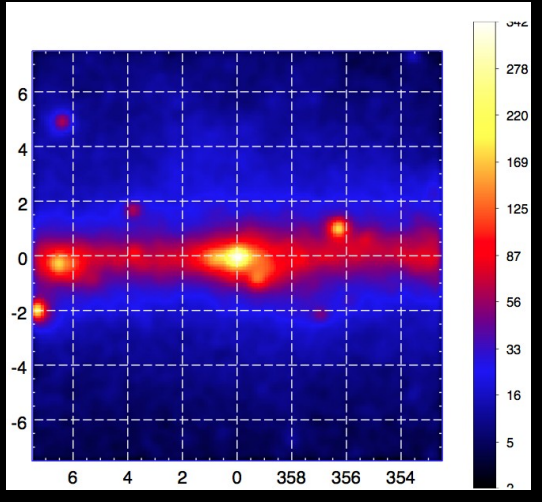
- Spherically symmetric, spectrum **consistent with DM**



2017, ApJ, 1, 43

Degenerate with potential **astrophysical contributions**

- Diffuse from CR inhomogeneities
- Pupulation of millisecond pulsars

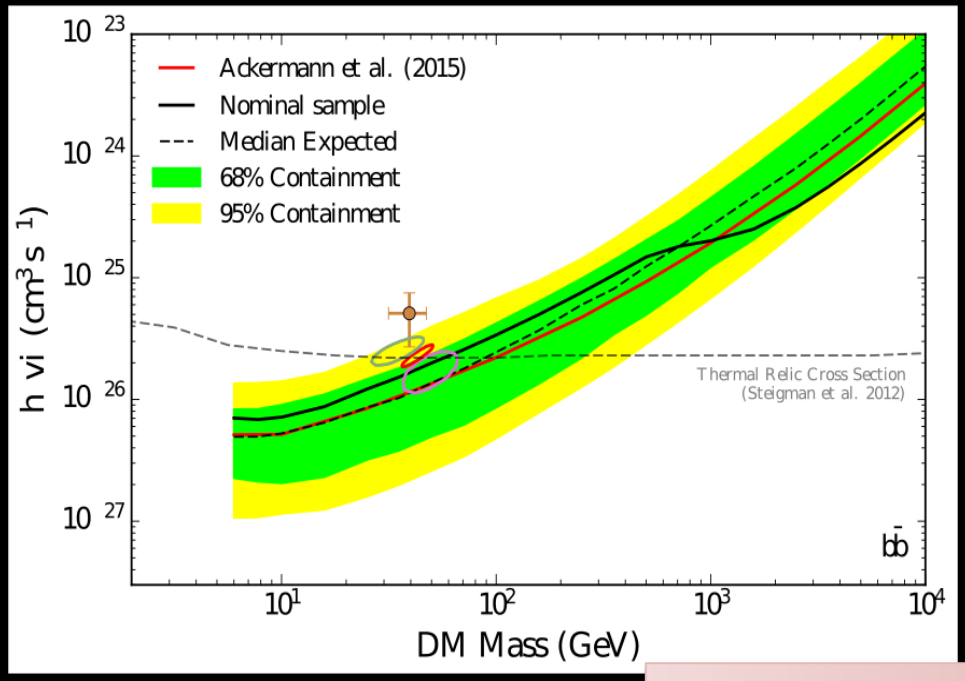


Probing DM: the Dwarf Spheroidal Satellite Galaxies

- Kinematics → dSphs of the Milky way contain a large DM component
- Optical surveys are significantly increasing the number of known dSphs [DES, Pan-STARRS]

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 28 dSphs (+17 candidates): 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 few years → exclude WIMP mass below ~400 GeV and rule out the DM GC excess

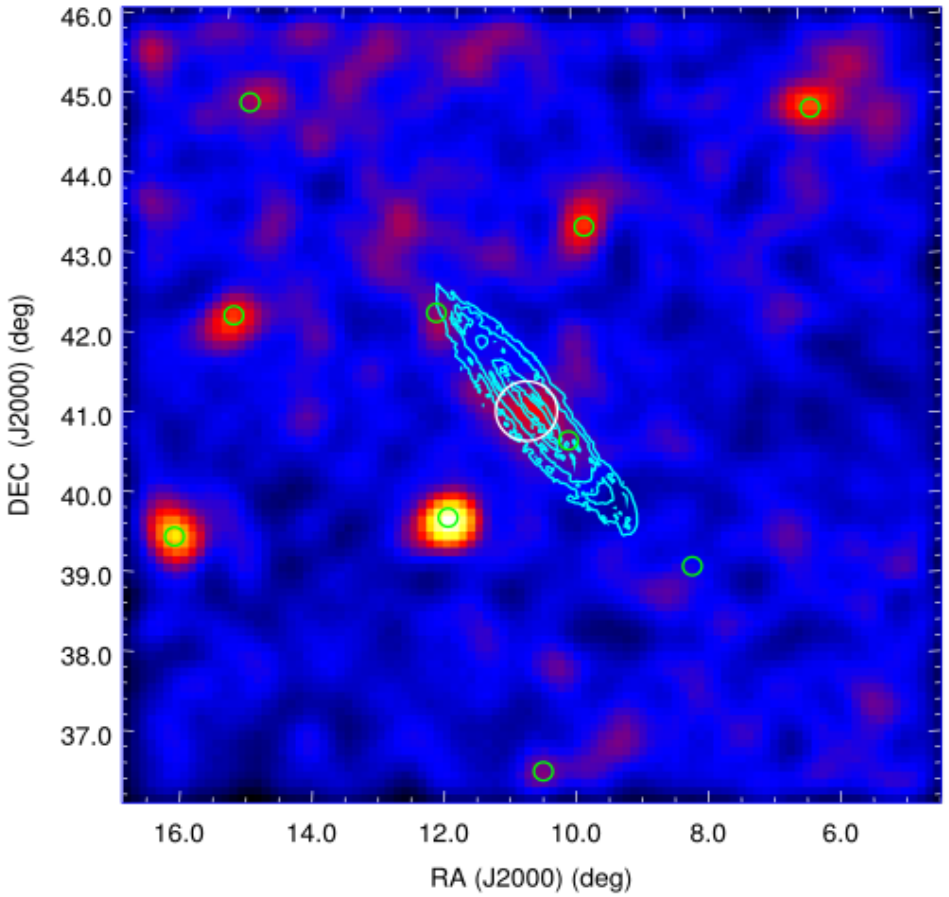
Update in preparation!

2017, ApJ, 834, 2

Probing DM: M31

2017, Apj, 836, 2

No disk emission detected!



Probing MW emission models

How to explain the emission?

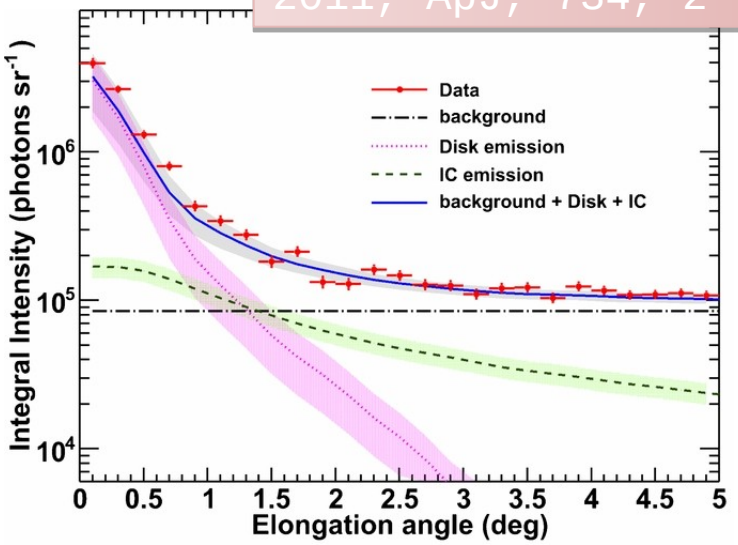
Cosmic-rays
Should be correlated with gas distribution or star-formation activity

DM
Is it compatible with GCE excess?

Millsecond Pulsars
Can explain GCE too?

A nearby source: the Sun

2011, ApJ, 734, 2

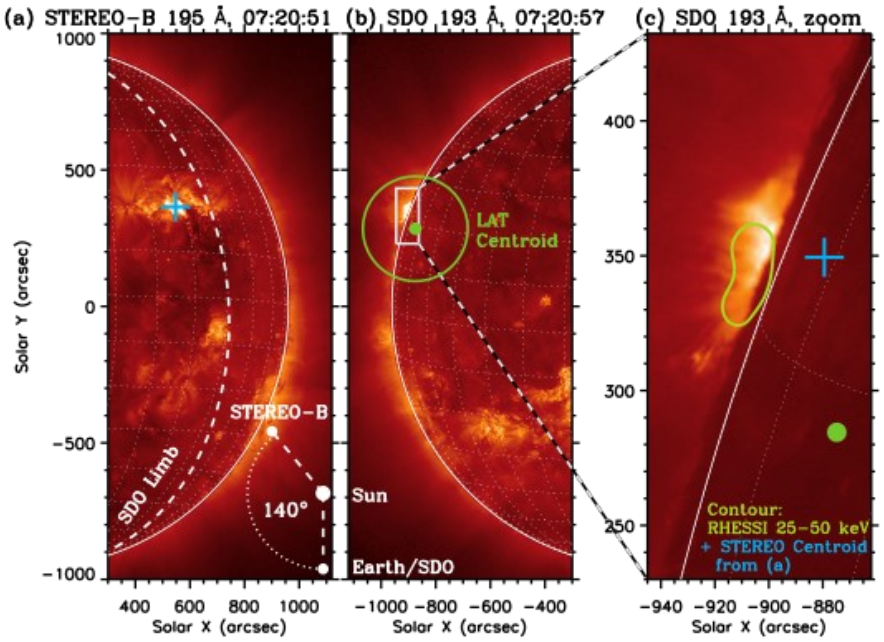


Solar flares observation:
45 observed.
First catalog in preparation!

First observation of behind the limb solar flares, probing transport of particles on the Sun surface.

Study of the emission from the quiet sun: disentangling CR induced from IC component.

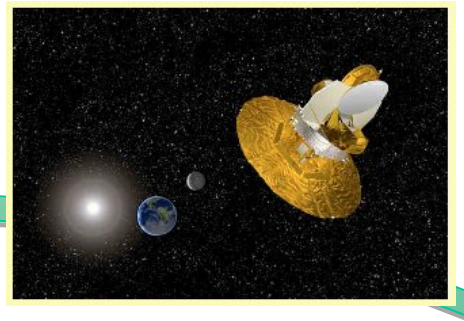
The LAT has observed a nearly complete solar cycle. Update in preparation



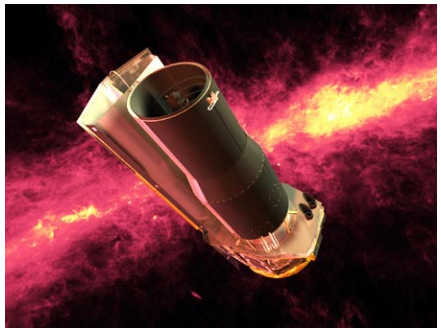
2017, ApJ, 835, 2

MW observations and synergies

Radio: pulsations, synchrotron emission, gas / dust maps, high resolution imaging of host galaxies…



Microwave: diffuse maps & morphology, host galaxy characteristics…

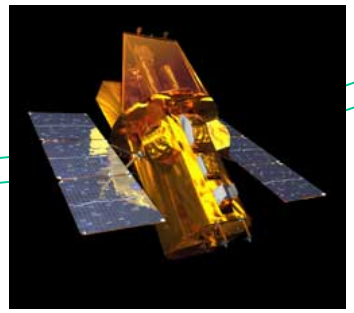


IR: gas/ dust maps, host galaxy characteristics

- LAT Source Localization better than 0.1°
- Great for followups

Energy

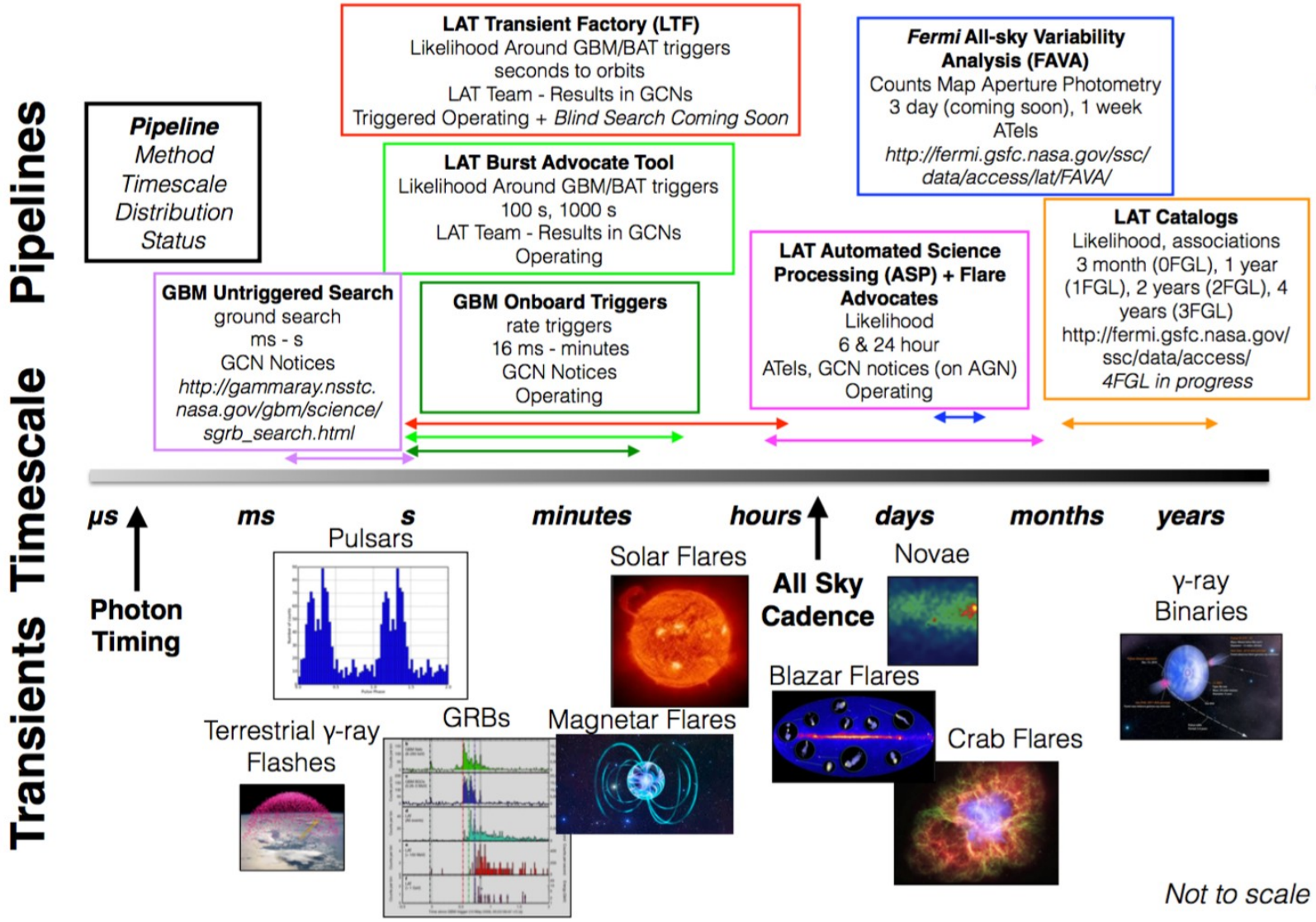
TeV: High-energy spectral breaks, supernovae morphology…



X-ray: GRB afterglows, Galactic source morphology & pulsar association…

Optical: GRB afterglows, AGN/GRB redshifts…

Transient searches



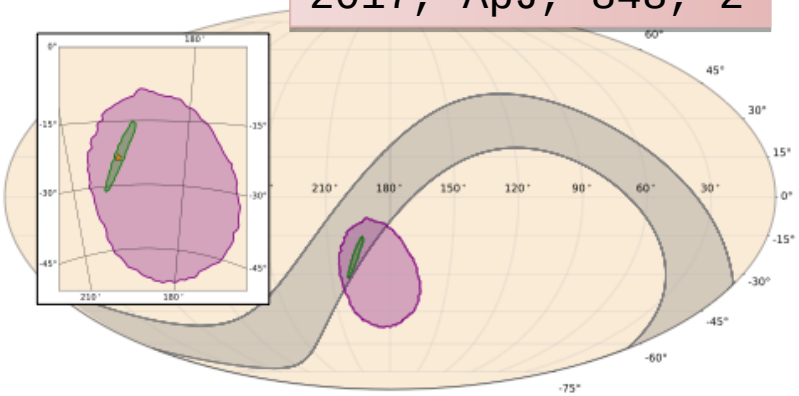
MW: Gravitational Waves

GRB 170817A: Counterpart to LIGO-Virgo event GW170817 seen by GBM.

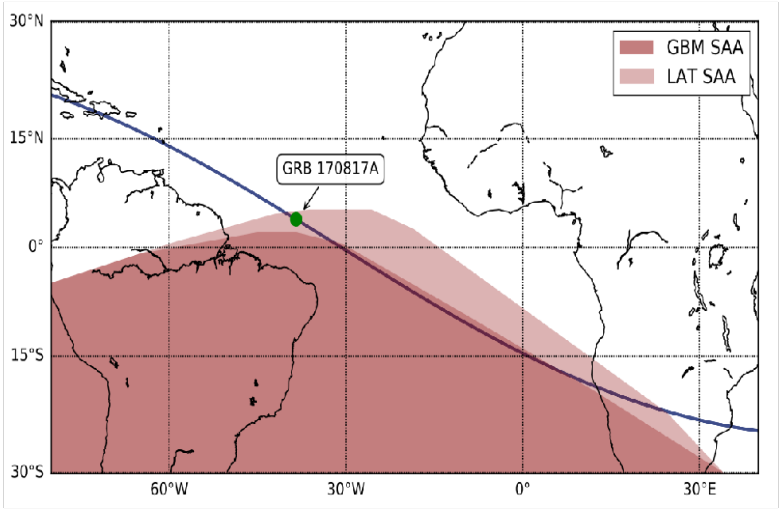
Follow-up across entire EM spectrum!

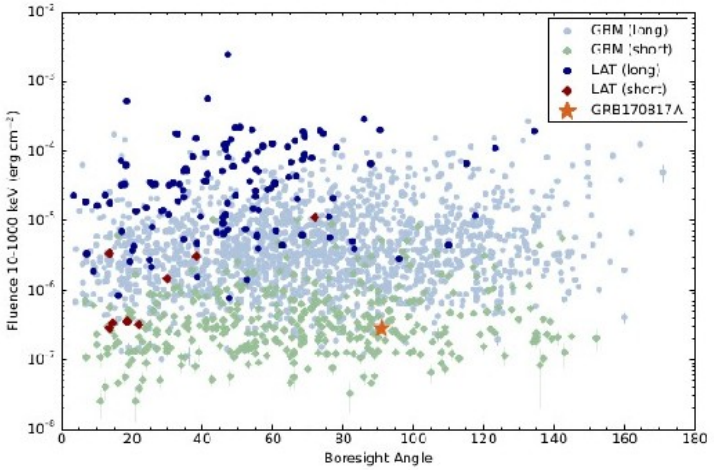
Estabilish long predicted conncetion between short GRBs and NS-NS merger.

2017, ApJ, 848, 2



Unfortunately LAT was inside SAA at the time (since 1 min!)



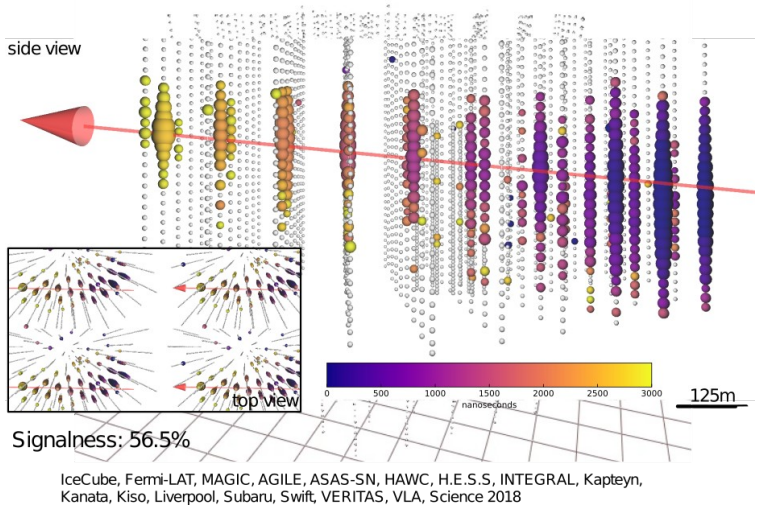


Counterpart observations with LAT possible with some luck!

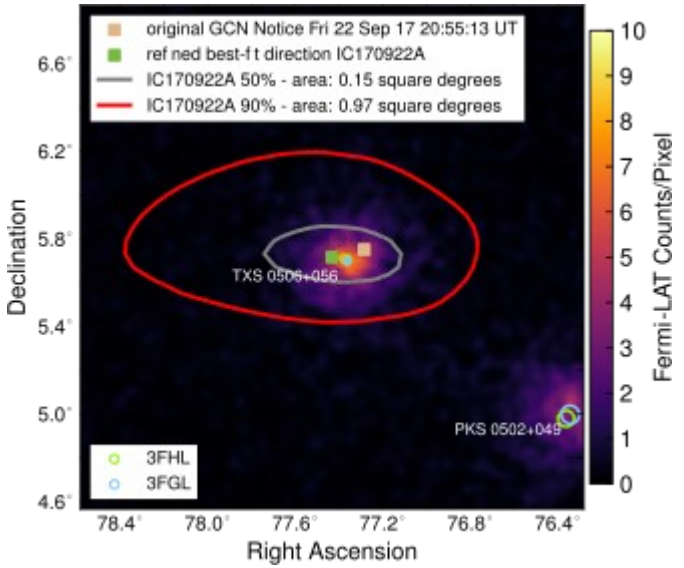
MW: Neutrino counterparts

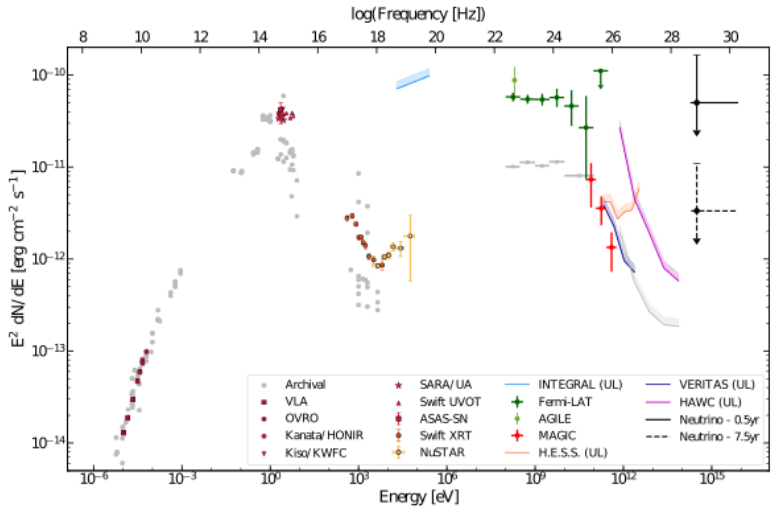
First observation of EM counterpart for a high-energy neutrino event!

September 22, 2017
Neutrino event IceCube-170922A (290 TeV) associated at 3σ with the location of known γ-ray blazar TXS 0506+056, flaring at that time



2018, Science, 361, 6398





Conclusions

- 10 years after the launch Fermi continue to produce first class science
- Committed to continue operations up to 2020 (and hopefully 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."

8th International Fermi Symposium

October 15–19, 2018

https://go.nasa.gov/2H5qhIg

10 years of Fermi-LAT

BACKUP

Current exposure of the LAT

Exposure maps (in celestial coordinates, AIT projection) at 1 GeV over one week (top), two weeks (center) and one month (bottom). All exposure maps start on the same date (May 6, 2018). The color scale is 0 (black) to maximum (white), linear.

The dates were chosen such that the first week is pure -50° rocking, the second week is pure +50° rocking and the rest of the month is mostly the modified sine profile.

The Sun's path over that month is overlaid to illustrate that the exposure troughs over one month are around the Sun and the anti Sun.