The High Energy view of the Gamma-ray sky with Fermi

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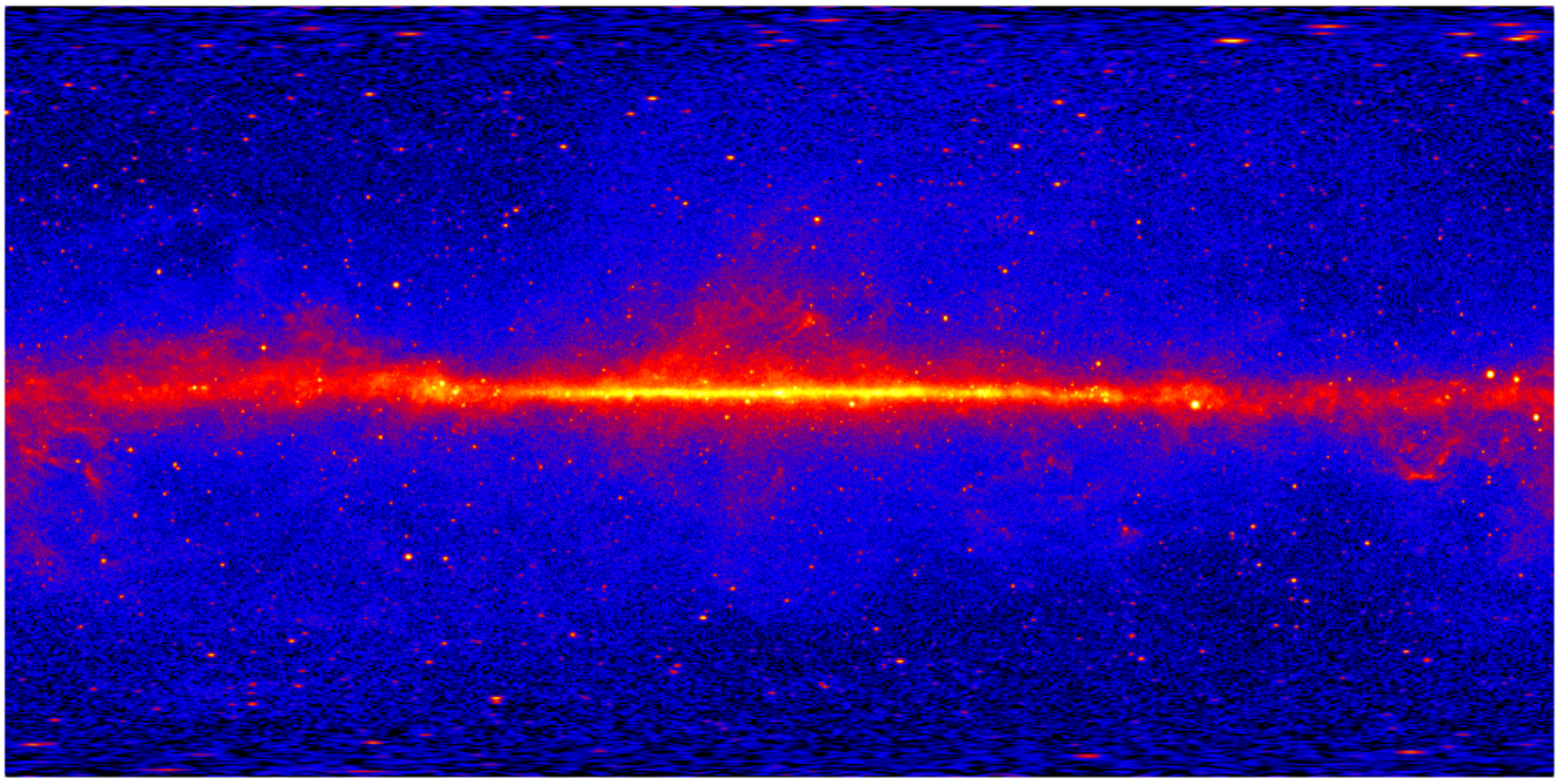
on behalf of the Fermi-LAT collaboration

Gamma Ray Astrophysics with CTA
Sexten CfA 24-29 July 2017

Outline

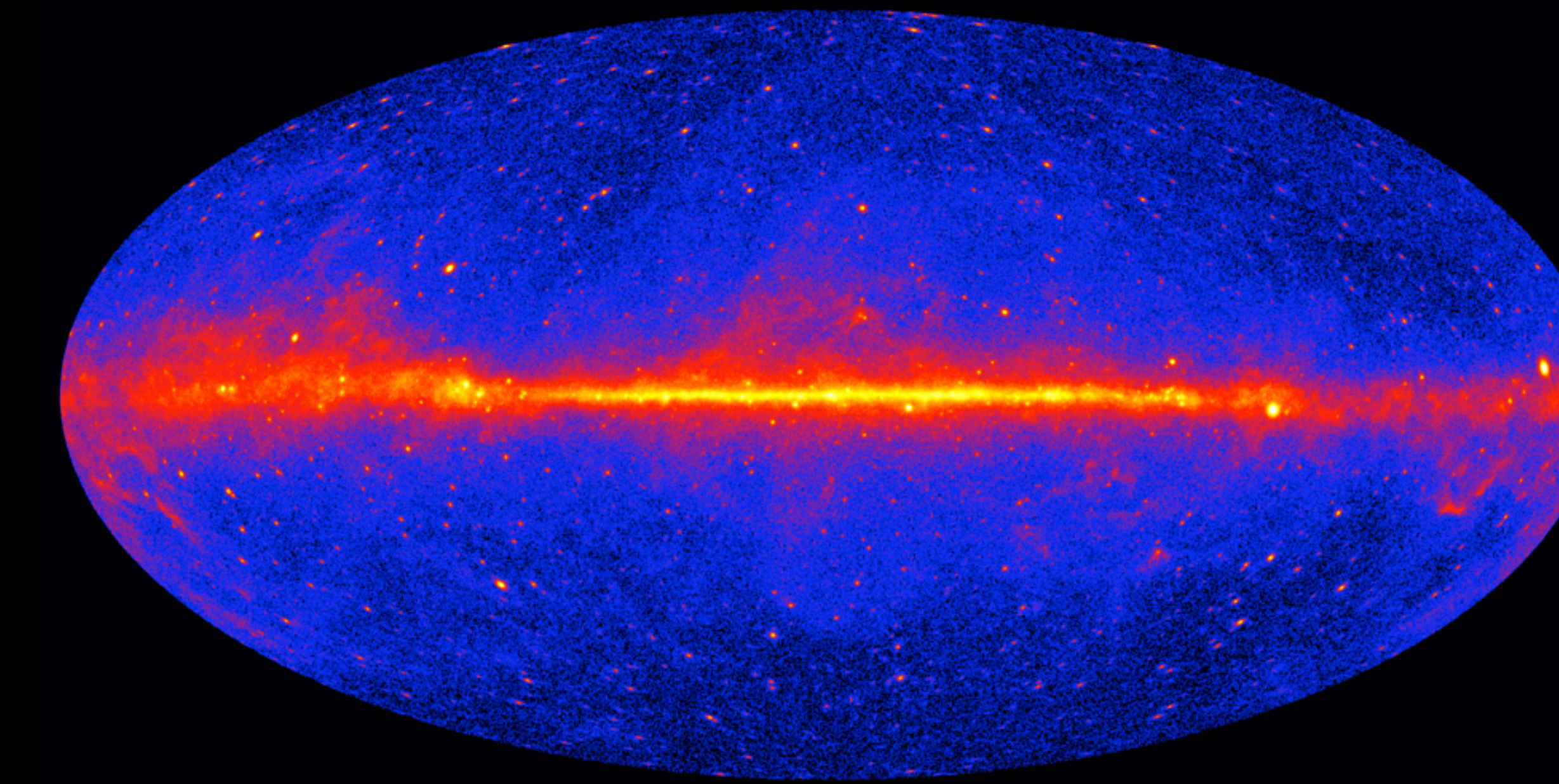
- Intro - gamma-ray skies
- Themes - the Fermi Observatory
- Themes - Physics

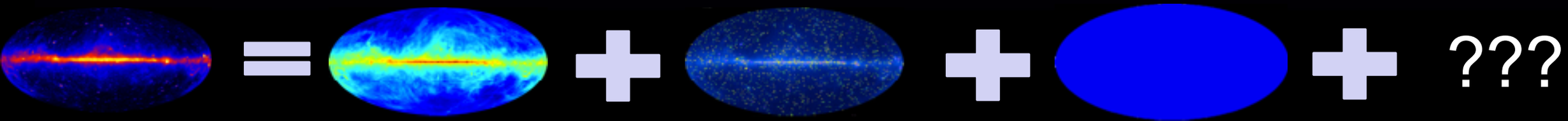


Fermi 8 years intensity map - cartesian coordinates

Intro - gamma-ray skies

The Fermi γ-ray sky





GeV Sky = Galactic + Point Sources + Isotropic + ???

next slides show examples of each component

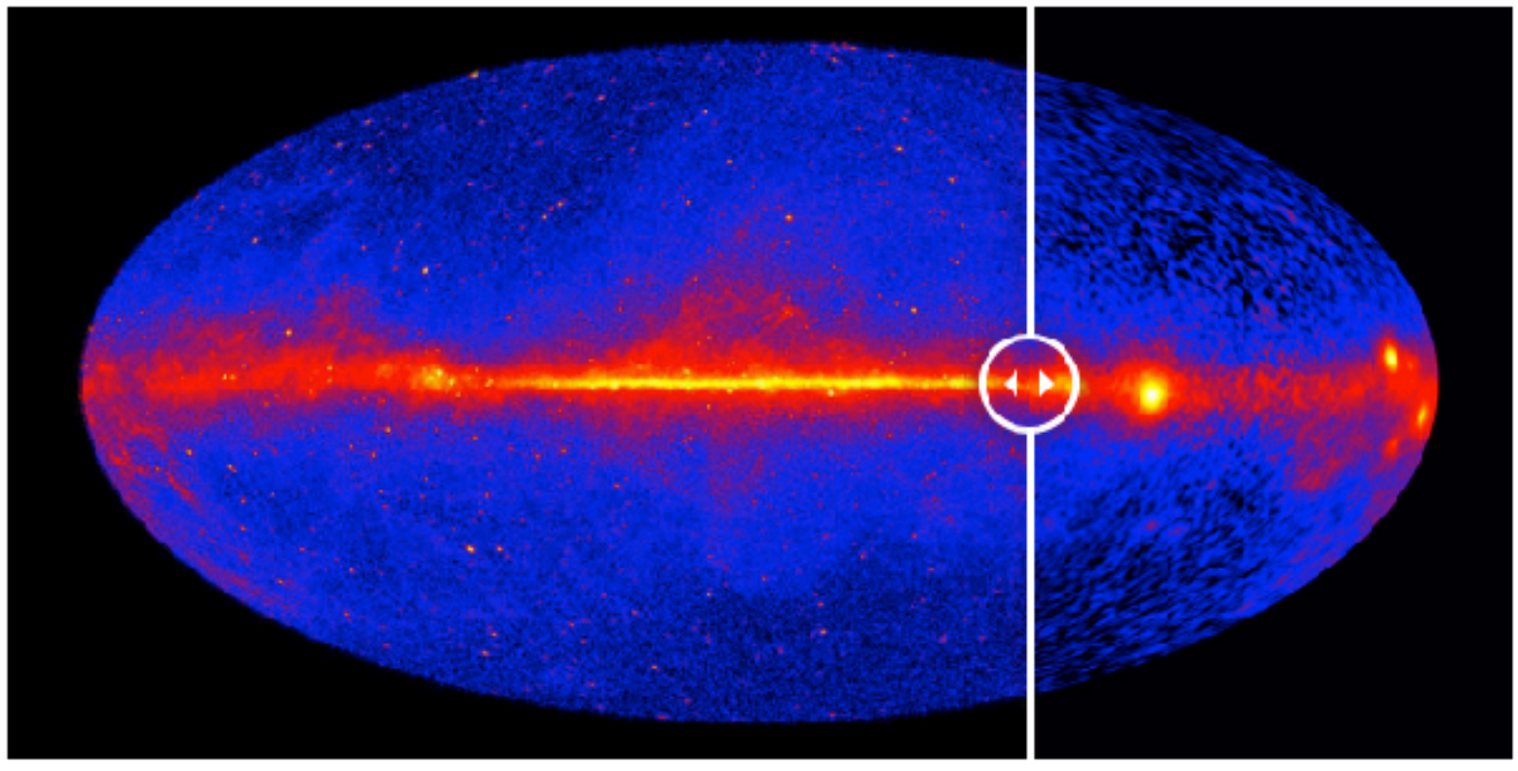
« News Feature Archive

Fermi Satellite Observes Billionth Gamma Ray with LAT Instrument

Spacecraft's Gamma-Ray Vision Provides Revolutionary Views of the Extreme Universe

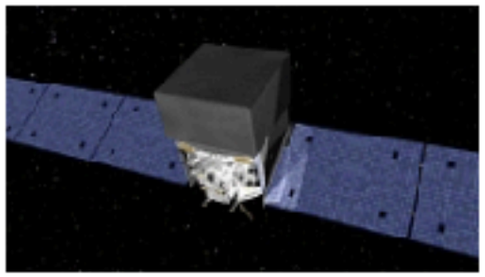
By Manuel Gnida

May 10, 2017

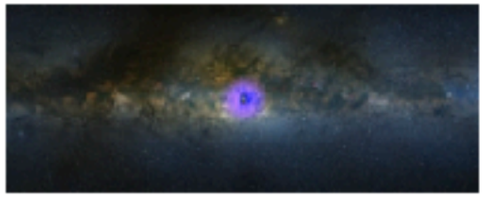


The sky in gamma rays. Drag the handle to compare the all sky maps of the LAT instrument (left) on the Fermi Gamma-ray Space Telescope and the previous-generation EGRET instrument (right) on the Compton Gamma-ray Observatory. The LAT data reveal much more detail. (NASA)

SHARE



Artist's conception of Fermi in orbit. (NASA)

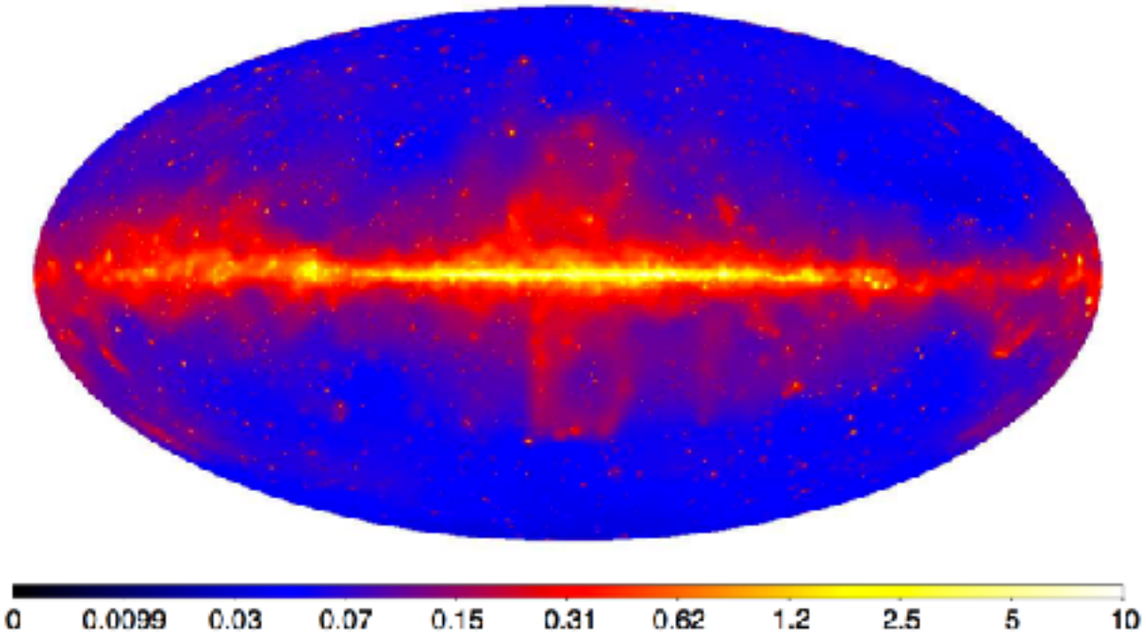


When astrophysicists model the Milky Way's gamma-ray sources detected by the LAT to the best of their knowledge, they are left with an excess glow at the galactic center. Signals like these could be telltale signs of hypothetical dark matter particles, but they could also have other cosmic origins. (NASA; A. Mellinger/Central Michigan University; T. Linden/University of Chicago)

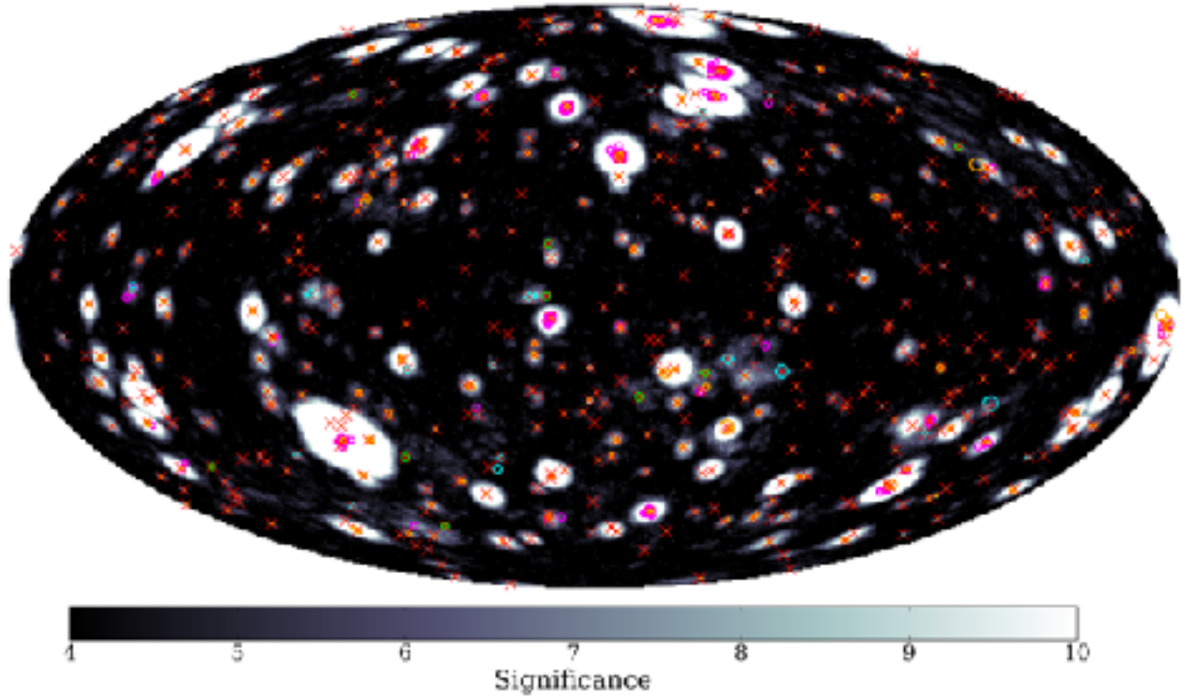
https://www6.slac.stanford.edu/news/2017-05-10-fermi-satellite-observes-billionth-gamma-ray-lat-instrument.aspx

Gamma-ray skies

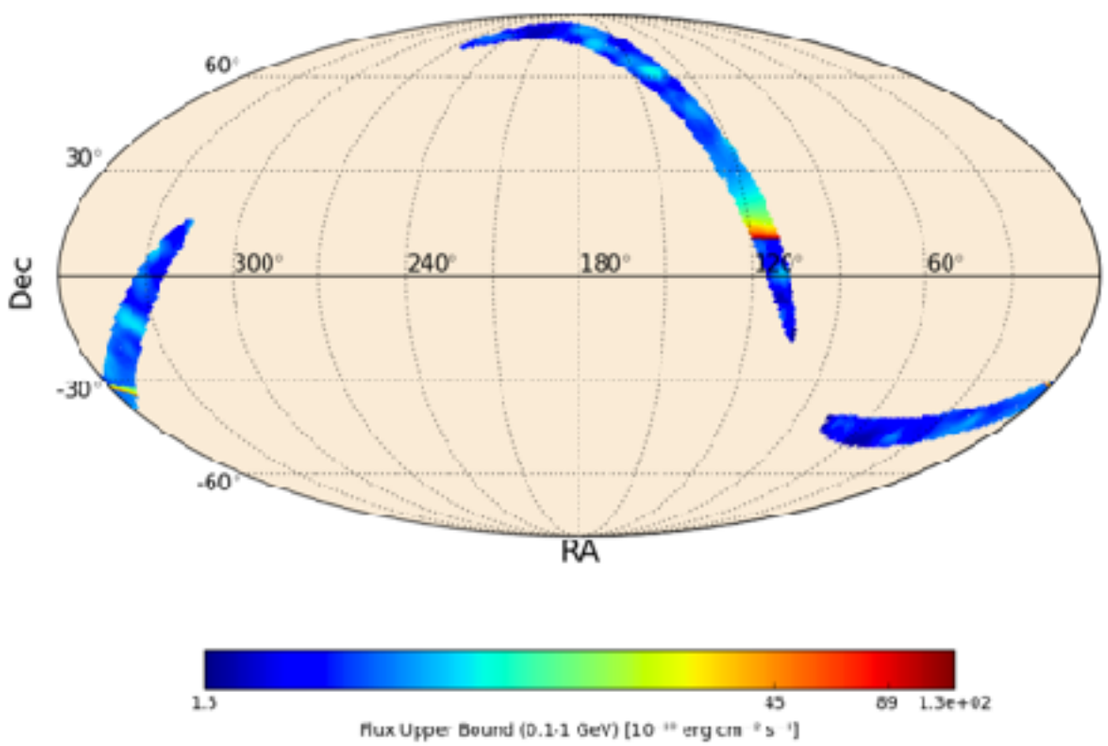
High Energy - 3FHL - arxiv.1702.00644



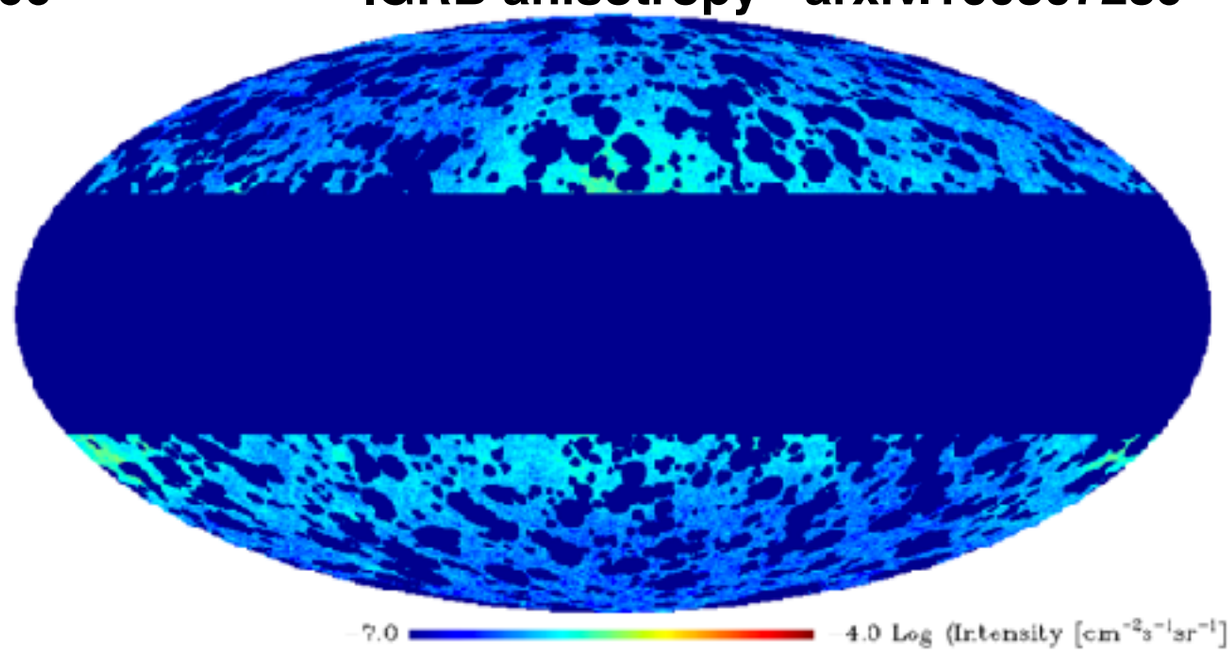
Flares - 2FAV - arxiv.1612.03165



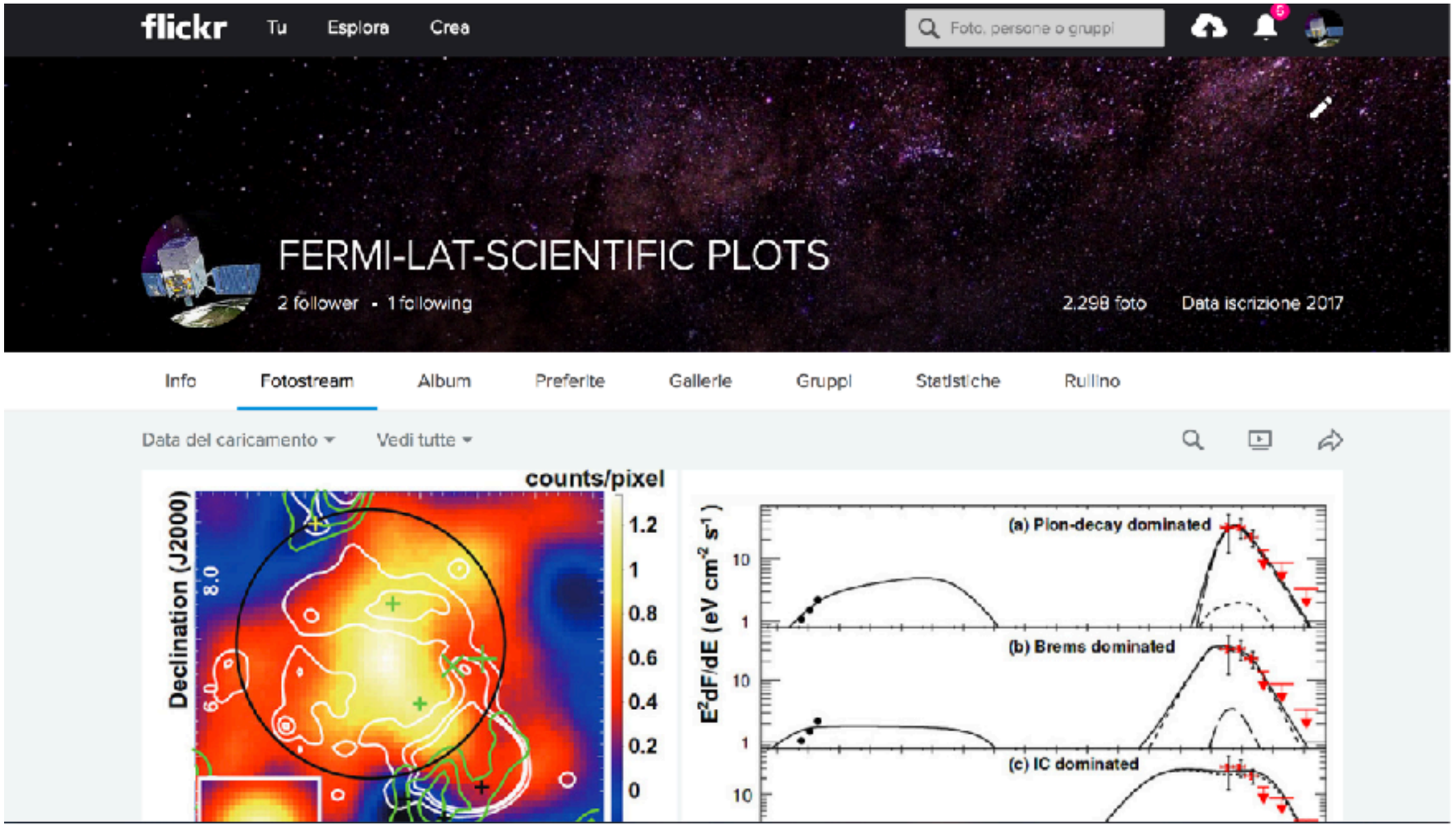
GW170104 EM counterpart searches - arxiv.1706.00199



IGRB anisotropy - arxiv.160807289



Gamma-ray skies



building a visual collection of tag-based science images as a high school traineeship program

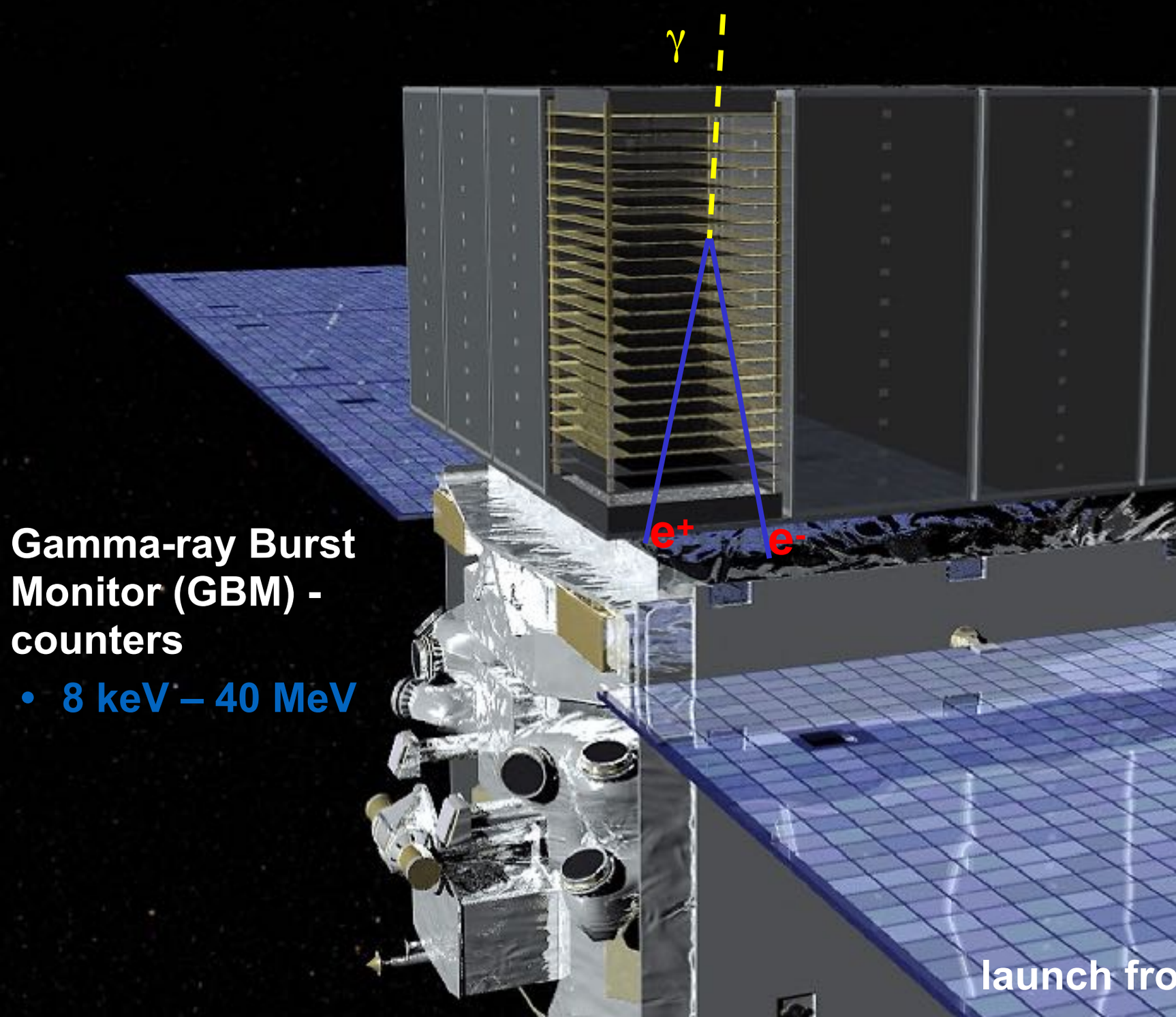
Fermi launchpad 2008

Themes - the Fermi Observatory

The Fermi Observatory

Large Area Telescope (LAT) - pair conversion telescope

- **20 MeV – > 300 GeV**



Huge field of view (2.4sr)

- **20% sky any instant**
- **All sky for 30’ every 3h**

Huge energy range

- **Including 10-100 GeV**

Public data

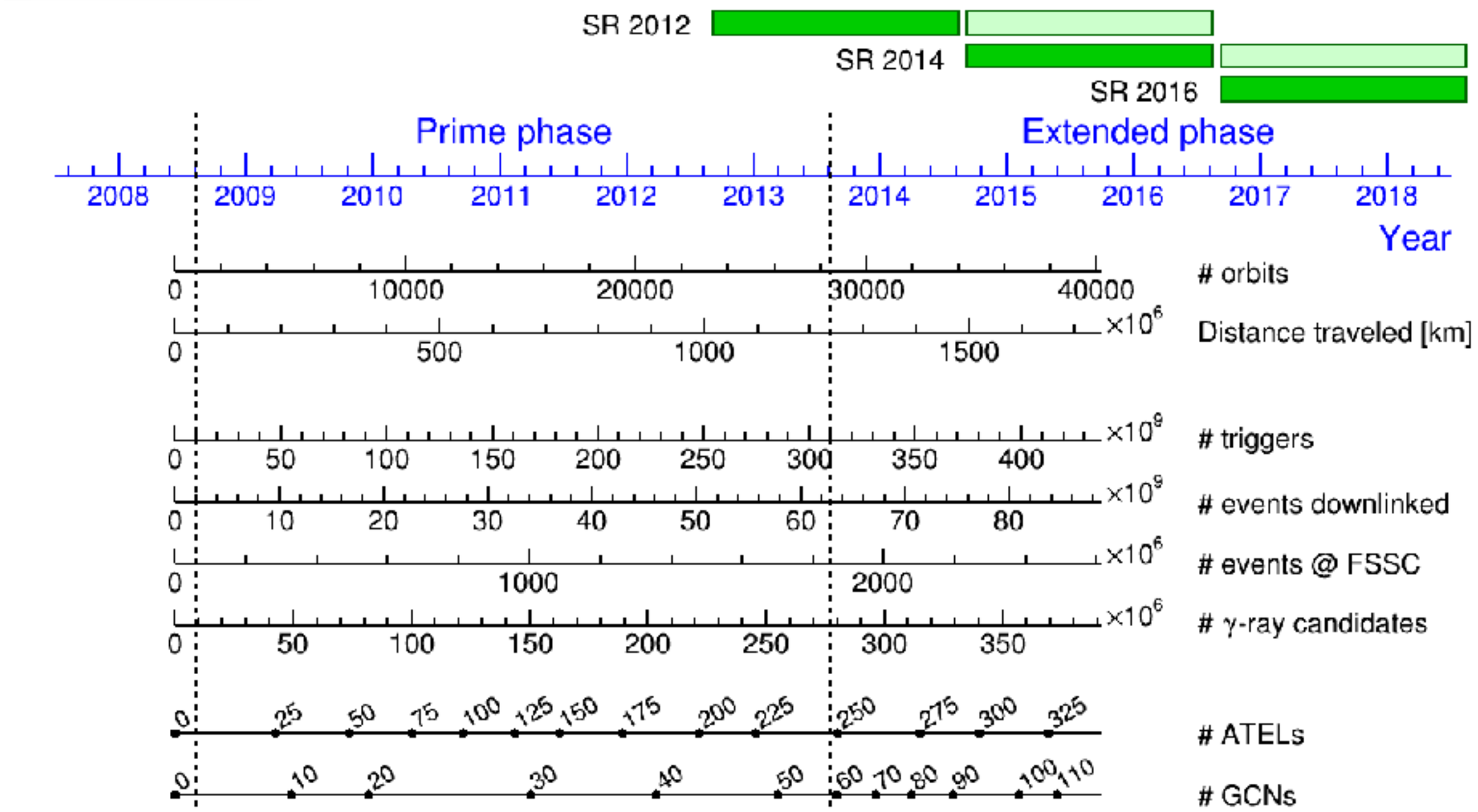
- **~500 collaboration papers**
- **~2500 total nb of papers**

Gamma-ray Burst Monitor (GBM) - counters

- **8 keV – 40 MeV**

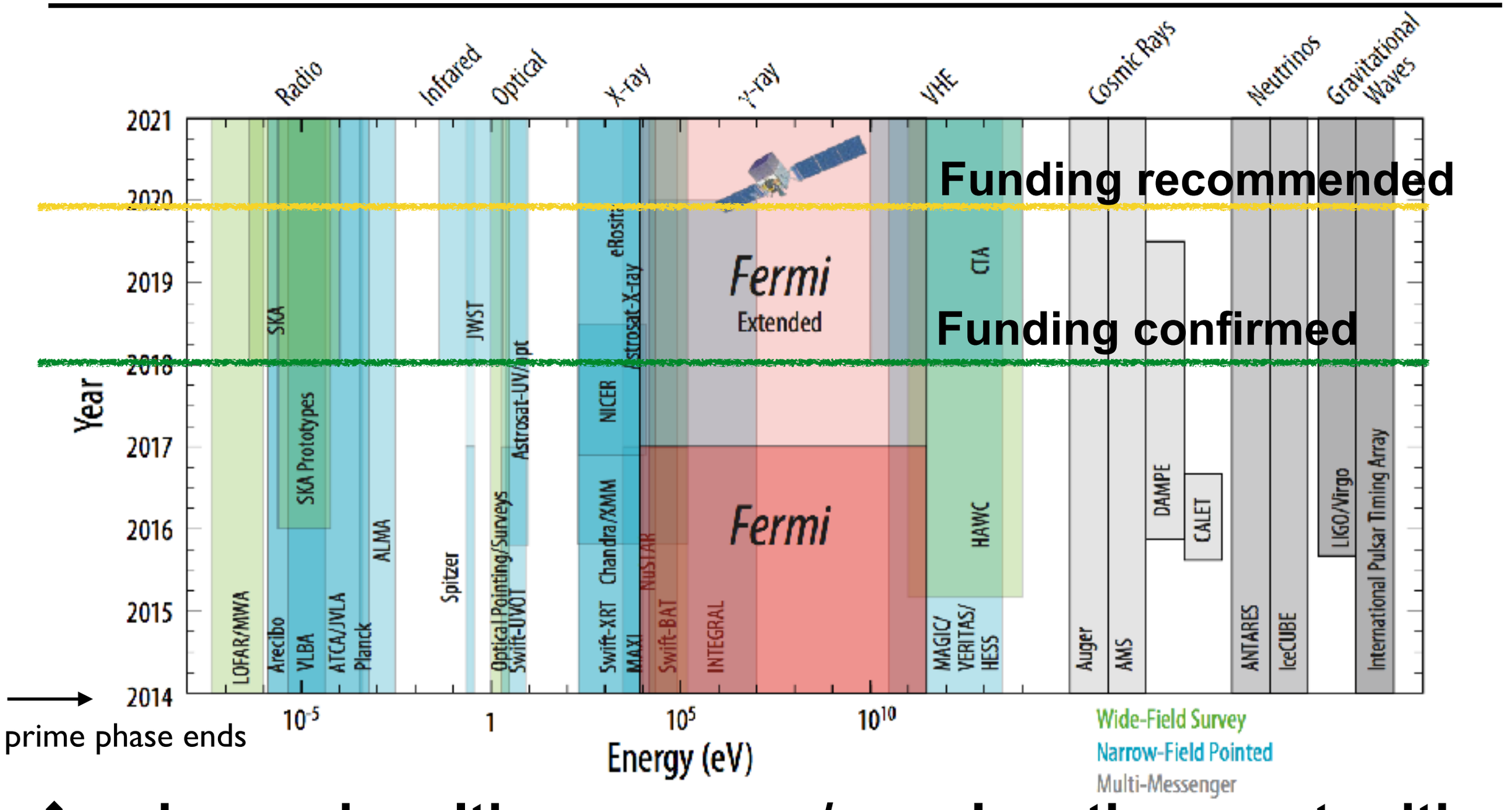
launch from Cape Canaveral 11-6-2008

Mission timeline



Extend operations through NASA Senior Reviews (SR)
Spring 2016 SR to confirm operations through 2018 and recommend through 2020 - http://science.nasa.gov/astrophysics/documents

Operating context

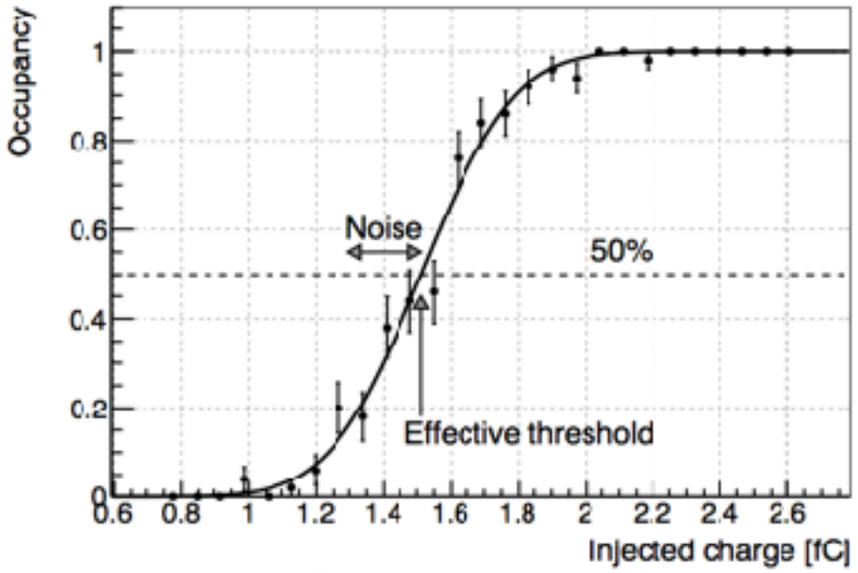


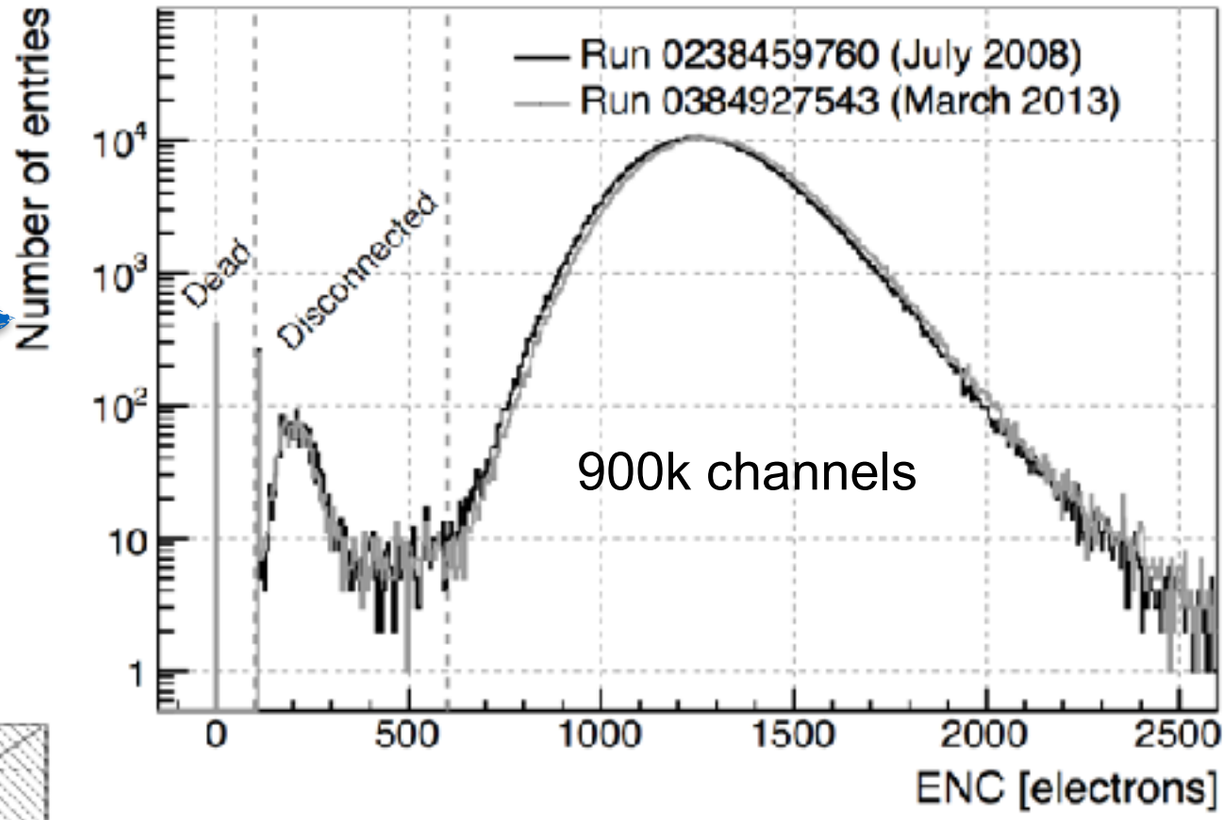
- ❖ **enhanced multi-messenger/wavelength opportunities**
- ❖ **Fermi unique all-sky monitor in a broad energy range**

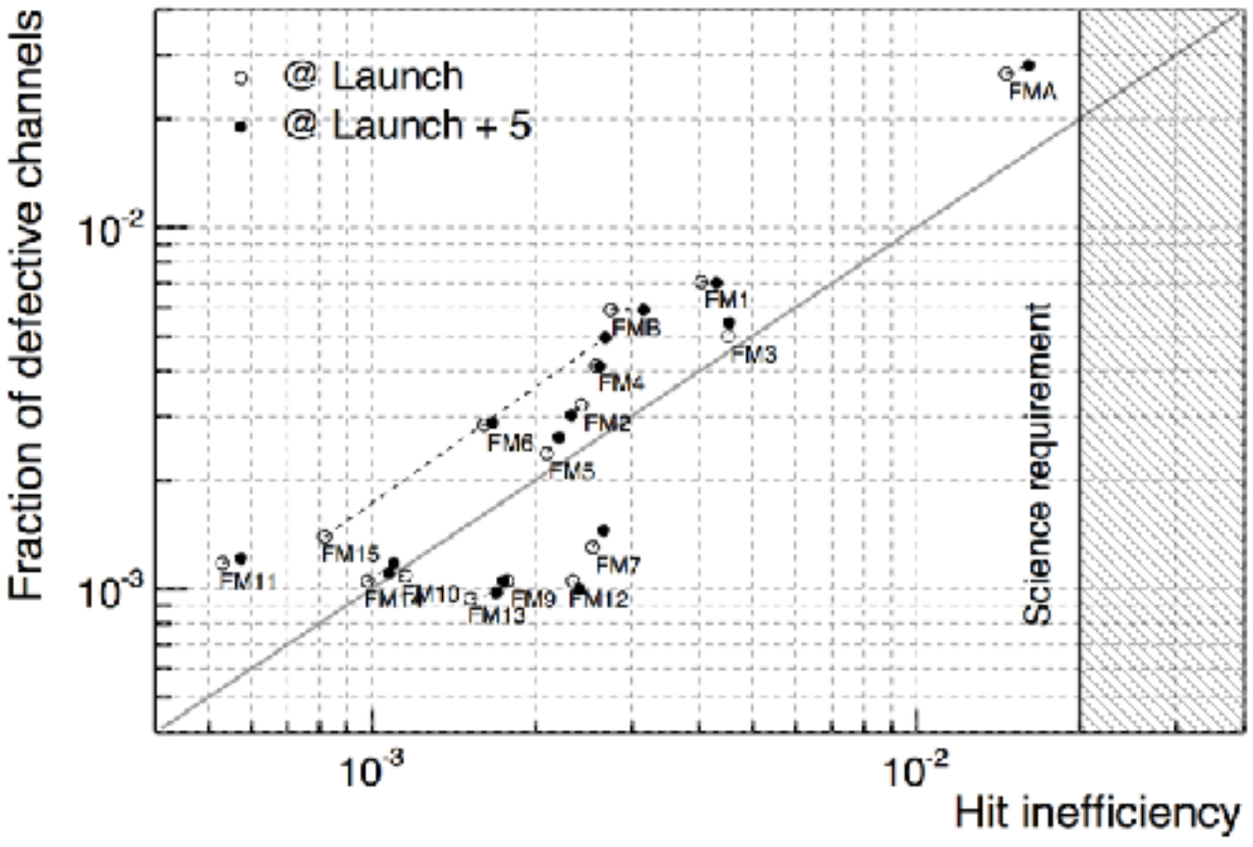
http://science.nasa.gov/astrophysics/2016-senior-review-operating-missions/

Status of the LAT telescope

single TKR channel noise calibration

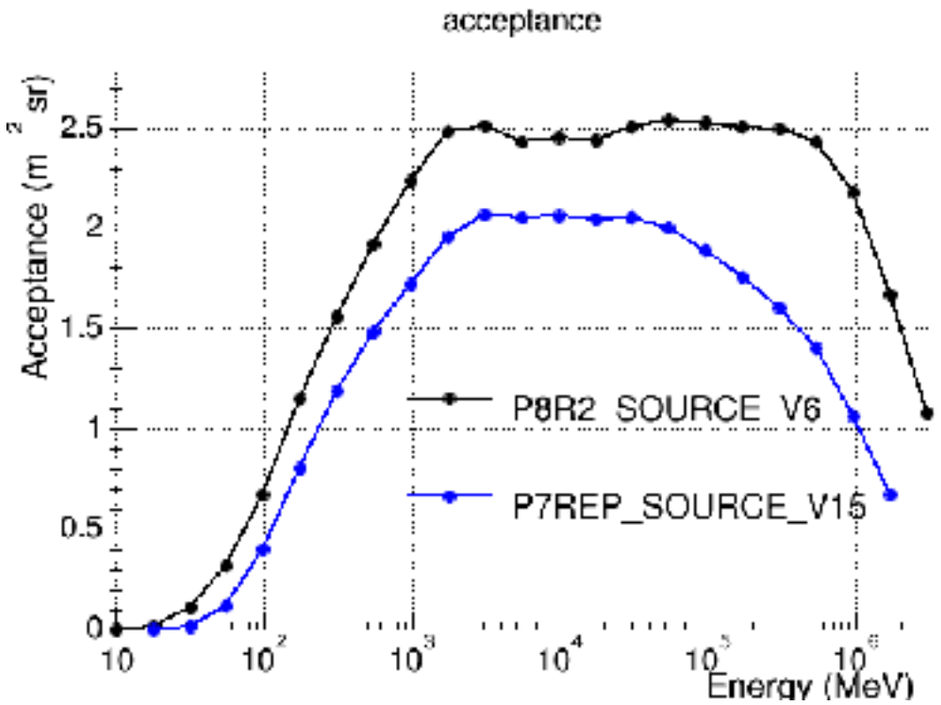


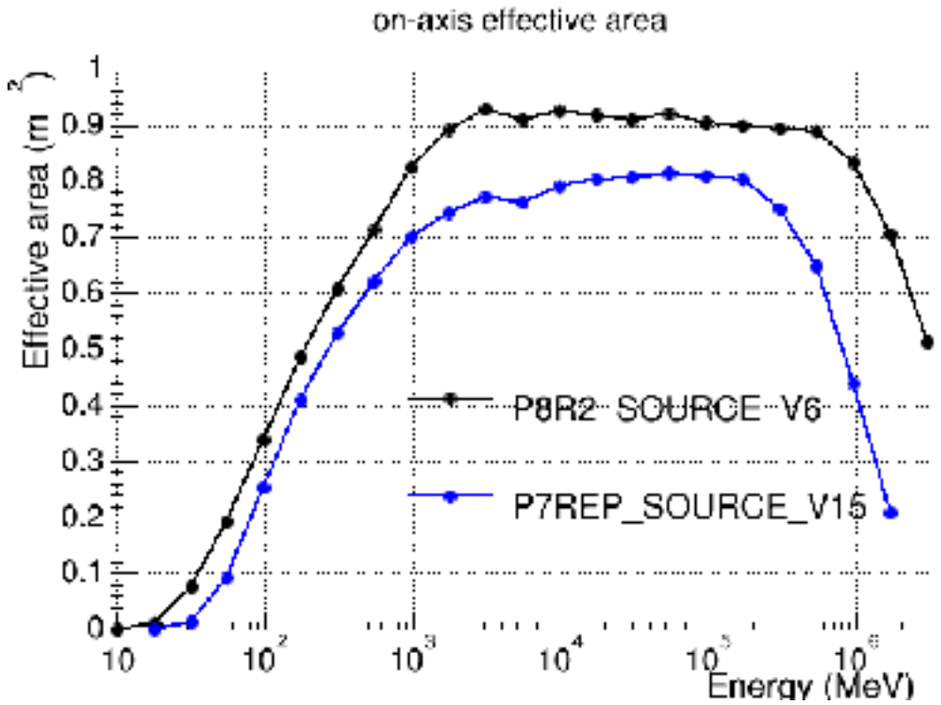


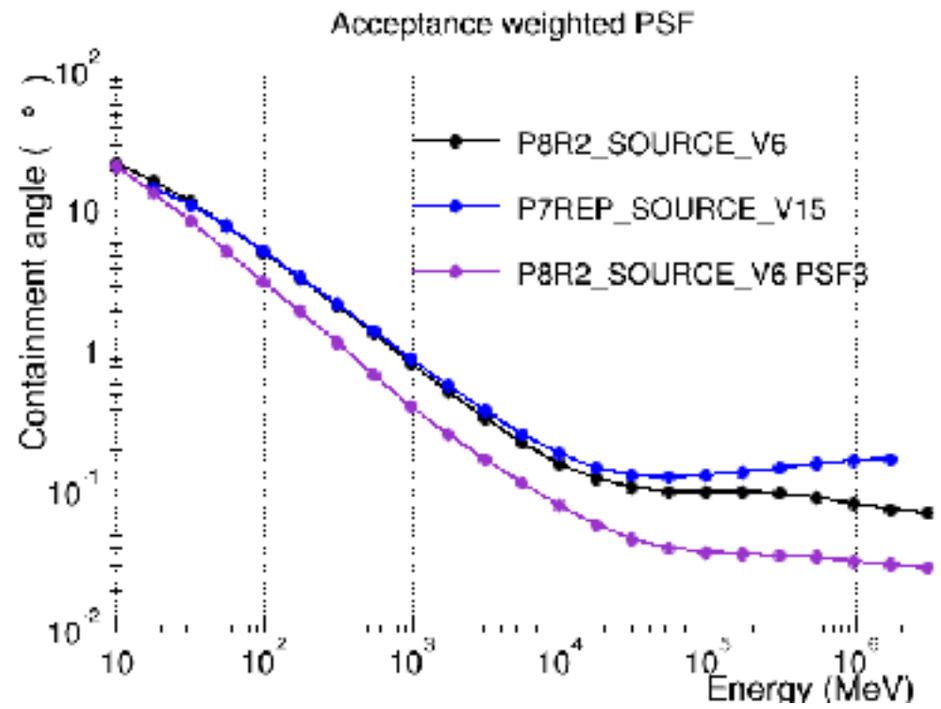


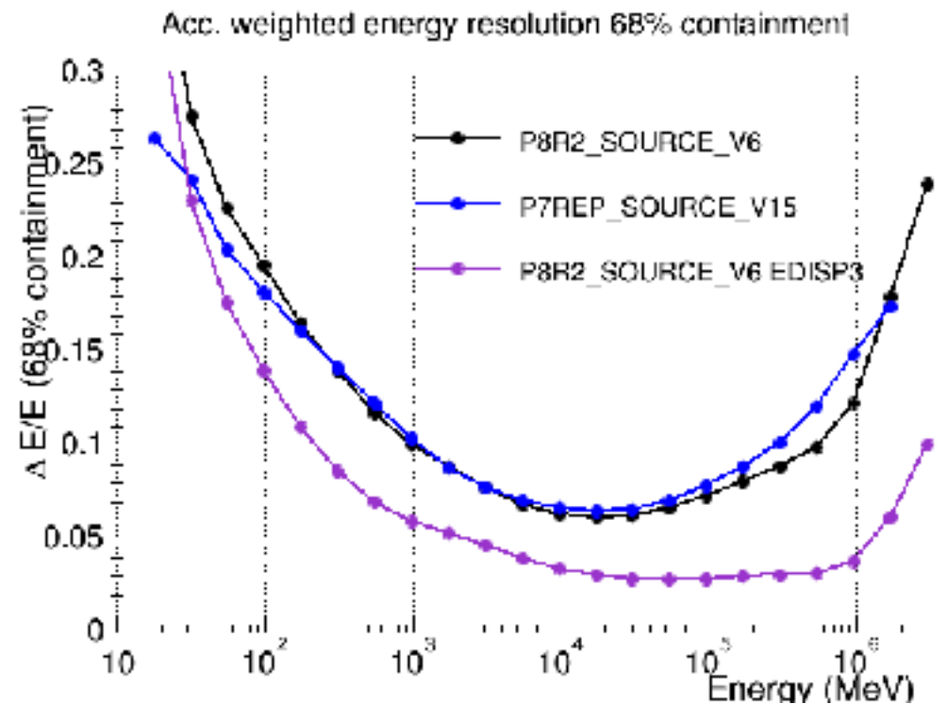
- 73m^2 active silicon, 900k chans
  - ~ATLAS Silicon tracker
- stable performance
  - +~2% noisy chans in 5 yrs
- similar stability in ACD and CAL
  - ~1% CAL aging in 2 yrs
- ~hrs/year spent in calibrations

LAT performance









- larger energy range, higher acceptance, better resolution
- *Pass 8* performance and data publicly released June 2015

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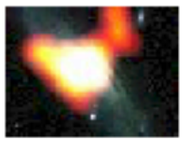
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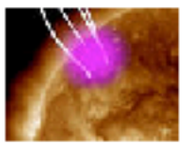
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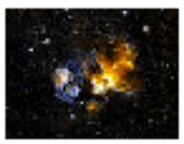
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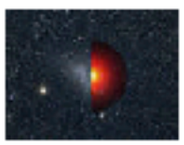
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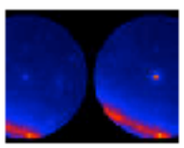
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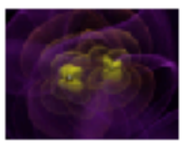
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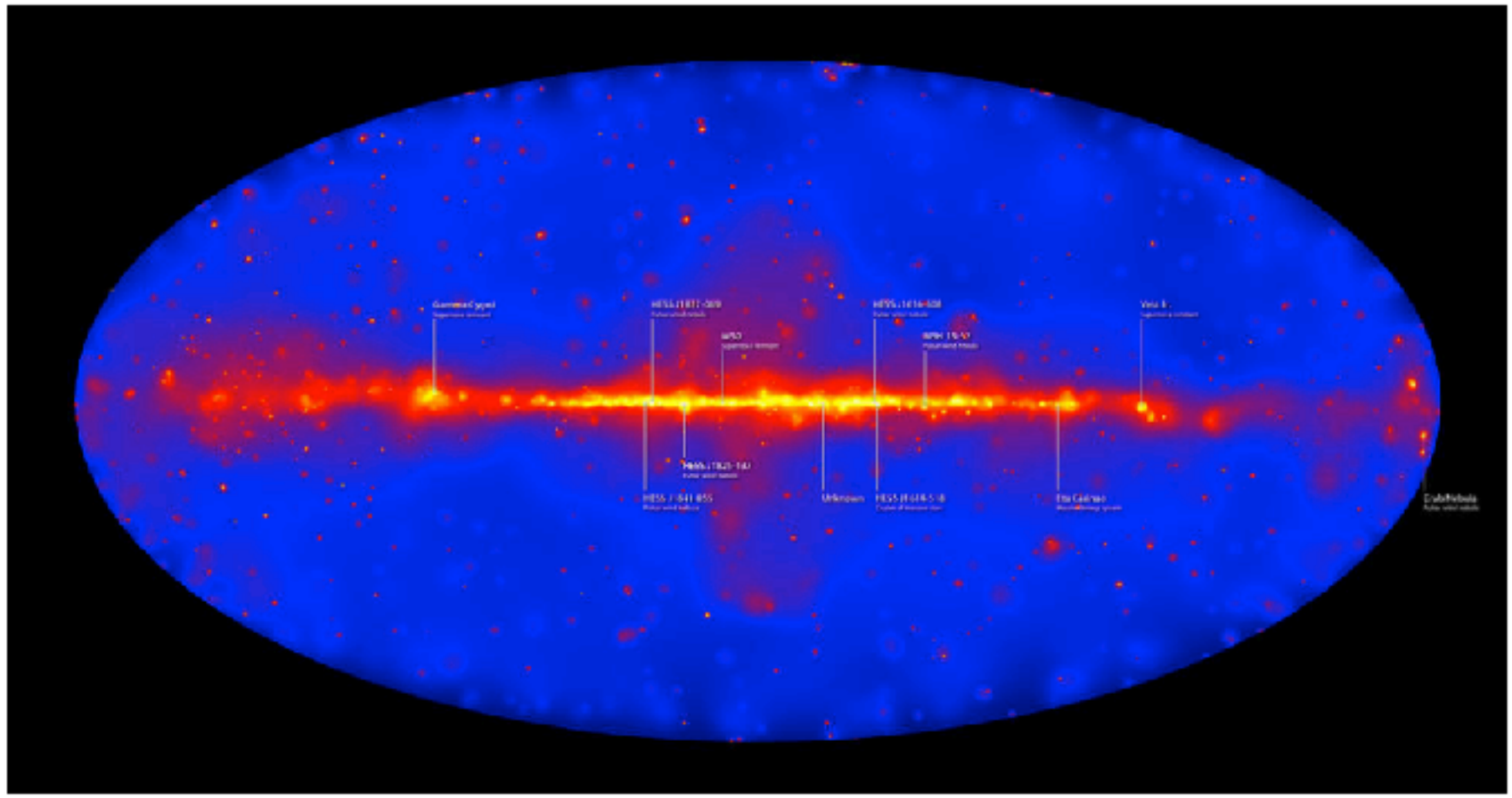
NASA Celebrates 25 Years of Breakthrough Gamma-ray Science

Fermi Space Telescope

Jan. 7, 2016

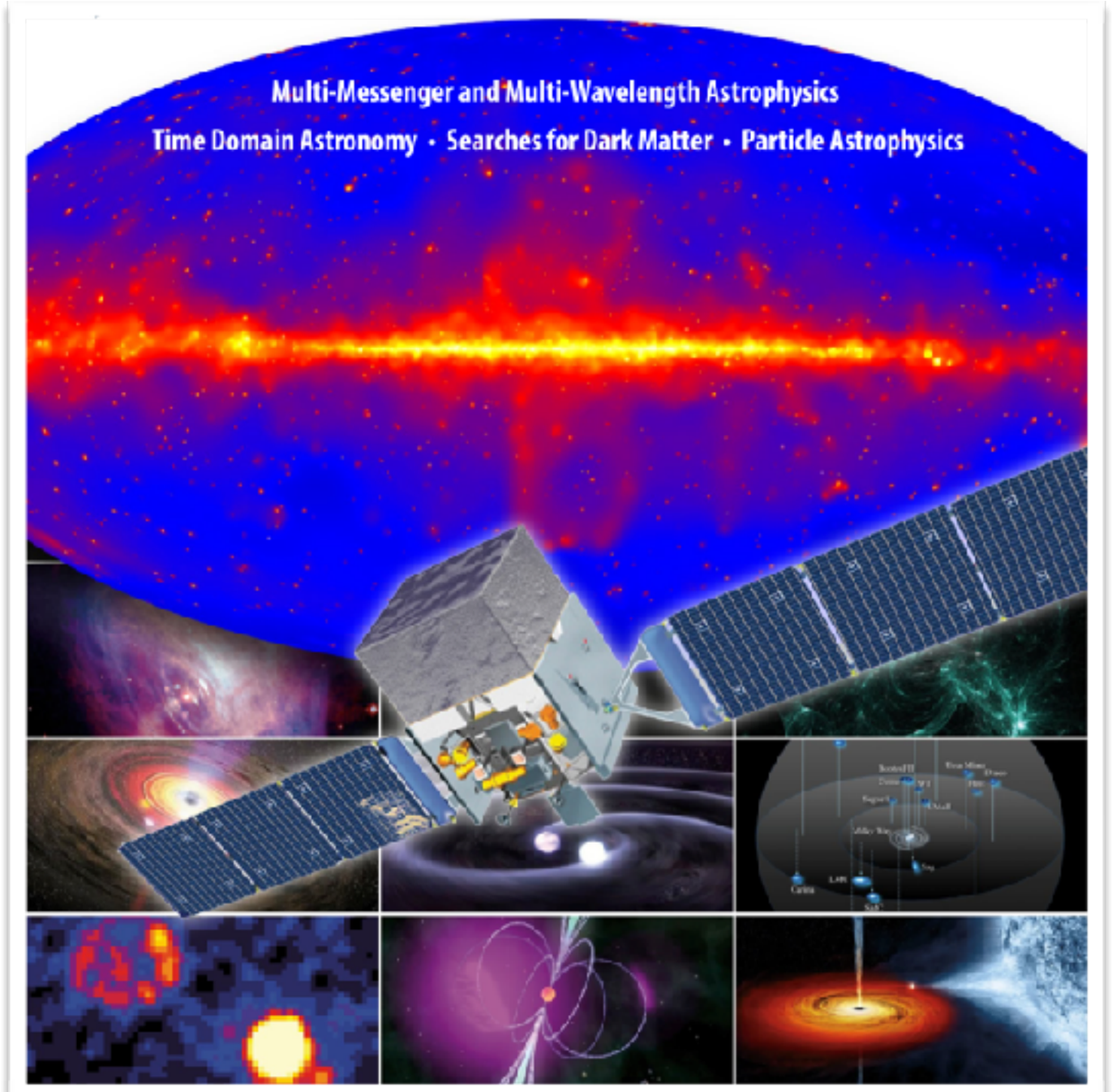
NASA's Fermi Space Telescope Sharpens its High-energy Vision

Major improvements to methods used to process observations from NASA's Fermi Gamma-ray Space Telescope have yielded an expanded, higher-quality set of data that allows astronomers to produce the most detailed census of the sky yet made at extreme energies. A new sky map reveals hundreds of these sources, including 12 that produce gamma rays with energies exceeding a trillion times the energy of visible light. The survey also discovered four dozen new sources that remain undetected at any other wavelength.



This image, constructed from more than six years of observations by NASA's Fermi Gamma-ray Space Telescope, is the first to show how the entire sky appears at energies between 50 billion (GeV) and 2 trillion electron volts (TeV). For comparison, the energy of visible light falls between about 2 and 3 electron volts. A diffuse glow fills the sky and is brightest in the middle of the map, along the central plane of our galaxy. The famous Fermi Bubbles, first detected in 2010, appear as red extensions north and south of the galactic center and are much more pronounced at these energies. Discrete gamma-ray sources include pulsar wind nebulae and supernova remnants within our galaxy, as well as distant galaxies called blazars powered by supermassive black holes. Labels show the highest-energy sources, all located within our galaxy and emitting gamma rays exceeding 1 TeV.

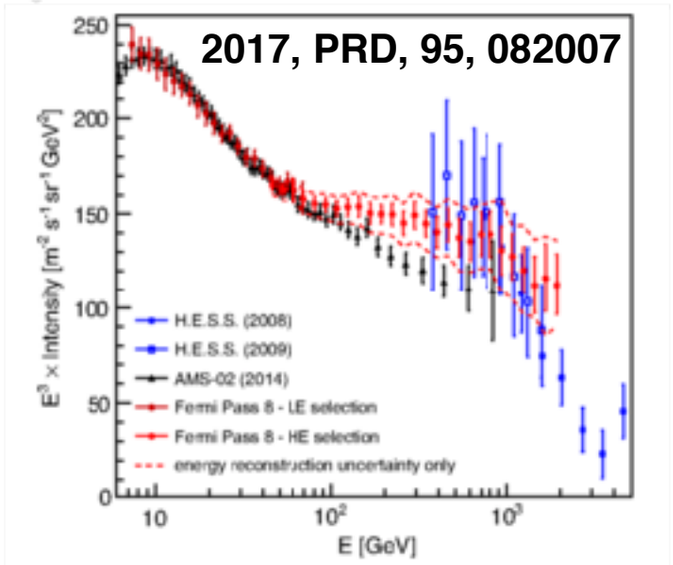
https://www.nasa.gov/feature/goddard/2016/nasas-fermi-space-telescope-sharpens-its-high-energy-vision

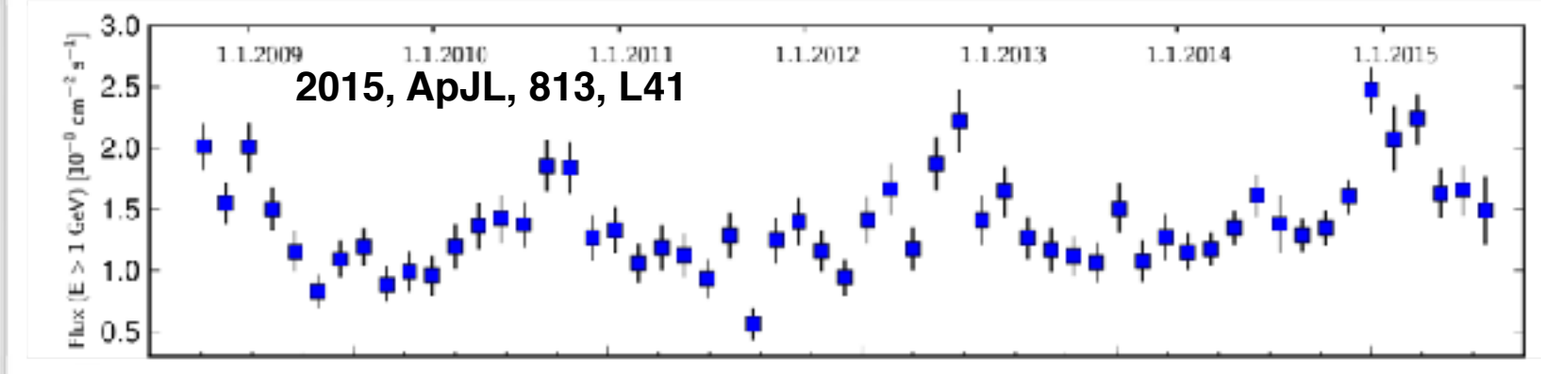


Fermi Senior Review Proposal 2016 - cover page

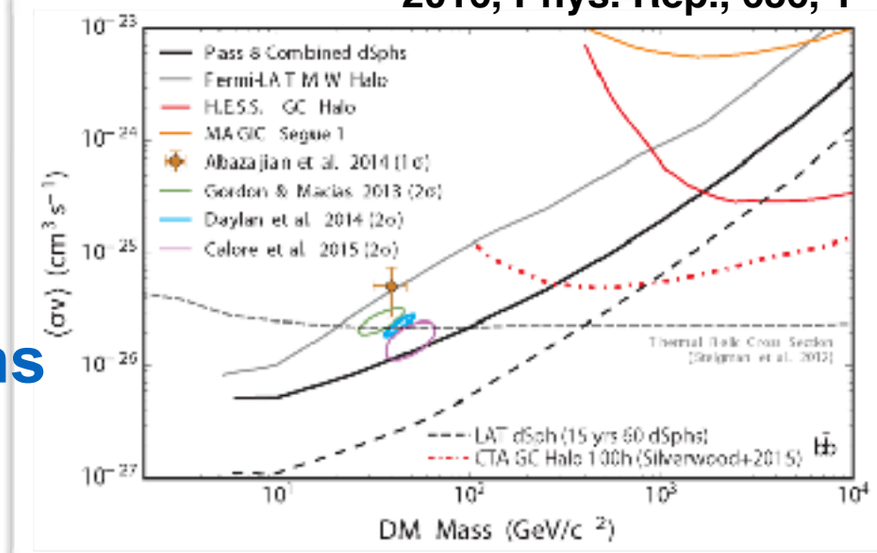
Themes - Physics

Science themes from the Sr Review

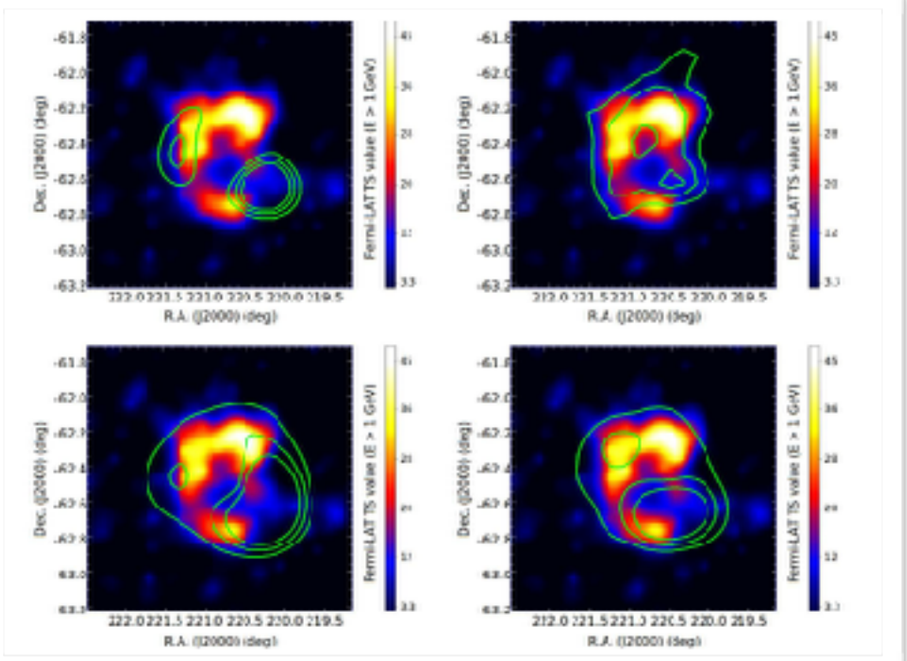




2016, Phys. Rep., 636, 1



2016, ApJ, 819, 98



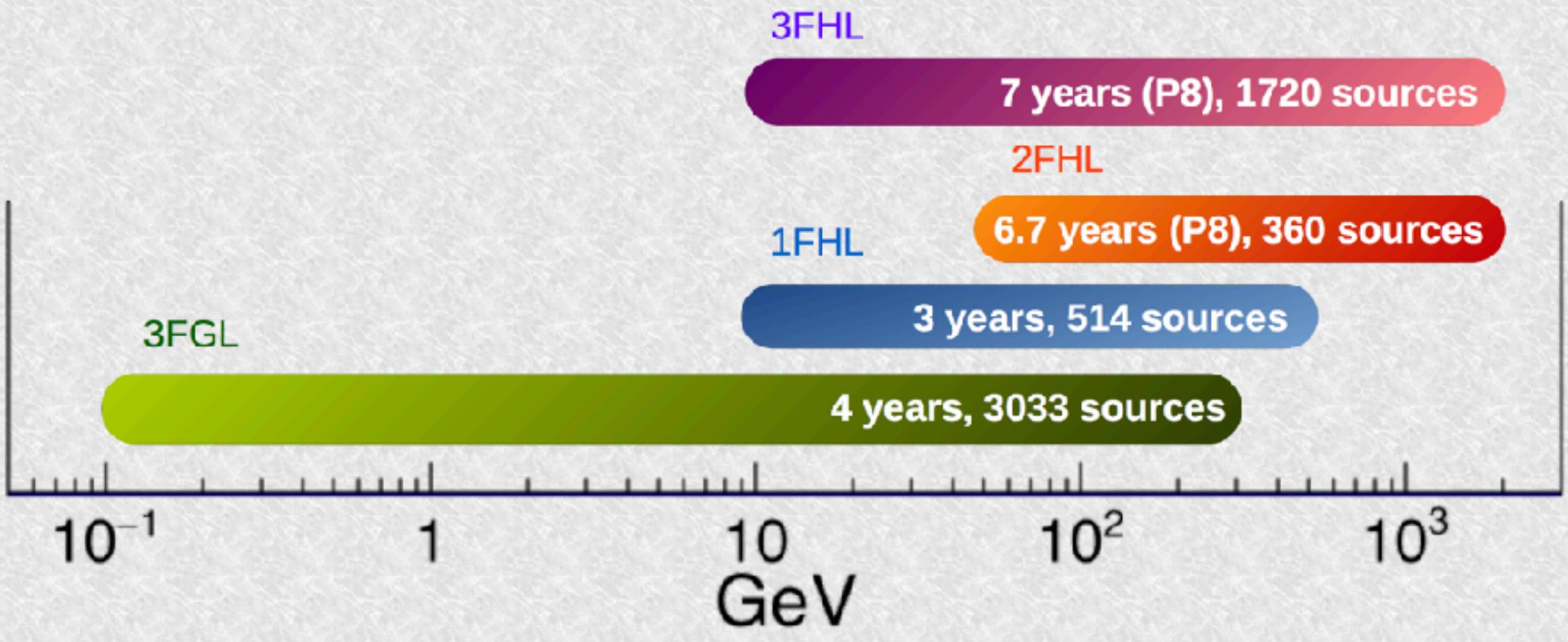
- **Messengers**
  - gammas, electrons
- **Time**
  - ms transients to multi-year periodicities
- **Dark Matter**
  - WIMP and axion candidates
- **Particle Astrophysics**
  - CR acceleration sites and mechanisms

HE Science themes

- **Hard source catalogs**
  - 3FHL, arxiv.1702.00664, submitted to ApJS
- **Extended sources**
  - 2017, ApJ, 843, 139
- **Resolving the Galactic Center**
  - 2016, ApJ, 819, 44, 2017, ApJ, 840, 43, arxiv. 1705.00009 (submitted to ApJ)
- **Diffuse emission and CR propagation**
  - 2017, PRL 119, 031101

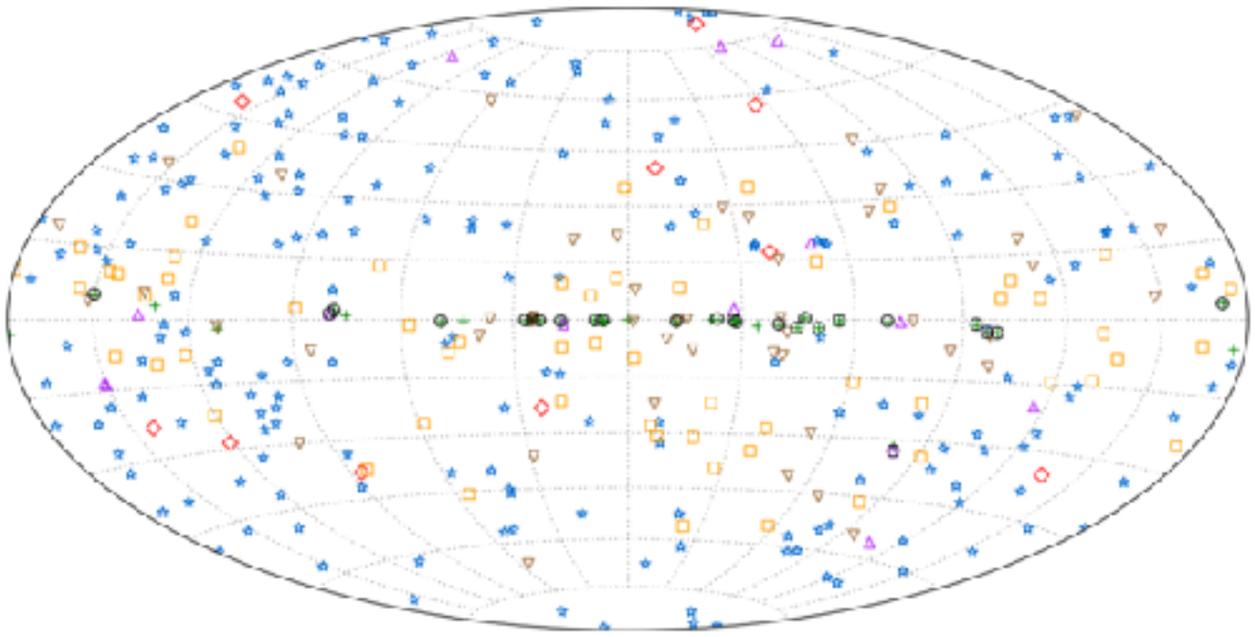
Fermi LAT HE Catalogs

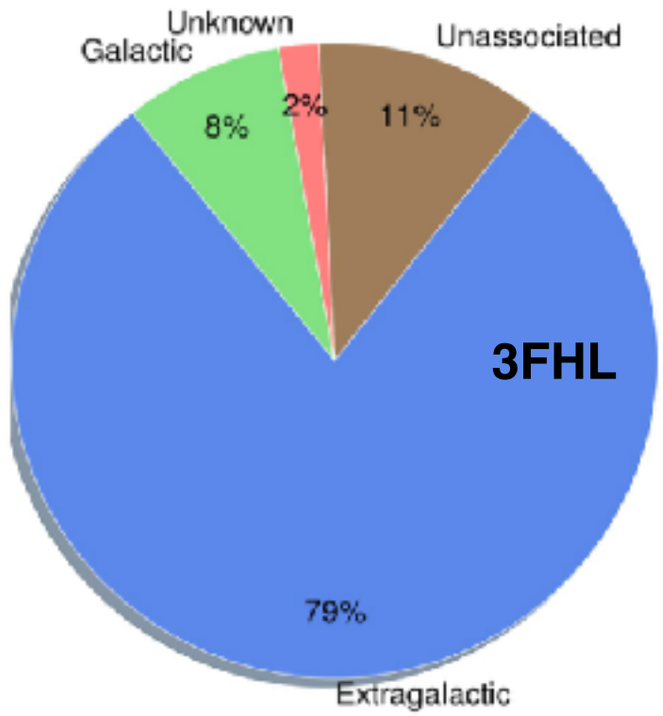
***n*FGL Catalogs detect and characterize sources in the ~0.1-300 GeV energy range**
***n*FHL Catalogs explore the higher-energy sky**



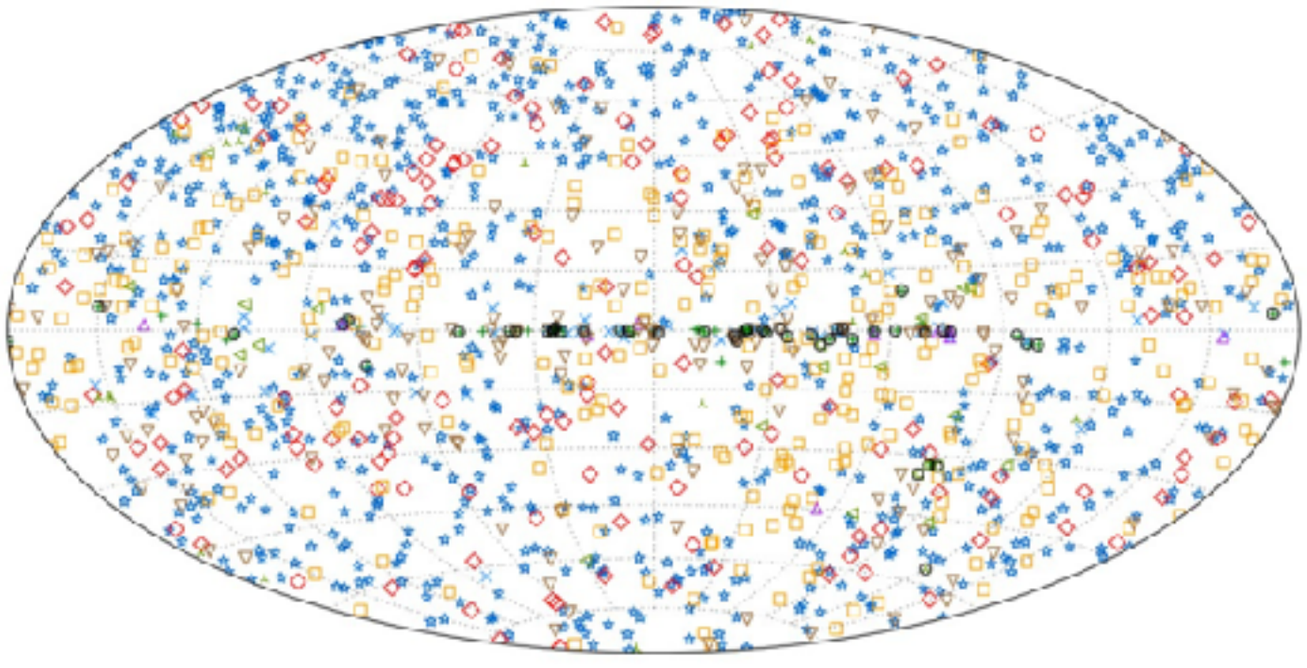
FHL associations

2FHL, E>50 GeV





3FHL, E>10 GeV

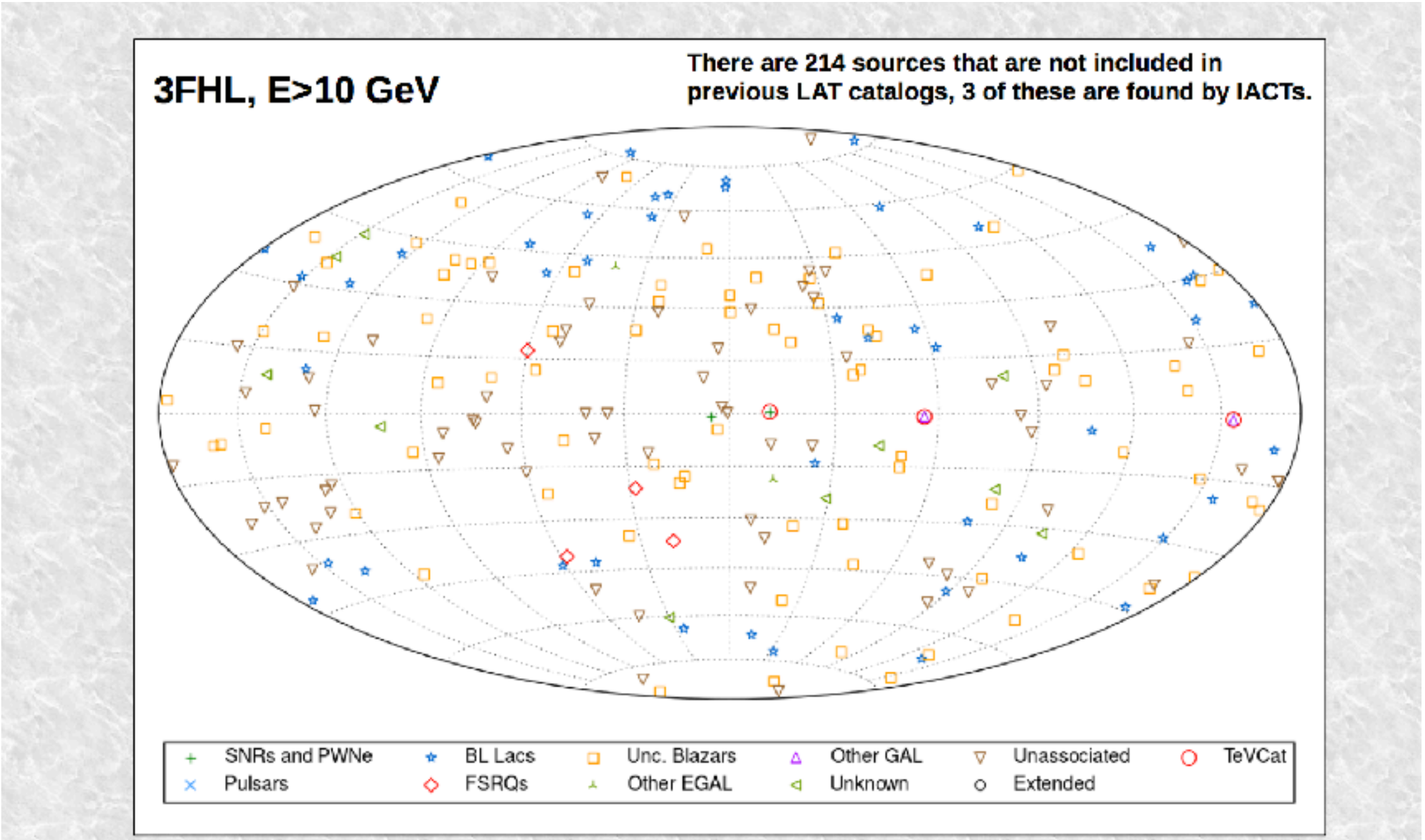


3FHL

- 1556 sources (vs. 514 1FHL):
  - 79% extragalactic, 8% Galactic sources, 13% unassociated (in 1FHL 13%)
- 48 extended sources (FGES paper, Ackermann et al. 2017)
- 1286 detected in 3FGL
- 476 detected in 1FHL
- 312 detected in 2FHL
- 133 detected by IACTs (TeVCat)
- 211 brand new sources (not in 1FHL/2FHL/3FGL/TeVCat)

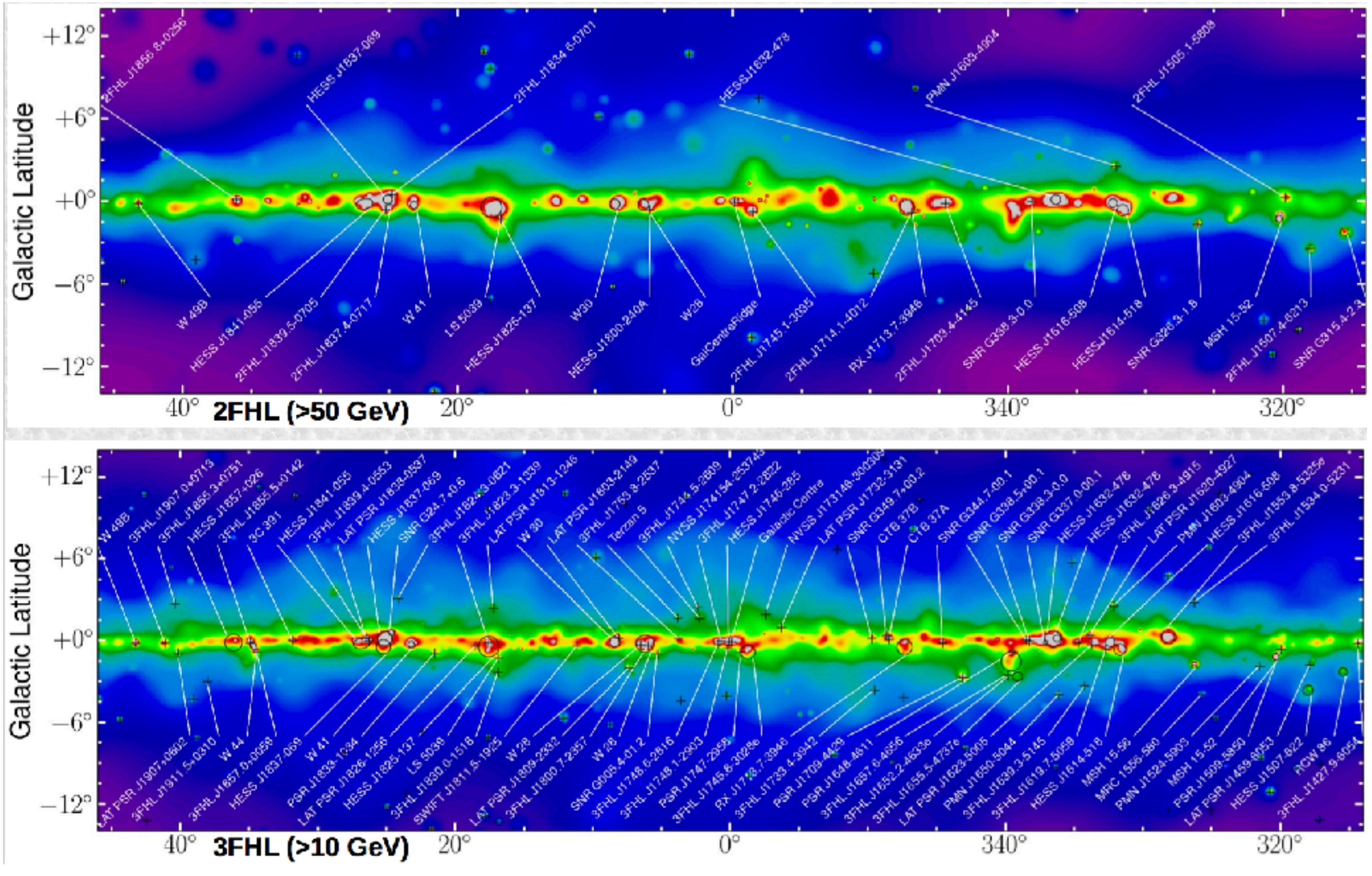
Many sources to hunt with CTA

3FHL association for new sources

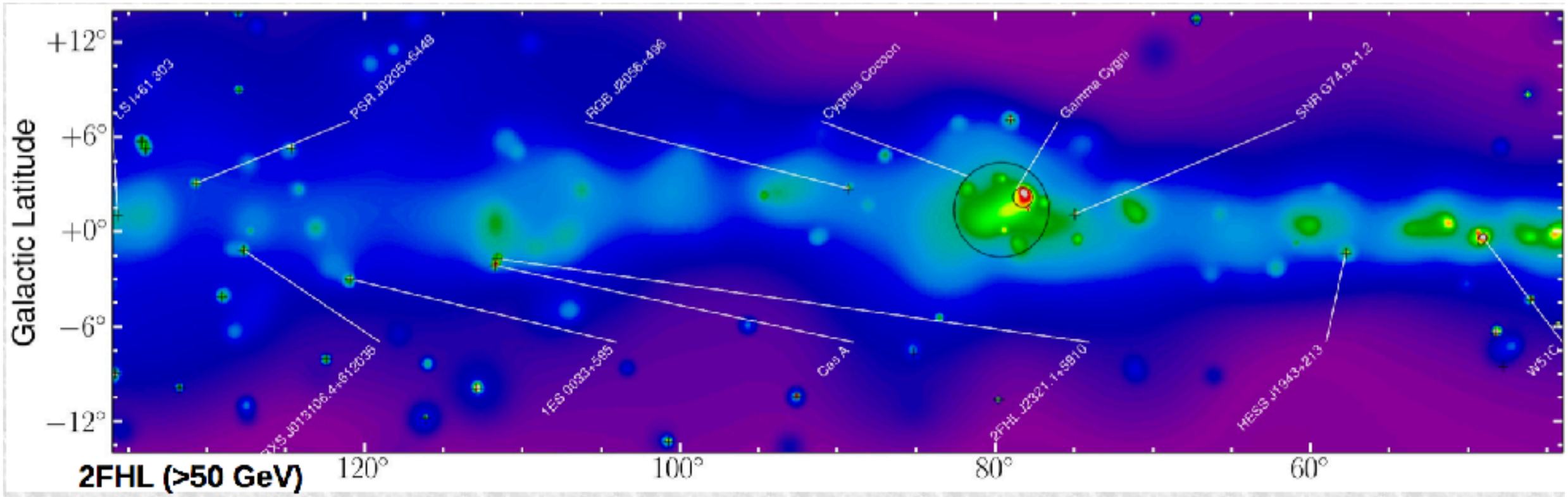


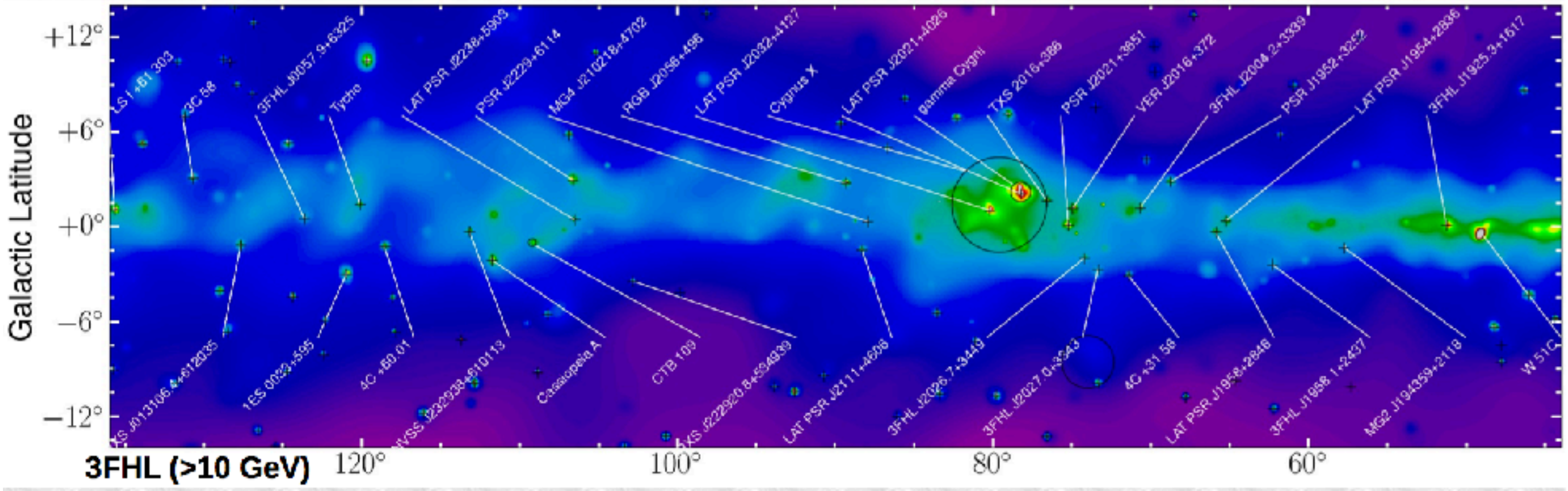
3FHL J0632.7+0550 (HESS J0632+057, Caliandro et al. 2015), 3FHL J1303.0−6350 (PSR B1259−63, which flared after the 3FGL time period), and 3FHL J1714.0−3811 (CTB 37B, previously unresolved).

Galactic plane - center region

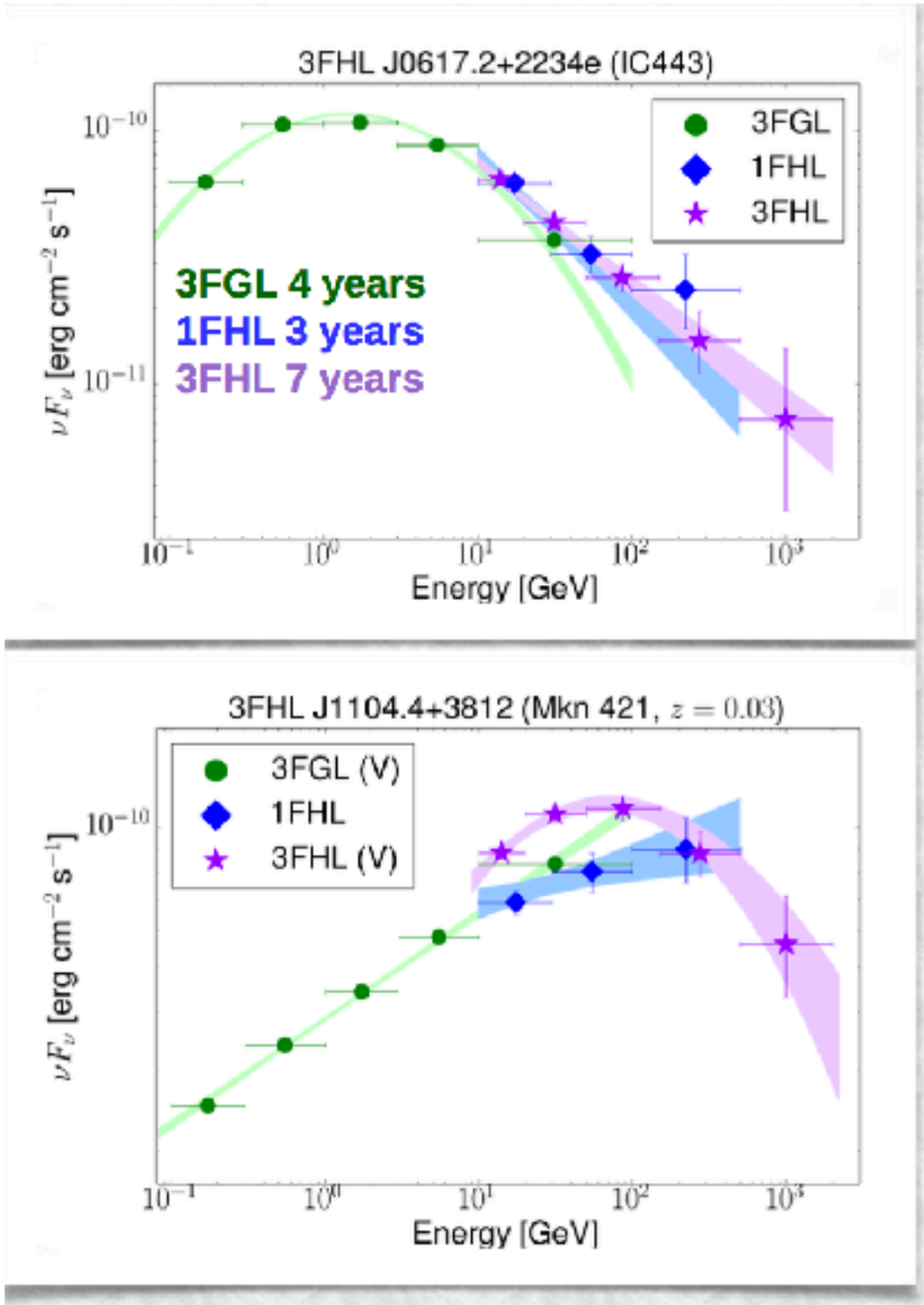


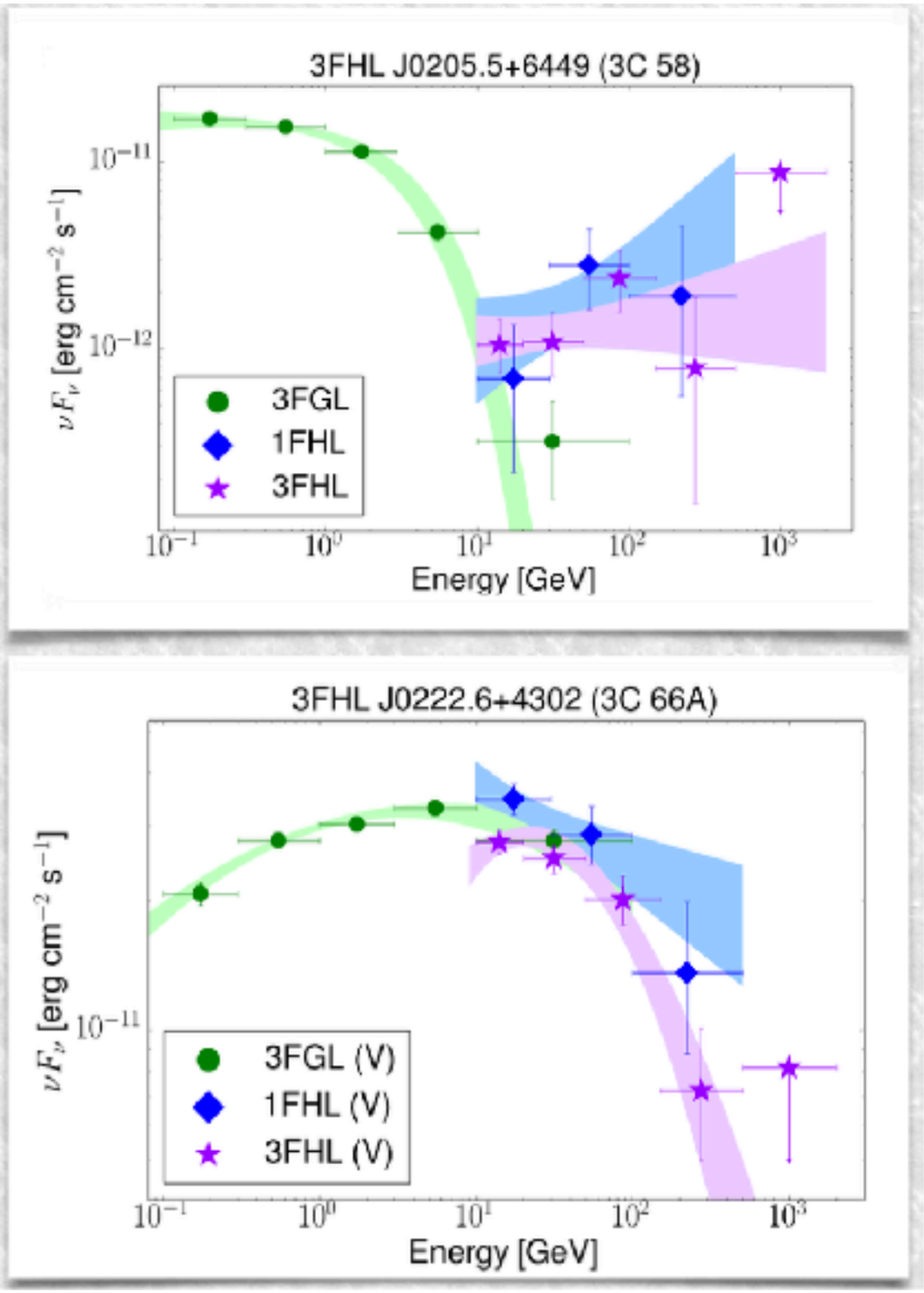
Galactic plane - around Cygnus



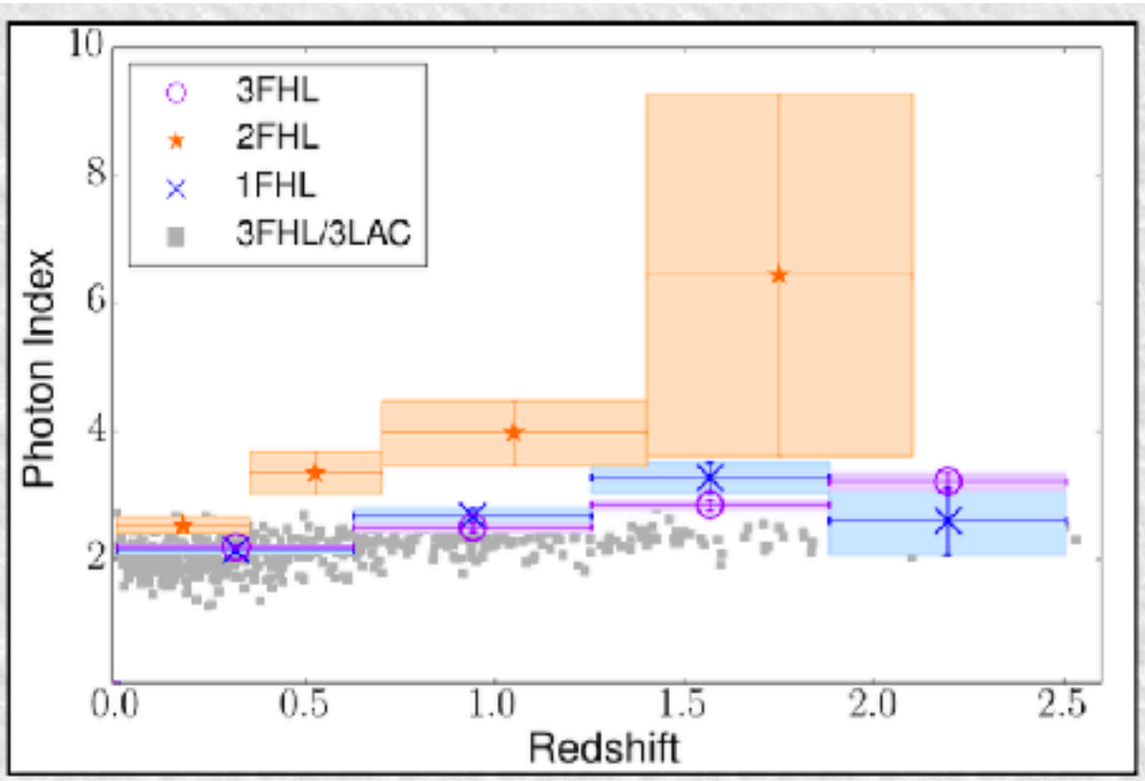


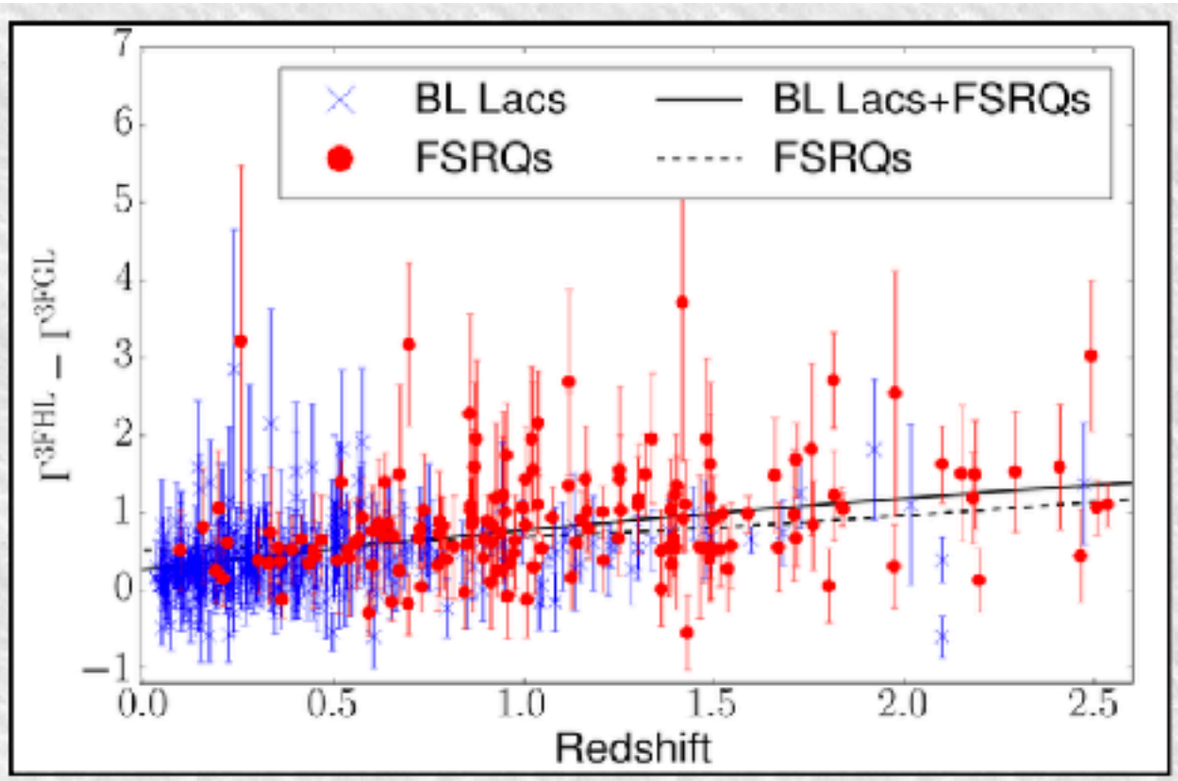
3FHL - Spectra





3FHL - Redshift evolution and EBL

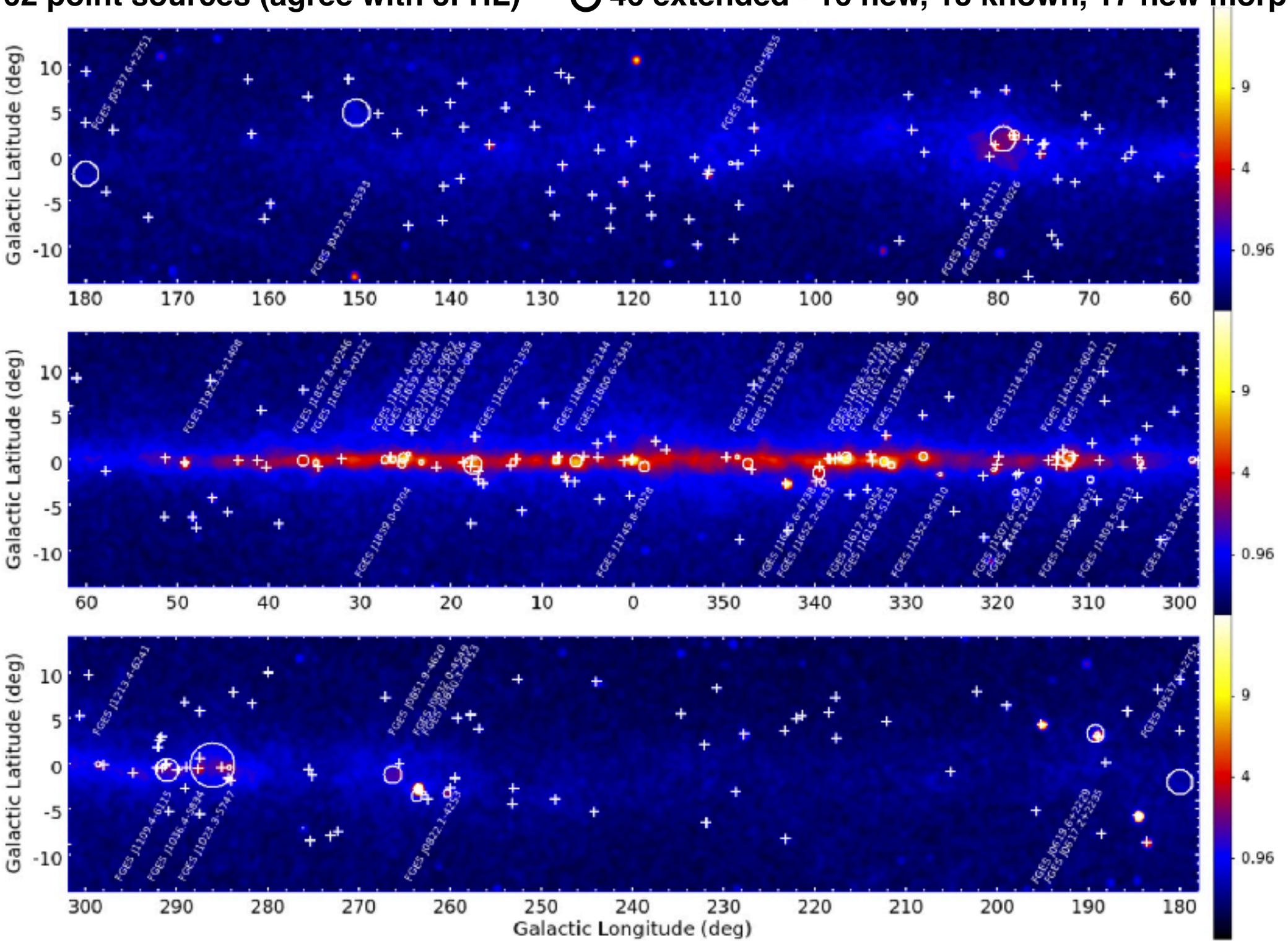




- **Clear evidence for softening of the E>10 GeV spectra at higher redshifts**
  - Most likely due to EBL
- **The difference between the 3FHL and 3FGL indexes with redshift behaves similarly for FSRQs and BL Lacs.**

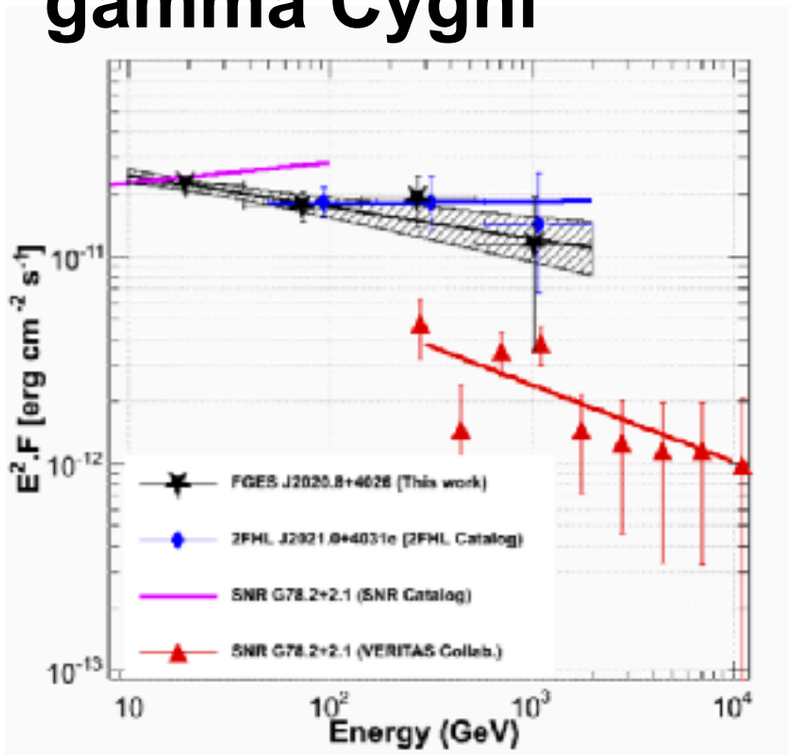
Extended sources - GP

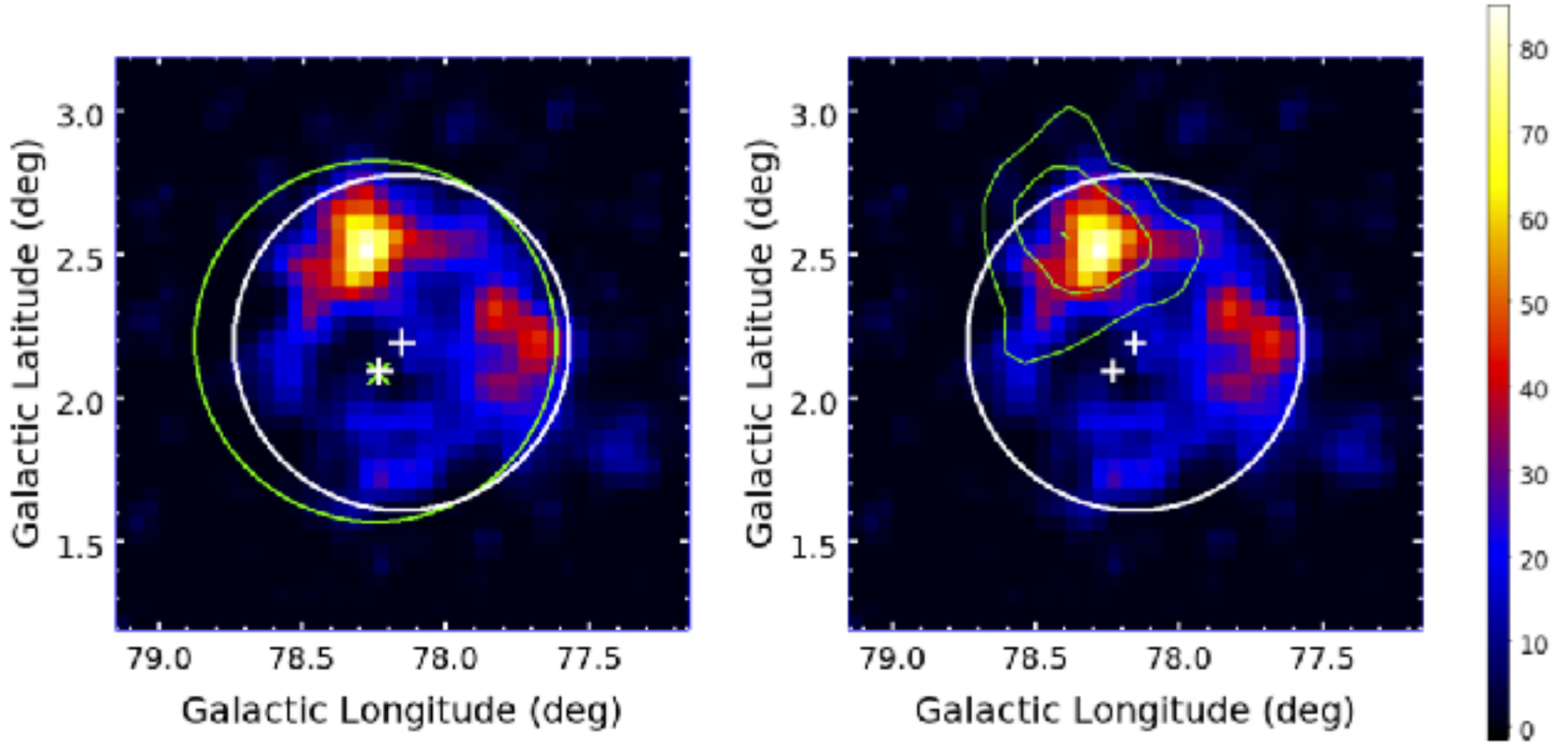
+ 162 point sources (agree with 3FHL) **○ 46 extended - 16 new, 13 known, 17 new morphology**



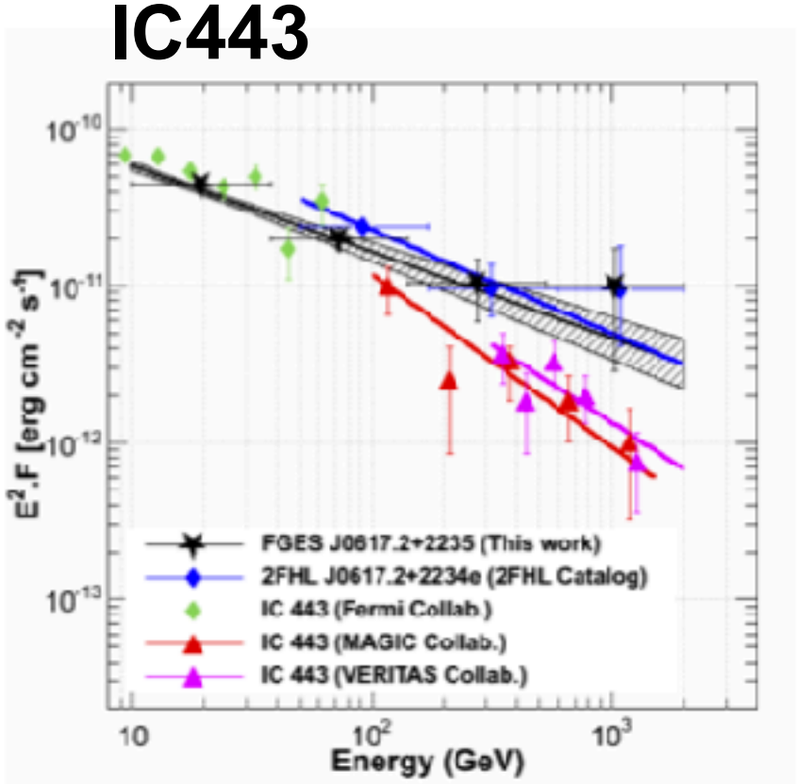
Extended sources

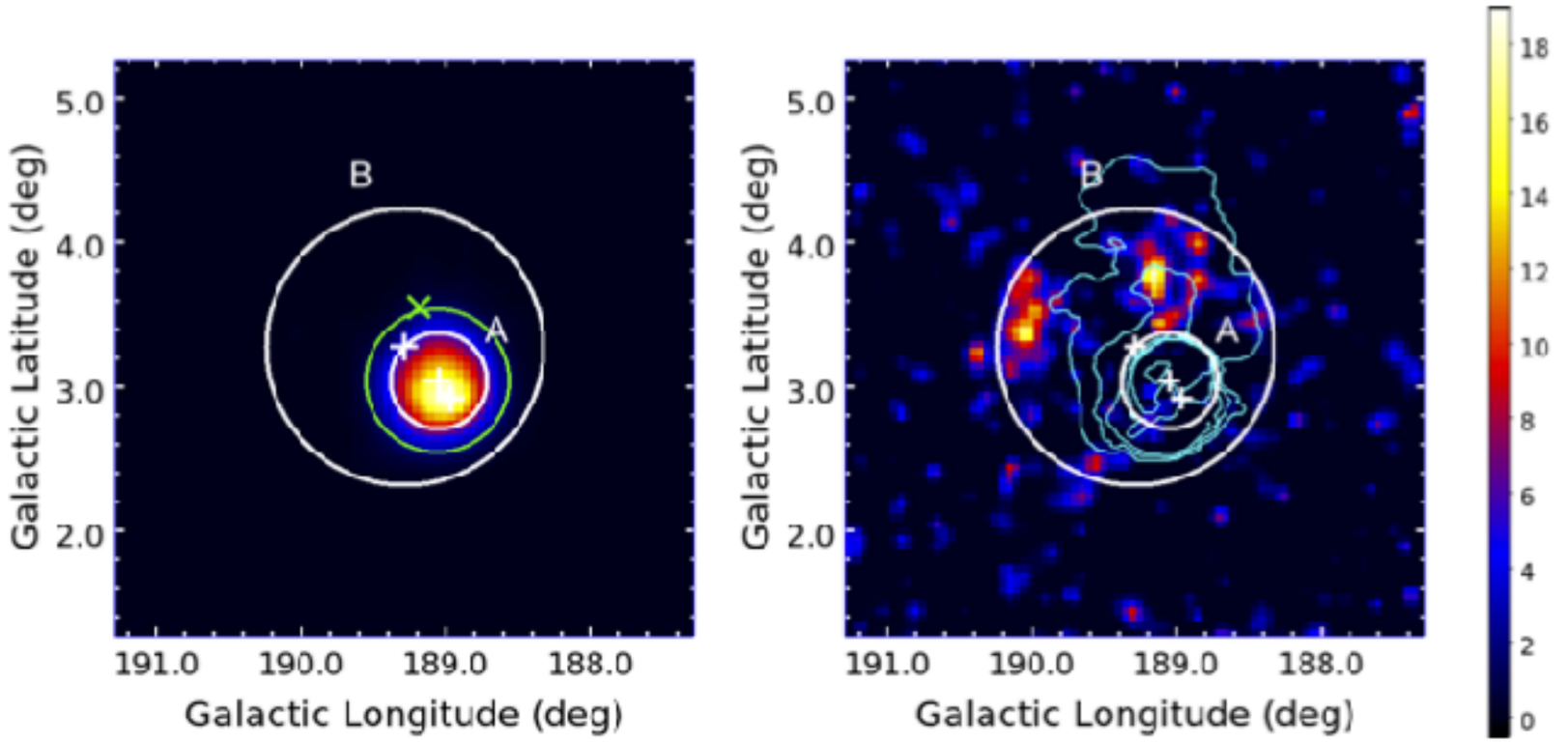
gamma Cygni



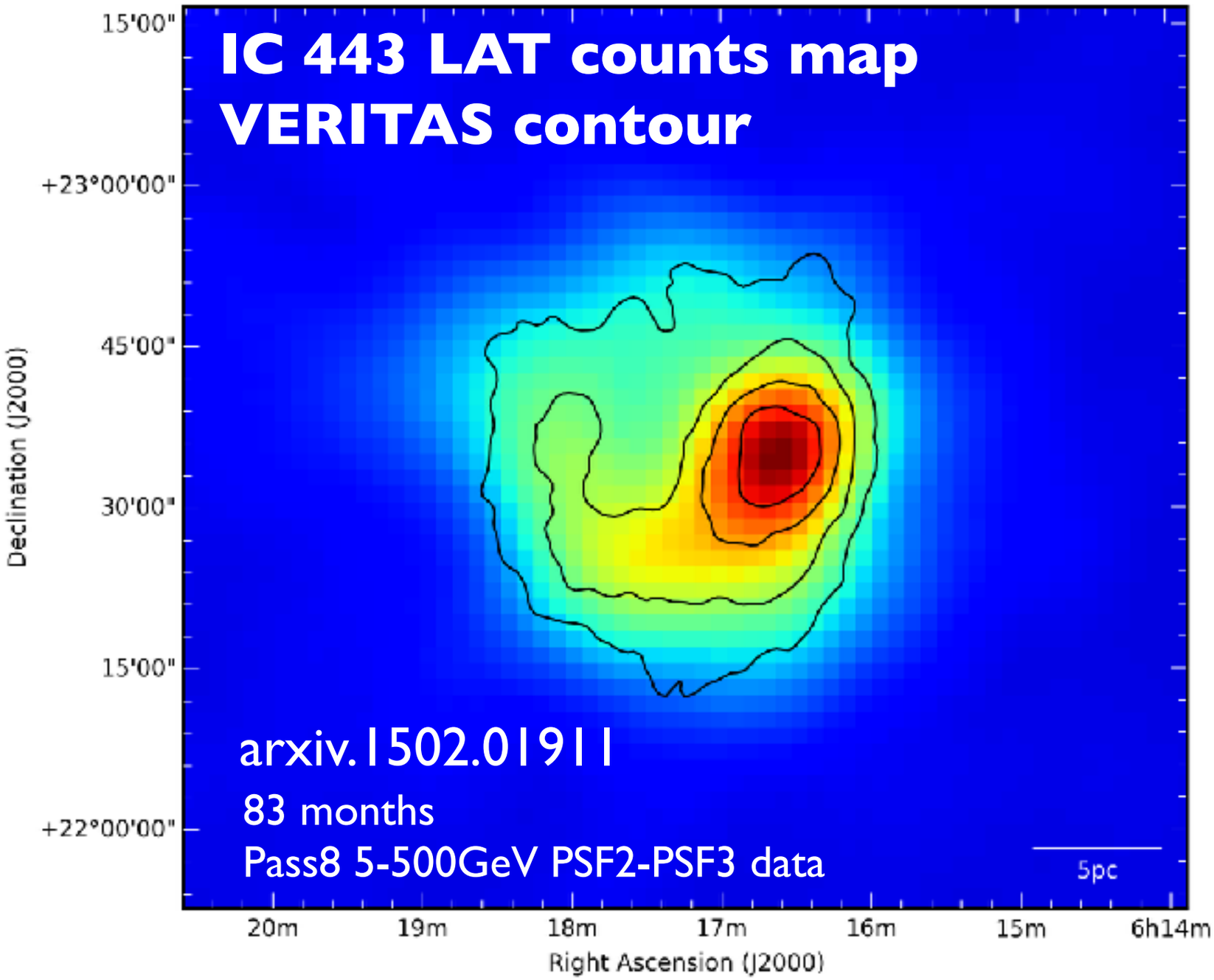


IC443



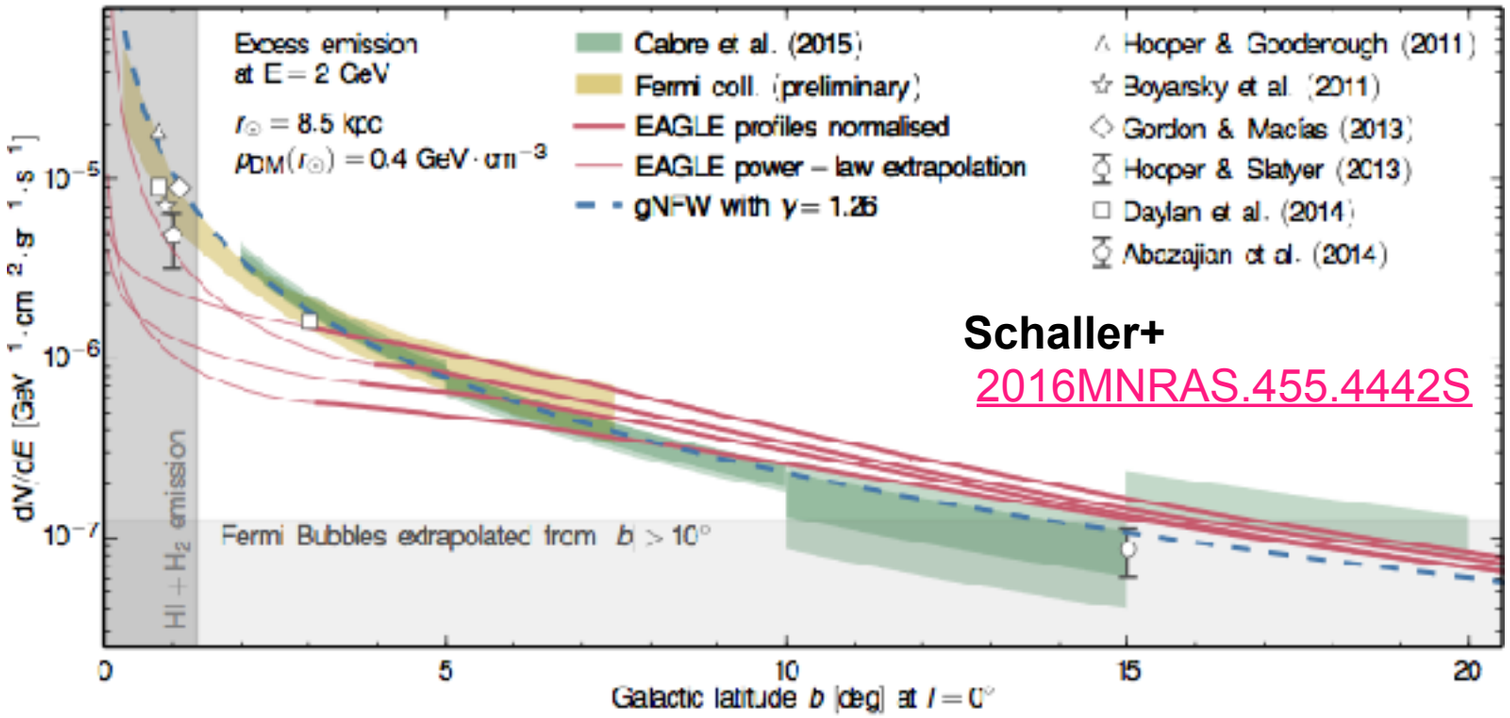


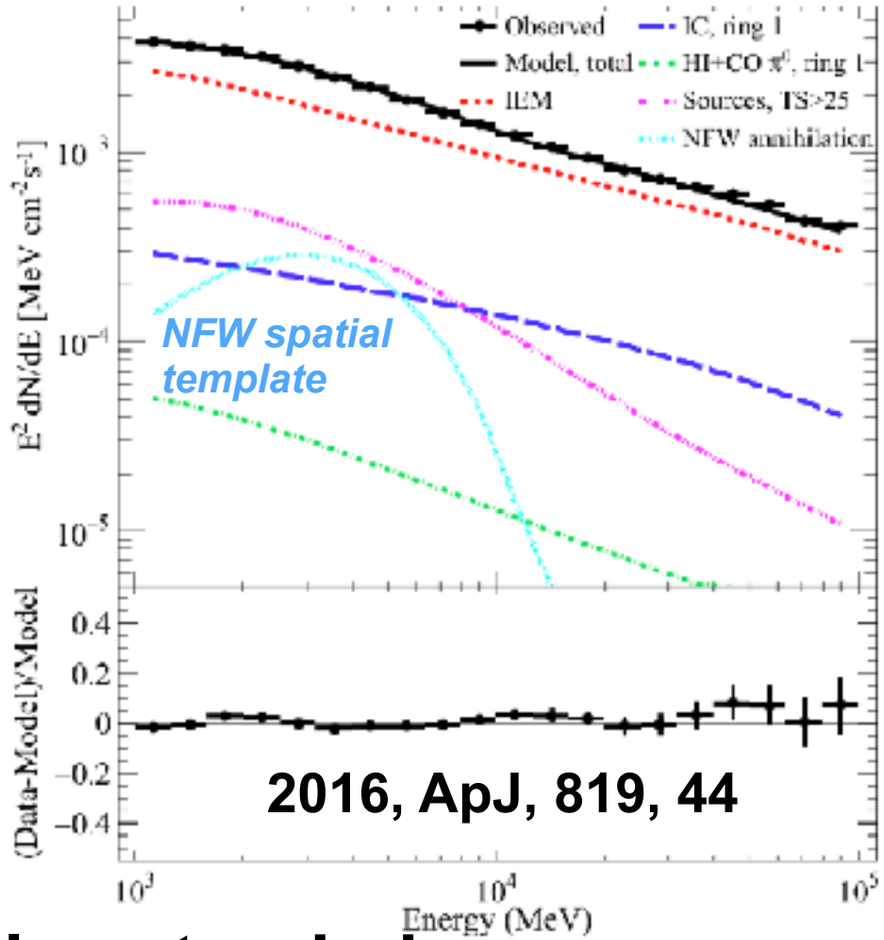
Complex morphologies



❖ potential to resolve morphologies and separate spectral components

Galactic Center excess

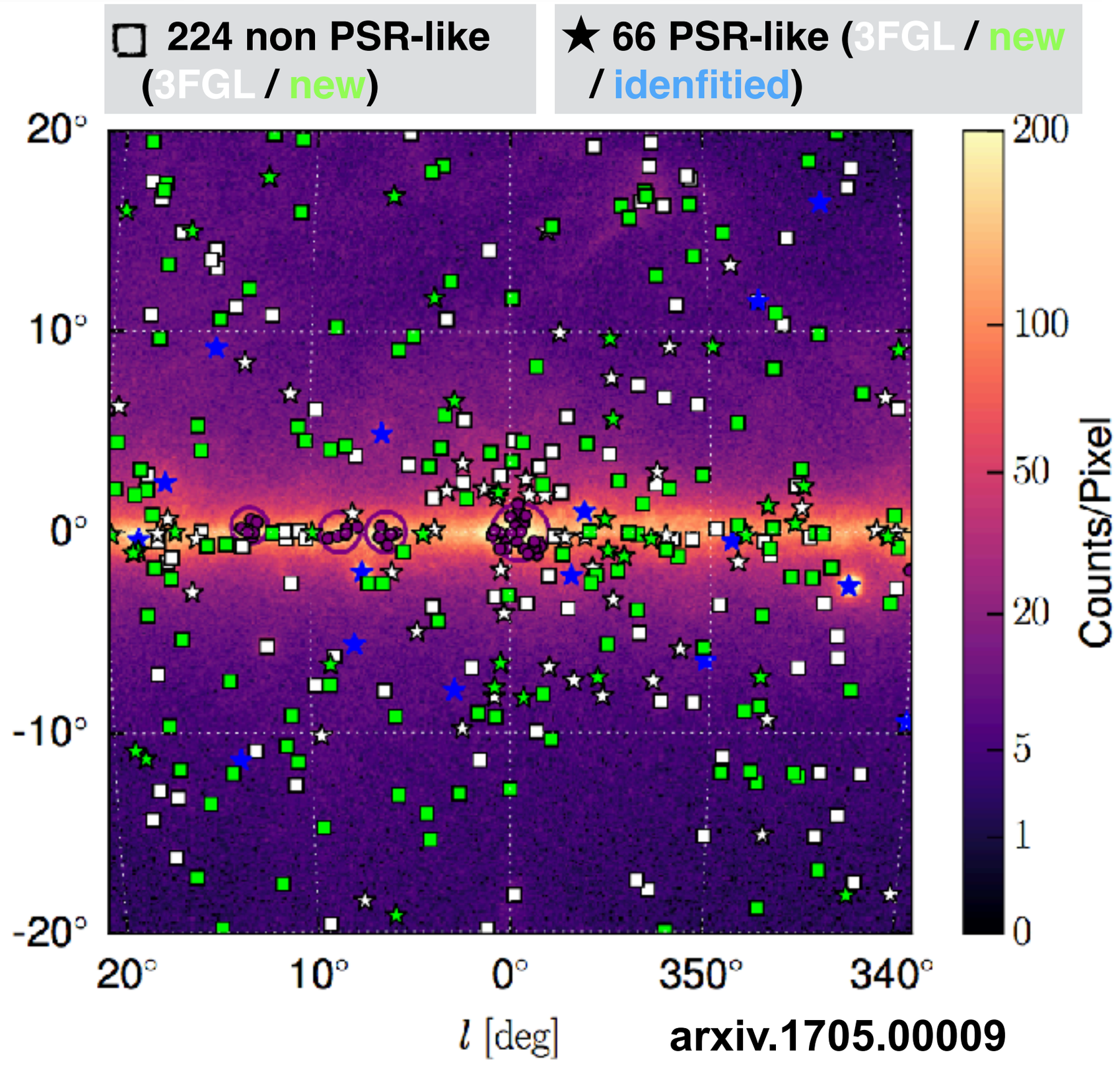




- **Independent analyses report a spatially extended excess**
- **Spherically symmetric, spectrum consistent with DM**
- **Degenerate with potential astrophysical contributions (diffuse from CR inhomogeneities, MSP)**
  - **upcoming study with Pass8 and diffuse templates**

Tracking MSP in the GC

- ❖ Dedicated source analysis
- ❖ PSR candidate selection criteria trained on identified PSR
- ❖PSR Number density compatible with expectations
- ❖ GC excess can be attributed to a population of unresolved ms PSR



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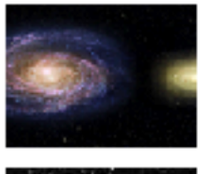
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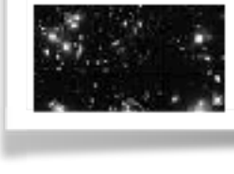
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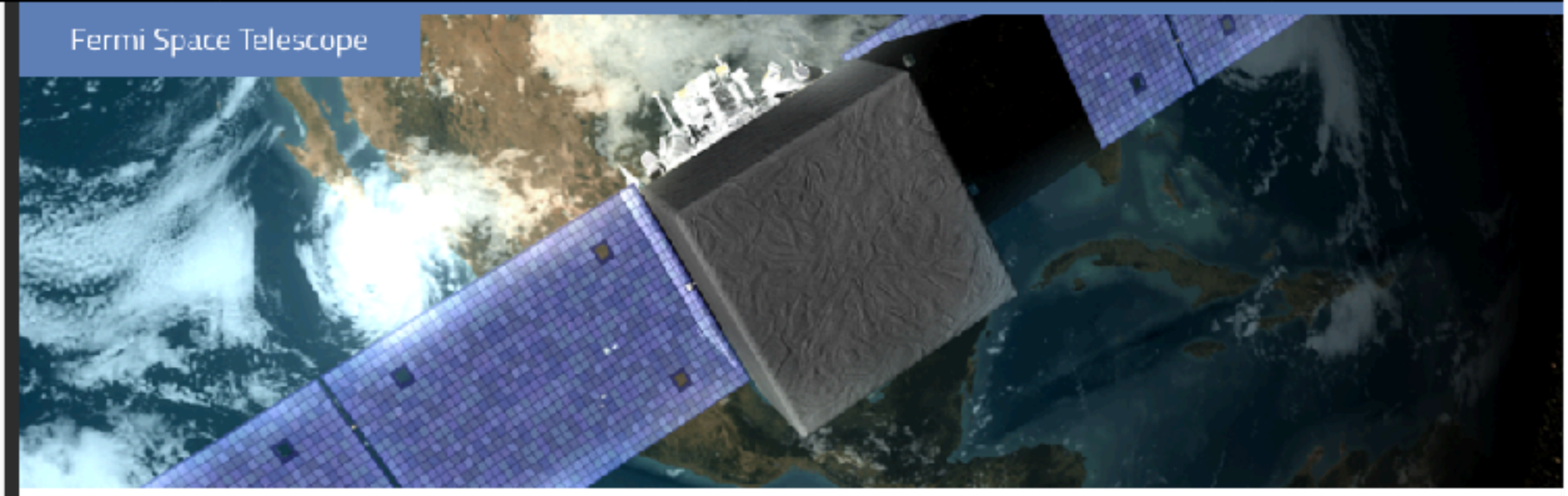


July 18, 2017

Gamma-ray Telescopes Reveal a High-energy Trap in Our Galaxy's Center

A combined analysis of data from NASA's Fermi Gamma-ray Space Telescope and the High Energy Stereoscopic System (H.E.S.S.), a ground-based observatory in Namibia, suggests the center of our Milky Way contains a "trap" that concentrates some of the highest-energy cosmic rays, among the fastest particles in the galaxy.

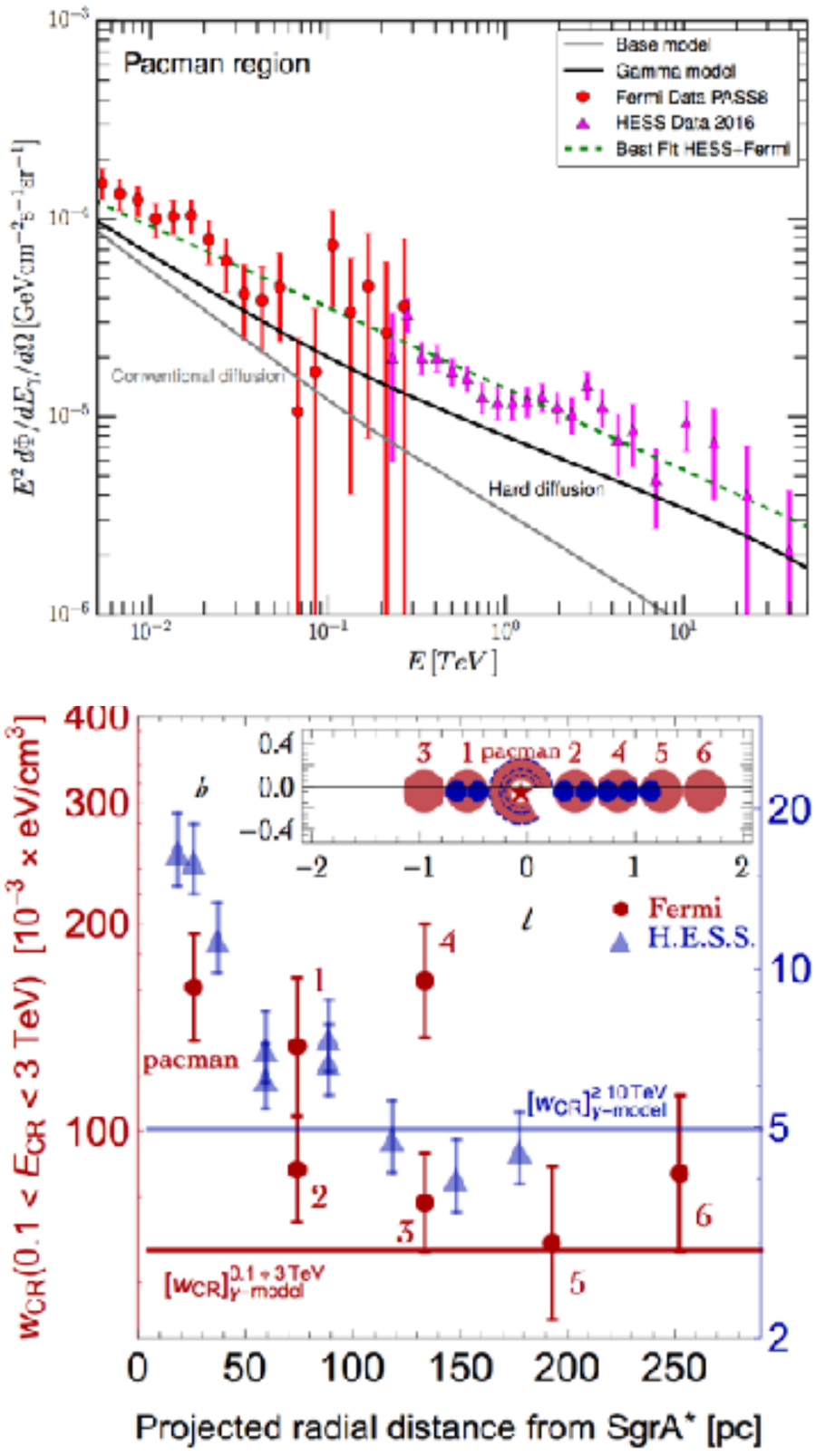
"Our results suggest that most of the cosmic rays populating the innermost region of our galaxy, and especially the most energetic ones, are produced in active regions beyond the galactic center and later slowed there through interactions with gas clouds," said lead author Daniele Gaggero at the University of Amsterdam. "Those interactions produce much of the gamma-ray emission observed by Fermi and H.E.S.S."

Cosmic rays are high-energy particles moving through space at almost the speed of light. About 90 percent are protons, with electrons and the nuclei of various atoms making up the rest. In their journey across the galaxy, these electrically charged particles are affected by magnetic fields, which alter their paths and make it impossible to know where they originated.

But astronomers can learn about these cosmic rays when they interact with matter and emit gamma rays, the highest-energy form of light.

https://www.nasa.gov/feature/goddard/2017/gamma-ray-telescopes-reveal-a-high-energy-trap-in-our-galaxys-center

Pevatron or not Pevatron?



- Same simple power law spectral shape around SgrA* and Galactic Ridge between Fermi and HESS suggest same origin
- consistent with energy independent shape of the CR density profile derived from gamma-ray luminosity (standard interaction with could)
- can be modeled by a CR population with diffusion parameter with galacto-centric radial dependence (*gamma* model)

$$w_{\rm CR}(E_{\rm CR} \geq 0.1\ {\rm TeV}) = 3.9 \times 10^{-2}\ \ {\rm eVcm}^{-3} \left(\frac{\eta_N}{1.5}\right)^{-1} \left(\frac{L_\gamma(\geq 10\ {\rm GeV})}{10^{34}\ {\rm erg/s}}\right) \left(\frac{M_{\rm gas}}{10^6\ M_\odot}\right)^{-1}$$

2017, PRL 119, 031101

Summary

- **Fermi is the reference gamma-ray observatory**
  - **~1G photons, thousands sources, public database**
- **Synergy with TeV observatories is strong**
  - **flares (not covered here)**
  - **association and morphology**
  - **DM searches**
  - **CR properties**