Fermi Collaboration Science Highlights

Luca Latronico
INFN-Torino
luca.latronico@to.infn.it

on behalf of the Fermi-LAT collaboration

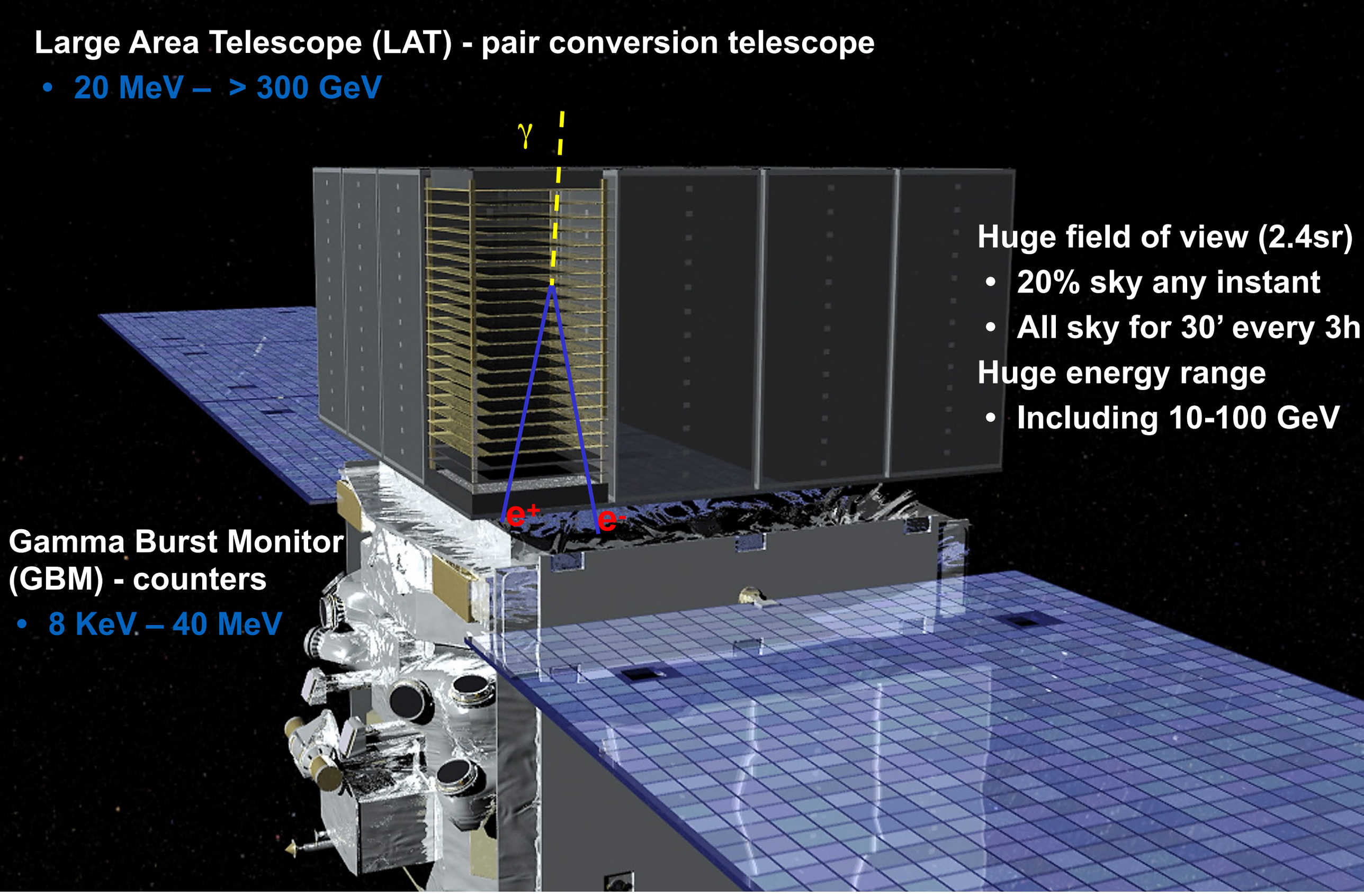
Torino - Fermi Open Day
4 September 2015

Talk outline

- ❖ LAT key design elements
- ❖ Impact on selected science results
- ❖ LAT key Pass8 performance elements
- ❖ New results and prospects

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**

Gamma Burst Monitor (GBM) - counters

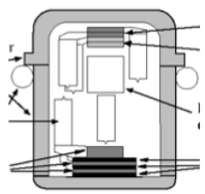
- **8 KeV – 40 MeV**

The Fermi Observatory

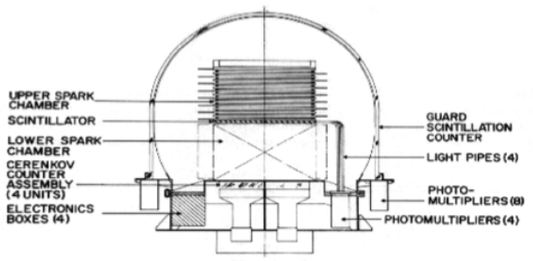
Brief History of Detectors Pre-Fermi

- 1967-1968, OSO-3 detected Milky Way as an extended γ-ray source, 621 γ-rays
- 1972-1973, SAS-2, ~8,000 celestial γ-rays
- 1975-1982, COS-B, orbit resulted in a large and variable background of charged particles, ~200,000 γ-rays.
- 1991-2000, EGRET, large effective area, good PSF, long mission life, excellent background rejection, and >1.4 × 10^6 γ-rays
- 2007-, AGILE, like 1/16-th LAT, with small calorimeter, sensitivity ~EGRET

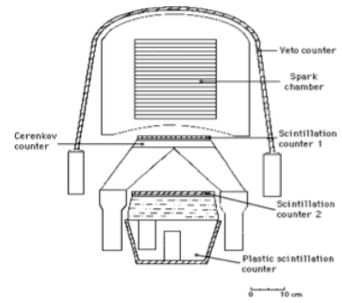
OSO-3



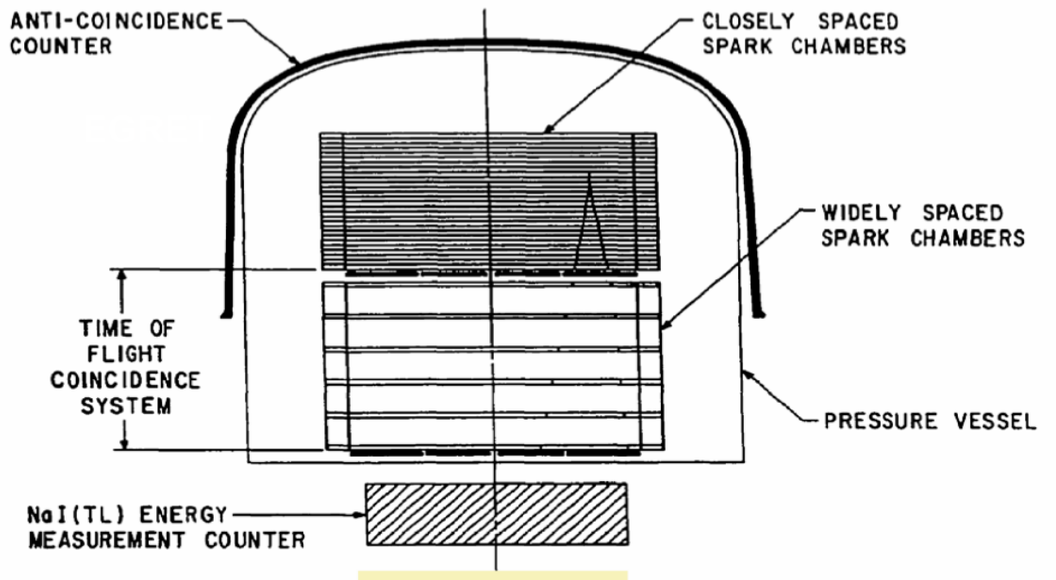
SAS-2



COS-B



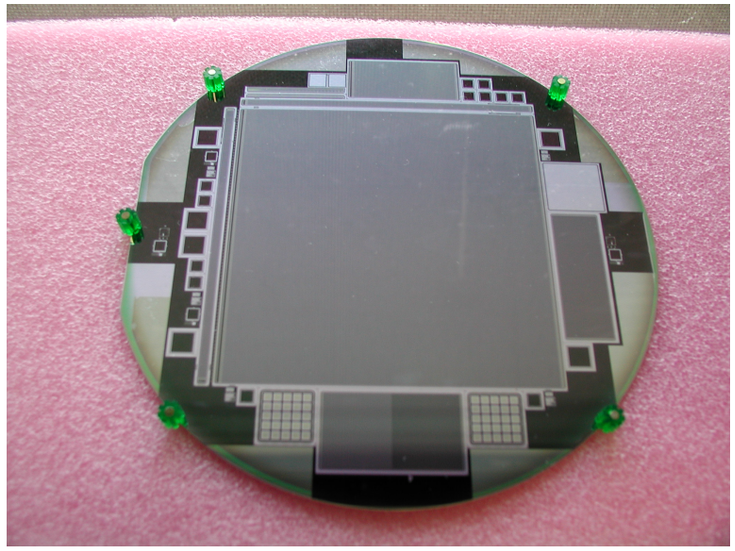
EGRET

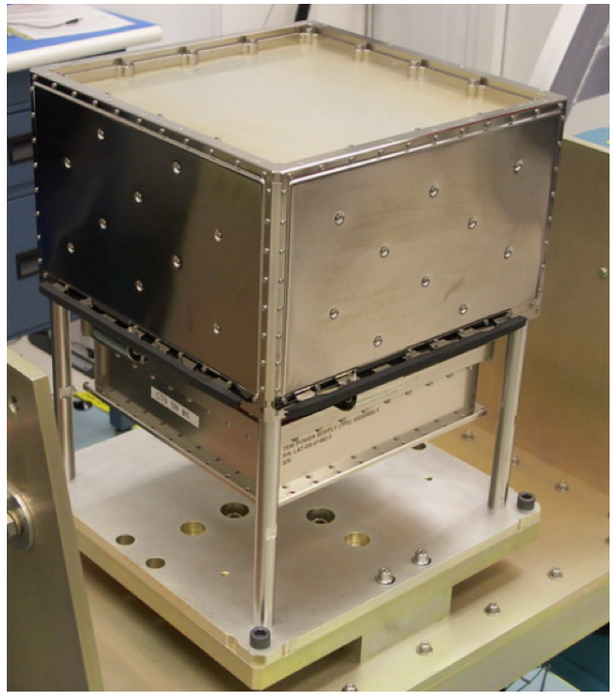


AGILE

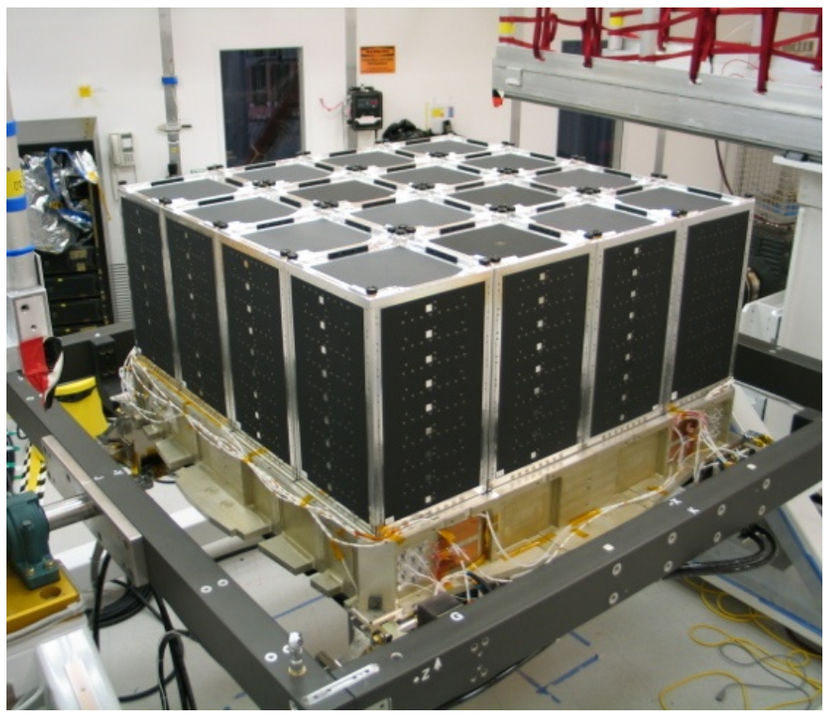
❖ Pair Conversion telescope concept

Large Area Telescope improvements



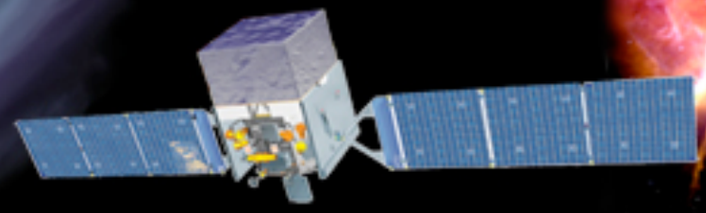


- **solid state detectors**
  - large FOV
  - no consumables
- **onboard processing**
  - soft trigger
- **detectors segmentation**
  - optimal performance

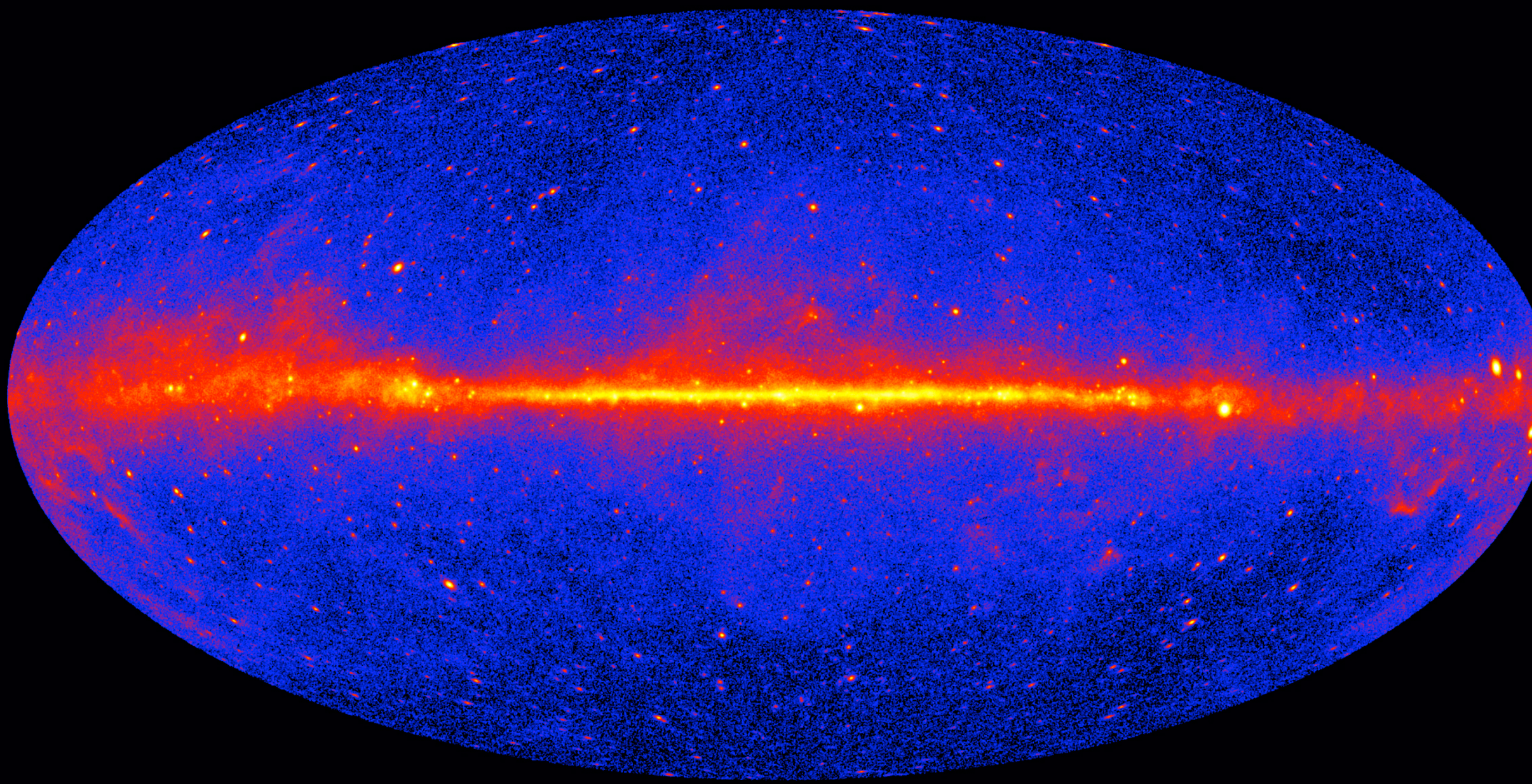


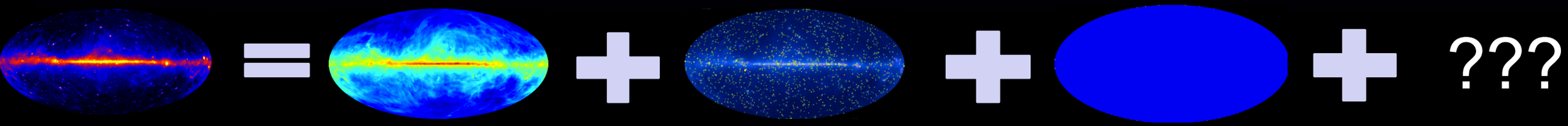
Fermi

Gamma-ray Space Telescope

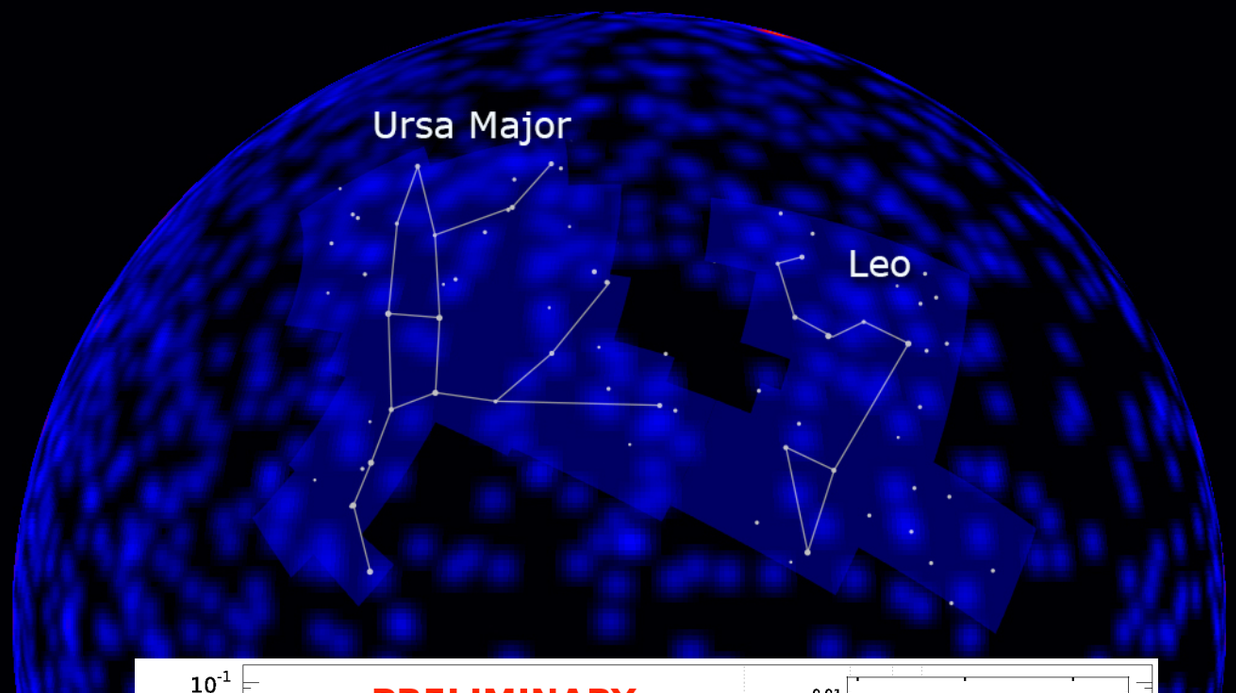


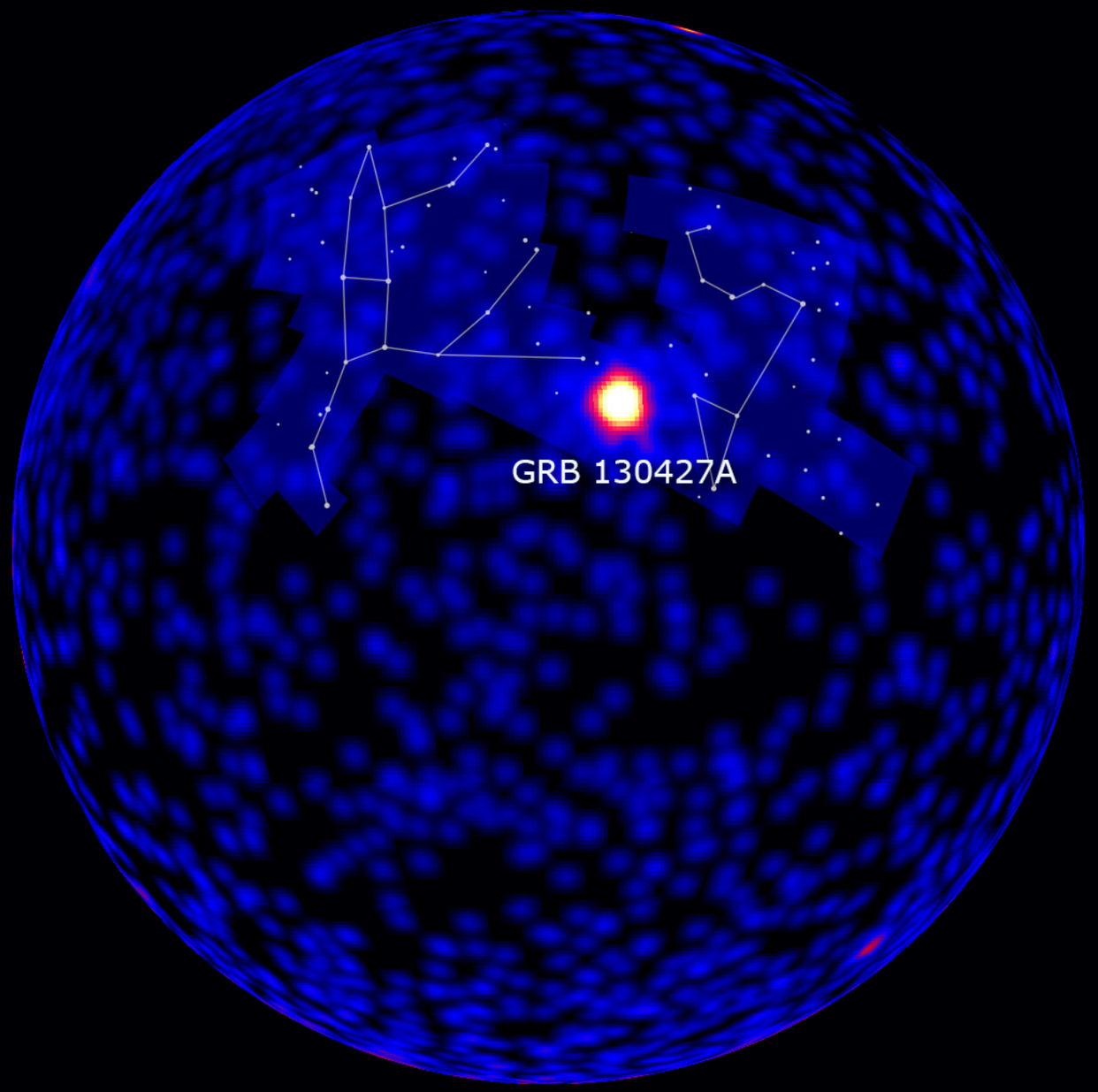
5 years γ-ray skymap showing thousands of sources and Galactic plane glowing in γ-rays

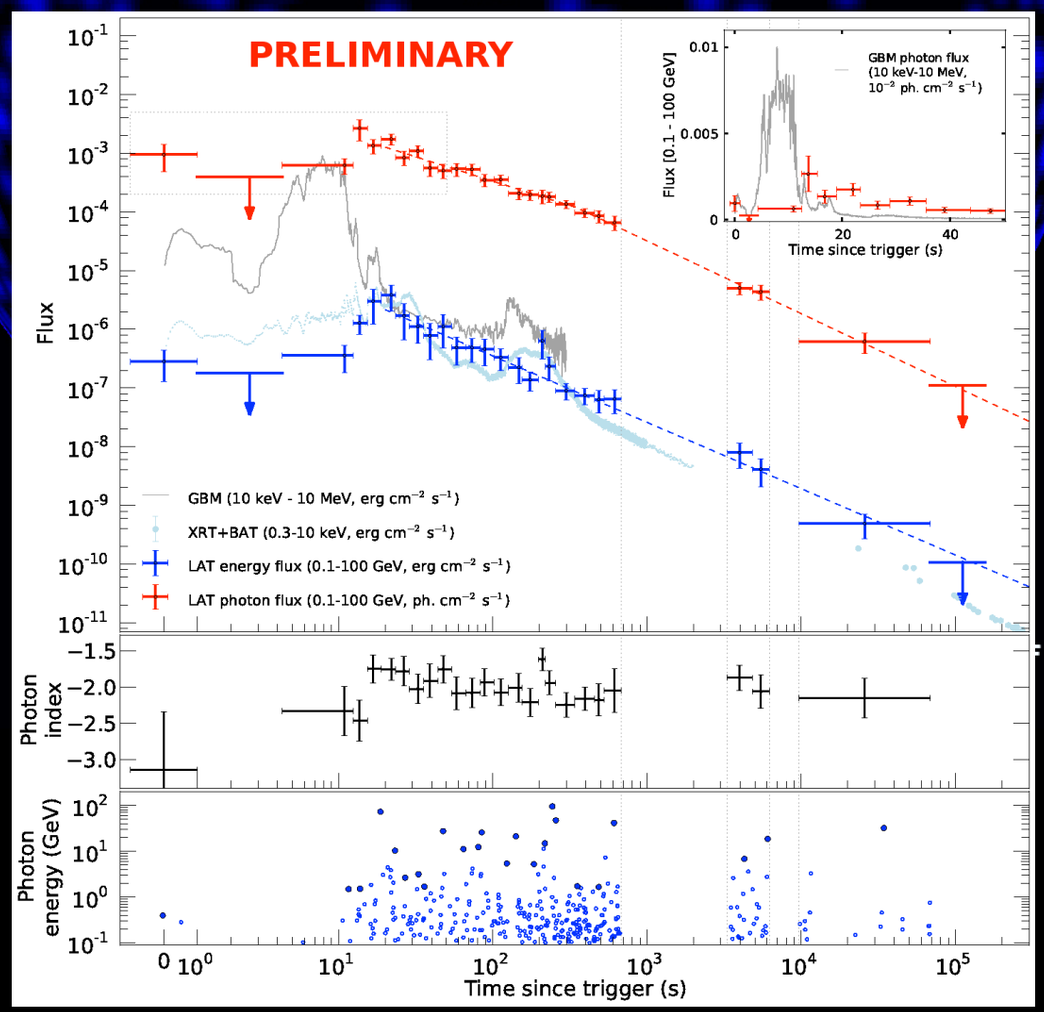




Surprises from the gamma-ray sky

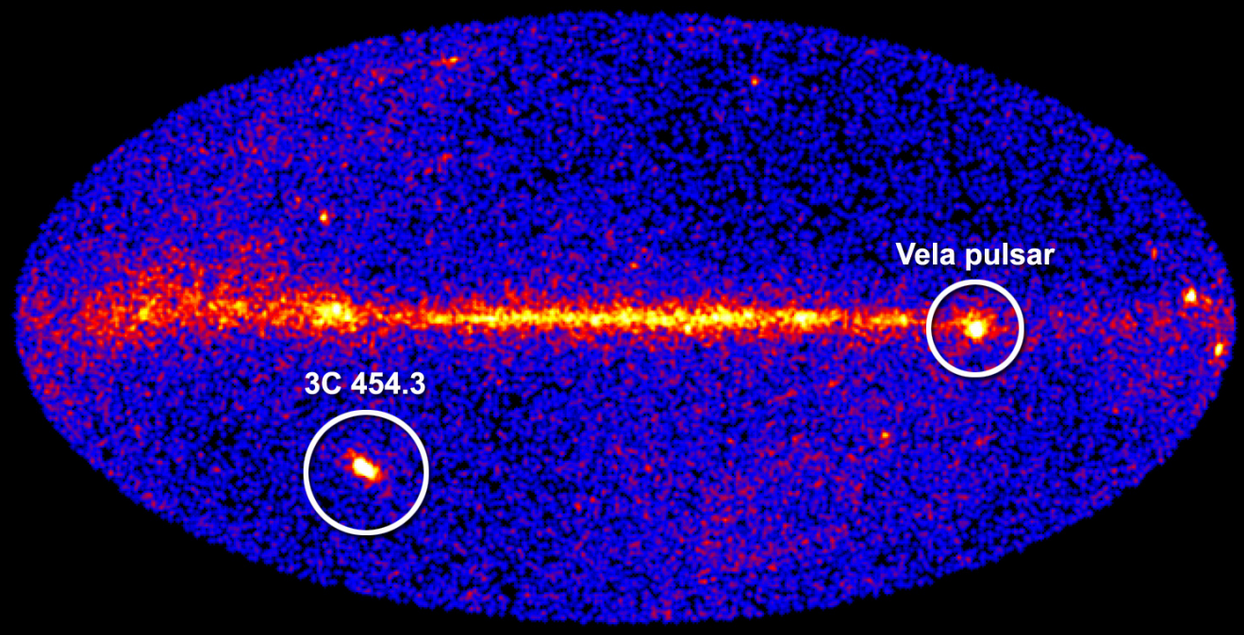




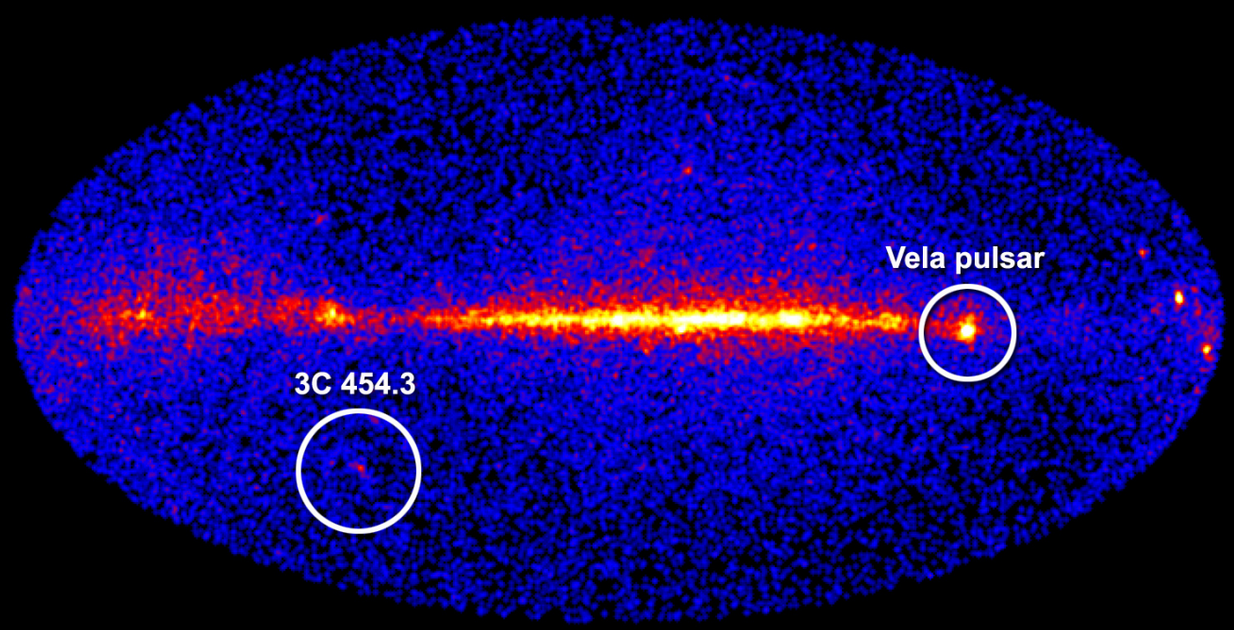


f GRB 130427A, centered on the north galactic pole

Blazar 3C 454.3's Record Flare



December 2, 2009

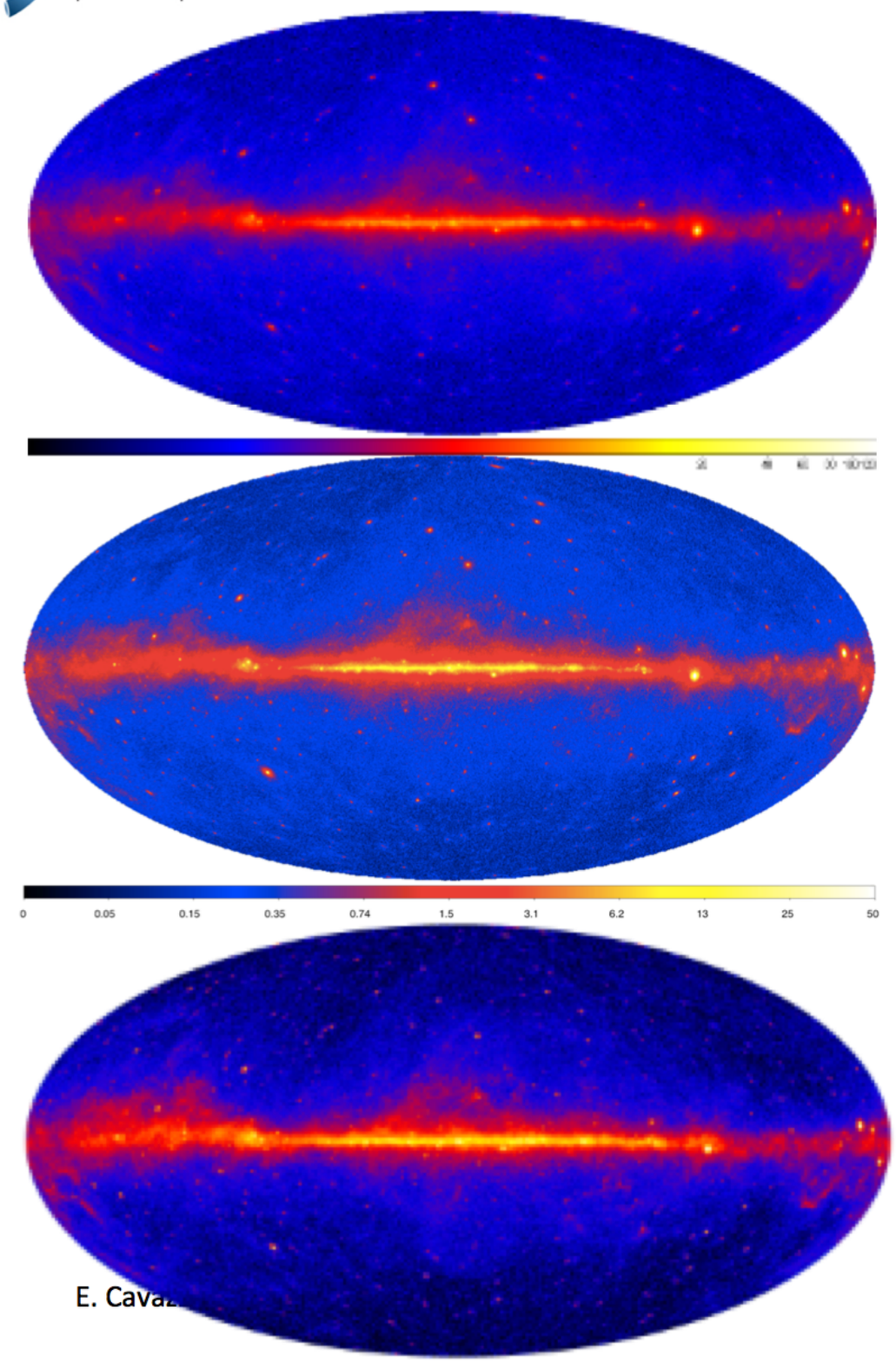


November 3, 2009

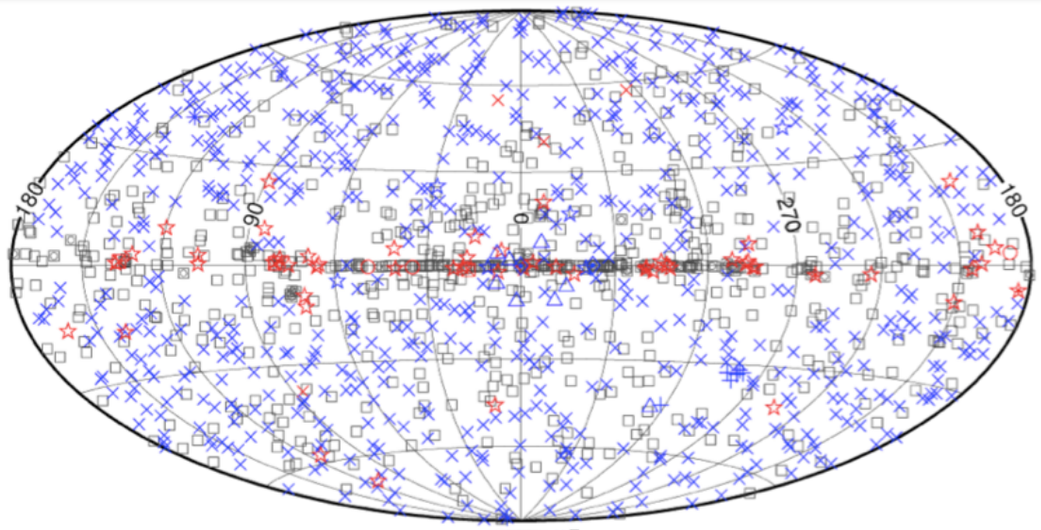
Fermi Gamma-ray Space Telescope

The LAT delivers a 4pi light curve of the Universe through many years
(W. Atwood)

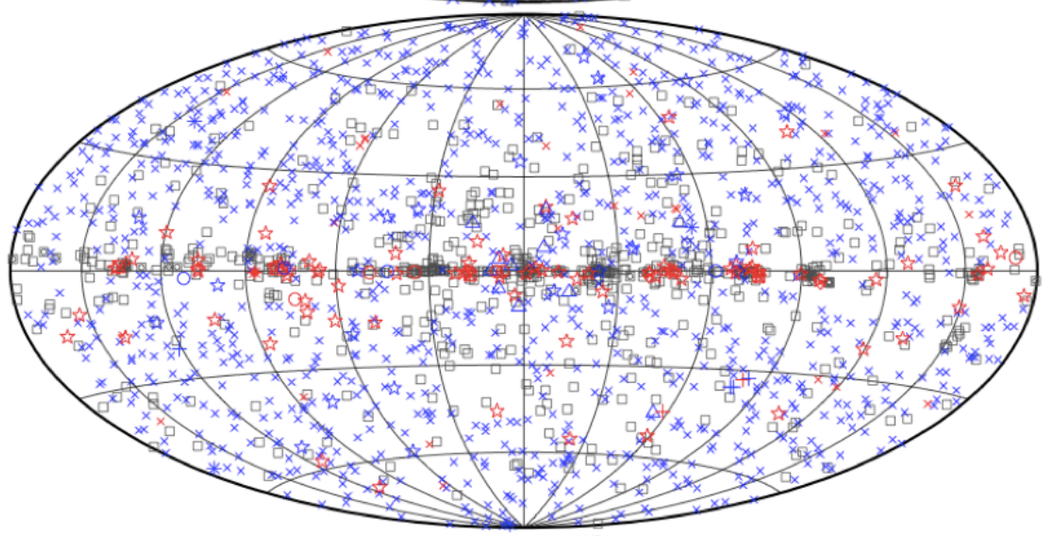
Intensity and source counts maps evolution



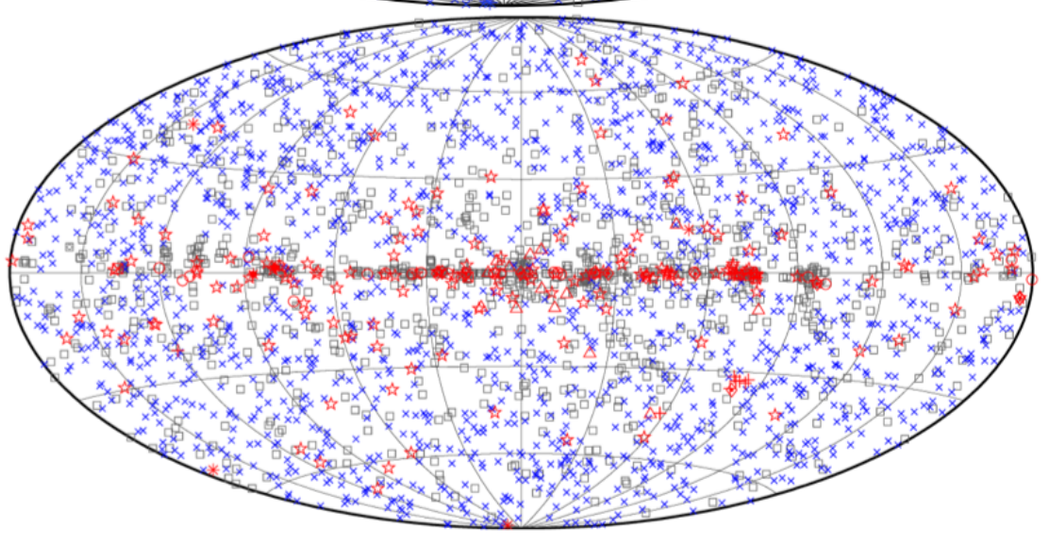
1FGL
11 m



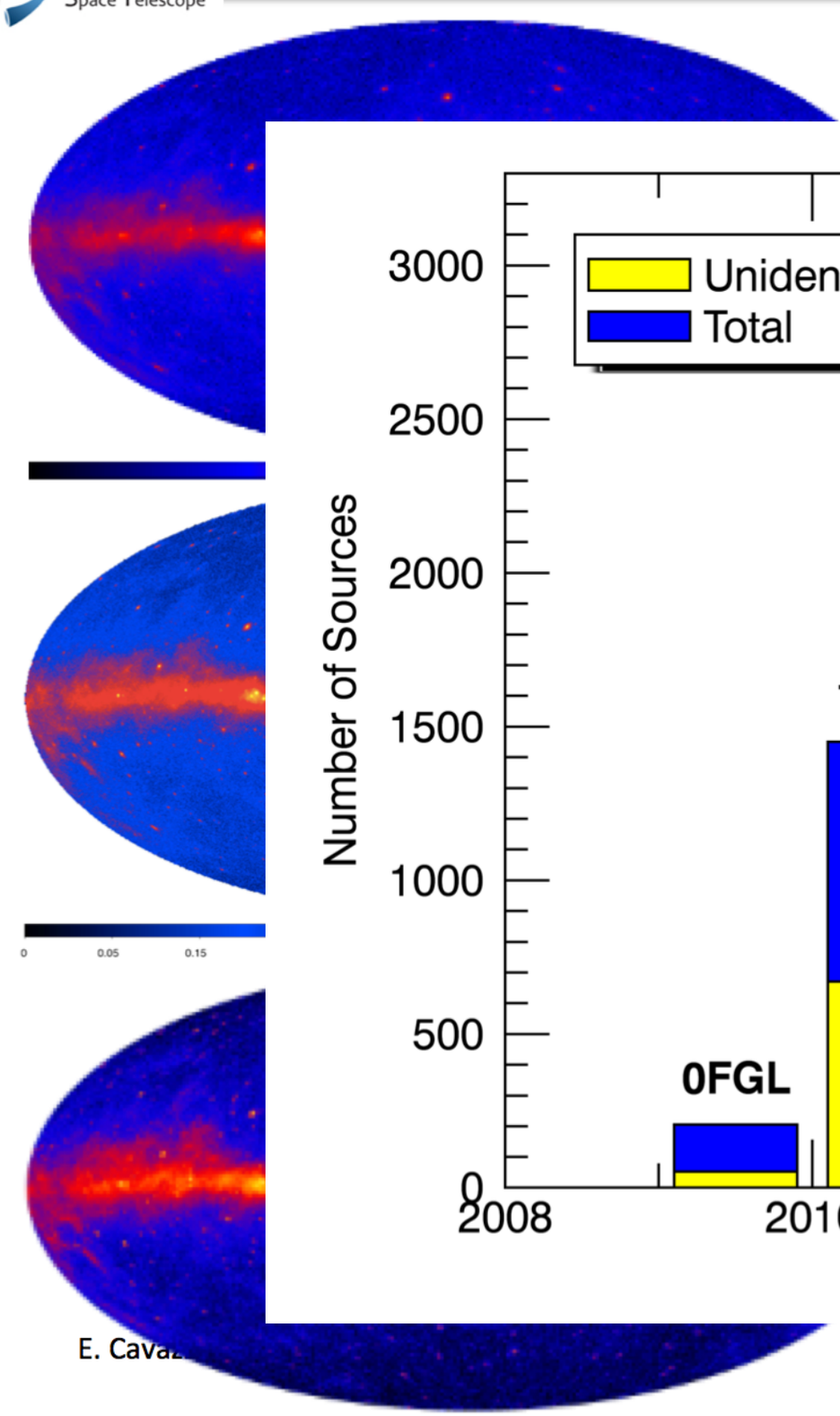
2FGL
2 y



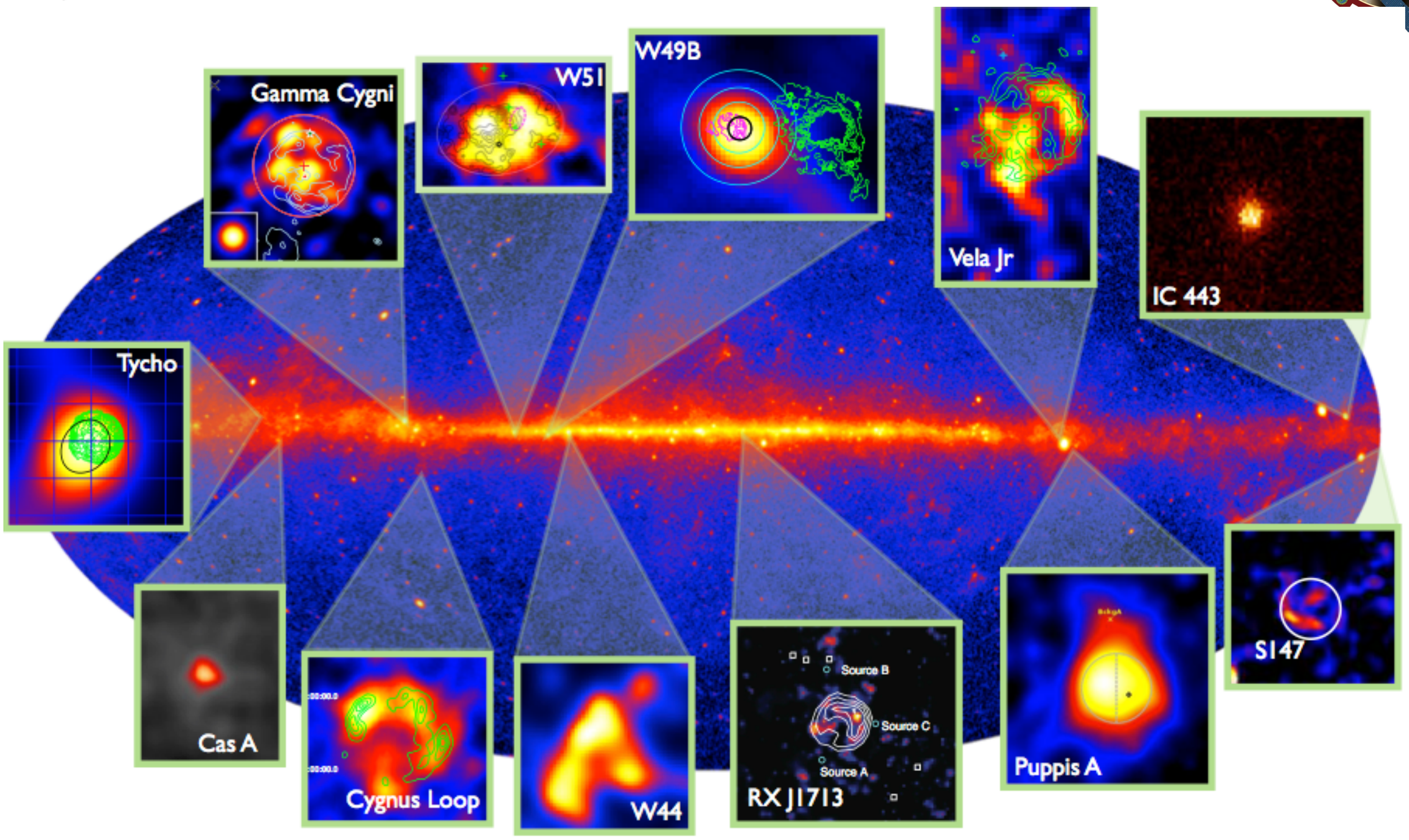
3FGL
4 y



Intensity and source counts maps evolution



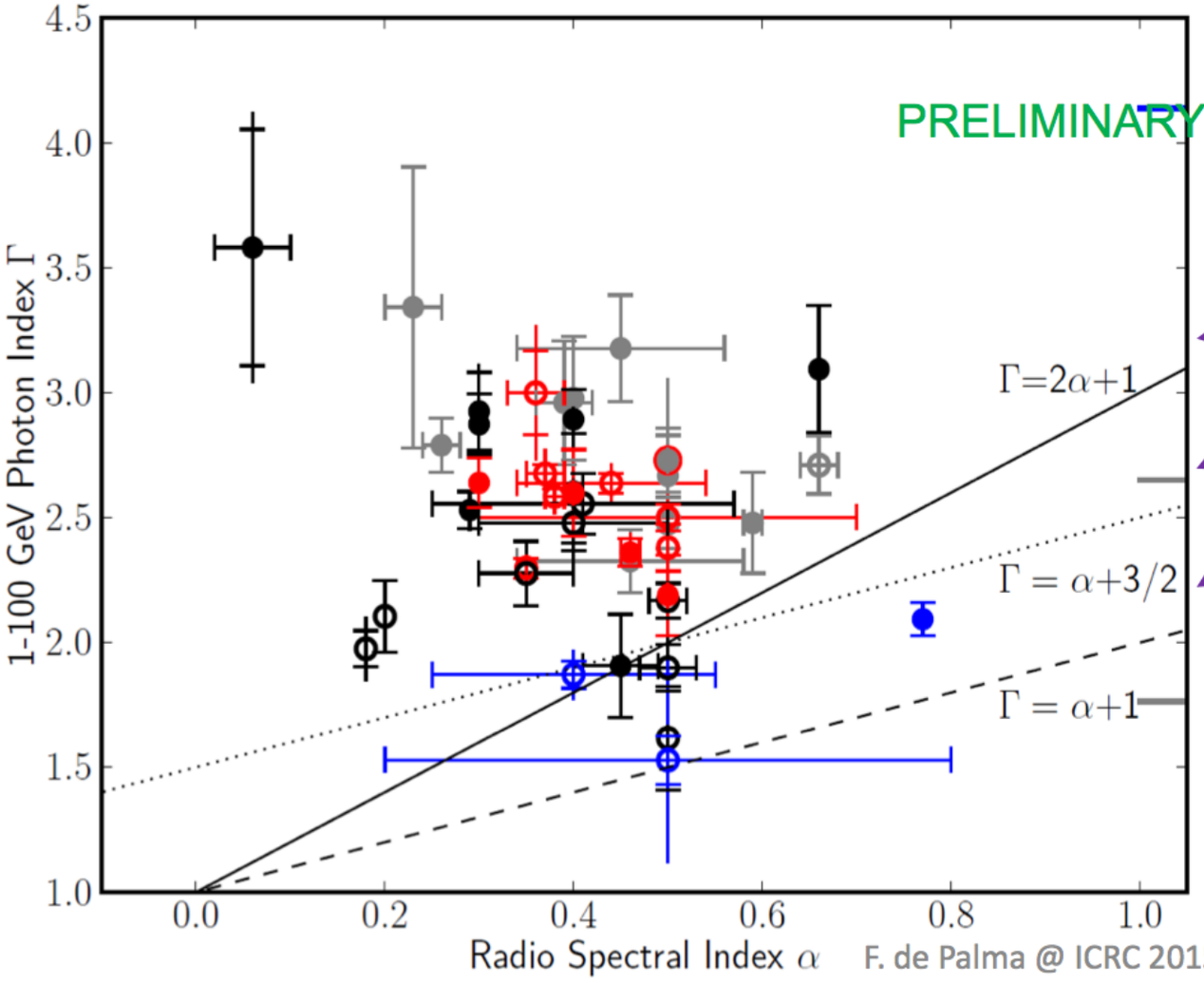
SuperNova Remnants catalog



- 3 years Pass7 data, 279 ROIs studied, 102 detections
- population studies, spectral and morphology studies
- Diffuse emission modeling systematics

Radio-GeV Index

If radio and GeV emission arise from the same particle population(s), under simple assumptions, the GeV and radio indices should be correlated:



- Young SNRs: seem consistent
- Others, including interacting SNRs: softer than expected

- π^0 decay or $e^{+/-}$ bremmstrahlung.
- Inverse Compton w cooling
- inverse Compton w/o cooling

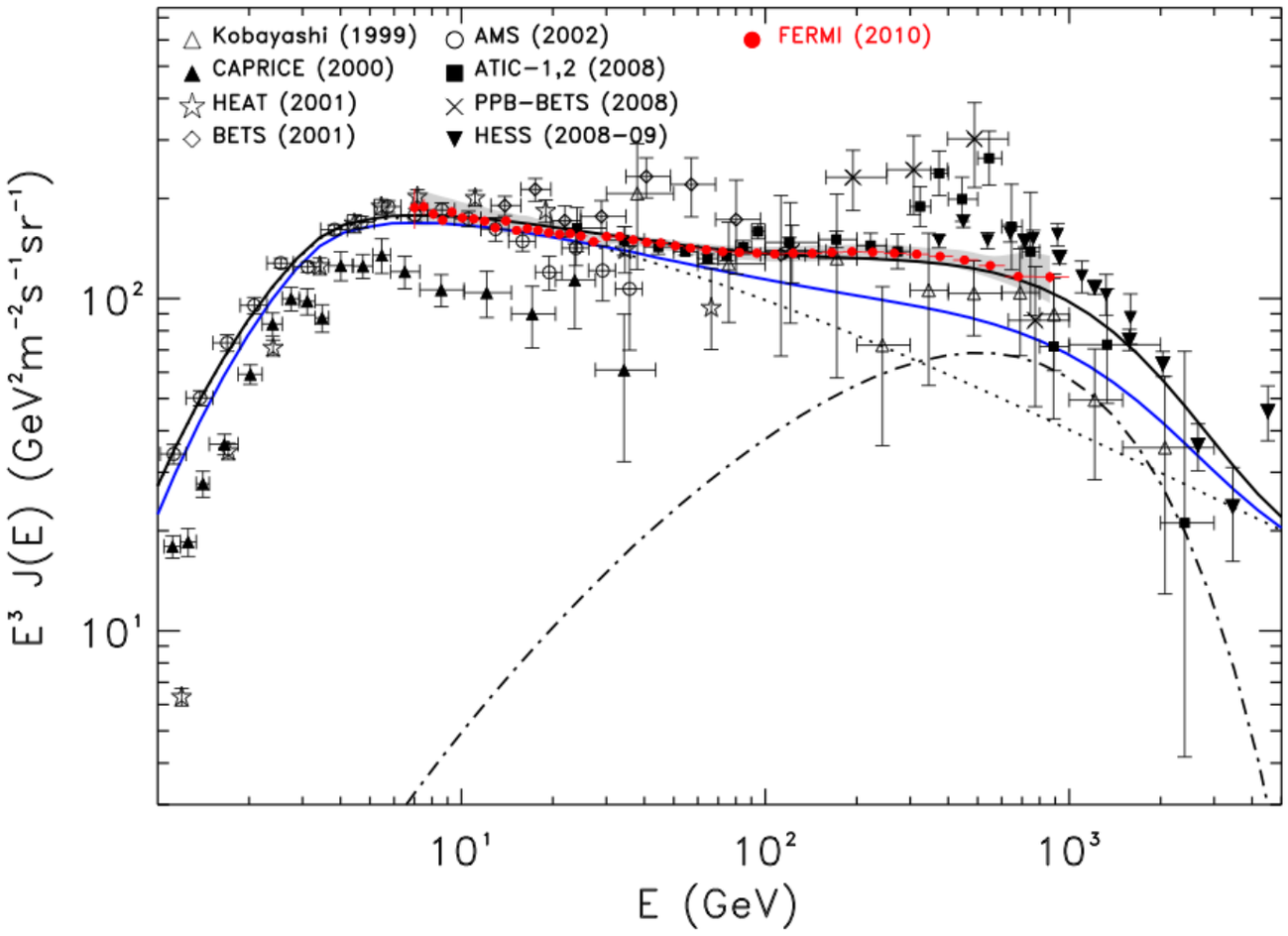
<u>Data now challenge model assumptions!</u>

- Underlying particle populations may have different indices.
- Emitting particle populations may not follow a power law: breaks?
- Multiple emission zones?

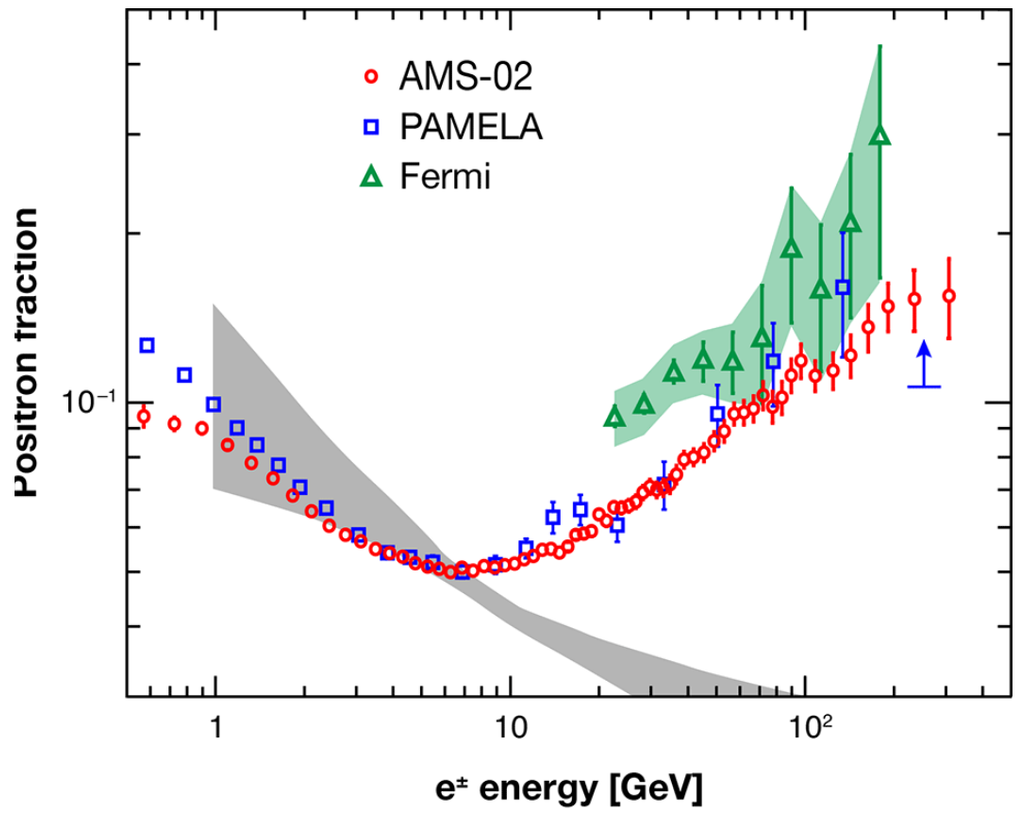
F. de Palma @ ICRC 2015

Cosmic Ray Electrons

Phys.Rev.D82:092004,2010



Phys. Rev. Lett. 110, 141102 (2013)

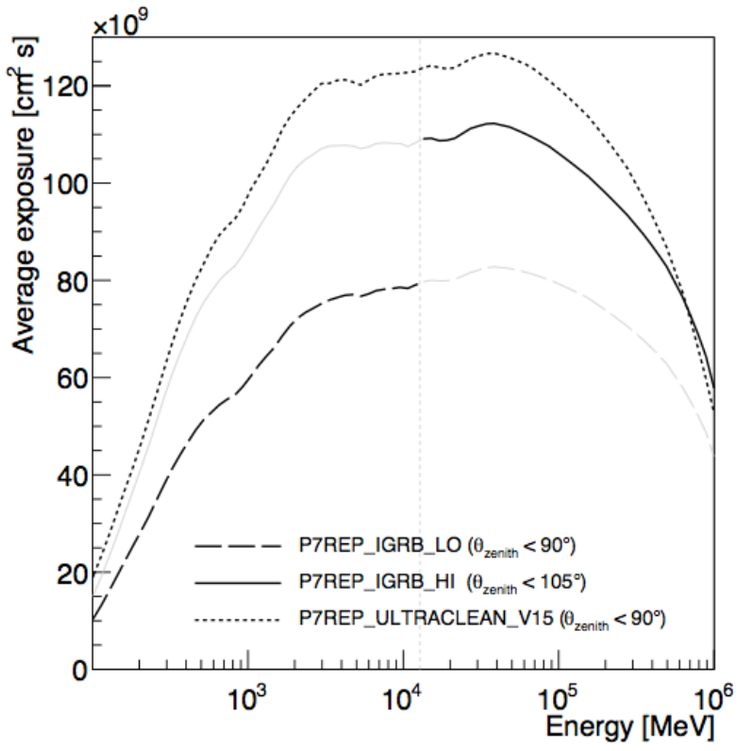


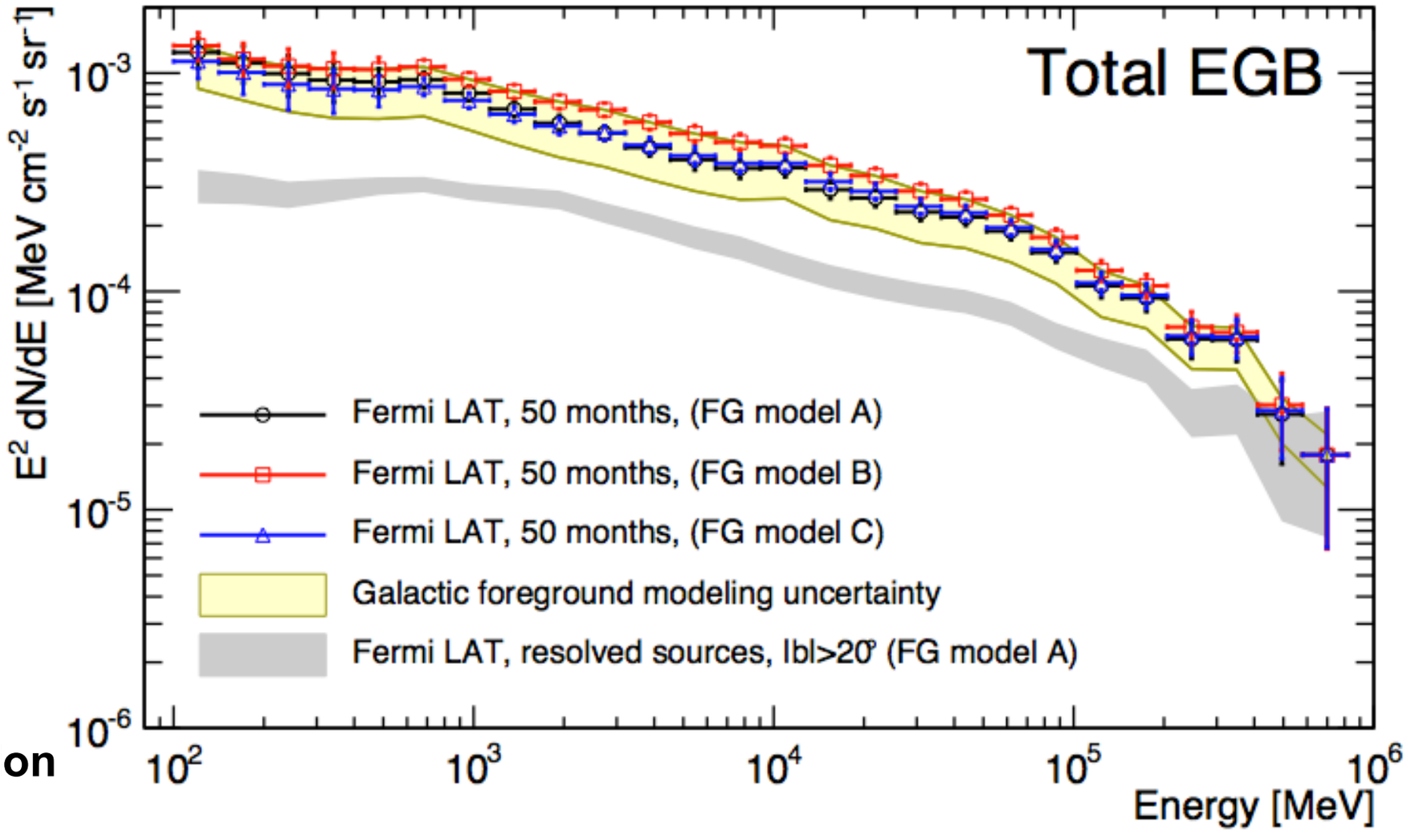
❖ **LAT detects many HE electrons thanks to flexible onboard trigger**

❖ **detailed analysis enabled measurement of CRE inclusive spectrum and positron fraction (with Earth magnetic field)**

The spectrum of isotropic diffuse gamma-ray emission between 100 MeV and 820 GeV

The Fermi LAT collaboration: M. Ackermann, M. Ajello, A. Albert, W. B. Atwood, L. Baldini, J. Ballet, G. Barbiellini, D. Bastieri, K. Bechtol, R.





Specific harsher event selection

Extended to 820 GeV
Includes foreground modeling uncertainties
Evidence for high energy cut-off consistent with EBL attuenation

Dark Matter Search Strategies

Satellites

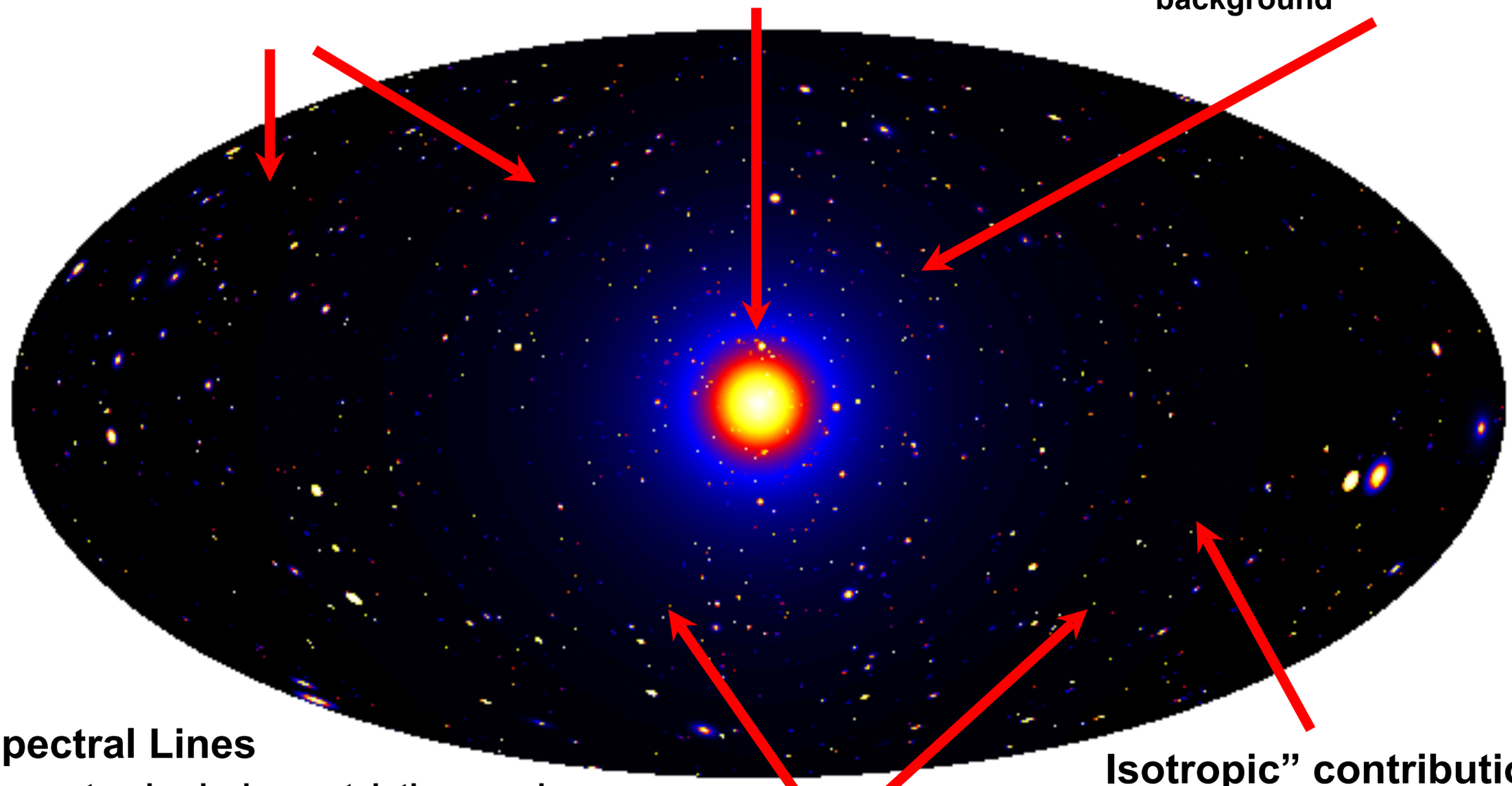
Low background and good source id, but low statistics

Galactic Center

Good Statistics, but source confusion/diffuse background

Milky Way Halo

Large statistics, but diffuse background



Spectral Lines

Little or no astrophysical uncertainties, good source id, but low sensitivity because of expected small branching ratio

Isotropic" contributions

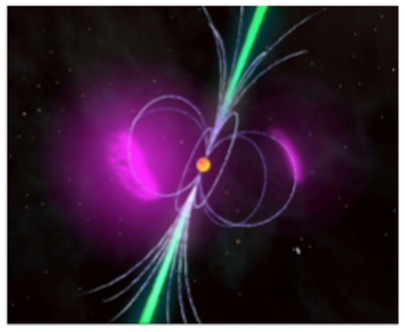
Large statistics, but astrophysics, galactic diffuse background

Galaxy Clusters

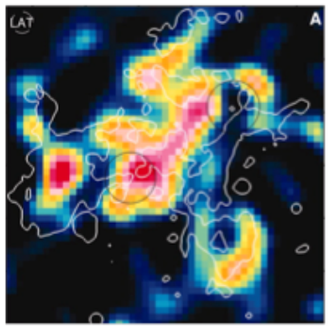
Low background, but low statistics

(some other) Fermi Science Results

- ***Fermi*** **data have forced fundamental changes in our understanding of almost every source of high energy γ rays, and of particle acceleration processes that drive them**

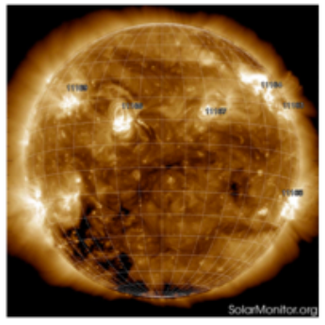


Pulsar γ-ray emission ***does not*** come from polar caps

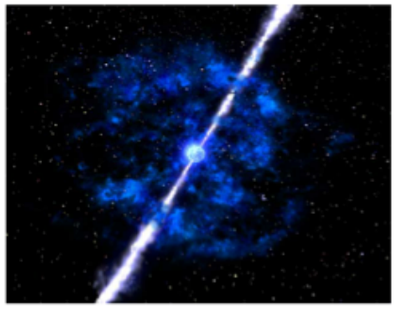


Cosmic rays ***are*** trapped in cocoons and bubbles

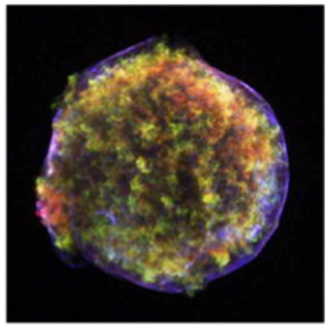
AGN γ-ray emission ***is not*** confined to region near the central black hole



Solar Flares high-energy γ rays **are associated** with mass ejections



GRBs ***are not*** adequately described by "Band" model

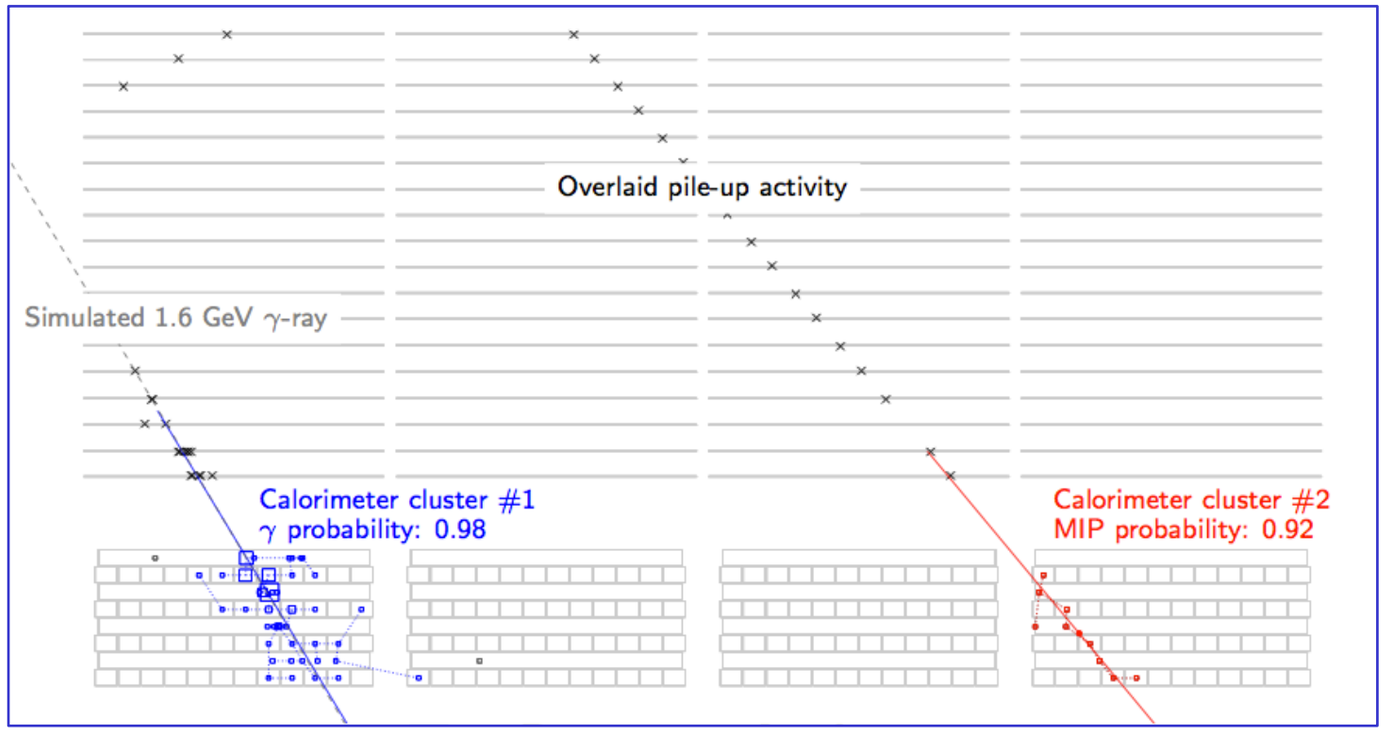


Supernova remnants ***are*** sites of hadronic acceleration

Pass8 New Event Reconstruction

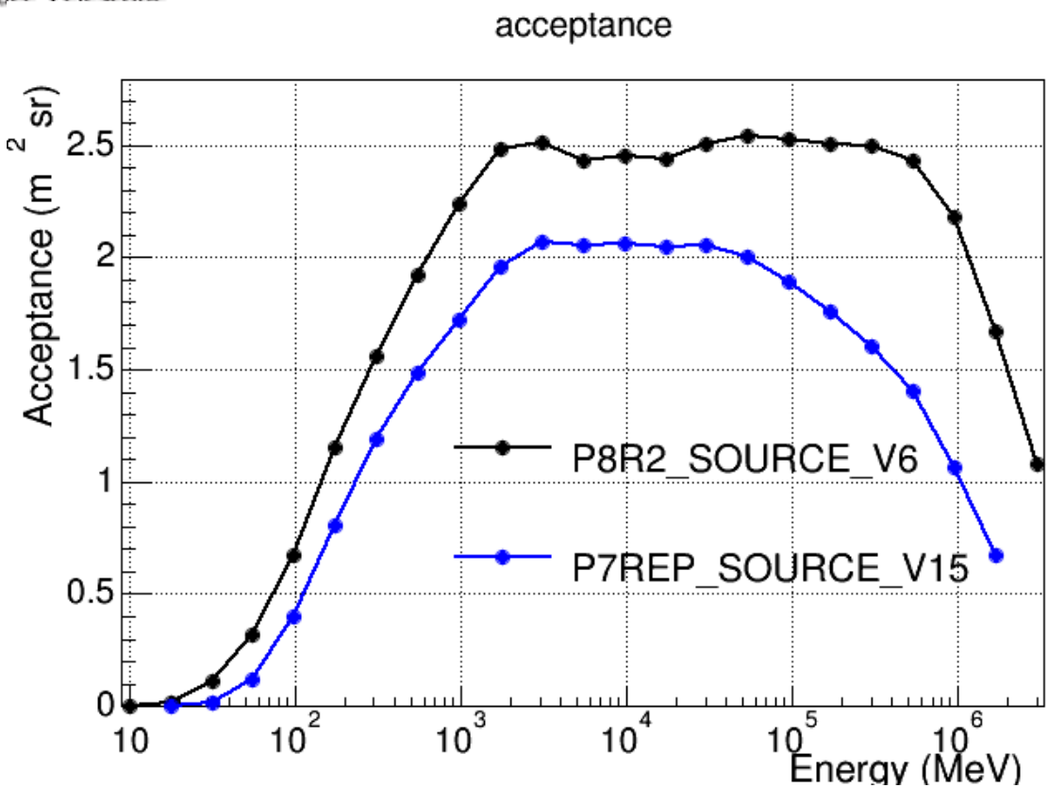
arxiv 1303.3514

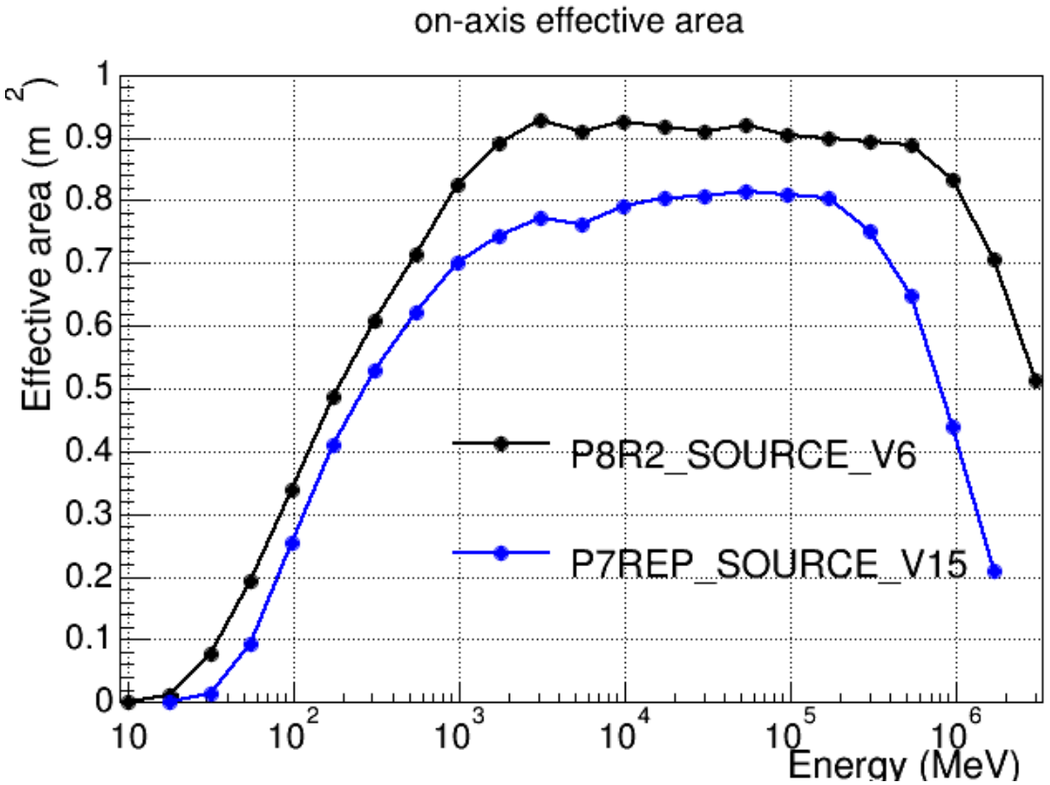
- Complete subsytems recon rewrite (ACD, CAL, TKR)
  - Well beyond original motivation of suppressing cosmic-ray pileup
- TKR: new tree-based pattern recognition
  - Mitigates mistracking at high energy and angle

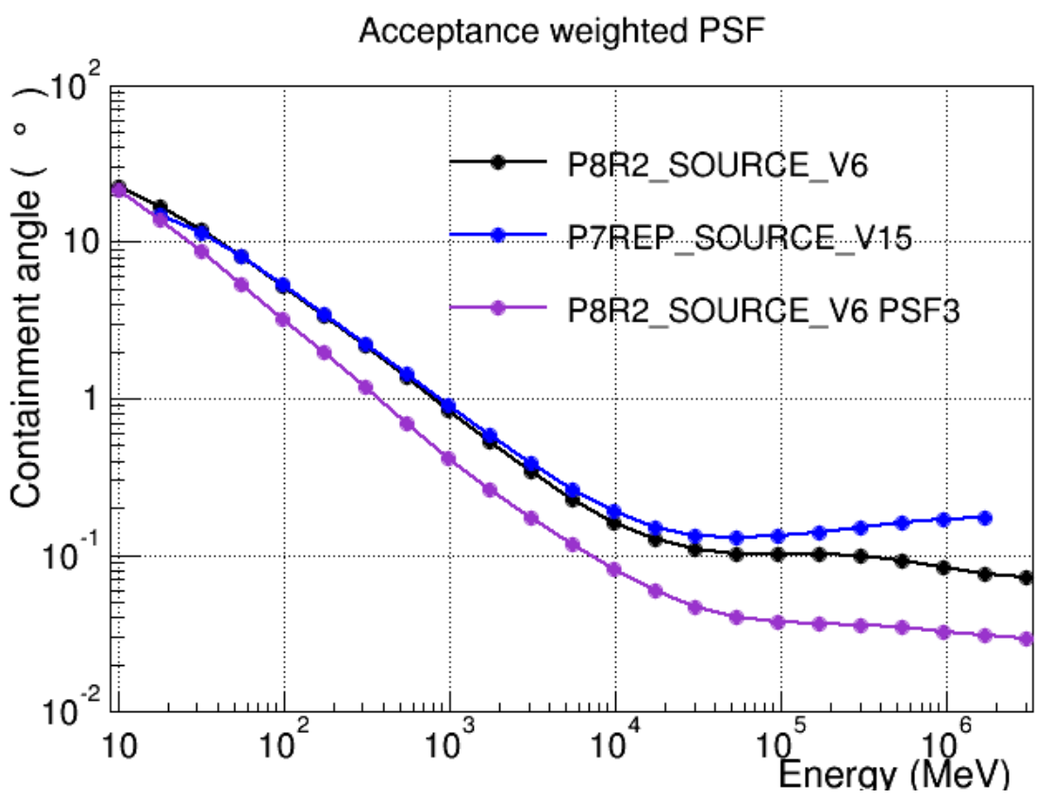


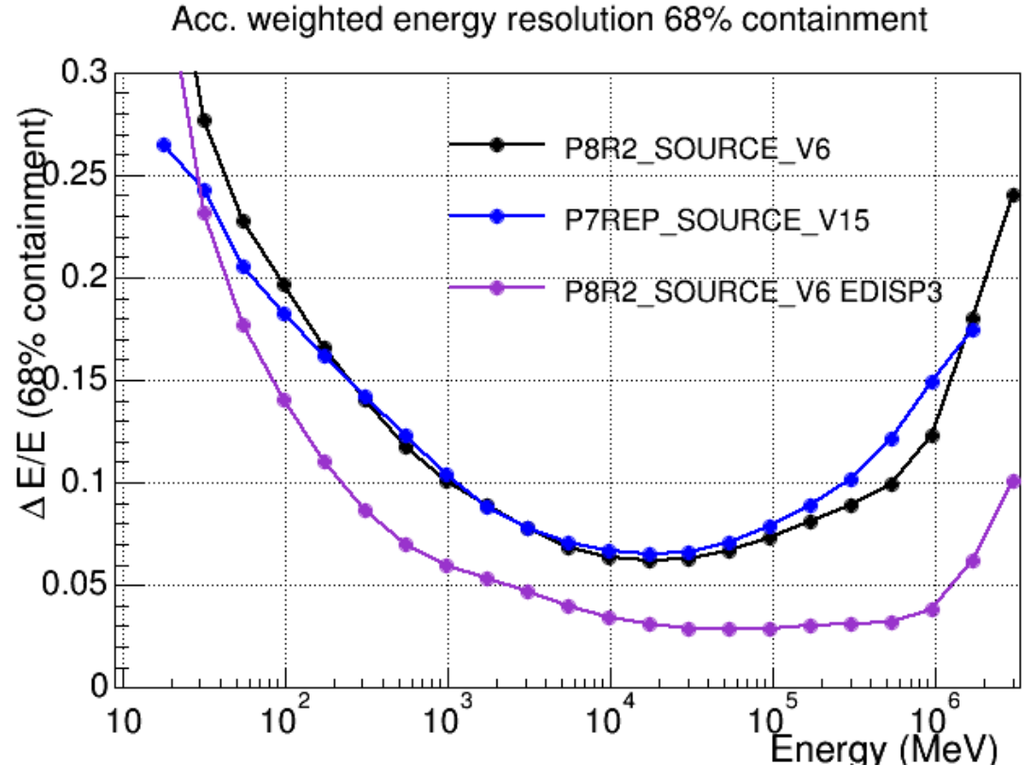
- CAL: new clustering stage
  - Separates ghost from primary photon
- CAL: revamped calorimeter shower profile fitting
  - Mitigates crystal saturation, opens multi-TeV domain
- ACD: improved track/cluster to tile fitting
  - Uses full covariant errors, avoids harsh background rejection cuts

Pass8 performance



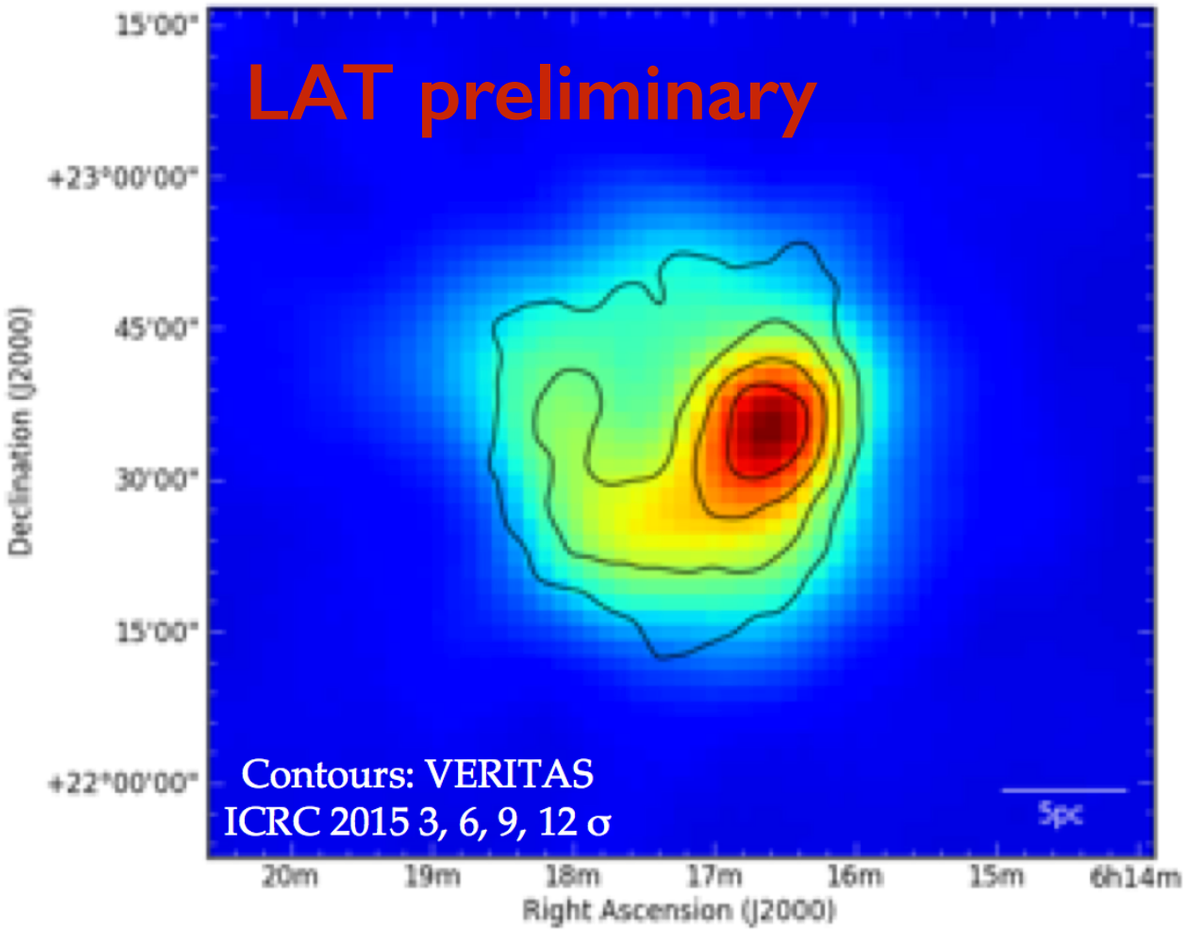






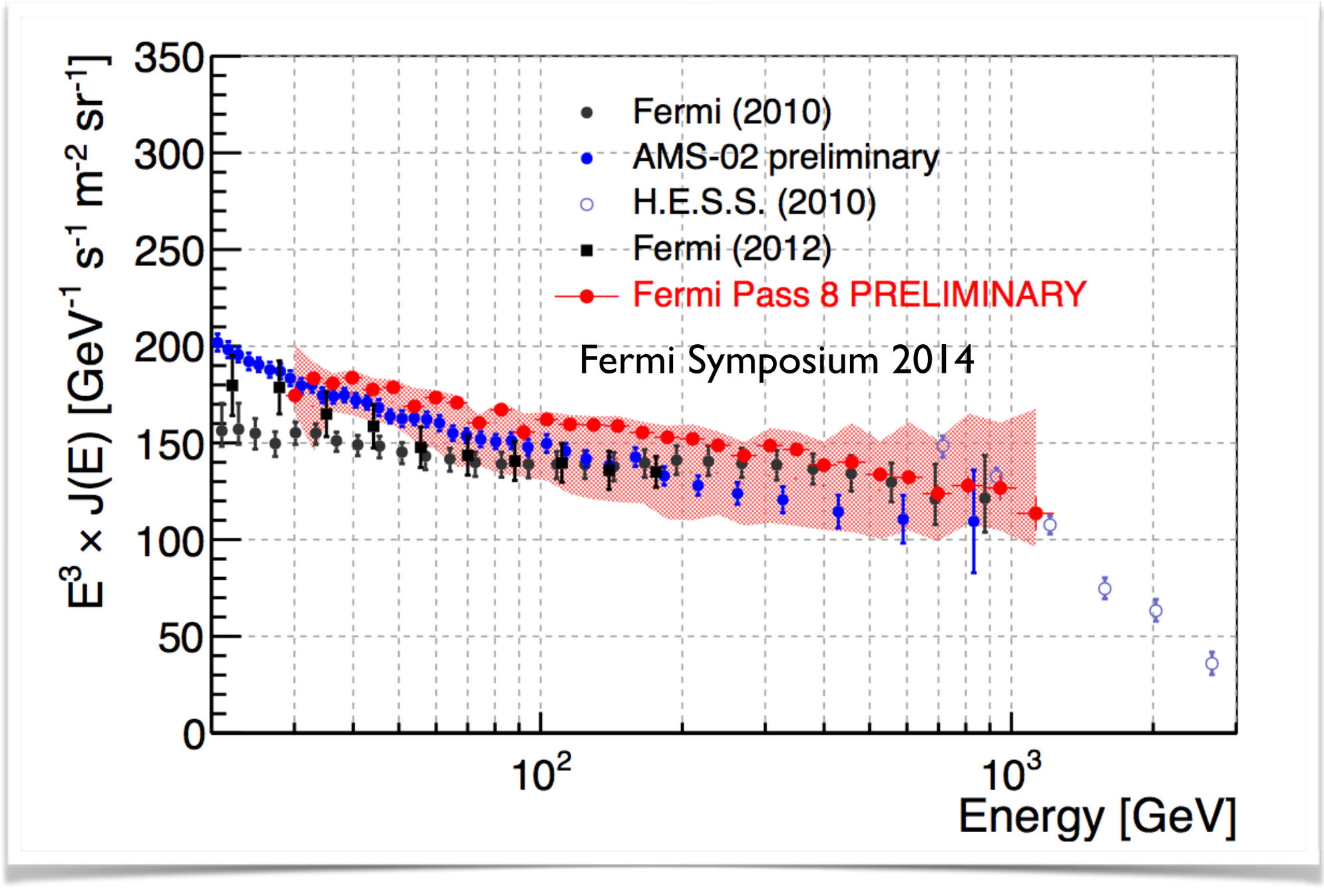
Comparing VERITAS to Fermi-LAT Pass 8

- Counts map: Fermi-LAT photons selected above 5 GeV.
  - 83 months of data; P8R2_SOURCE_V6; Fermi Science Tools v10r0p5
  - Event classes PSF2 and PSF3 (50% events with best PSF).
- GeV, TeV emission show remarkable spatial correlation.
  - Single population of CRs interacting with shocked gas?



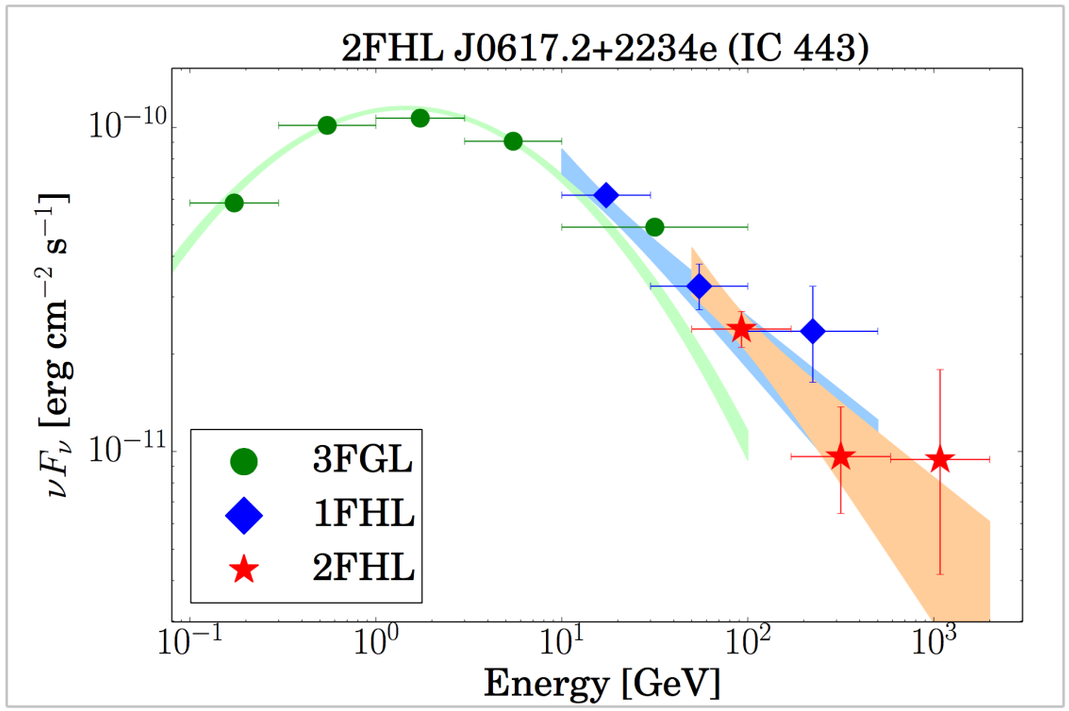
courtesy: J. Hewitt for Fermi-LAT Collaboration

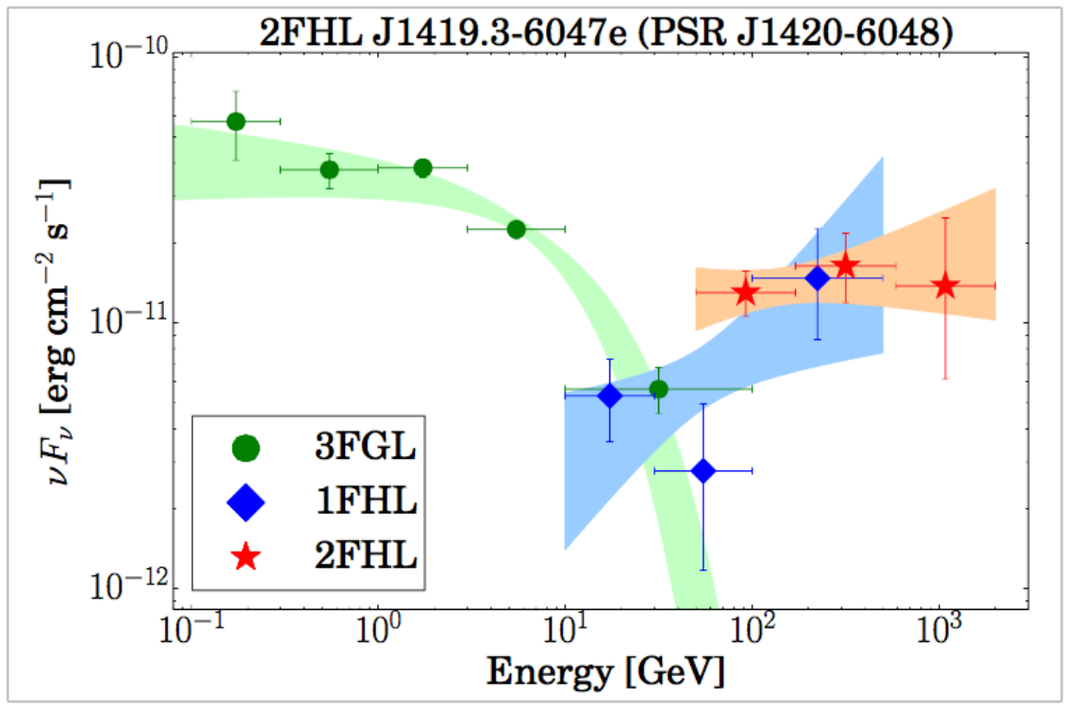
CRE spectrum



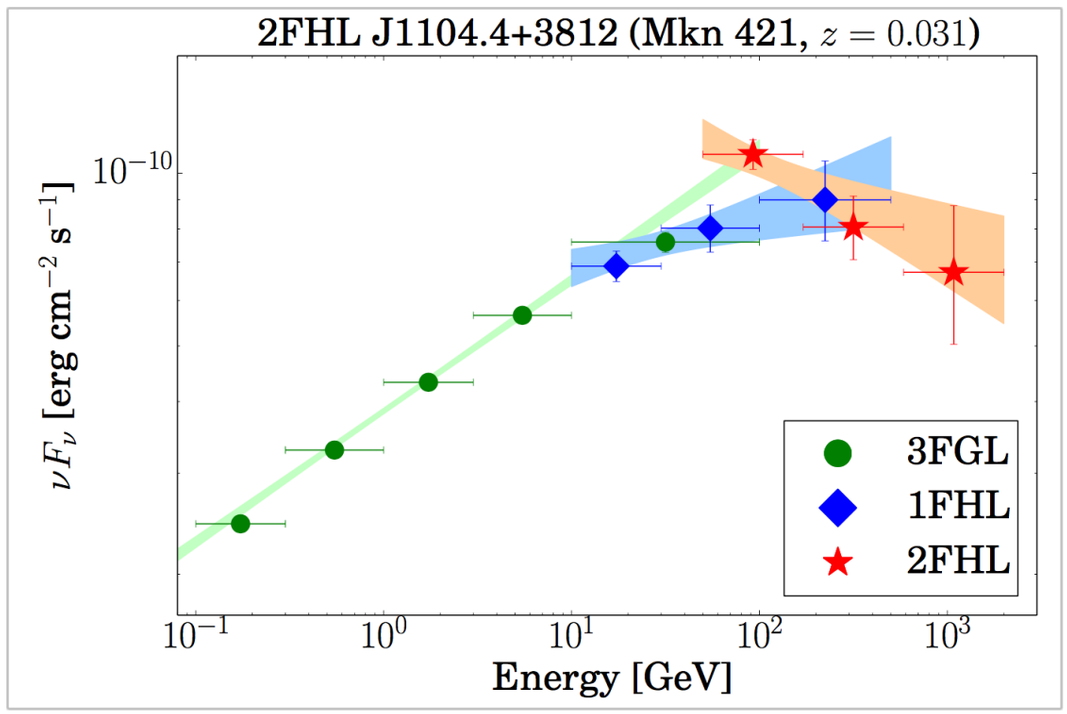
❖ **working on E>1TeV, systematics, anisotropies**

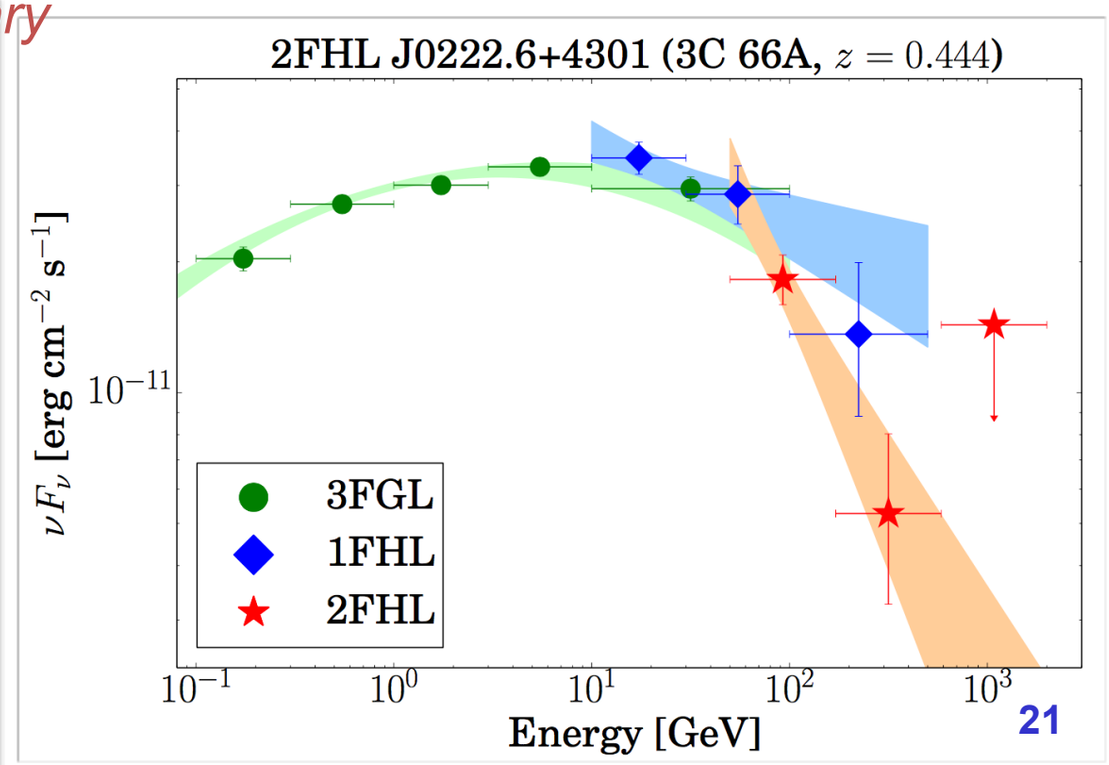
2FHL Spectral Energy Distributions





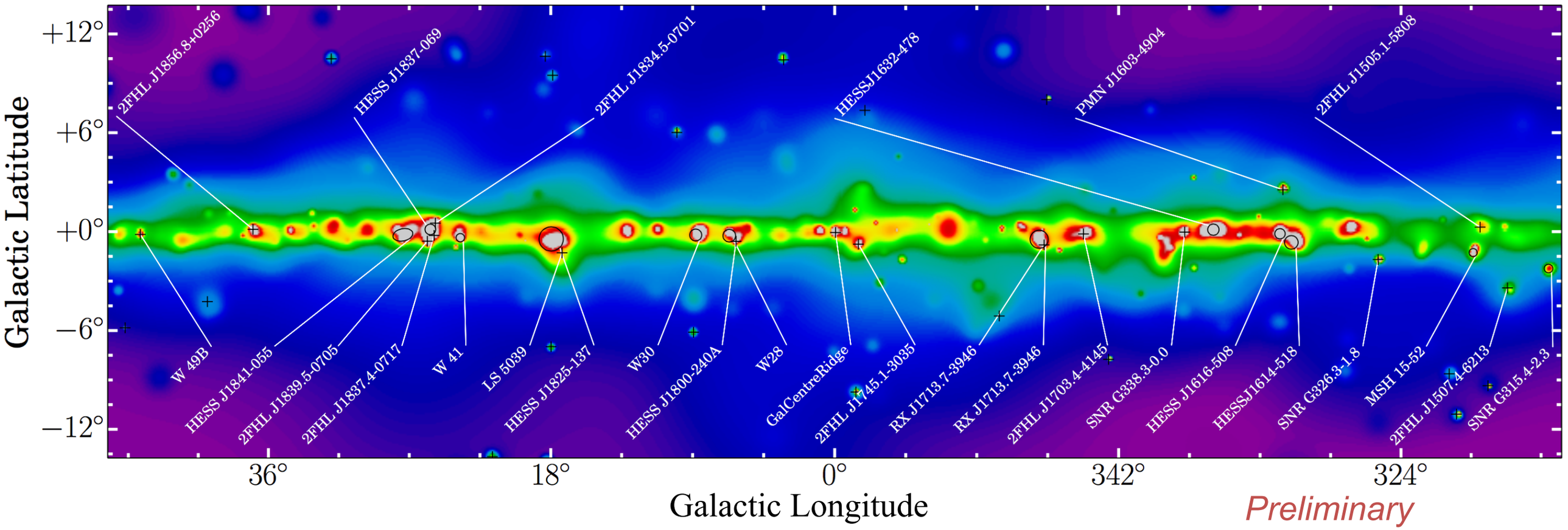
Preliminary





M. Ajello ICRC 2015 - arxiv 1508.04449

2FHL Galactic Sources



- **103 sources at |b|<10°**
  - 42 blazars, 39 Galactic objects, 13 unassociated and 9 Dark Acc.
  - PWNe/SNRs represent 87% of the Galactic population
  - Half of the unassociated sources are hard and thus (likely) Galactic

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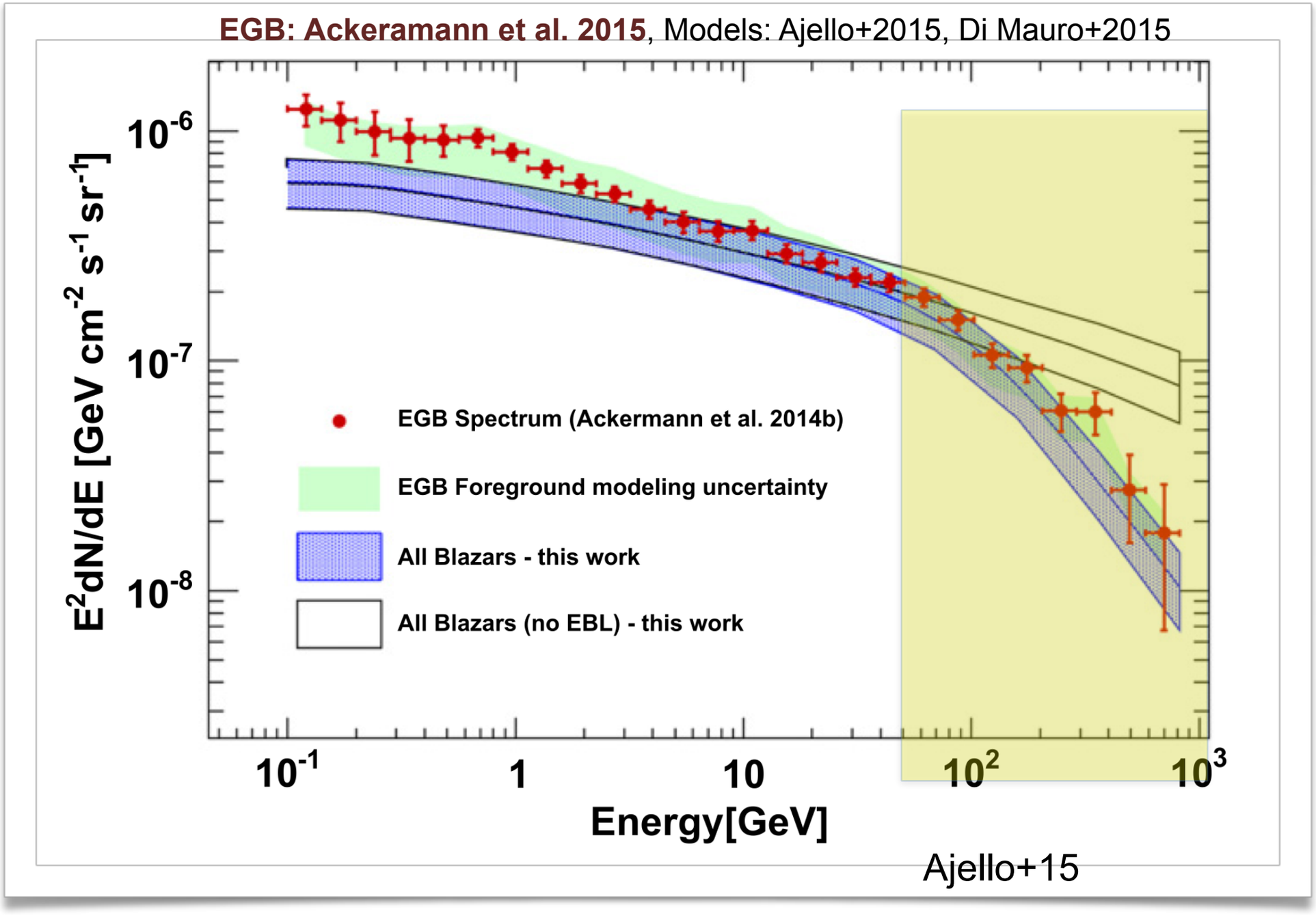
Extragalactic Gamma-ray Background

- **Models predict that the >50 GeV EGB is produced by blazars**



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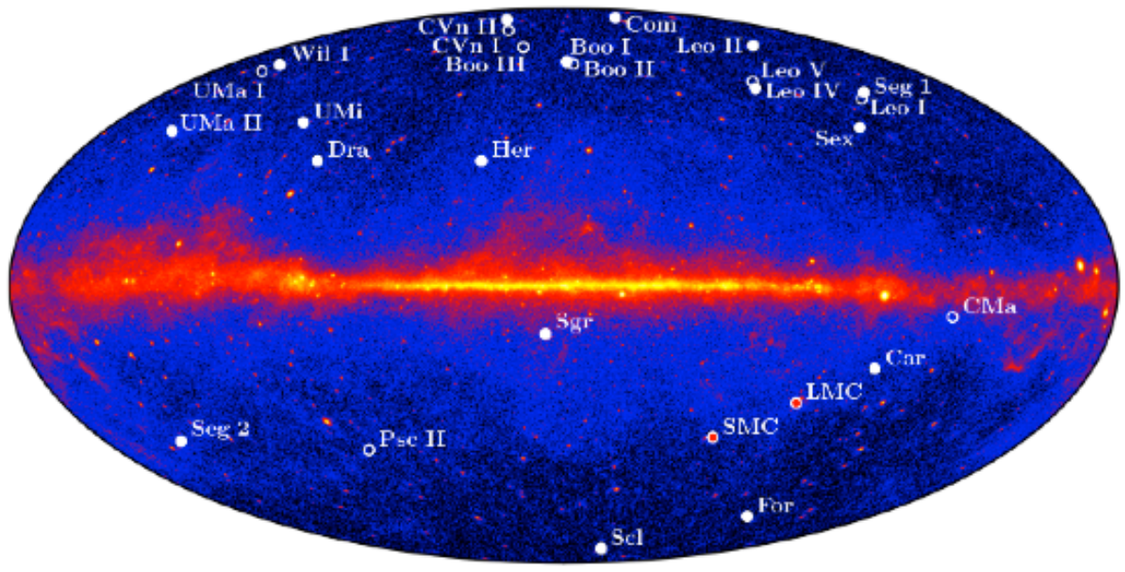
Dark Matter constraints with dwarf spheroidals

2011, PRL 107, 241302 - 2012, AstroPart. Phys., 37, 2014 2014, PRD, 89

- **Dwarfs are DM dominated**
  - **up to ~1000x visible matter**
  - **No star-formation, no gas, no magnetic field**
- **Clean Upper Limit analysis of high latitude point sources**

FOURTH GENERATION				
tag	**irf**	**time**	**targets**	**joint?**
1001.4531	P6	11 mo.	10	no
1108.3546	P6	24 mo.	10	yes
1310.0828	P7	48 mo.	15	yes
Current	P8	60 mo.	15	yes x2!



EFFECTIVE LIKELIHOOD

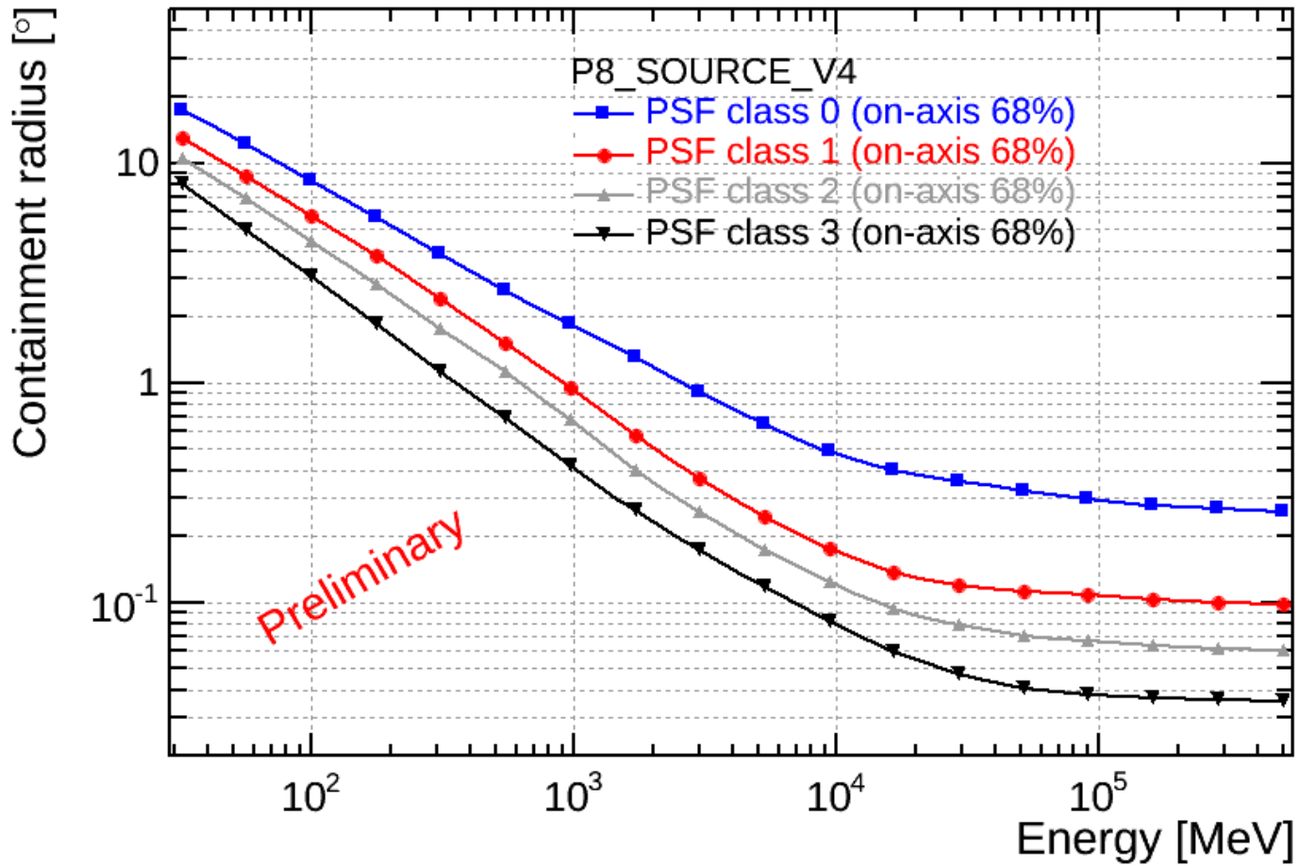
(term accounts for uncertainty in J-factor)

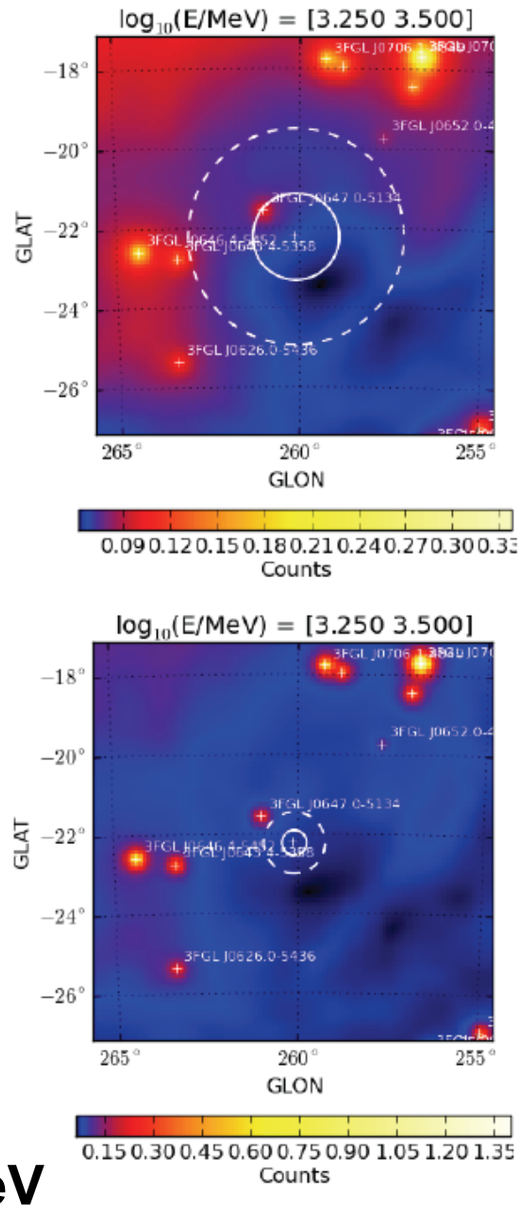
$$L_2(\mathcal{D}|\boldsymbol{\mu},\boldsymbol{\theta_t}) = L_t^{\mathrm{LAT}}(\mathcal{D}_t|\boldsymbol{\mu},\boldsymbol{\theta_t}) \times \frac{1}{\ln(10)\mathrm{J_t}\sqrt{2\pi}\sigma_\mathrm{t}} e^{-(\log_{10}(\mathrm{J_t})-\overline{\log_{10}(\mathrm{J_t})})^2/2\sigma_\mathrm{t}^2}$$

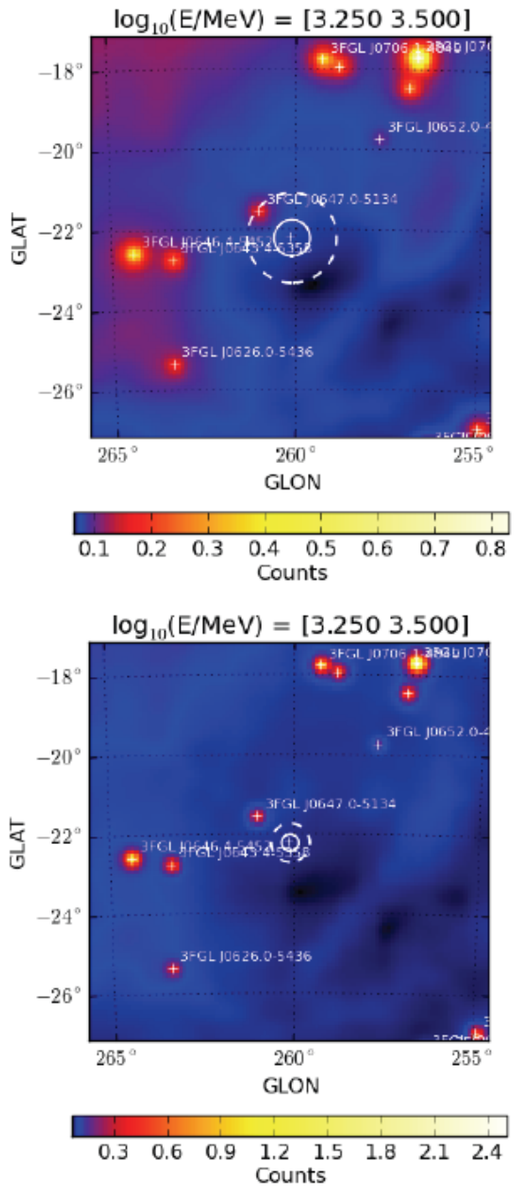
$$L_3(\mathcal{D}|\boldsymbol{\mu},\{\boldsymbol{\theta_t}\}) = \prod_{targets} L_2(\mathcal{D}|\boldsymbol{\mu},\boldsymbol{\theta_t})$$ ← (combine information from all targets)

$$L_4(\mathcal{D}|\boldsymbol{\mu},\{\boldsymbol{\theta_t}\}) = \prod_{classes} L_3(\mathcal{D}_c|\boldsymbol{\mu},\{\boldsymbol{\theta_t}\})$$ ← (combine information from all psf classes)

Pass 8 Improvements Relevant for Dwarfs





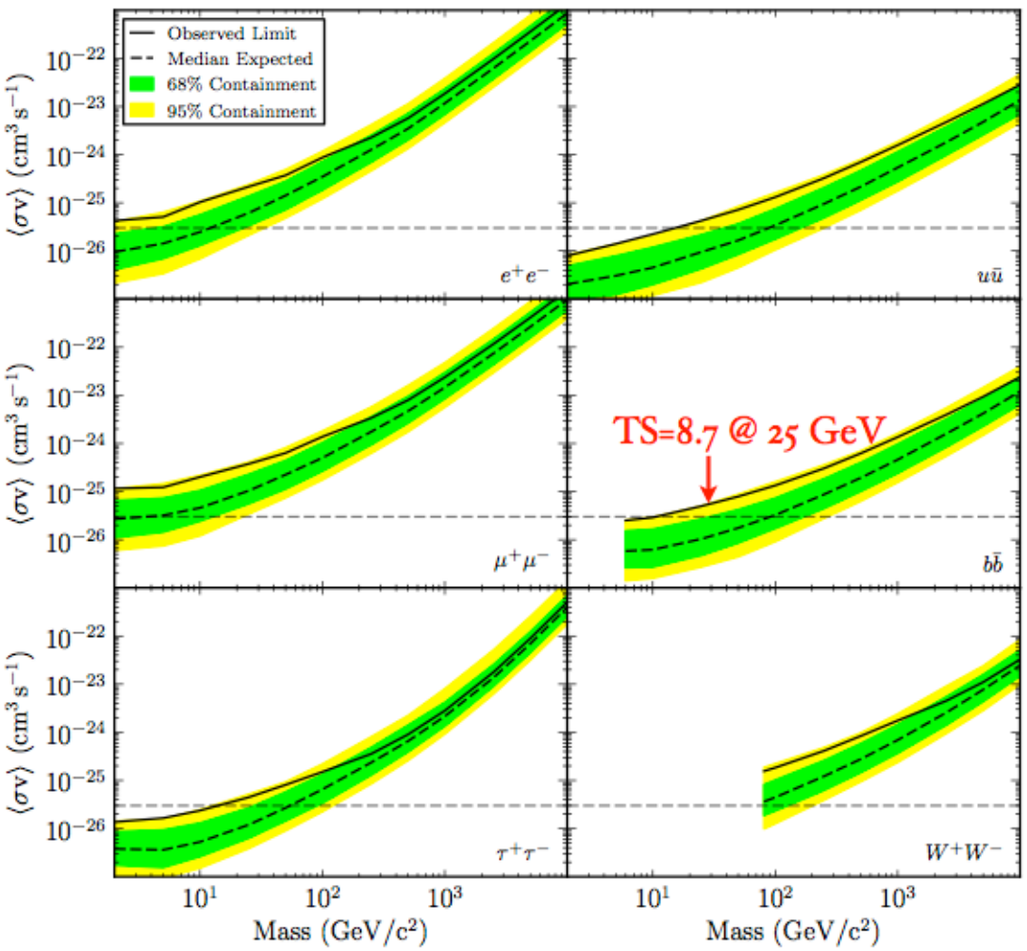


- **Effective area increase by ~25% above 1GeV**
- **Angular resolution improved by ~10-15% above 1 GeV**
- **Point-source sensitivity improved by ~40% for 1-10 GeV**
- **Joint likelihood with all PSFs types improves sensitivity by ~15%**
  - **Similar to using energy reconstruction quality in line analysis**

Simulation of region around dwarf

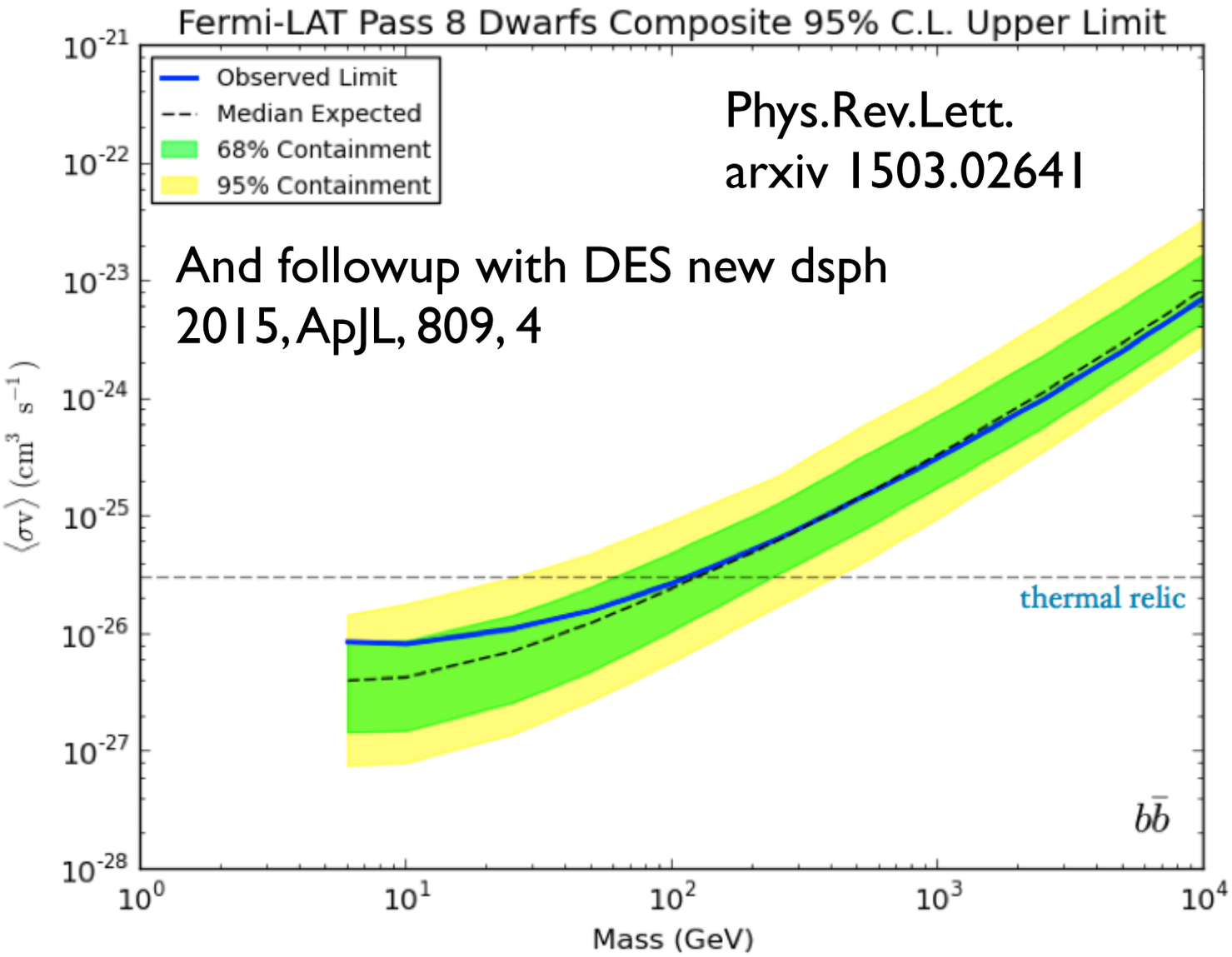
Dwarf spheroidals with Pass8

P7REP_CLEAN



2014, Phys. Rev. D, 89,

Pass8



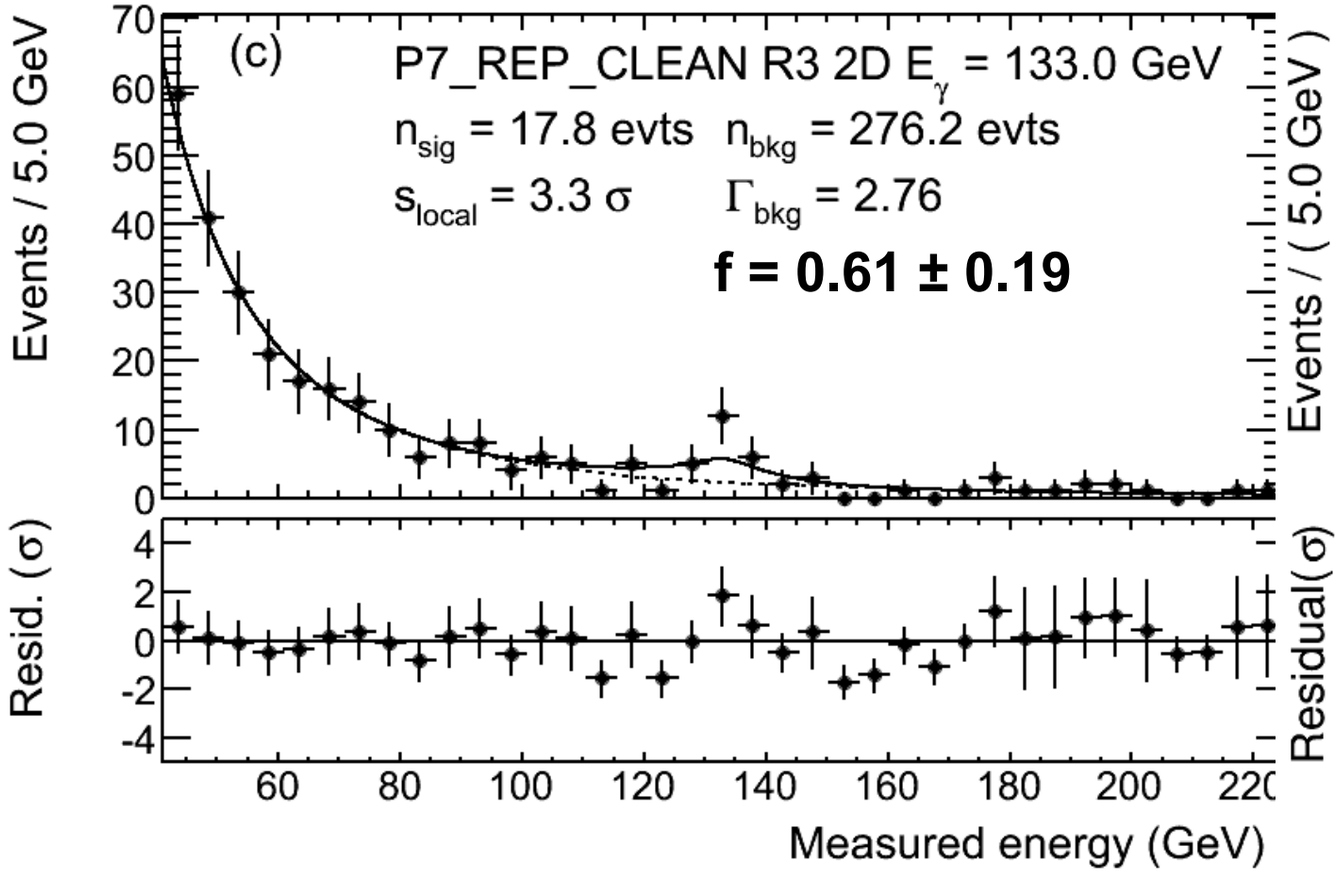
Phys.Rev.Lett.
arxiv 1503.02641

And followup with DES new dsph
2015, ApJL, 809, 4

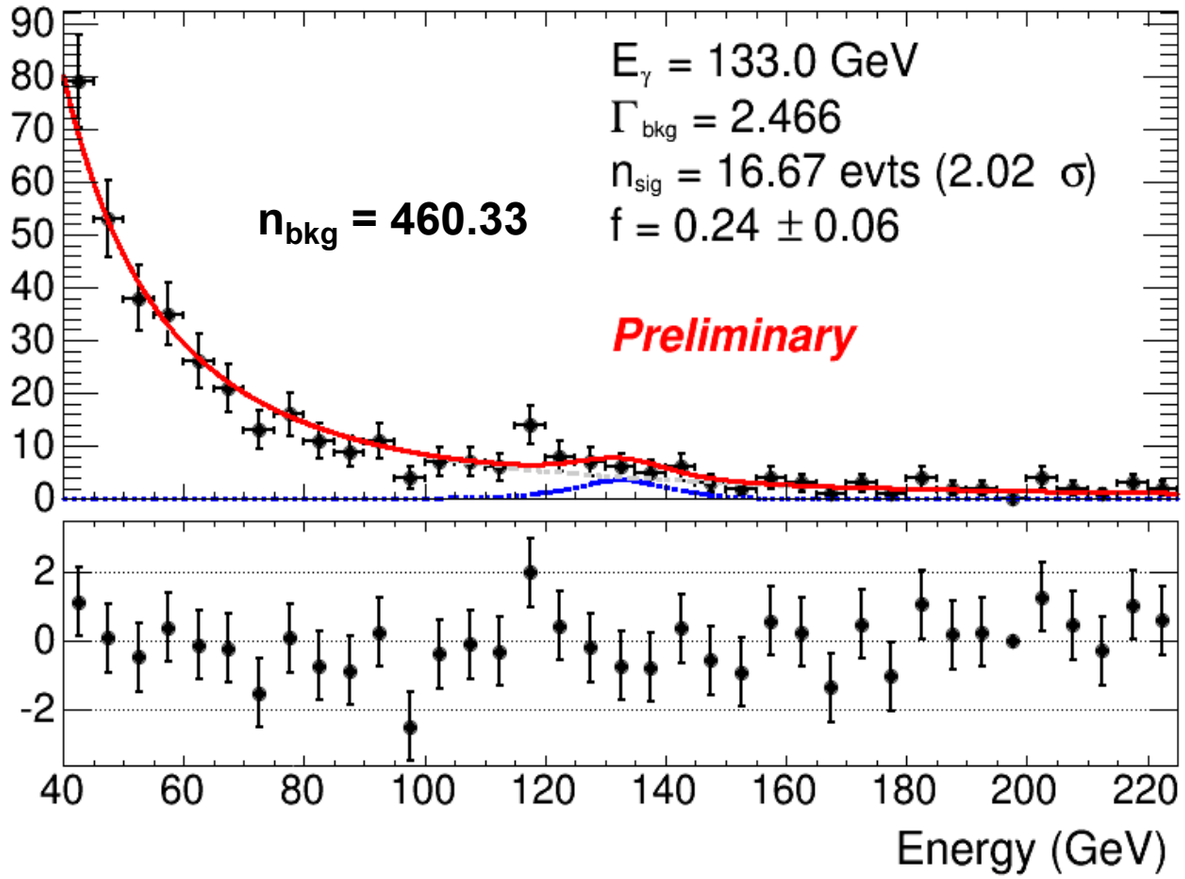
Minor deviation from expectations likely due to combination of better catalog and diffuse model - all possible with improved performances and strong multi-wavelength synergies (room for further improvements by minimizing LAT UNIDs, see eg arxiv 1409.1572)

Line-like Feature Near 133 GeV – 3.7 year

P7REP_Clean

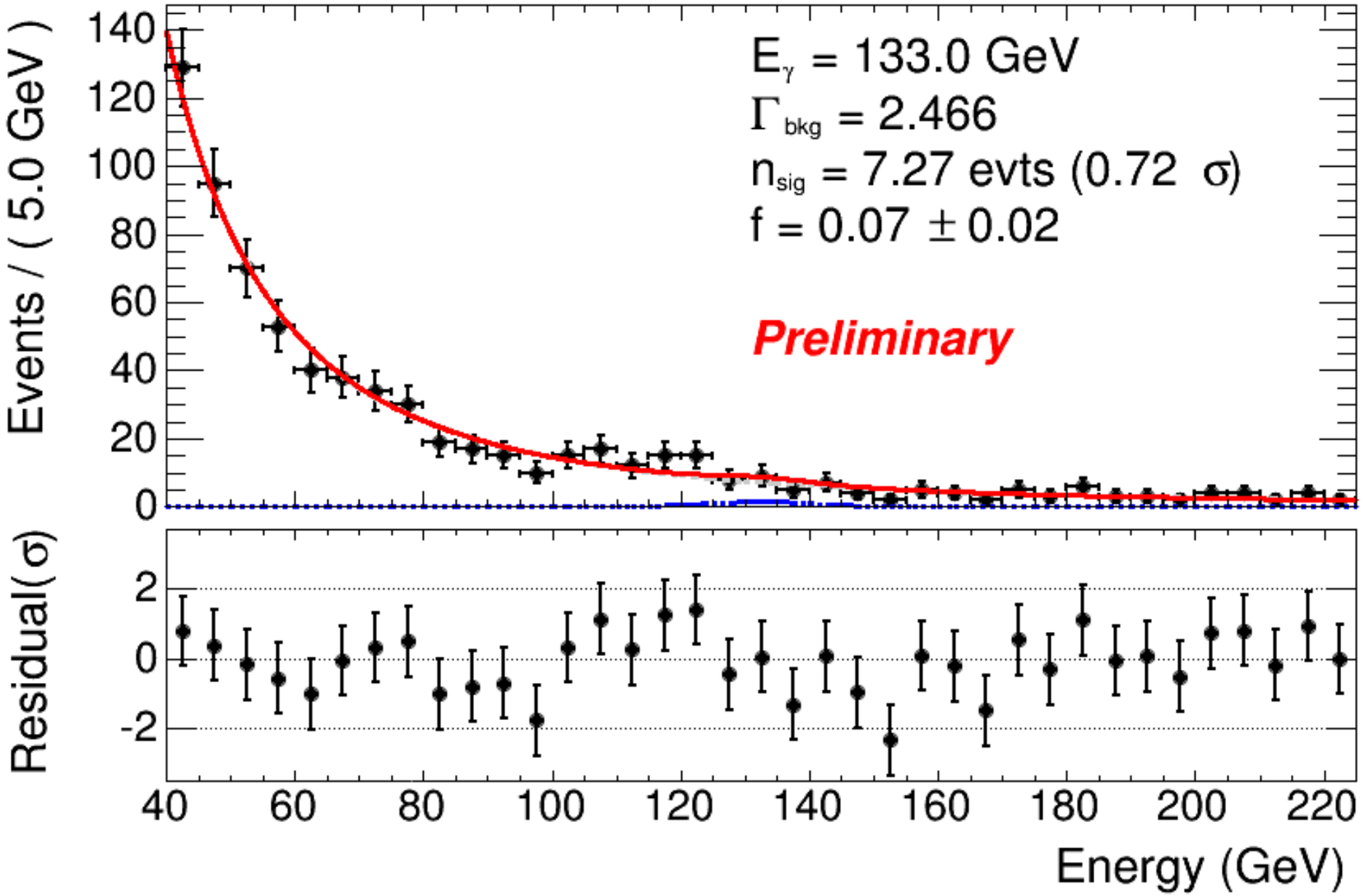


P8_Clean



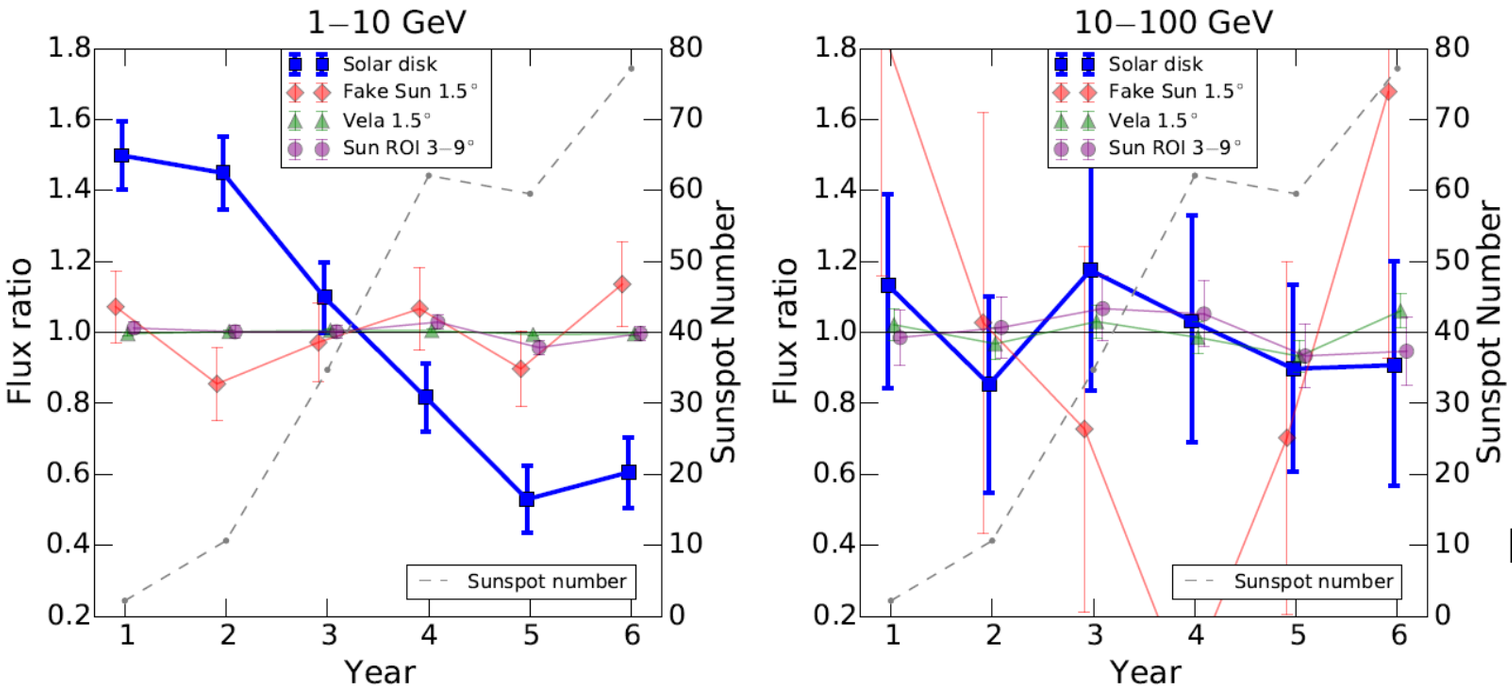
- **Same fit parameters as 3.7 year line search (Ackerman et al. PRD 88, 082002 (2013))**
  - **Fits in R3, 3.7 year, $\pm 6\sigma_E$ fit window**
- **No strong evidence of 133 GeV Feature in Pass 8**
  - **Lower fractional size and significance**
  - **Energy recon. in P7 vs. P8 changes within expected energy resolution**

Line-like Feature Near 133 GeV – 5.8 yr



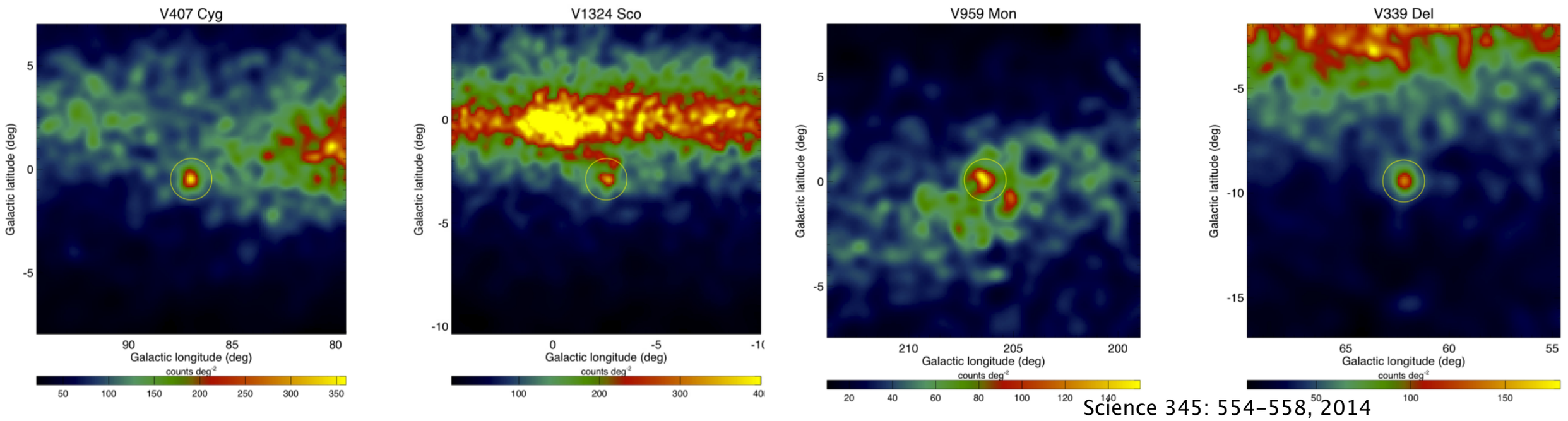
- **Feature is even smaller in 5.8 year P8 Clean dataset**
  - **Consistent with statistical fluctuation in P7 REP 3.7 year dataset**

Long-term observations opportunities



Ng et al, arxiv 1508.06276

- Gamma-rays from the Sun and variations with solar cycle
- Recurrent Novae
- PSR state change (eg J2021+4026), years-long orbital periods



Science 345: 554-558, 2014

Conclusions

❖ LAT design provides all-sky, high sensitivity monitor of gamma-ray sky enabling new science

❖ Pass8 radical performance improvement started opening new window

❖ extended long term operations unique opportunity for time domain astrophysics and multi wavelength observations