



Fermi highlights & perspectives

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NASA-GSFC/CRESST/UMBC

On behalf of the *Fermi* LAT
collaboration

The Future of Research on Cosmic Gamma Rays

26 - 29 August 2015

La Palma - Canary Islands



- Large Area Telescope (LAT)
 - 20 MeV – > 300 GeV
- Gamma Burst Monitor (GBM)
 - 8 KeV – 40 MeV

- Launched 11 June 2008, Delta II Rocket
 - Circular orbit, 565km altitude, 25.6 deg inclination
- Operations
 - Primary mode: sky survey
 - scan entire sky every 3 hours
 - Autonomous Repoint Request
 - Target of Opportunity



Public Data Release:

All γ -ray data made public within 24 hours (usually less)

Si-Strip Tracker:

convert $\gamma \rightarrow e^+e^-$
reconstruct γ direction
EM v. hadron separation

Hodoscopic CsI Calorimeter:

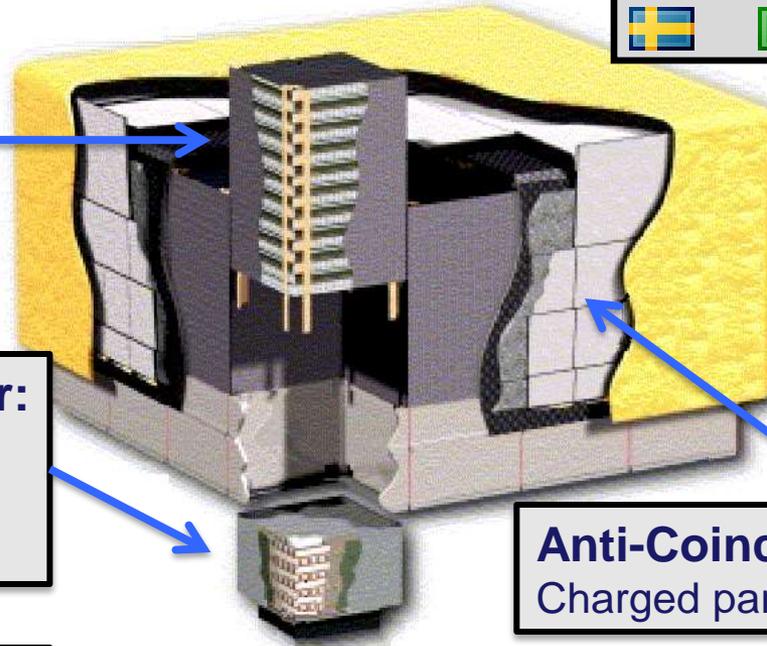
measure γ energy
image EM shower
EM v. hadron separation

Sky Survey:

With 2.5 sr Field-of-view LAT sees whole sky every 3 hours

Fermi LAT Collaboration:

~400 Scientific Members,
NASA / DOE & International Contributions



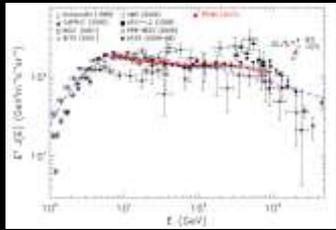
Anti-Coincidence Detector:

Charged particle separation

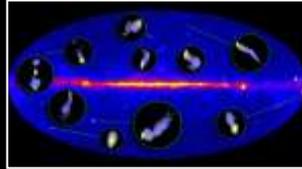
Trigger and Filter:

Reduce data rate from ~10kHz to 300-500 HZ

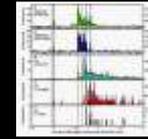
Fermi Highlights and Discoveries



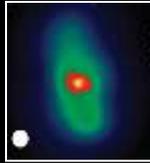
e^+e^- spectrum



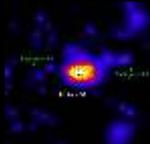
Blazars



GRBs

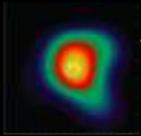
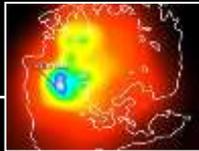


Radio Galaxies



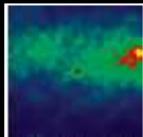
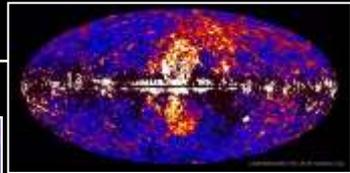
Starburst Galaxies

LMC & SMC



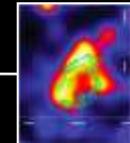
Globular Clusters

Fermi Bubbles

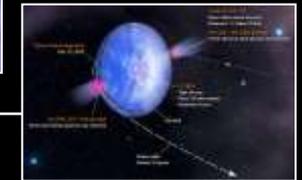


Novae

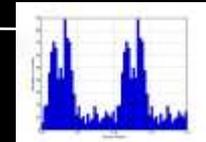
SNR & PWN



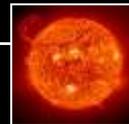
γ -ray binaries



Pulsars: young & millisecond (MSP)



Sun: flares & CR interactions



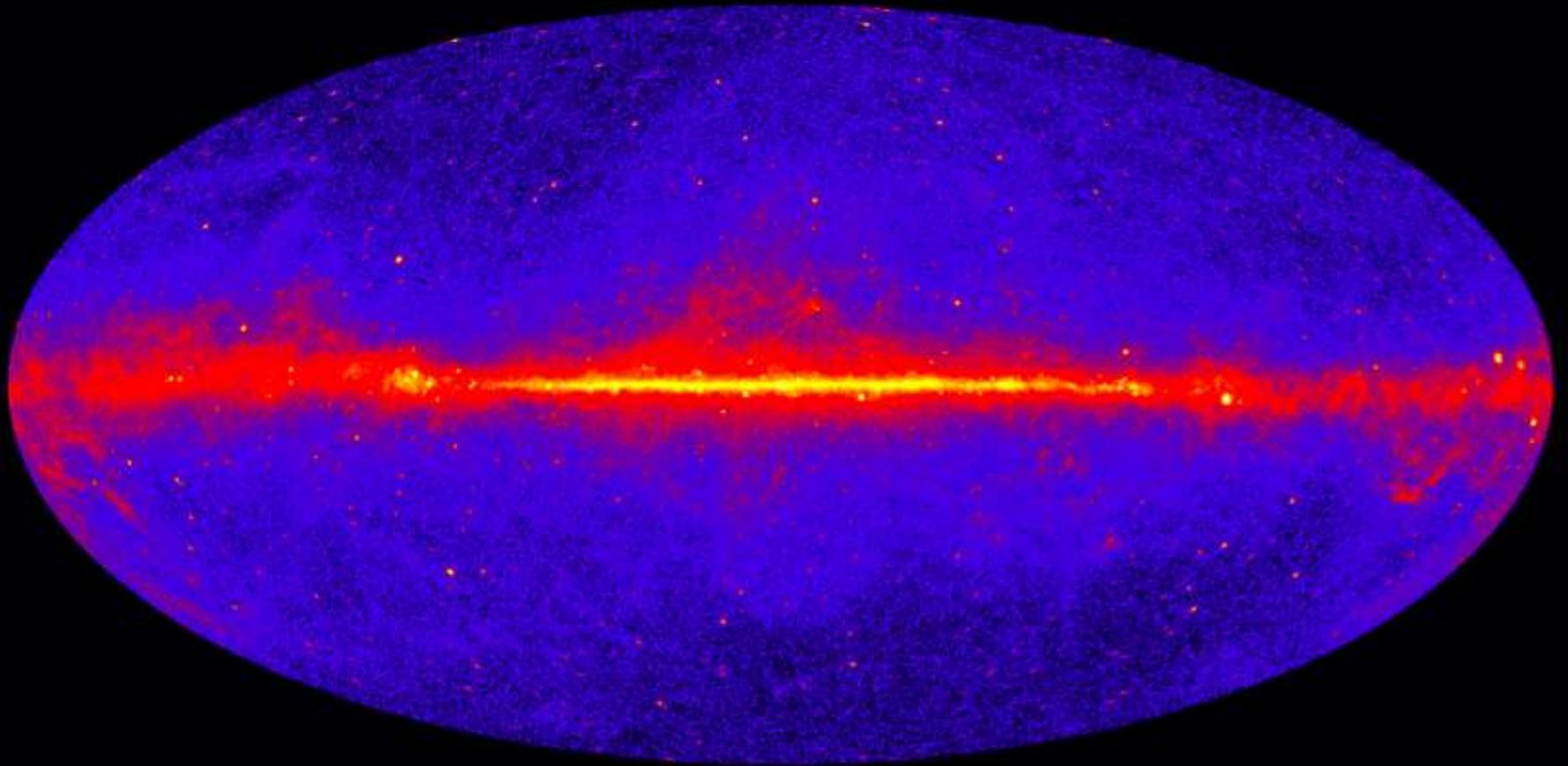
Local

Terrestrial Gamma-ray Flashes



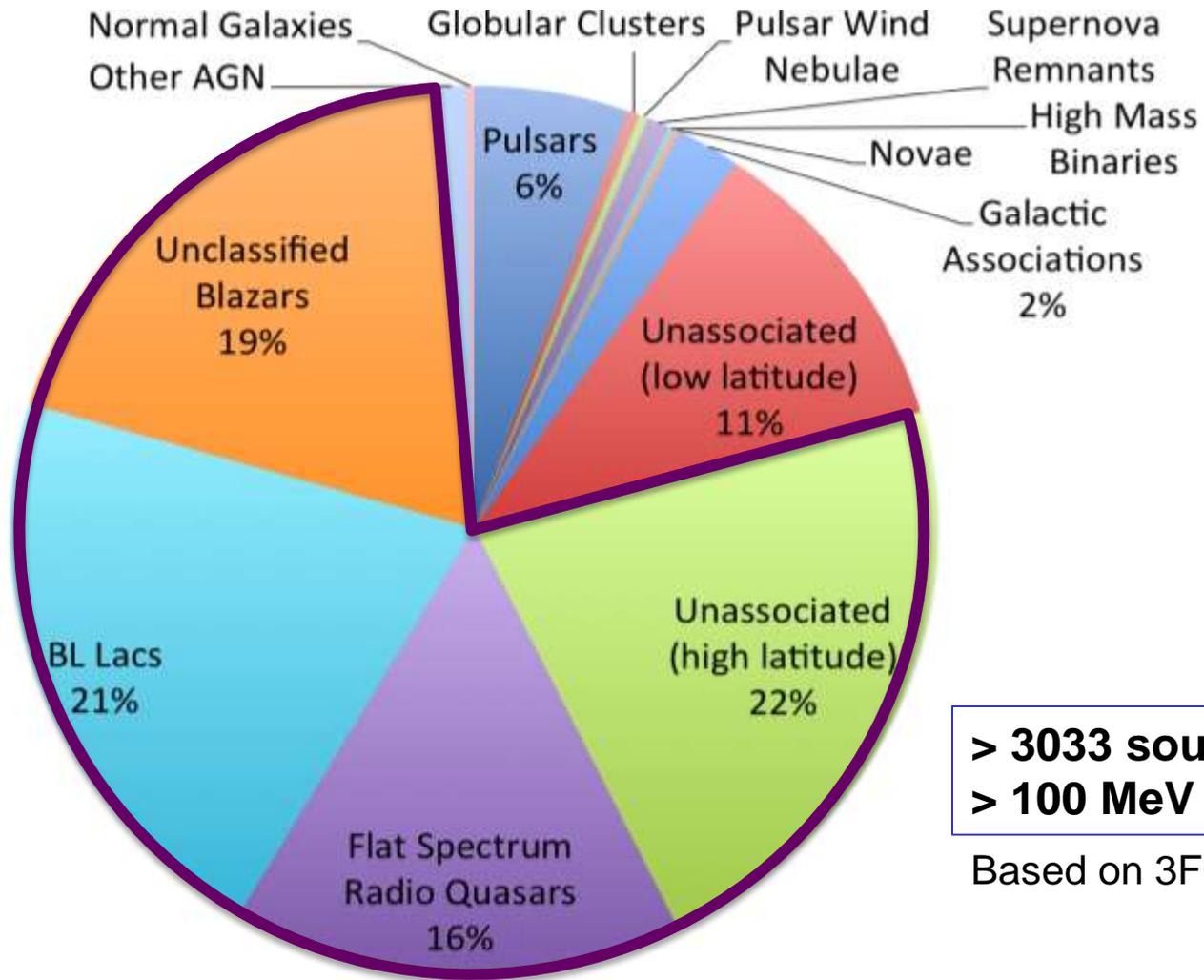
Unidentified Sources

The Persistent High Energy Sky



Front-converting events > 1 GeV
All-sky map, exposure corrected,
Aitoff projection, Galactic coordinates

Demographics: High Energy – 3FGL

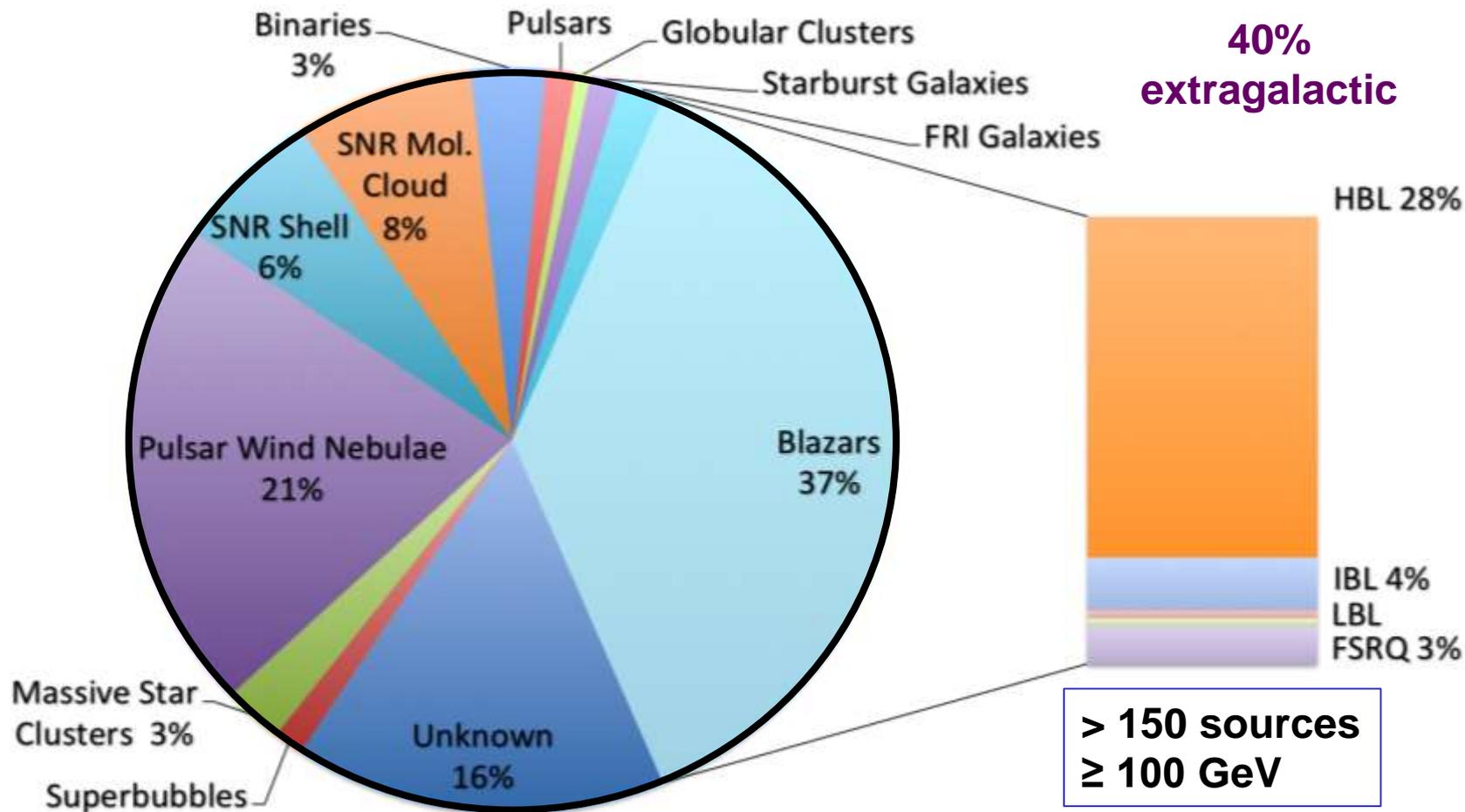


**80%
extragalactic**

**> 3033 sources
> 100 MeV**

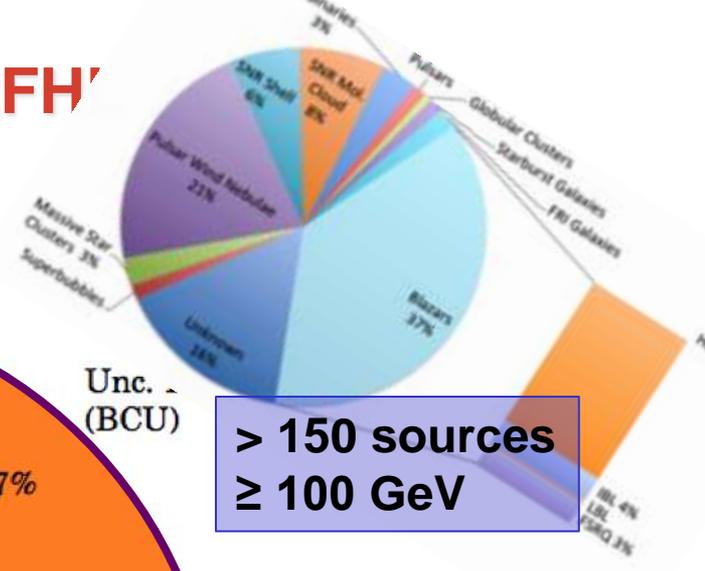
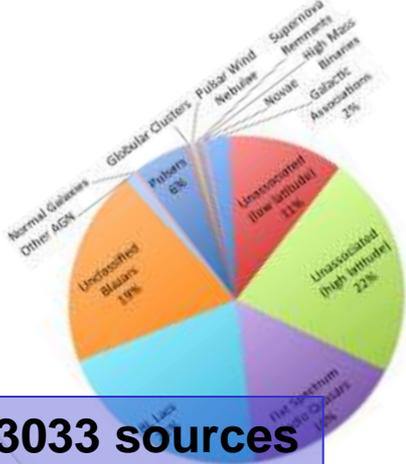
Based on 3FGL

Third Catalog of *Fermi*-LAT Sources



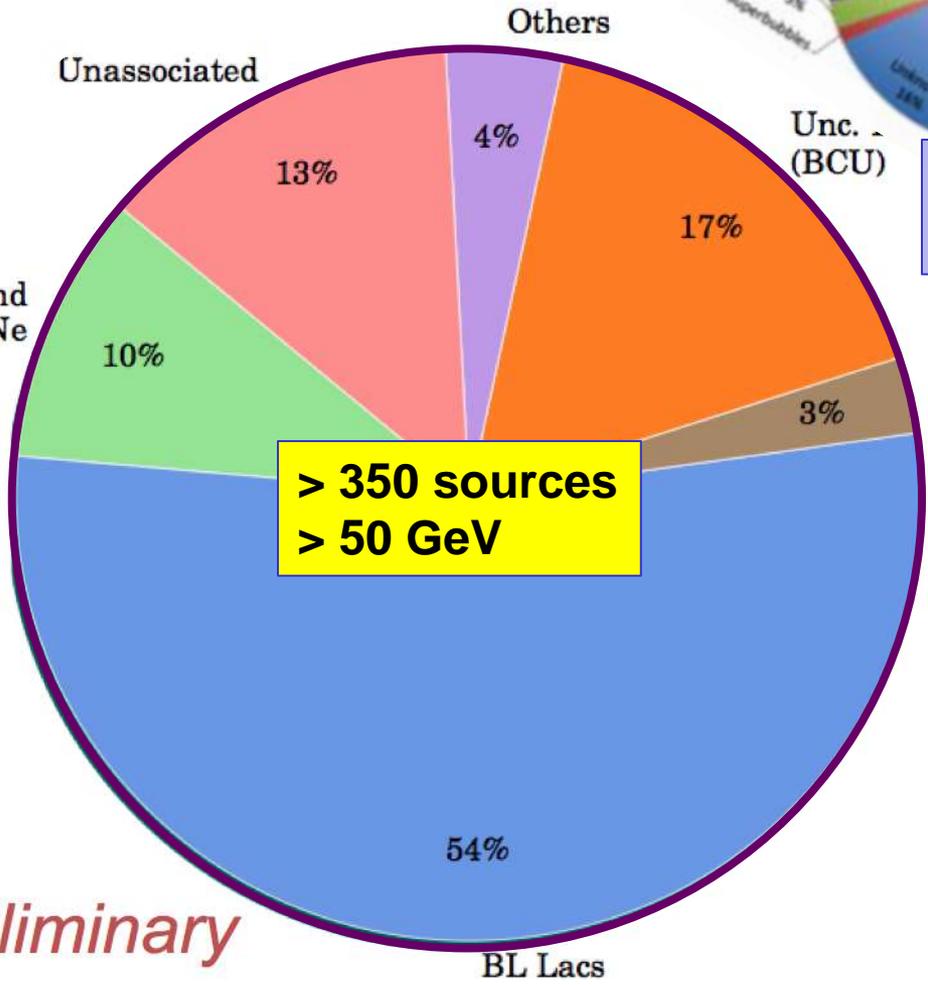
TeVcat
<http://TeVcat.uchicago.edu>

Bridging the Gap – 2FH⁺



**> 3033 sources
> 100 MeV**

**> 150 sources
≥ 100 GeV**

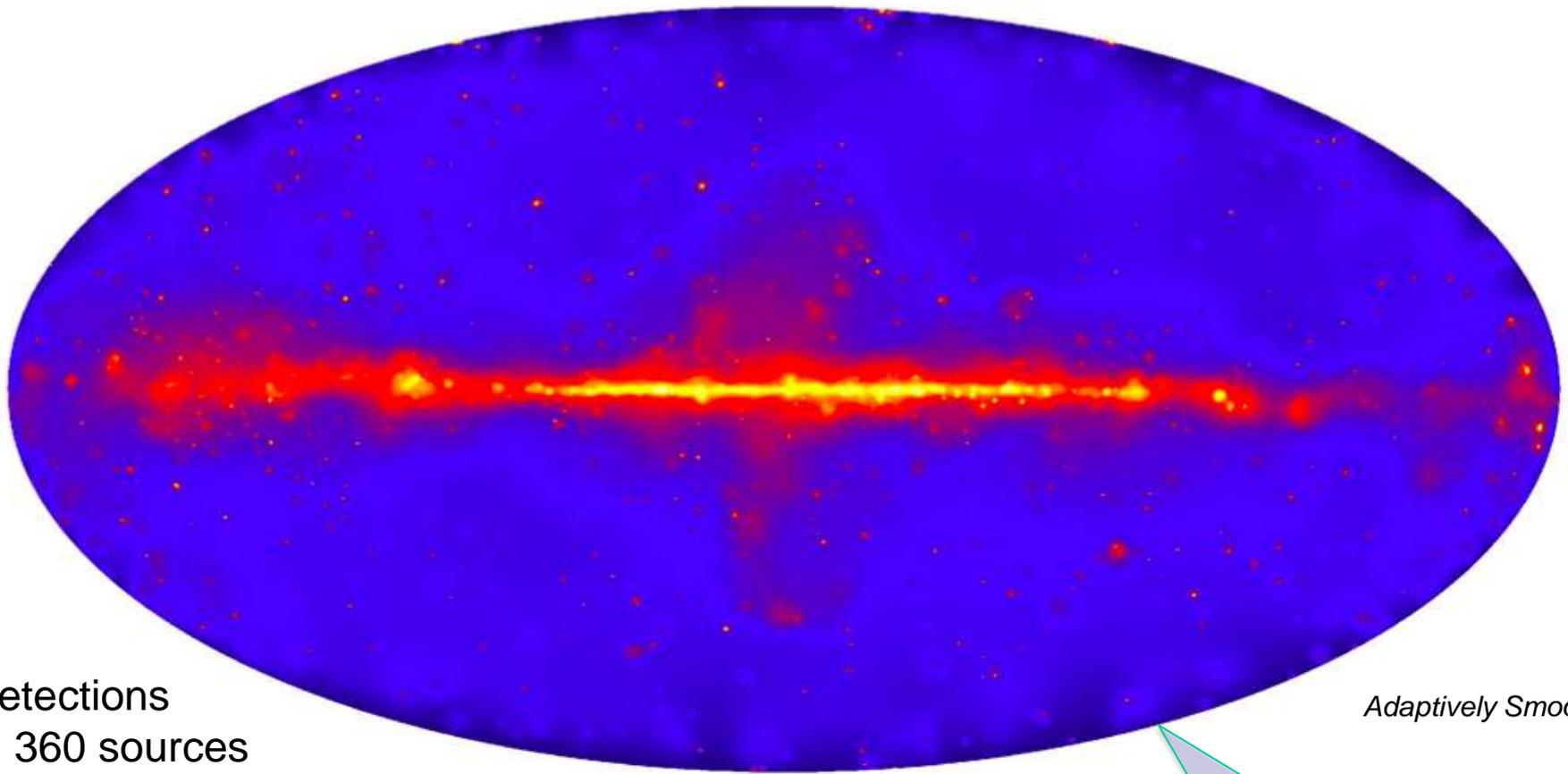


**> 350 sources
> 50 GeV**

Preliminary

Second Catalog of Hard *Fermi*-LAT Sources

The Second Catalog of Hard *Fermi*-LAT Sources



Adaptively Smoothed

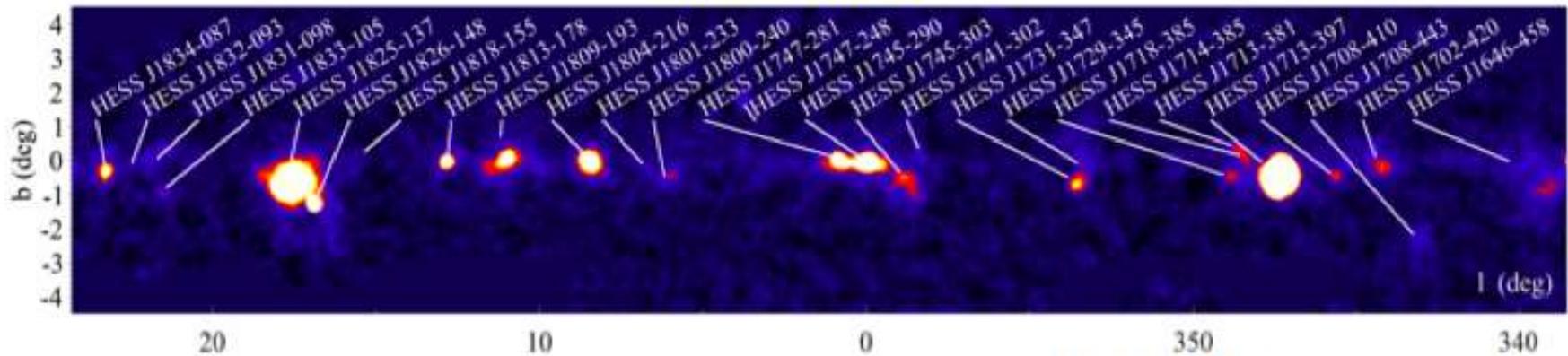
Detections

- 360 sources
- 78 detected by IACTs (TeVCat)
- 230 detected in 1FHL
- 303 detected in 3FGL
- 57 brand new sources (not 1FHL/3FGL)

**80 months
P8 data
50GeV–2TeV**

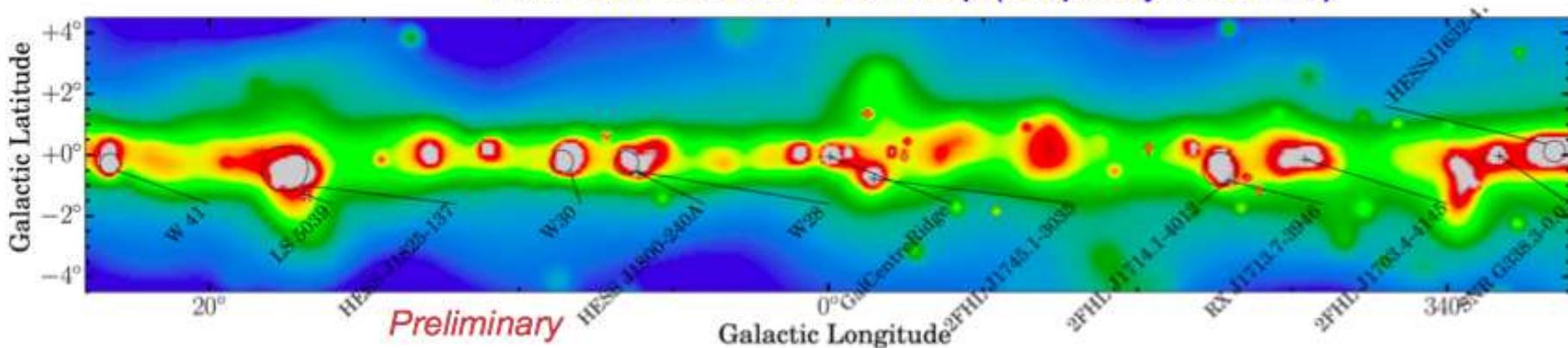


Significance Map



Aharonian et al. 2006, Carrigan et al. 2013

Fermi-LAT >50 GeV Count Map (adaptively smoothed)



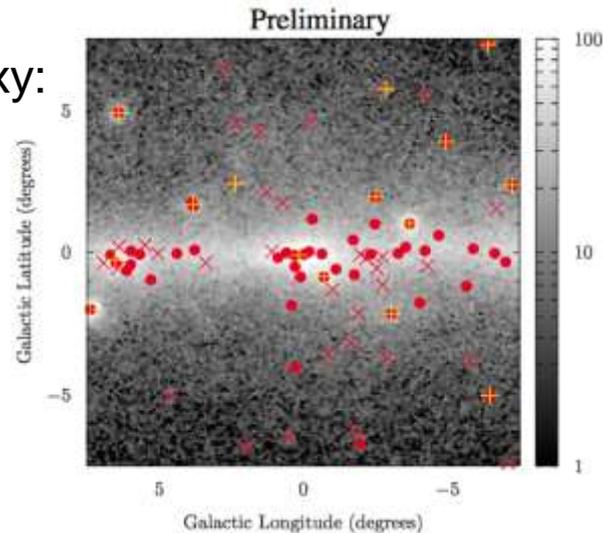


- **2FHL opens a new window on the high-energy sky**
 - 360 sources detected between 50 GeV and 2 TeV
 - 75% blazars, 14% Galactic and 11 % unassociated
 - only 25% detected in TeVCat
 - *plenty of sources for TeV telescopes!*
- **Extragalactic science:**
 - >80% of 2FHL sources are blazars (BL Lacs), up to $z \sim 2$
 - Clear signs of EBL attenuation (and nothing else)
 - Almost all the IGRB is accounted for by blazars
- **Galactic science:**
 - all display hard spectra
 - 5 new extended sources, 9 dark accelerators, 87% of PWNe/SNRs
 - good match to the H.E.S.S. Galactic plane survey



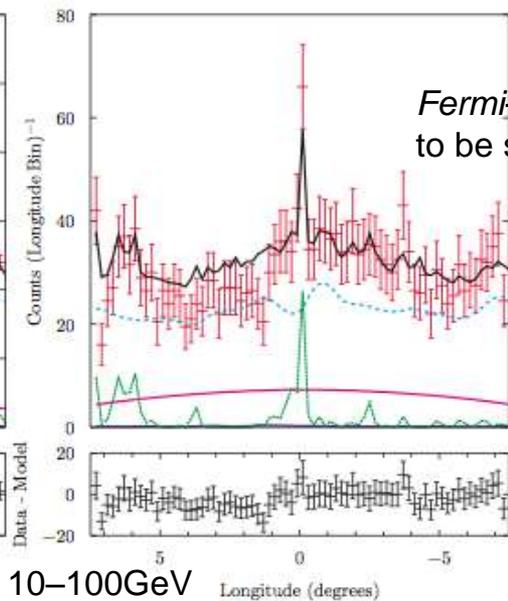
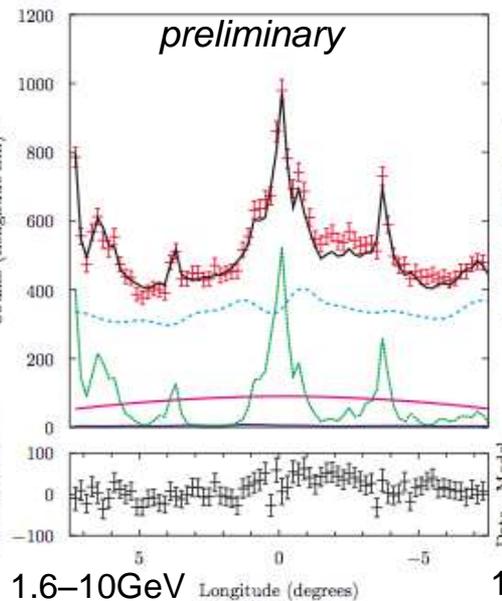
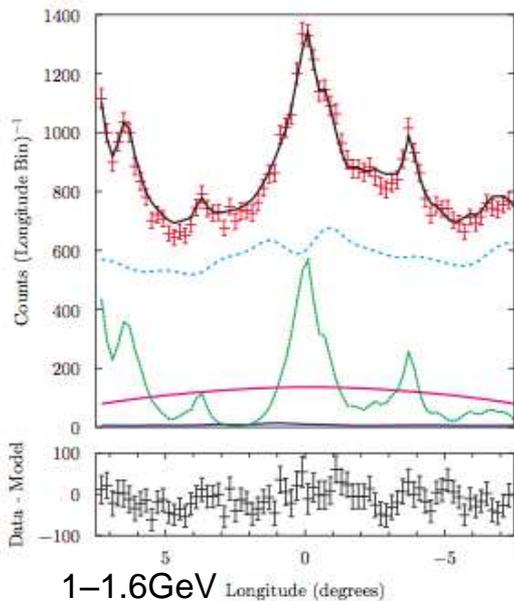
Gamma-ray emission in the inner Galaxy:

- Interactions of CR particles with the interstellar gas and radiation fields
- Resolved point sources
- Potential contribution by:
 - Supermassive black hole
 - Candidate for dark matter
 - Unresolved sources



CR intensities, interstellar gas and radiation field densities are highest .. but most uncertain!

Longitude profiles
for data-model

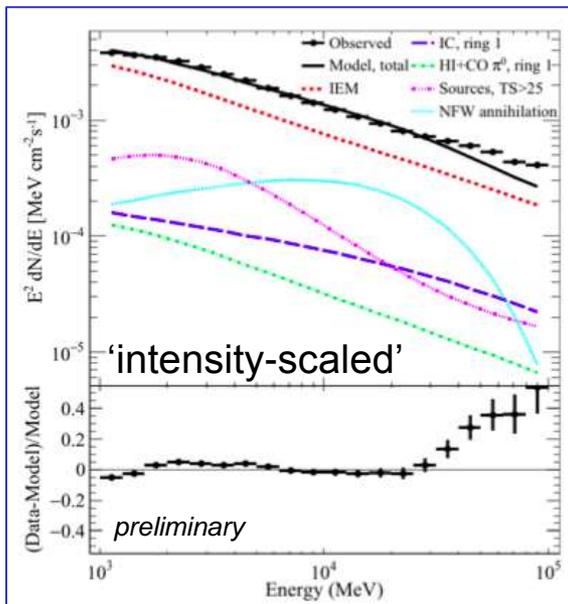


Fermi-LAT coll.,
to be submitted



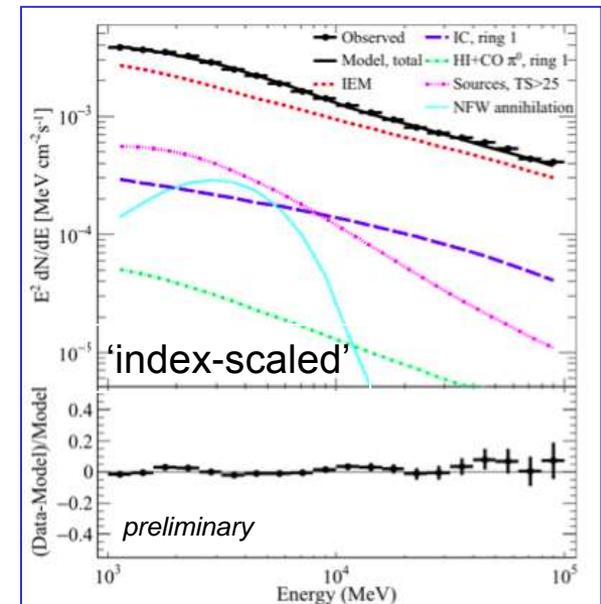
- Model over prediction at lowest energies is primarily correlated with the GP, could be due to mis-modelling of the IEMs gas component.
- (some) positive residual in the few GeV range could be due to an extended component, more concentrated toward the GC compared to IEM components
- Test for additional comp. centered at the GC (2D gaussians, Navarro-Frenk-White, or a gas-like distribution as proxy for unresolved sources)

Differential fluxes for the $15^\circ \times 15^\circ$ region about the GC for IEMs models based on Pulsars



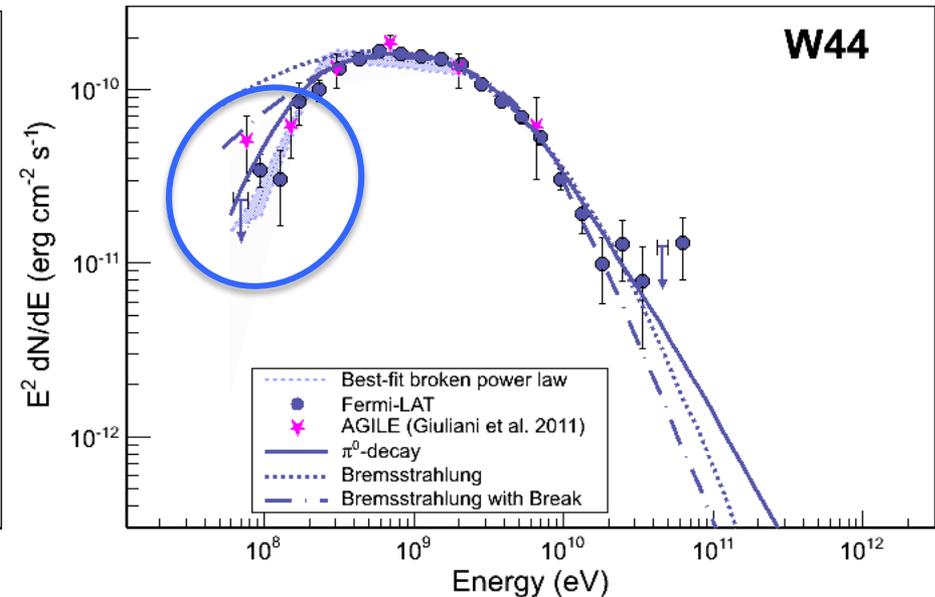
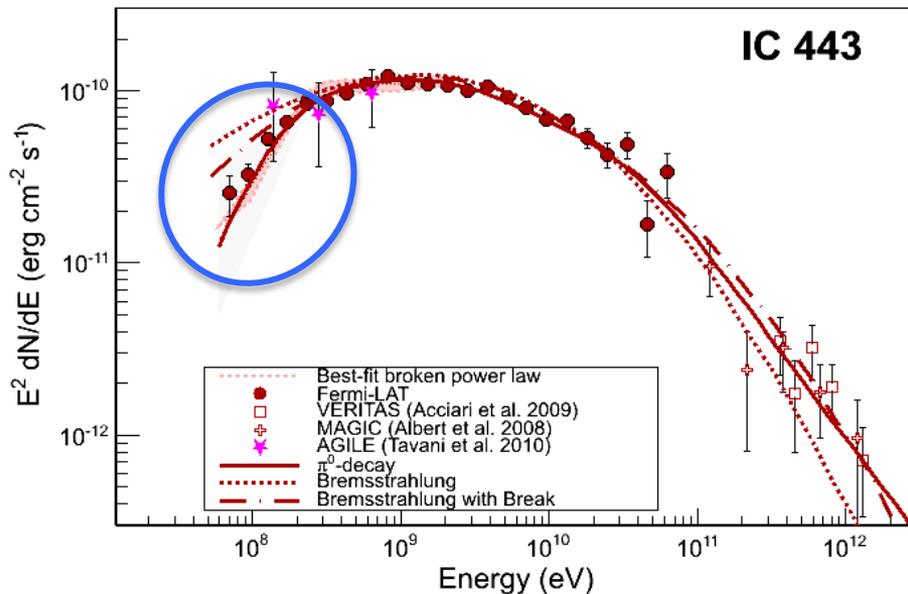
- Including the NFW-profile component yields the most significant improvements in the data-model agreement, but broad range for the best-fit parameters!

➔ The predicted spectrum depends on the foreground/background models.





Despite wide agreement that supernova remnants (SNRs) are the sources of galactic cosmic rays, unequivocal evidence for the acceleration of protons in these objects is still lacking.

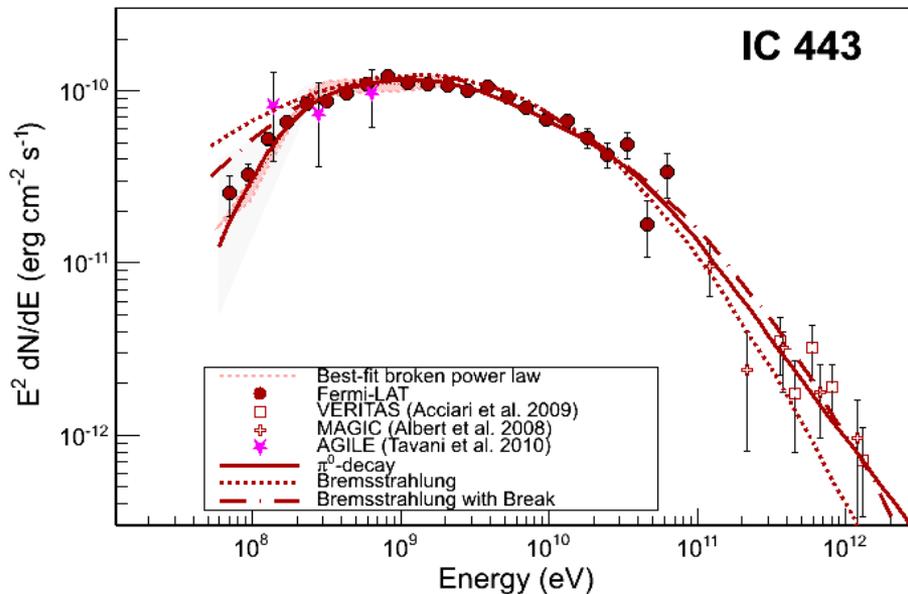


- Evidence of pion decay bump in W44 and IC443 (thanks to increased low energy Pass7 acceptance)
- Proof that SNR accelerate protons

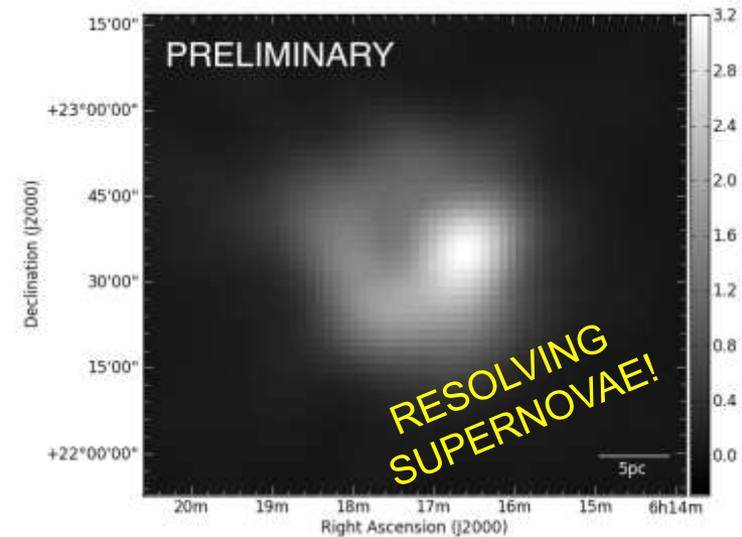
Detection of the pion-decay cutoff in Supernova remnants, 2013, Science, 339, 807



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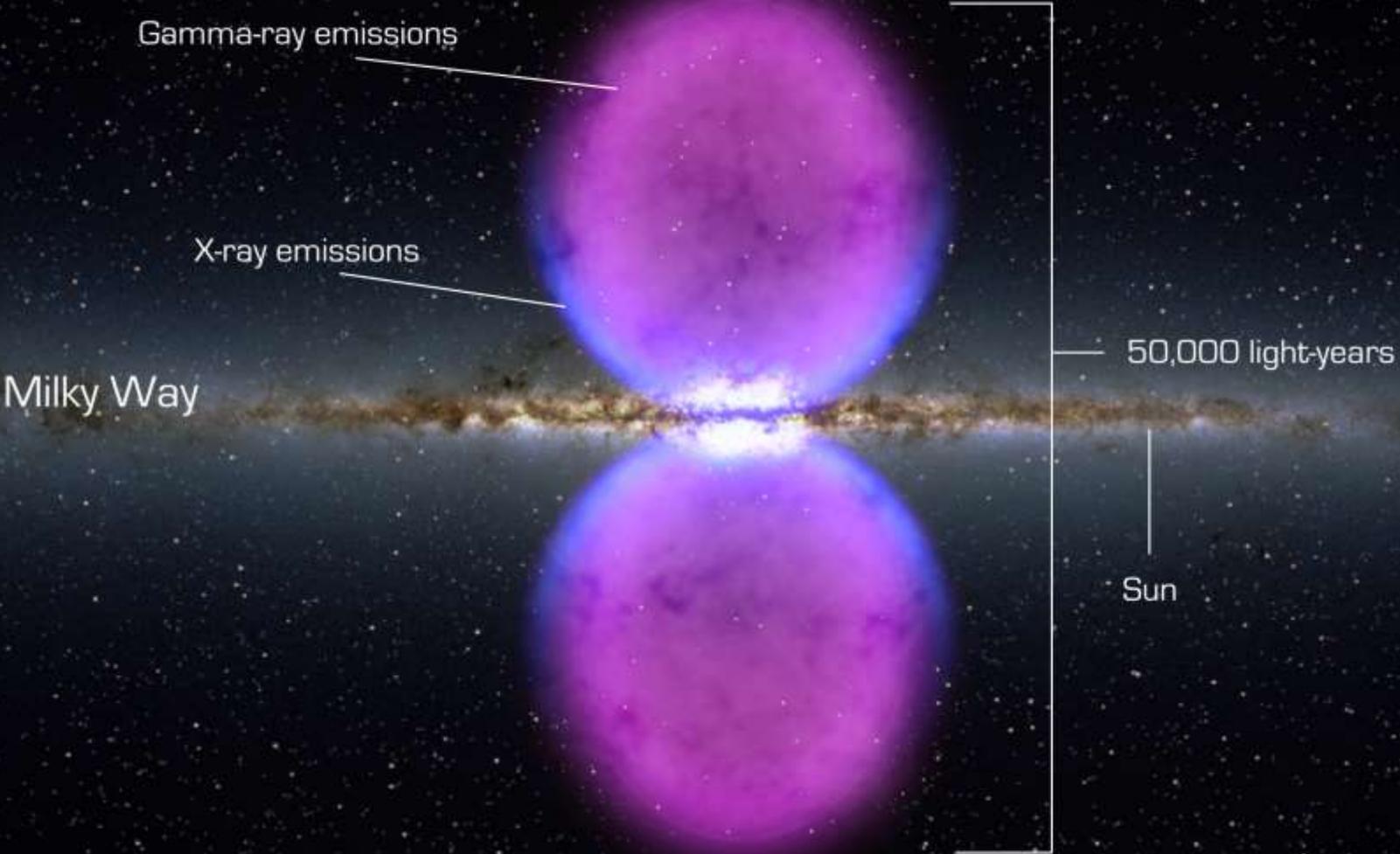
LAT E>5 GeV 83 months (Pass 8)



- Evidence of pion decay bump in W44 and IC443 (thanks to increased low energy Pass7 acceptance)
- Proof that SNR accelerate protons

Detection of the pion-decay cutoff in Supernova remnants, 2013, Science, 339, 807

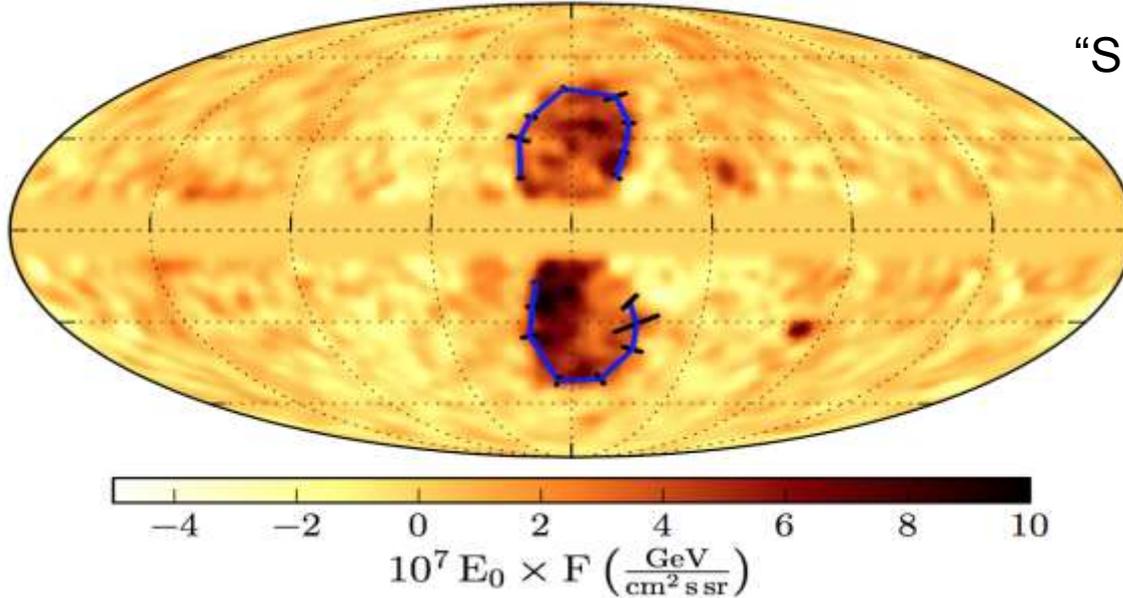
Milky Way – Fermi Bubbles



Su et al. 2010

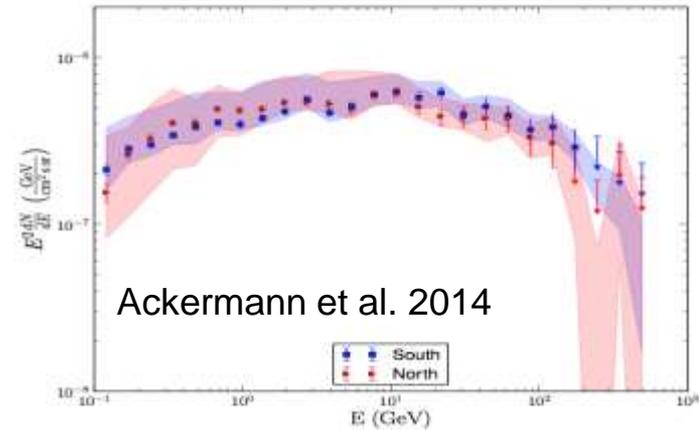


Residual intensity, $E = 10 - 500$ GeV

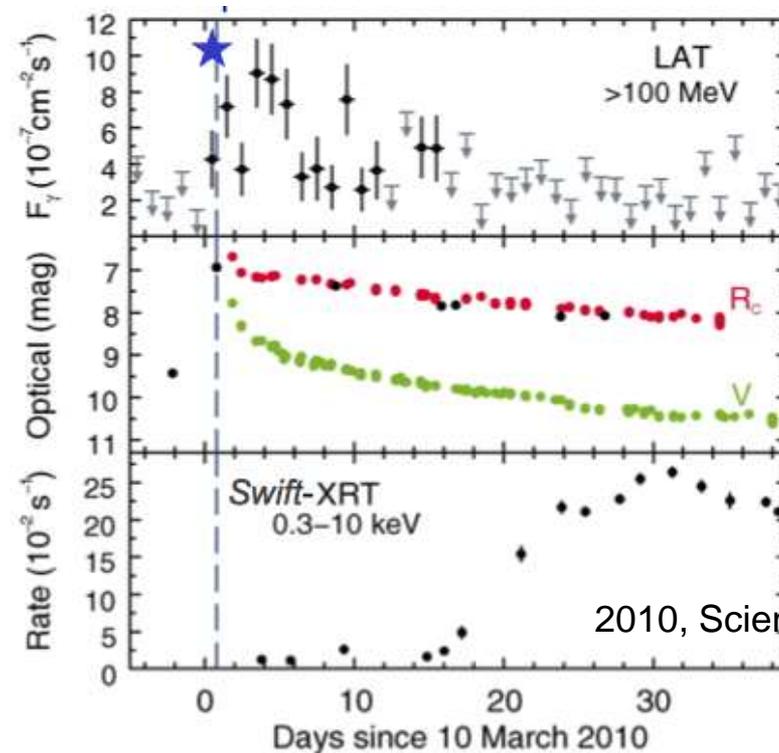
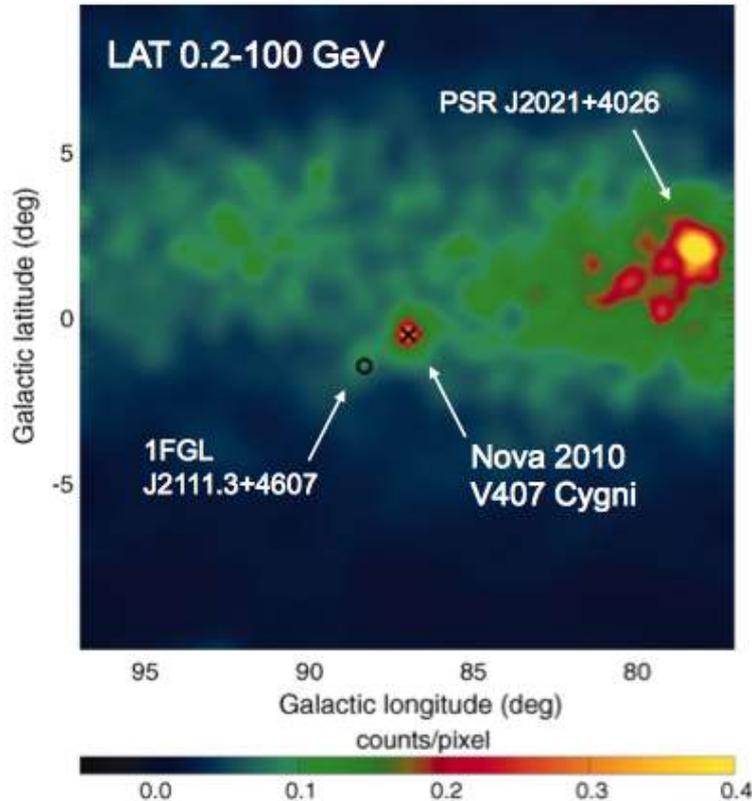


“Sharp” edges

Spectra for North and South in good agreement



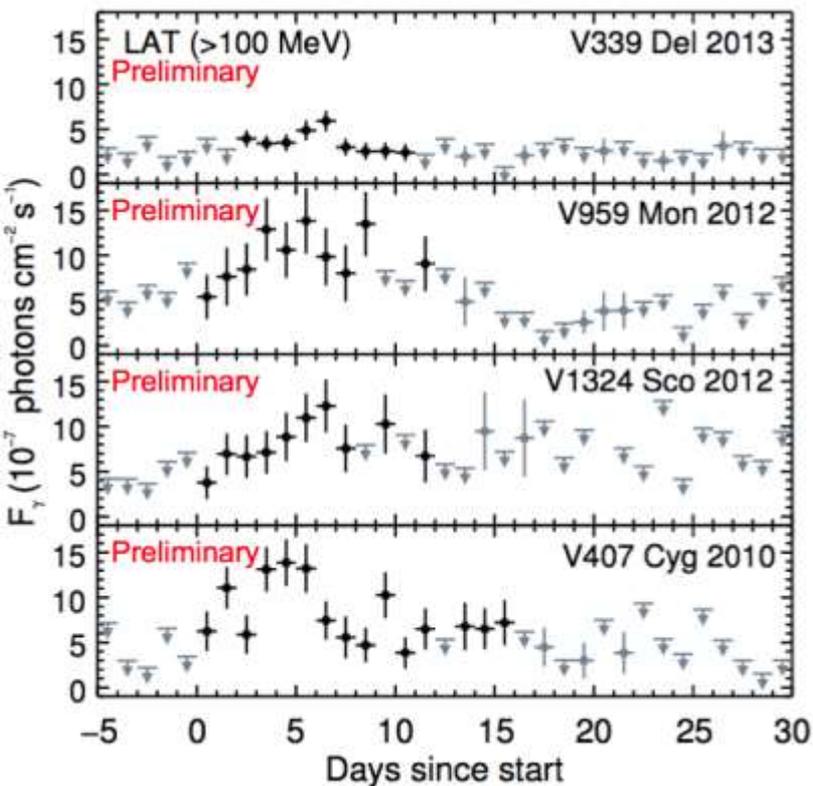
Recent outburst from the black hole or longer activity driven by star formation or tidal disruption?
Crocker et al. 2015, Lacki 2014, Muo et al. 2014, Yang et al. 2015



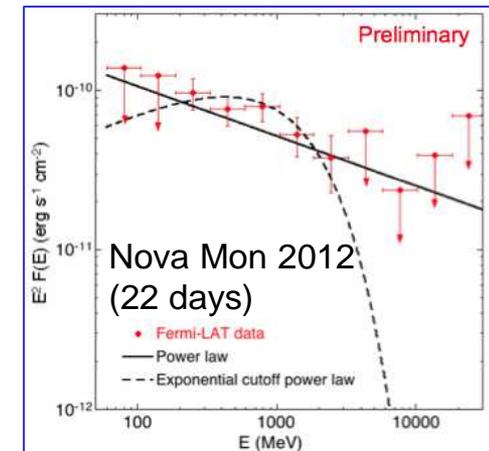
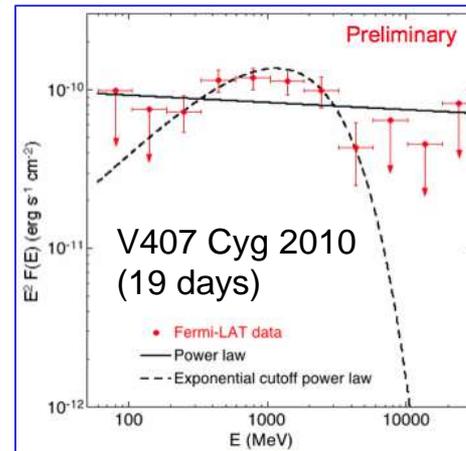
Initial LAT detection 2010 March 10, same day as nova V407 Cyg optical discovery

→ γ -ray identification via spatial ($r_{95\%}=3.7'$) & temporal coincidence with a symbiotic recurrent nova

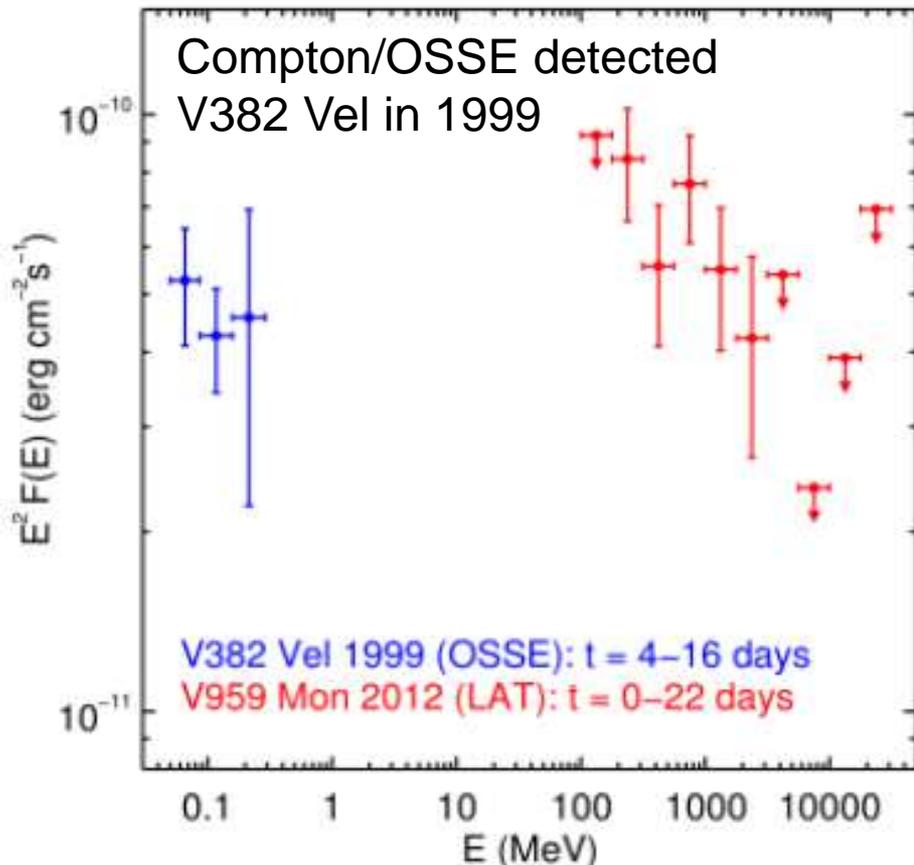
New Population of Gamma-ray Novae



Ackermann et al. 2014, Science 345, 554



- Fermi acceleration in nova shell & interaction with massive red giant wind plays important role in symbiotic recurrent novae
- Similarities & differences may not necessarily point to the same γ -ray emission mechanism
- Necessary conditions: massive WD & fast and massive ejecta; companion, environment come into play, and all appear nearby



V382 Vel 1999:
Compton/OSSE observations detected
at 7sigma over 12 days starting 4 days
after the peak; non-detection in the next

*Origin and production site of the LAT
observed γ -ray emission is an open
problem* : Hadronic and leptonic
models satisfactory fits LAT spectra
(Abdo et al. 2010 Sci 329, 817)

Compton/OSSE observed spectrum of
V382 Vel 1999 indicates classical
novae spectra extend down to ~0.1
MeV energies
→ important for modeling

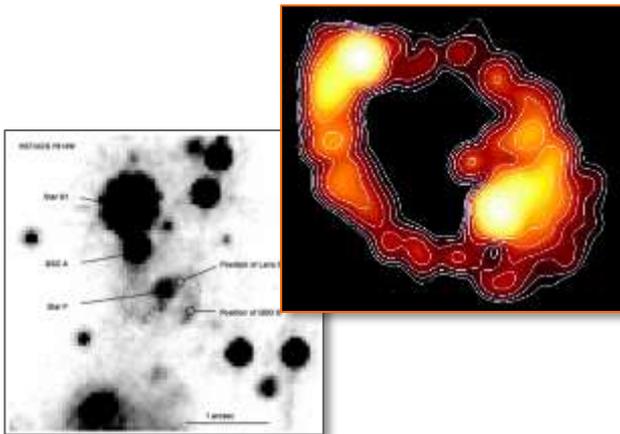
Fermi revisions of these discoveries!

Looking forward to explore the next
lower-energy and higher-energy
window!

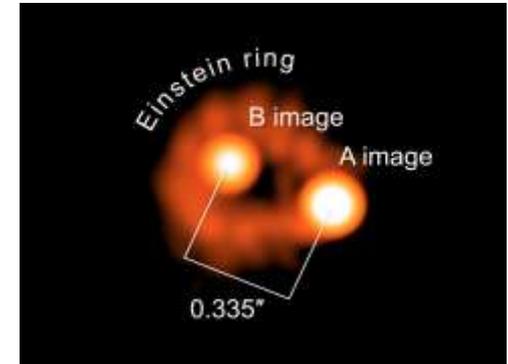


- FSRQ at $z=2.507$; lens separation of $0.98''$
- **Lensing galaxies at $z=0.886$ and $z=0.19$**
- Radio delays claimed: 26 ± 5 days, 24 ± 5 days
- magnification ratio ~ 1.5

PKS 1830-211



B0218+357

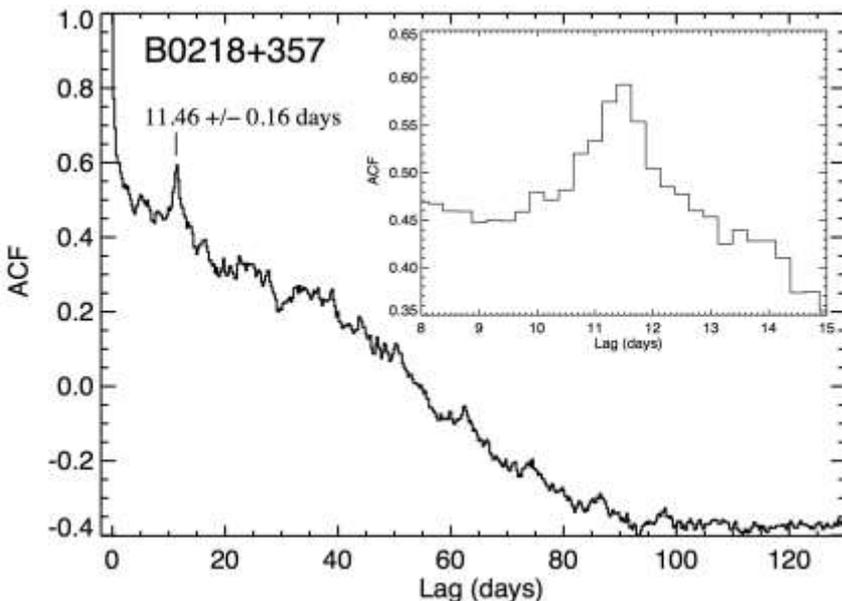
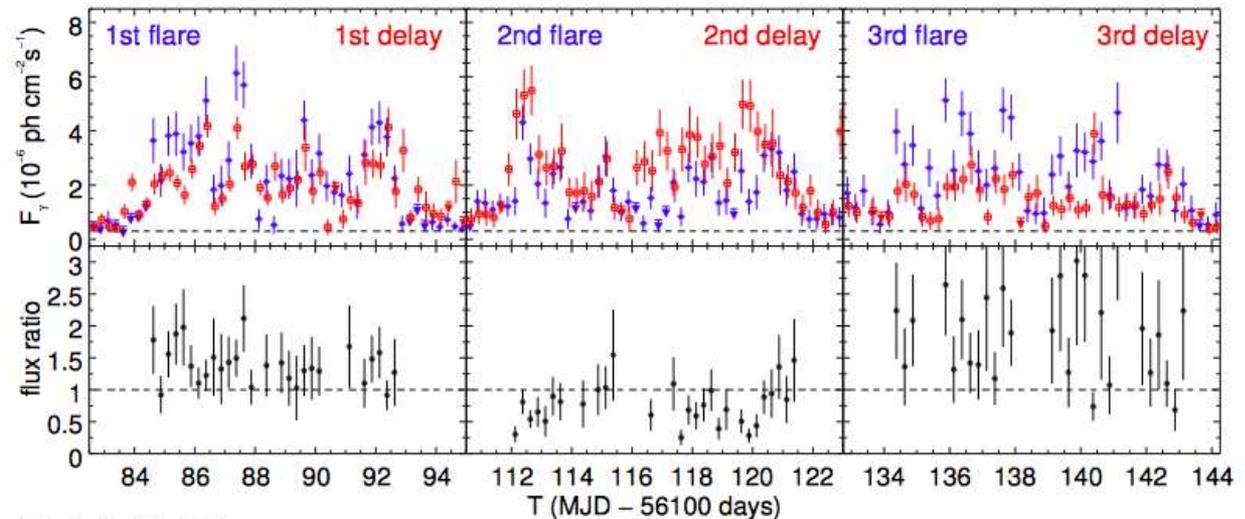


- $z = 0.944$
- Smallest separation lens from CLASS survey ($0.335''$); Einstein ring
 - **Lensing galaxy $z = 0.6847$**
- Delay 10.5 ± 0.4 day (95% CL, Biggs et al. 1999)
- Associated with LAT gamma-ray source (2FGLJ0221.0+3555)



Fermi-LAT provides excellent light curves:

- ✓ long
- ✓ evenly sampled
- ✓ low noise



B0218+357

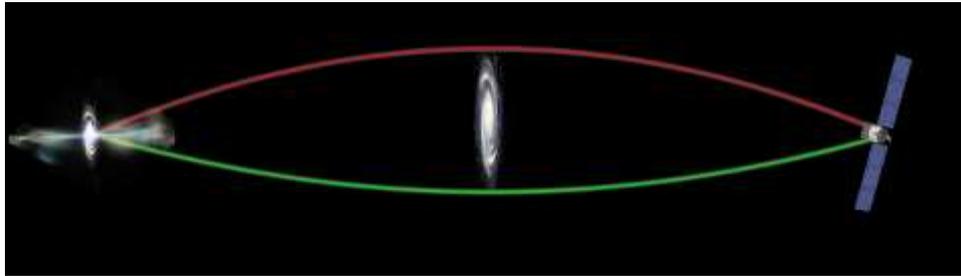
Delay estimated = 11.46 +/- 0.16 days
→ Most competitive delay estimate for the system!

Flux ratio = 1.16 +/- 0.07

Magnification ratio = 1.32 +/- 0.09

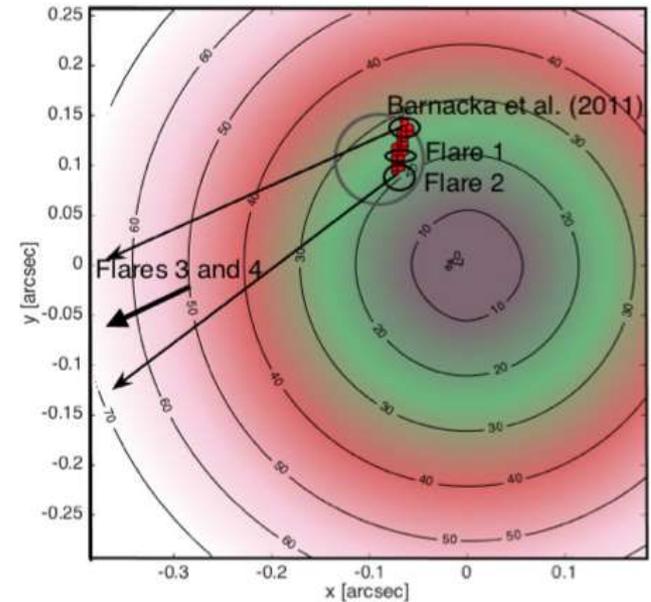
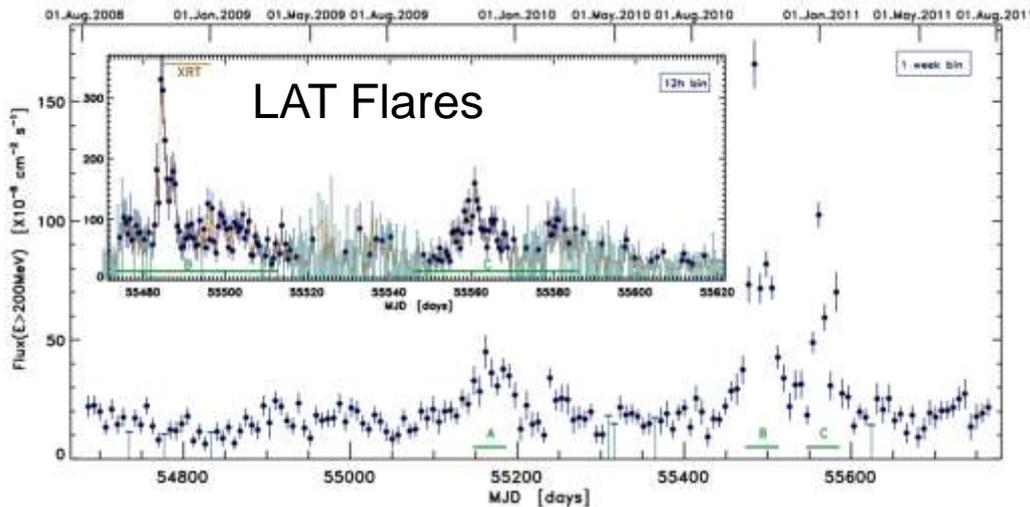
Cheung+ 2014, ApJL, 782, L14

Grav. Lensing: a tool to pinpoint emission regions



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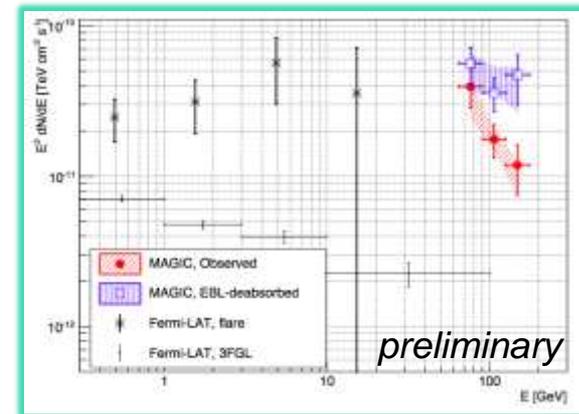
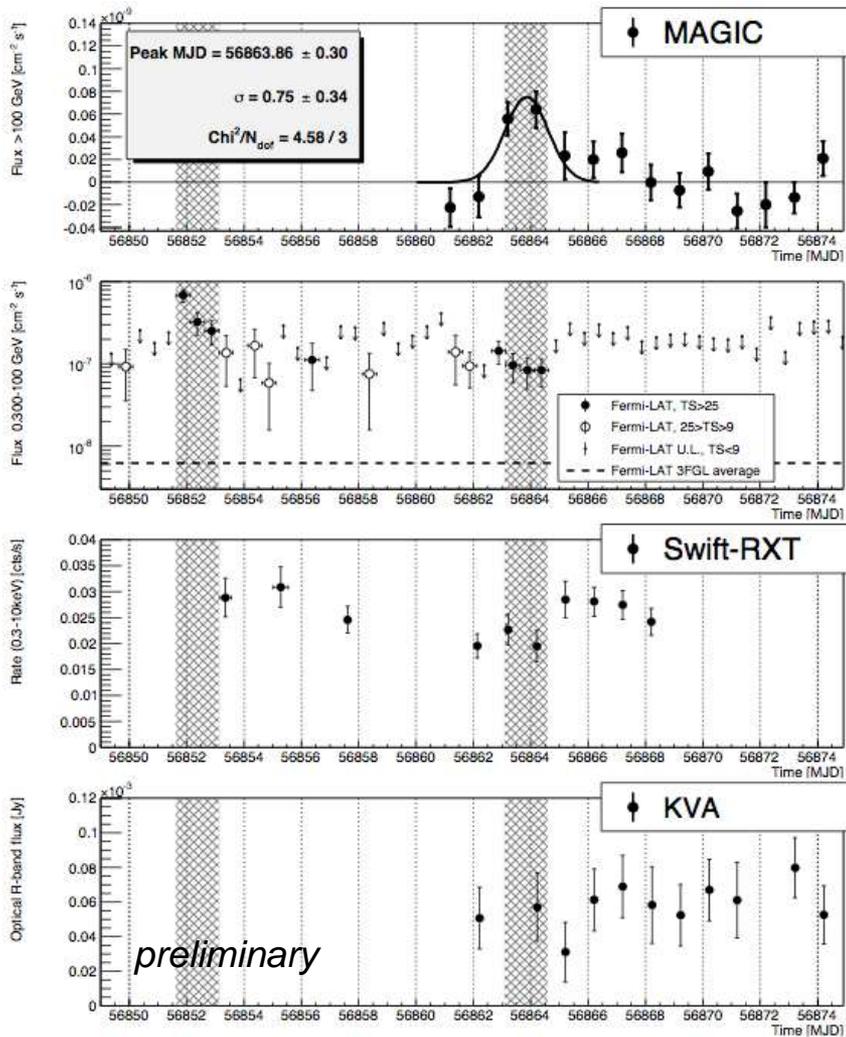
Abdo et al. 2014



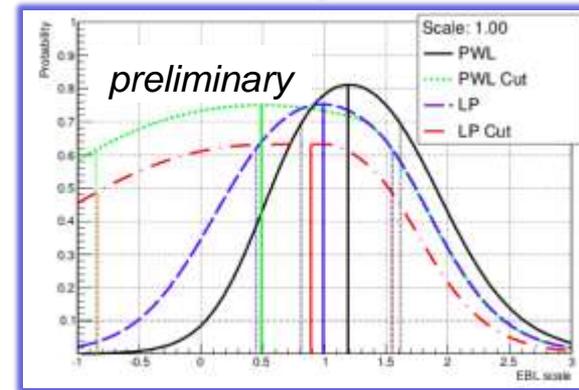
Barnacka et al. 2015

Gamma-ray emission region located \sim kpc from the central BH
 .. but be aware, *microlensing* may play an important role!
 (see talk by Vovk)

B0218+357 – Up to VHE !



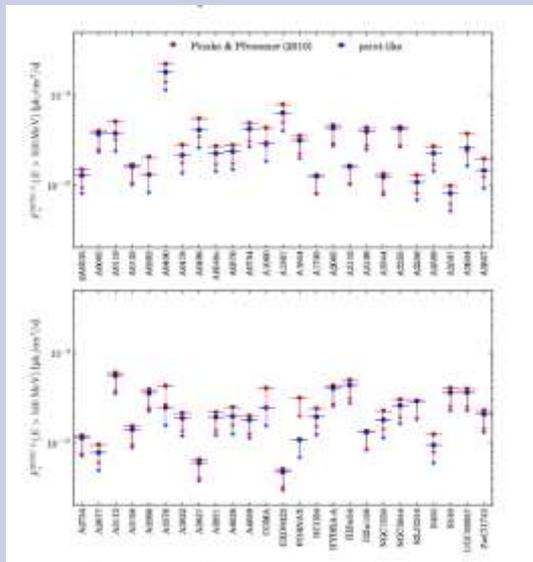
MAGIC coll.,
in prep



EBL consistent with current models



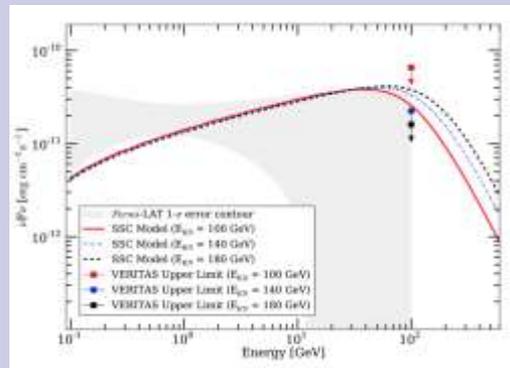
Galaxy Clusters



Ackermann et al. 2014

(TeV, e.g., Aleksic et al. 2012, Abromowski et al. 2012, Arlen et al. 2012)

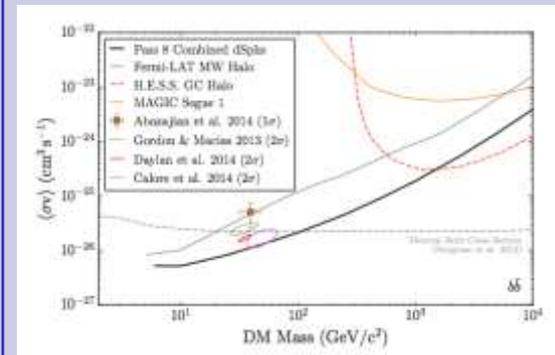
GRBs at $E > 100 \text{ GeV}$



Aliu et al. 2014

Waiting the trigger for the right burst...!

Dwarf Spheroidals



Ackermann et al. 2015

Sensitivity improves with new dwarf galaxies (DES)

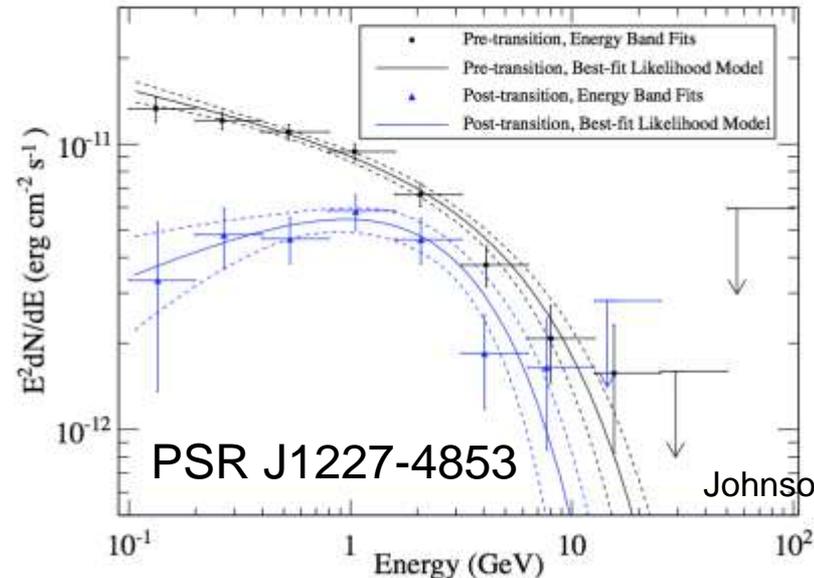
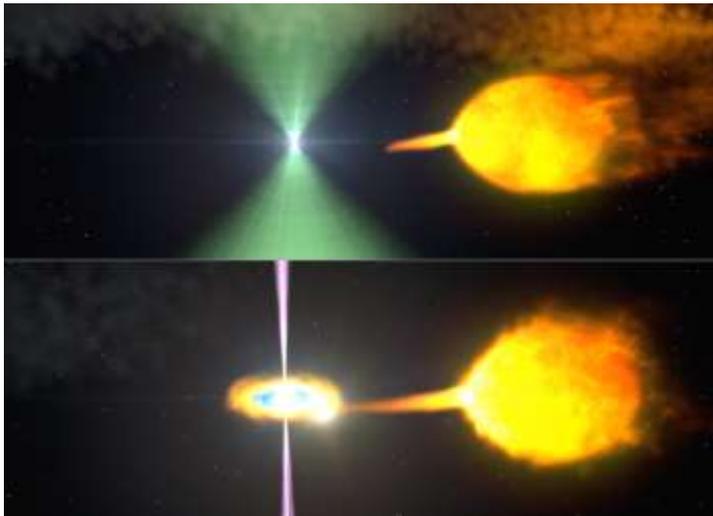


~~The Crab pulsar wind nebula is a steady source of high energy emission.~~

~~Pulsars are persistent sources of gamma rays~~



LMXB transition to a rotation-powered millisecond pulsar state
MSP in the process of ablating low mass companion ($\sim 0.2 M_{\odot}$, orbital period < 1 day)



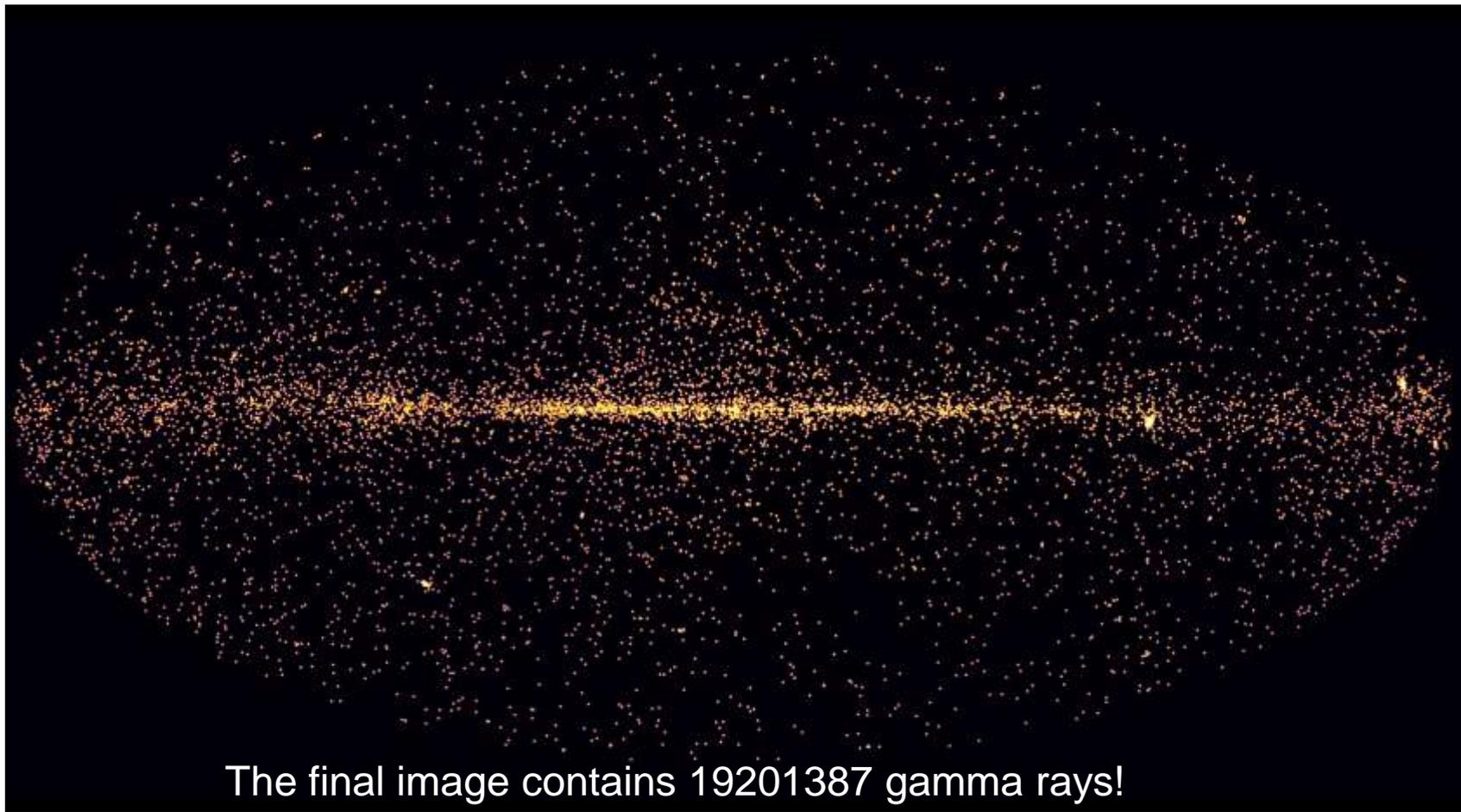
In LMXB state, the disk penetrates the pulsar magnetosphere quenching the rotation-powered pulsar emission mechanism

Synchrotron and SSC scattering from electrons accelerated at the interface between the disk and the pulsar magnetosphere

Other systems may transition while *Fermi* keeps observing!



Fermi-LAT All-sky intensity for the Pass 8 (source events) from 30 hours to 7 years



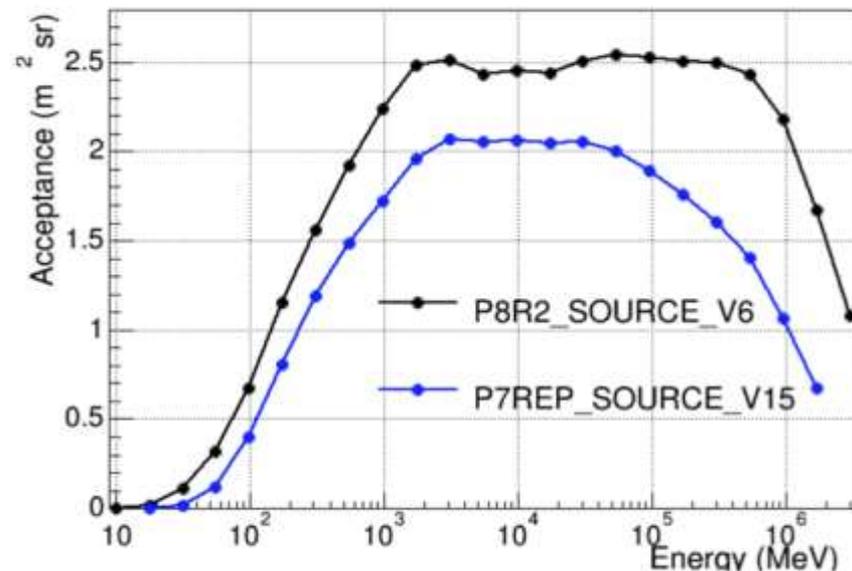
The final image contains 19201387 gamma rays!



- **What?**
 - The data reconstruction we always wanted
 - Comparable to a “servicing mission” (years of effort)
- **So what?**
 - Increased effective area
 - Refined angular resolution capability
 - Refined energy resolution capability
 - Wider energy range
 - Wider field of view



More photons!





- ***Fermi* shapes our understanding of the sky from ~100 MeV to 1 TeV**
 - **New analysis capability and extension to higher and lower energies**
 - **Sensitivity linear with time in upper range**
 - **Best localization accuracy approaching ~arcminute**
 - **New dwarf spheroidal discoveries enhance dark matter sensitivity**
 - **New ground for long baseline studies for blazars, binaries, and pulsars**
 - **Exploit new synergies → explore new fields:**
 - **Search for neutrino counterparts**
 - **Overlap with enhanced gravitational wave observatories**



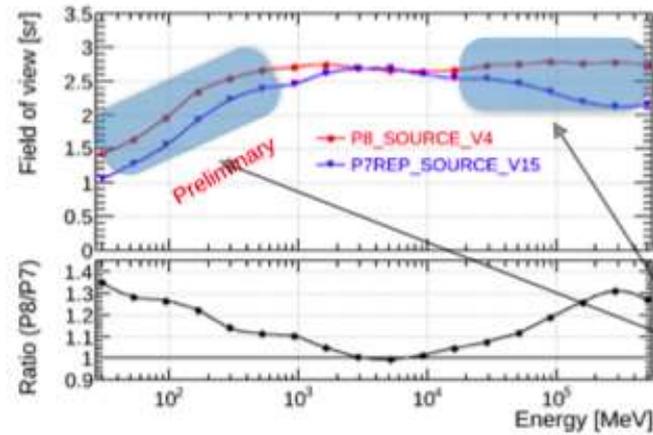
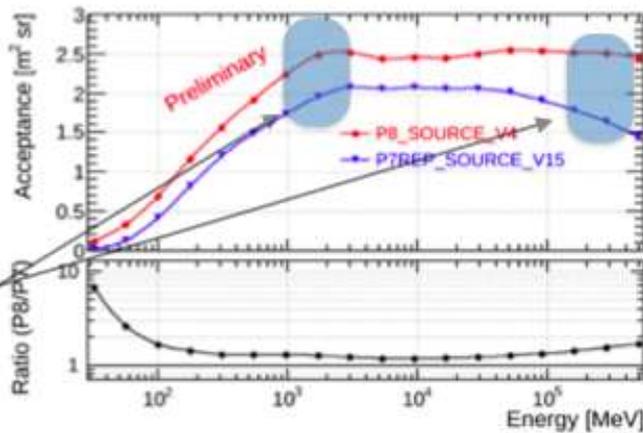
- **Fermi shapes our understanding of the sky from ~100 MeV to 1 TeV**
 - New analysis capability and extension to higher and lower energies
 - Sensitivity linear with time in upper range
 - Best localization accuracy approaching ~arcminute
 - New dwarf spheroidal discoveries enhance dark matter sensitivity
 - New ground for long baseline studies for blazars, binaries, and pulsars
 - Exploit new synergies → explore new fields:
 - Search for neutrino counterparts
 - Overlap with enhanced gravitational wave observatories
 - Exploring new energy bands: optimize for the breadth of science
 - Top *Fermi* results were unpredicted and from many scientific areas
 - Fermi “bubbles”, millisecond γ -ray pulsars, Crab flares discoveries
 - New γ -ray source classes
 - Unresolved AGN account for most or all of isotropic backgrounds
- Don't push a single performance metric at the expense of others

Back Up



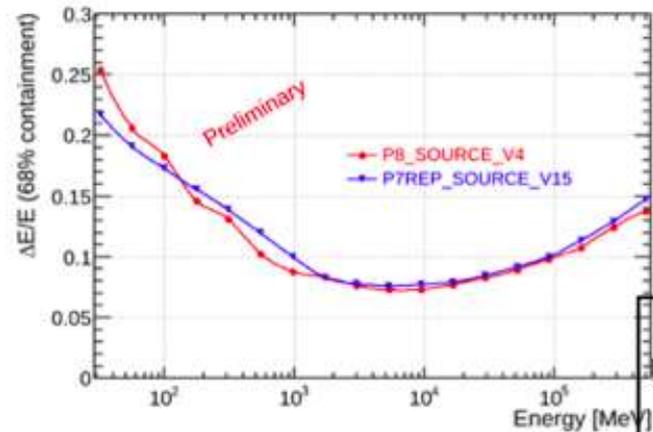
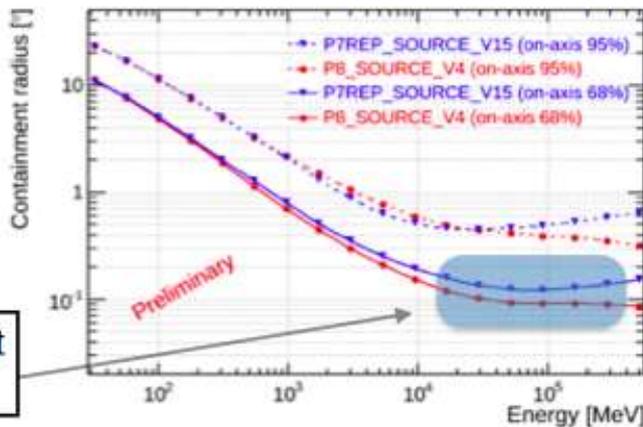


25 - 40%
increase in
acceptance

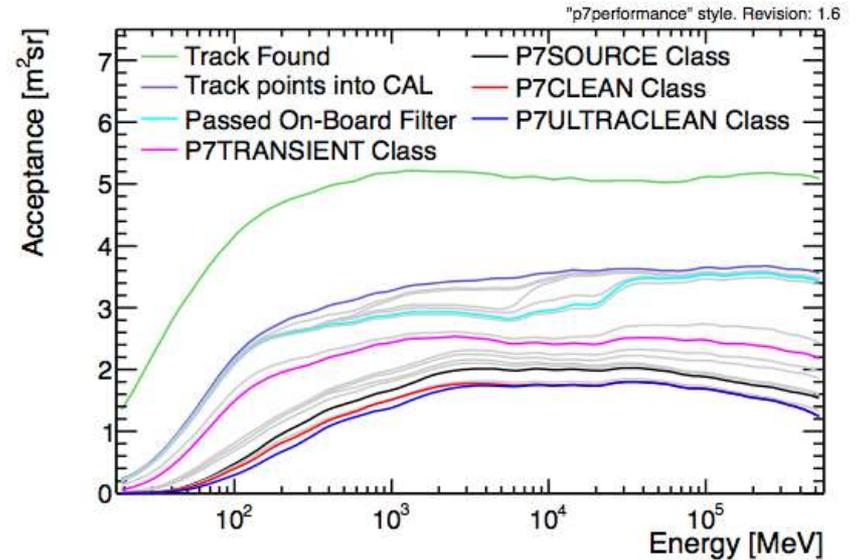
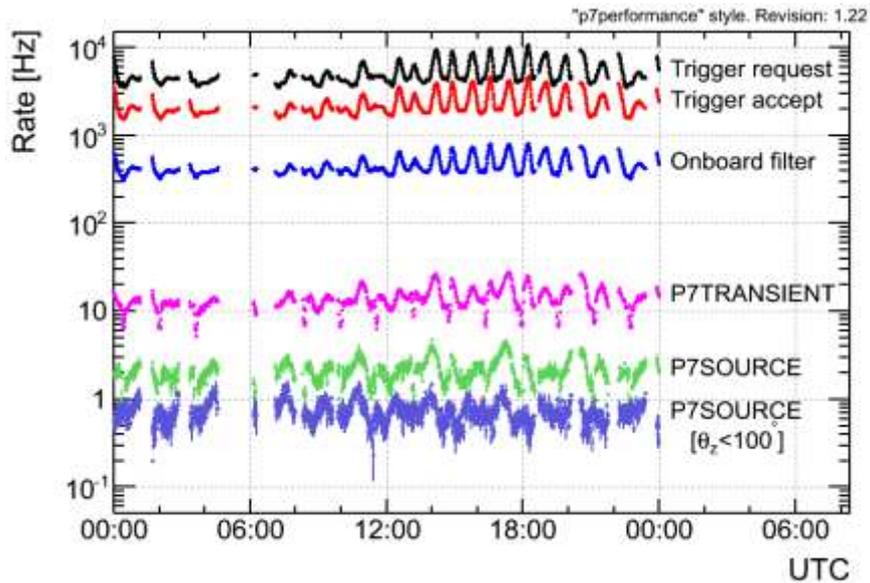


Larger Field
of View

Improvement
in the PSF



Better
Understanding
of the
Systematics



Factor of $> 10^5$ in bkg. reduction is achieved in several stages

About 50% γ -ray efficiency inside fiducial volume from 1-100 GeV

Ackermann+ 2012, ApJS, 203, 4A



ComPair

A Wide-Aperture Discovery Mission for the MeV Band

- Science focus: **extreme astrophysics** - high matter densities, strong magnetic fields, powerful jets
- Monitor the whole gamma-ray sky in the energy range 200 keV – > 500 MeV with sensitivity **~100 times better than COMPTEL at ~1 MeV** and improved angular resolution over *Fermi* LAT
- Optimized for **continuum sensitivity** and **field of view** but also will provide other ground-breaking capabilities, e.g. **polarization, spectroscopy**

