Fermi Gamma-rays and high-energy Neutrinos

Anna Franckowiak for the Fermi-LAT Collaboration

"VLVNT 2018" Dubna, October 3, 2018

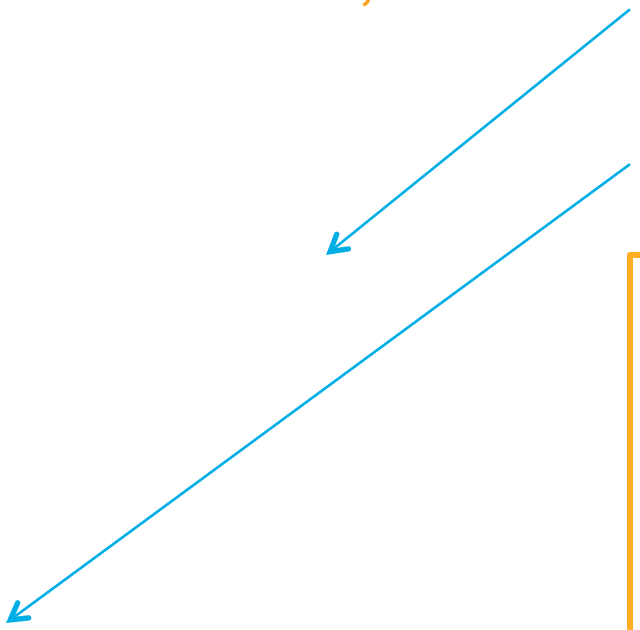
HELMHOLTZ
Young Investigators

DESY.


Satellite of Love

How does Fermi work?

Launched on June 11, 2008



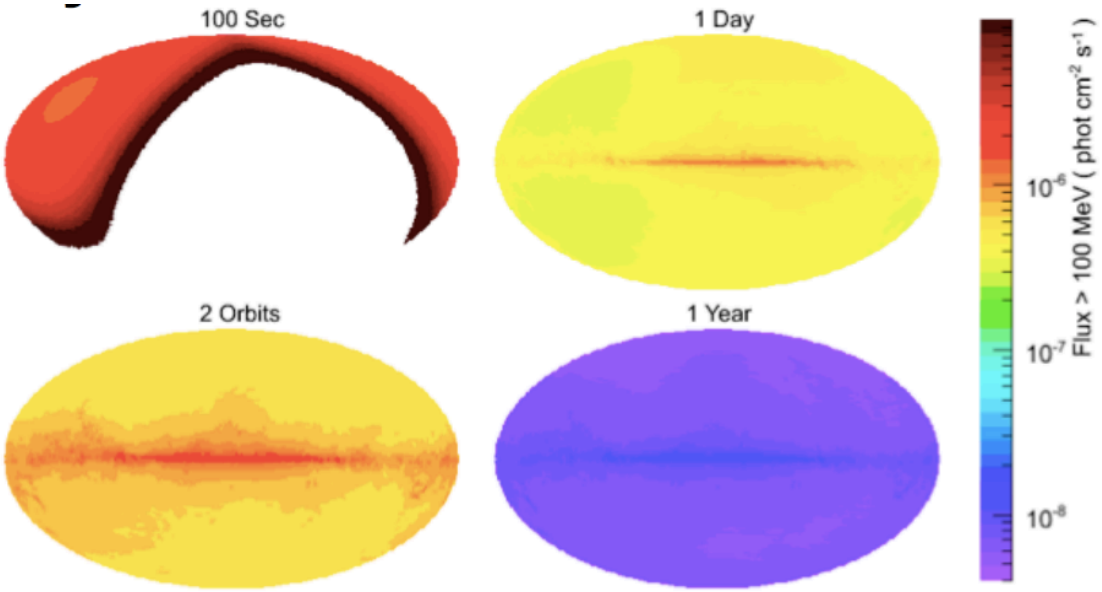
Large Area Telescope (LAT): silicon tracker, CsI calorimeter

Gamma-Ray Burst Monitor (GBM): NaI and BGO detectors

Key Features

- Huge field of view
  - LAT: 2.4 sr (20% of the sky)
  - GBM: 8sr (whole unocculted sky)
- Broad energy range
  - LAT: 20 MeV – >300 GeV
  - GBM: 8 keV – 40 MeV
  - Total of >7 energy decades
- Spatial resolution:
  - LAT: <1° above 1GeV
  - GBM: 5-10°, GCN within 1min, 3-5° improved localization (few hours)
- Every photon can be time tagged
  - 1 μs accuracy

LAT Observing Profile

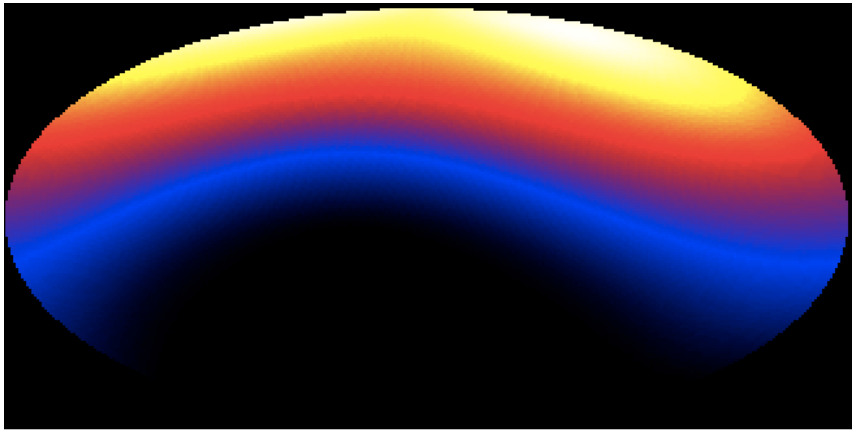


- Mostly – uniform sky survey
- Dec 2013 – Dec 2014, transitioned to Galactic center biased survey for 1 year
- Target of opportunity observations generally between 1 day – few weeks in duration: flaring AGN, Novae, Sun, Crab, Binary systems, etc.
- 2.5 hour autonomously commanded pointed observations following detection of bright hard-spectrum GRB

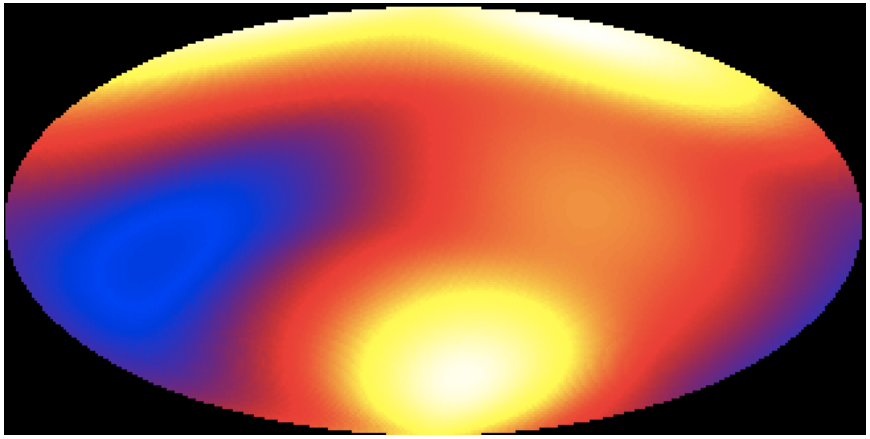
Modified Observing Profile

After one solar panel got stuck on March 16, 2018

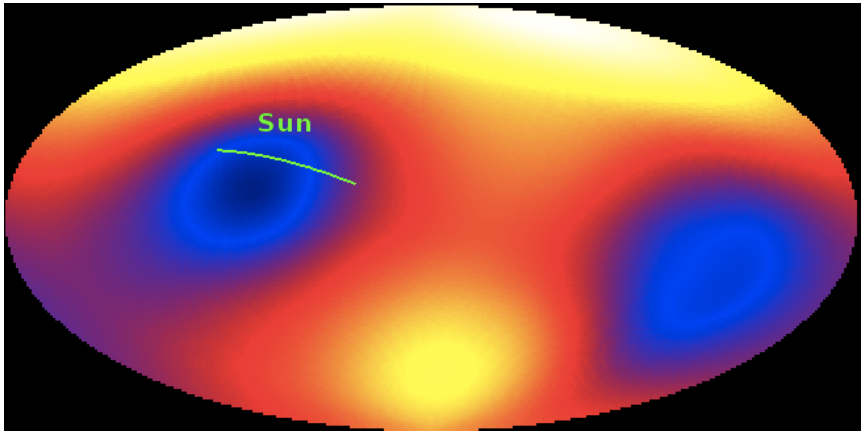
1 week



2 weeks



1 month

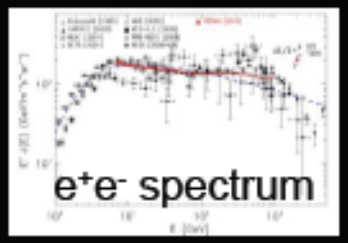


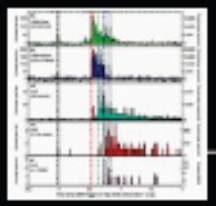
Minima 20-25% of maxima

Average over one year similar to previous survey mode

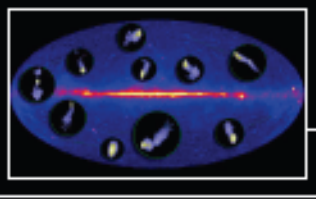
Observing profile is still being optimized

Fermi Reveals the High-Energy Universe

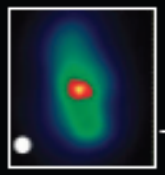




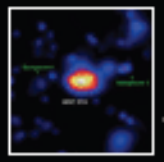
GRBs



Blazars

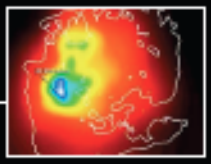


Radio Galaxies

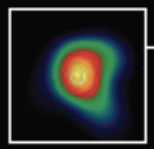


Starburst Galaxies

LMC & SMC

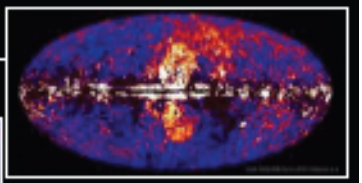


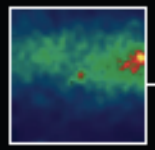
Extragalactic



Globular Clusters

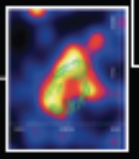
Fermi Bubbles

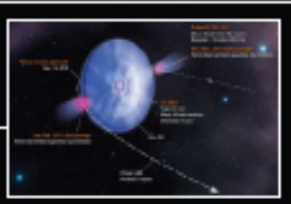




Nova

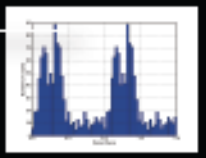
SNRs & PWN





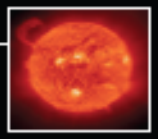
γ-ray Binaries

Pulsars: isolated, binaries, & MSPs



Local

Sun: flares & CR interactions



Terrestrial γ-ray Flashes

Unassociated Sources
(1010 of 3033)

Neutrino Gamma-ray Connection

Hadronuclear (e.g. star burst galaxies and galaxy clusters)

$$pp \rightarrow \begin{cases} \pi^0 \rightarrow \gamma\,\gamma \\ \pi^+ \rightarrow \mu^+\,\nu_\mu \rightarrow e^+\,\nu_e\,\nu_\mu\,\bar{\nu}_\mu \\ \pi^- \rightarrow \mu^-\,\bar{\nu}_\mu \rightarrow e^-\,\bar{\nu}_e\,\bar{\nu}_\mu\,\nu_\mu \end{cases}$$

TeV gamma-rays cascade down to lower energies

Photohadronic (e.g. gamma-ray bursts, active galactic nuclei)

$$p\gamma \rightarrow \Delta^+ \rightarrow \begin{cases} p\,\pi^0 \rightarrow p\,\gamma\,\gamma \\ n\,\pi^+ \rightarrow n\,\mu^+\,\nu_\mu \rightarrow n\,e^+\,\nu_e\,\bar{\nu}_\mu\,\nu_\mu \end{cases}$$

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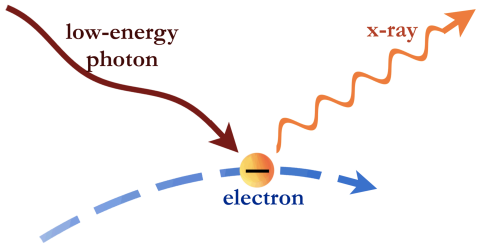
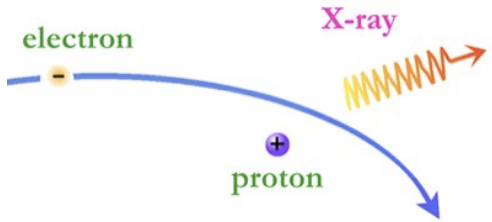
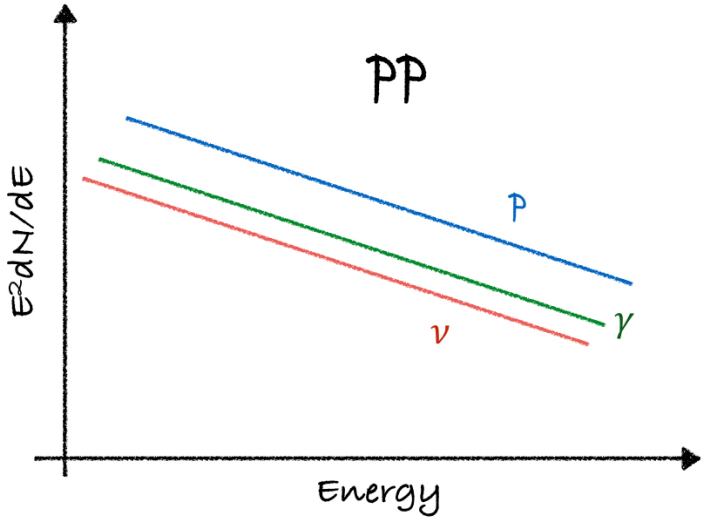
Gamma-rays are not exclusively produced in hadronic processes

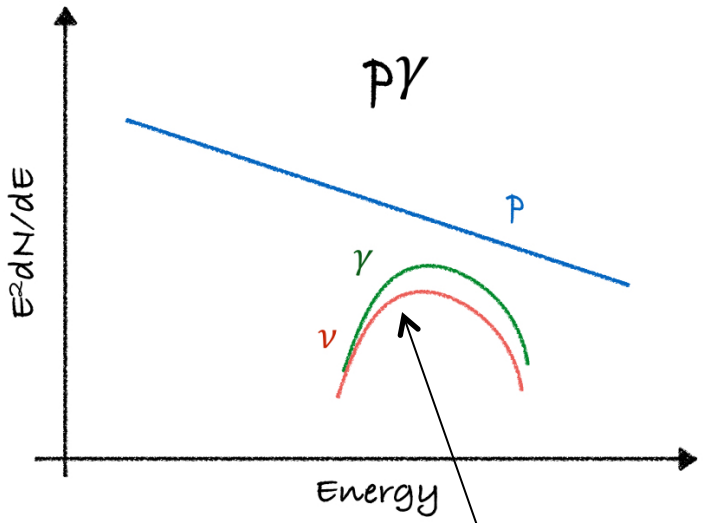




Expected Spectral Shape

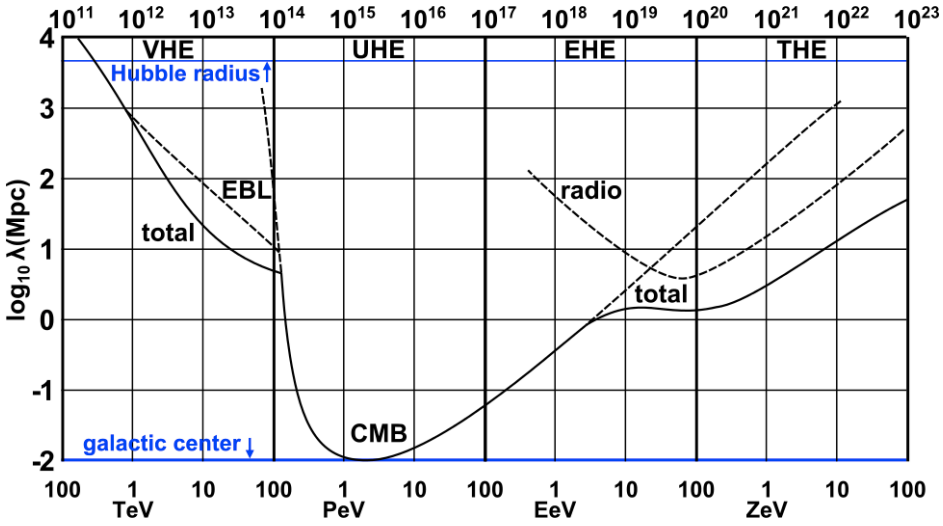
At the source



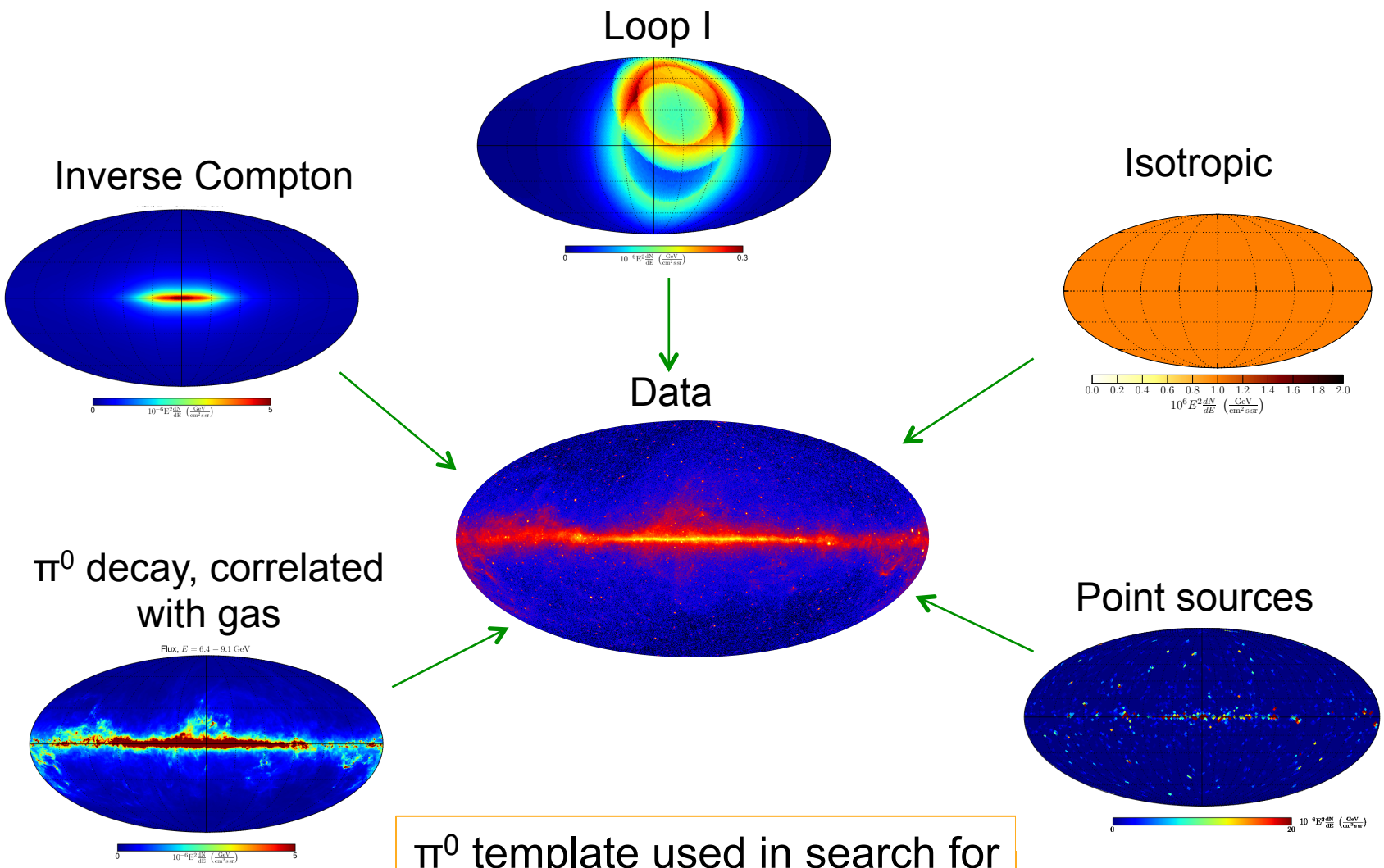


Peak position depends on photon field

High-energy photons will cascade down



The Gamma-ray Sky

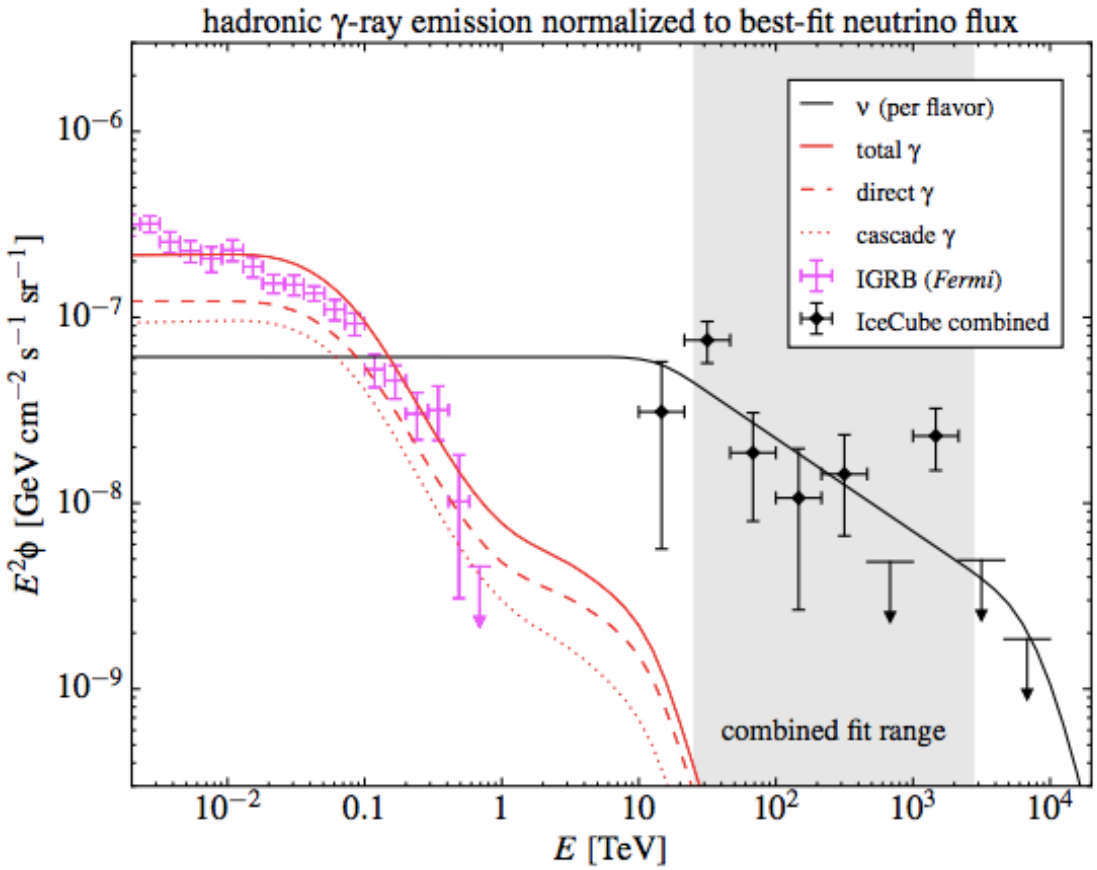


π^0 template used in search for neutrinos from Galactic plane

Fermi-LAT Coll. ApJ 750 (2012), IceCube Coll., ApJ 849 (2017)

Extragalactic Gamma-ray Background

Generic Calorimetric Sources

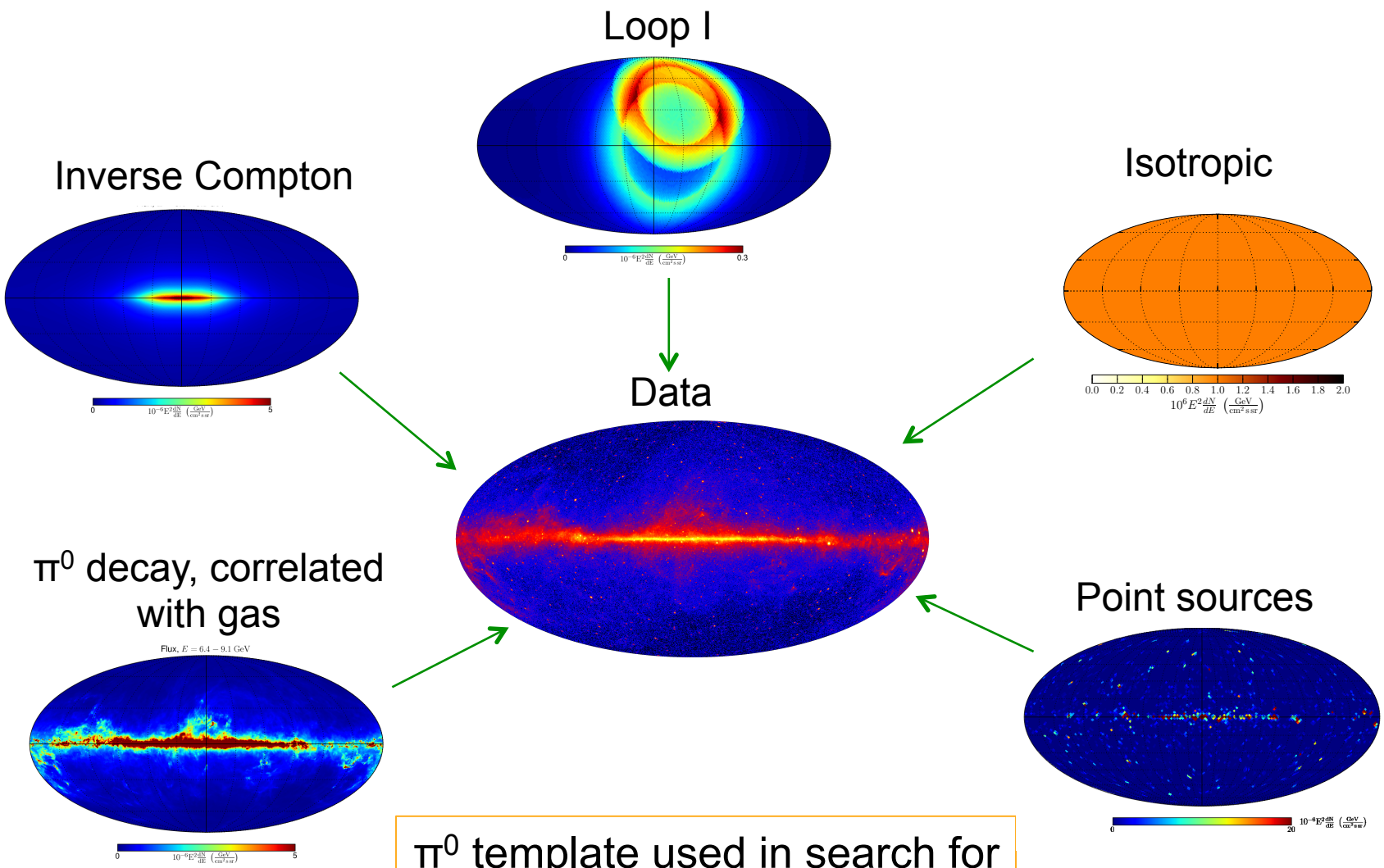


Fit to diffuse neutrino flux

Extragalactic gamma-ray background constrains neutrino source classes

Bechtol et al. ApJ 836 (2017)

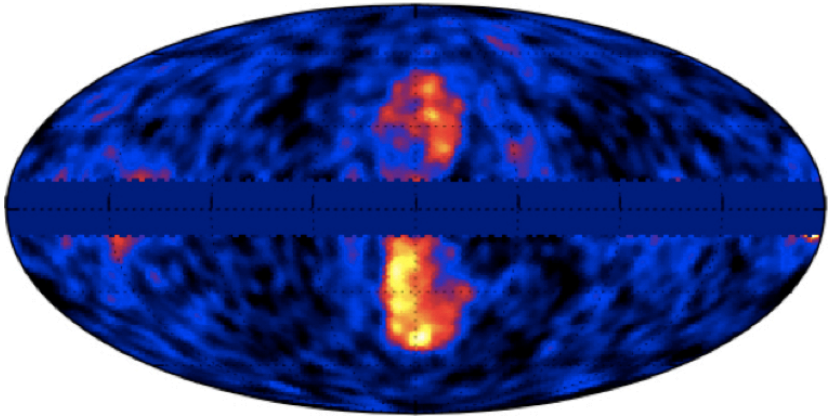
The Gamma-ray Sky

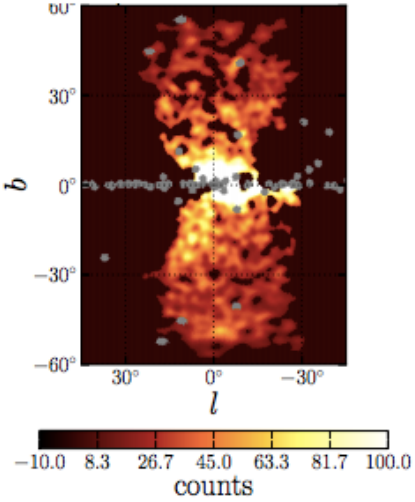


Fermi-LAT Coll. ApJ 750 (2012), IceCube Coll., ApJ 849 (2017)

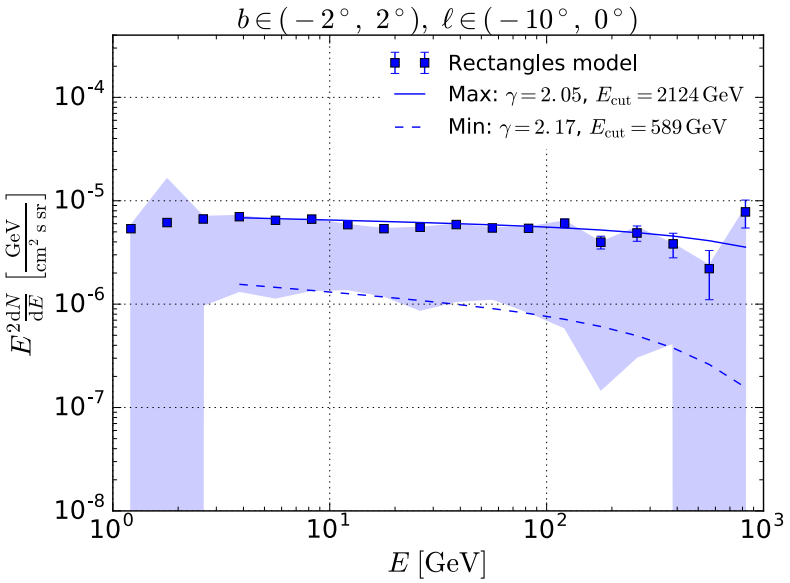
Fermi Bubbles

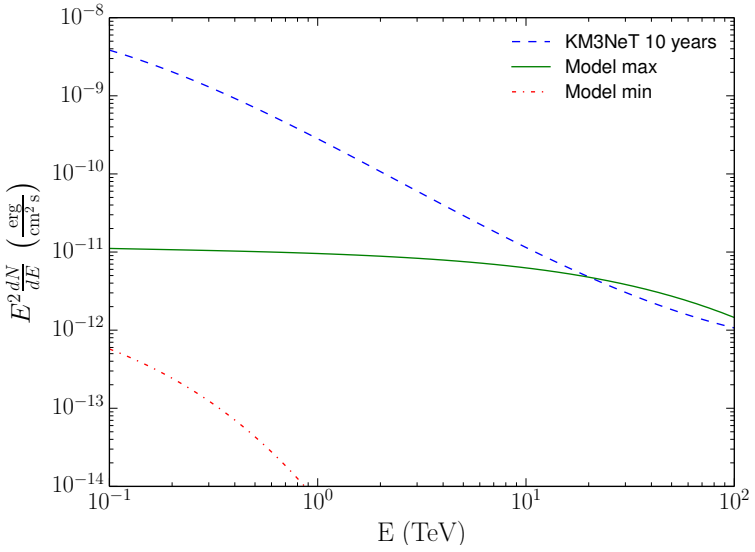
Remnant of jets? Wind driven by star formation?





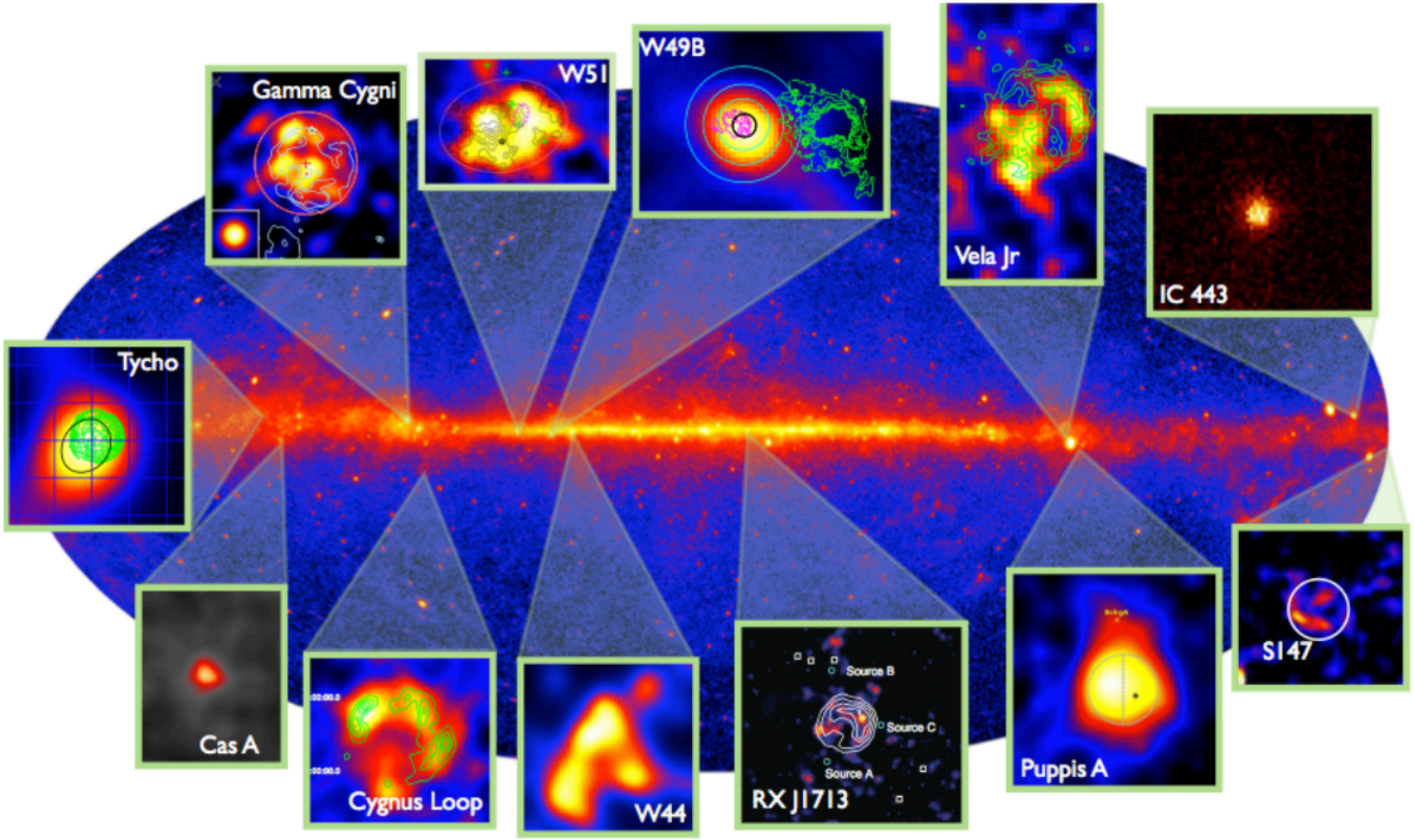
Brightening of the bubbles towards the base





Fermi-LAT Collaboration, ApJ 793 (2014), D. Malyshev, TeVPA 2018

Supernova Remnants (SNRs)



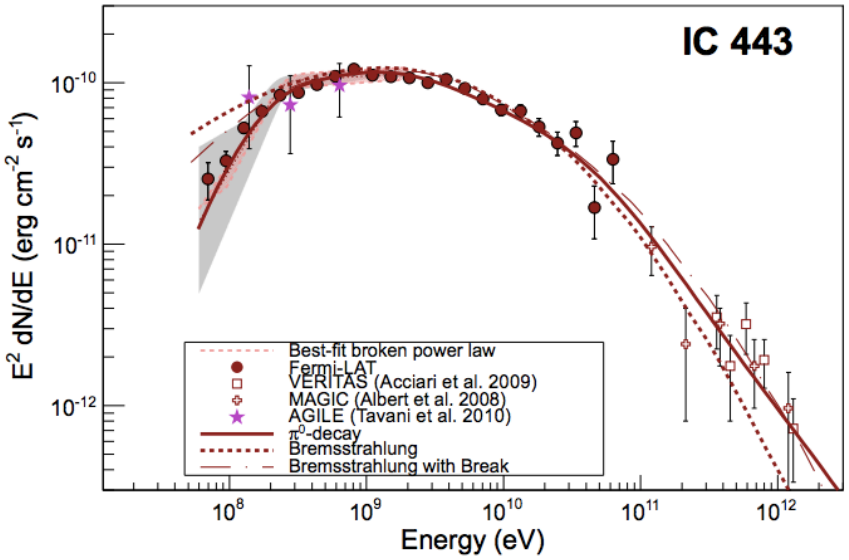
- 3 years data, 279 positions studied, 102 detections
- Population studies, spectral and morphology studies
- Diffuse emission modeling systematics

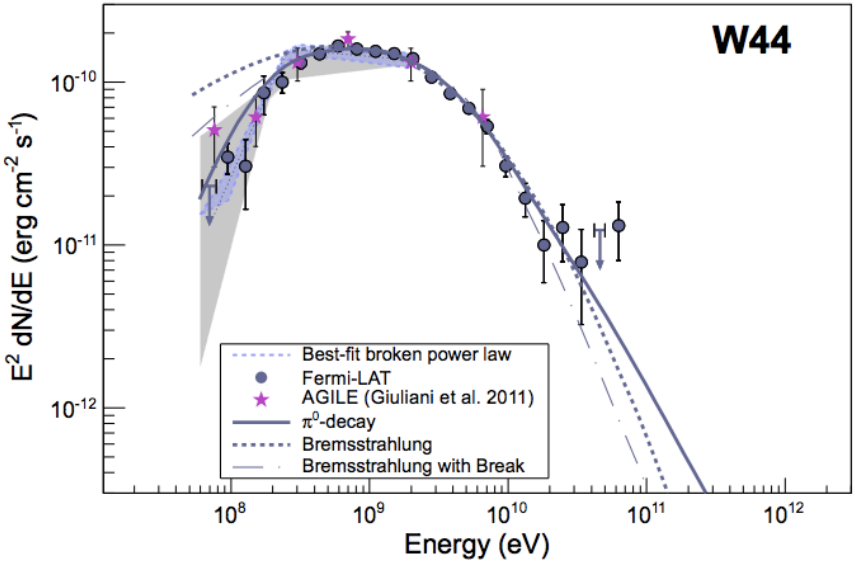
Tracing particle acceleration

Fermi-LAT Collaboration, ApJS 224, 2016

Pion Bump in SNRs

Direct evidence for hadronic acceleration

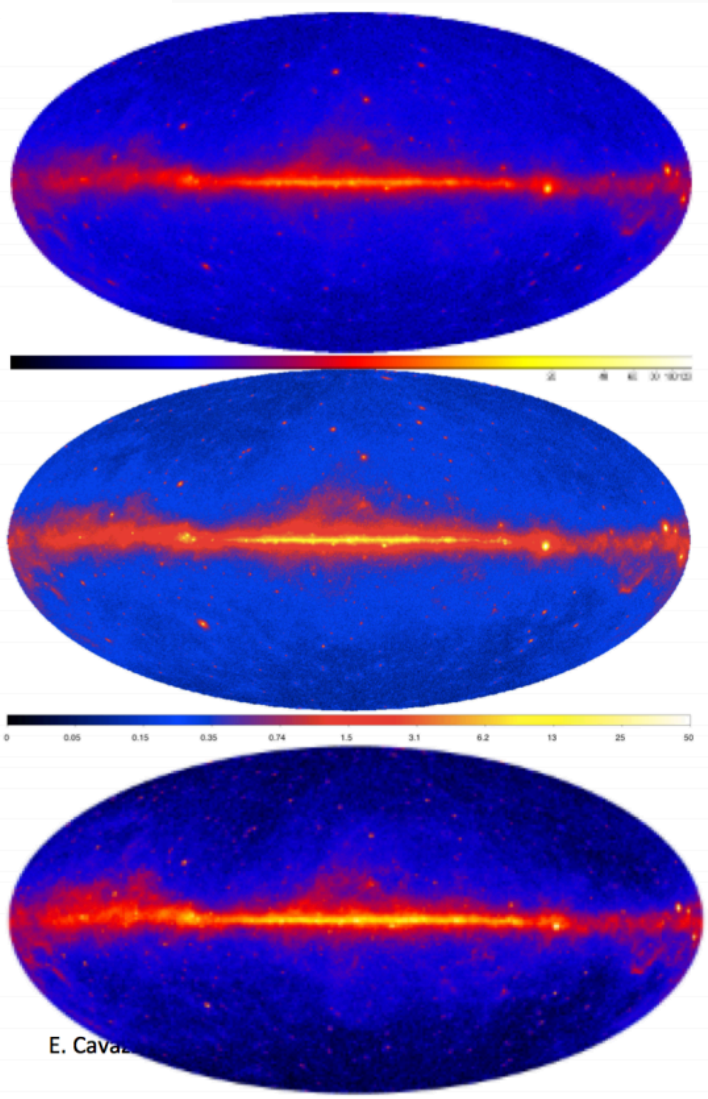




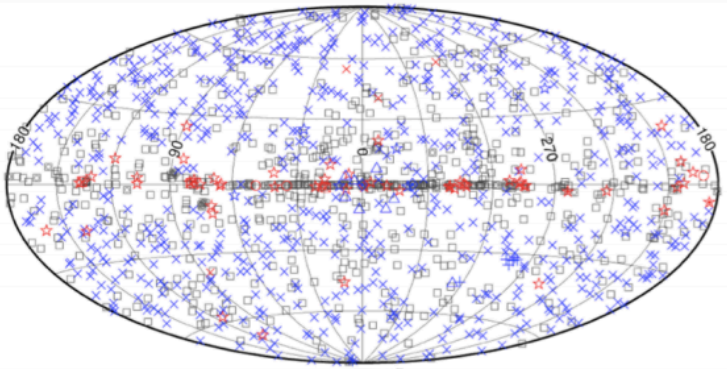
Confirmed pion bump signature in 3 SNRs.
However, those are not PeVatrons.

Fermi-LAT Collaboration, Science 339 (2013)

Individual Sources - Catalogs

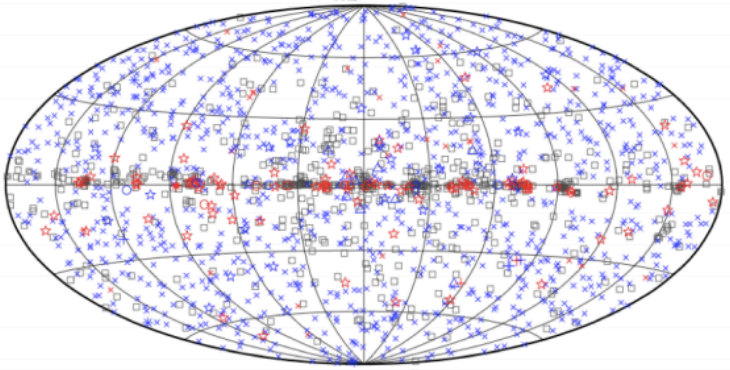


1FGL
11 m



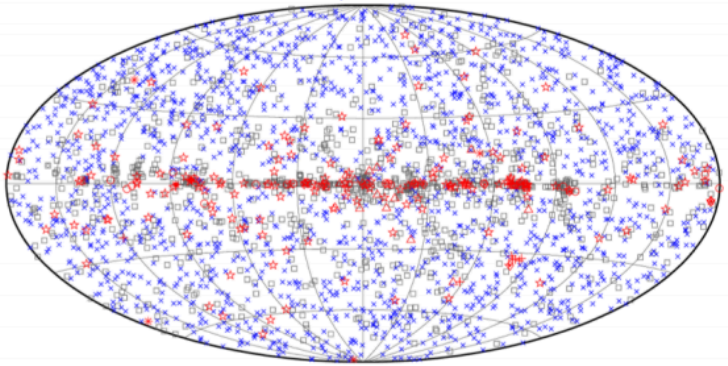
1451 sources

2FGL
2 y



1873 sources

3FGL
4 y



3033 sources

Acero et al. ApJSS, 218, 41 (2015)

Individual Sources - Catalogs

Preliminary 8-year source list: FL8Y

Table 5. LAT FL8Y Source Classes

Description	Identified		Associated	
	Designator	Number	Designator	Number
Pulsar, identified by pulsations	PSR	184	...	...
Pulsar, no pulsations seen in LAT yet	...	...	psr	34
Pulsar wind nebula	PWN	8	pwn	11
Supernova remnant	SNR	22	snr	17
Supernova remnant / Pulsar wind nebula	...	...	spp	96
Globular cluster	GLC	0	glc	28
High-mass binary	HMB	4	hmb	2
Binary	BIN	1	bin	1
Nova	NOV	1	nov	0
Star-forming region	SFR	1	sfr	1
Compact Steep Spectrum Quasar	CSS	0	css	1
BL Lac type of blazar	BLL	22	bll	1008
FSRQ type of blazar	FSRQ	42	fsrq	618
Non-blazar active galaxy	AGN	0	agn	16
Radio galaxy	RDG	5	rdg	16
Seyfert galaxy	SEY	0	sey	1
Blazar candidate of uncertain type	BCU	5	bcu	1229
Normal galaxy (or part)	GAL	2	gal	2
Starburst galaxy	SBG	0	sbg	4
Narrow line Seyfert 1	NLSY1	3	nlsy1	6
Soft spectrum radio quasar	SSRQ	0	ssrq	1
Total	...	300	...	3092
Unassociated	...	...	...	2131

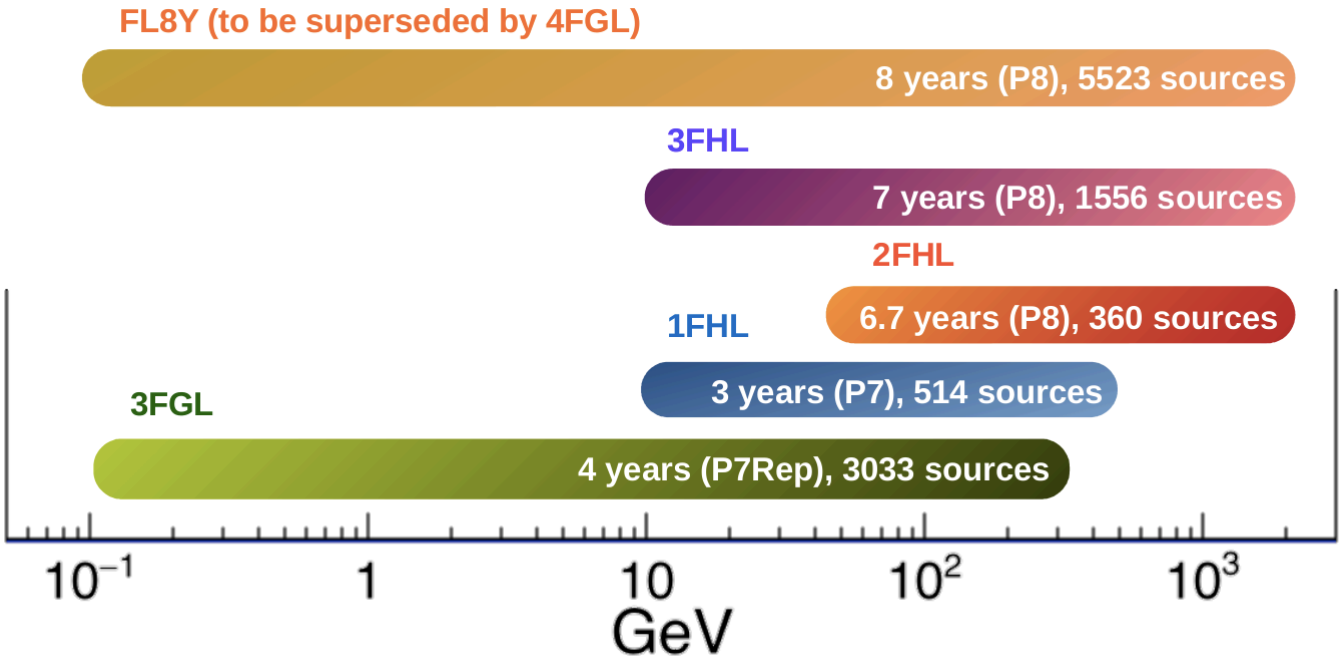
preliminary

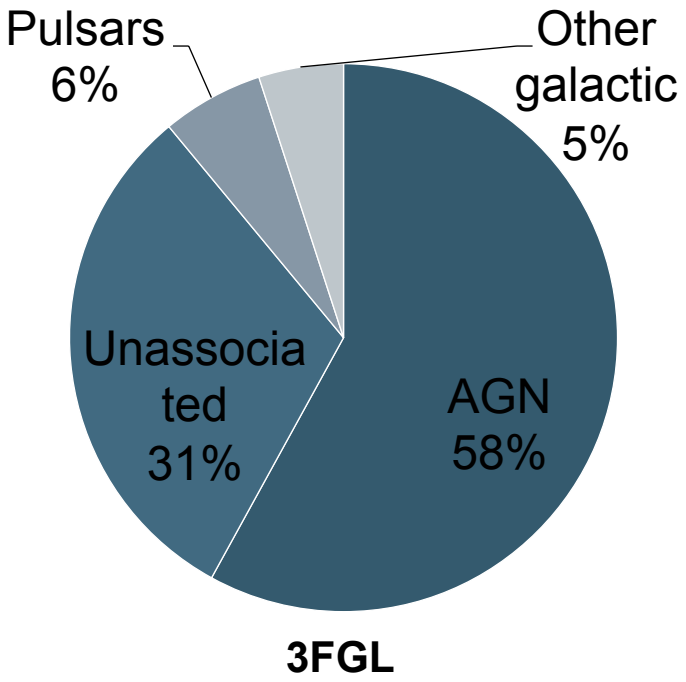
5523 sources

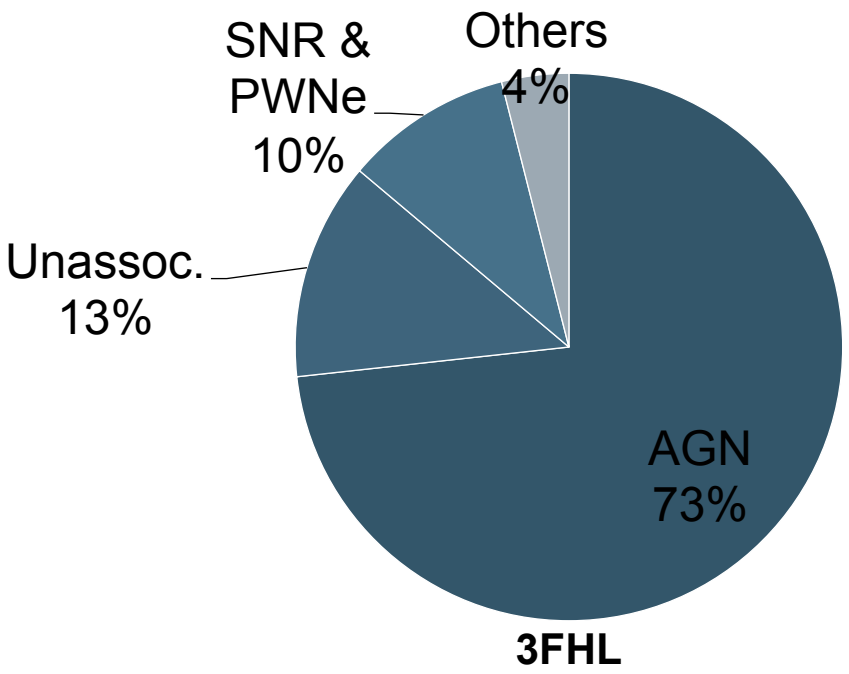
2131 unidentified

>2900 AGN and blazars

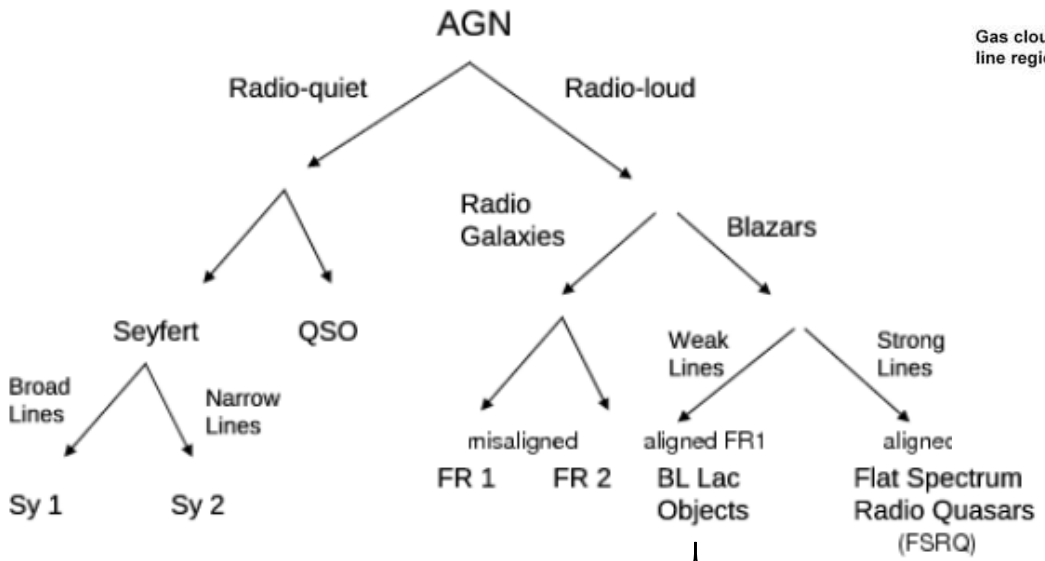
https://fermi.gsfc.nasa.gov/ssc/data/access/lat/fl8y/

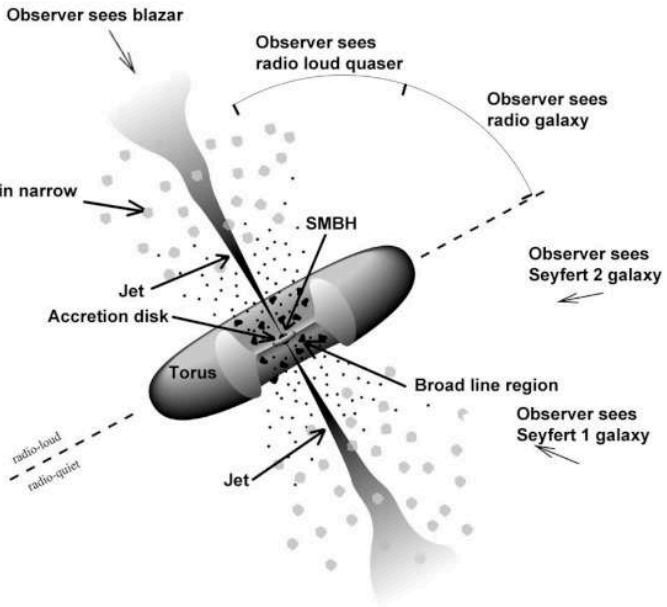

FL8Y (to be superseded by 4FGL)
8 years (P8), 5523 sources
3FHL
7 years (P8), 1556 sources
2FHL
6.7 years (P8), 360 sources
1FHL
3 years (P7), 514 sources
3FGL
4 years (P7Rep), 3033 sources
10^{-1}
1
10
10^2
10^3
GeV

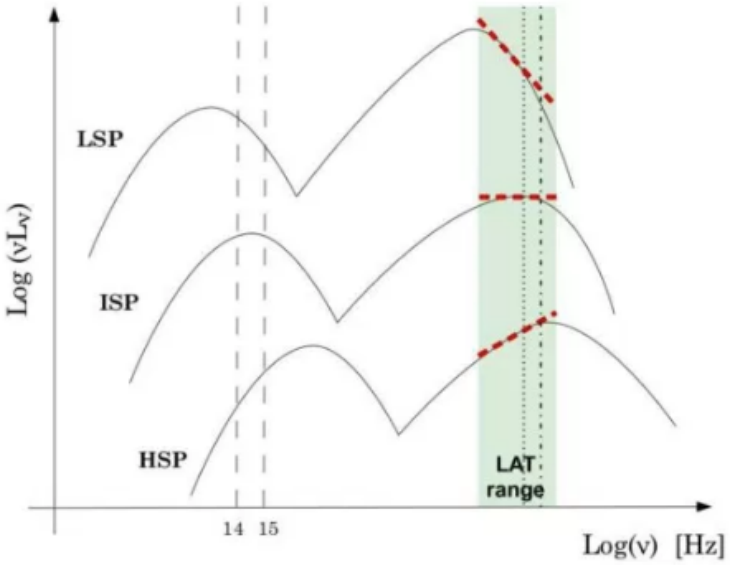

Pulsars
6%
Other
galactic
5%
Unassocia
ted
31%
AGN
58%
3FGL


SNR &
PWNe
10%
Others
4%
Unassoc.
13%
AGN
73%
3FHL

AGN Classification



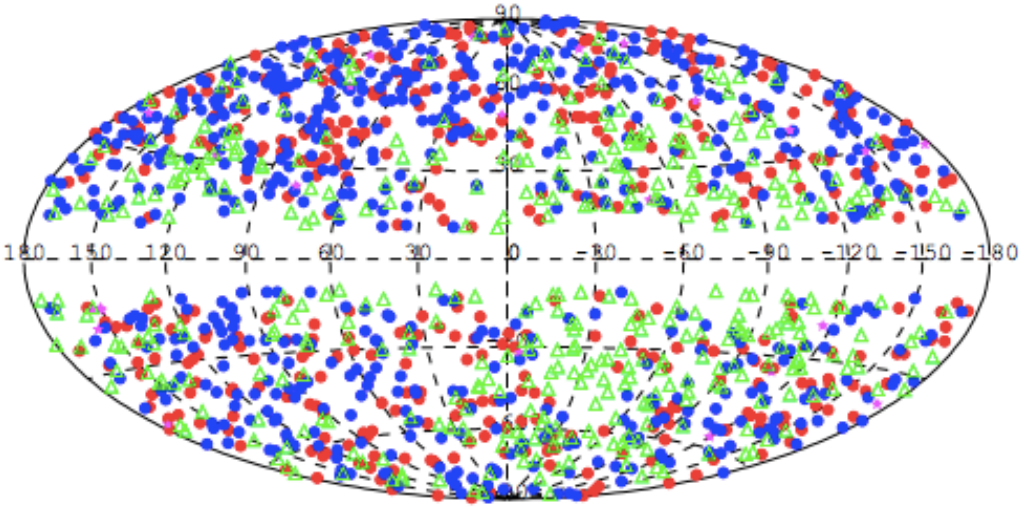




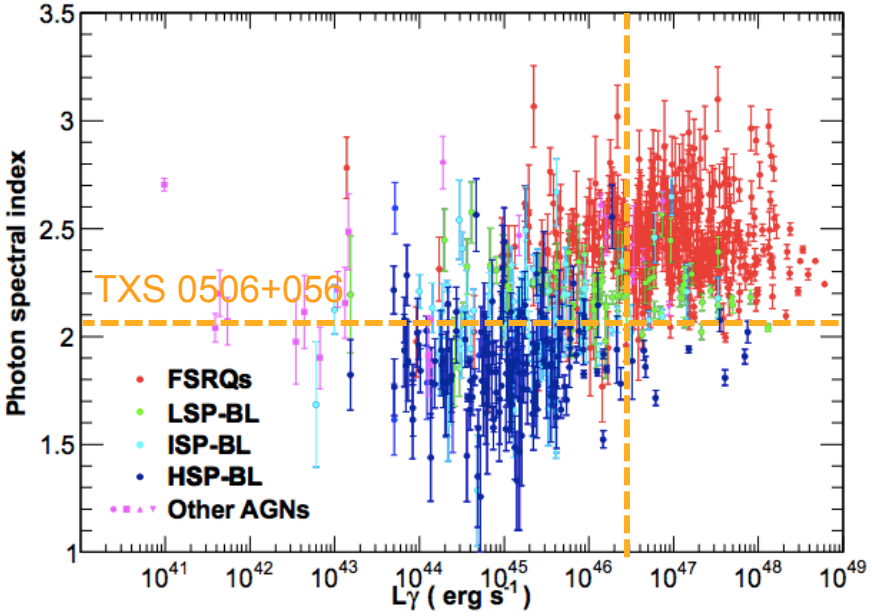
AGN Catalog

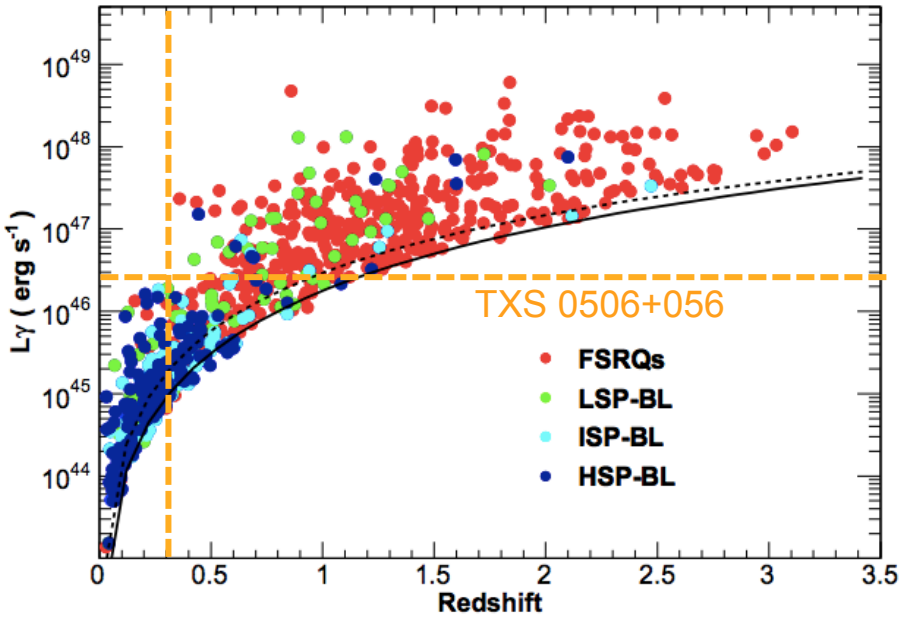
3LAC

1563 AGN, 98% blazars
467 FSRQ
632 BL Lac



TXS 0506+056: Among 50 brightest blazars (3%) in 3LAC

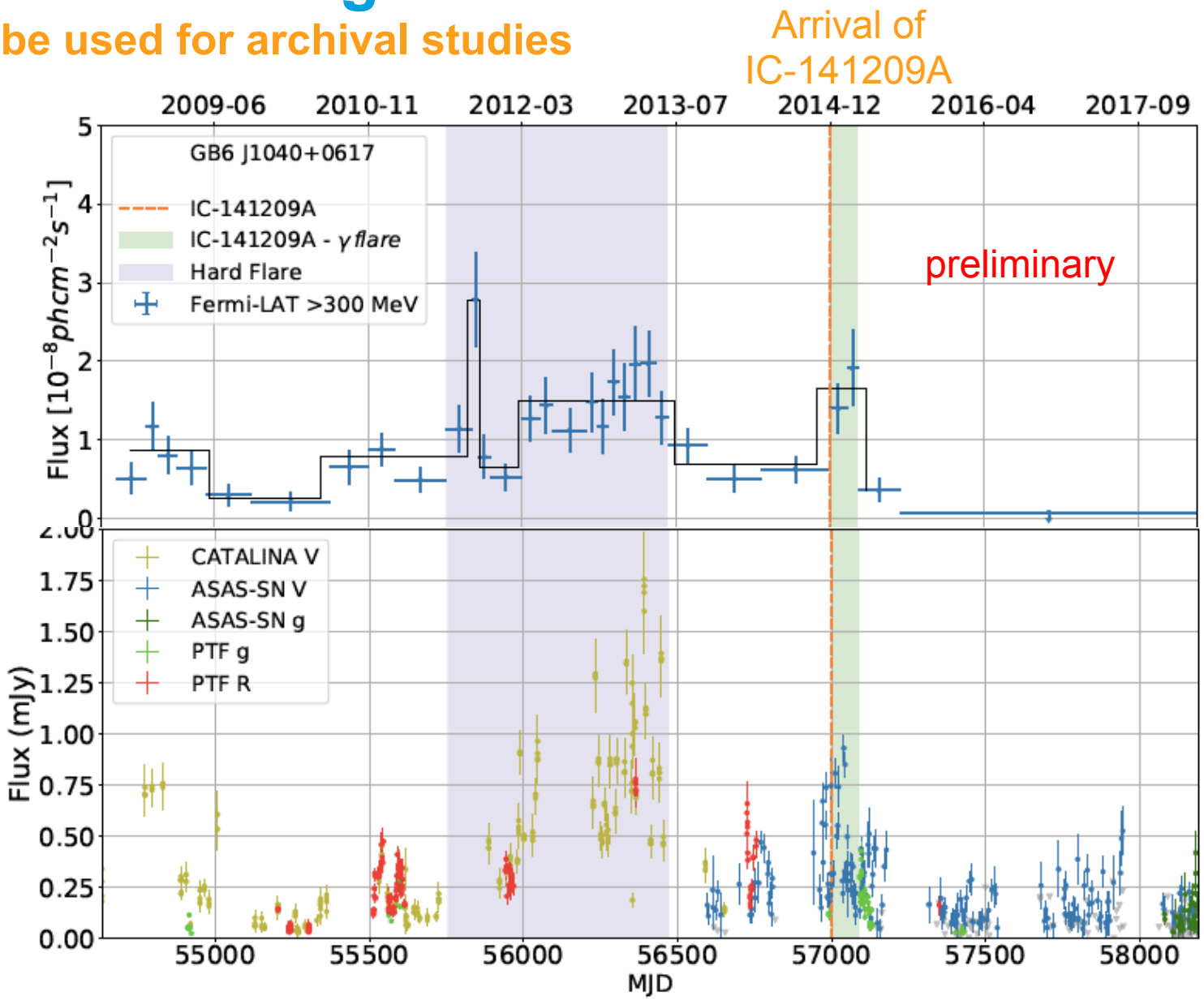




Fermi-LAT Collaboration, ApJ 810 (2015)

Continuous Light Curves

Can be used for archival studies



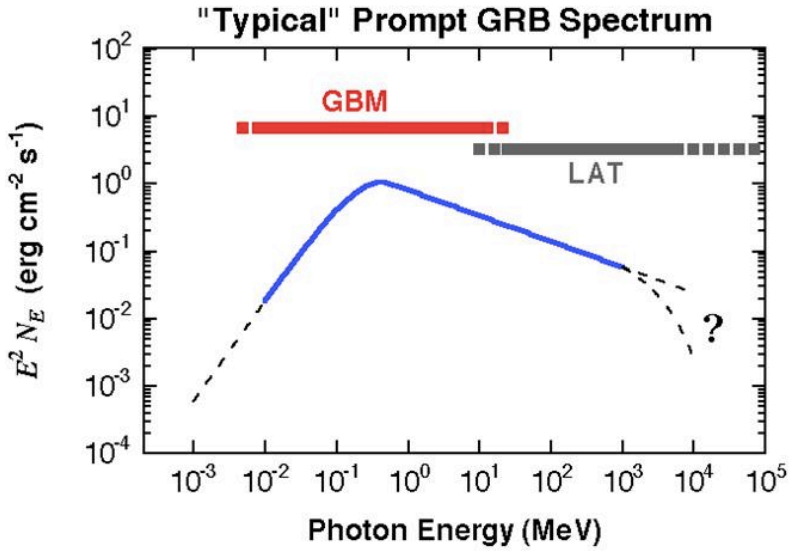
Garrappa et al. in preparation

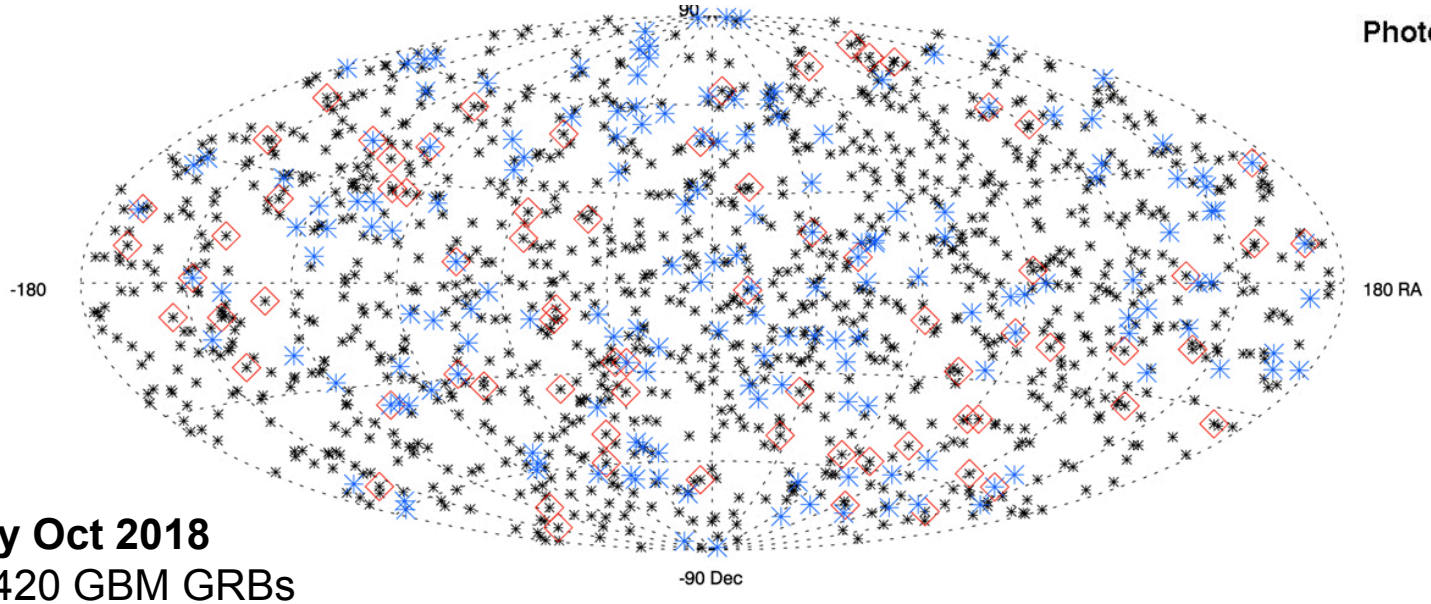
Real-time Blazar Flares

The Fermi All-sky Variability Analysis (FAVA) – weekly time scale

Gamma-ray Bursts

- GBM detects ~240 GRBs per year (~10% LAT detected).
- On-board trigger starts autonomous re-point recommendation
- Time for trigger to reach ground ~5s, GCN notice send out.



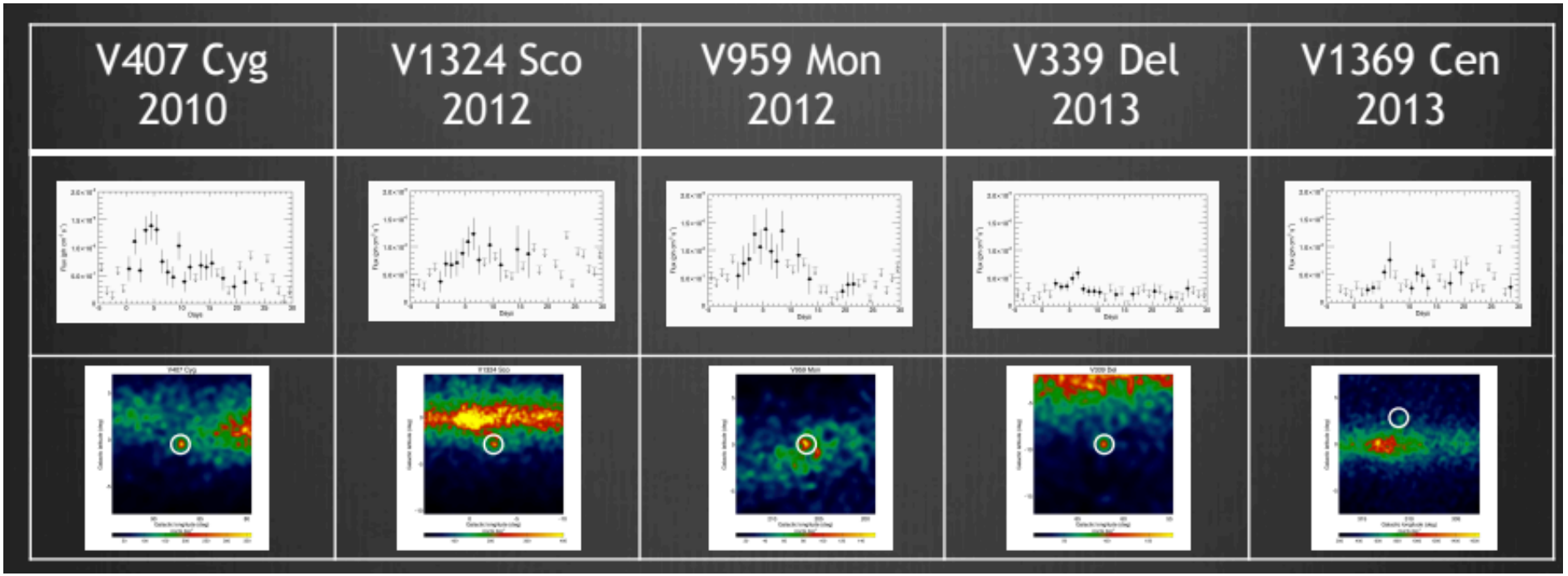


GBM position uncertainty: 5-15°, 3-5° improved localization (few hours)

By Oct 2018
2420 GBM GRBs
1247 Swift GRBs
146 LAT GRBs

Galactic Novae

An unexpected class of gamma-ray emitters

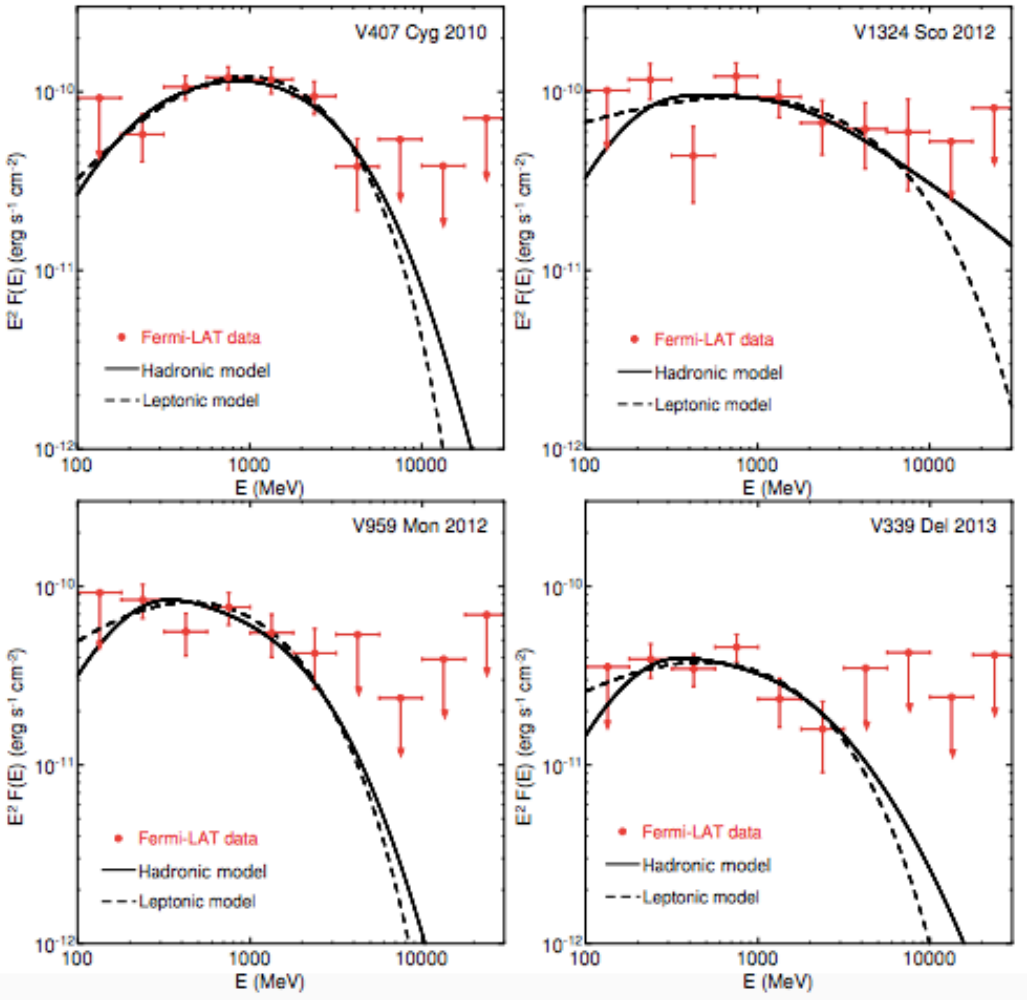


- Serendipitous discovery of gamma-ray transient at the time and location of V407 Cyg – found something that we were not looking for!
- Later found 10 more, largely due to target of opportunity

Fermi-LAT Collaboration, Science 345, 2014

Novae

Leptonic or hadronic?



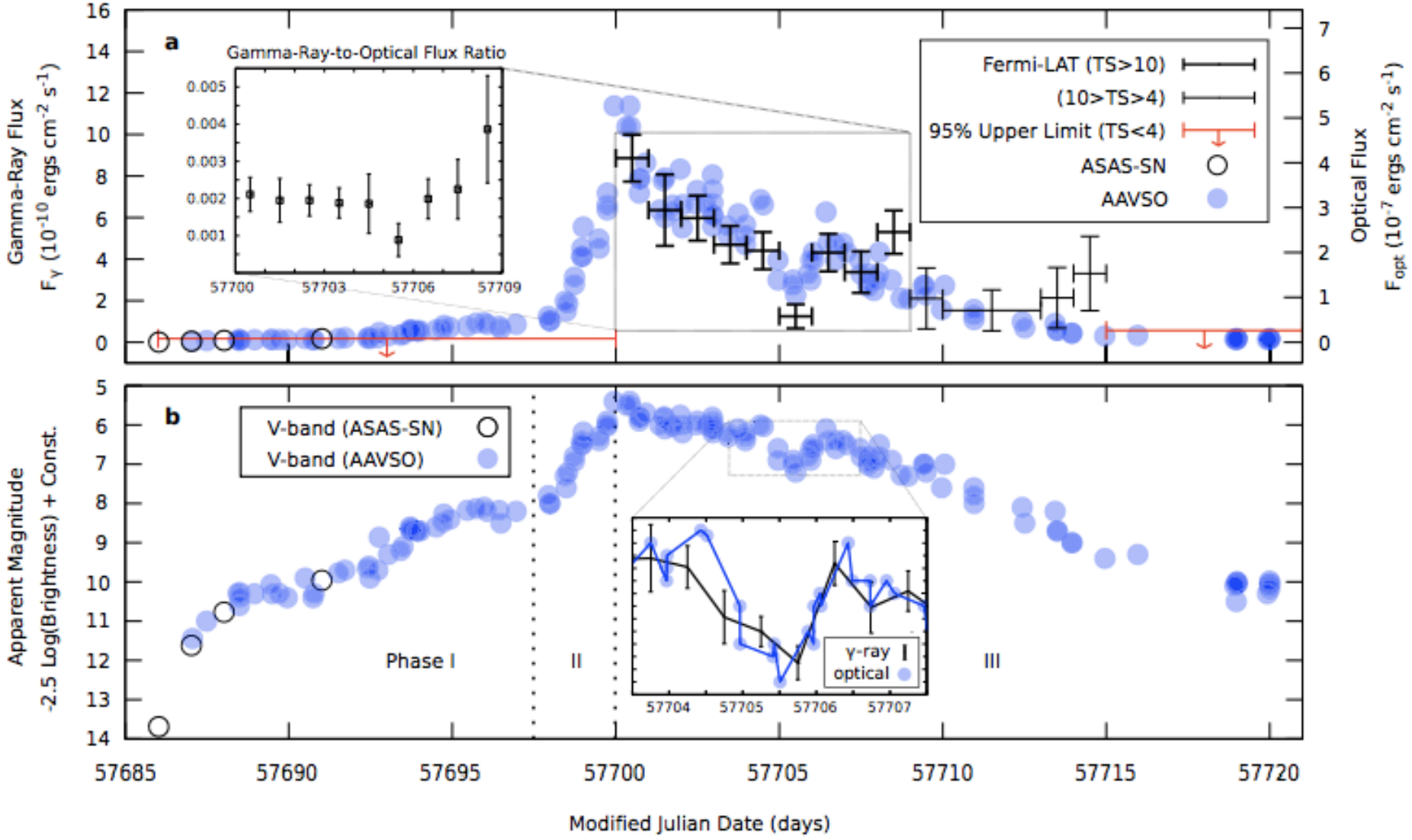
Data cannot distinguish between hadronic or leptonic spectral models

Fermi-LAT Collaboration, Science 345, 2014

Novae

Leptonic or hadronic?

Short time correlation of optical and gamma-ray → hadronic



Li et al, Nature Astronomy (2017)

Summary

- TeV Gamma-rays are produced along side high-energy neutrinos
  - Cascade down to lower energies / absorption
- Gamma-ray background constrains calorimetric sources
- Gamma-ray π^0 template is input for Galactic plane neutrino search
- Gamma-ray catalogs are a crucial input for source correlation analyses
- All-sky gamma-ray monitoring delivers transient positions and time windows for time-dependent neutrino searches

Backup

Supernovae (SNe)

Some extra-galactic SNe could be gamma-ray emitters

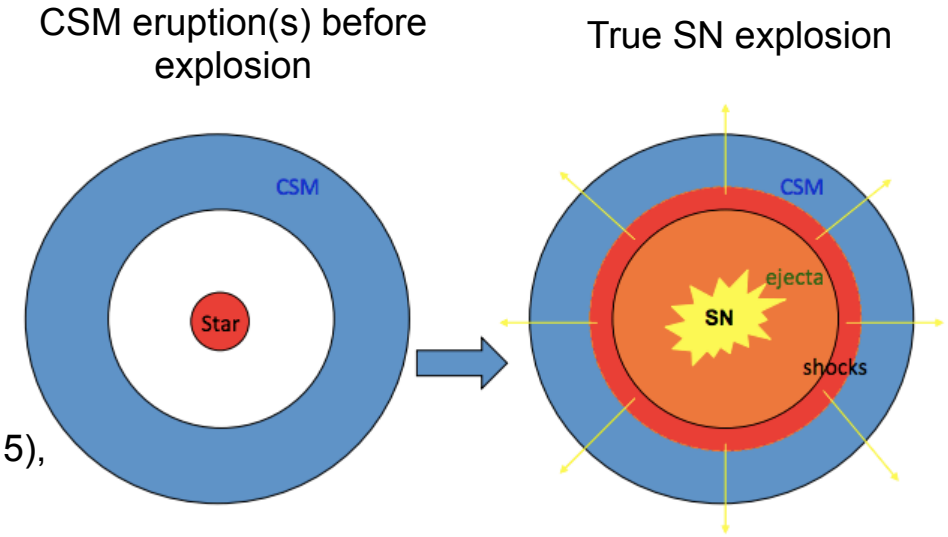
Stacking

- interacting SNe
- Superluminous Sne

No excess found

→ Upper limits

Fermi-LAT Collaboration, ApJ, 807, 169 (2015),
Renault-Tinacci, A&A 611, A45 (2018)



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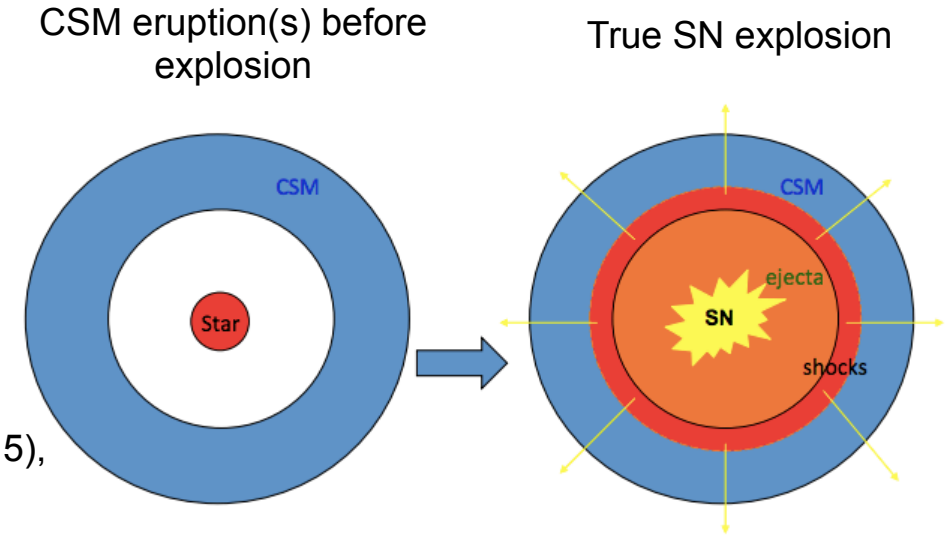
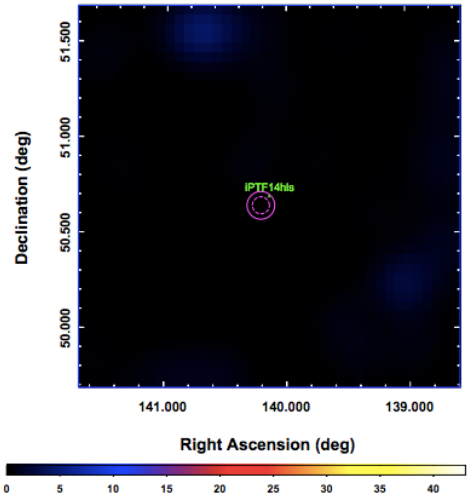
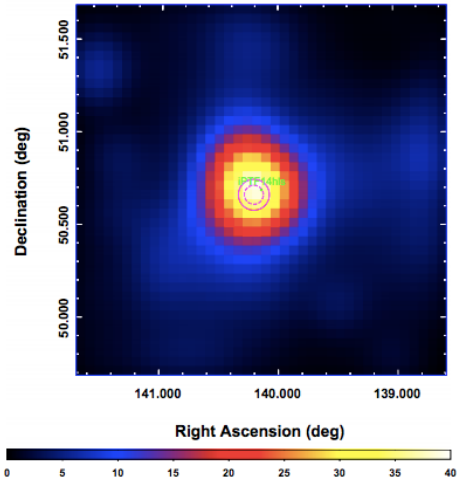
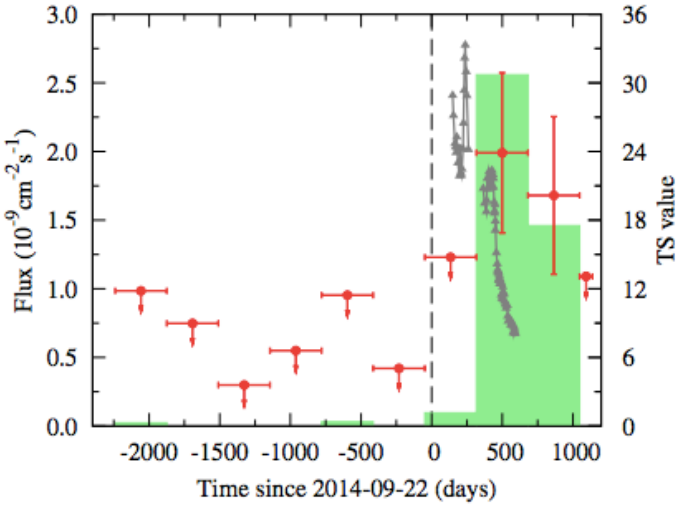


Gamma-ray emission from peculiar SN iPTF14hls



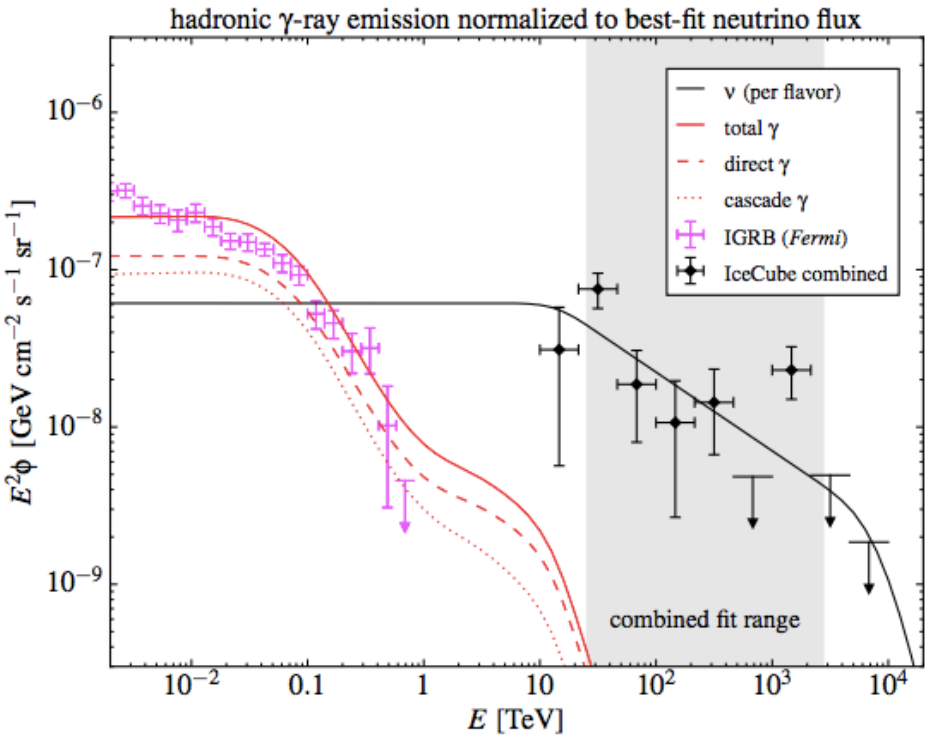




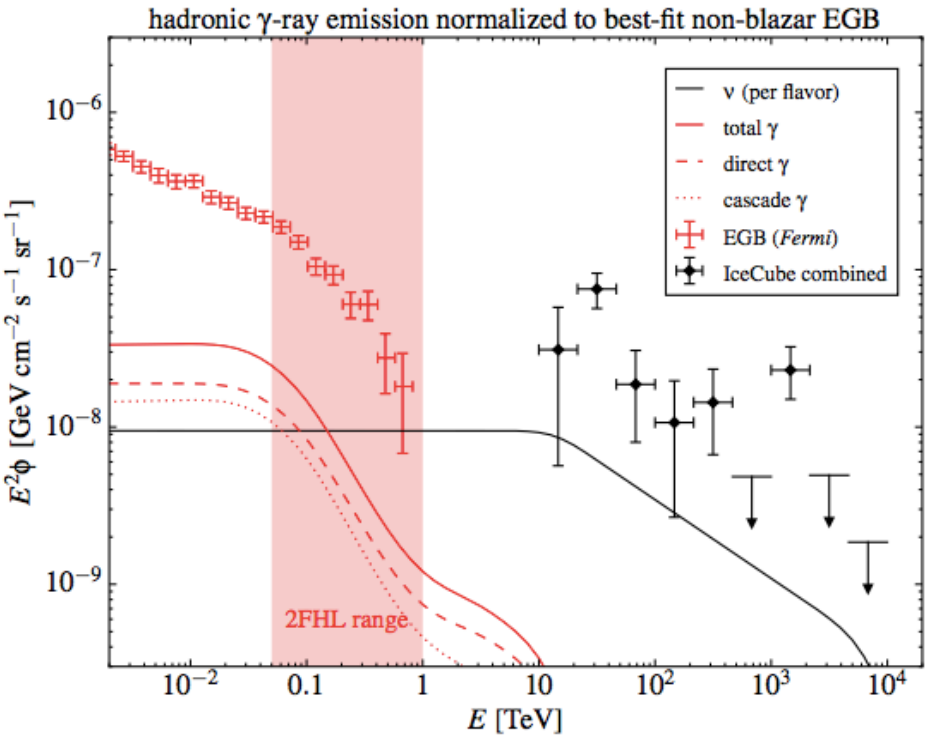
Yuan et al., ApJ 854 (2018)

Extragalactic Gamma-ray Background

Generic Calorimetric Sources



Fit to diffuse neutrino flux



Fit to saturate the 14% non-blazar contribution

Extragalactic gamma-ray background constrains neutrino source classes

Bechtol et al. ApJ 836 (2017)