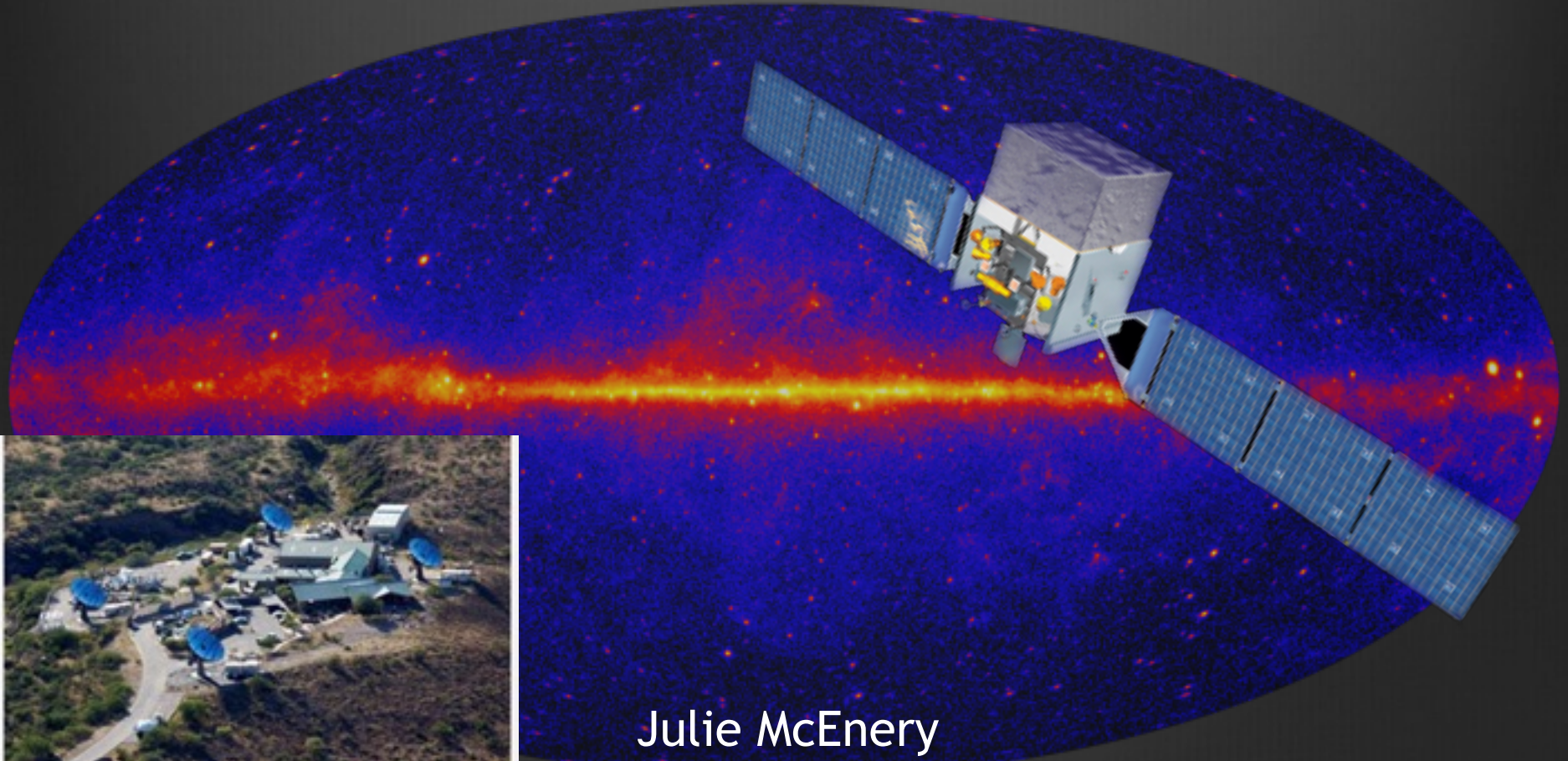


Fermi and VERITAS synergies - Past, present and future



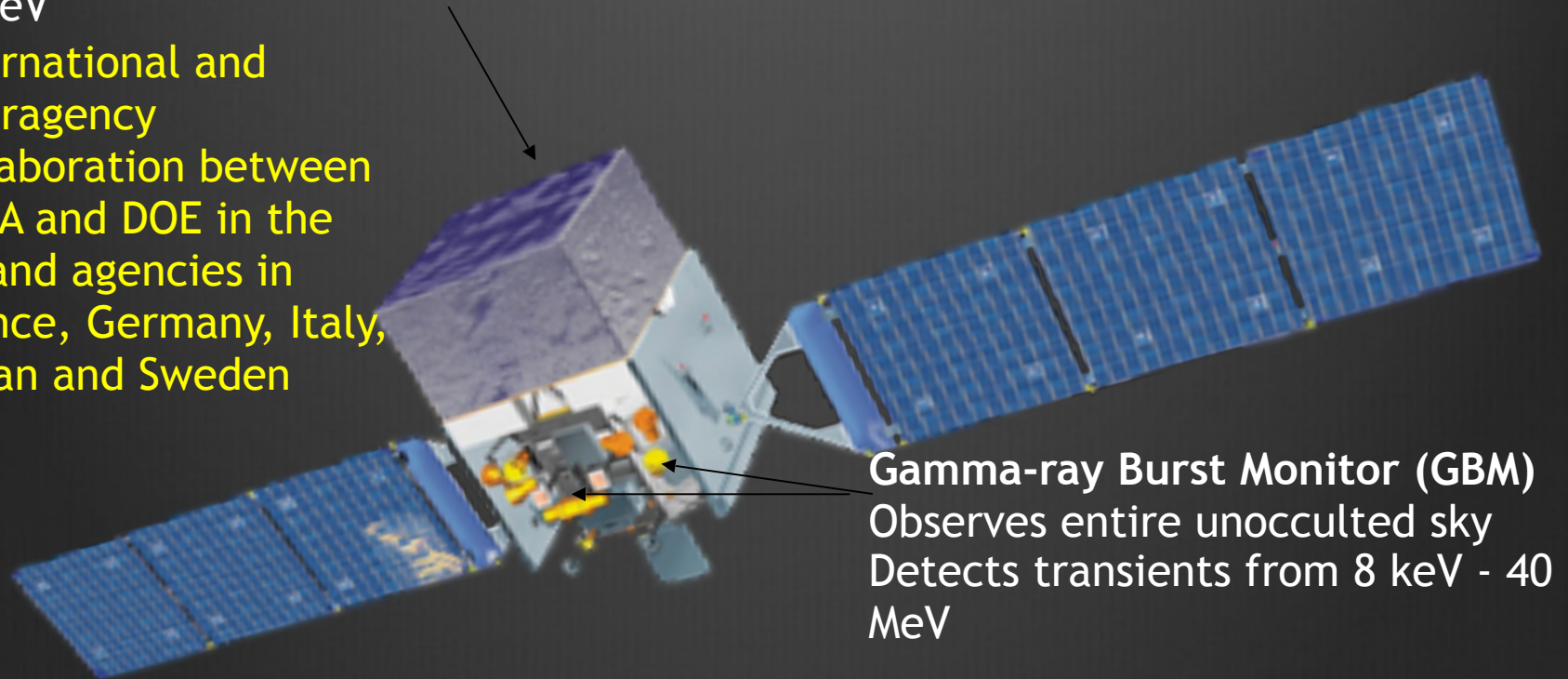
Julie McEnery
NASA/Goddard Space Flight Center

The *Fermi* Observatory

Large Area Telescope (LAT)

Observes 20% of the sky at any instant, views entire sky every 3 hrs
20 MeV - >300 GeV - includes unexplored region between 10 - 100 GeV

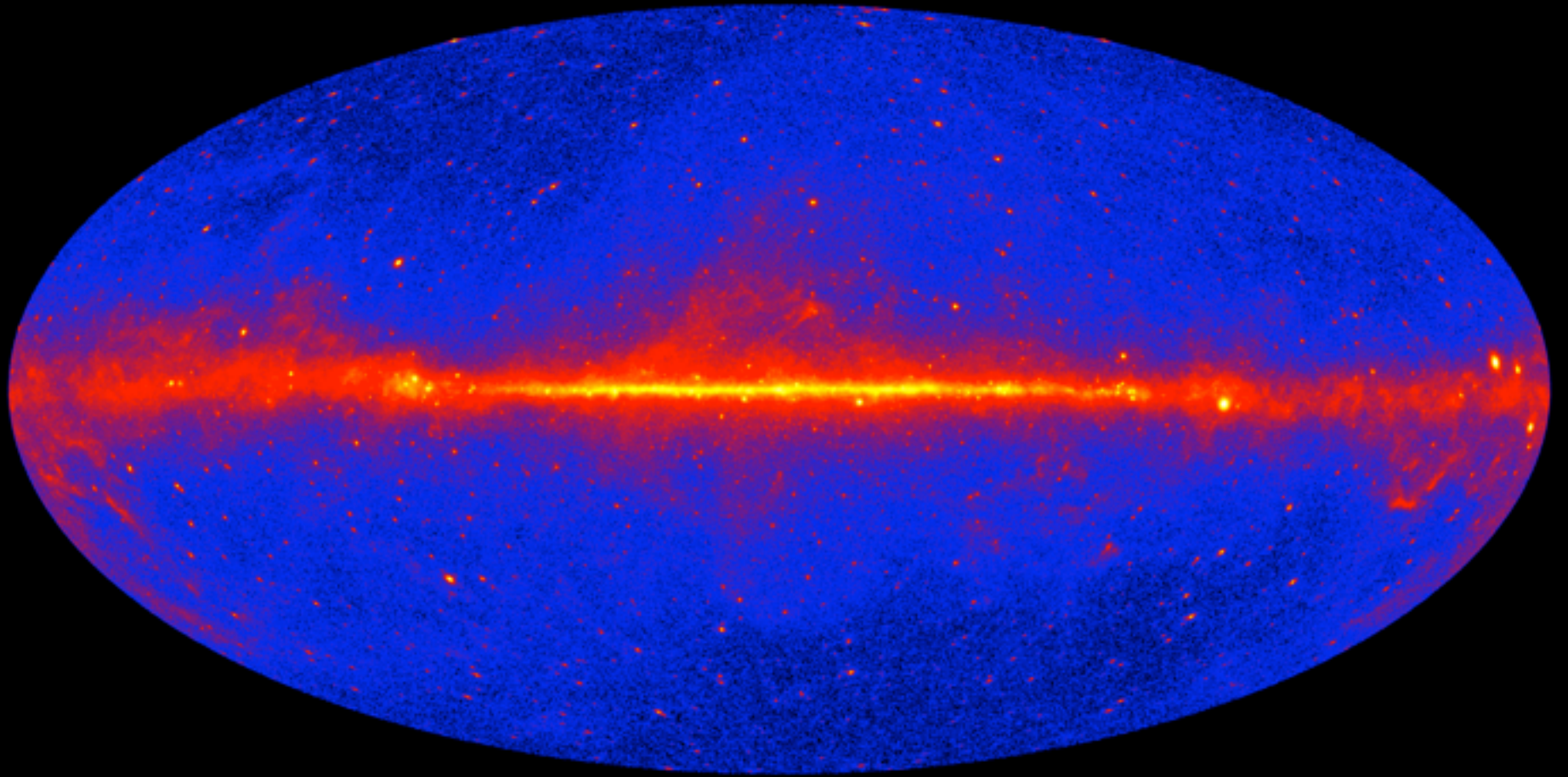
International and interagency collaboration between NASA and DOE in the US and agencies in France, Germany, Italy, Japan and Sweden



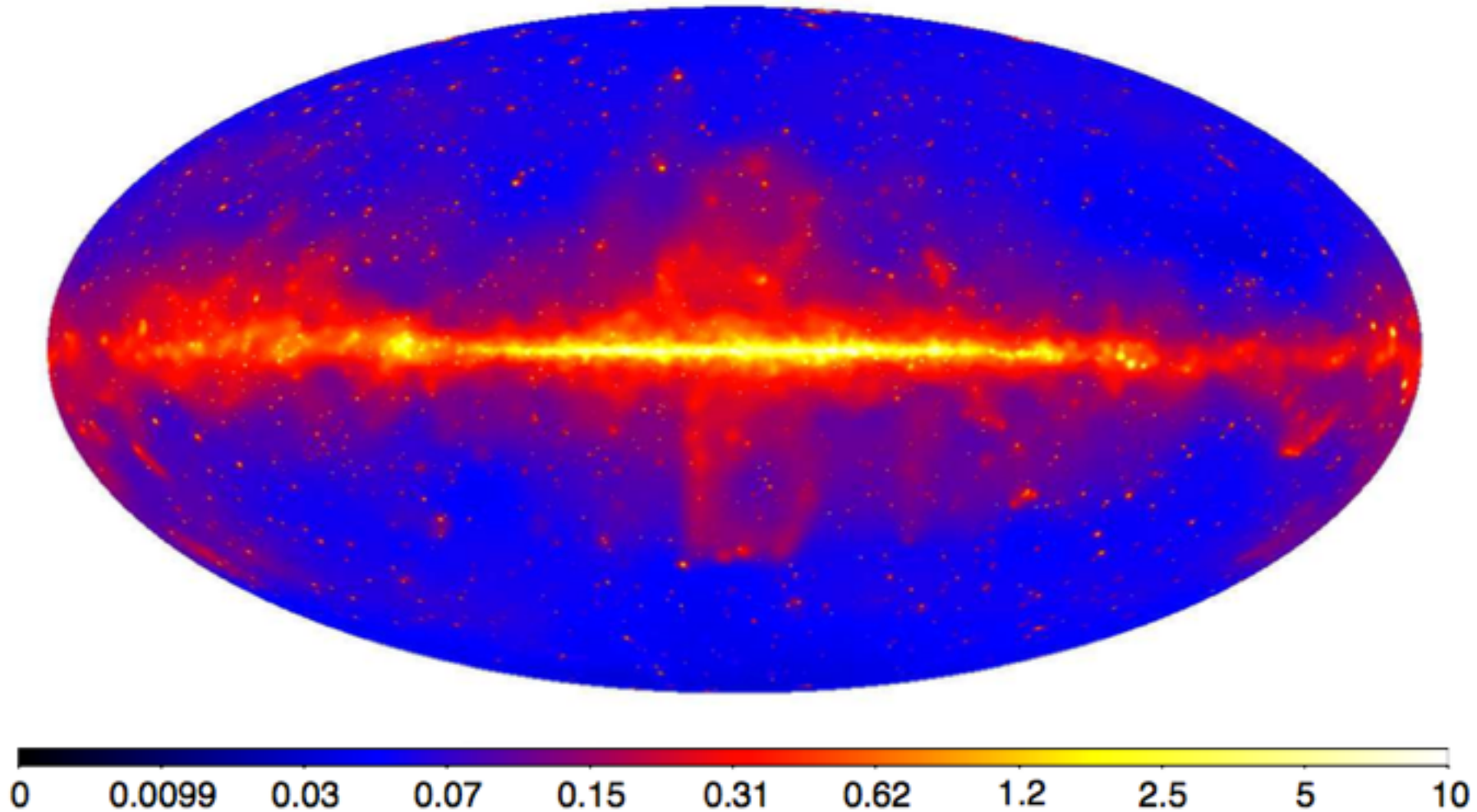
Gamma-ray Burst Monitor (GBM)

Observes entire unocculted sky
Detects transients from 8 keV - 40 MeV

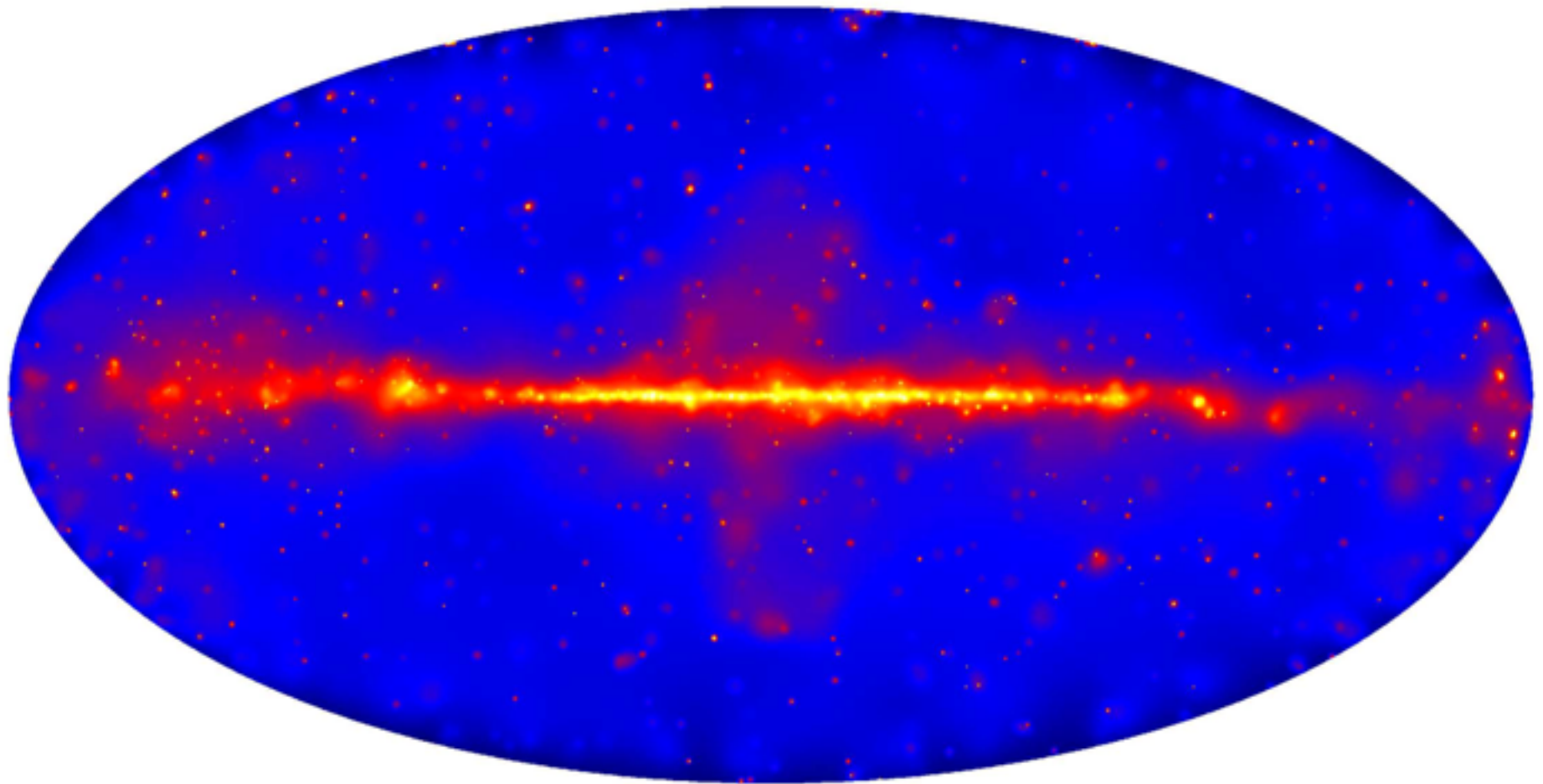
The Fermi Sky (>1 GeV)



Fermi Sky >10 GeV



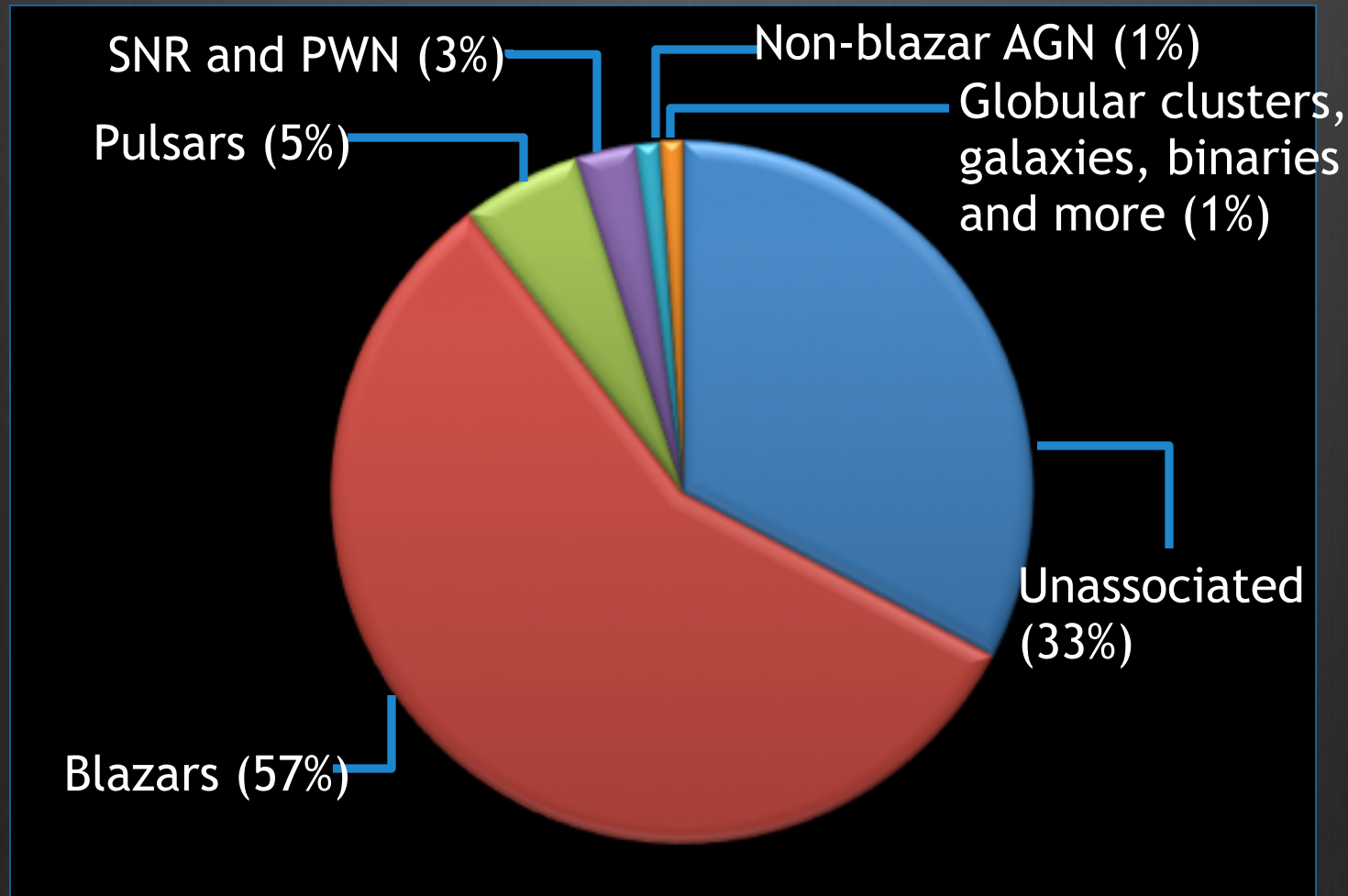
Fermi Sky (>50 GeV)



61,000 photons $E > 50$ GeV
22,100 photons $E > 100$ GeV
2,000 photons $E > 500$ GeV

80 months of P8 data (50 GeV - 2 TeV)

3rd Fermi-LAT Catalog (>100 MeV)

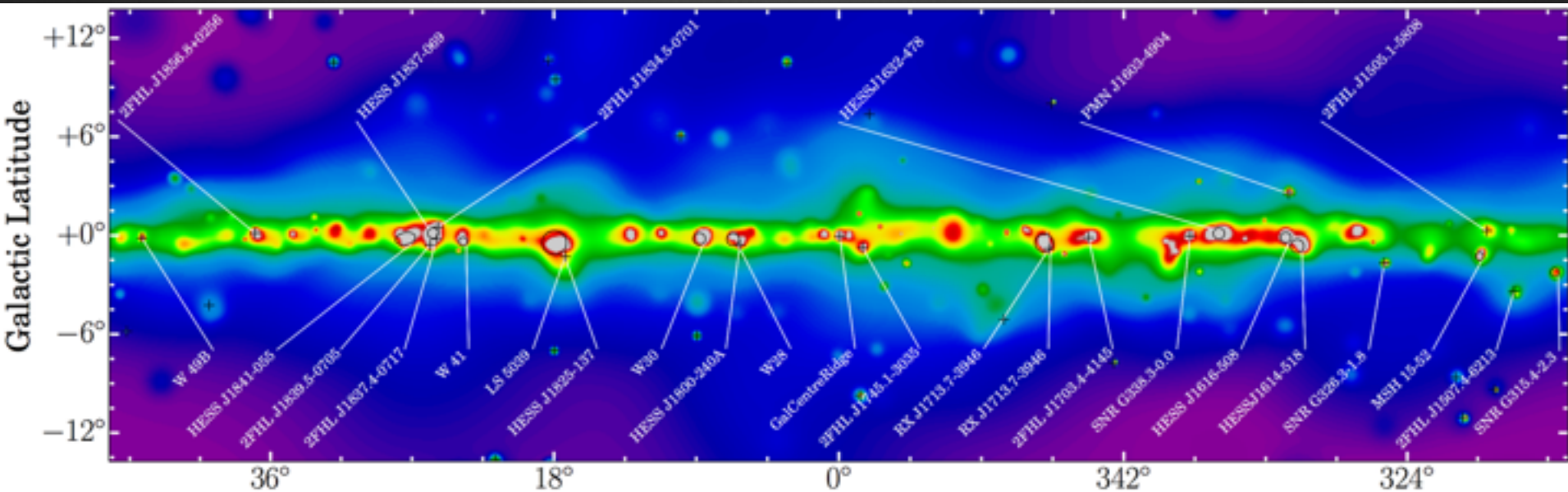


🌀 4 years of P7 Rep data, >3000 sources

🌀 4FGL comes out later this year...

2nd Hard Source Catalog


- 6 years, Pass 8 data
- 50 GeV - 2 TeV
- 360 sources (75% extragalactic, 11% Galactic, 13% unassociated)
 - 47 new gamma-ray sources (not in any previous gamma-ray catalog)



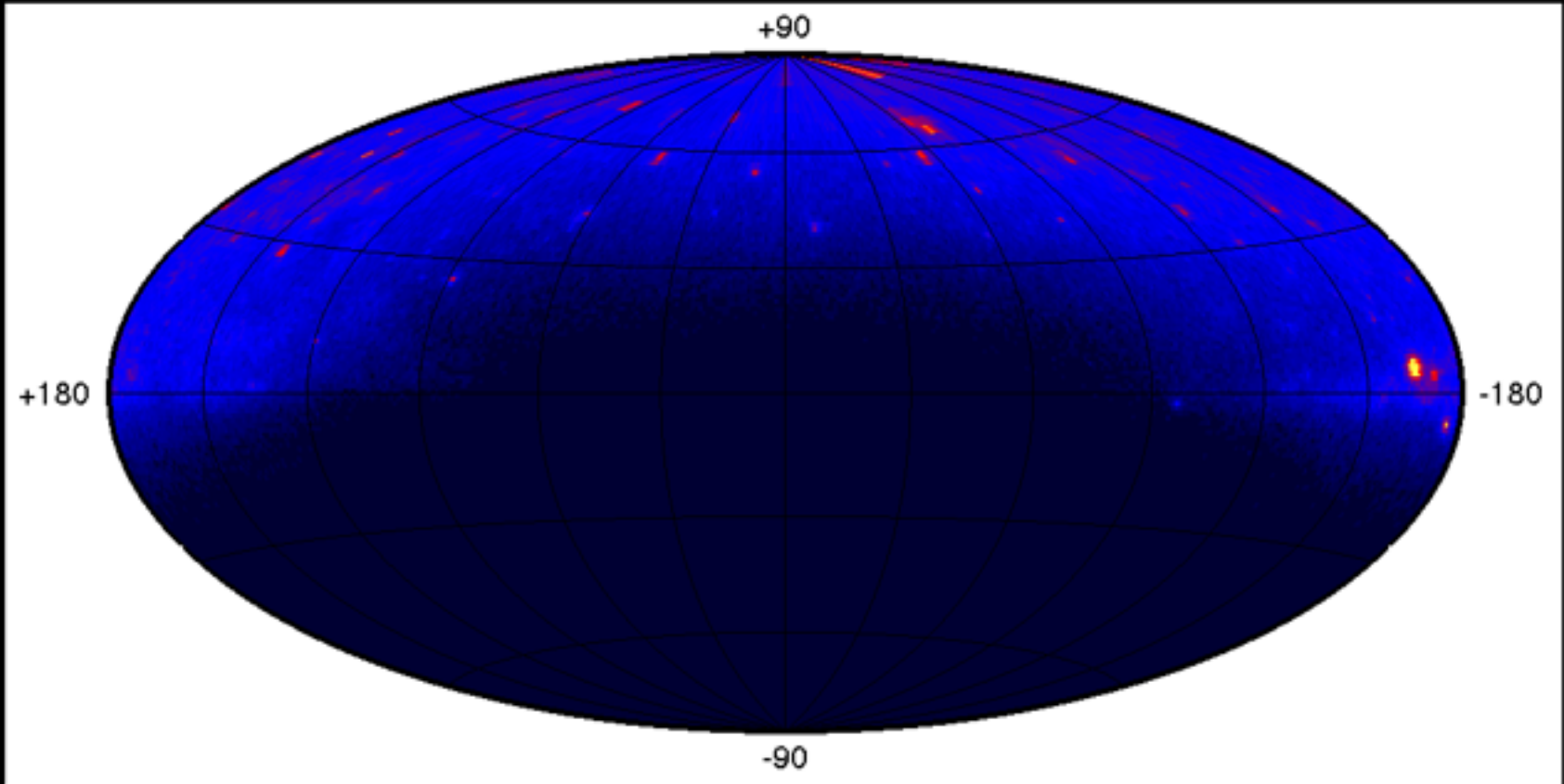
3rd Hard Source Catalog

TABLE 2
3FHL SOURCE CLASSES

Description	Identified		Associated	
	Designator	Number	Designator	Number
Pulsar	PSR	53	psr	6
Pulsar Wind Nebula	PWN	9	pwn	8
Supernova remnant	SNR	13	snr	17
Supernova remnant / Pulsar wind nebula	...	...	spp	9
High-mass binary	HMB	4	hmb	1
Binary	BIN	1	...	...
Globular cluster	...	...	glc	2
Star-forming region	SFR	1	sfr	1
Starburst galaxy	...	...	sbg	4
BL Lac type of blazar	BLL	19	bll	712
Flat spectrum radio quasar type of blazar	FSRQ	30	fsrq	141
Non-blazar active galaxy	...	...	agn	1
Narrow-line Seyfert 1	NYLS1	1	...	...
Radio galaxy	RDG	4	rdg	9
Blazar candidate of uncertain type	...	...	bcu	309
Total	identified	136	associated	1219
Unclassified	...	...	unknown	24
Unassociated	...	...	...	177
Total in the 3FHL	...	...	...	1556

 >10 GeV, pass 8, 7 years of data

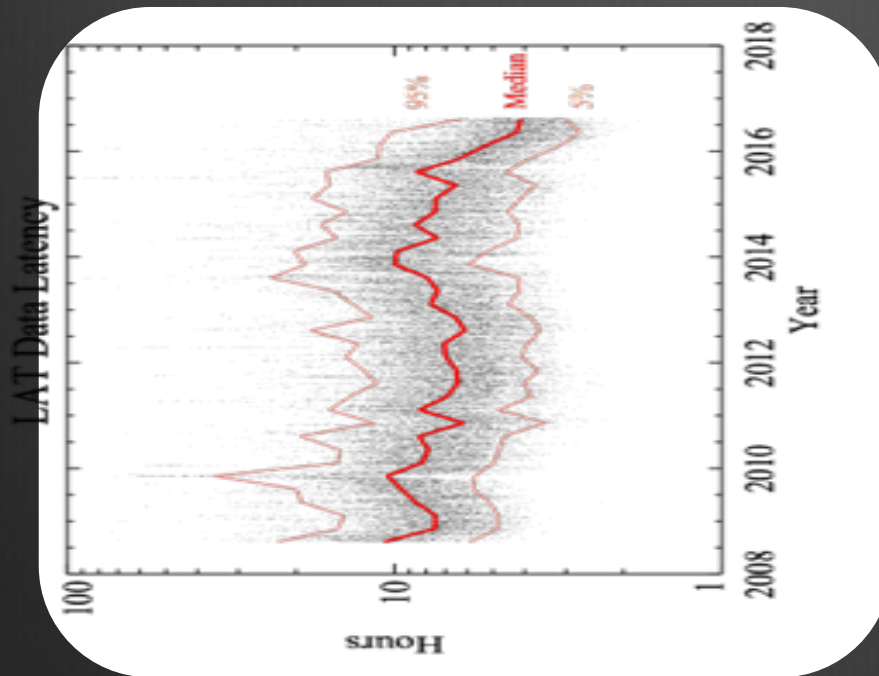
Fermi Observations



Observe entire sky every 3 hours
Opens up the time domain

What's changing (other than the sky...)

🎬 Focus on reducing data latency

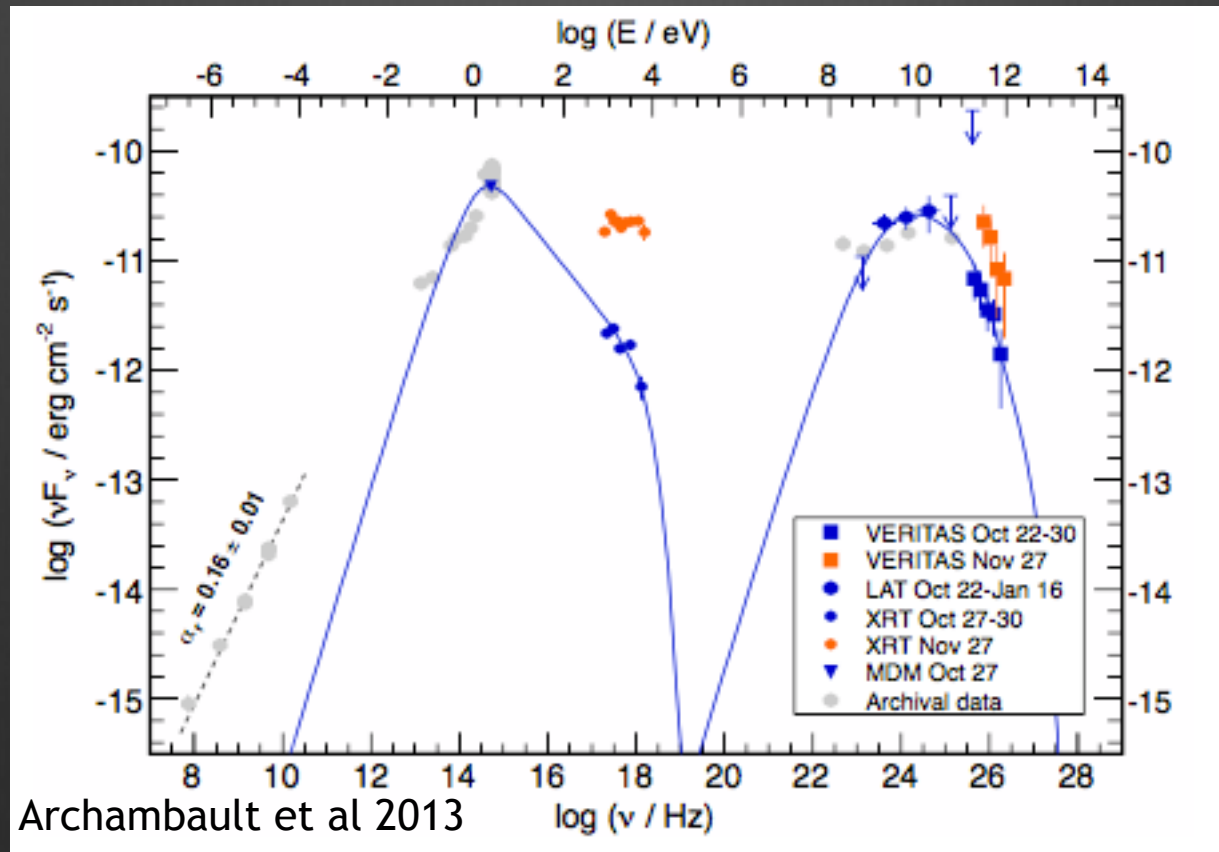


Significantly improved performance after Flight Operations team optimization

Continuing to work on improvements to LAT analysis pipelines

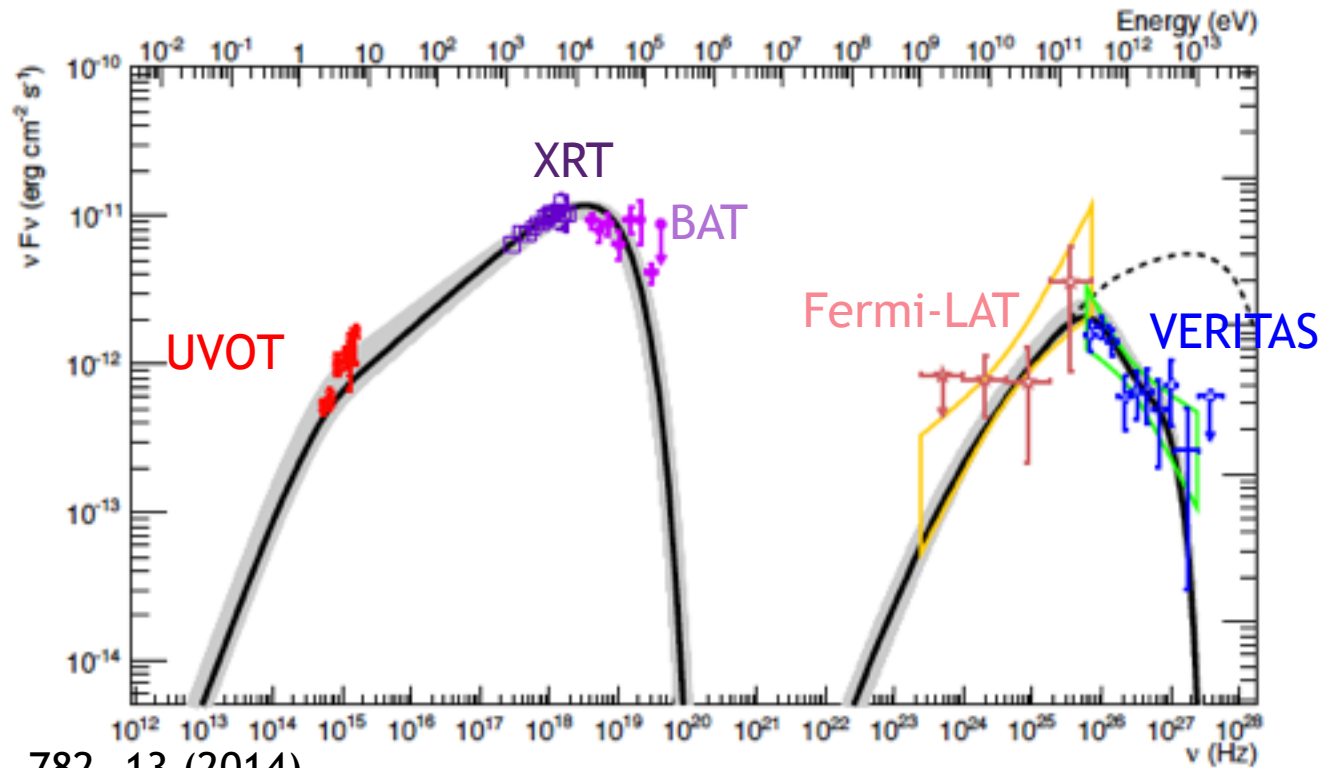
🎬 Continue to deepen sensitivity, especially at high energies, where the sensitivity improves linearly with time

Working Together to Find New Things



- 🎬 Discovery of VER J0521+211, via VERITAS observations at the location of a cluster of >30 GeV photons in the first year of LAT data

Blazars - Most Populous Fermi Source Class

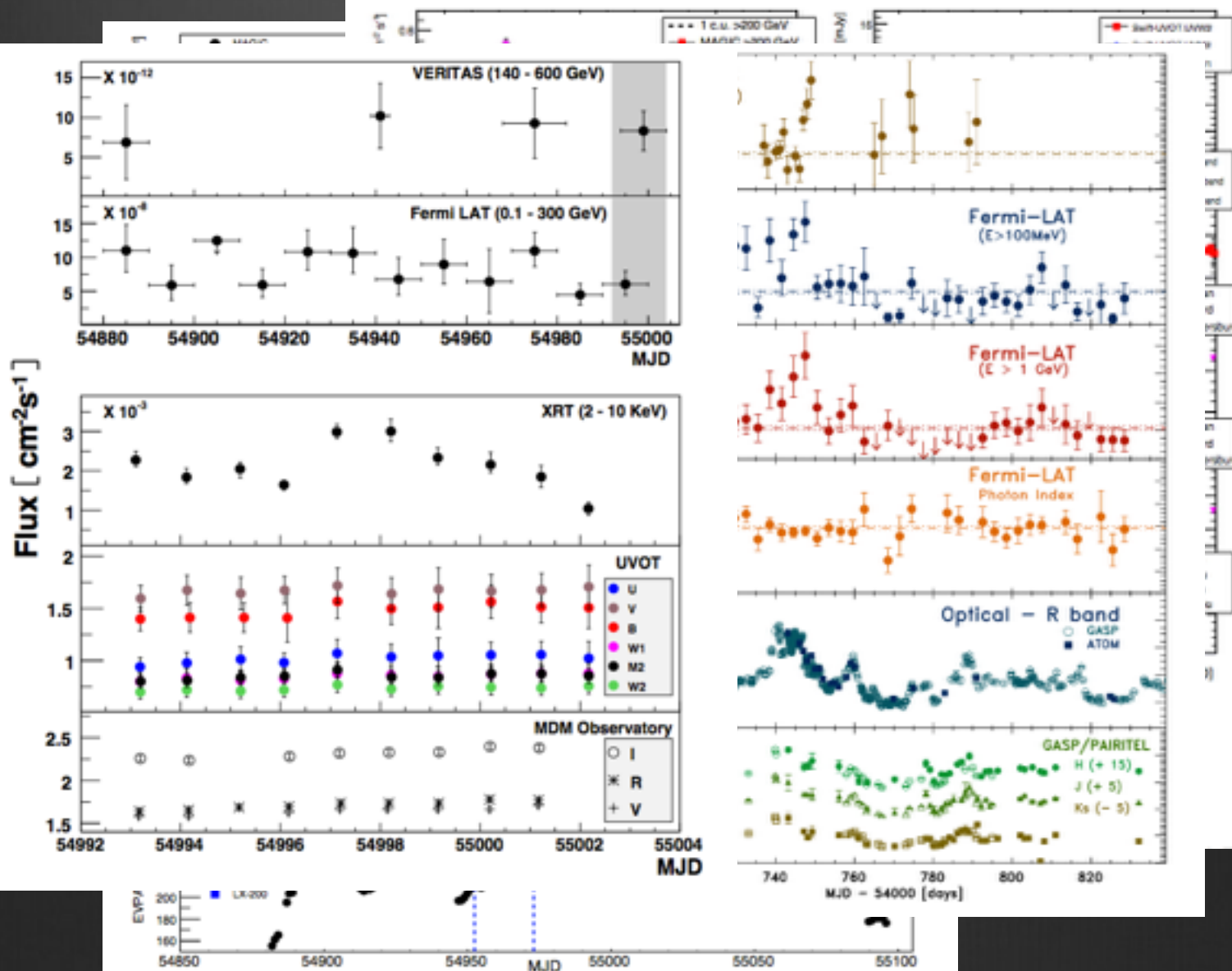


1ES 0229+200

ApJ, 782, 13 (2014)

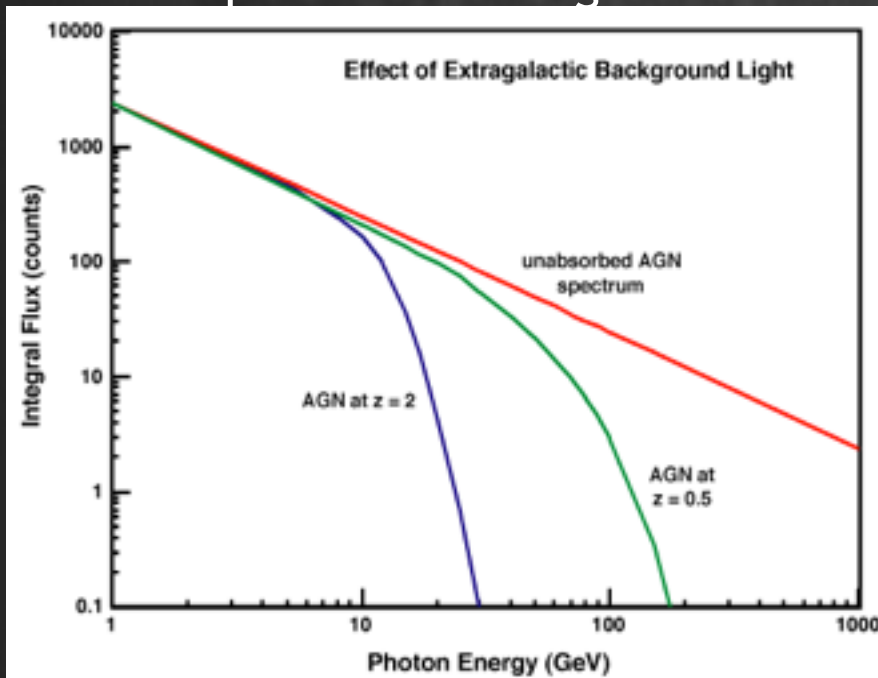
- ☉ VERITAS observations critical to characterize the shape of the second peak.
- ☉ Gamma-ray emission mechanisms
- ☉ Gamma-ray attenuation on extragalactic background light

Lots and Lots of MW Campaigns Together



Gamma-ray absorption

- ☉ The Universe is largely transparent to gamma-rays below ~ 10 GeV - thus we can see to great distances in all directions.
- ☉ At higher energies gamma-rays are absorbed as they traverse intergalactic space by IR-optical-UV photons.
- ☉ The amount of absorption depends on the distance to the gamma-ray source and on the density and spectrum of the IR-optical-UV background radiation.



The distance to active galaxies can be determined from optical observations.

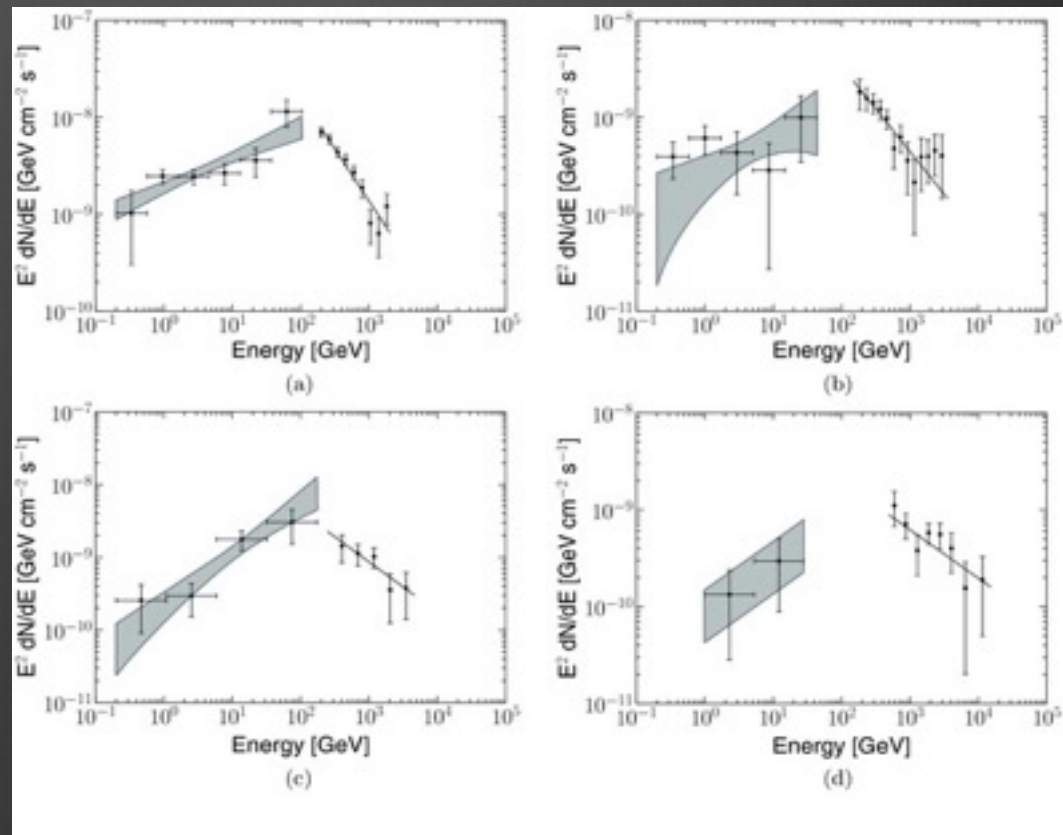
Thus a measurement of gamma-ray cutoffs provides information on the IR-optical-UV background \rightarrow galaxy and star formation as a function of time.

Extragalactic Background light

two experiments are better than one!

● Fermi-LAT can measure intrinsic (unattenuated) spectrum

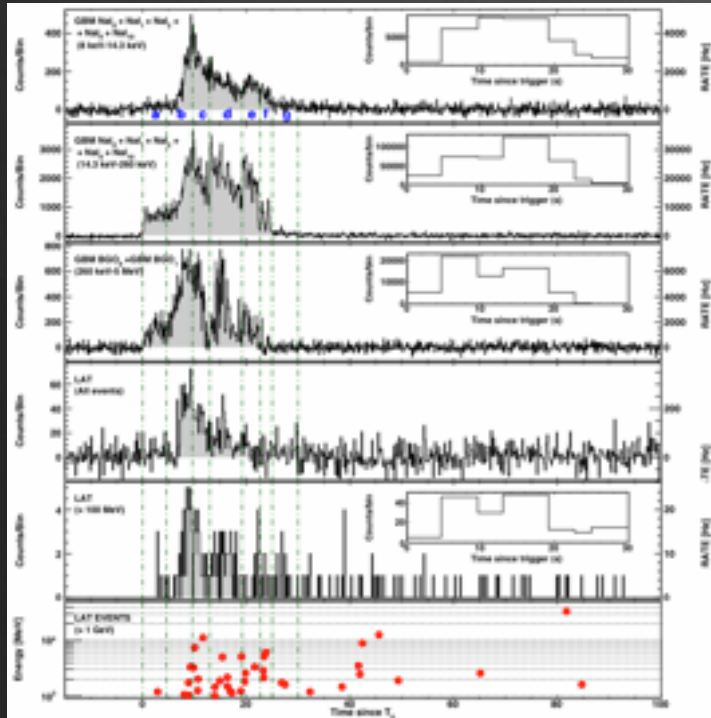
● VERITAS provides measurements of spectral breaks caused by attenuation on the EBL



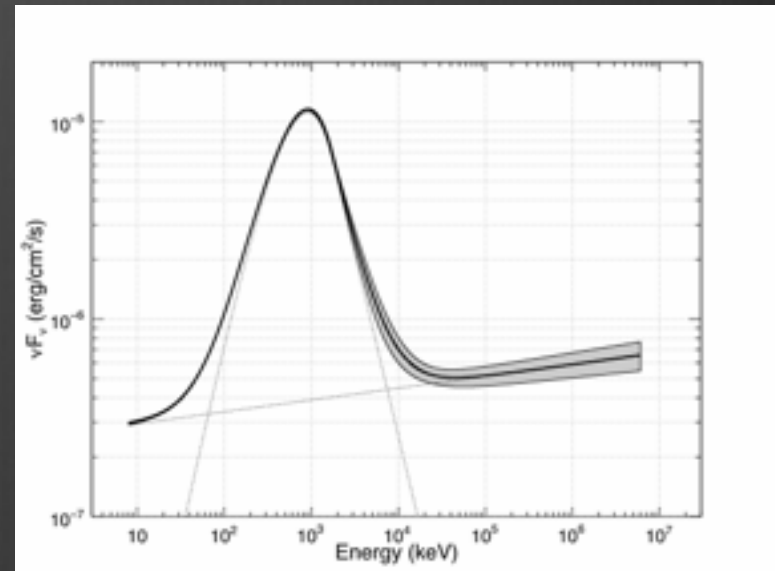
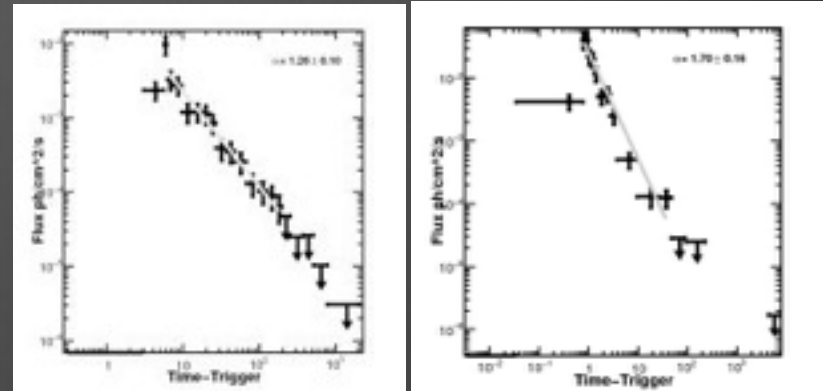
GeV GRB Properties

GeV Afterglow with Powerlaw decay

Delayed onset of prompt emission



Extra Spectral Component

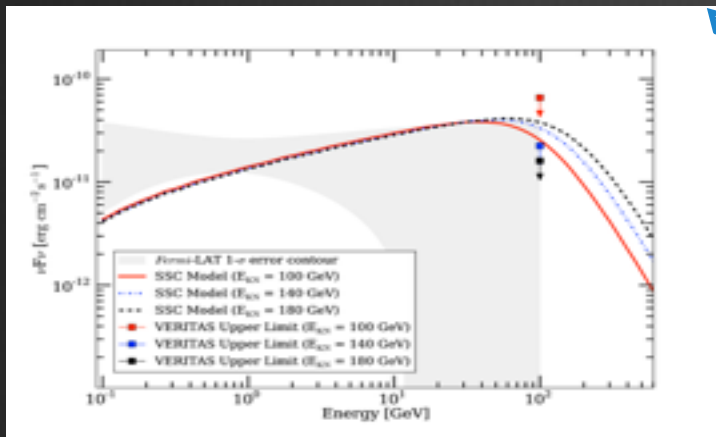
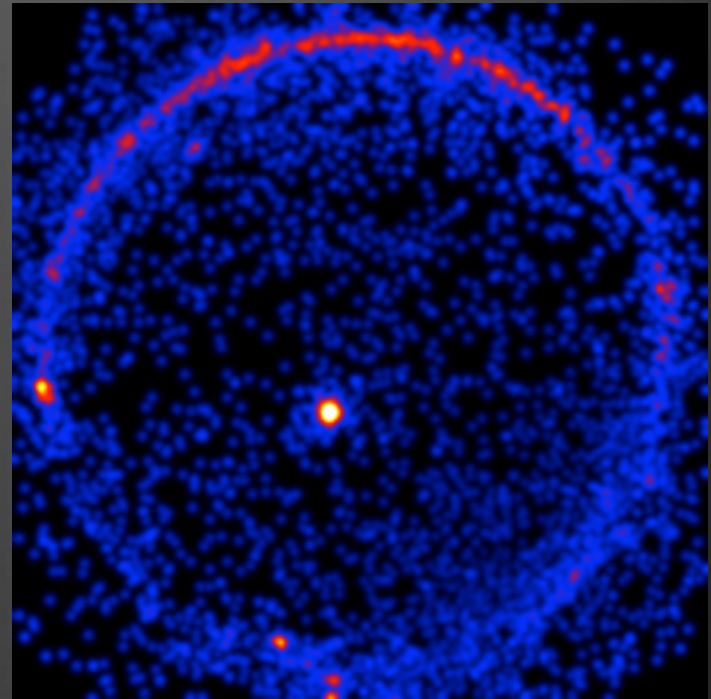
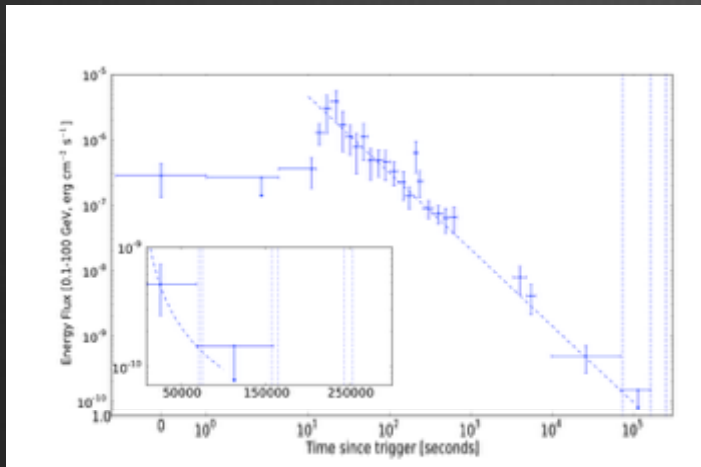


Remarkably, these features are seen in most bright LAT-detected GRB!
Great for VHE: time to get on target and hard spectrum components to explore

GRB 130427A

GRB 130427A was a nearby exceptionally bright GRB

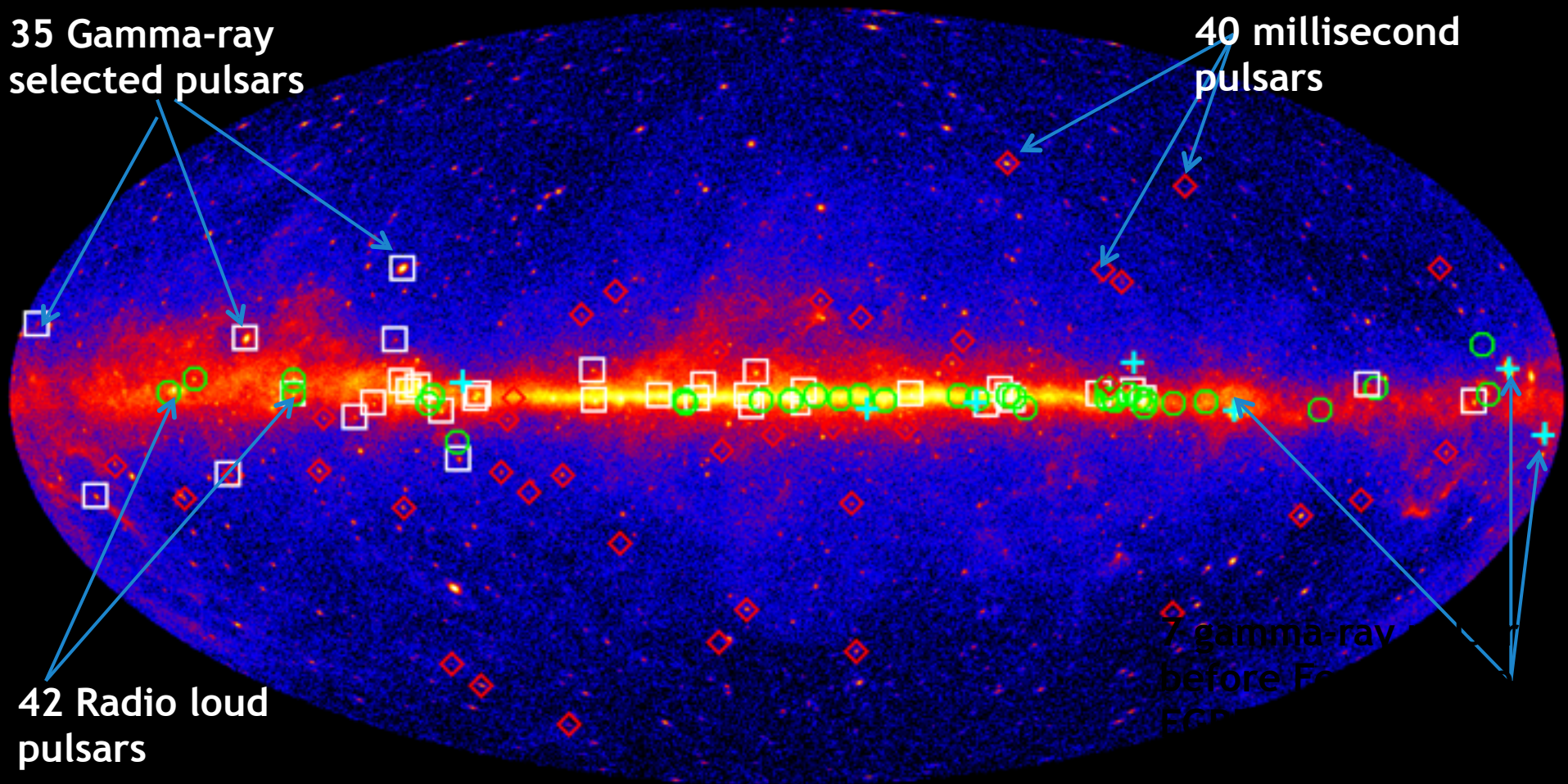
LAT emission for ~20 hours



VERITAS Observations of GRB 130427A provide constraints on the spectrum or lightcurve of GRB 130427A

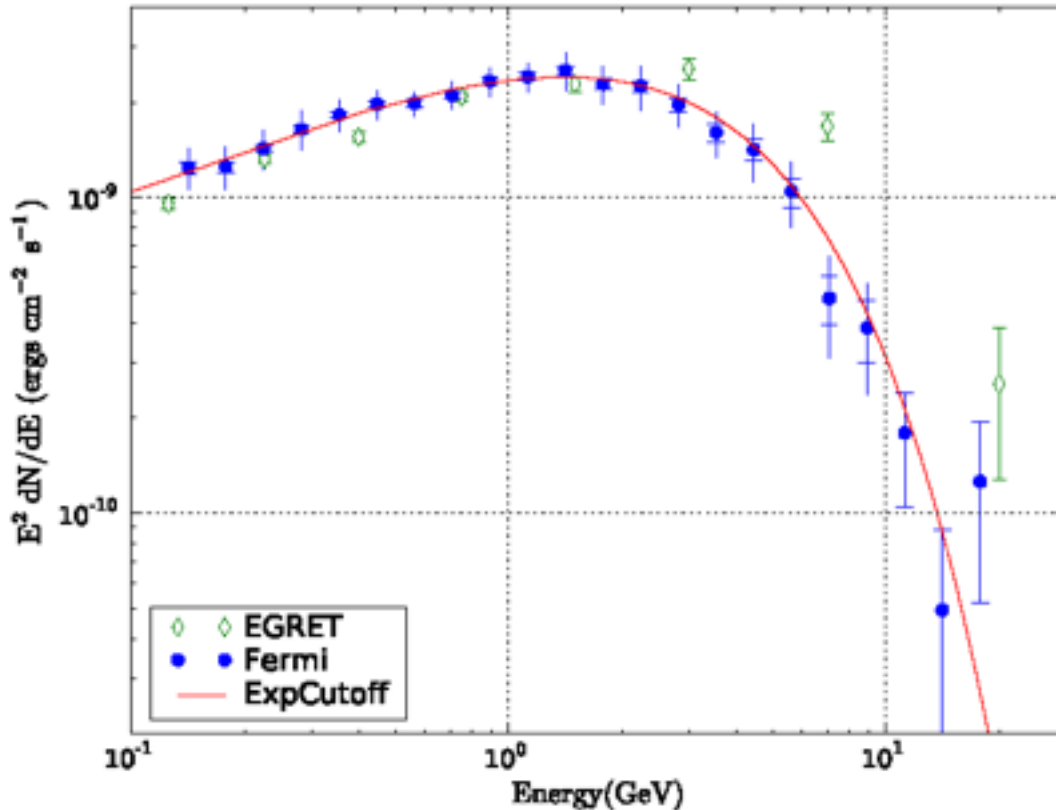
Moving to our Galaxy

117 Gamma-ray Pulsars in 2PC



 Second Fermi-LAT pulsar catalog
Now have over 200 Fermi-detected pulsars

Vela Pulsar - Fermi-LAT Phase Averaged SED



$$N(E) = N_0 E^\Gamma e^{-(E/E_c)^b}$$

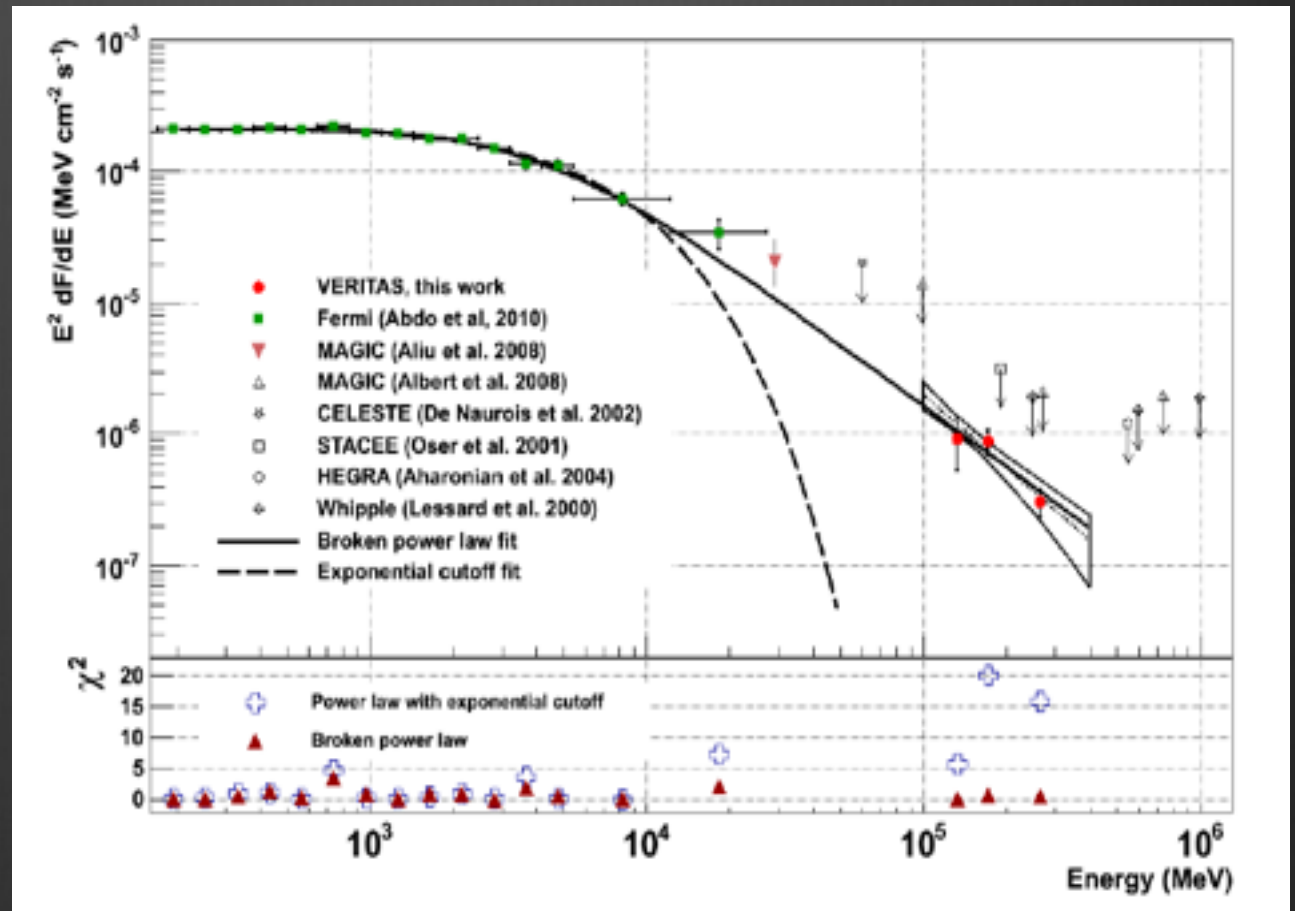
Consistent with $b=1$
(simple exponential)

$b=2$ (super-exponential)
rejected at 16.5σ

No evidence for magnetic
pair attenuation:
Near-surface emission
ruled out

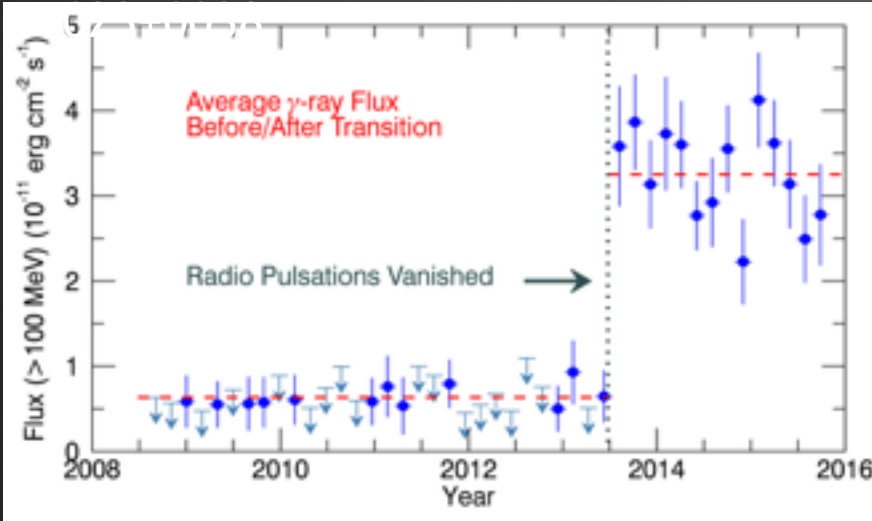
VERITAS and Fermi-LAT Observations of the Crab Pulsar

- Crab pulsar at >100 GeV!
- Above 100 GeV, peaks are narrower
- Cutoff of combined spectrum is not exponential
- Extension of Fermi spectrum or new component (e.g. inverse Compton)?



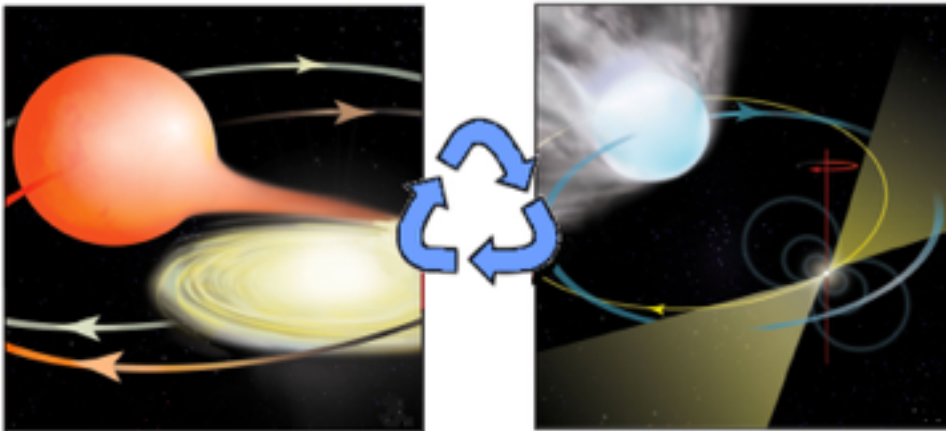
Transitional Millisecond Pulsars

Gamma-ray Transition of PSR



- Transition between rotation powered and accretion powered state
- More expected - LAT already detected two transitions between accreting and radio MSP states
- **γ -ray emission brighter in the accreting state** - a mystery since accreting sources are *not* typical γ -ray emitters.

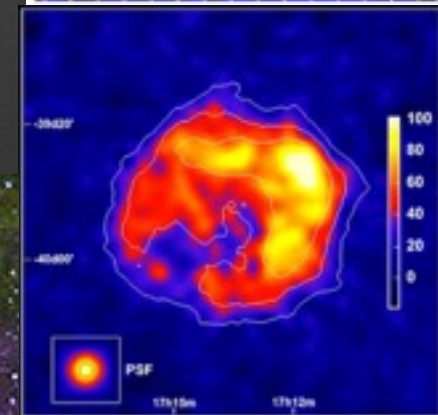
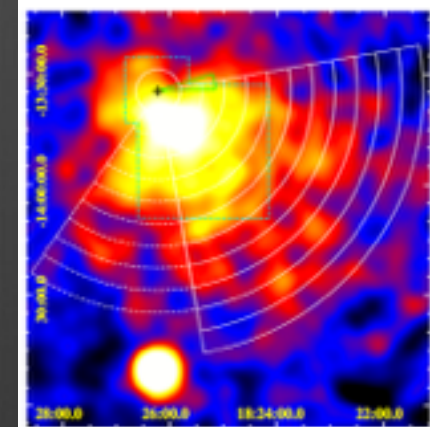
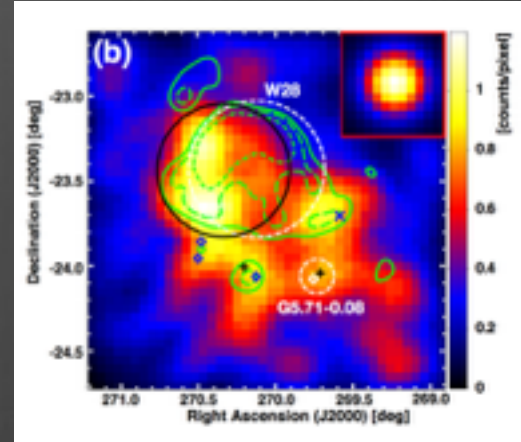
Balance between gravity and field pressure



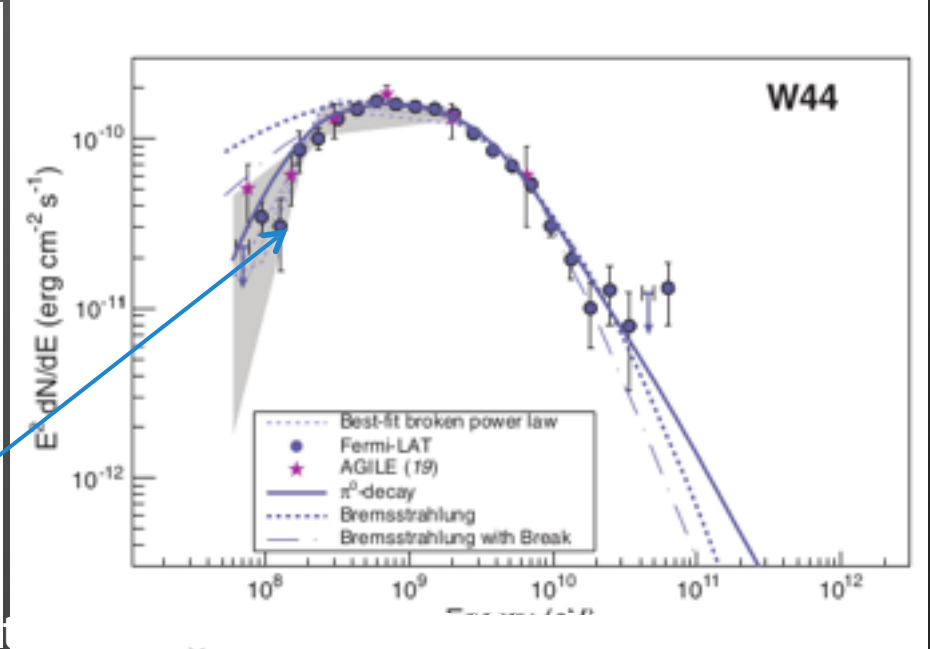
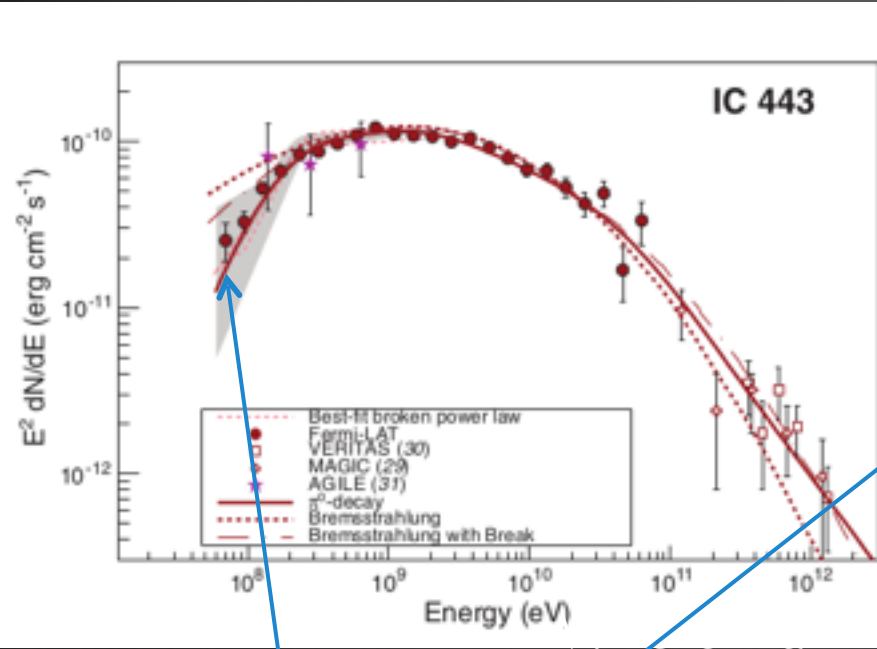
A new area of study for *Fermi* - will it become one for VERITAS too?

Gamma-ray Studies of SNR

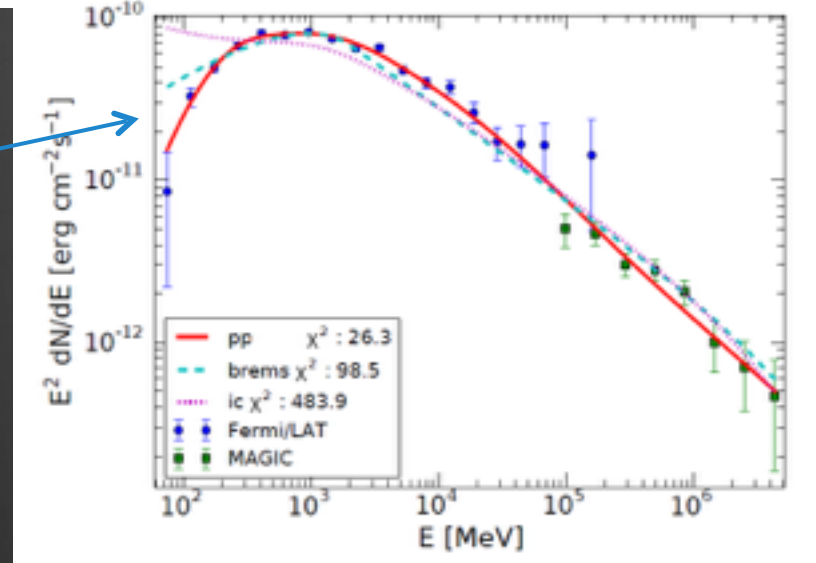
- ❶ Origin of Cosmic-rays
- ❷ Particle acceleration
- ❸ SNR evolution
- ❹ Cosmic-ray feedback



Pion Bumps - clear evidence for protons



Pi-0 cutoff

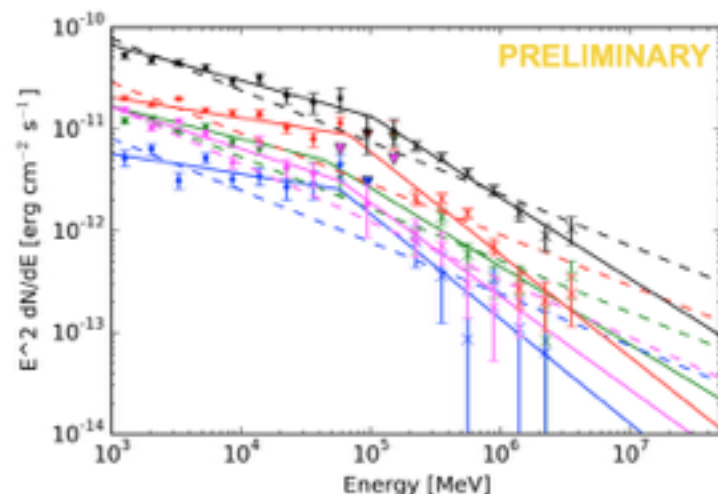
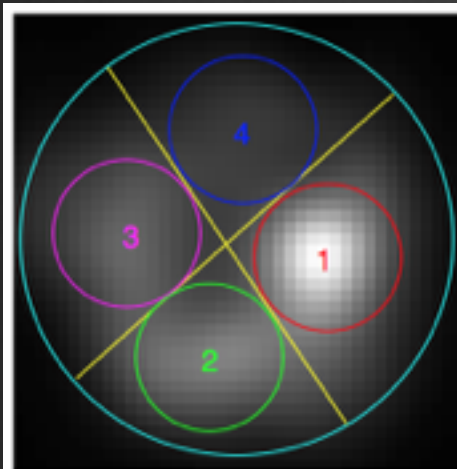


Resolving a Proton Accelerator

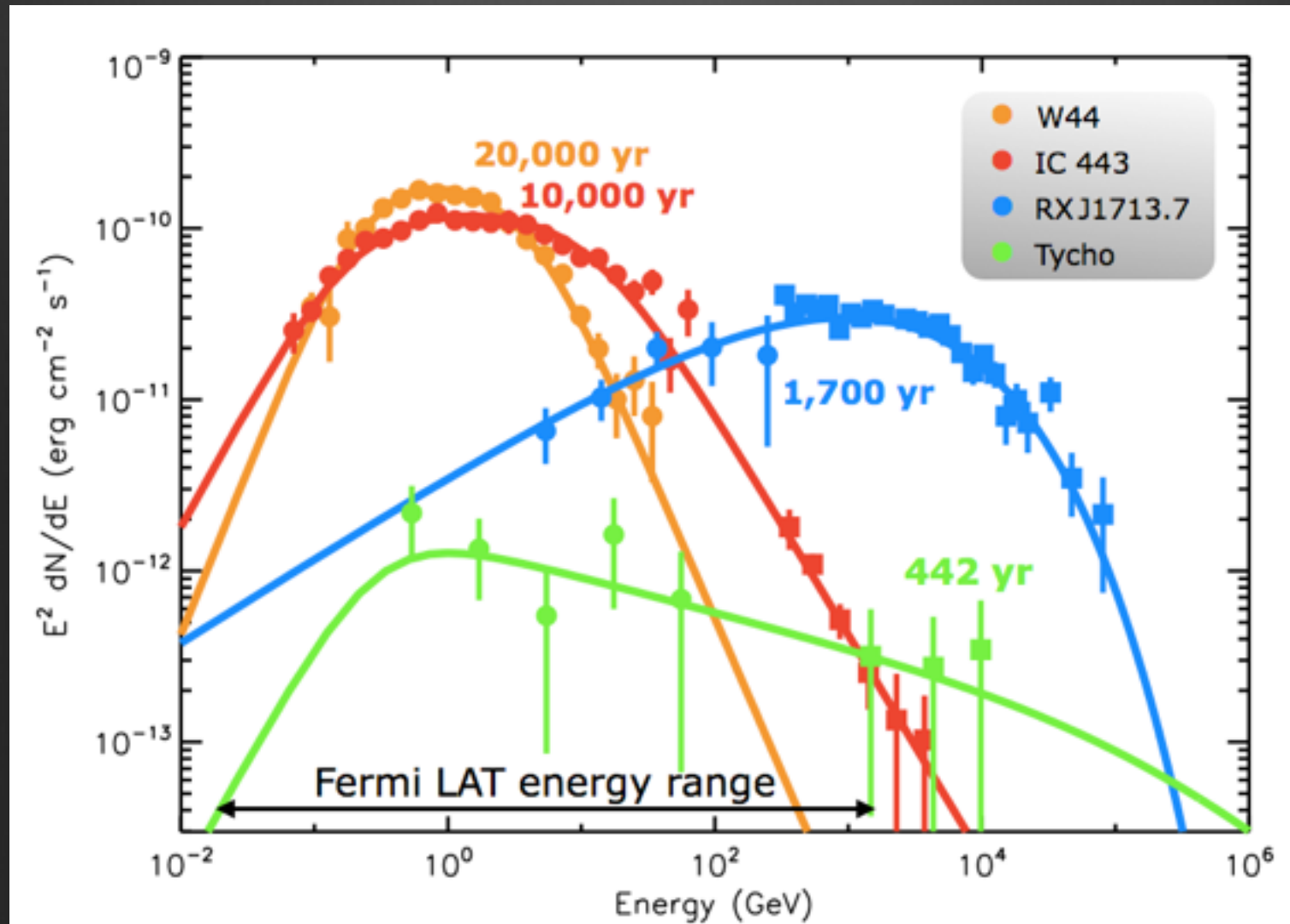
- Pass 8 data resolve the shell of IC 443 at physical scales of ~ 5 pc GeV/TeV gamma-rays match the distribution of shocked gas
- Dense molecular and diffuse atomic (fast shock) regions differ in flux by $\sim 10\times$, but spectra are surprisingly consistent.

Deconvolved 1–300 GeV events.
Pass 8 gives 2.4x statistics of
P7REP with cut on PSF68 < 0.4°

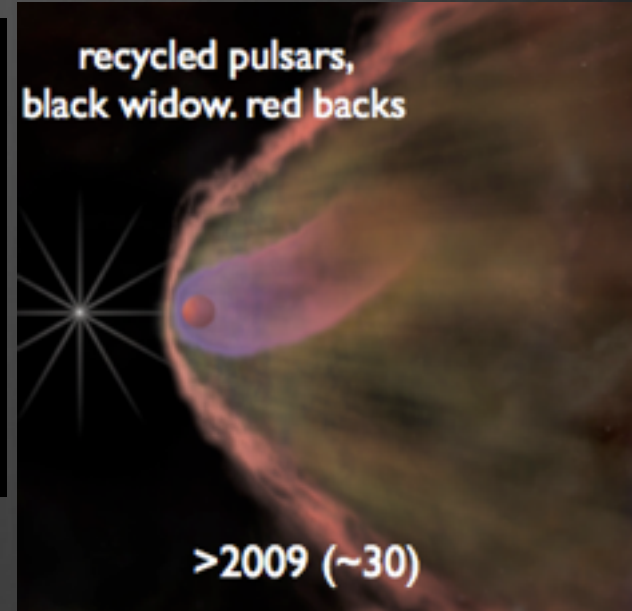
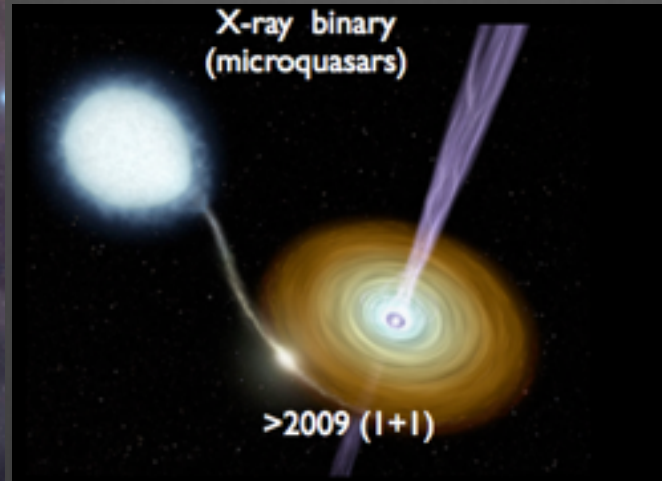
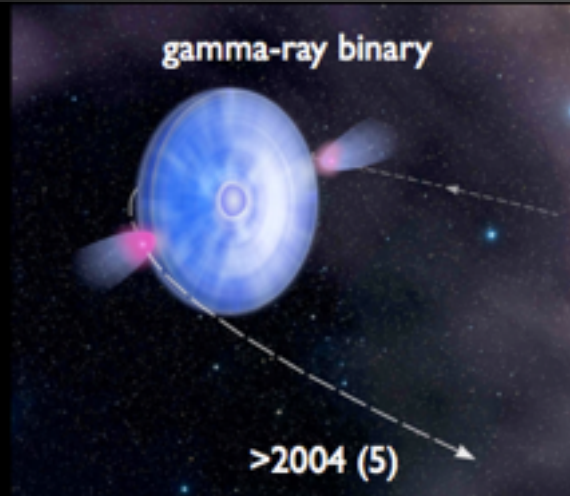
shocked HCO^+ contours



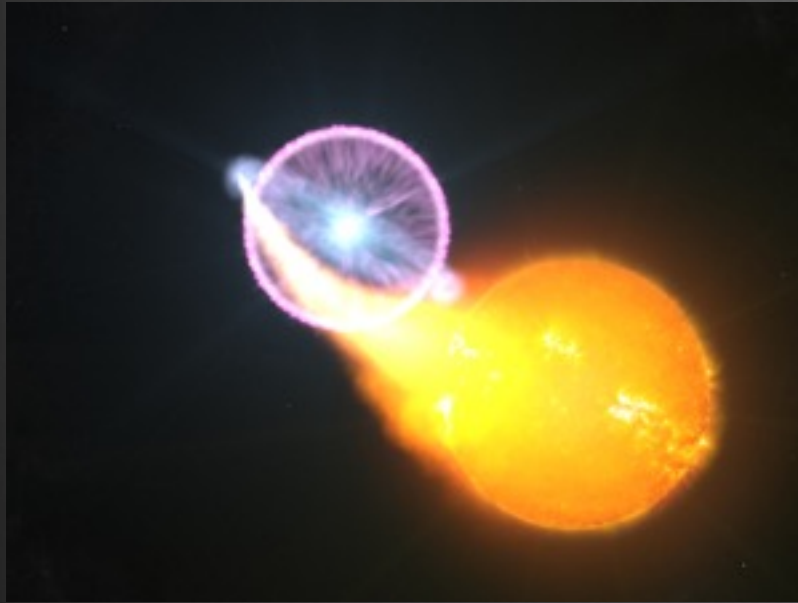
Gamma-ray properties appear to evolve with SNR age



Binary Systems

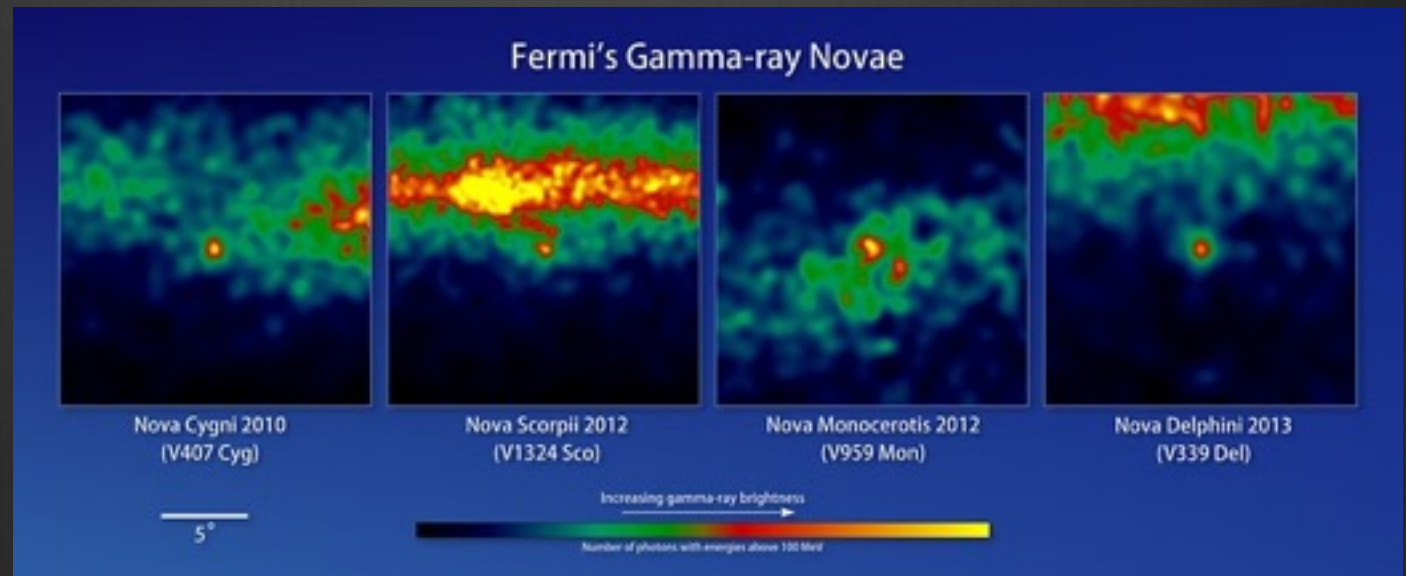


A New Class of Gamma-ray Source



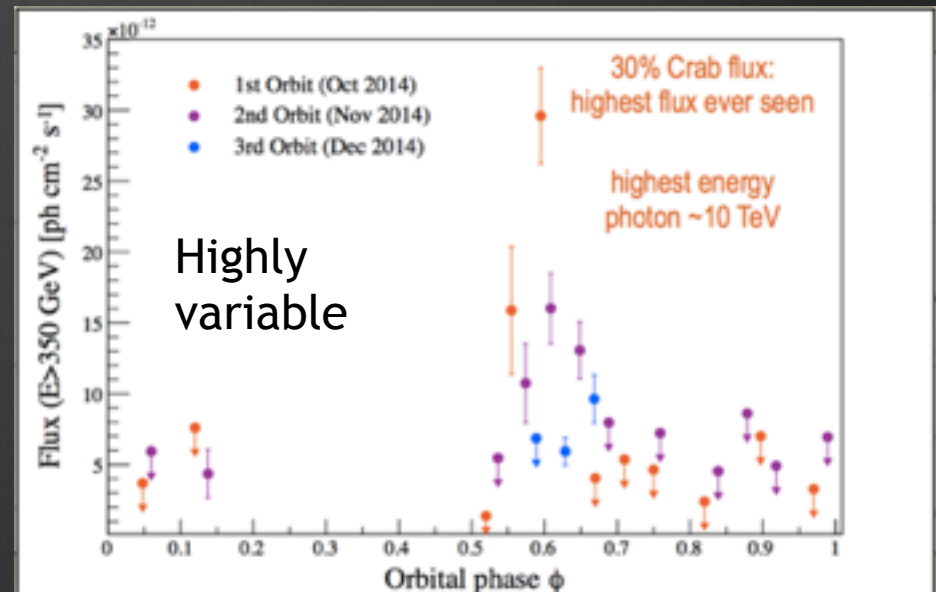
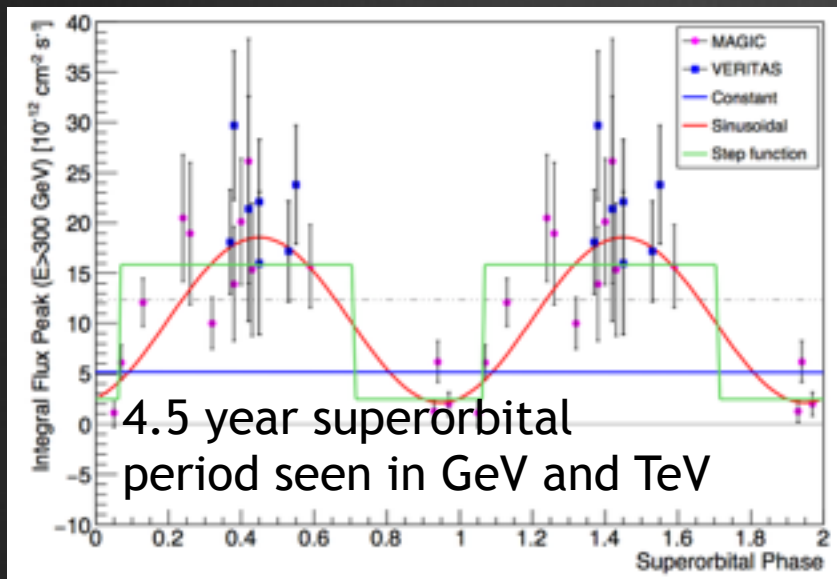
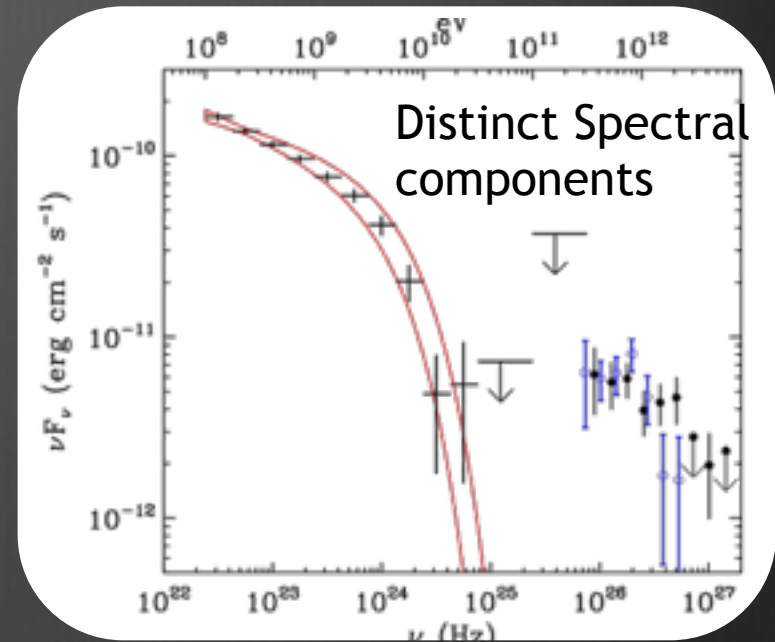
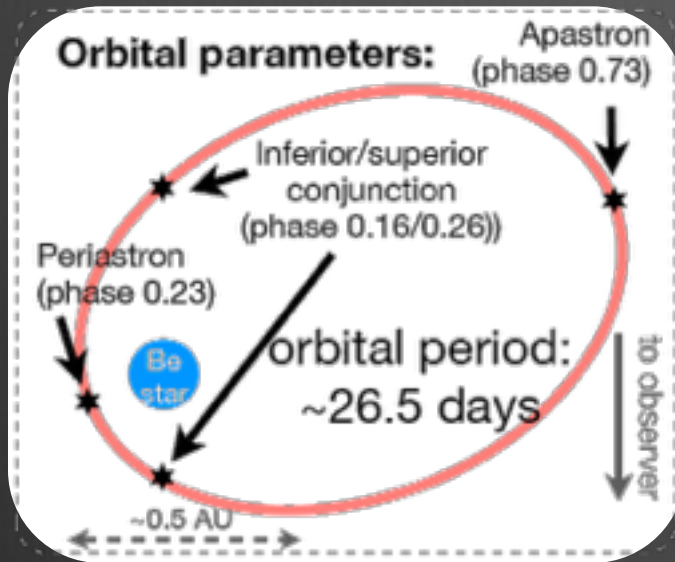
- ☉ Particles accelerated in multiple shock waves in the rapidly expanding debris shell
- ☉ An unexpected discovery - only possible because Fermi surveys the sky

Now have 7
detected
Novae



Gamma-ray binaries - LSI +61 303

LSI +61 303
26.5 days



Conclusions

- VERITAS and Fermi have made (and continue to make) great partners!
- We should look to the future:
 - The sky is always changing - there will continue to be new things to find
 - Things on new (longer) timescales
 - Rare transients
 - Spectral overlap between Fermi-LAT and VERITAS for persistent sources will improve with time

Fermi Highlights and Discoveries

