Gamma Ray Overview

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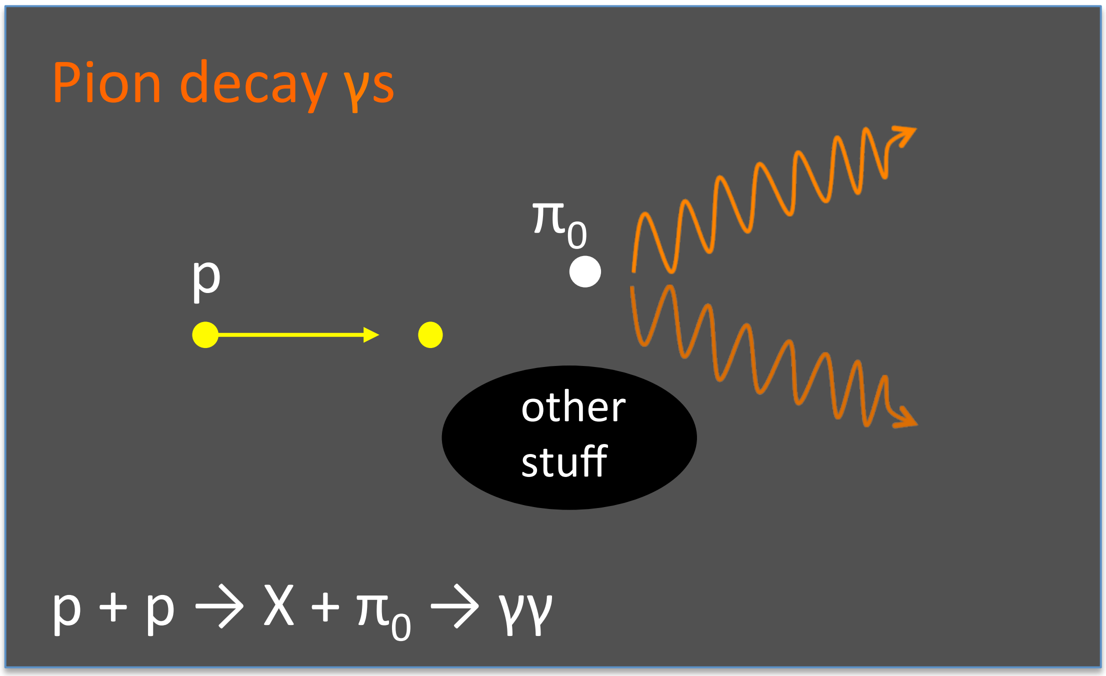
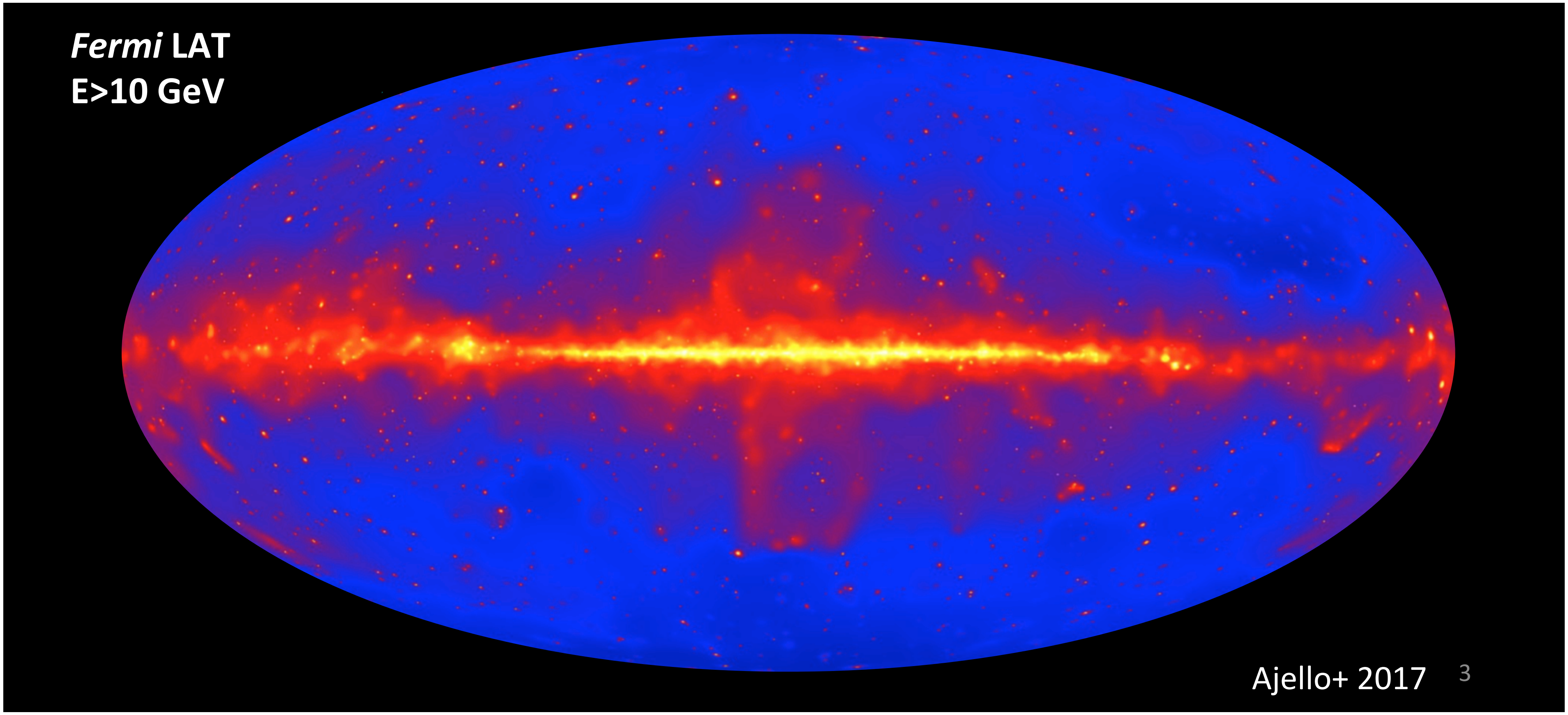
Gamma Rays and Cosmic Rays



The High-Energy Gamma-ray Sky



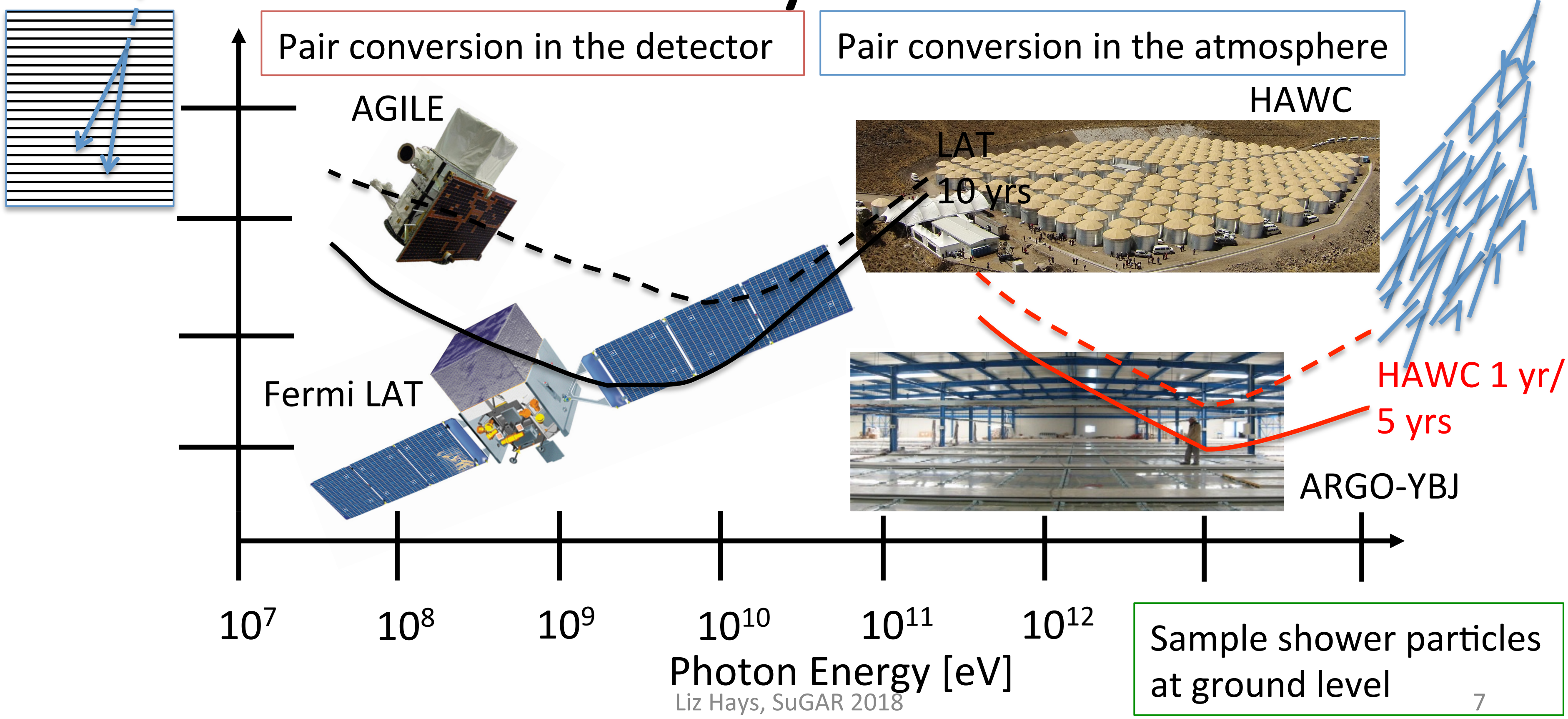
- So we’re done right? Universe in gamma rays – 1000s of sources – all questions answered!

What makes this hard?

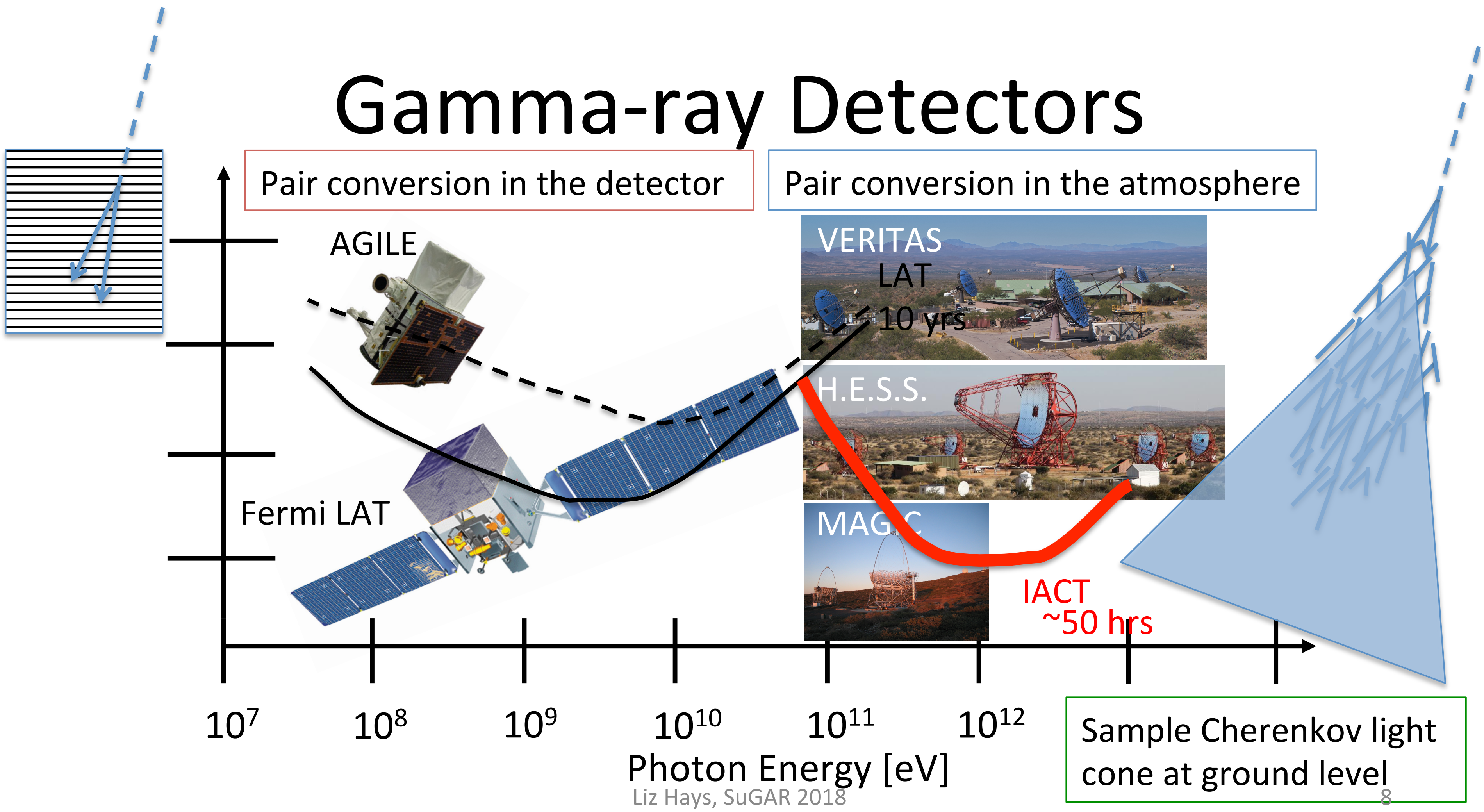
- 2D projection
- Confusion
- Sampling
  - Selection effects
  - Geometric effects
  - Horizon effects
- Photon astronomy is only skin deep

Collecting Gamma Rays

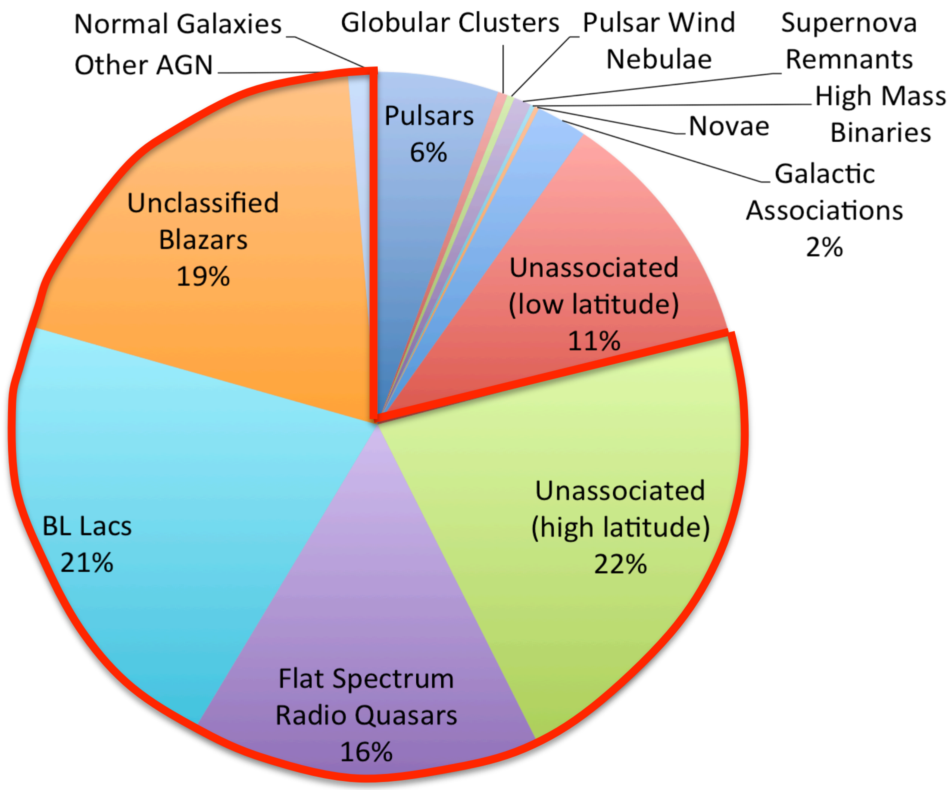
Gamma-ray Detectors



Gamma-ray Detectors



Demographics: High Energy

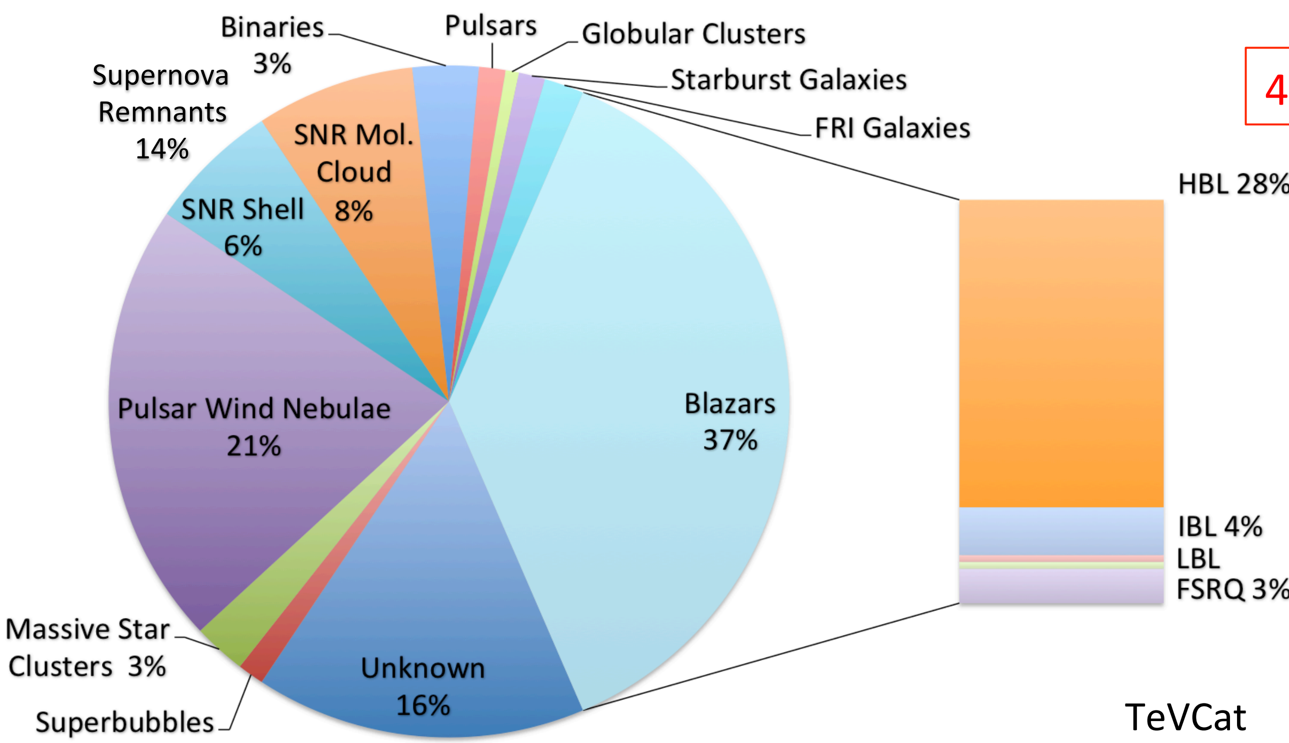


80% extragalactic

>3033 sources
>100 MeV

Based on 3FGL

Demographics: Very High Energy



40% extragalactic

>200 sources
>~100 GeV

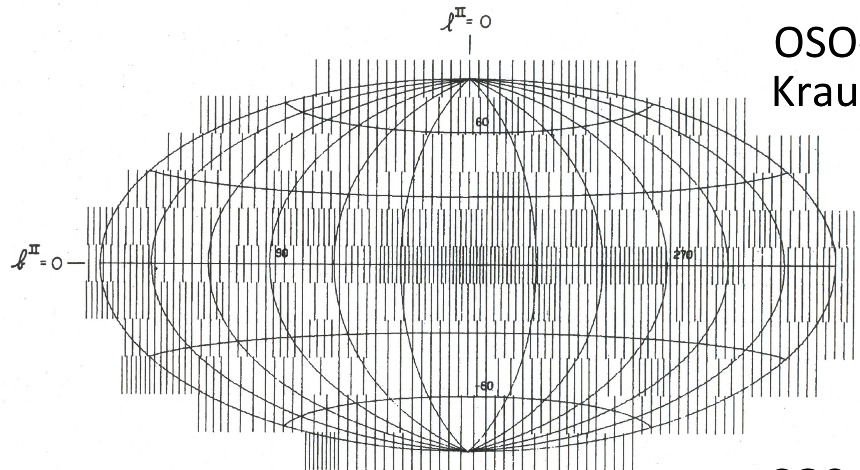
TeVCat
http://TeVCat.uchicago.edu

Pre-Fermi Expectations

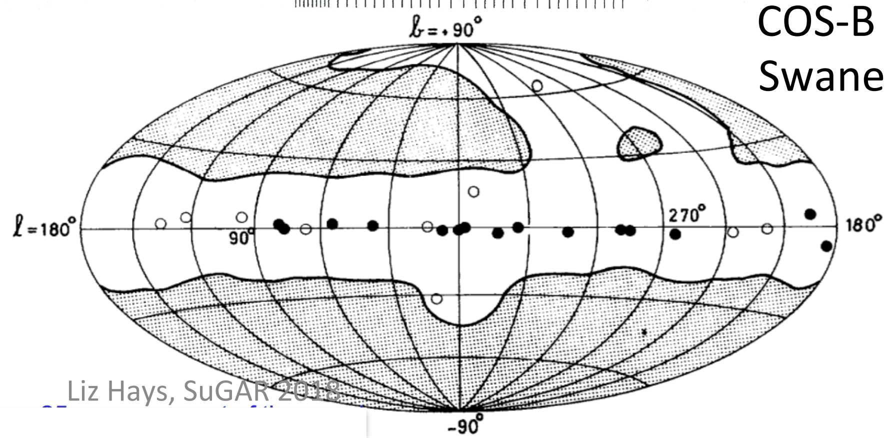
The Promise of the High-Energy Sky (pre-Fermi)

Locate candidate cosmic-ray accelerators

Following earlier balloon and satellite exploratory work, OSO-3, SAS-2, and COS-B mapped cosmic gamma-ray emission, found Galactic and extragalactic components, and ultimately resolved individual sources.



OSO-3
Kraushaar+ 1972



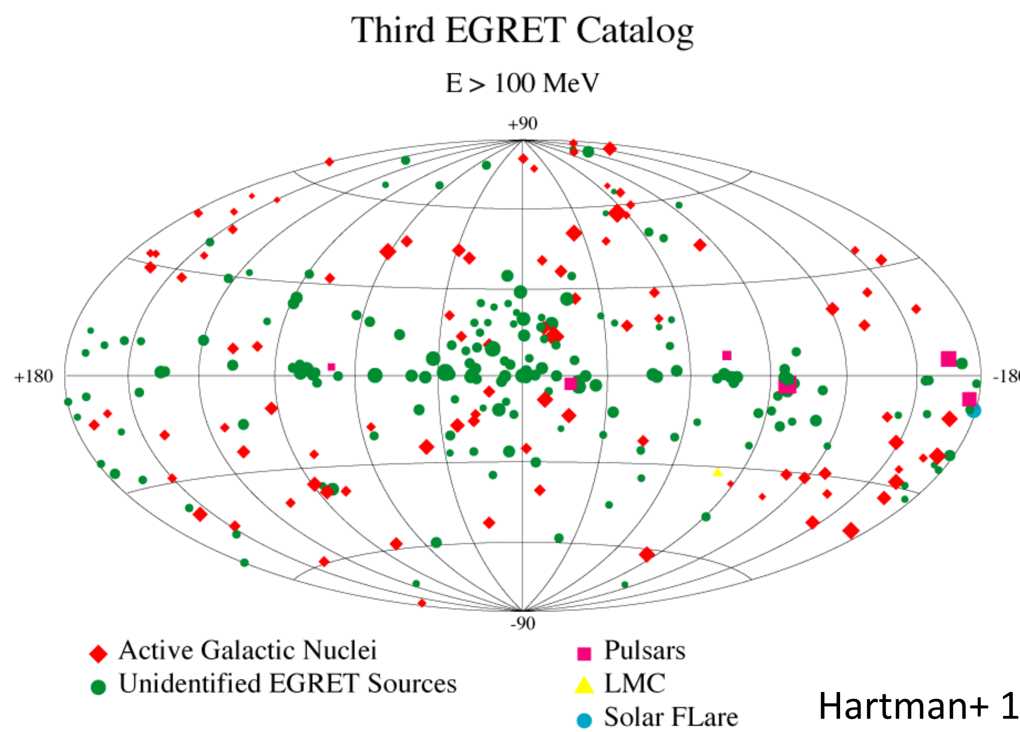
COS-B
Swanenburg+ 1981

The Promise of the High-Energy Sky (pre-Fermi)

Locate candidate cosmic-ray accelerators

EGRET on the Compton Gamma-ray Observatory found 10X more sources – many difficult to associate with counterparts.

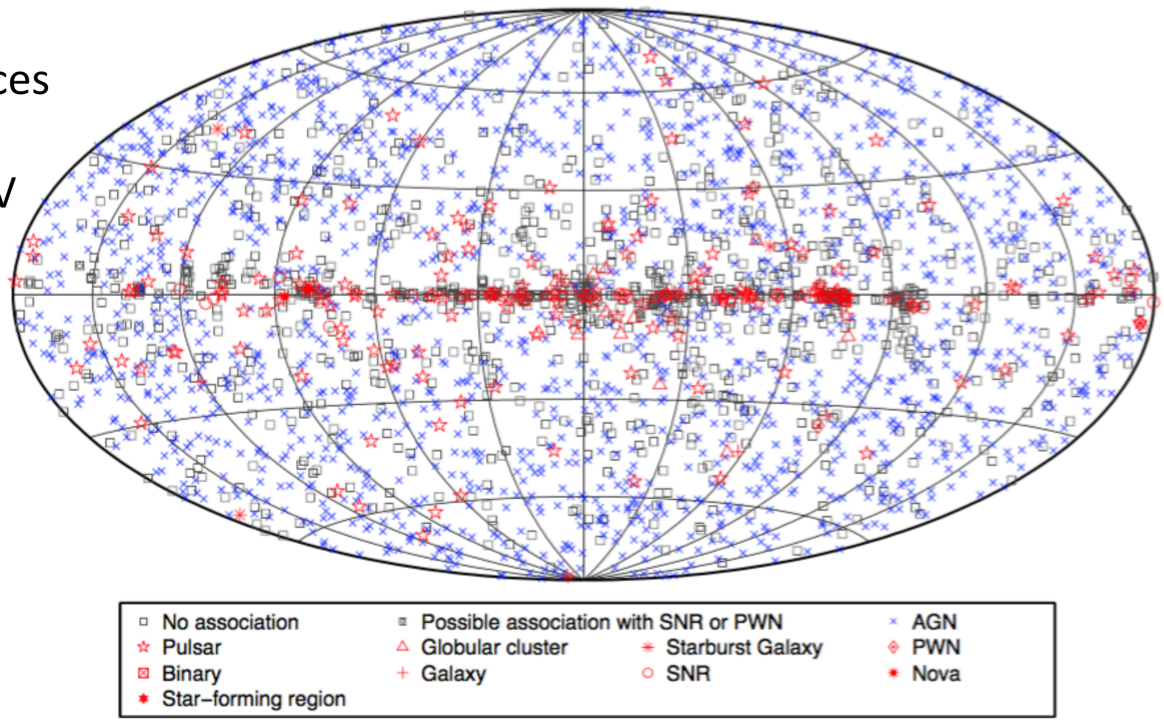
No definitive detection of gamma-ray emission from supernova remnants by EGRET



Hartman+ 1999

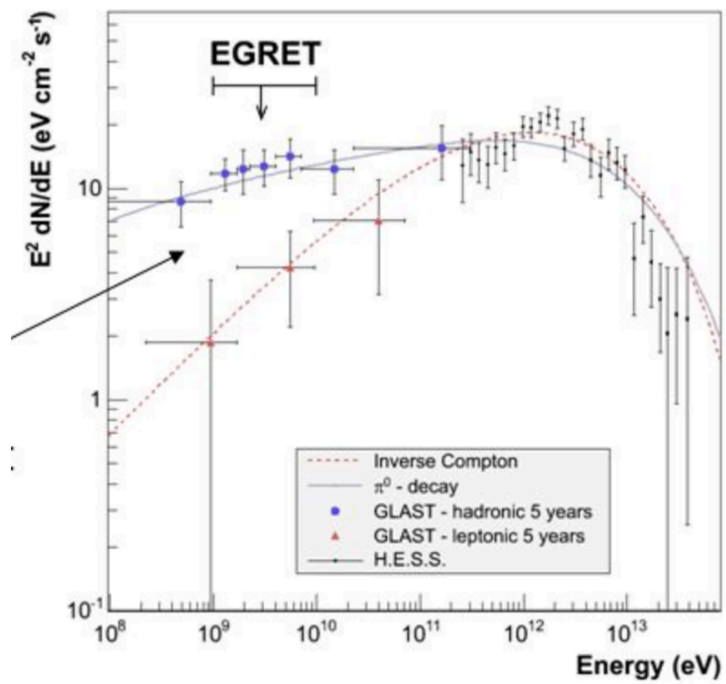
What Fermi Found

3FGL
3033 sources
48 months
E>100 MeV



The Promise of the High-Energy Sky (pre-Fermi)

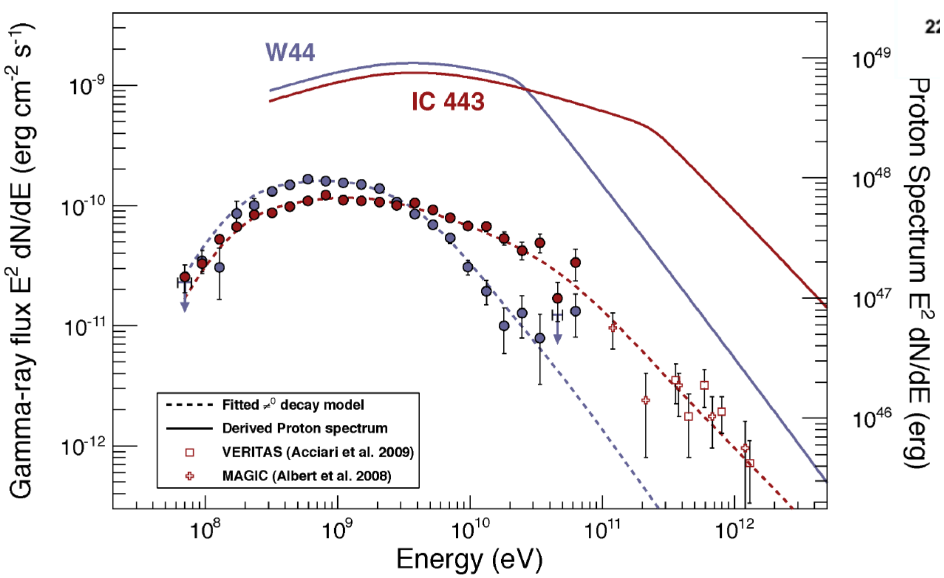
Measure spectral signature of neutral pion decay



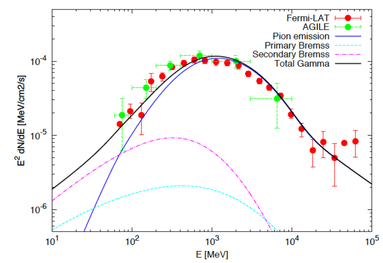
Two models for RX J1713.7-3946. Hadronic in blue and leptonic in red.

What Fermi Found

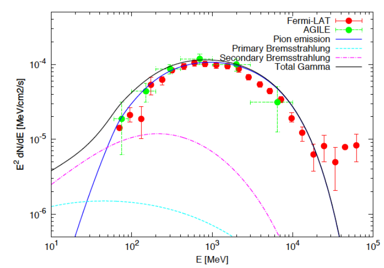
Measure spectral signature of neutral pion decay



Ackermann+ 2013



Reaccel



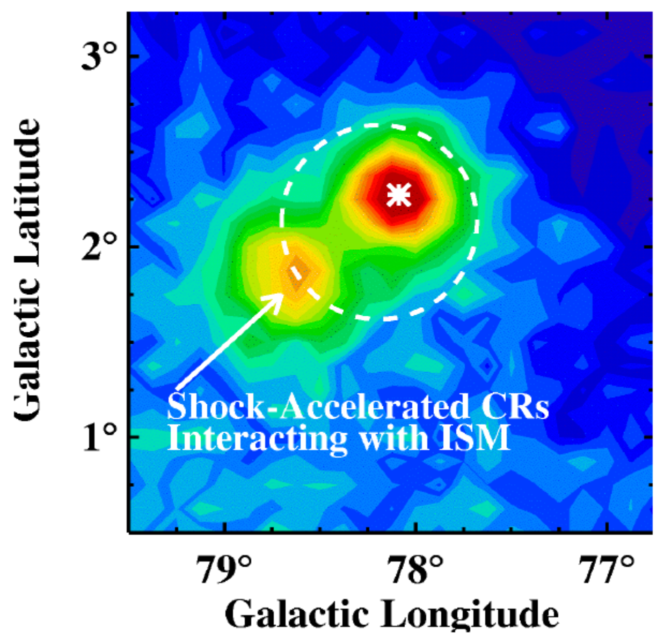
Accel

But is it acceleration or reacceleration of previously existing CRs?

E.g., Cardillo, Amato, & Blasi 2016

The Promise of the High-Energy Sky (pre-Fermi)

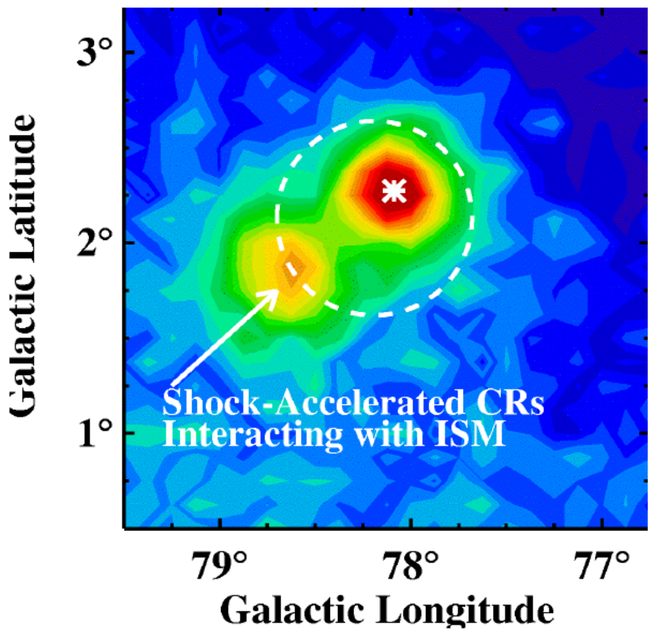
Resolve sites of fresh cosmic-ray acceleration

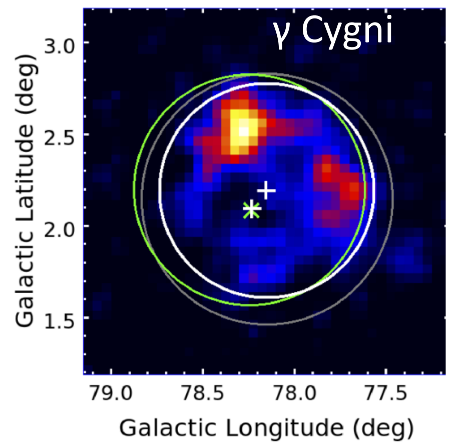


Ormes+ 2000

What Fermi Found

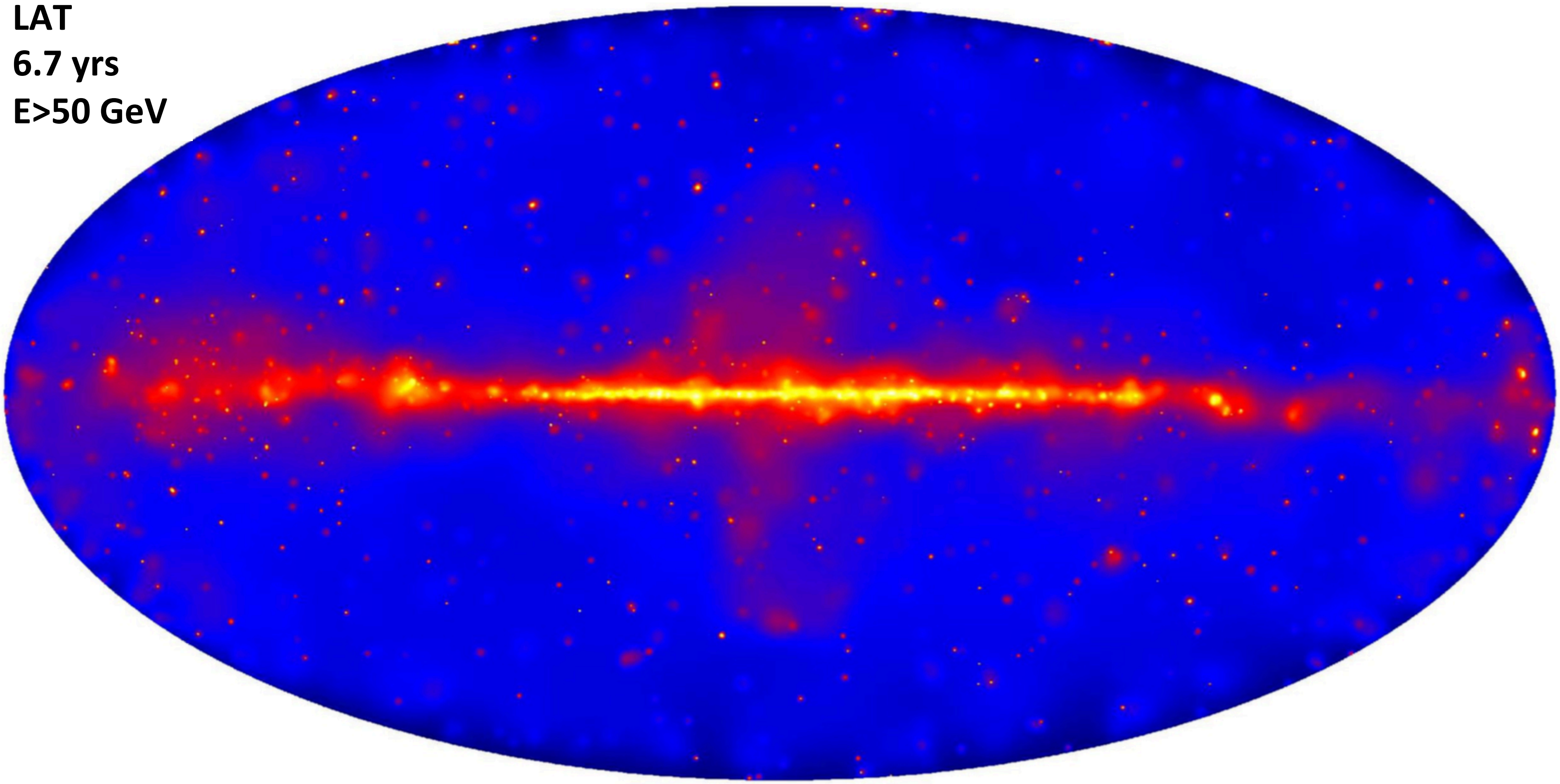
Resolve sites of fresh cosmic-ray acceleration



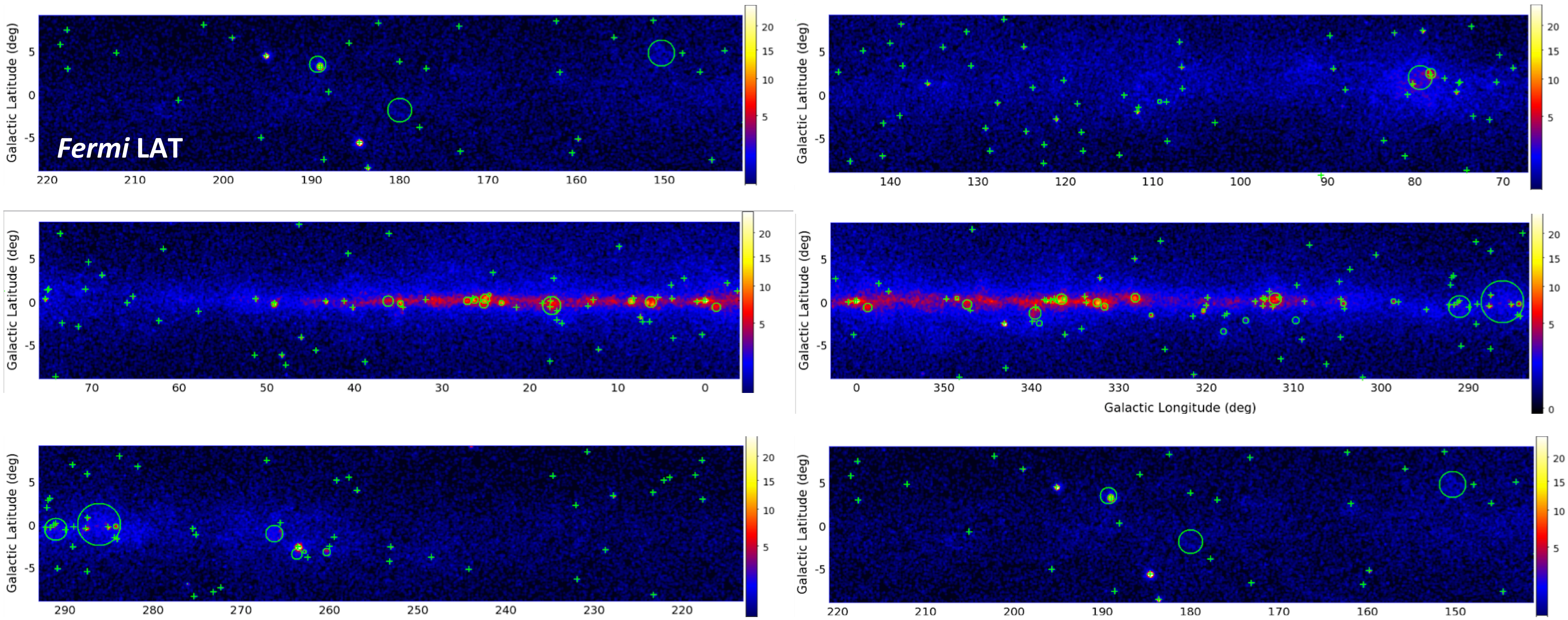


Ackermann+ 2017

LAT
6.7 yrs
E>50 GeV



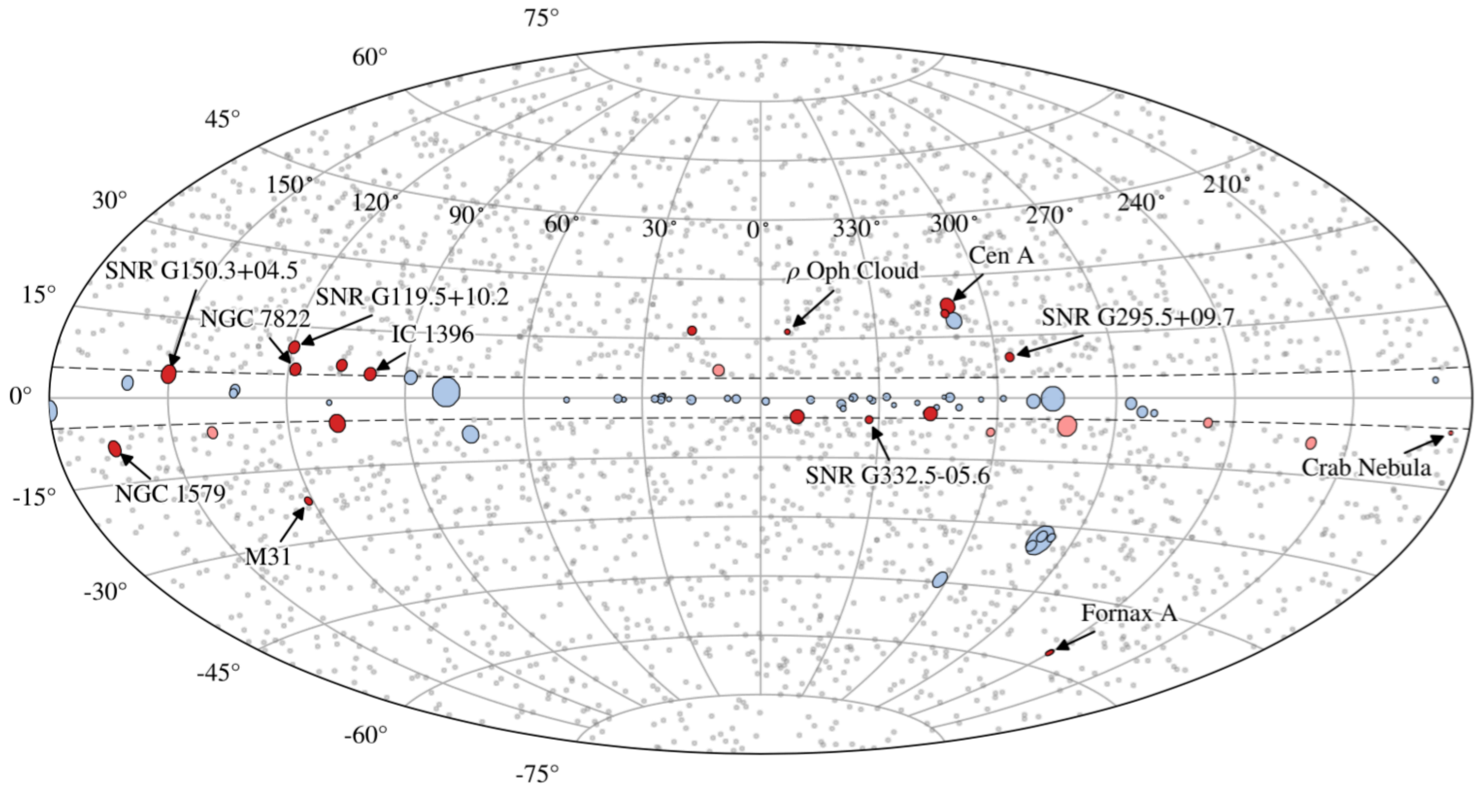
High-Energy Galactic Sources



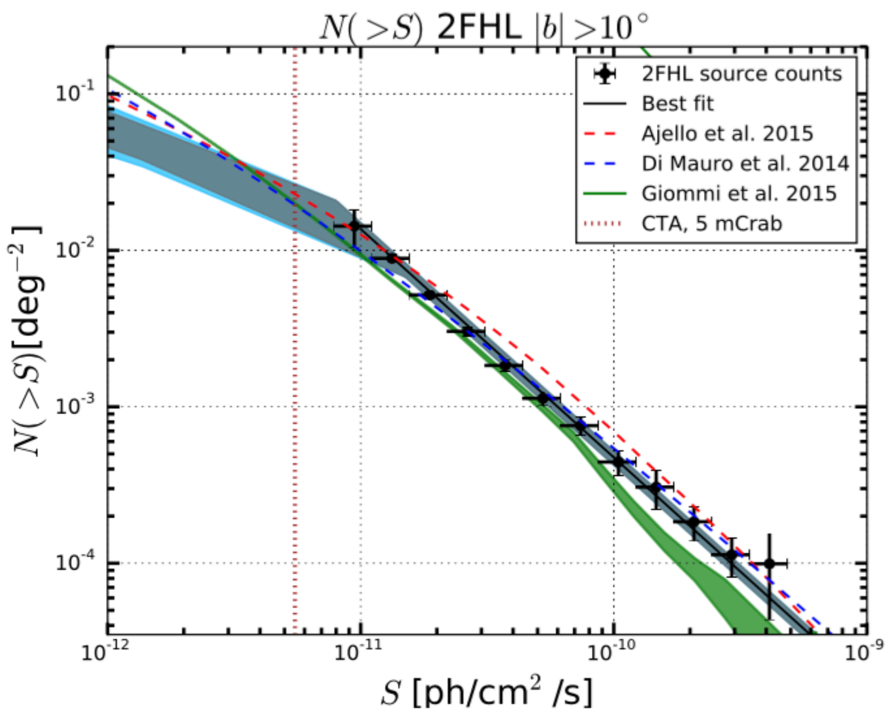
Emphasis on spatially extended sources with energy >10 GeV

Ackermann+ 2017

Full-Sky Extended Source Search



Using LAT sources to Resolve the Extragalactic Background



Ackermann et al. 2016

Point sources (blazars) explain 86 (+16 -14)% of the EGB above 50 GeV

Blazars not found to be dominant contributor to IceCube neutrino flux.

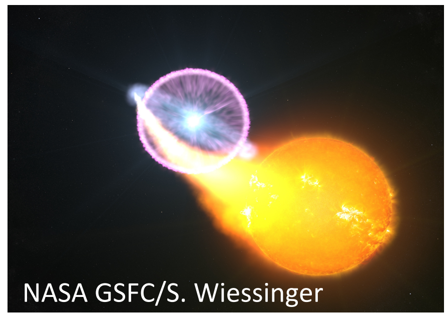
Constrains contribution of other source classes to neutrino background.

Variability and Transients

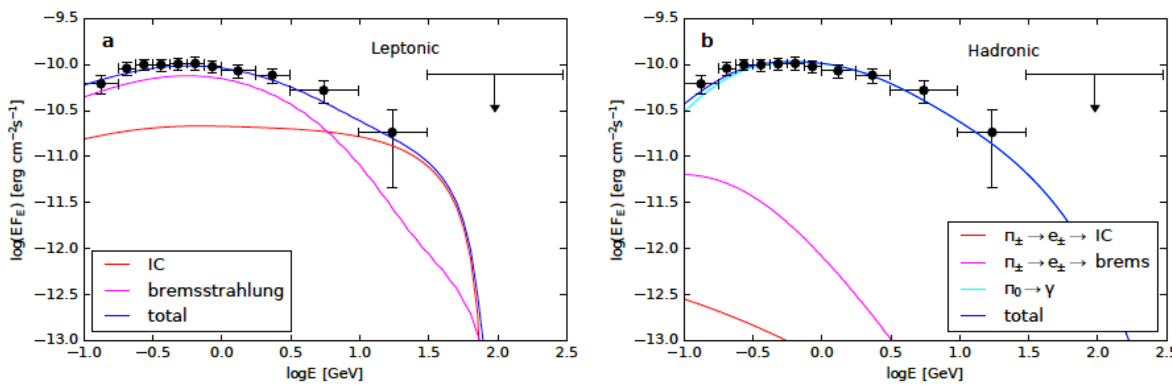
Gamma Rays from Stellar Novae

Stellar novae predicted to accelerate CR to high energy (Hernanz & Tatischeff) but gamma rays not anticipated for LAT.

Fermi-LAT detects ~1 classical nova per year.



Thermonuclear explosion from white dwarf with stellar companion

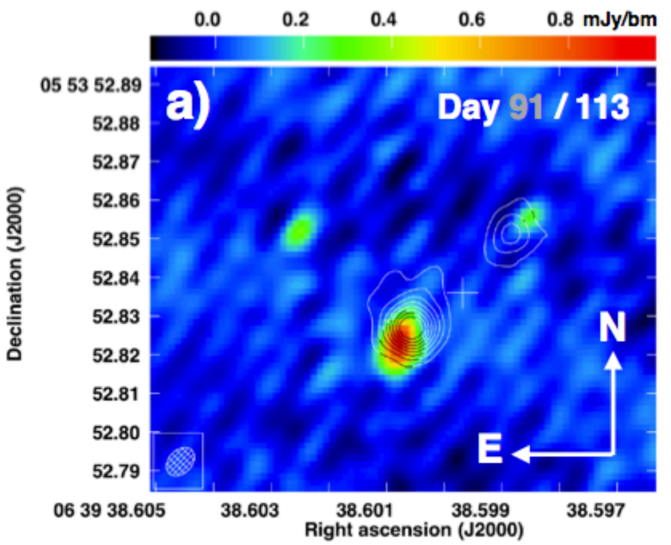


Li+ 2017

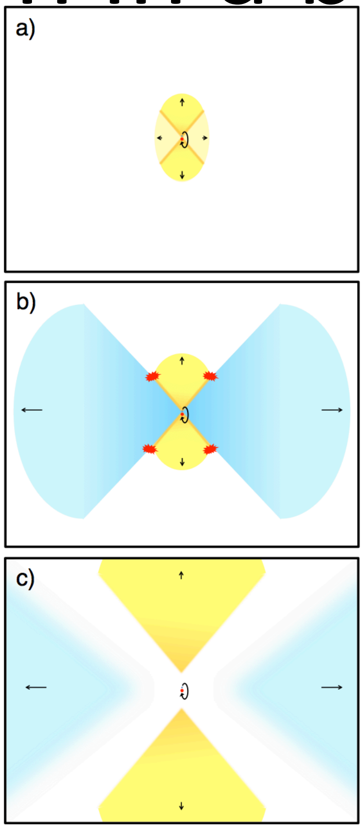
Hadronic model favored to avoid uncomfortably high efficiency for IC.

Shock expansion in a binary system

Radio imaging of the shock evolution for V959 Mon.



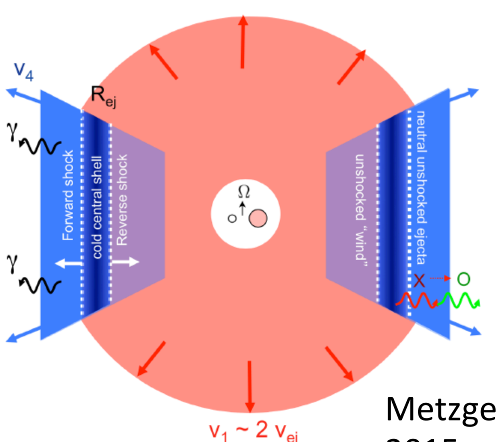
V959 Mon, 5 GHz EVN
Chomiuk et al. 2014



Nova expansion into binary creates asymmetrically expanding shock and polar wind from the white dwarf.

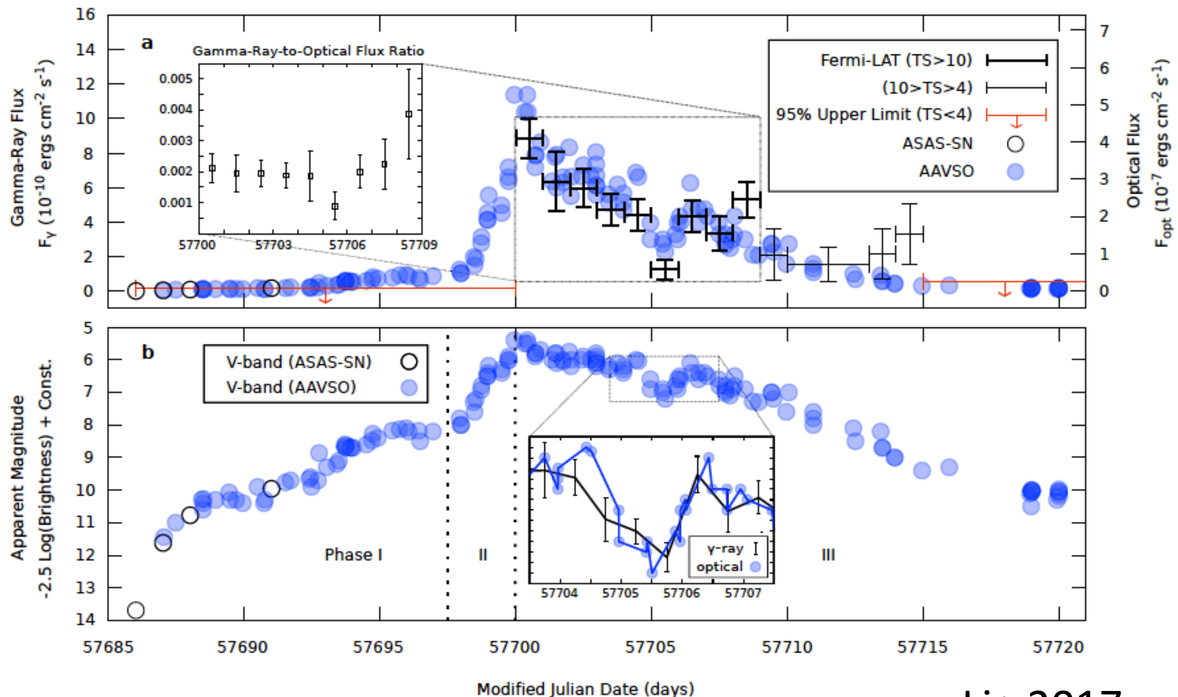
ASASSN-16ma Time Development

Tracking of optical and gamma implies that optical is reprocessed emission from shocks and NOT the white dwarf



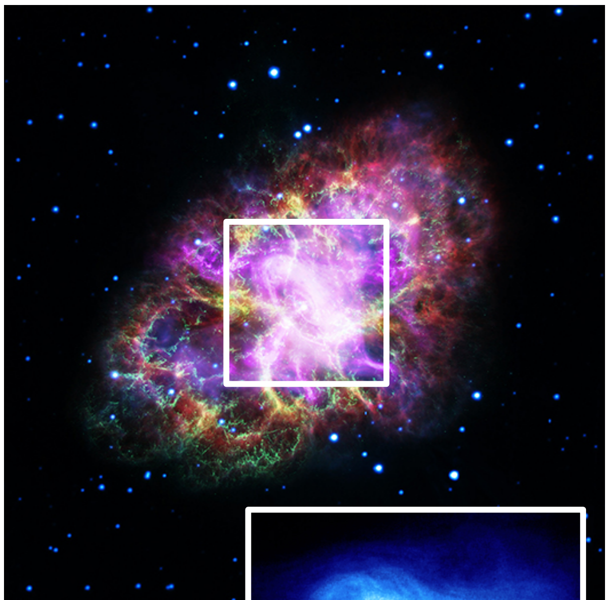
Metzger+ 2015

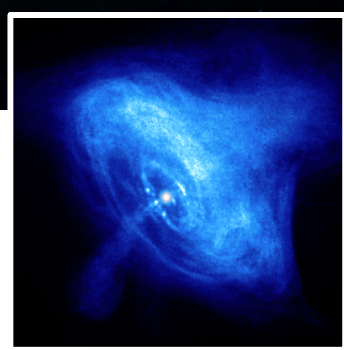
ASASSN-16ma



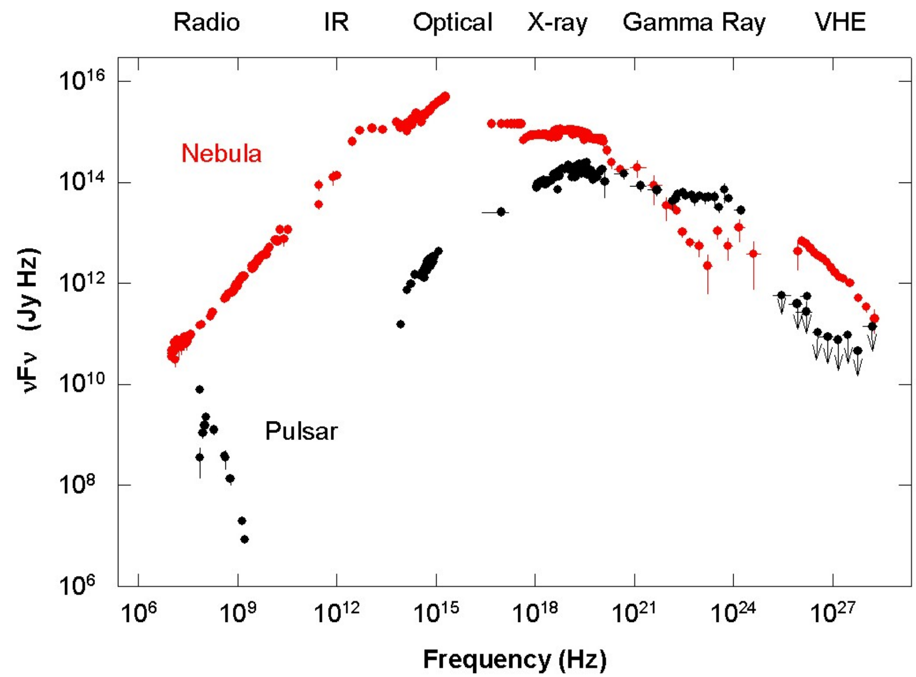
Li+ 2017

The Crab Nebula





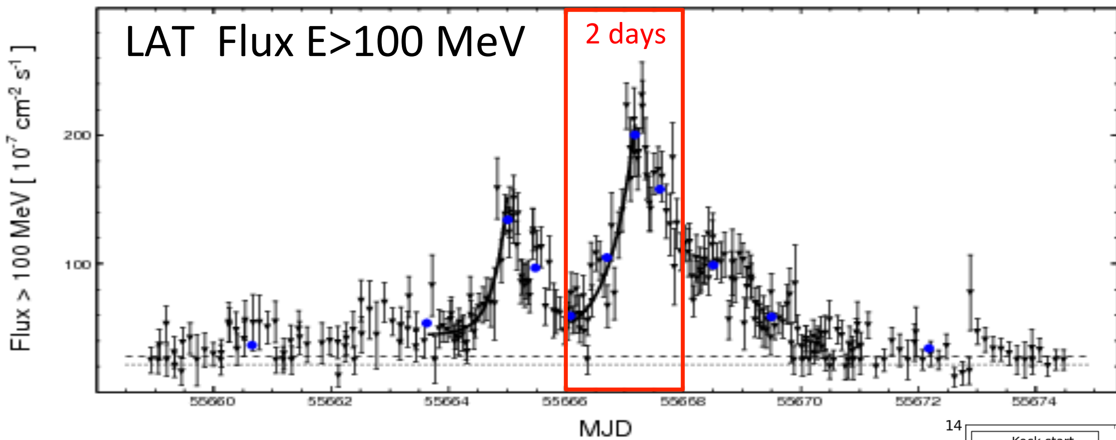
NASA/CXC/SAO; NASA/STScI; NASA/JPL/Caltech; NSF/NRAO/VLA; ESA/XMM-Newton



Spectrum from D. Thompson, compiled ~2006

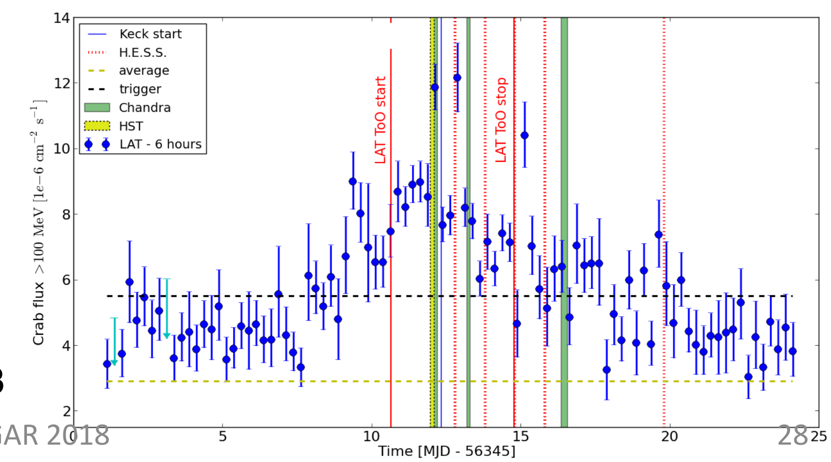
>5500 references for Crab Nebula in ADS

Extremely Rapid Gamma-ray Flares



Buehler+ 2012

Crab gamma-ray flux (>100 MeV) doubles in hours.

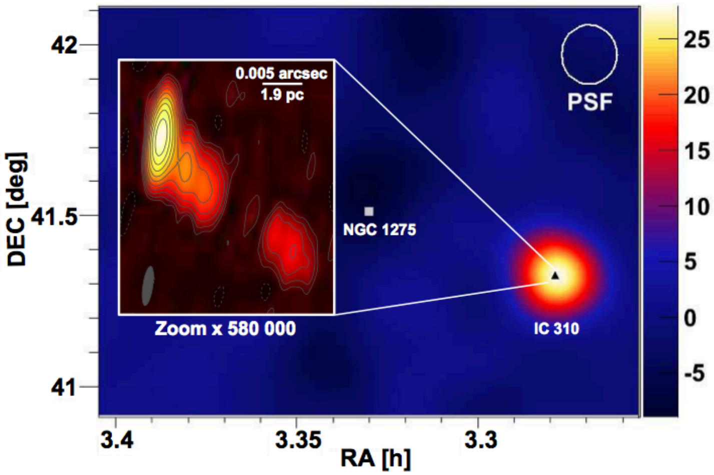


Meyer+ 2013

Where are the gamma rays from?

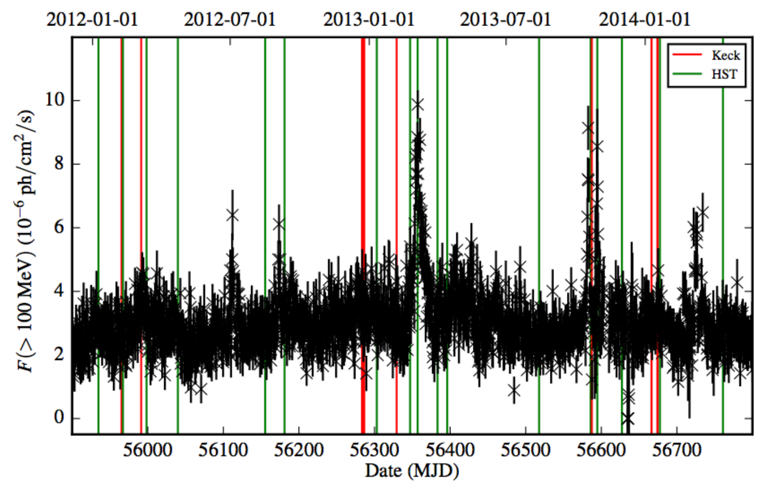
Rapid variability observed in blazars, Crab Nebula maxes out resolution capabilities of multiwavelength observations and defies shock acceleration.

IC 310



Aleksic et al. 2014

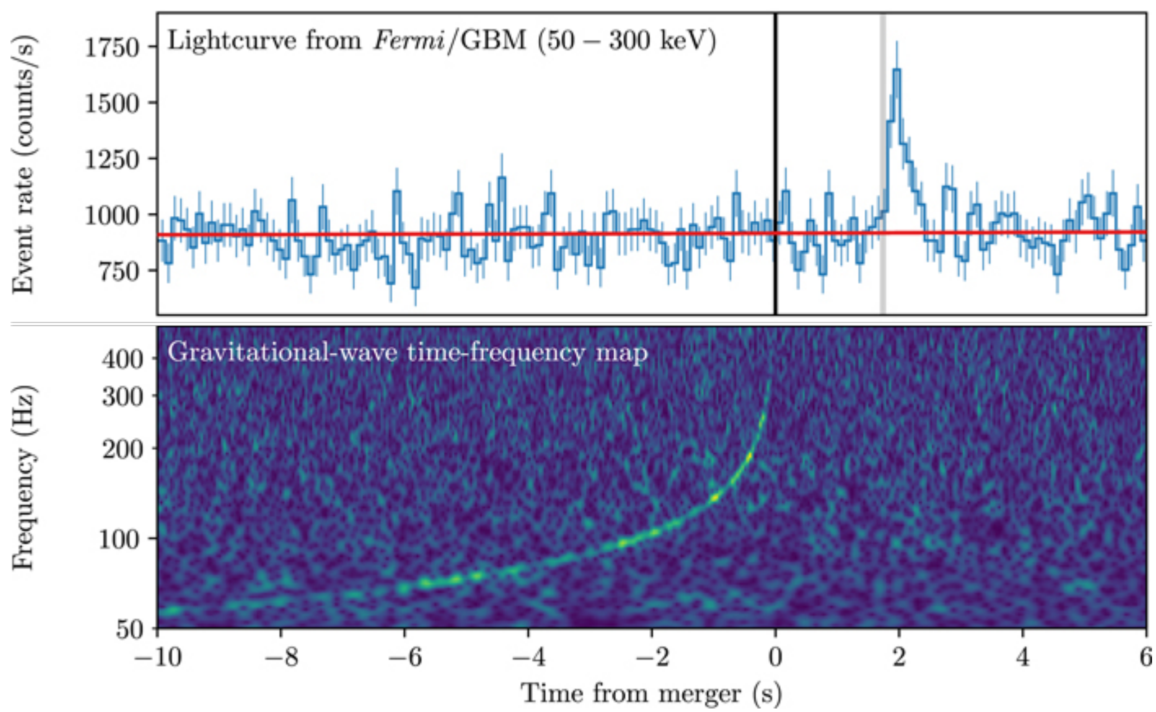
Crab LAT E>100 MeV 12-hr



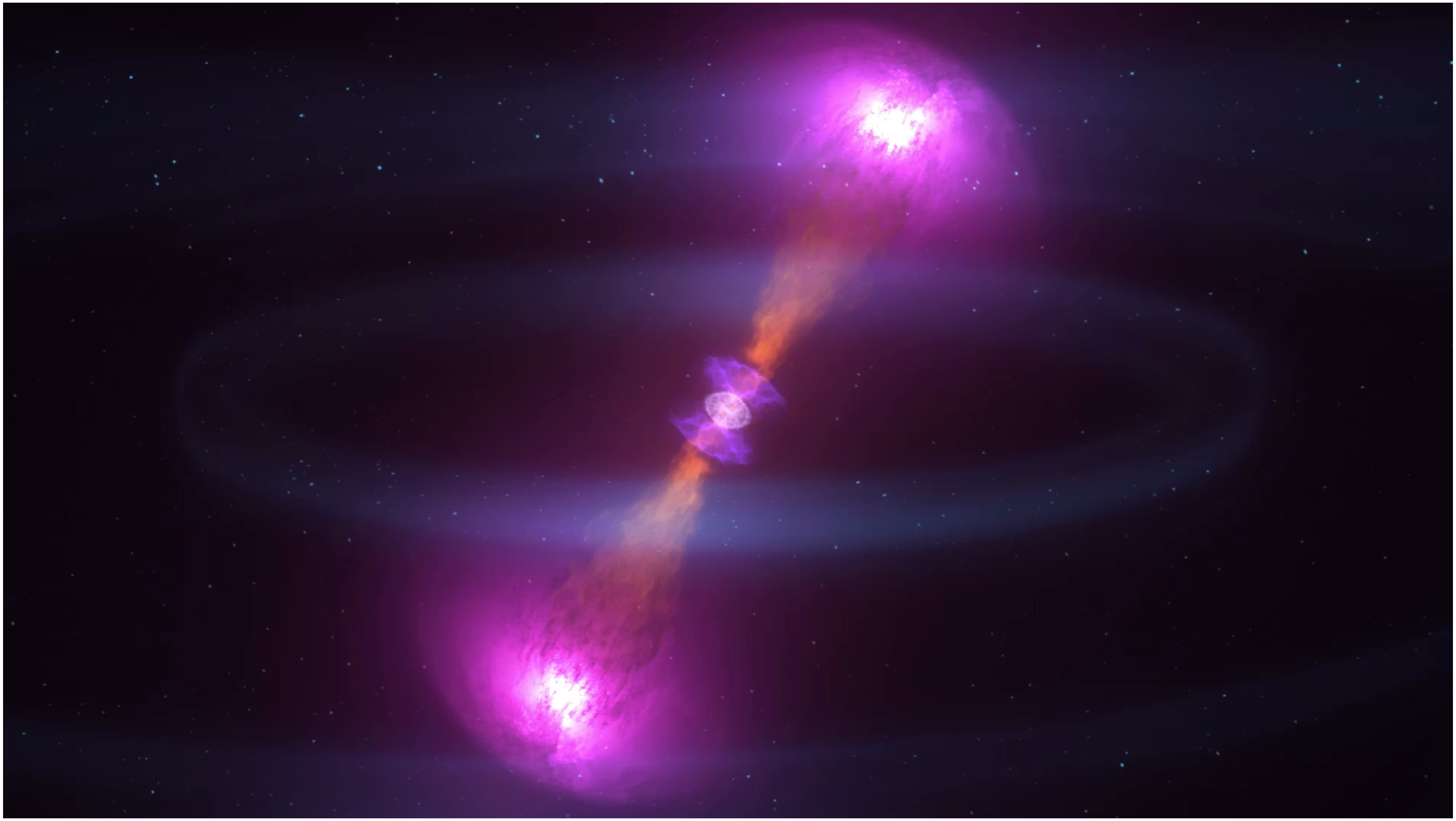
Rudy et al. 2016

Binary Neutron Star Mergers

Fermi-GBM independently triggered on a short GRB matching GW 170817

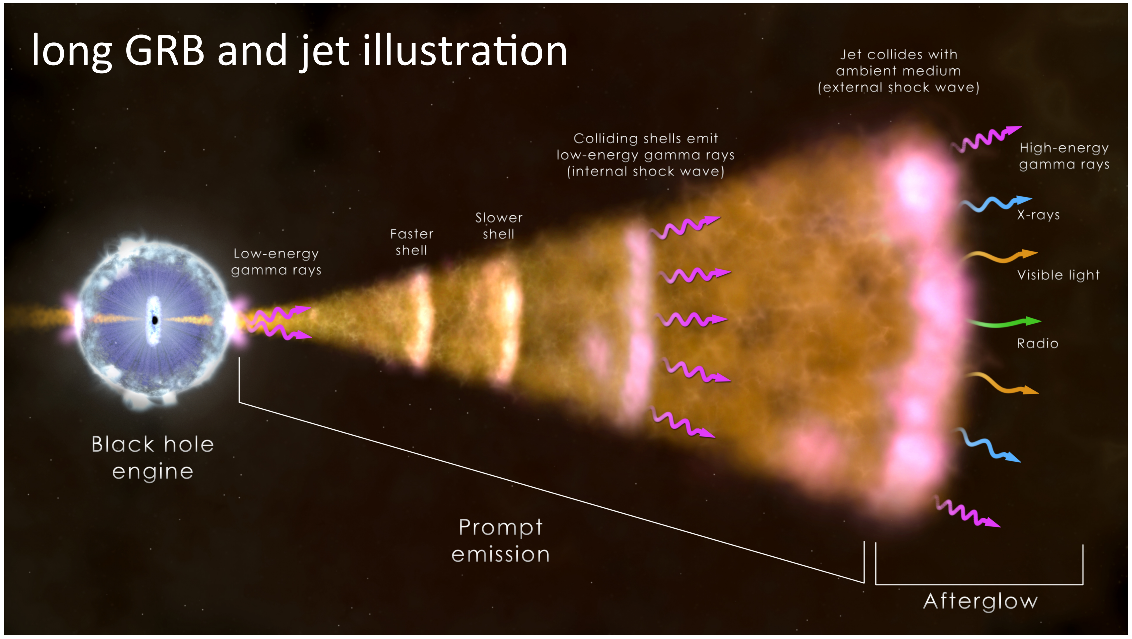


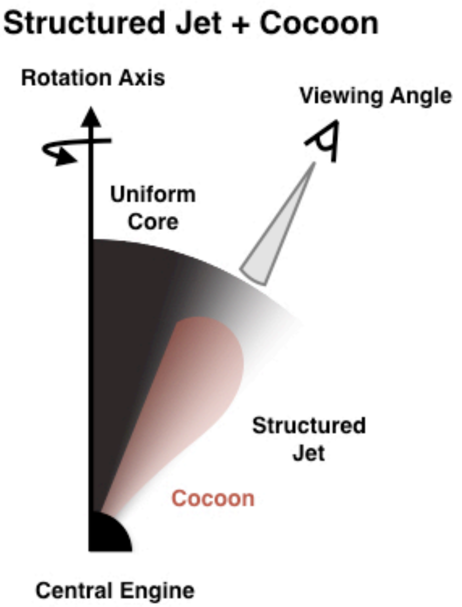
Abbott et al. 2017, ApJL, 848, 2



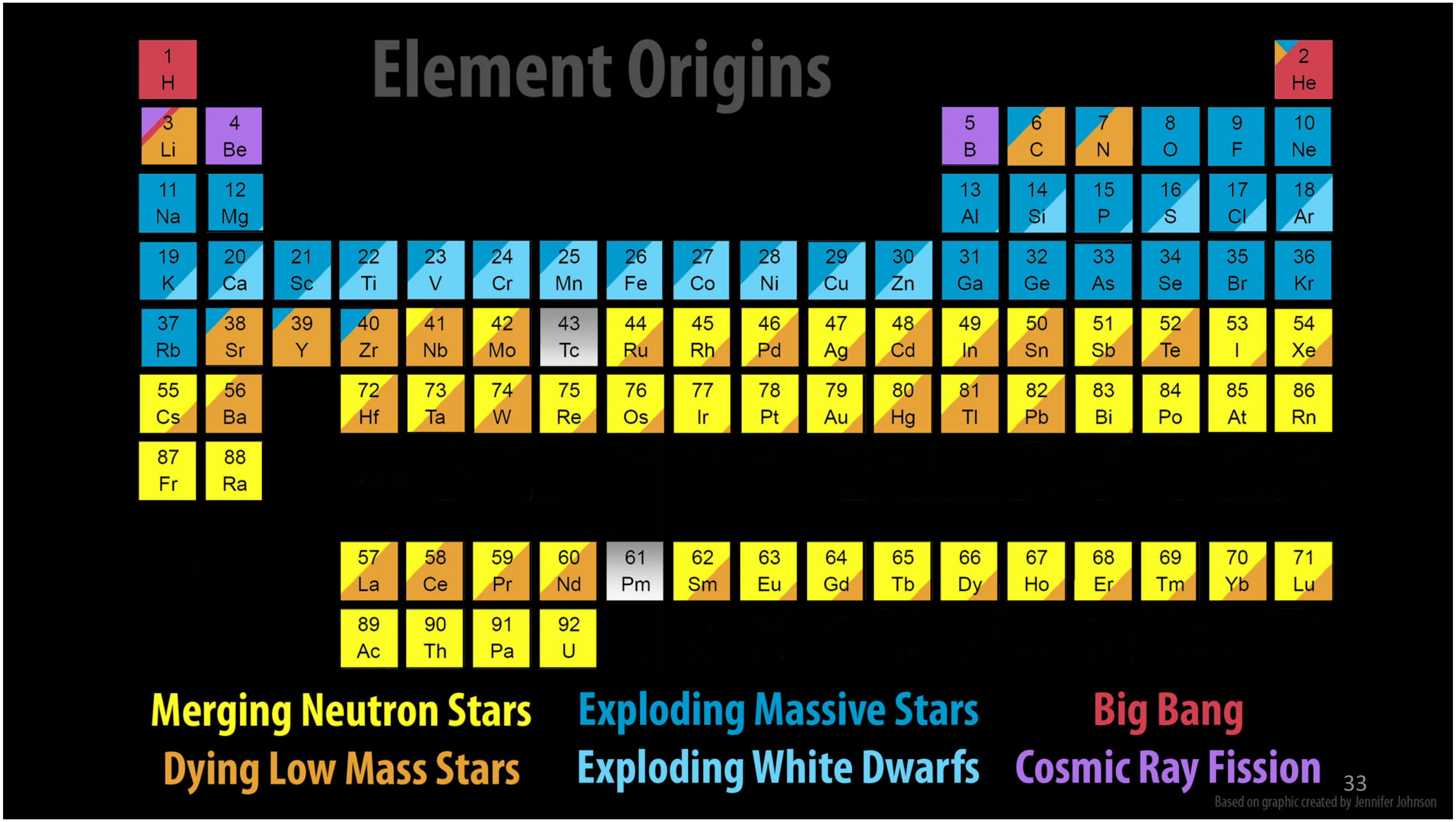
Where are the Gamma Rays From? II

GRB 170817A was not very bright for being close (43 Mpc). Why?



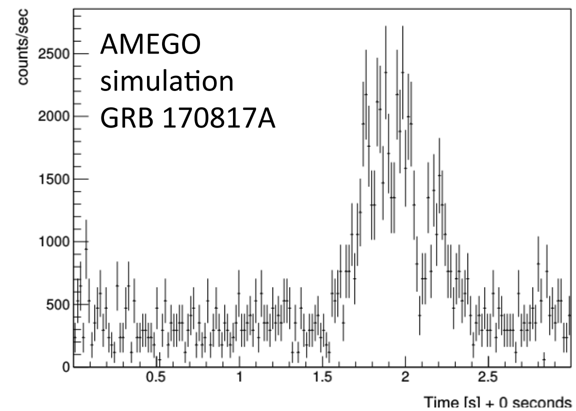


Possibly off-axis, implying a structured jet or cocoon (wind) component.


Element Origins
1 H
2 He
3 Li 4 Be
5 B 6 C 7 N 8 O 9 F 10 Ne
11 Na 12 Mg
13 Al 14 Si 15 P 16 S 17 Cl 18 Ar
19 K 20 Ca 21 Sc 22 Ti 23 V 24 Cr 25 Mn 26 Fe 27 Co 28 Ni 29 Cu 30 Zn 31 Ga 32 Ge 33 As 34 Se 35 Br 36 Kr
37 Rb 38 Sr 39 Y 40 Zr 41 Nb 42 Mo 43 Tc 44 Ru 45 Rh 46 Pd 47 Ag 48 Cd 49 In 50 Sn 51 Sb 52 Te 53 I 54 Xe
55 Cs 56 Ba 72 Hf 73 Ta 74 W 75 Re 76 Os 77 Ir 78 Pt 79 Au 80 Hg 81 Tl 82 Pb 83 Bi 84 Po 85 At 86 Rn
87 Fr 88 Ra
57 La 58 Ce 59 Pr 60 Nd 61 Pm 62 Sm 63 Eu 64 Gd 65 Tb 66 Dy 67 Ho 68 Er 69 Tm 70 Yb 71 Lu
89 Ac 90 Th 91 Pa 92 U
Merging Neutron Stars
Exploding Massive Stars
Big Bang
Dying Low Mass Stars
Exploding White Dwarfs
Cosmic Ray Fission
Based on graphic created by Jennifer Johnson

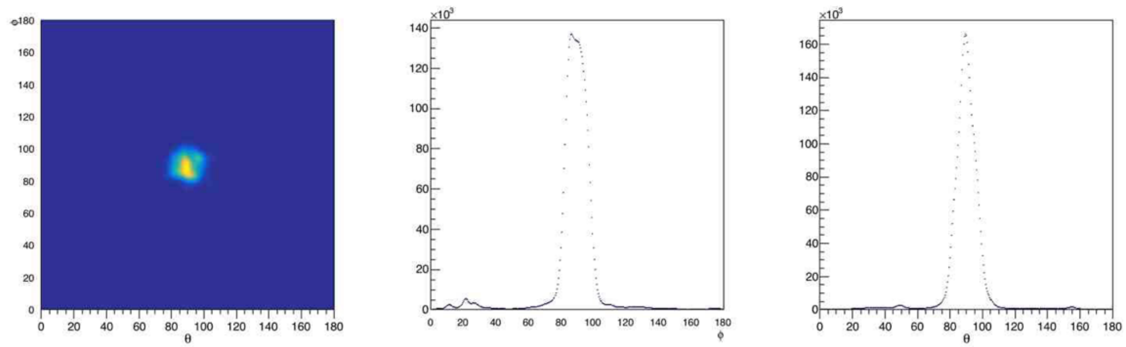
MeV Prospects for Neutron Star Mergers

GRB 170817A would only have been detected by GBM onboard to ~80 Mpc



An MeV instrument like AMEGO will detect a similar GRB to >130 Mpc with a localization of <6 deg radius (1σ)

AMEGO will detect 10's of short GRBs per year (uncertainty in intrinsic rate, redshift distribution and jet structure)

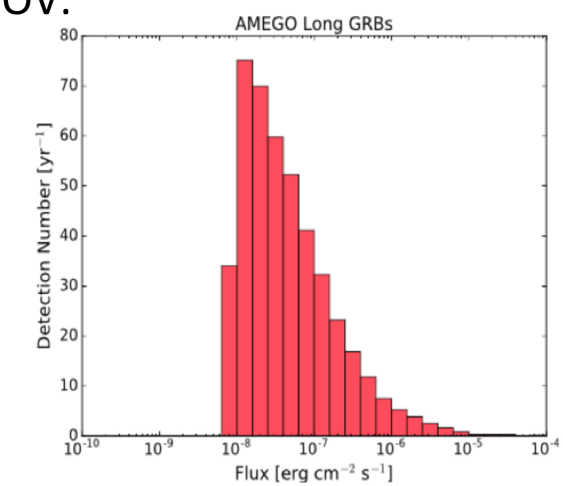


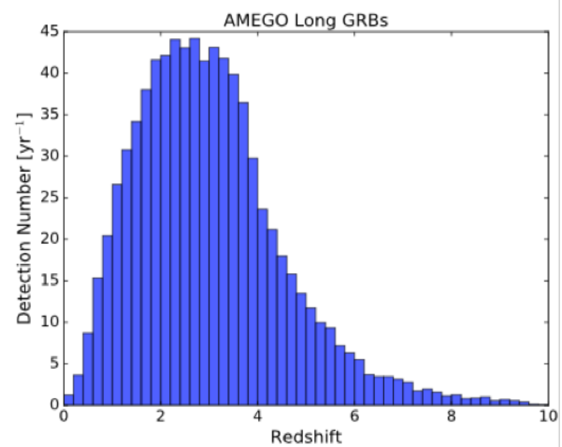
MeV Prospects for GRBs

Intrinsic population of long duration GRBs given luminosity function, redshift distribution, prompt light curves/spectra derived from Swift-BAT using method of Lien et al. 2014.
Sample subset of population above sensitivity limit for an MeV instrument (AMEGO) and adjust for FOV.

~400 Long GRBs/yr
(~19 @ z>6)

~80 Short GRBs/yr
(scaling by
GBM population fraction)



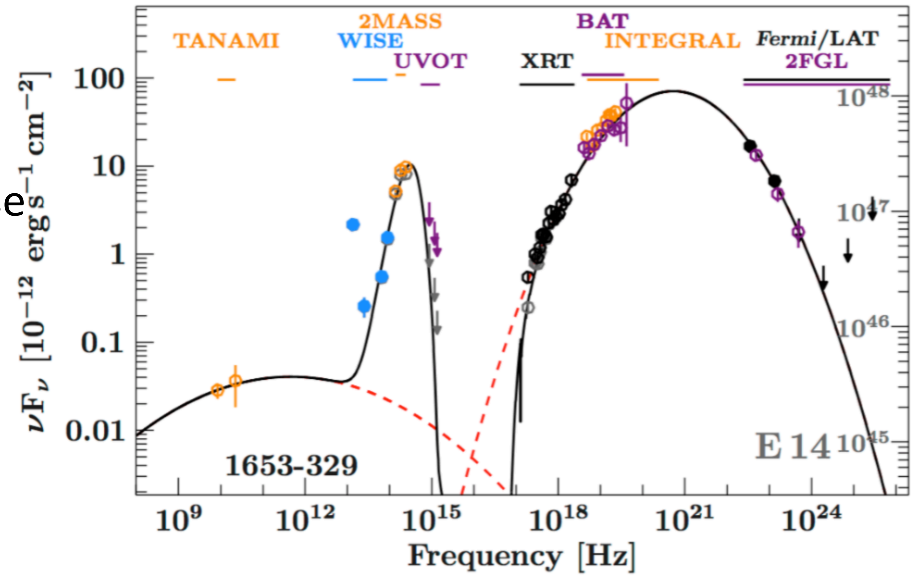


Reminder about Beamed Sources

- Gamma-ray emission from GRBs is relativistically beamed
- Detected GRBs are a few percent of the entire population (depending on jet angle)
- The detection of a few GRBs at high redshift provides a sample of the entire population existing in a younger Universe
- *(That goes for blazars, too)*

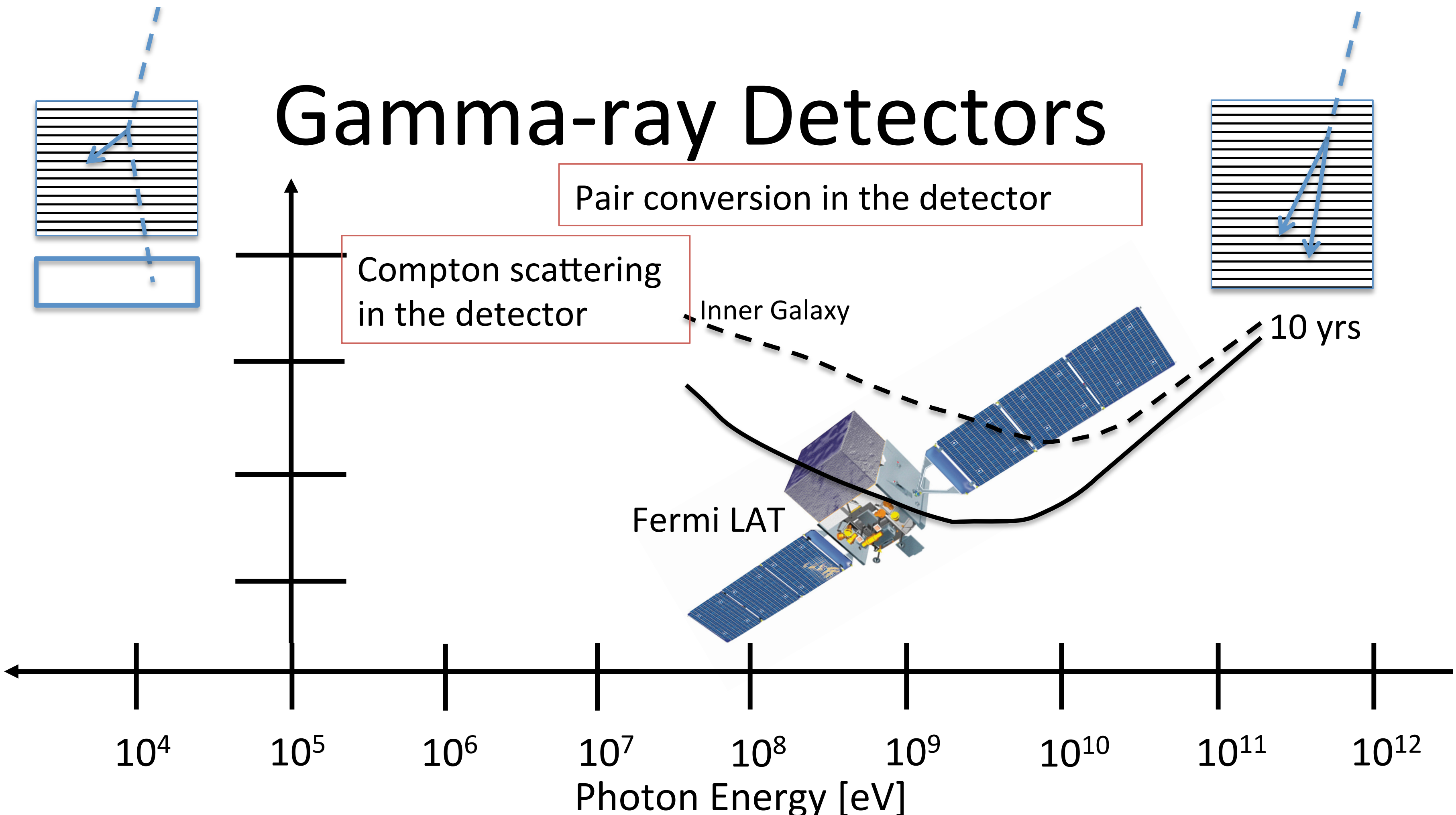
MeV prospects for blazars

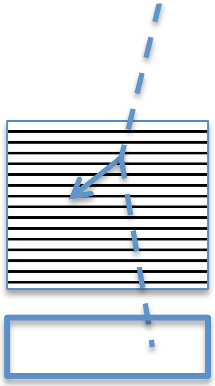
- Energy output peaks in MeV, below LAT band
- Among the most powerful persistent sources in the Universe
- Large jet power, > accretion luminosity
- Host massive black holes, ~10^9 solar masses or more
- Detected up to high redshift (expect ~100 at z>3)
- Evolution of MeV blazars is stronger than any other source class – maximum density might be very early



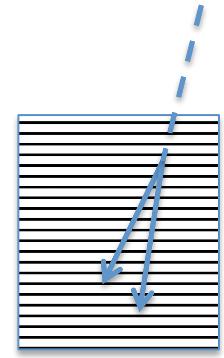
J1653-329 a candidate PeV neutrino emitter (Krauss+ 2014)

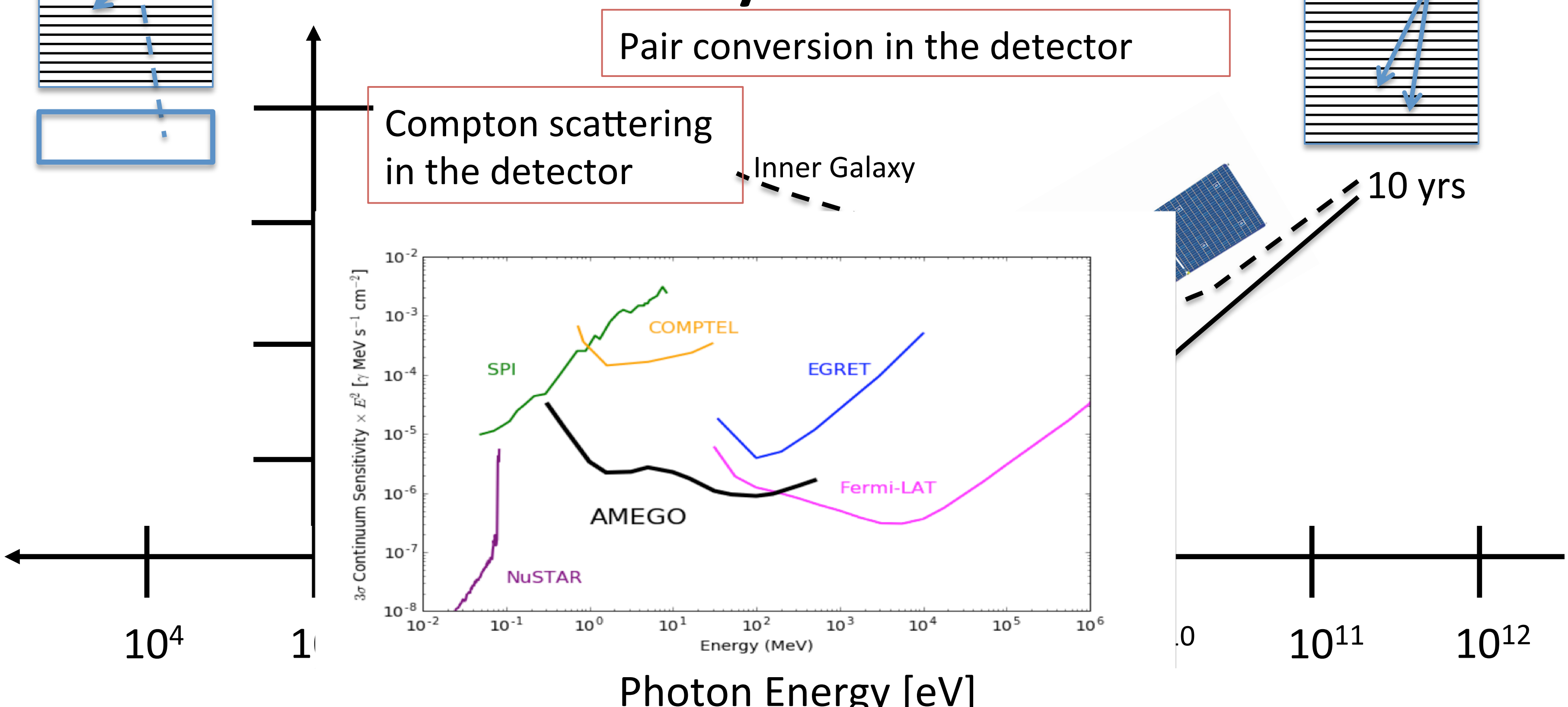
Gamma-ray Detectors





Gamma-ray Detectors





Themes for the Future in Gamma Rays

- Fermi-LAT continues to deepen all-sky view above in the multi-GeV to TeV range, especially important for spatially extended and diffuse studies
- Fermi all-sky monitoring (GBM and LAT) continue to promote discovery and uniquely support multiwavelength variability and transient work
- Enhanced context
  - Multiwavelength overlap and complementarity
    - Challenges for interpreting relationship of emission sites and processes within a source and making connecting to acceleration sites and populations
  - MeV is critical for extending horizon of GRBs and blazars in support of multimessenger studies (and loads of other reasons – see e-ASTROGAM talk)
- Angular Resolution
  - I begin to see what I would really like to see better

Concluding Thoughts

- Relation between gamma rays and cosmic rays remains complex
  - Fermi LAT has answered many questions, but raised many more.
  - The sites of gamma-ray emission do not provide a complete answer about where and how cosmic rays are accelerated
  - Gamma rays from freshly accelerated cosmic rays remain elusive
  - In some of the most interesting cases for understanding acceleration, the sites are surprisingly compact, but difficult to localize