Status Overview of Gamma-ray Astronomy

Increasing Capabilities, Key Discoveries and Future Promise

Elizabeth Hays
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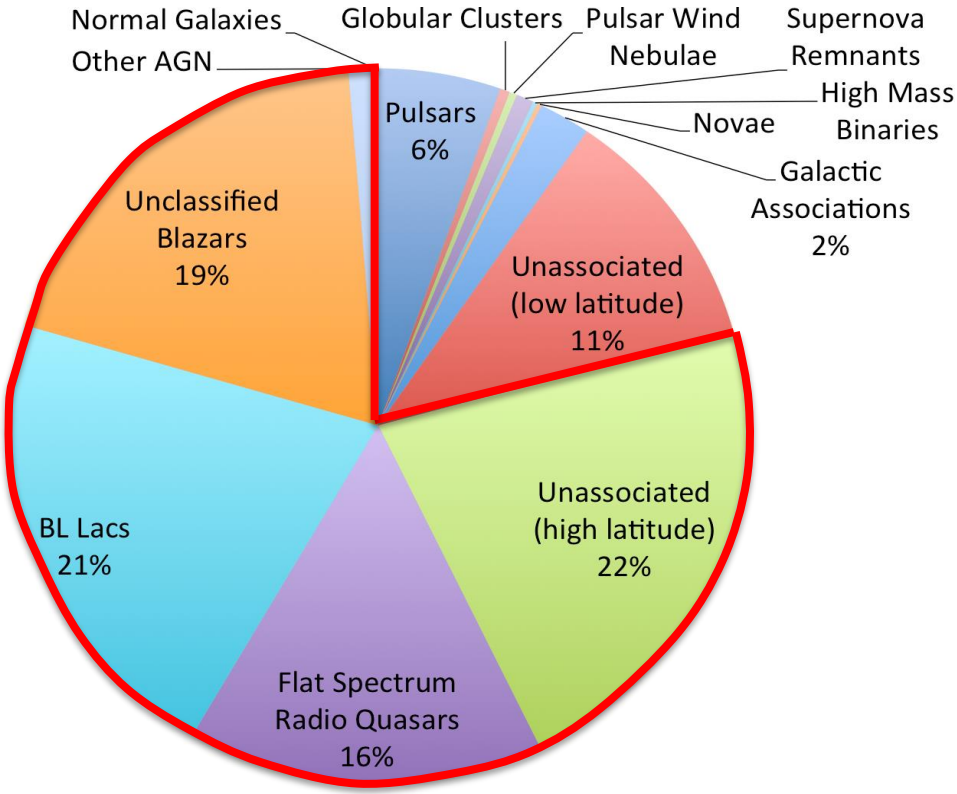
Overview

- Overview of gamma-ray science and instrumentation
- A few interesting things we have learned
- Some questions for the future

It is a great time for gamma rays!

- The gamma-ray sky is full of sources
  - Detailed spectral and spatial measurements for the brightest
  - Population studies
- The era of catalogs
  - Deeper exposures over all or large regions of sky
  - Broad spectral coverage
  - Increasing variety of sources
  - Rich multiwavelength data sets

Demographics: High Energy

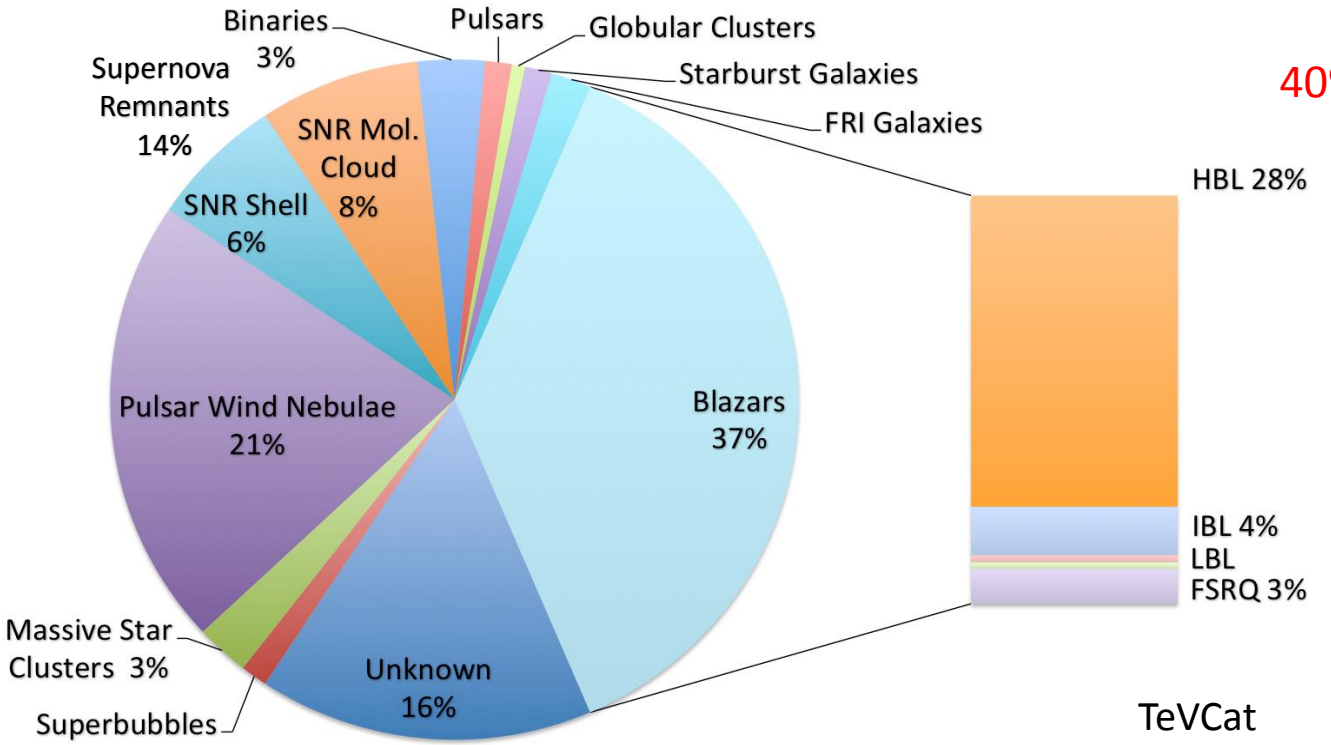


80% extragalactic

>3033 sources
>100 MeV

Based on 3FGL

Demographics: Very High Energy



40% extragalactic

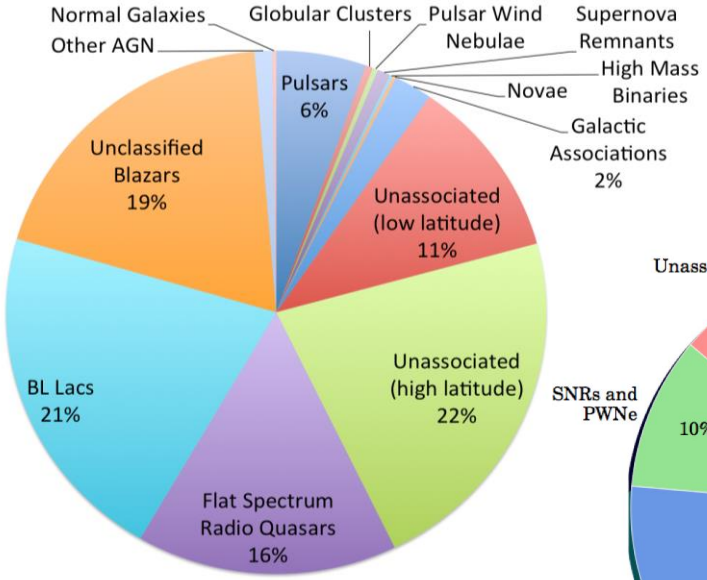
>150 sources

>~100 GeV

TeVCat

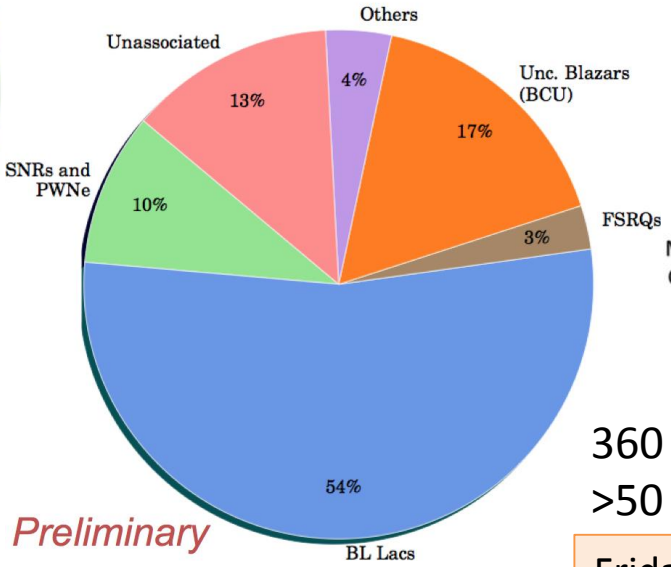
http://TeVCat.uchicago.edu

Bridging the Gap

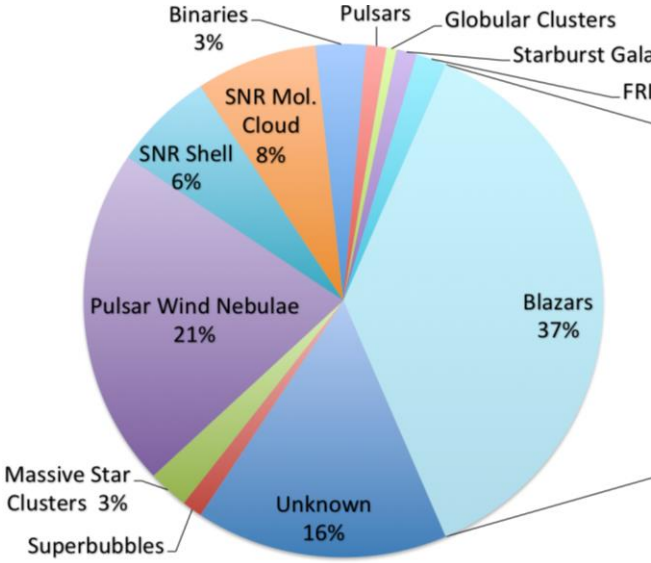


>3033 sources
>100 MeV

Second Catalog of Hard Fermi-LAT Sources



360 sources
>50 GeV

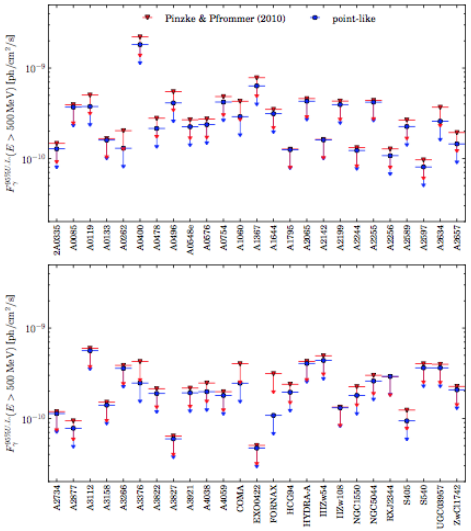


>150 sources
>~100 GeV

Friday Highlight Talk

Notable Absences

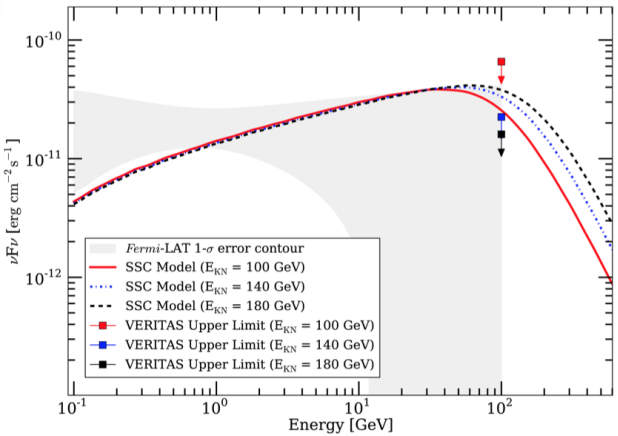
Galaxy Clusters



Ackermann et al. 2014 (TeV, e.g., Aleksic et al. 2012, Abromowski et al. 2012, Arlen et al. 2012)

GRBS at E>100 GeV

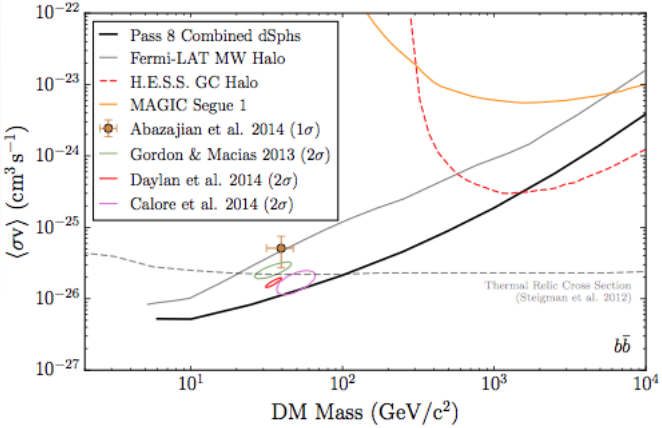
GRB 130427A at 71 - 75 ks



Aliu et al. 2014

Waiting for the right burst…

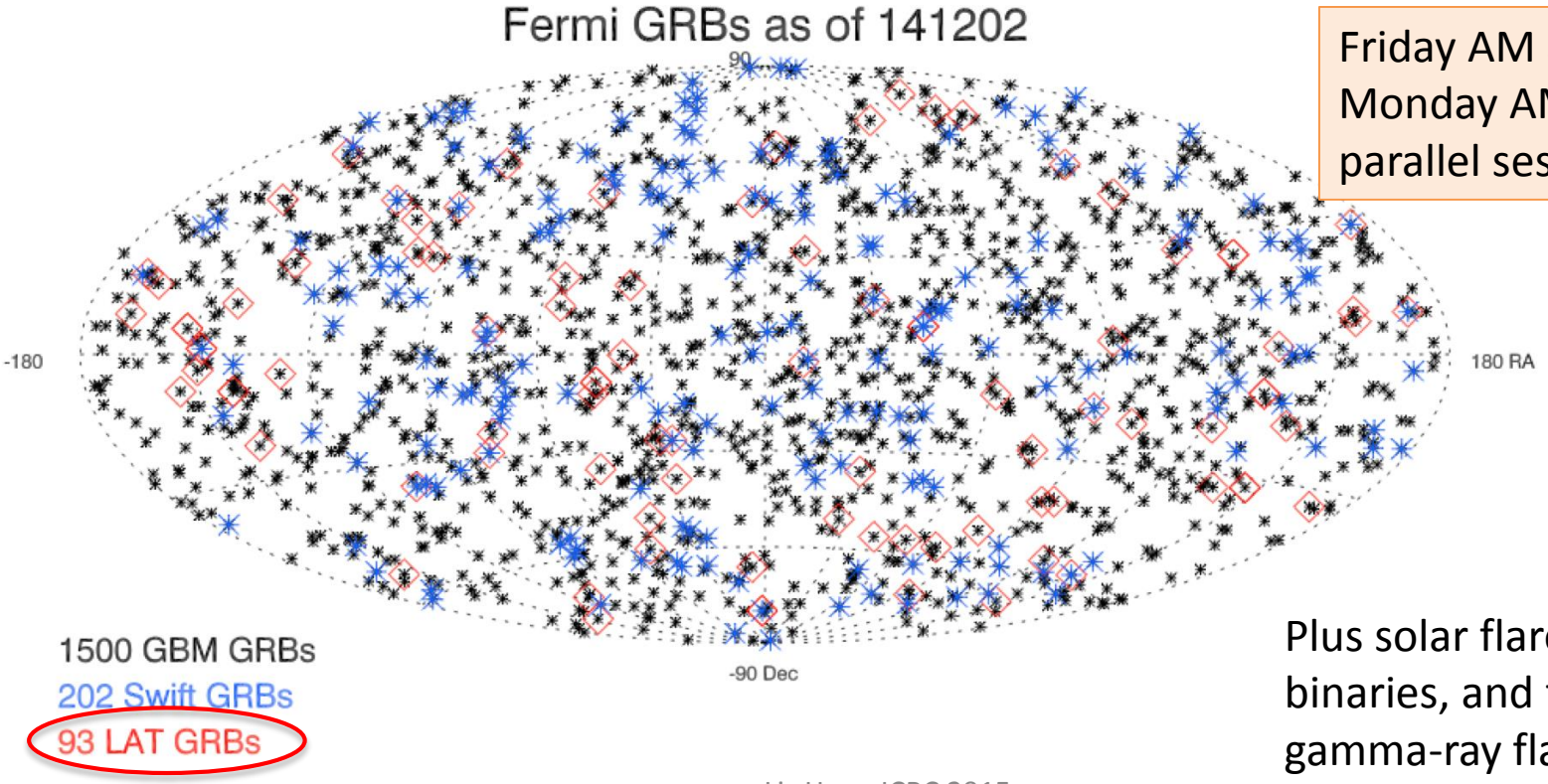
Dwarf Spheroidals



Ackermann et al. 2015

Sensitivity improves with new dwarf galaxies (DES)

Transients



Friday AM and Monday AM parallel sessions

Plus solar flares, Galactic binaries, and terrestrial gamma-ray flashes

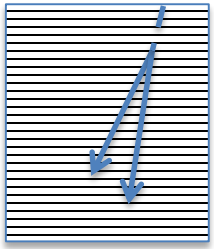
Resources!

Fermi Science Support Center hosts Fermi catalogs and a variety of data products
http://fermi.gsfc.nasa.gov/ssc/data/access/
Analysis tools and documentation for Fermi instrument data
http://fermi.gsfc.nasa.gov/ssc/

ASI Science Data Center hosts resources for both Fermi and AGILE
http://www.asdc.asi.it

TeVCat provides an online VHE gamma-ray catalog
http://tevcat.uchicago.edu/

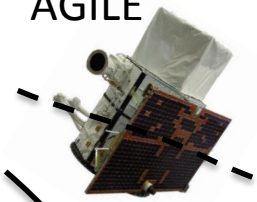
Gamma-ray Detectors



Pair conversion in the detector

Pair conversion in the atmosphere

AGILE



HAWC

LAT

10 yrs

Fermi LAT

HAWC 1 yr/

5 yrs

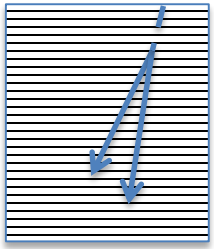
ARGO-YBJ

10^7 10^8 10^9 10^{10} 10^{11} 10^{12}

Photon Energy [eV]

Sample shower particles at ground level

Gamma-ray Detectors

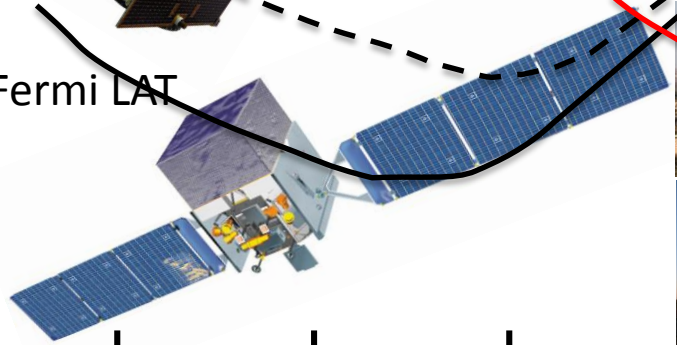


Pair conversion in the detector

Pair conversion in the atmosphere

AGILE

Fermi LAT



VERITAS
LAT
10 yrs

H.E.S.S.
MAGIC

MAGIC

H.E.S.S./VERITAS
50 hrs

10^7 10^8 10^9 10^{10} 10^{11} 10^{12}

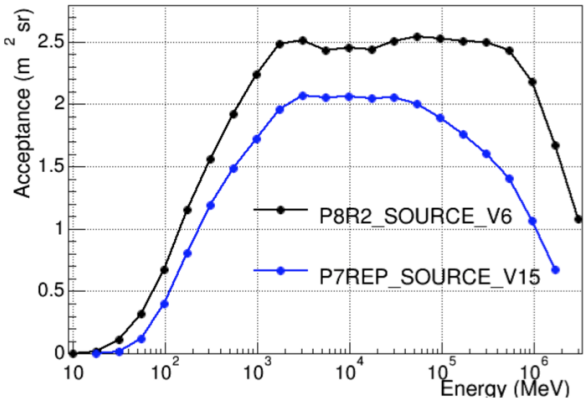
Photon Energy [eV]

Sample Cherenkov light cone at ground level

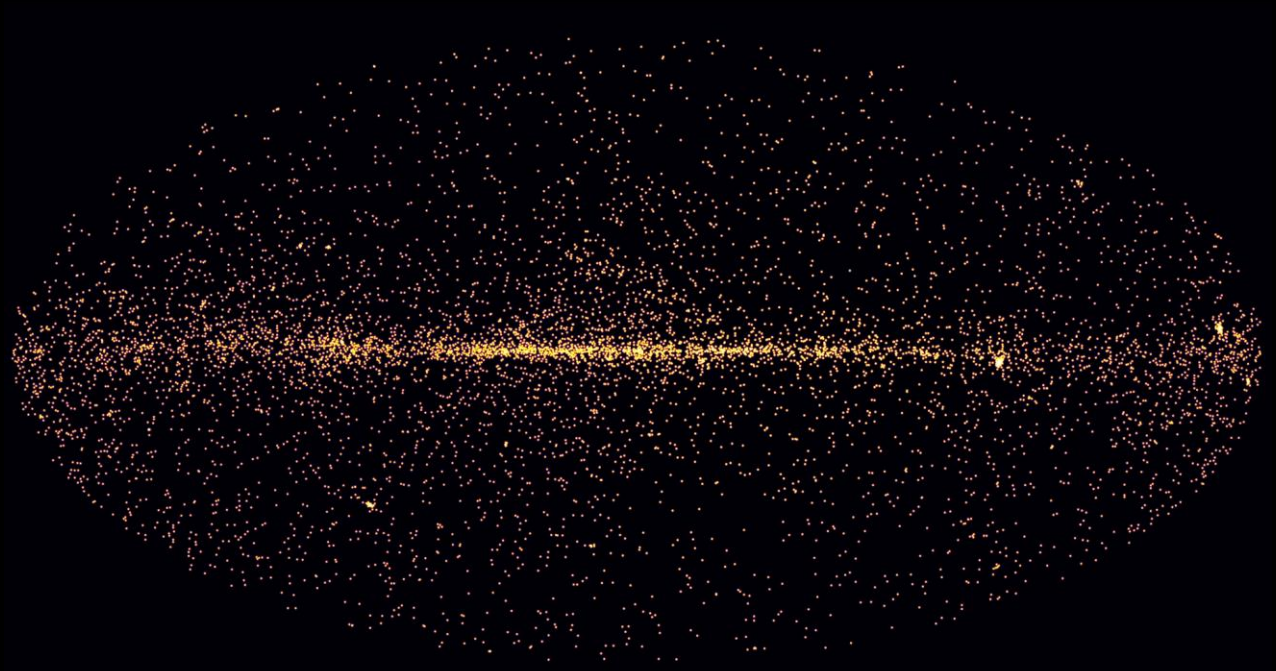
Fermi-LAT Upgrade - Pass 8

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

More photons!

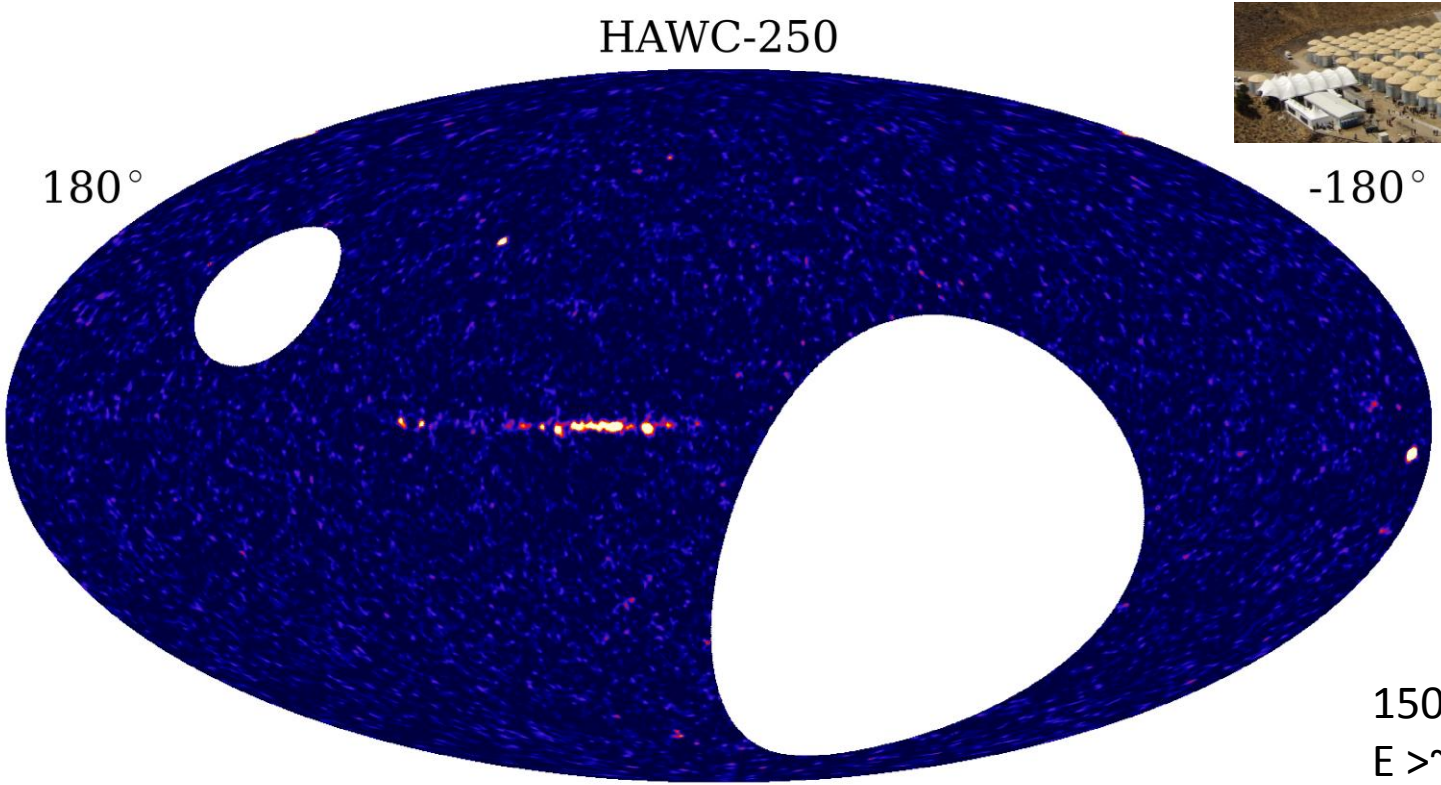


7 Years of LAT All-sky Coverage



E > 1 GeV

Wide Field Coverage of the TeV sky

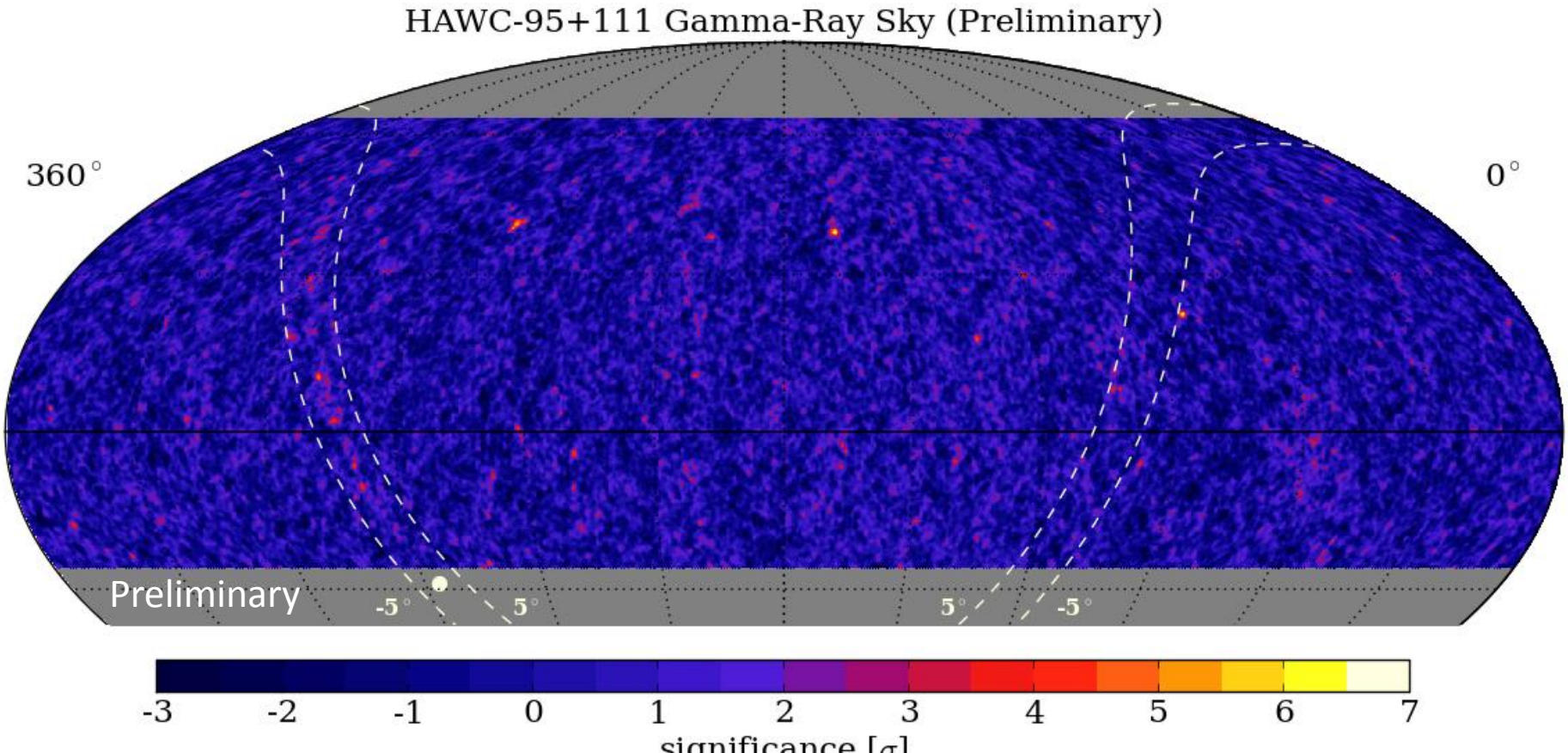


150 days
E >~ 100 GeV

Liz Hays, ICRC 2015

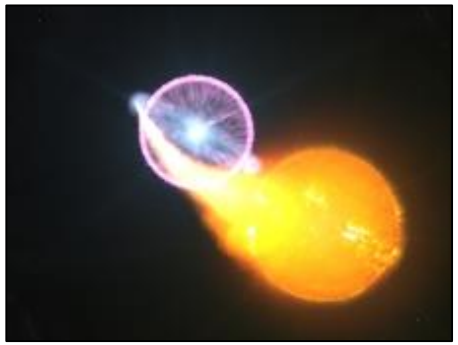
Wednesday Highlight Talk

Connecting the GeV and TeV Skies

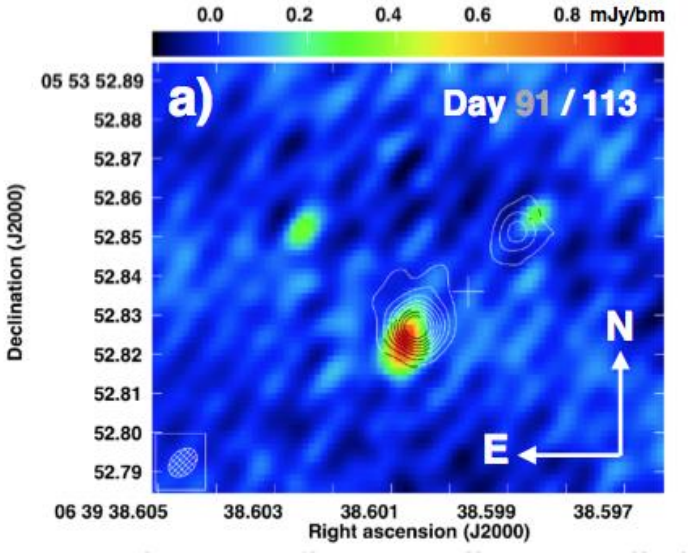


What Have We Learned?

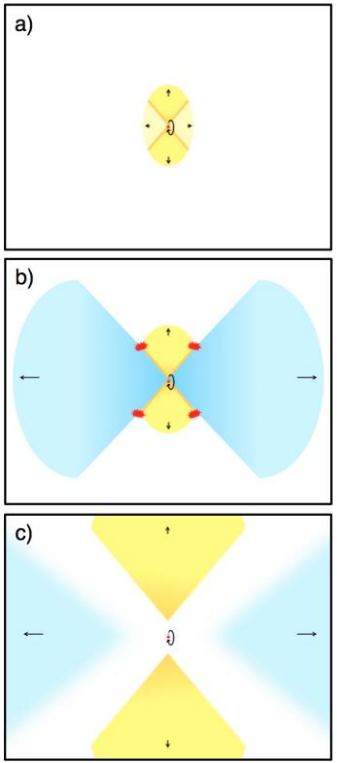
- About accelerators?
  - Gamma rays probing a variety of astrophysical shocks, but the devil is in the dissipation
- About dark matter and fundamental physics?
- About the high energy Universe?



Gamma-ray Novae



V959 Mon, 5 GHz EVN
Chomiuk et al. 2014



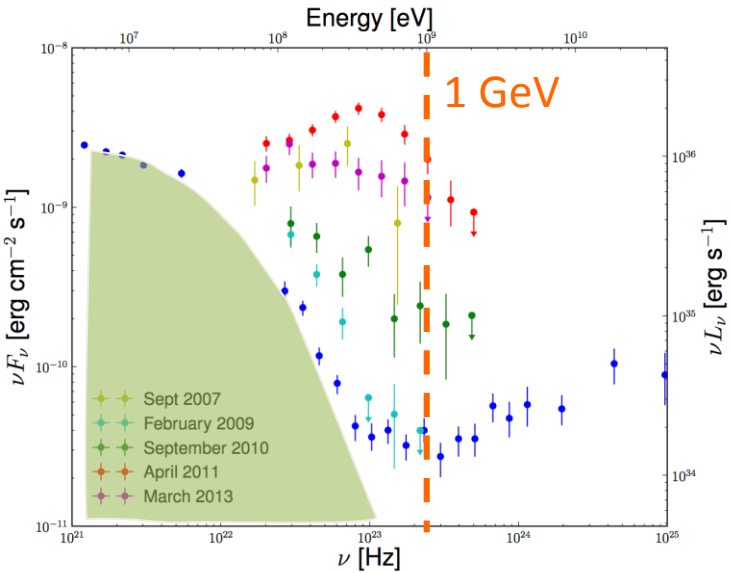
Radio imaging of the shock evolution for V959 Mon.

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

Wednesday PM parallel session talk

Rise of Reconnection

Standard shock acceleration scenario does not fit observations in some cases, e.g. Crab Nebula flares.



R. Buehler 2014

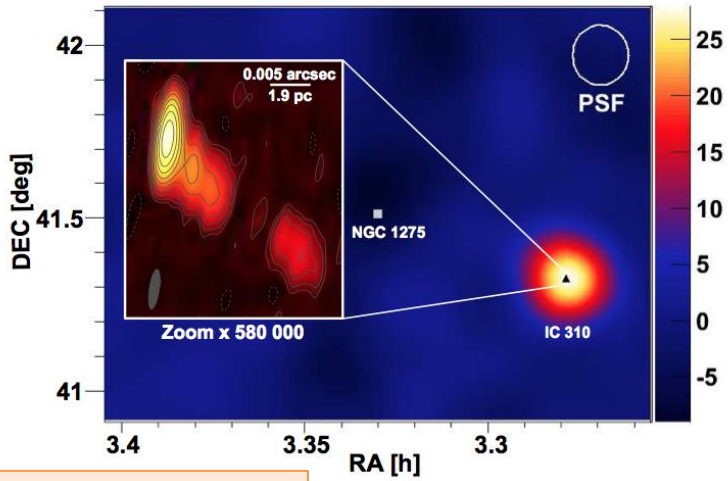
- Hard electron spectrum
- Electron energy exceeds synchrotron limit at ~160 MeV
- Time scale shorter than that of Larmor gyration

Lots of work happening!
E.g. Sironi & Spitkovsky, Cerutti et al., Porth et al., Guo et al., Lyutikov et al.,

Rapid Variability

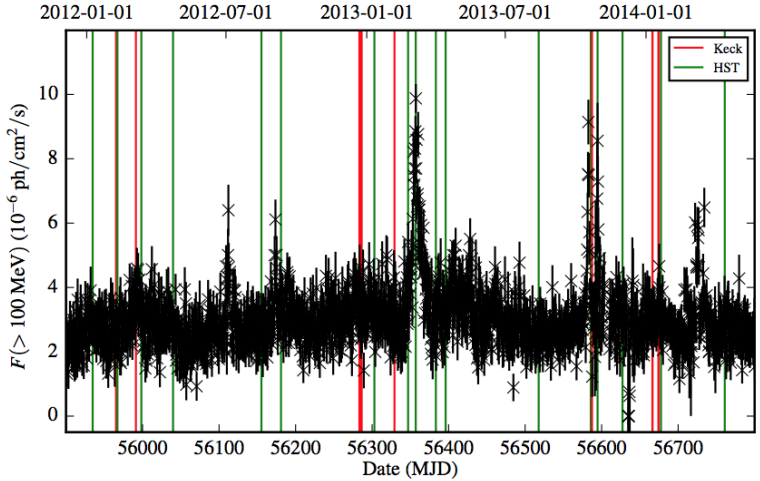
Current gamma-ray detectors have comparatively poor angular resolution within broader astronomy. However fast photon counting enables excellent time resolution and requires substantial resolution in multiwavelength observations.

IC 310



Aleksic et al. 2014

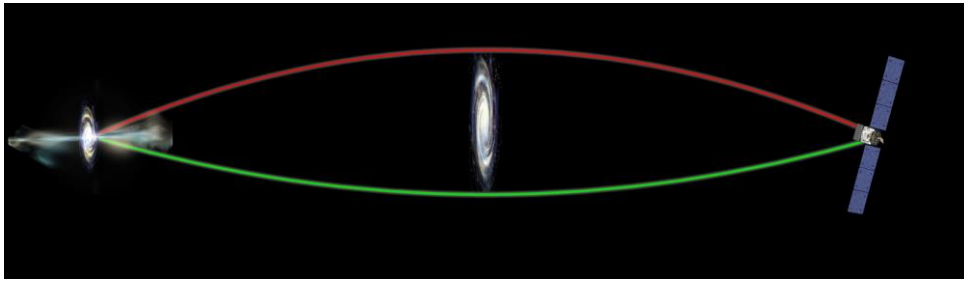
Crab LAT E>100 MeV 12-hr



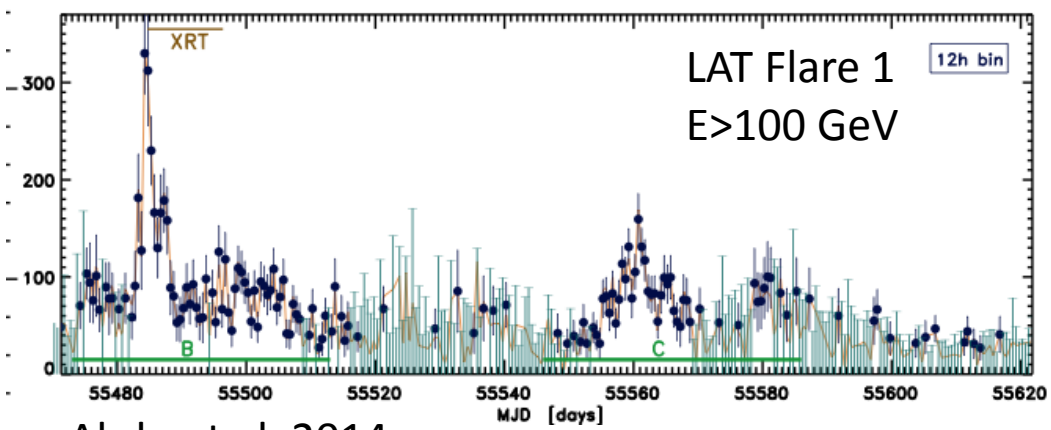
Rudy et al. in press

Friday PM
parallel session talk

Gravitationally Lensed Blazars

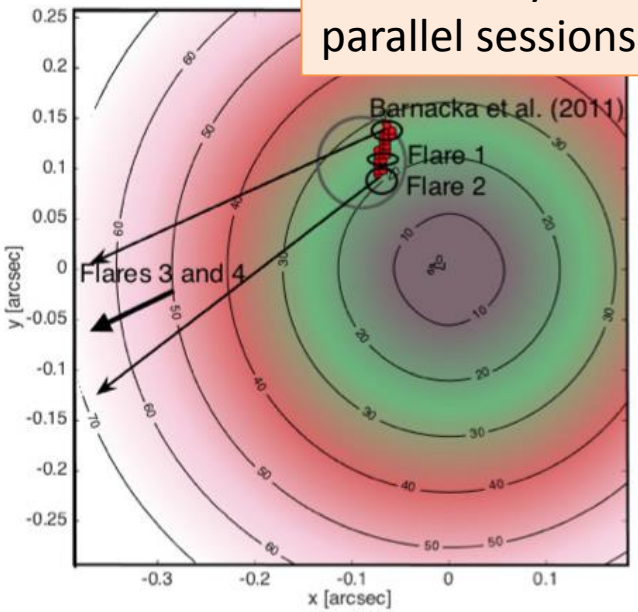


PKS 1830-211 FSRQ at z=2.507



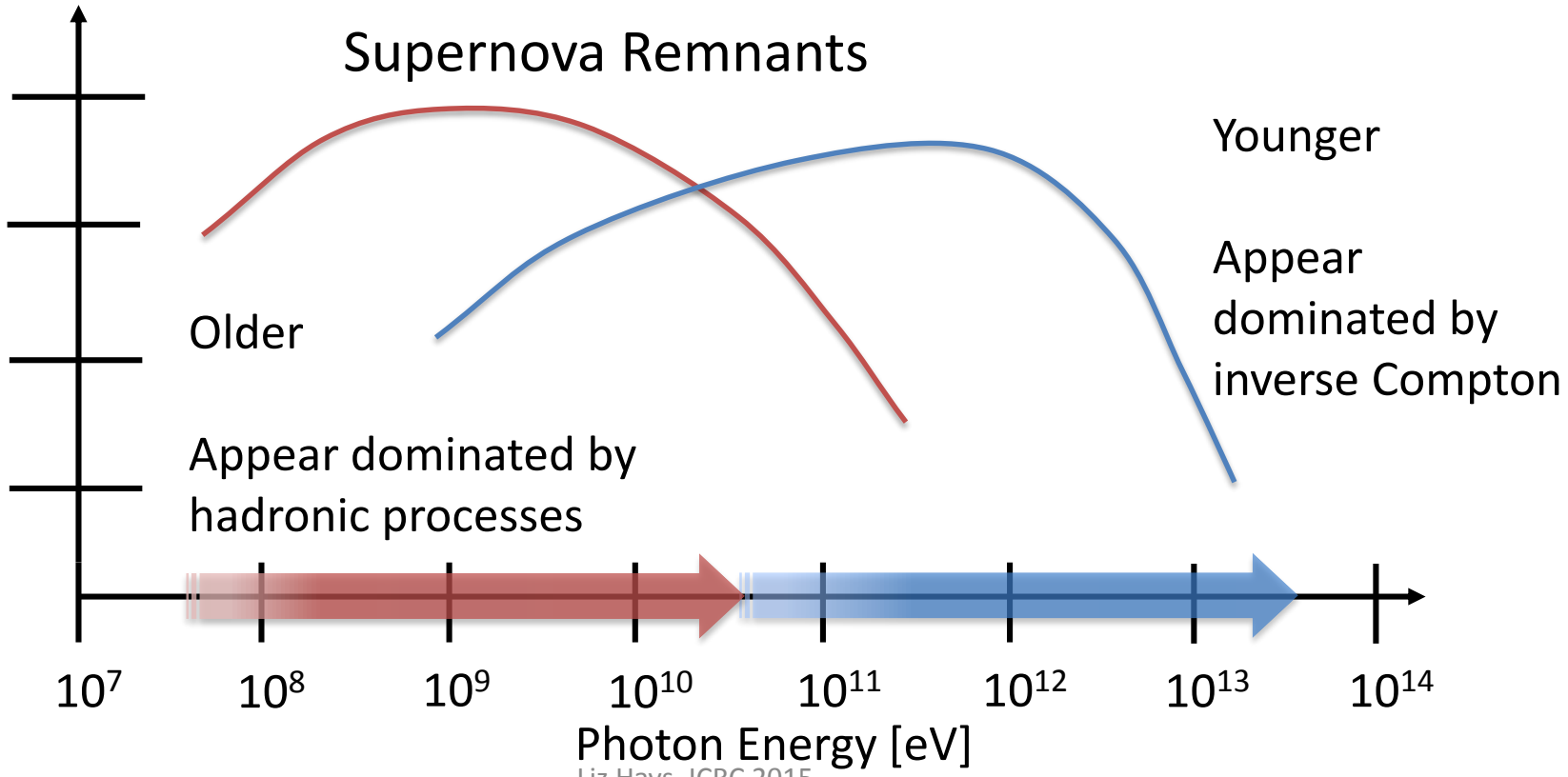
Abdo et al. 2014

Saturday AM and Wednesday PM parallel sessions



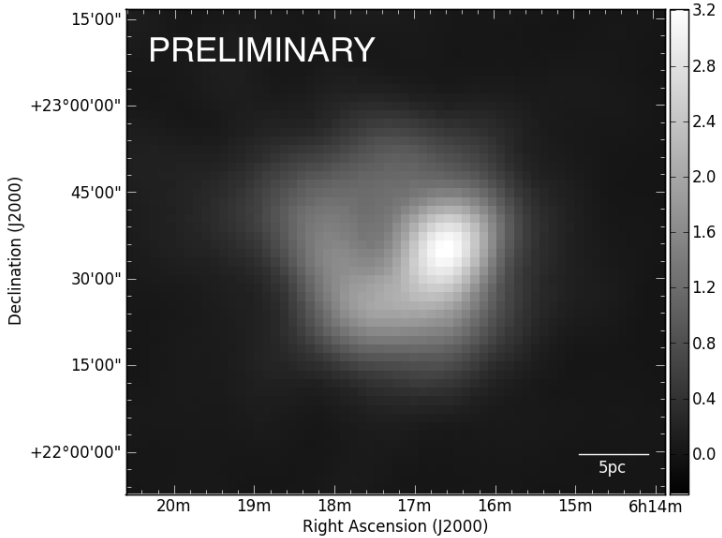
Barnacka et al. to appear in ApJ

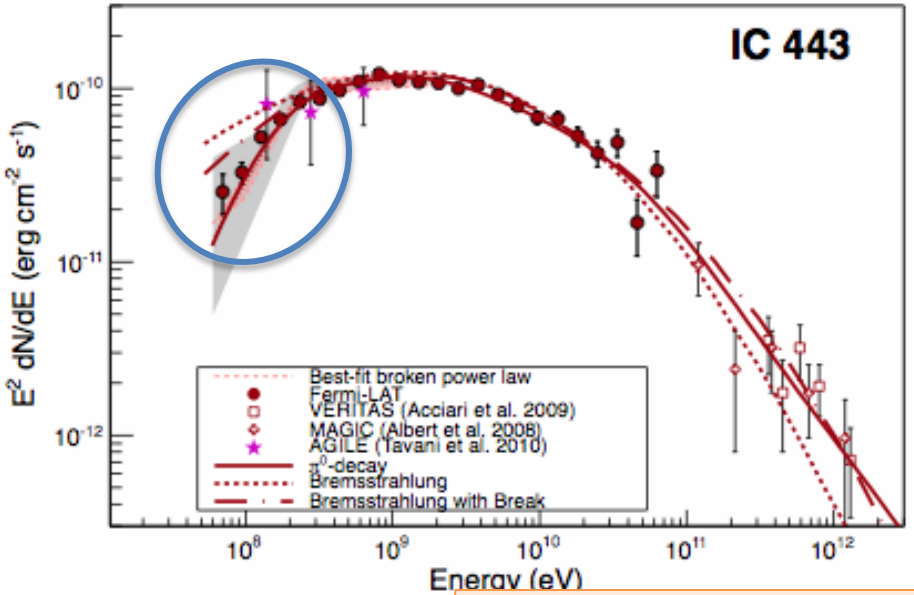
Gamma-ray Science



Resolving Supernova Remnants

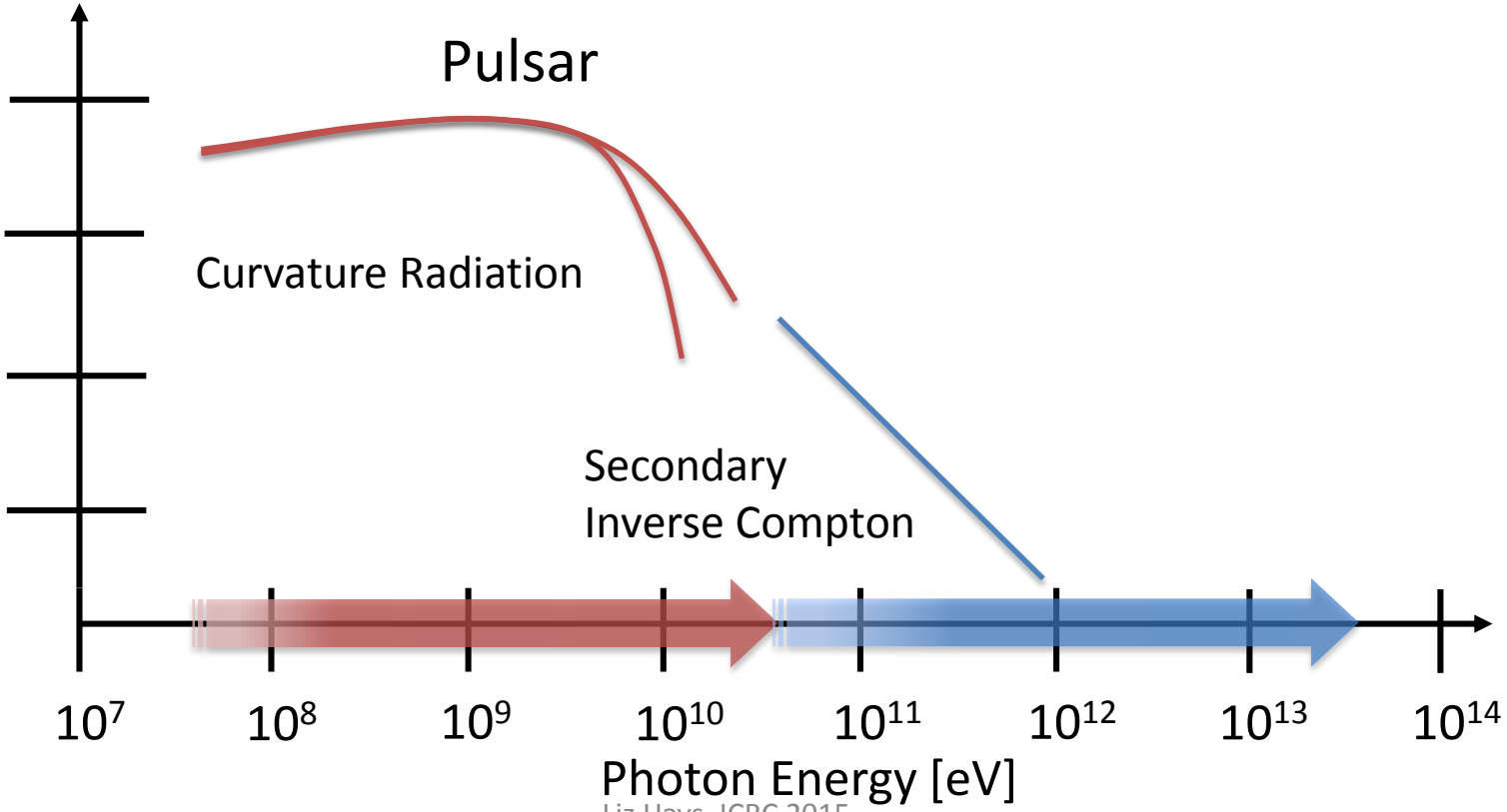
LAT E>5 GeV 83 mo (Pass 8)



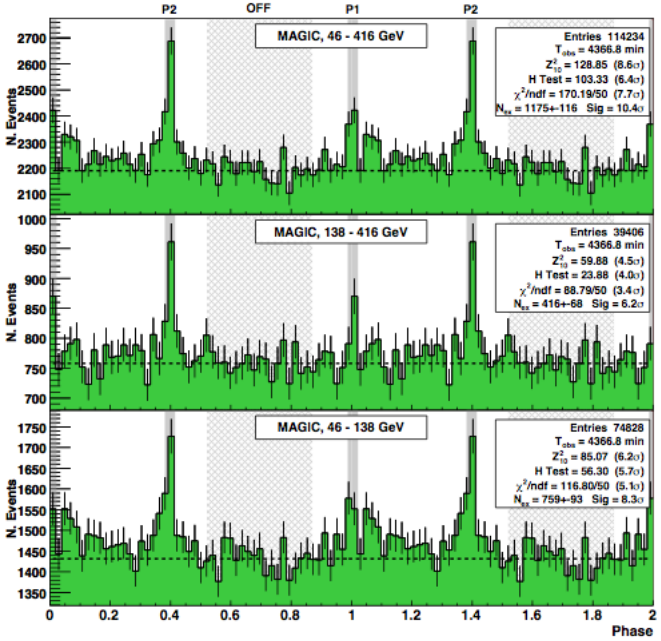


Wednesday AM parallel session on SNRs

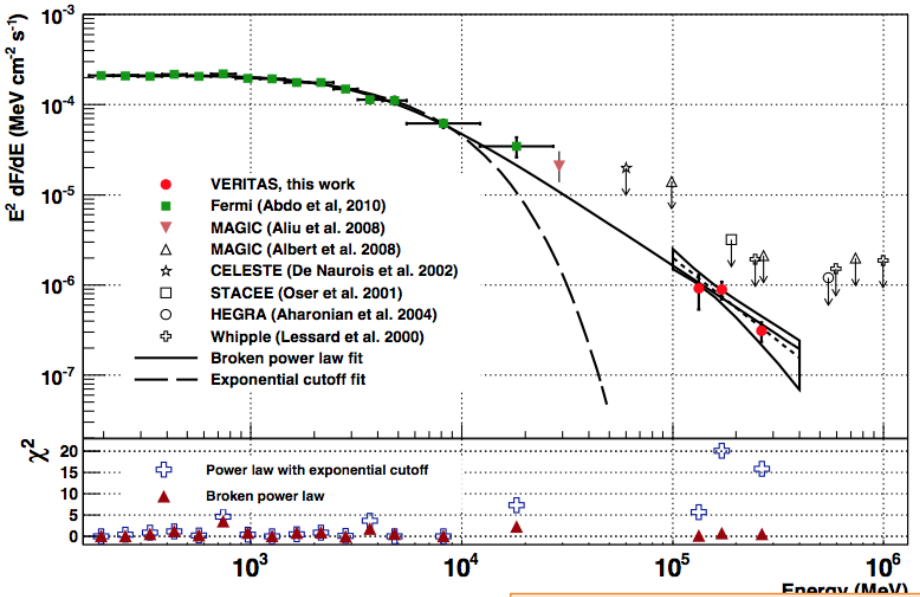
Gamma-ray Science



VHE Pulsars



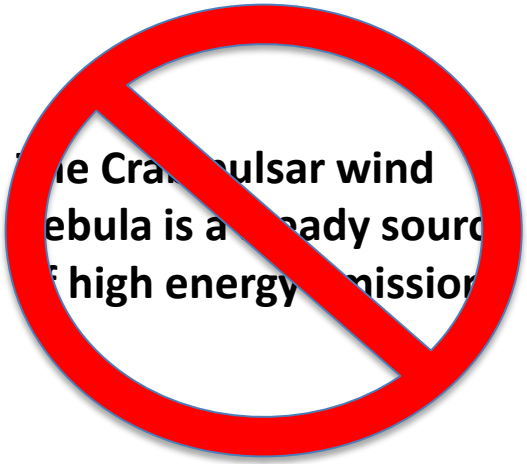
Aleksic et al. 2011



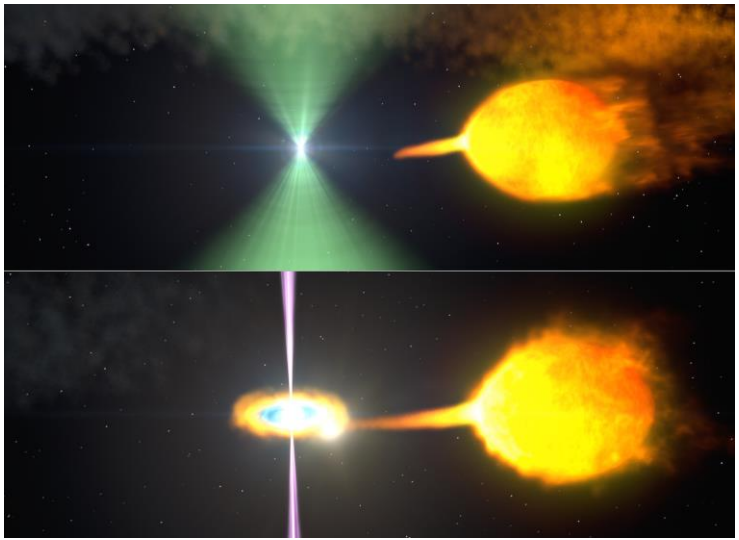
Aliu et al. 2011

Tuesday and Wednesday PM parallel session talks

Gamma-ray Mythbusters

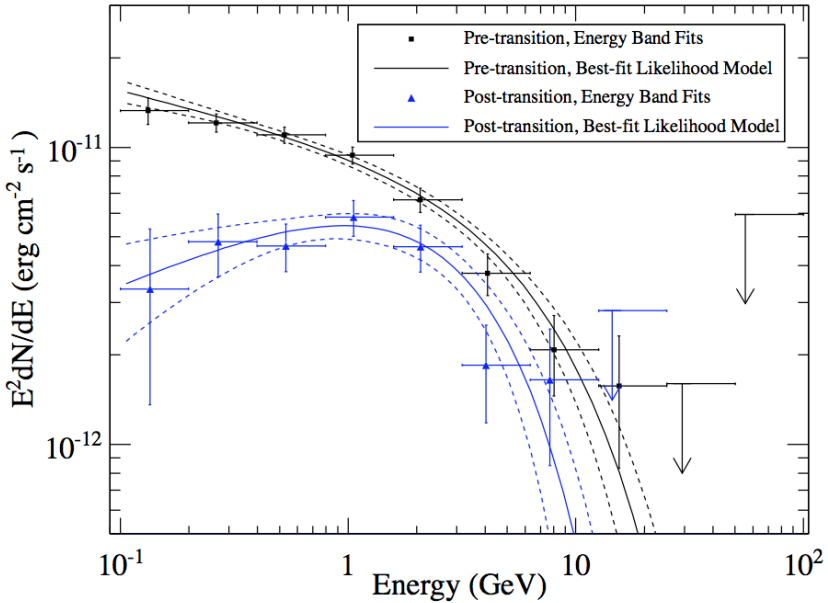


Transitional Pulsars



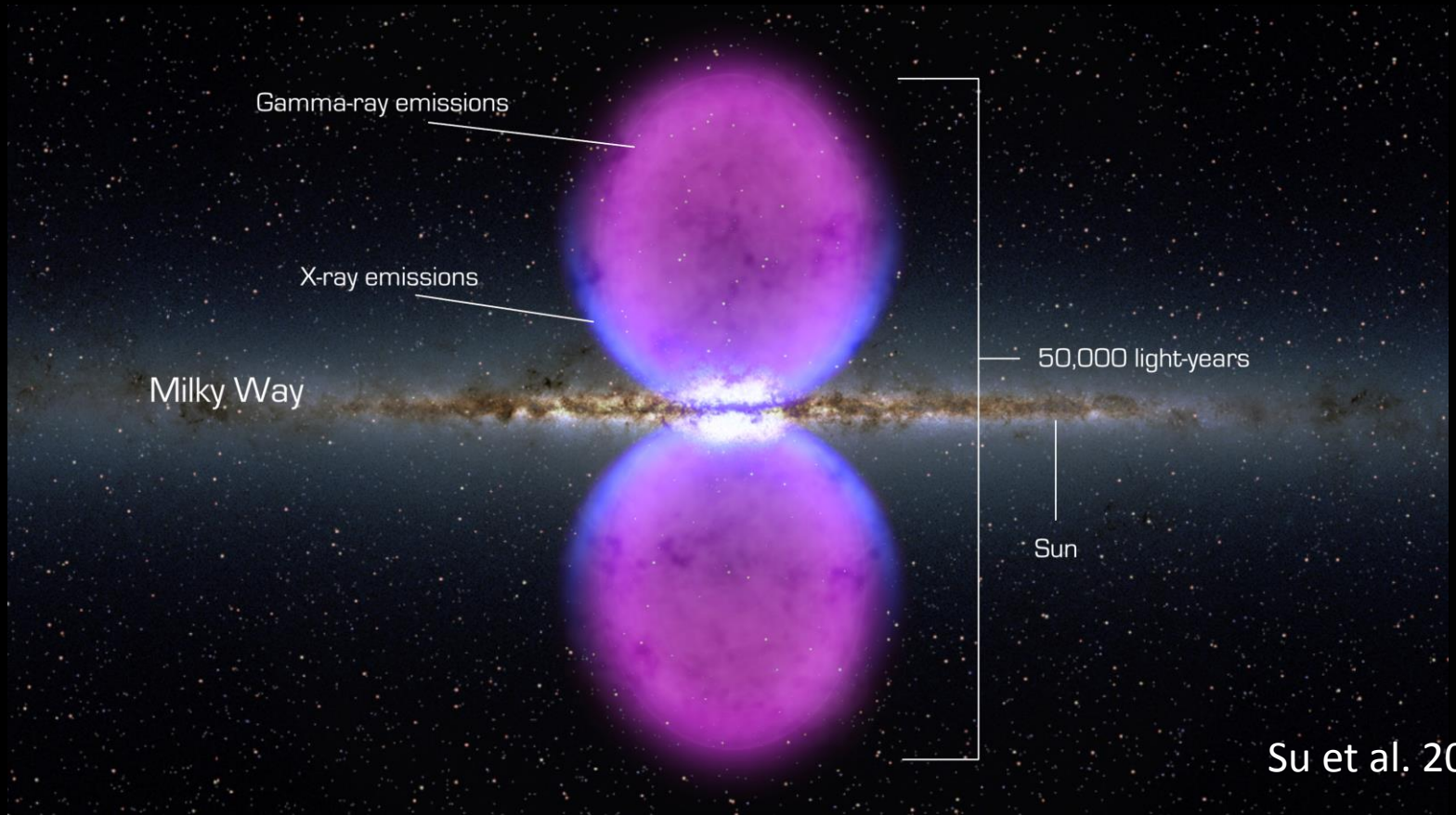
Millisecond pulsar (redback system) in the process of ablating low mass companion (~0.2 Msol, orbital period <1 day)

Gamma-ray spectral modes for PSR J1227-4853



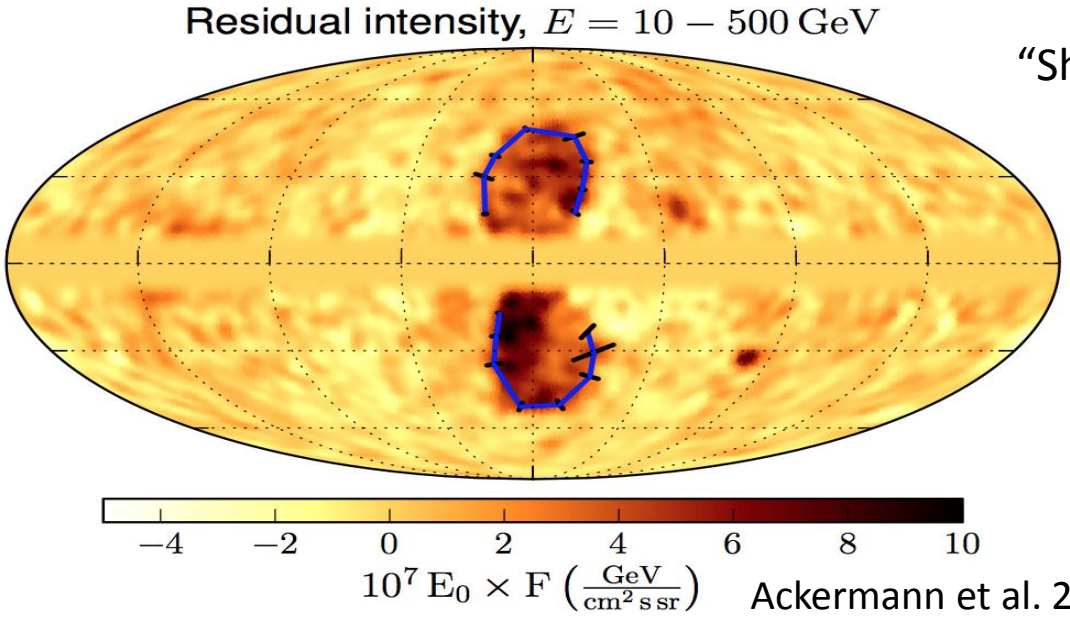
Johnson et al. 2015

Milky Way – Fermi Bubbles



Su et al. 2010

Characterizing the Fermi Bubbles

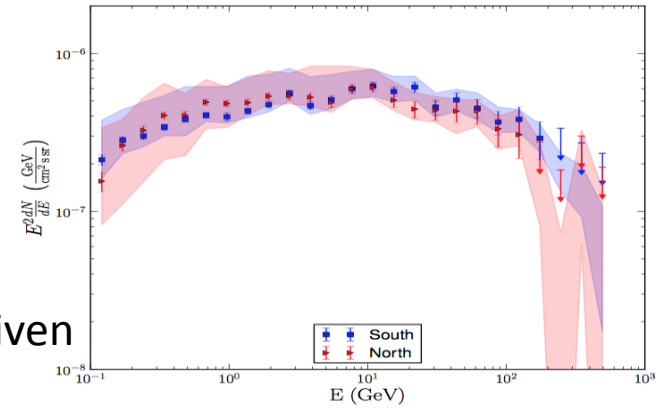


Ackermann et al. 2014

"Sharp" edges

Tuesday AM parallel session

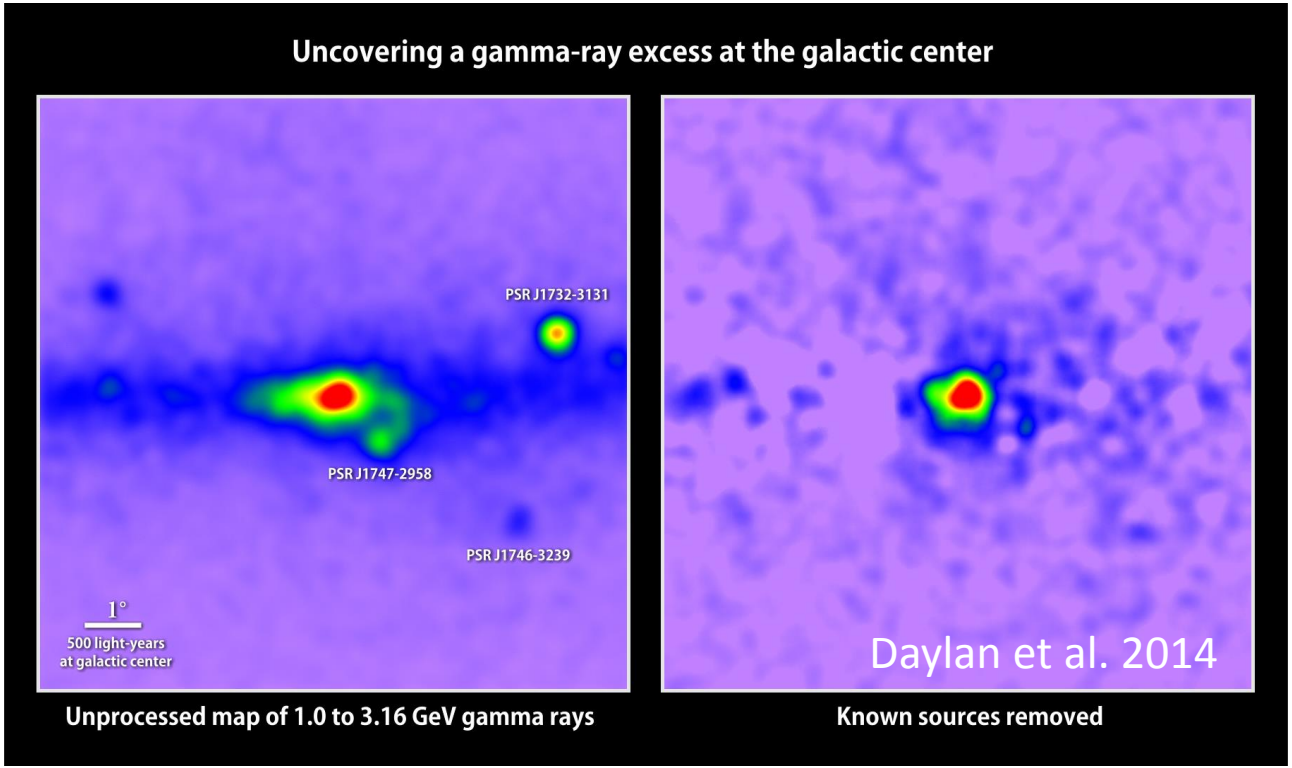
Spectra for North and South in good agreement



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.

Excess GeV emission from the Galactic Center



The inner Galaxy:

- Supermassive black hole
- Candidate for dark matter
- Unresolved sources
- Interstellar emission
- Lots of recent work here!

Friday AM parallel session
Saturday Highlight Talk

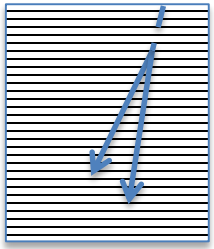
Big Questions

- Can we find and map **dark matter** using gamma rays?
- Can we distinguish **acceleration mechanisms** in play for particles generating rapidly varying gamma-ray emission?
- How similar are **cosmic ray population** properties across our Galaxy, in other galaxies?
- Population of **gamma-ray "probes"** within and far beyond the Milky Way is growing. How else will we use these?

The Future

In terms of mapping gamma rays,
we have barely opened our eyes.

Gamma-ray Detectors



Pair conversion in the detector

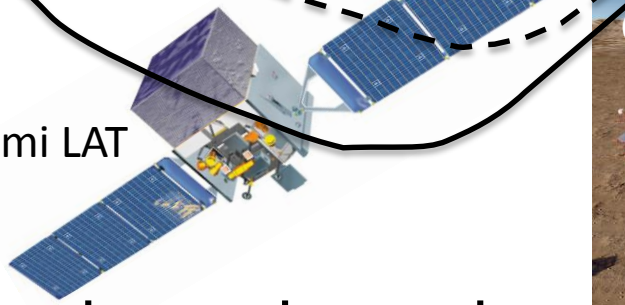
Pair conversion in the atmosphere

Inner Galaxy

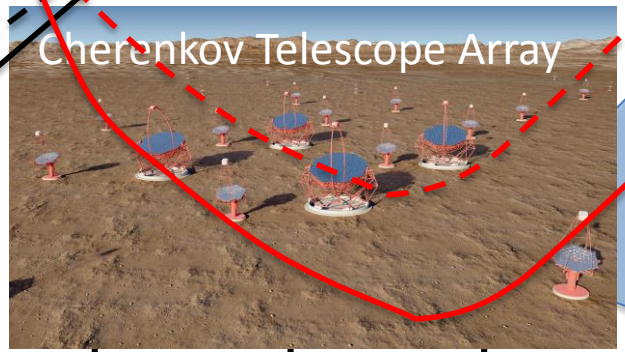
10 yrs

Monday PM
parallel session

5 hrs



Fermi LAT

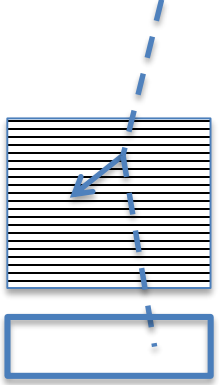


50 hrs

10^7 10^8 10^9 10^{10} 10^{11} 10^{12} 10^{13} 10^{14}

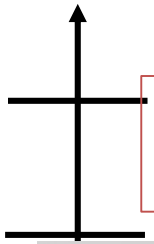
Photon Energy [eV]

Gamma-ray Detectors

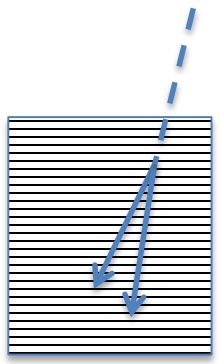


Pair conversion in the detector

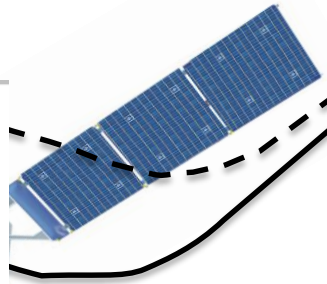
Compton scattering in the detector

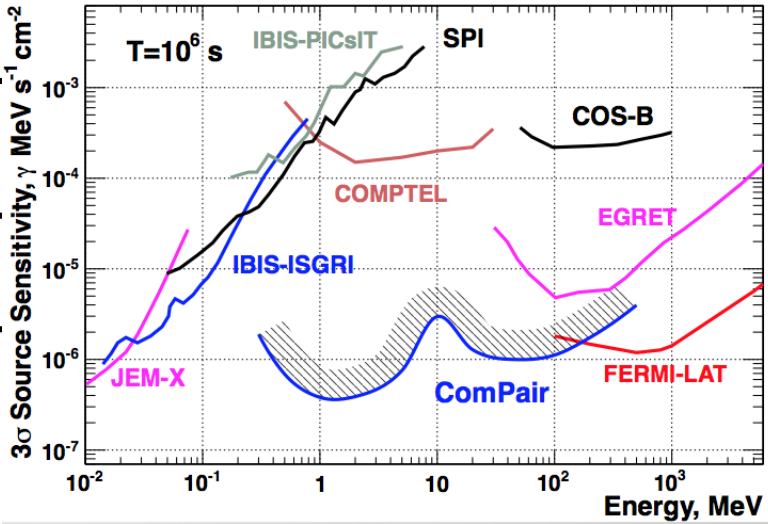


Inner Galaxy



10 yrs





10^4

9

10^{10}

10^{11}

10^{12}

My Wish List

Tuesday AM parallel session

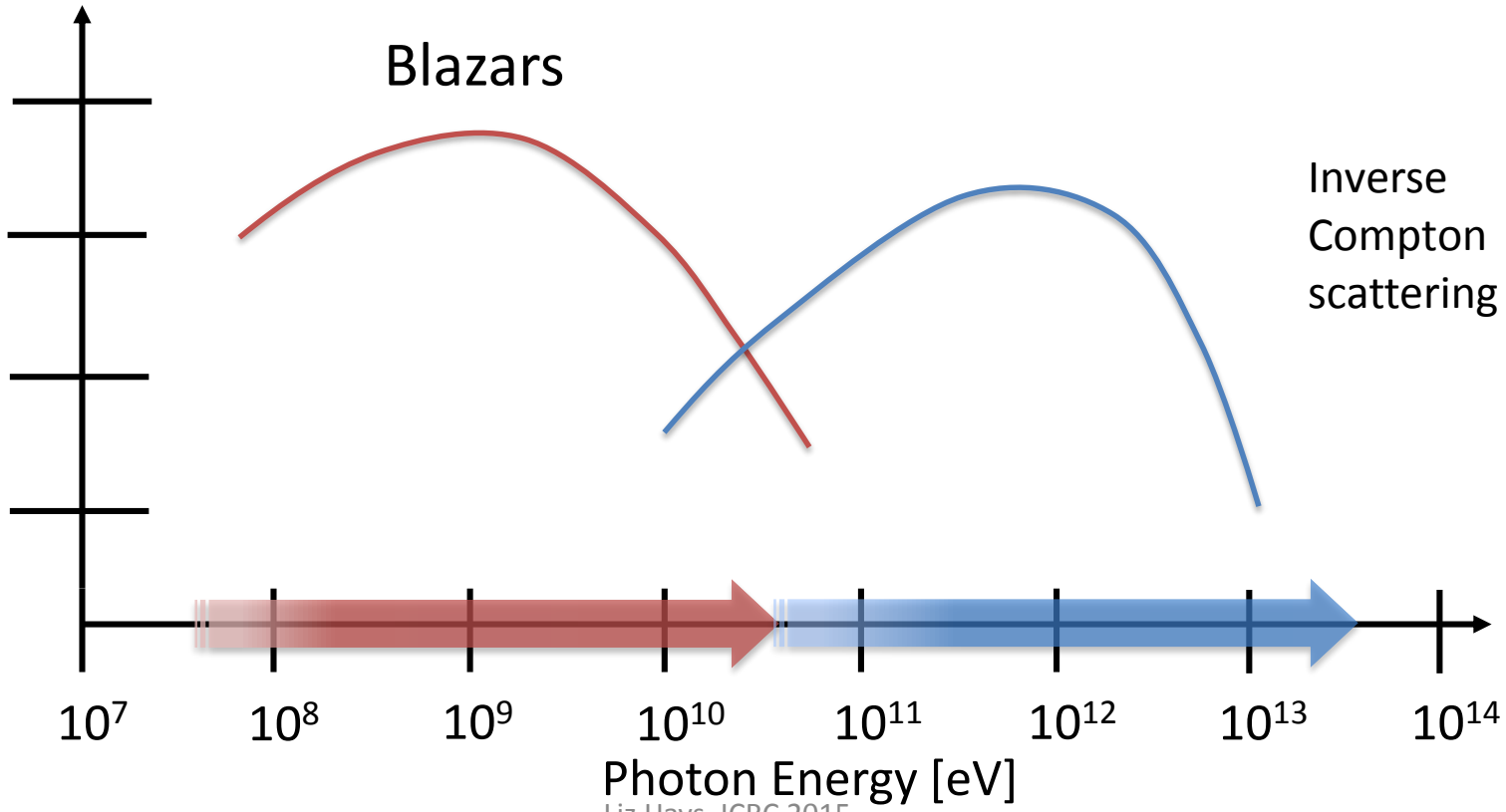
- ❑ Extend gamma-ray spectra below 100 MeV
  - Features and components, transition into the nonthermal Universe, nuclear lines
  - Technology exists for next generation and is in development for instruments beyond that.
- ❑ More resolution
  - Transformational capability
  - On the ground – systematics are important and challenging
  - In space – will be confusion limited in portions of the spectrum with current instruments, particularly in key regions of the sky.
- ❑ Polarization capability
  - New capability – discovery space!
  - Transformational science with sufficient sensitivity
- ❑ More acceptance at 1 GeV

Thank you!

Spectral Complexity

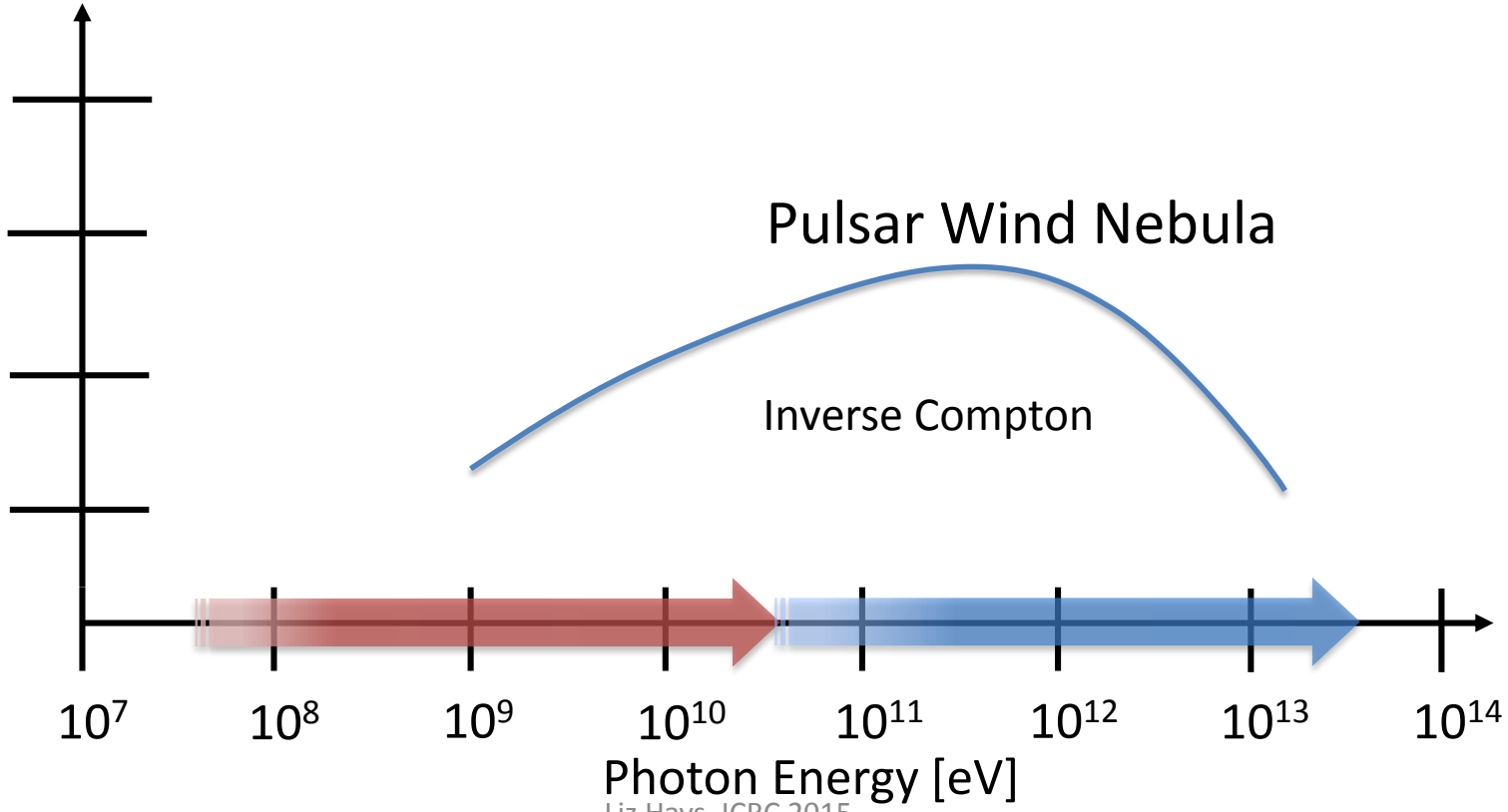
Features
Breaks
Cutoffs
Multiple components

Gamma-ray Science



Liz Hays, ICRC 2015

Gamma-ray Science



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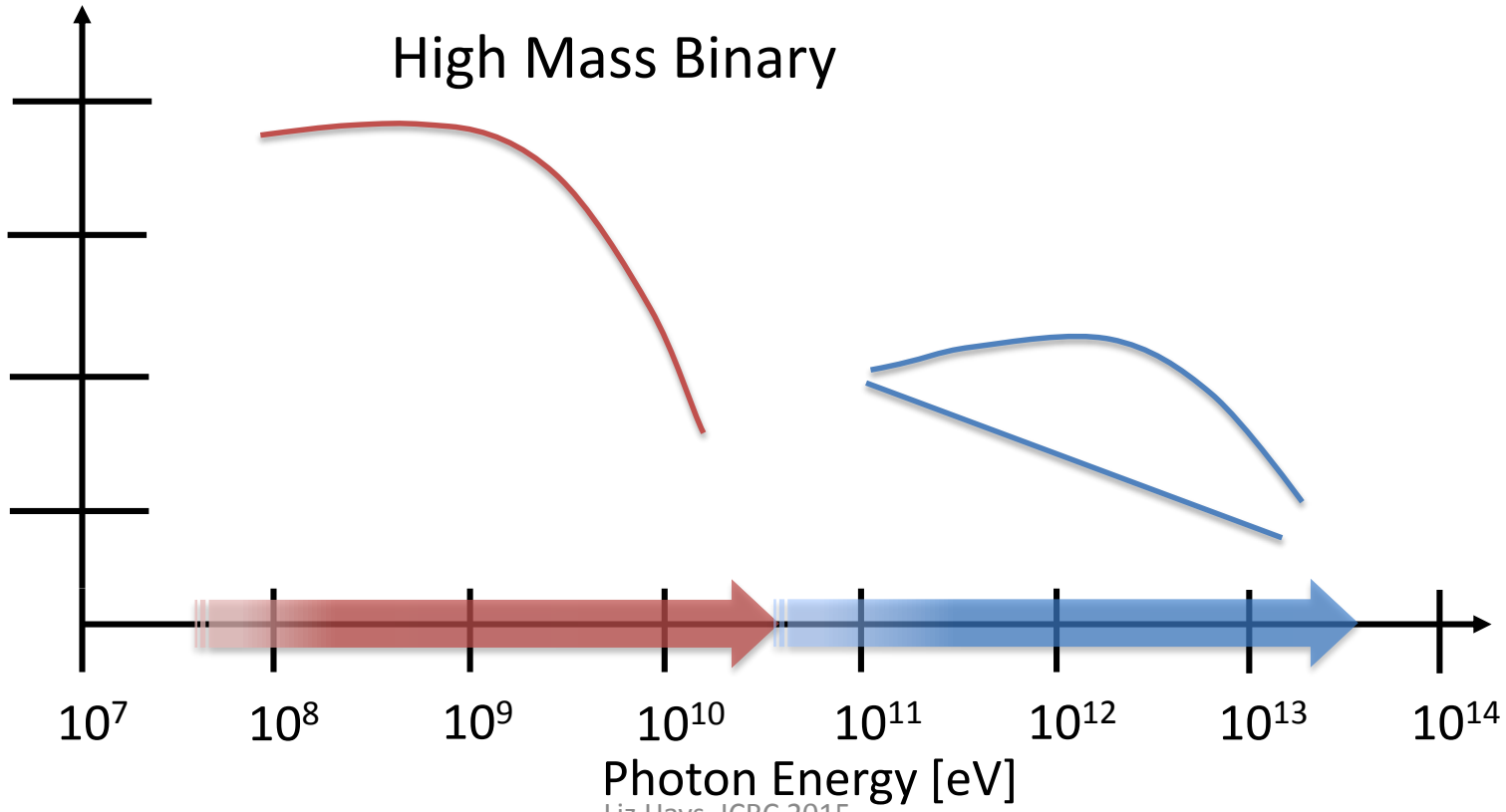
Gamma-ray Science



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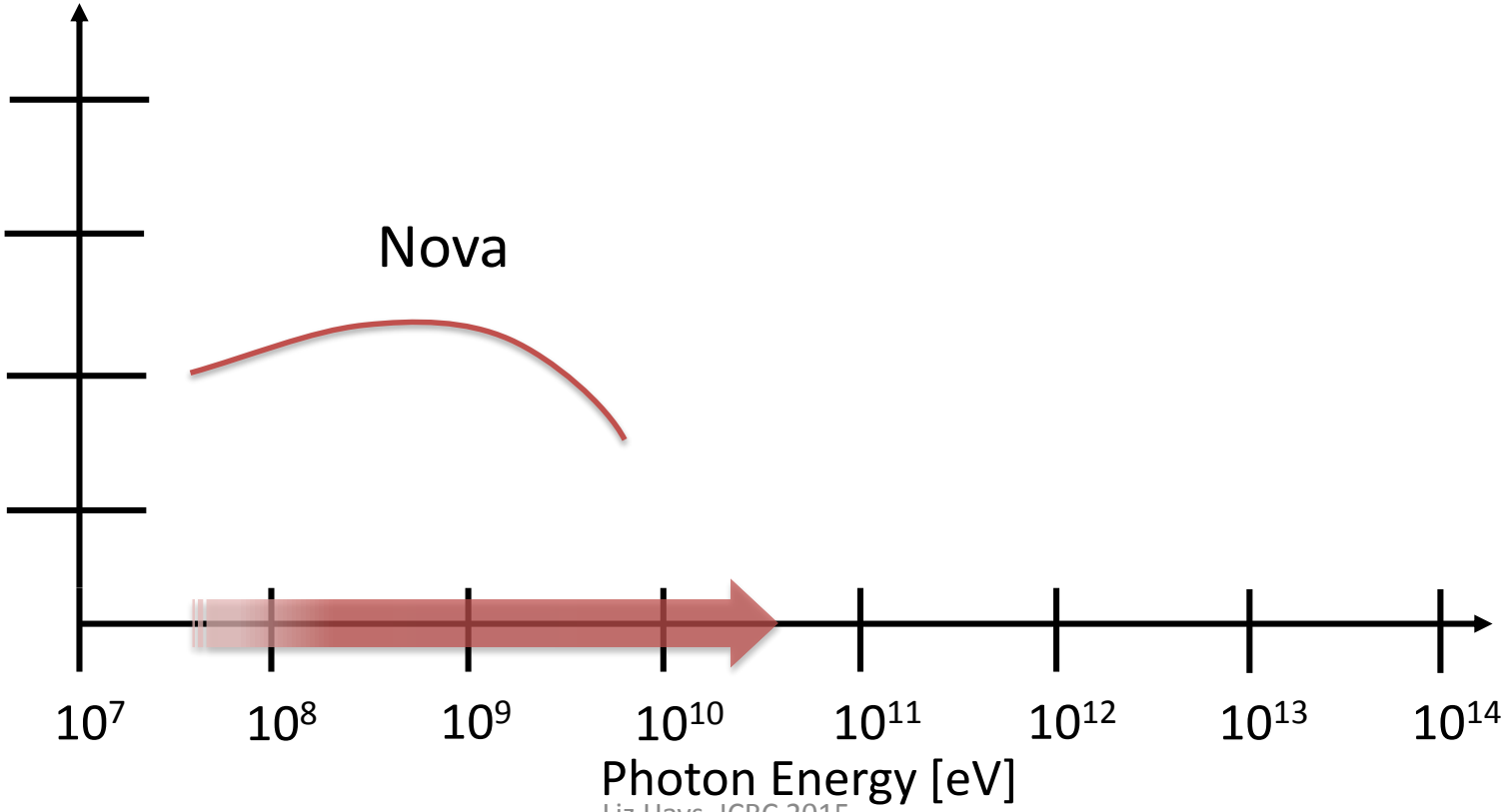
Gamma-ray Science



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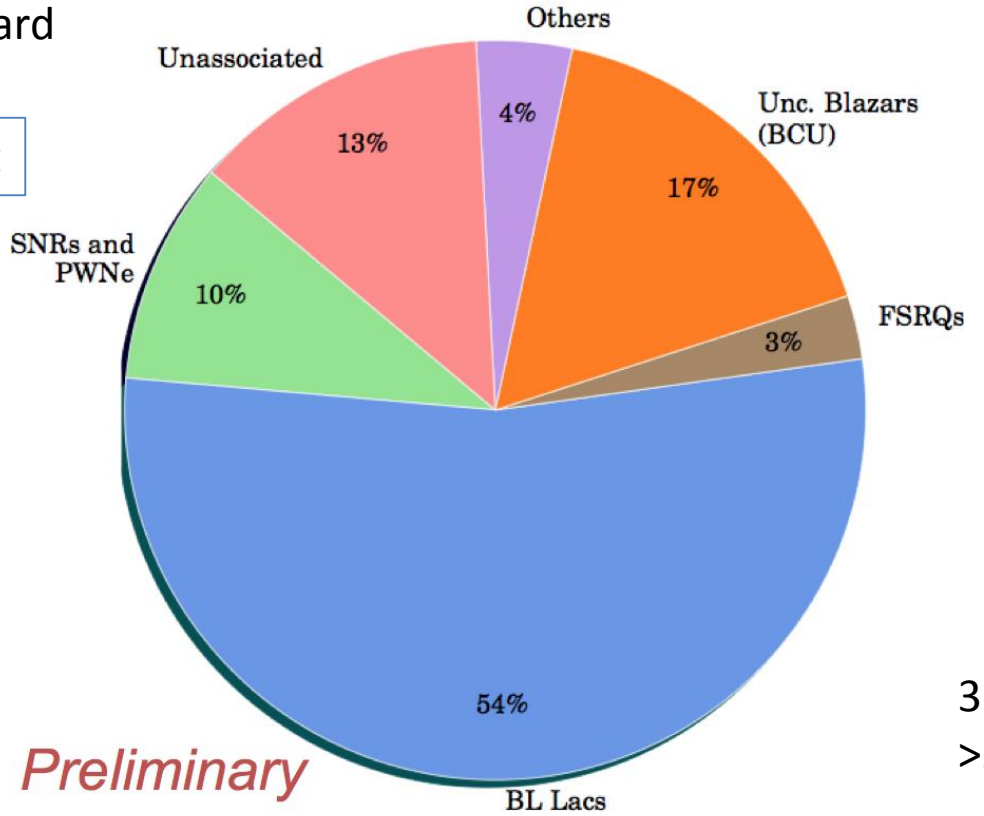
Bridging the Gap

Second Catalog of Hard Fermi-LAT Sources

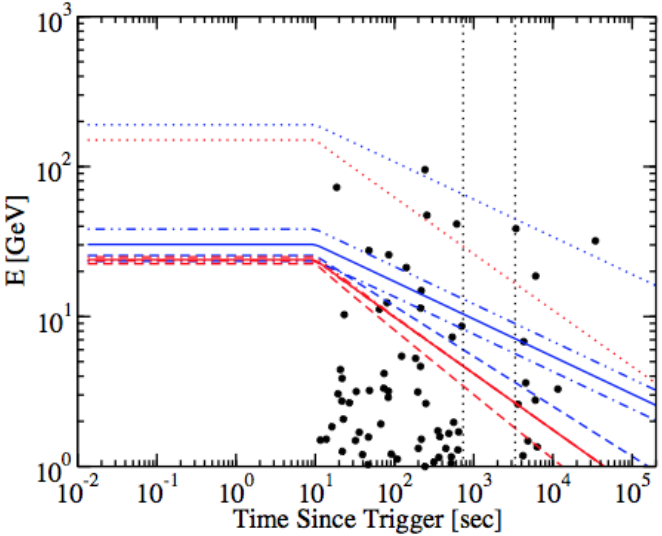
Ajello – Fri. Highlight



360 sources
>50 GeV

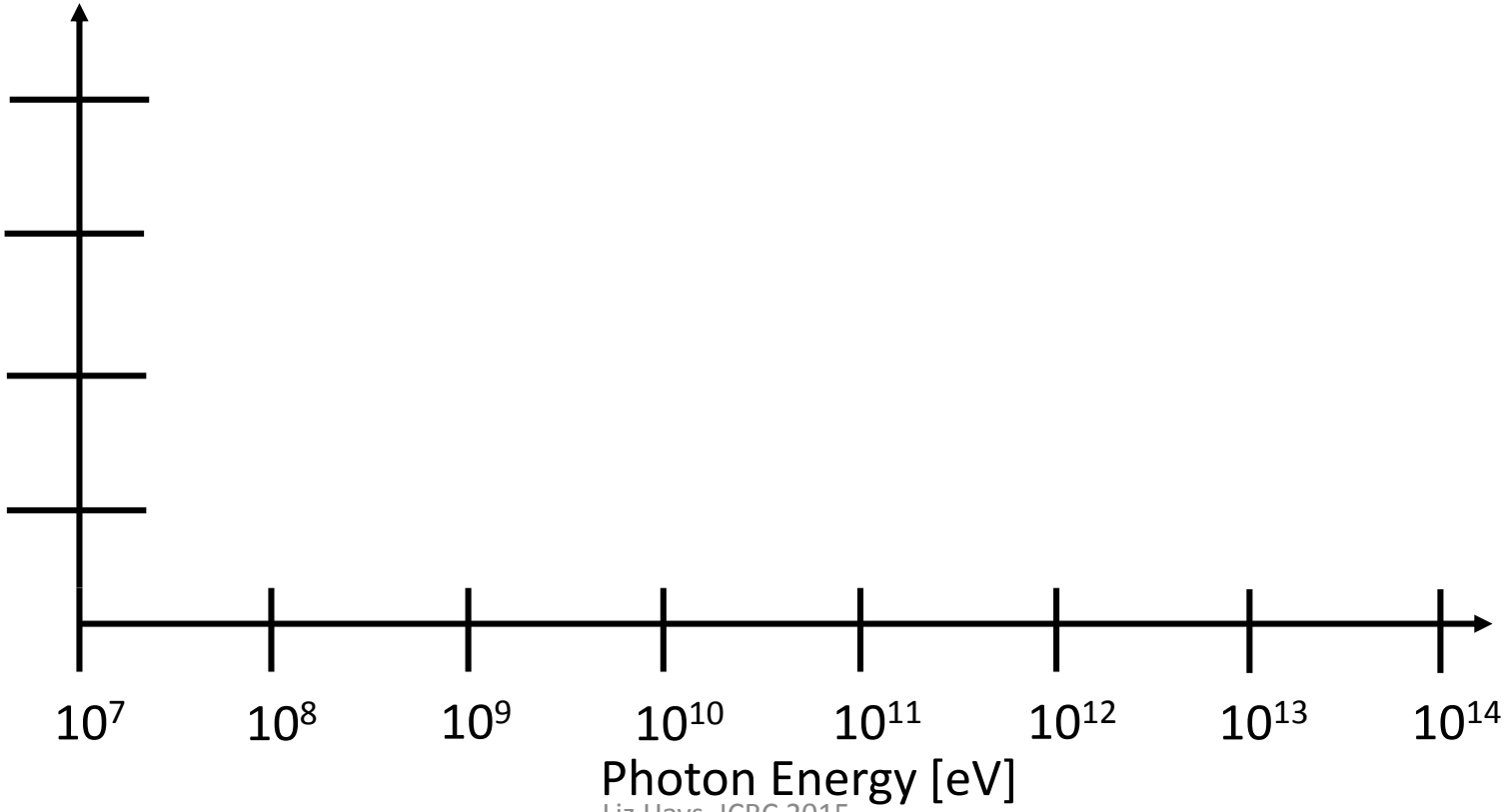
Pushing synchrotron limits

GRB 130427A



LAT photon energies and times compared to predictions for maximum synchrotron photon energy

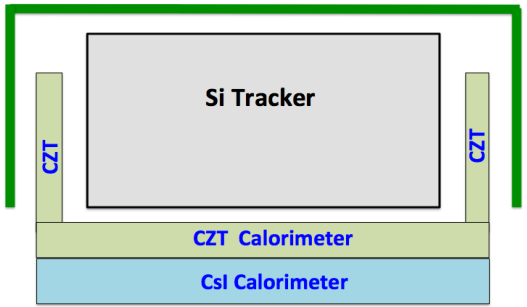
Gamma-ray Science

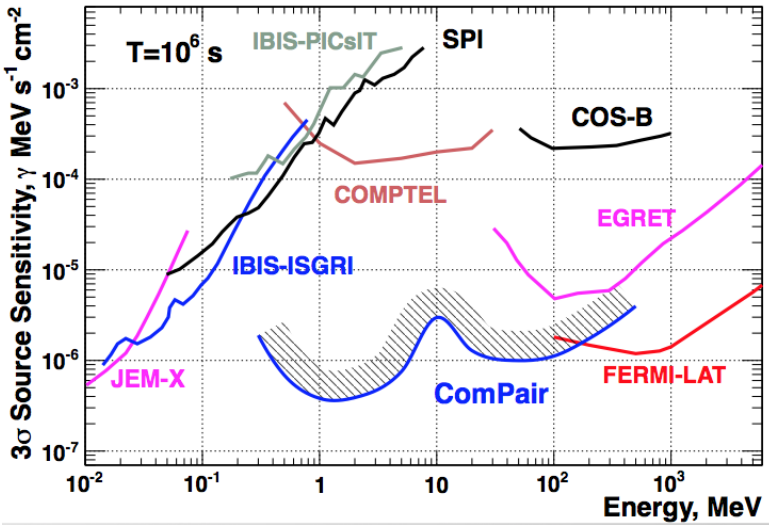


ComPair

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**





Thoughts

- Sensitivity across *most* of the gamma-ray band now allows access to a wealth of gamma-ray source classes
  - Commonalities among classes are interesting
  - Differences within classes are even more interesting
  - Outliers are baffling
- What are we missing?
  - We find what we seek. It is no accident that typical spatial and variability studies are matched to current instrument capabilities.

Data Prospects

- Wide-field TeV observations
  - New sources
  - Extended sources
  - Large scale structures
- Deep IACT observations and lower energy thresholds
  - Spectral detail
  - Capturing rapid variability
- Fermi continues
  - 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 territory for long baseline studies for blazars, binaries, and pulsars
  - Search for neutrino counterparts
  - Overlap with enhanced gravitational wave observatories

Transient Detection

- Fermi GBM is a GRB machine
  - >xxxx bursts since launch (plus solar flares, soft gamma-ray repeaters, and terrestrial gamma-ray flashes)