The Gamma-Ray Bright Future: The HAWC Perspective

Michelle Hui for the HAWC Collaboration
Michigan Technological University

What are we learning from the gamma-ray sky?
October 12, 2013

The Gamma-Ray Bright ~~Future~~ Present: The HAWC Perspective

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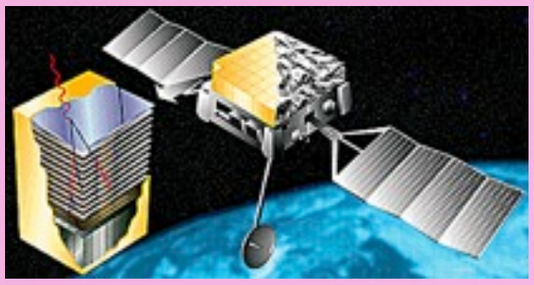
Gamma-Ray Detectors

Wide Field of View, Continuous Operations



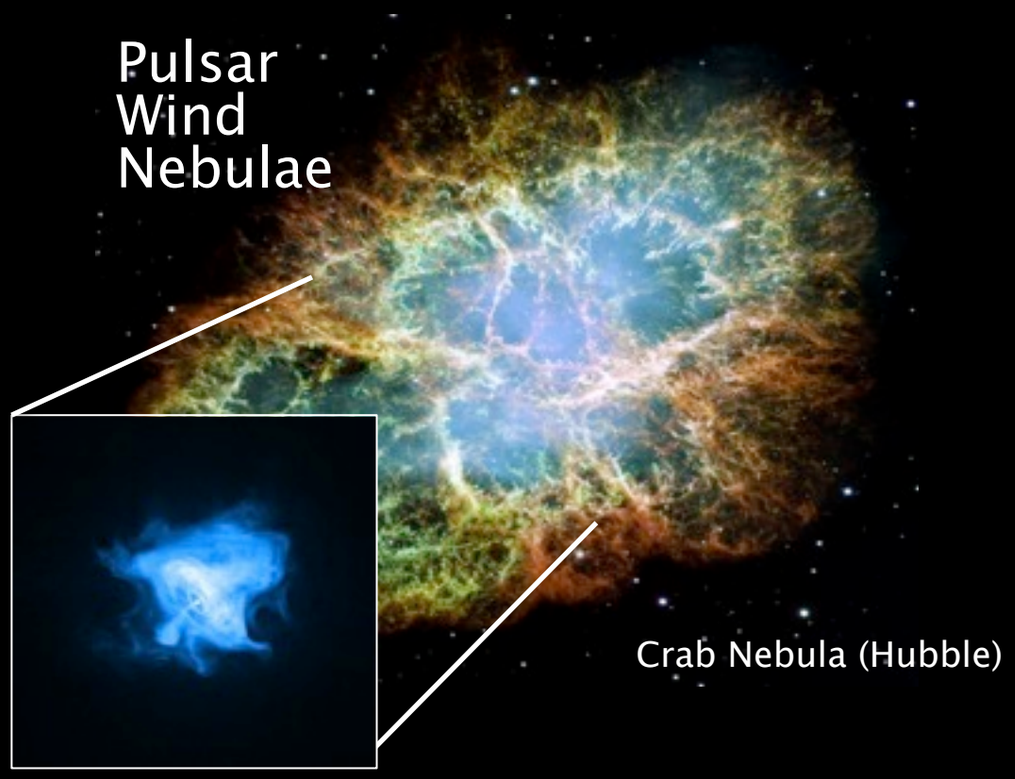
Fermi
AGILE
EGRET

TeV Sensitivity

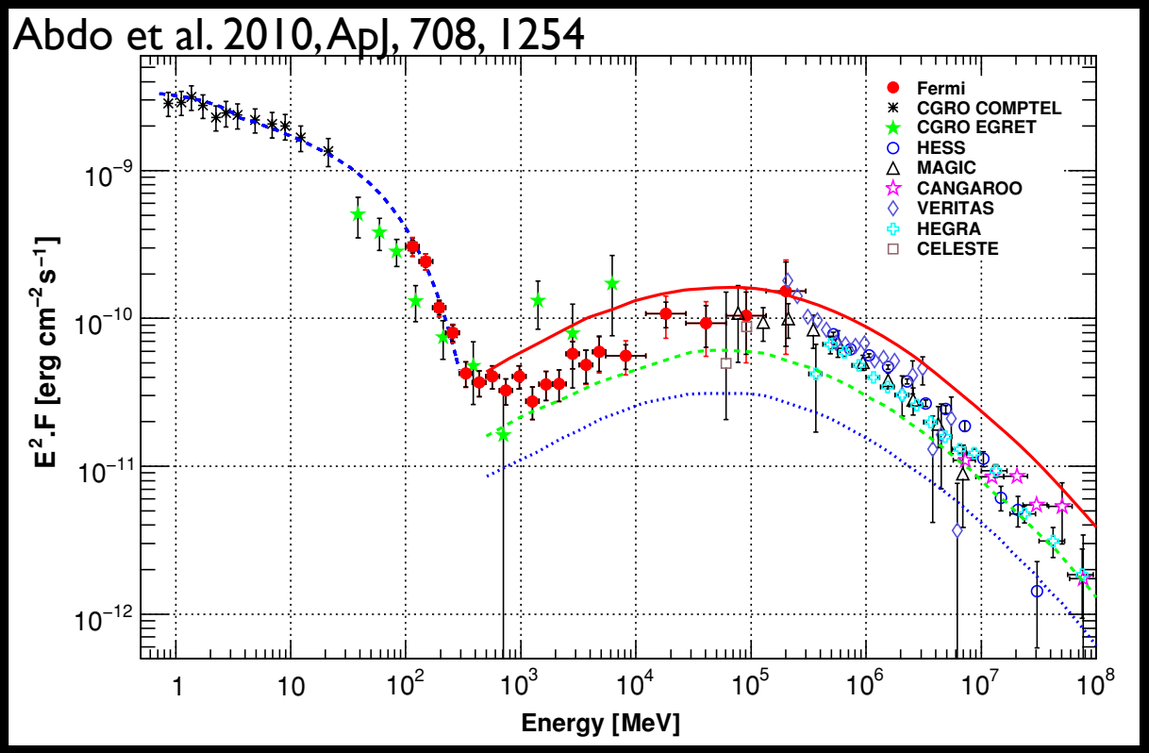
HAWC
ARGO
Milagro
Tibet ASγ

VERITAS
HESS
MAGIC

Pulsar Wind Nebulae



- Most common Galactic TeV source. Many show significant extent.
- Background for more exotic gamma-ray production mechanisms (dark matter).
- Gamma-rays from Geminga PWN consistent with PAMELA/AMS data on positron fraction (Yuksel et al. 2009, PRL 103, 051101).
- Crab flares unexplained.
  - Continues to TeV inverse-Compton emission?
  - Flares in other PWN?
- Not ruled out as a potential source of cosmic rays.



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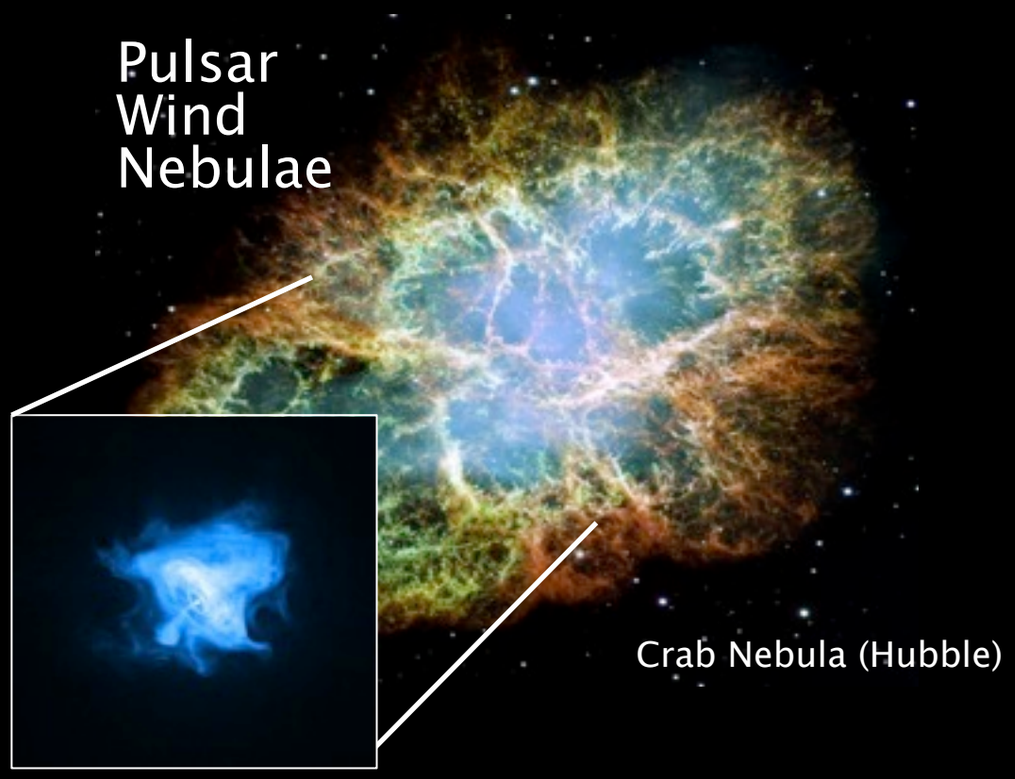

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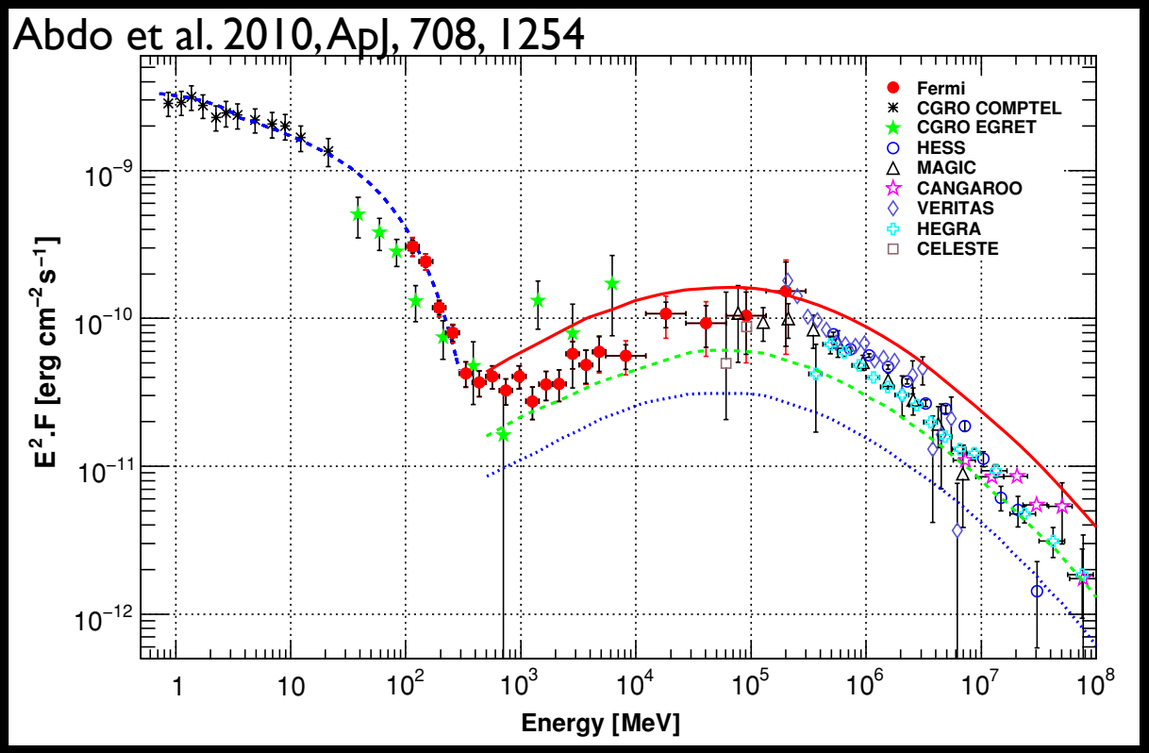
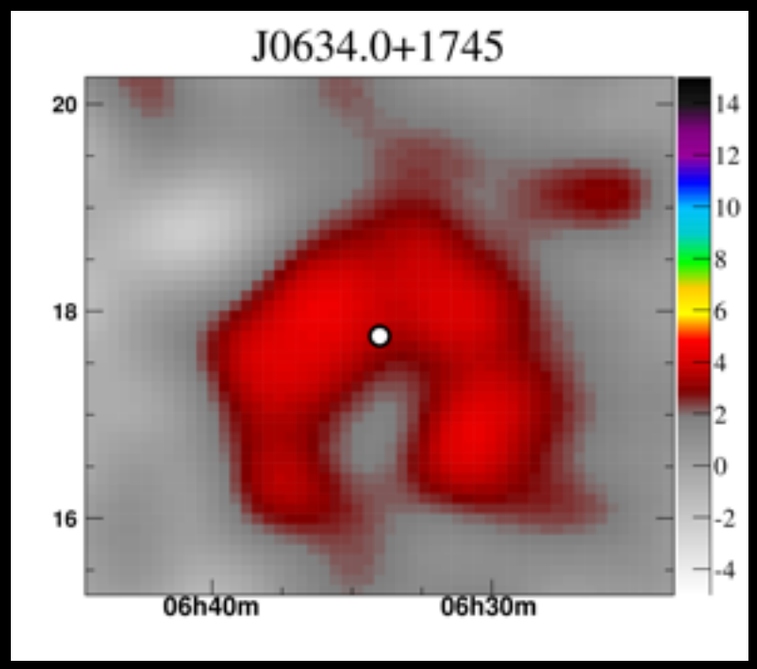


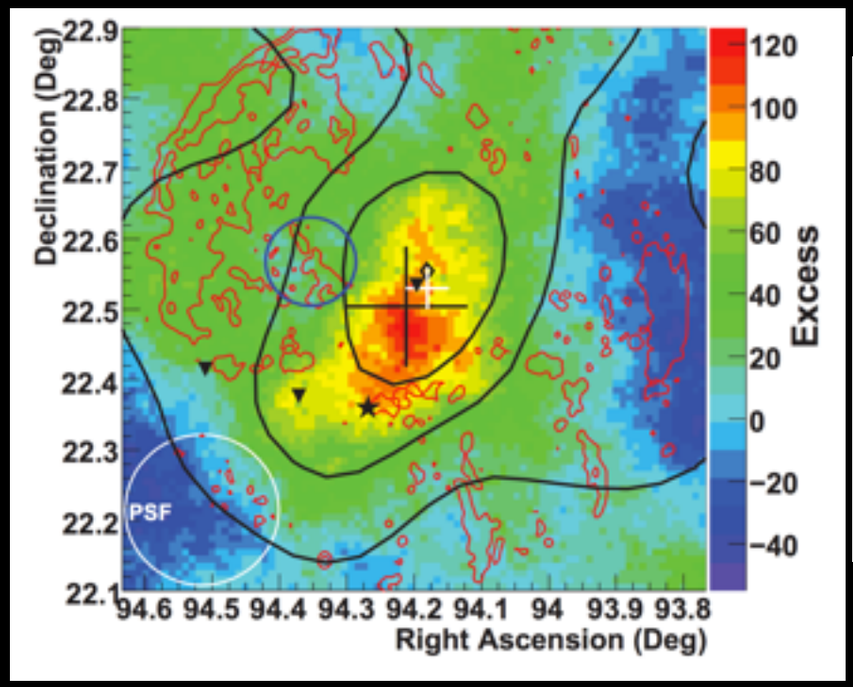


Geminga PWN in Milagro

Abdo et al. 2009, ApJL, 700, 127

Supernova Remnants

- Strong evidence for cosmic-ray acceleration.
  - Association of HE emission from molecular clouds.
  - Observation of characteristic pion emission
- How high does the emission go?
- Flux implied by Milagro observation of IC443 is 10x larger than extrapolating VERITAS spectrum.



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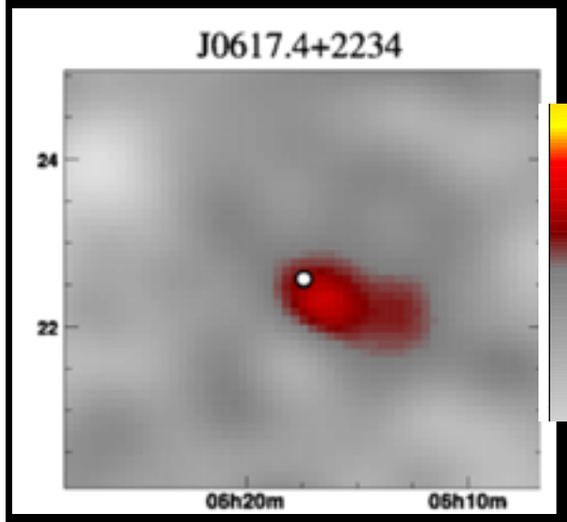

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Credit: Chandra X-ray: NASA/CXC/B.Gaensler et al; ROSAT X-ray: NASA/ROSAT/Asaoka & Aschenbach; Radio Wide: NRC/DRAO/ D.Leahy; Radio Detail: NRAO/VLA; Optical: DSS

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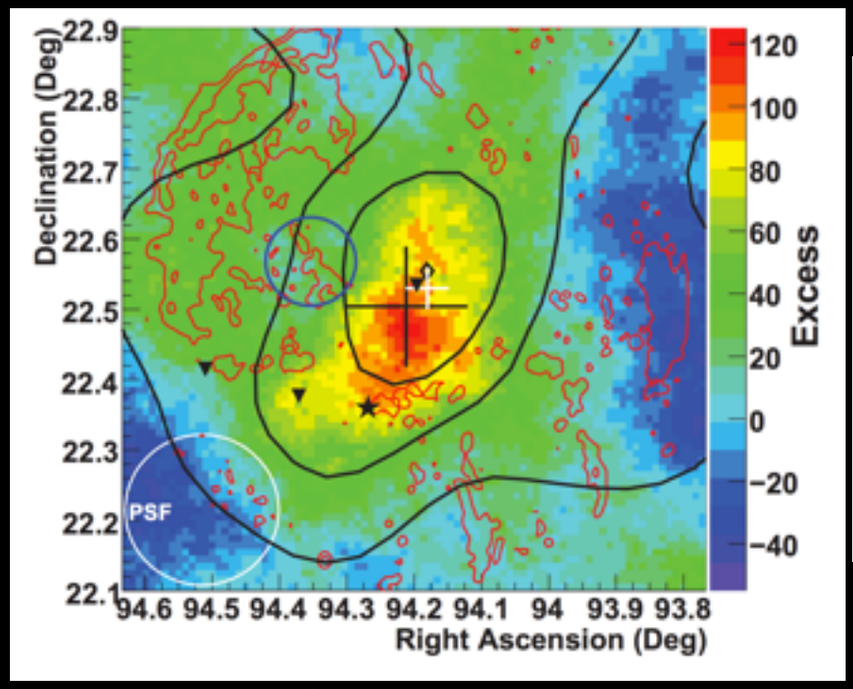

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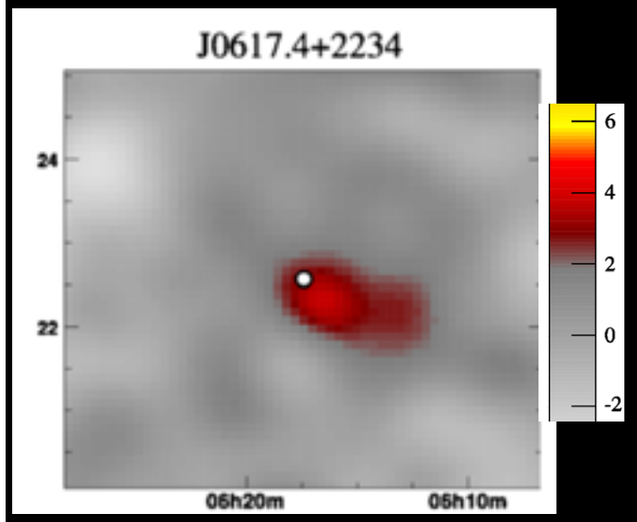

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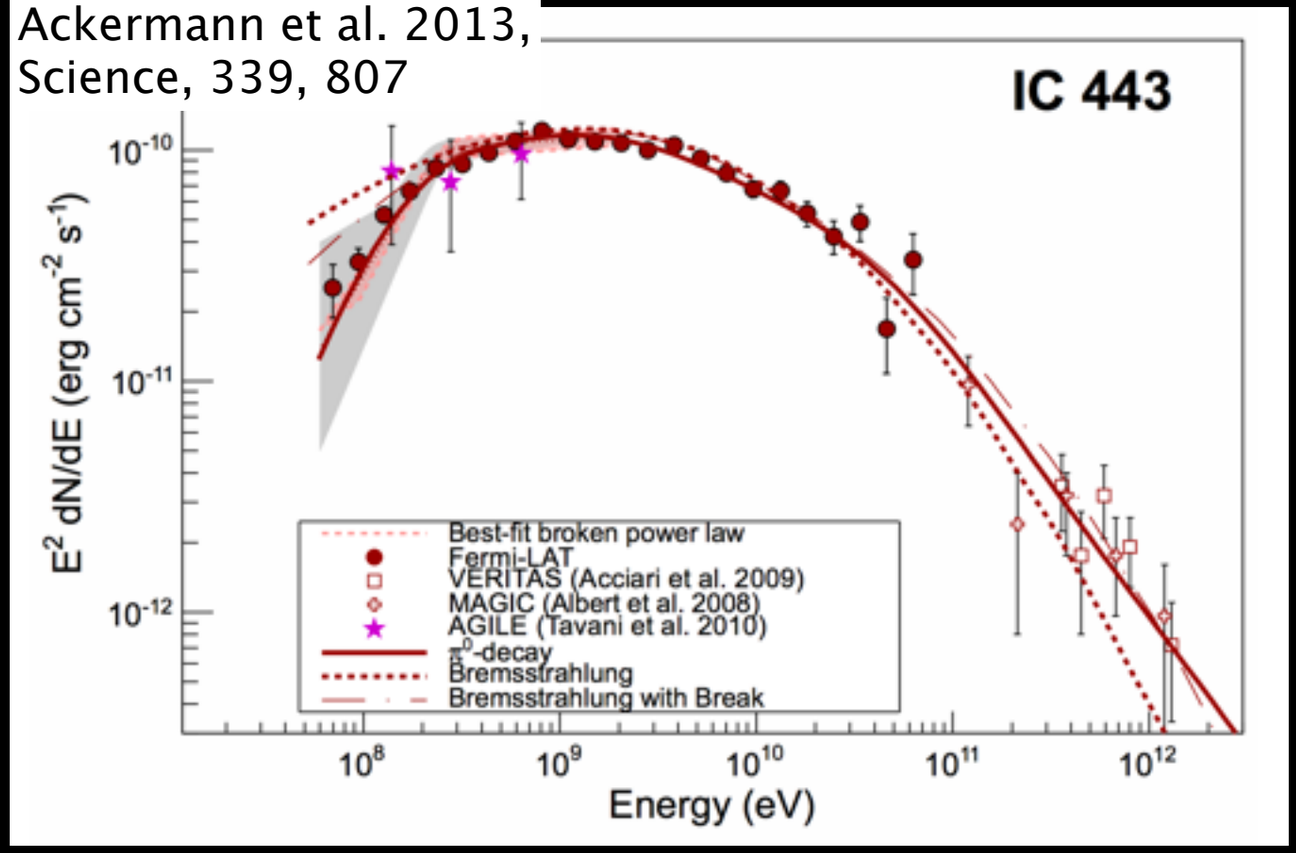
Ackermann et al. 2013, Science, 339, 807



Active Galactic Nuclei

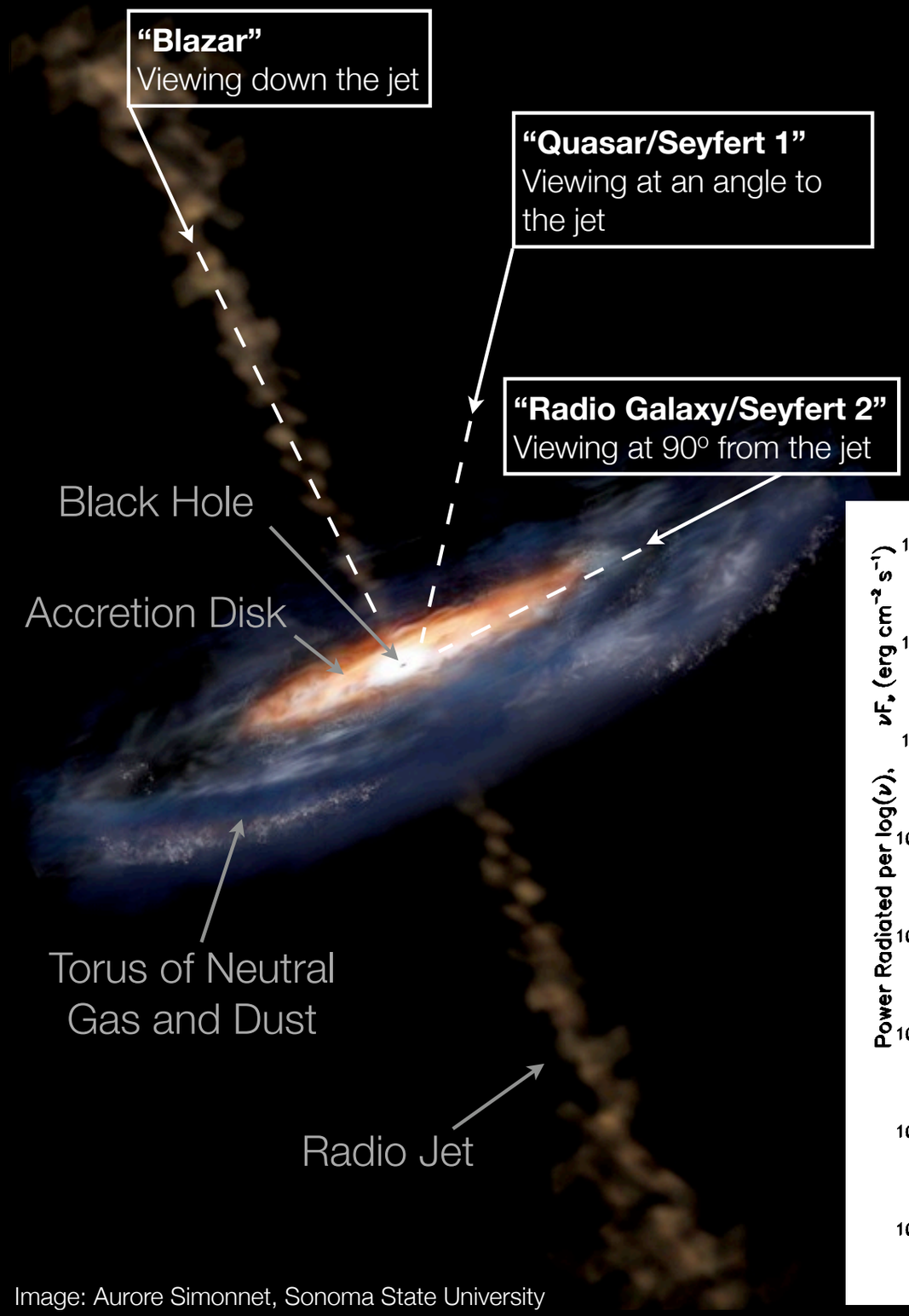


Image: Aurore Simonnet, Sonoma State University

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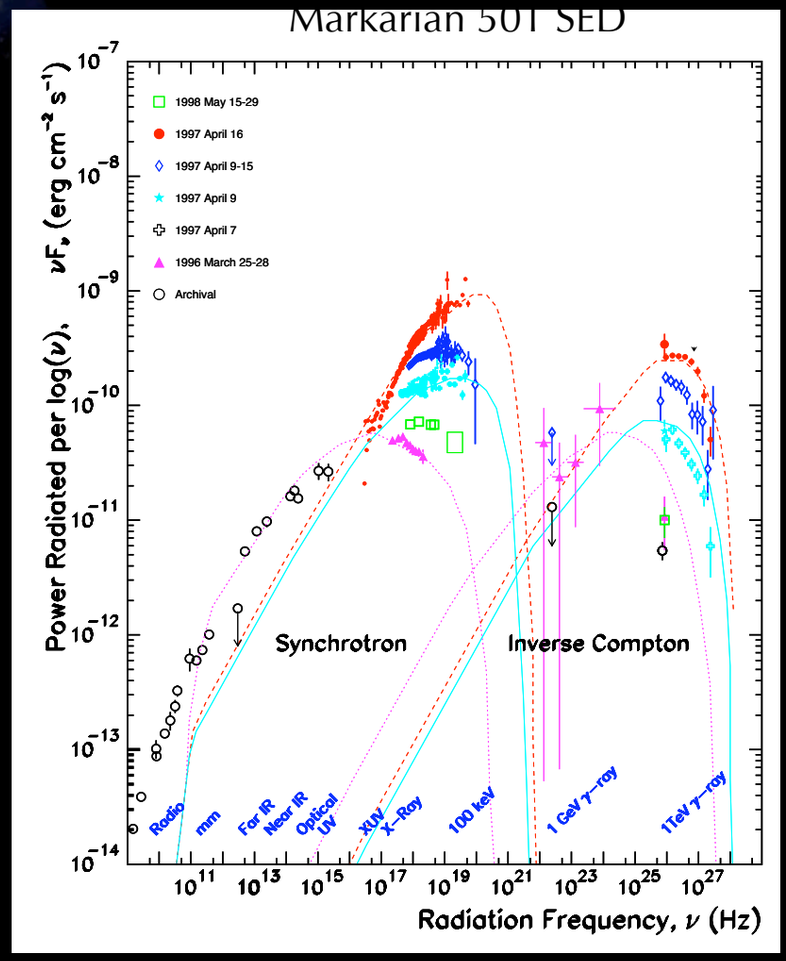
- Unbiased TeV survey will collect many more flares.
- Correlation between Synchrotron and Inverse Compton emission. Quadratic or linear?
- Orphan flares require high-energy trigger.



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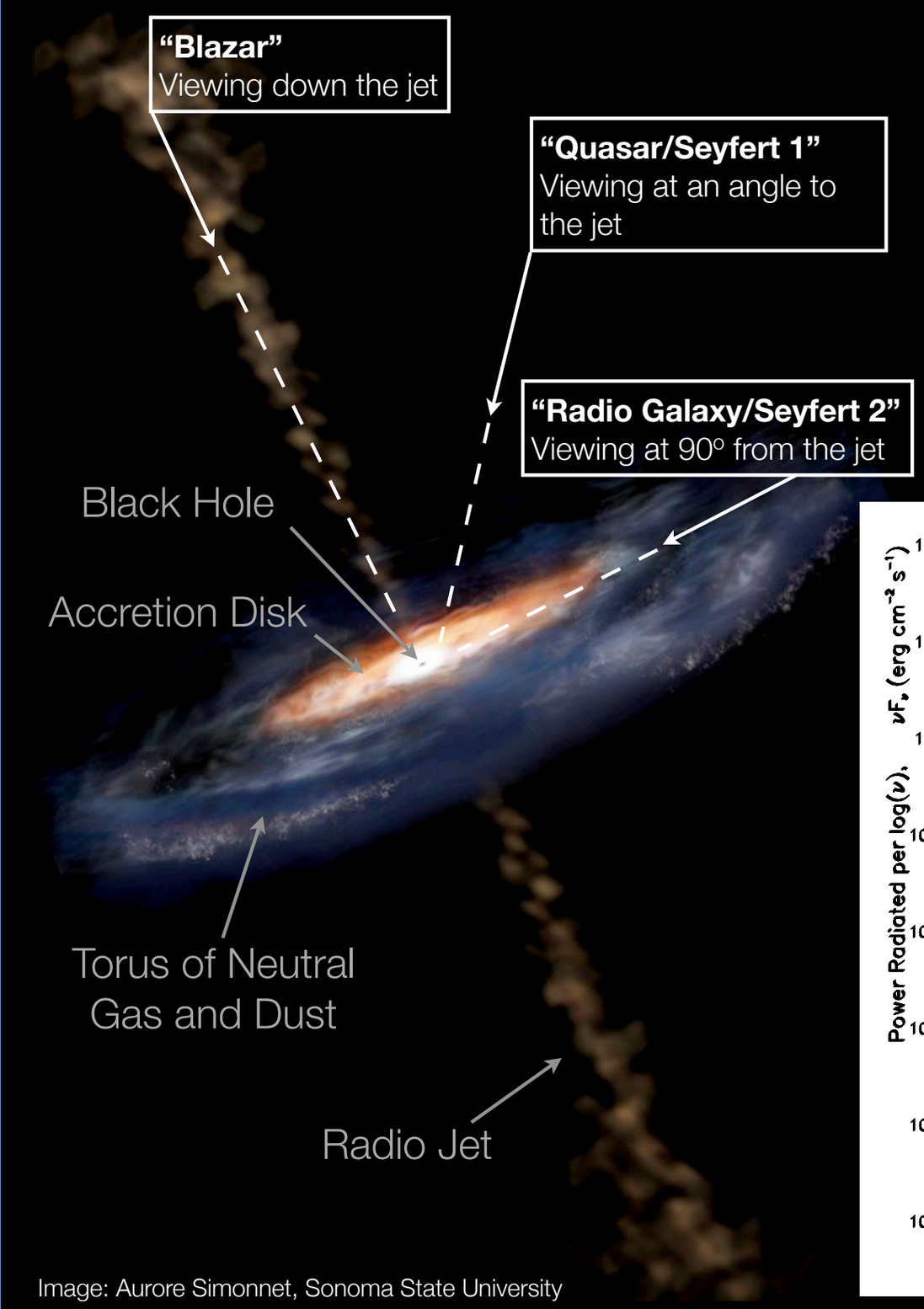

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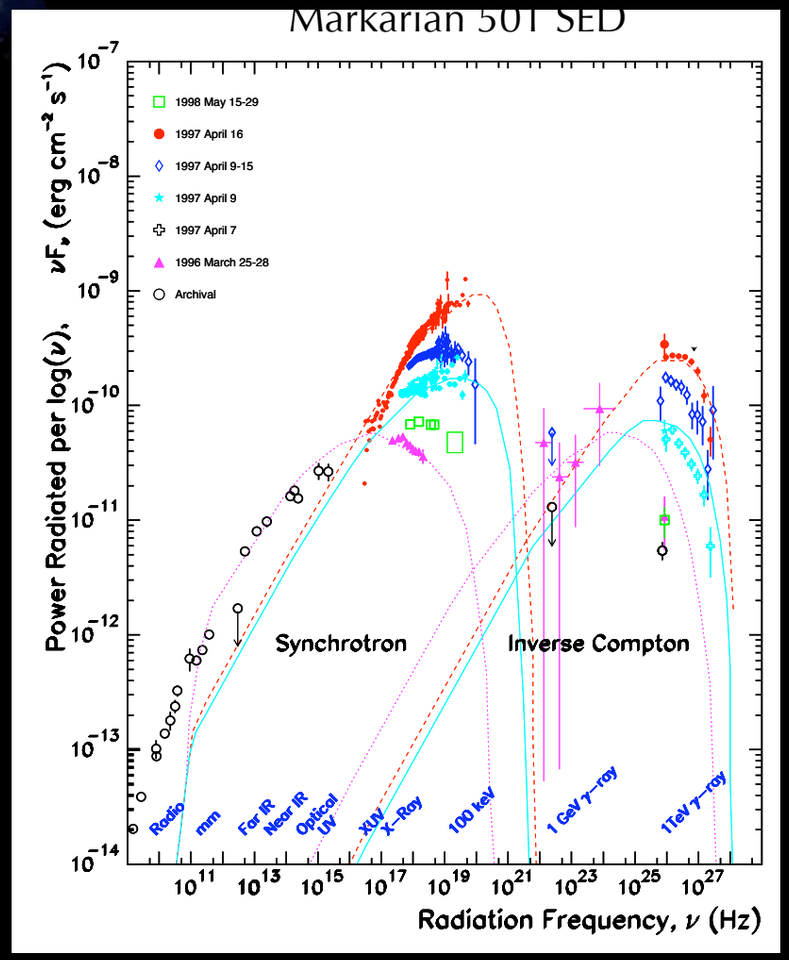
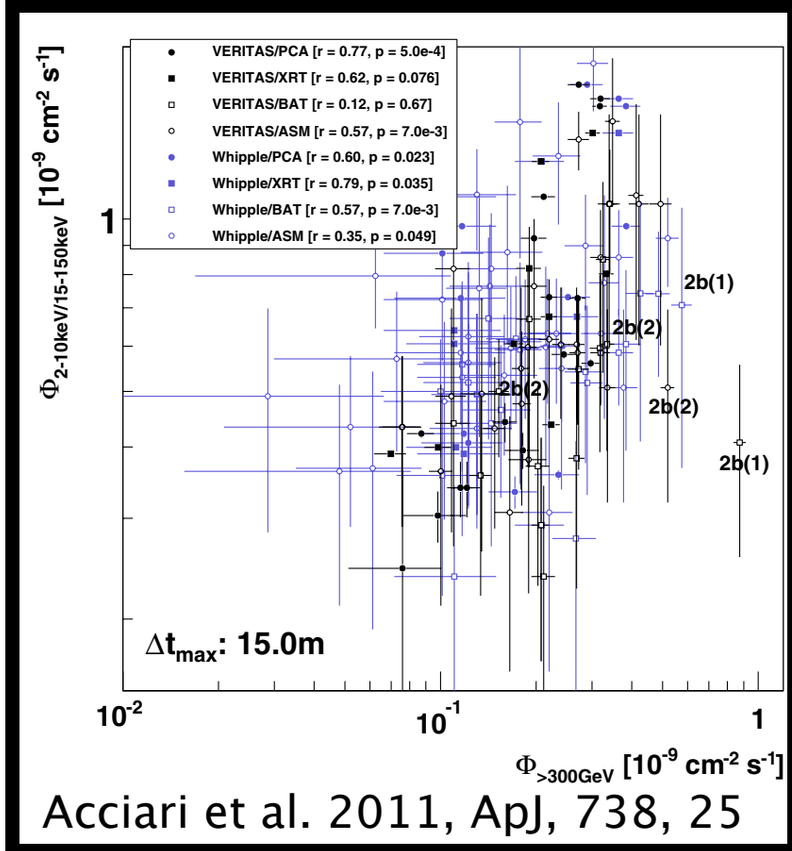
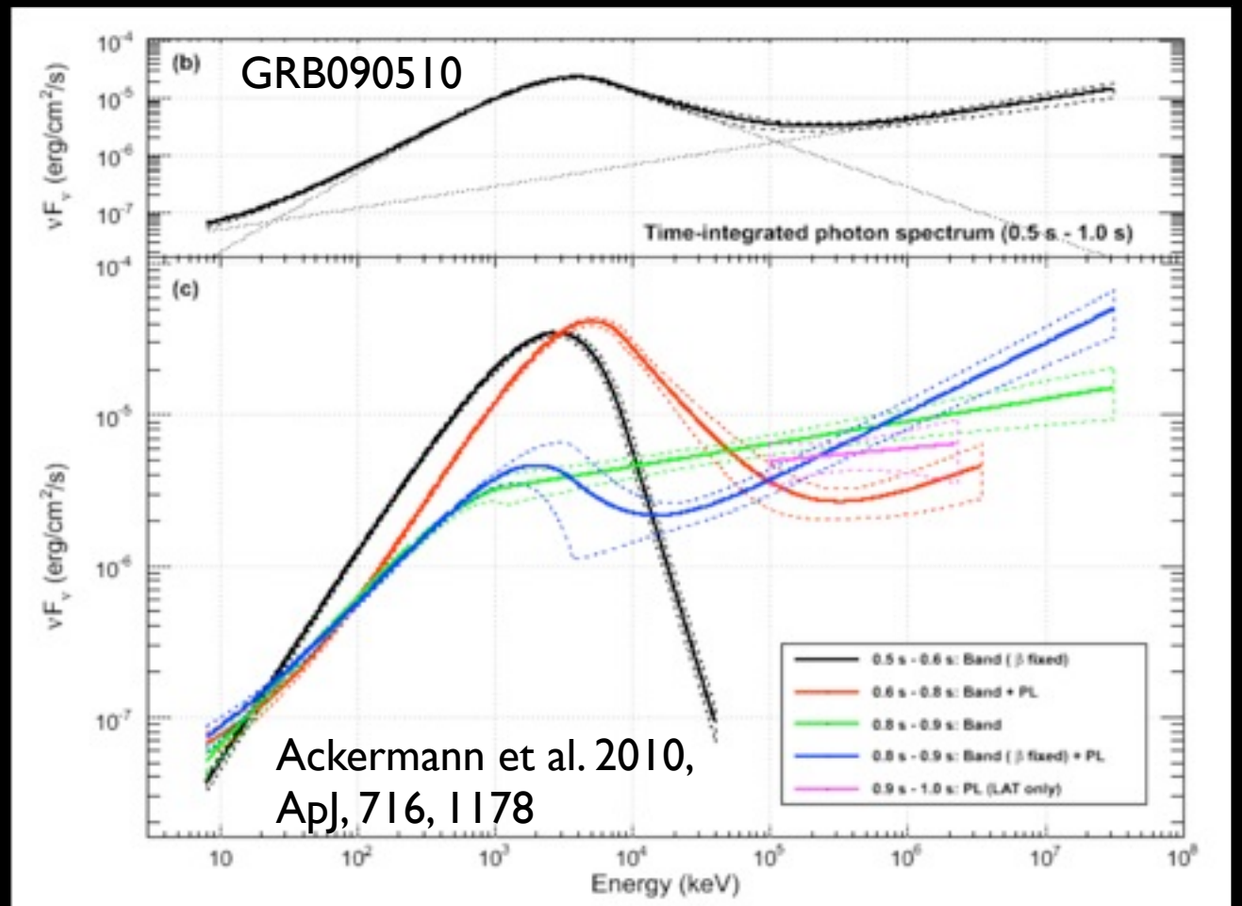




Acciari et al. 2011, ApJ, 738, 25

Gamma-Ray Bursts



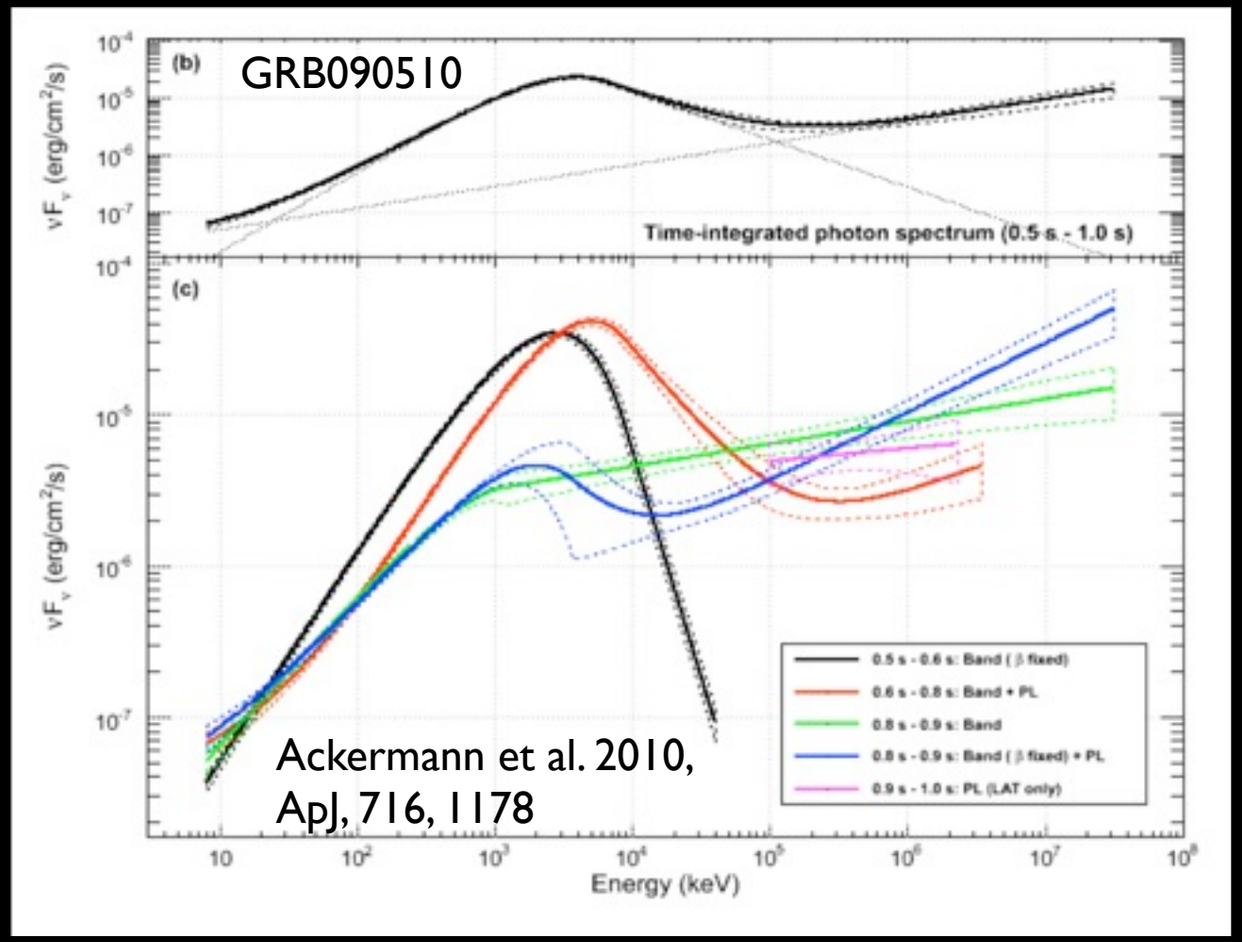
Ackermann et al. 2010, ApJ, 716, 1178

- Continuation of Fermi-LAT "rising" GeV component.

- Assume Fermi GBM trigger, GRB spectra continues up to 1TeV, predicts 1.65 GRBs/year for HAWC (Taboada & Gilmore, arXiv:1306.1127).

- HAWC can be a ground-based trigger for IACTs.

Gamma-Ray Bursts



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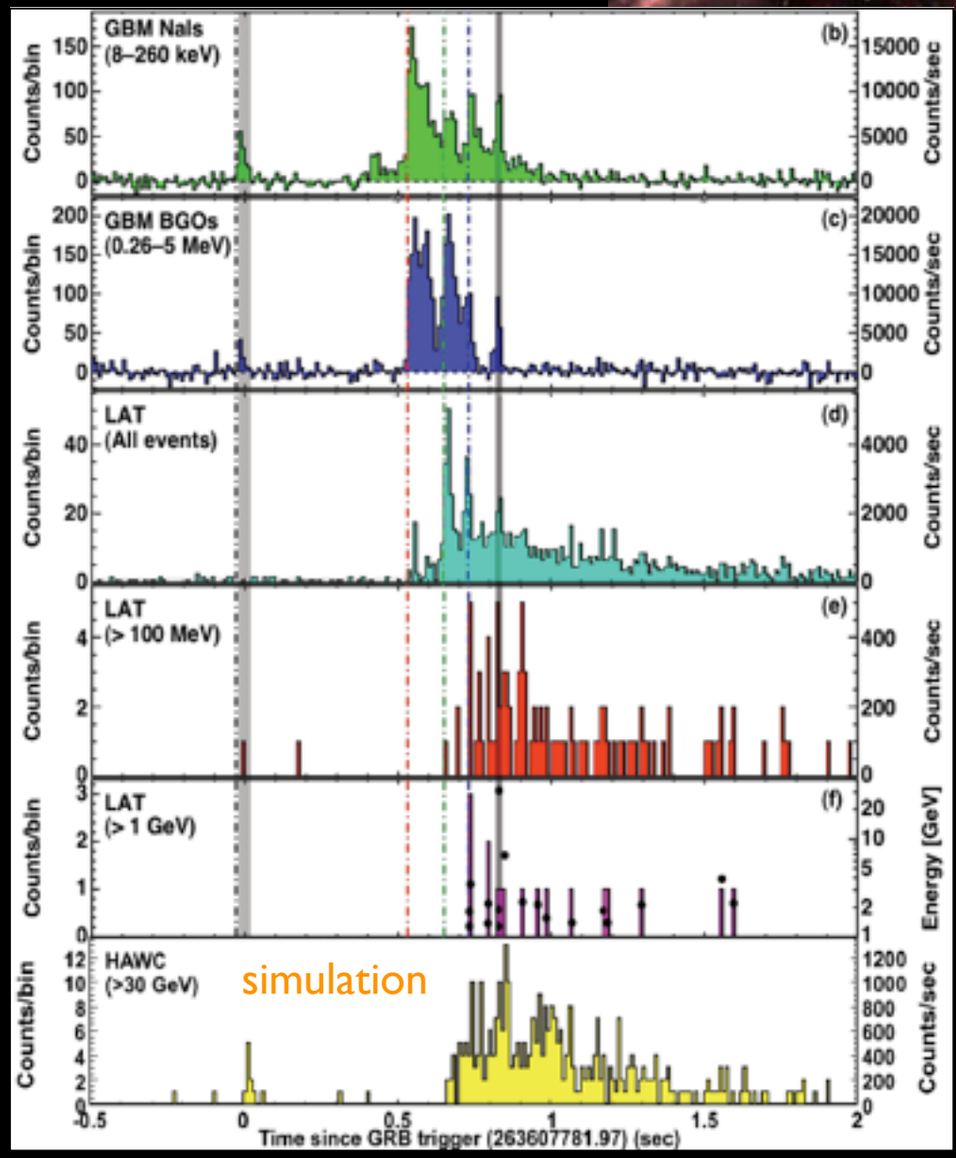
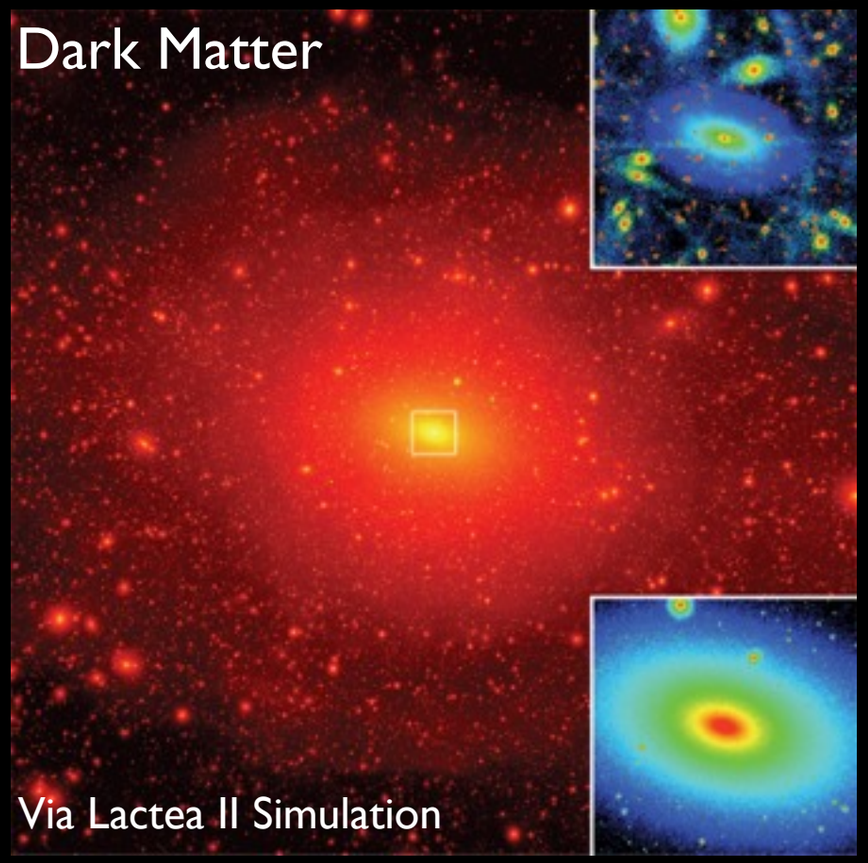


Additional Science Topics



Annihilation signatures from
High-mass (> I TeV WIMPs).
Direct searches for slow-moving
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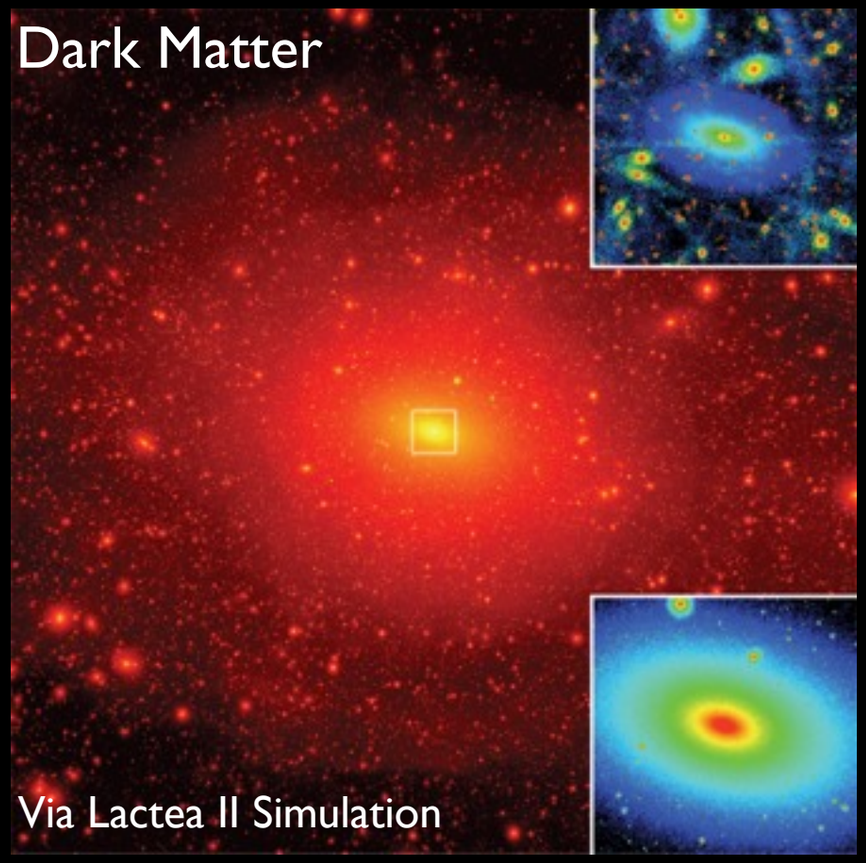

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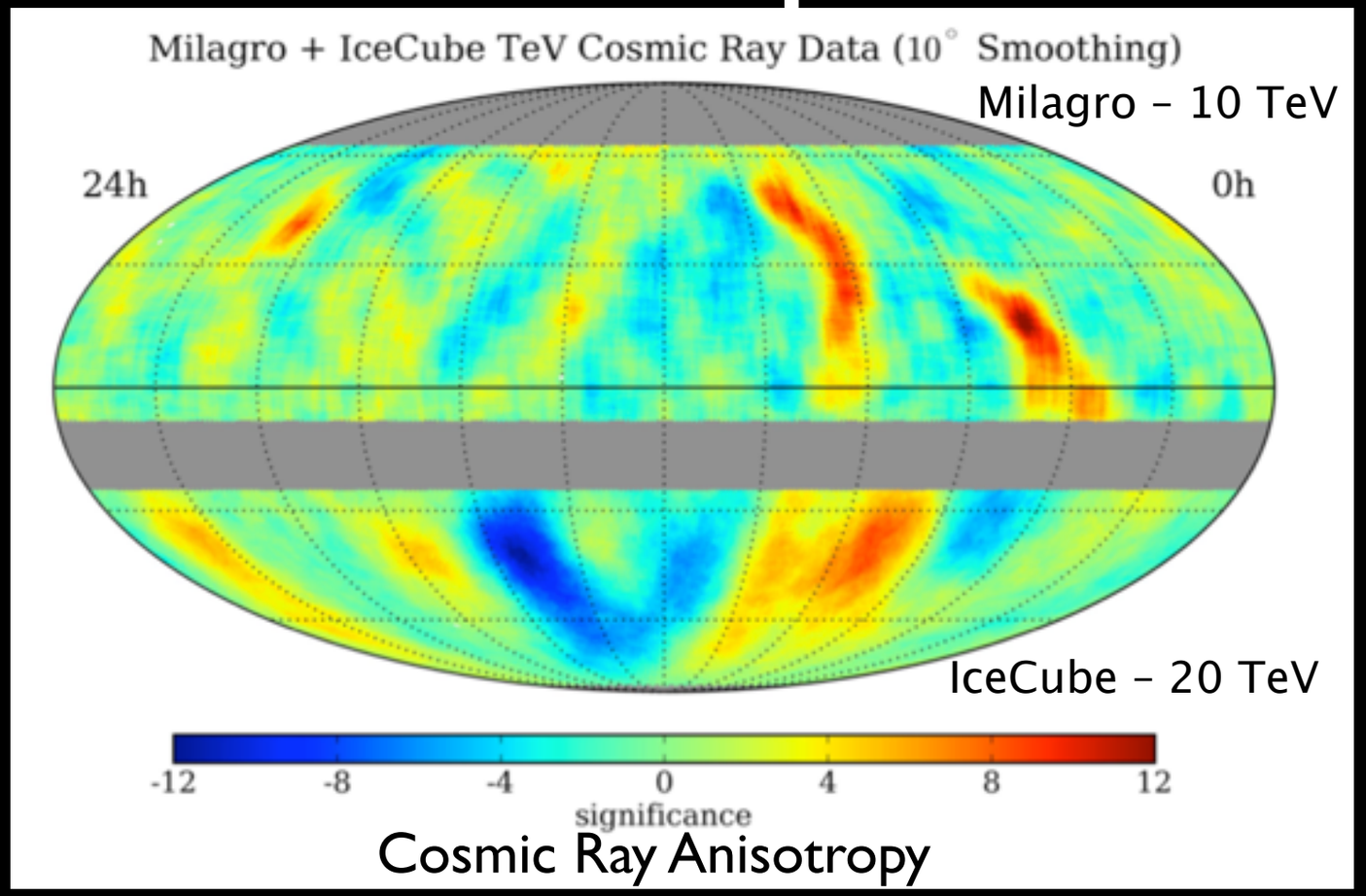
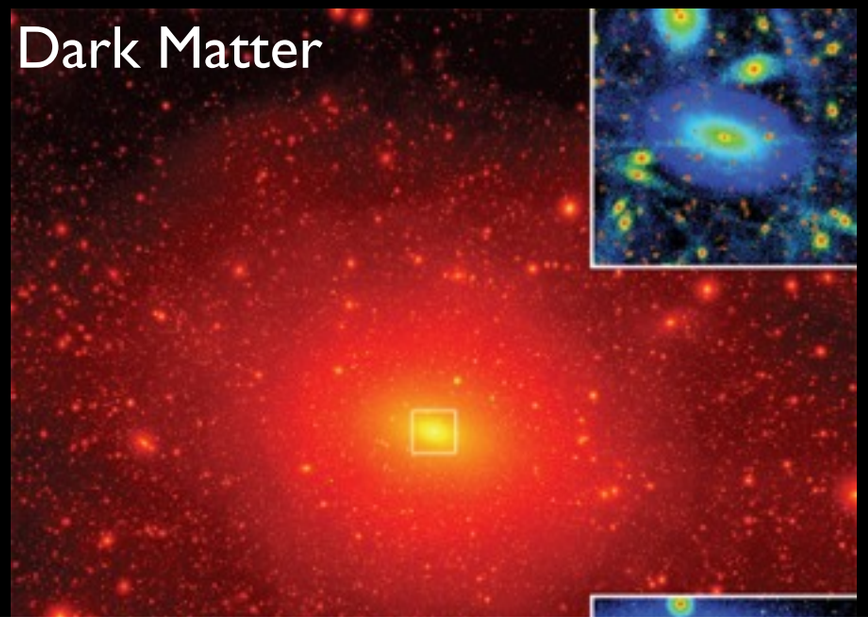
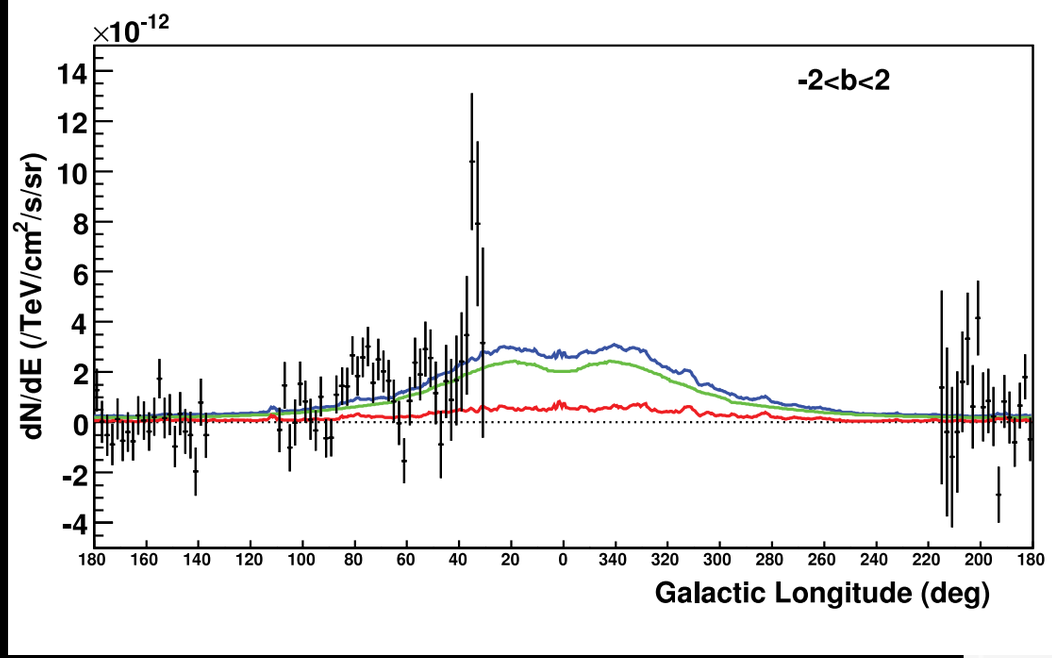


Cosmic Ray Anisotropy

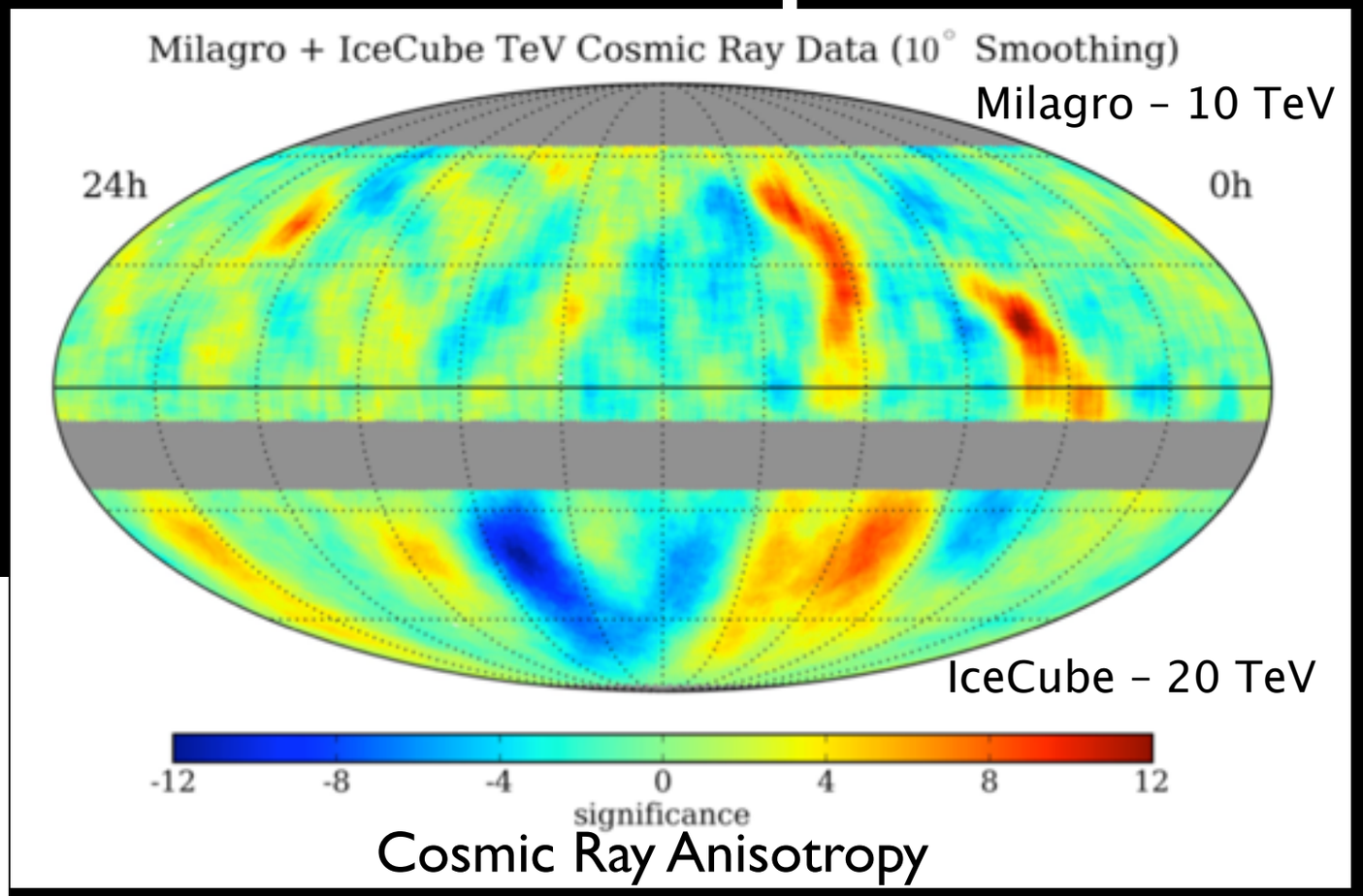
Additional Science Topics





TeV Diffuse Emission

Unbiased Galactic Plane survey



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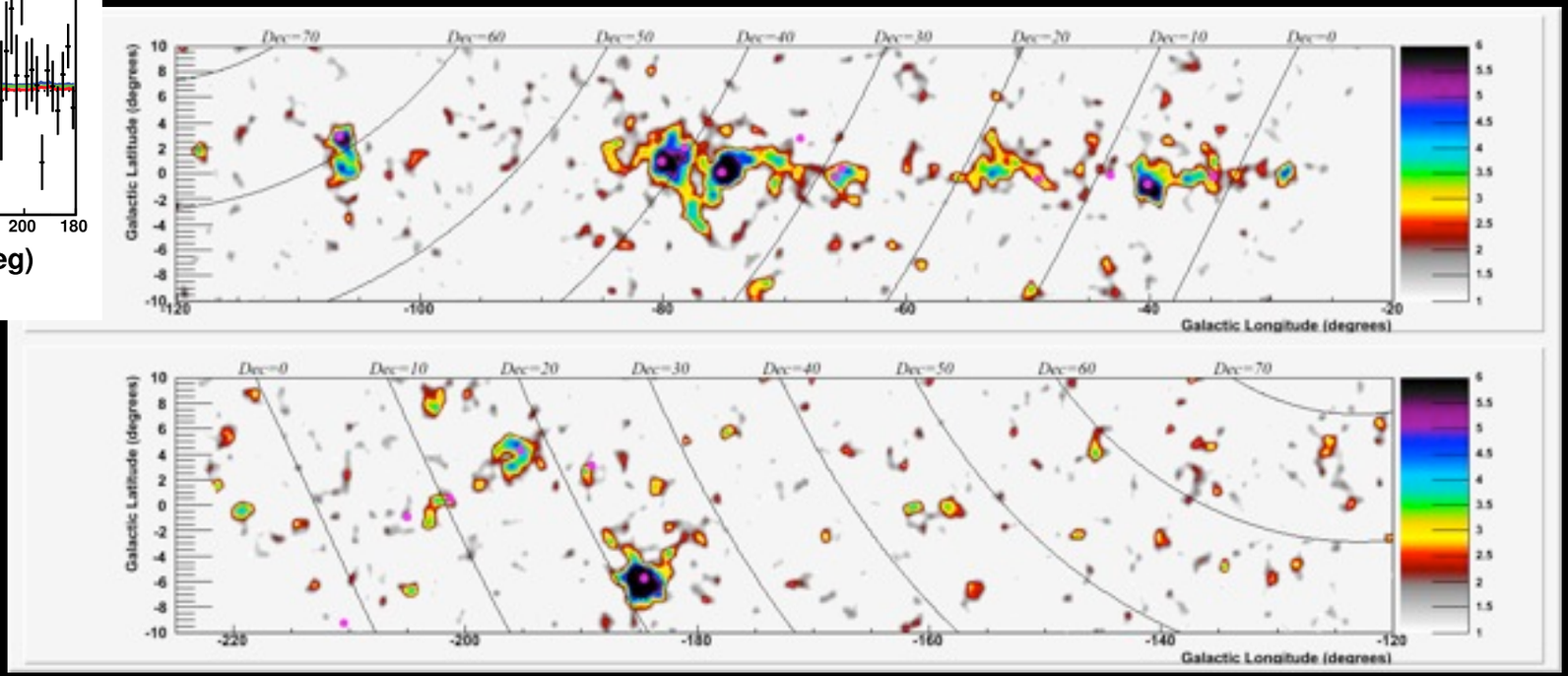
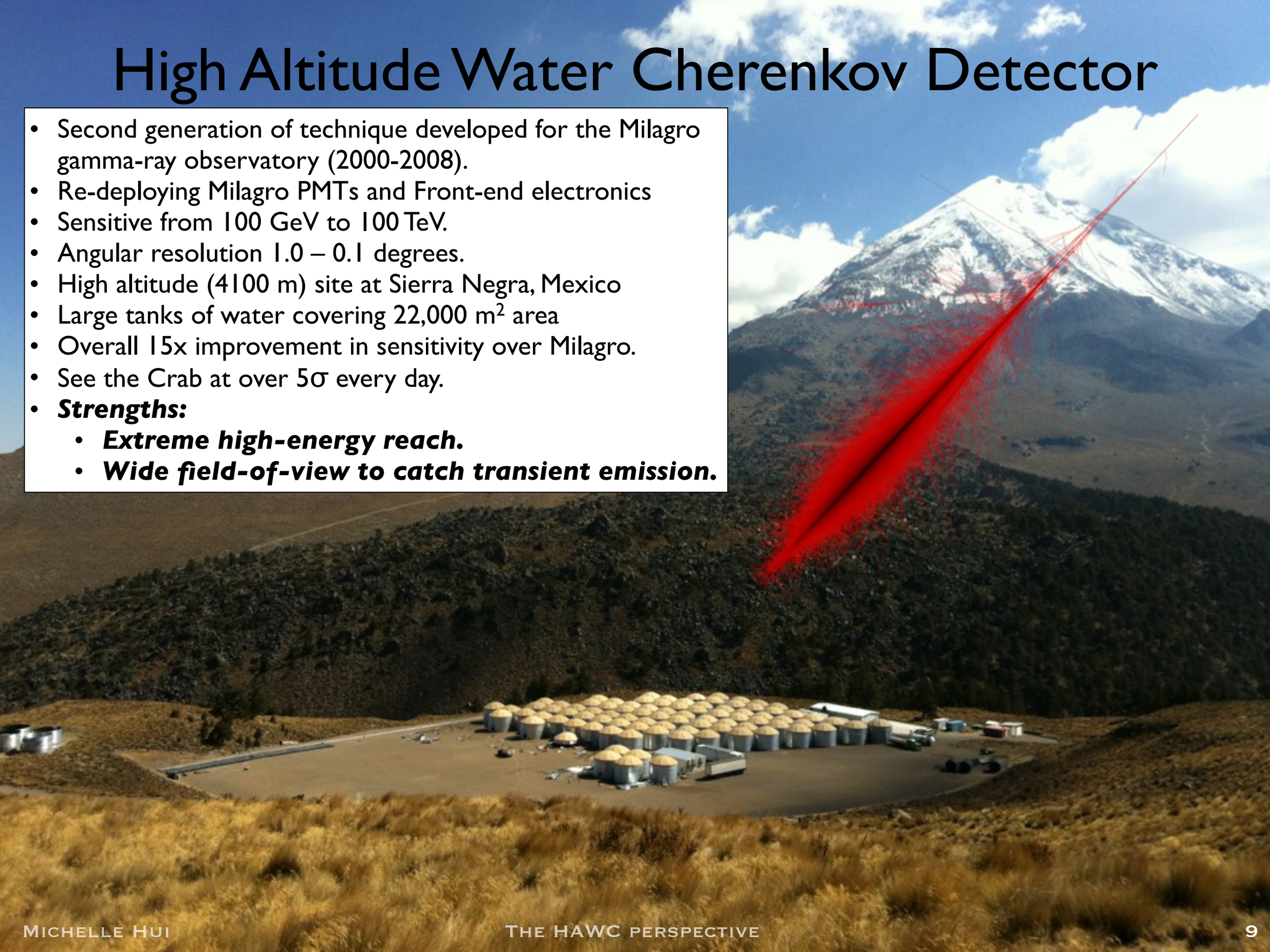


High Altitude Water Cherenkov Detector

- Second generation of technique developed for the Milagro gamma-ray observatory (2000-2008).
- Re-deploying Milagro PMTs and Front-end electronics
- Sensitive from 100 GeV to 100 TeV.
- Angular resolution 1.0 – 0.1 degrees.
- High altitude (4100 m) site at Sierra Negra, Mexico
- Large tanks of water covering 22,000 m^2 area
- Overall 15x improvement in sensitivity over Milagro.
- See the Crab at over 5σ every day.
- ***Strengths:***
  - ***Extreme high-energy reach.***
  - ***Wide field-of-view to catch transient emission.***



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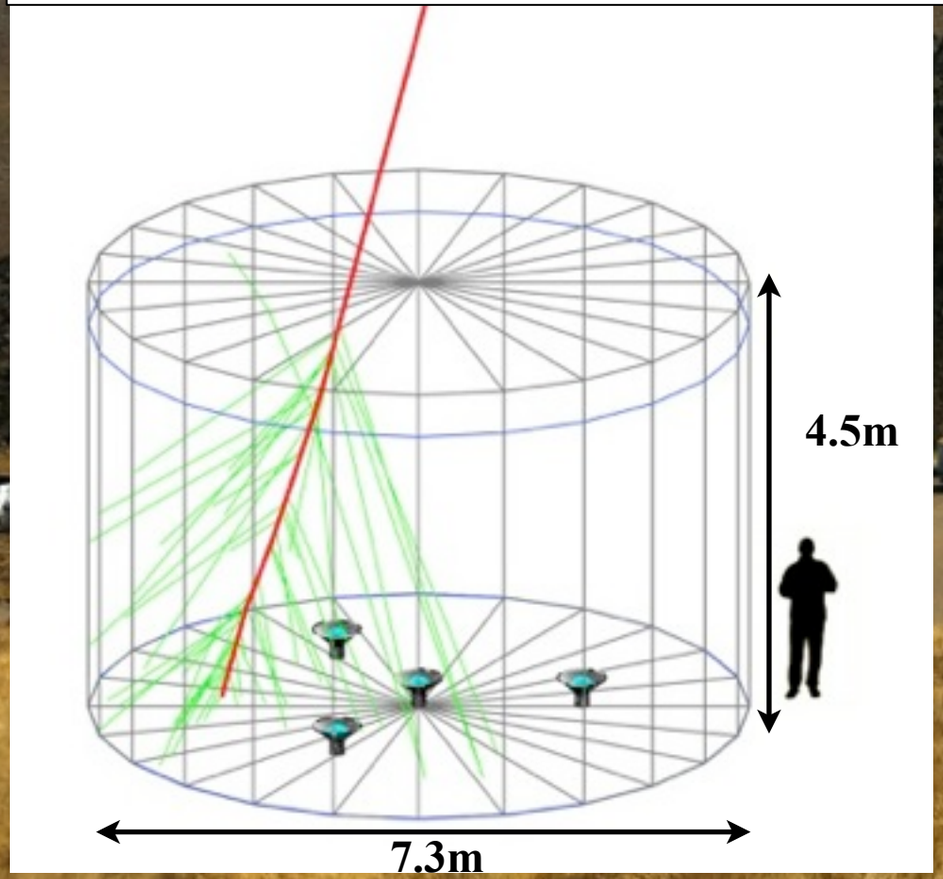

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Georgia Institute of Technology
George Mason University
Los Alamos National Laboratory
Michigan State University
Michigan Technological University
University of New Hampshire
Pennsylvania State University
University of Alabama
University of California, Irvine
University of California, Santa Cruz
University of Maryland
University of New Mexico
University of Wisconsin-Madison
University of Utah

Centro de Investigacion en Computacion, Instituto Politecnico Nacional
Centro de Investigacion y de Estudios Avanzados del IPN
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- Instituto de Ciencias Nucleares
- Instituto de Física
- Instituto de Geofísica

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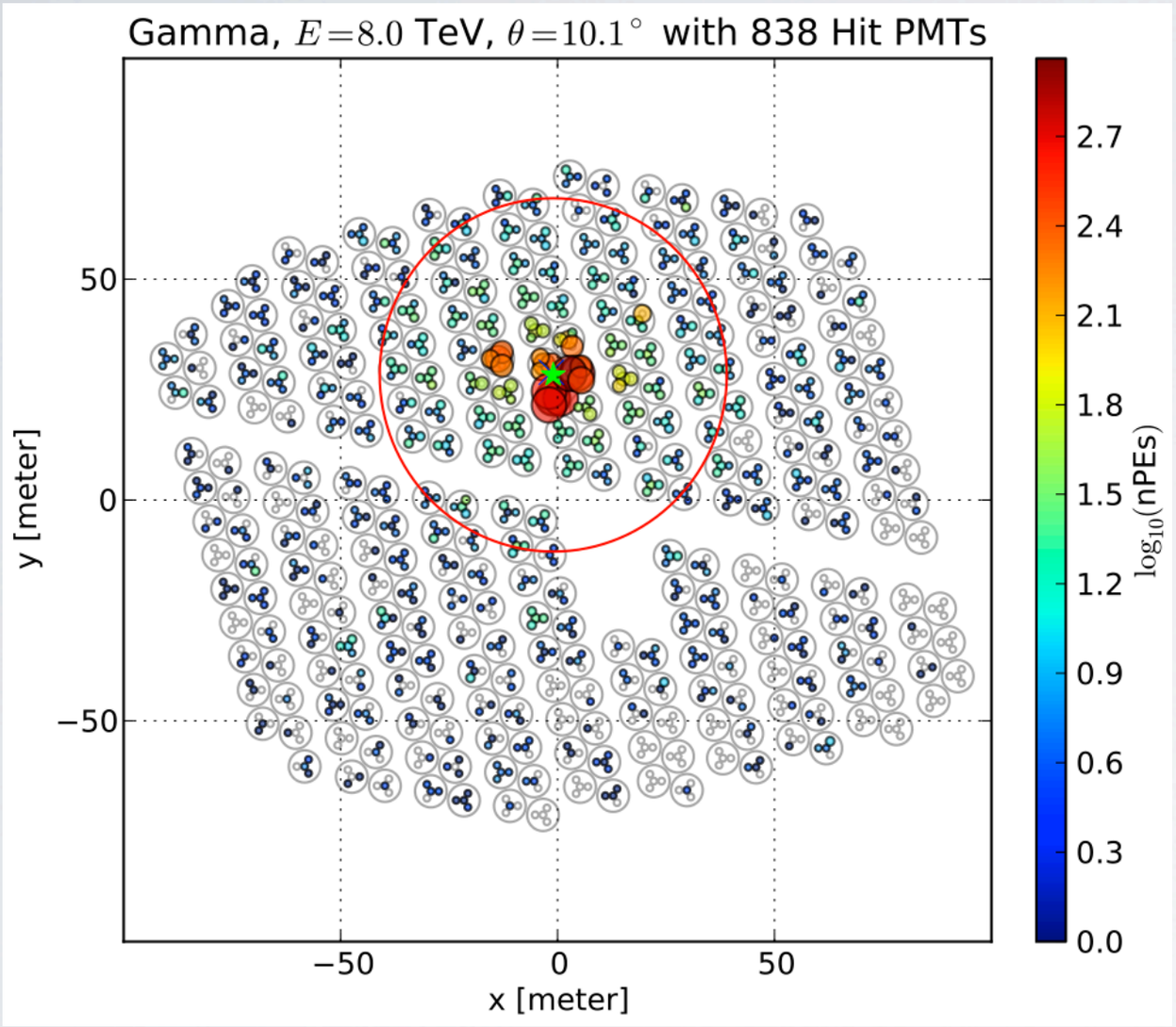
Universidad Autónoma del Estado de Hidalgo
Universidad Michoacana de San Nicolás de Hidalgo
Universidad Autónoma de Chiapas
Universidad Politecnica de Pachuca
Universidad de Guadalajara

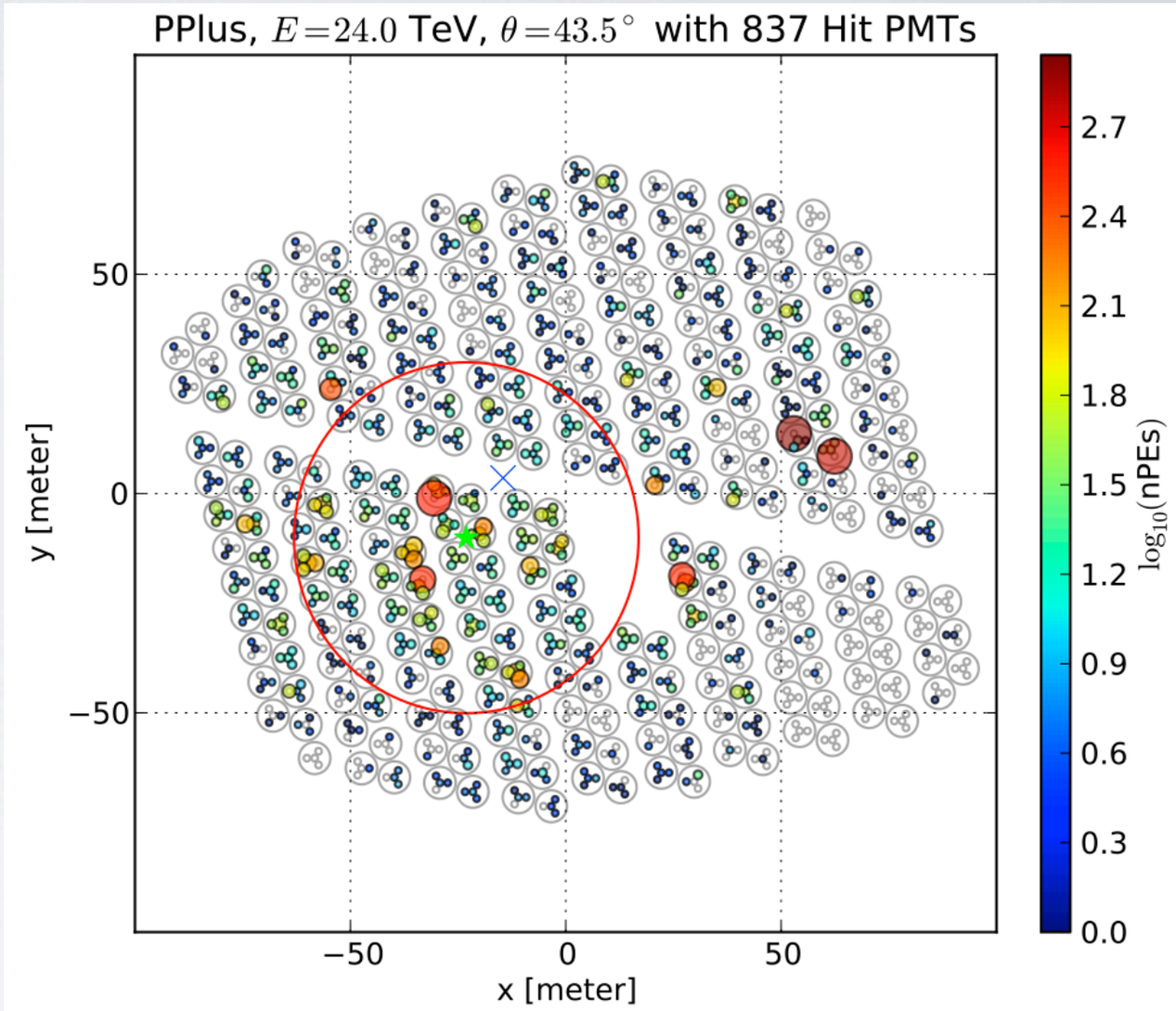
HAWC
High Altitude Water Cherenkov
Gamma-Ray Observatory

~100 members
15 U.S. institutions
13 Mexican institutions

HAWC Meeting
September 23–25, 2013
Michigan Technological University
Houghton, Michigan

Gamma / Hadron Separation





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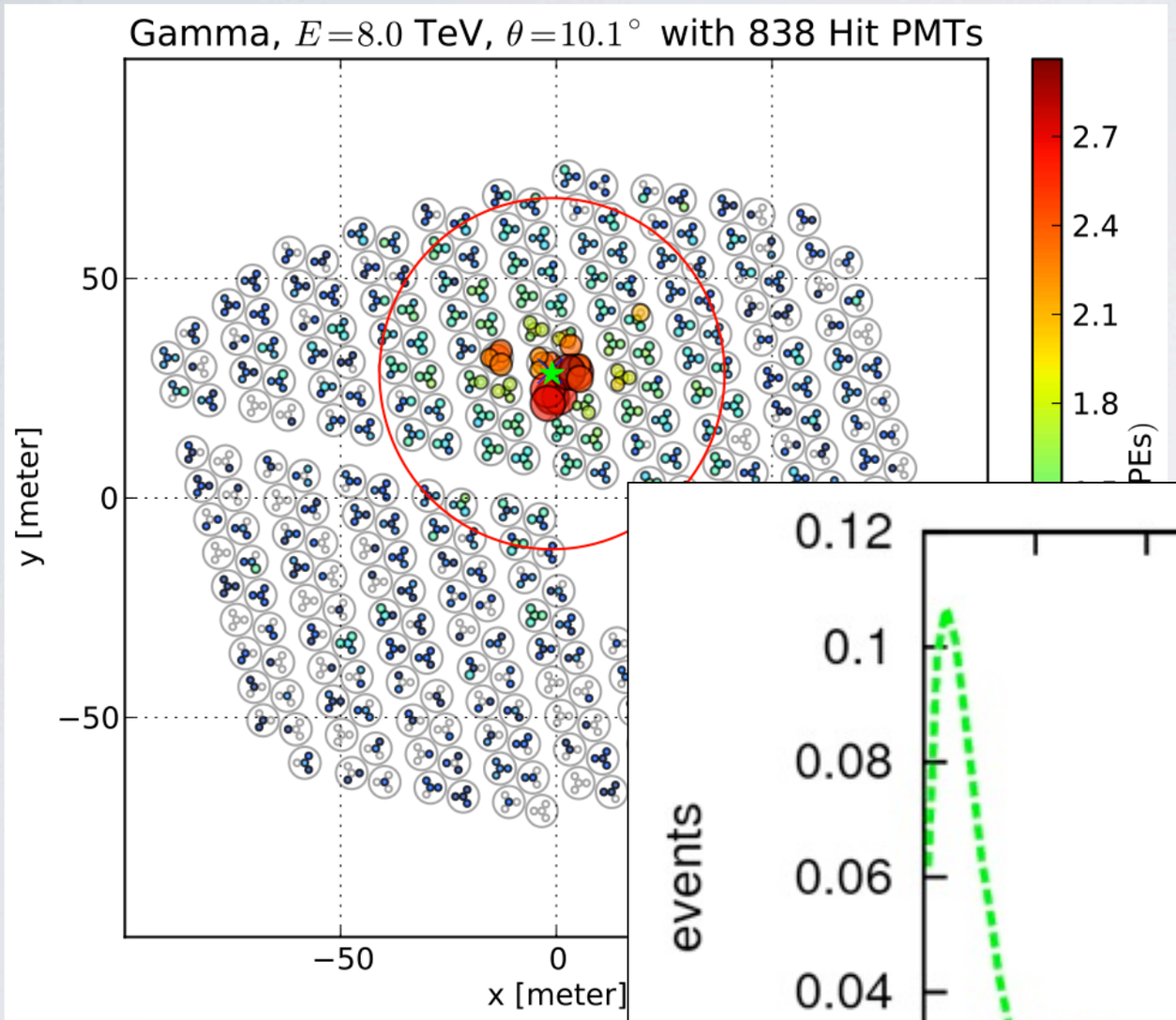
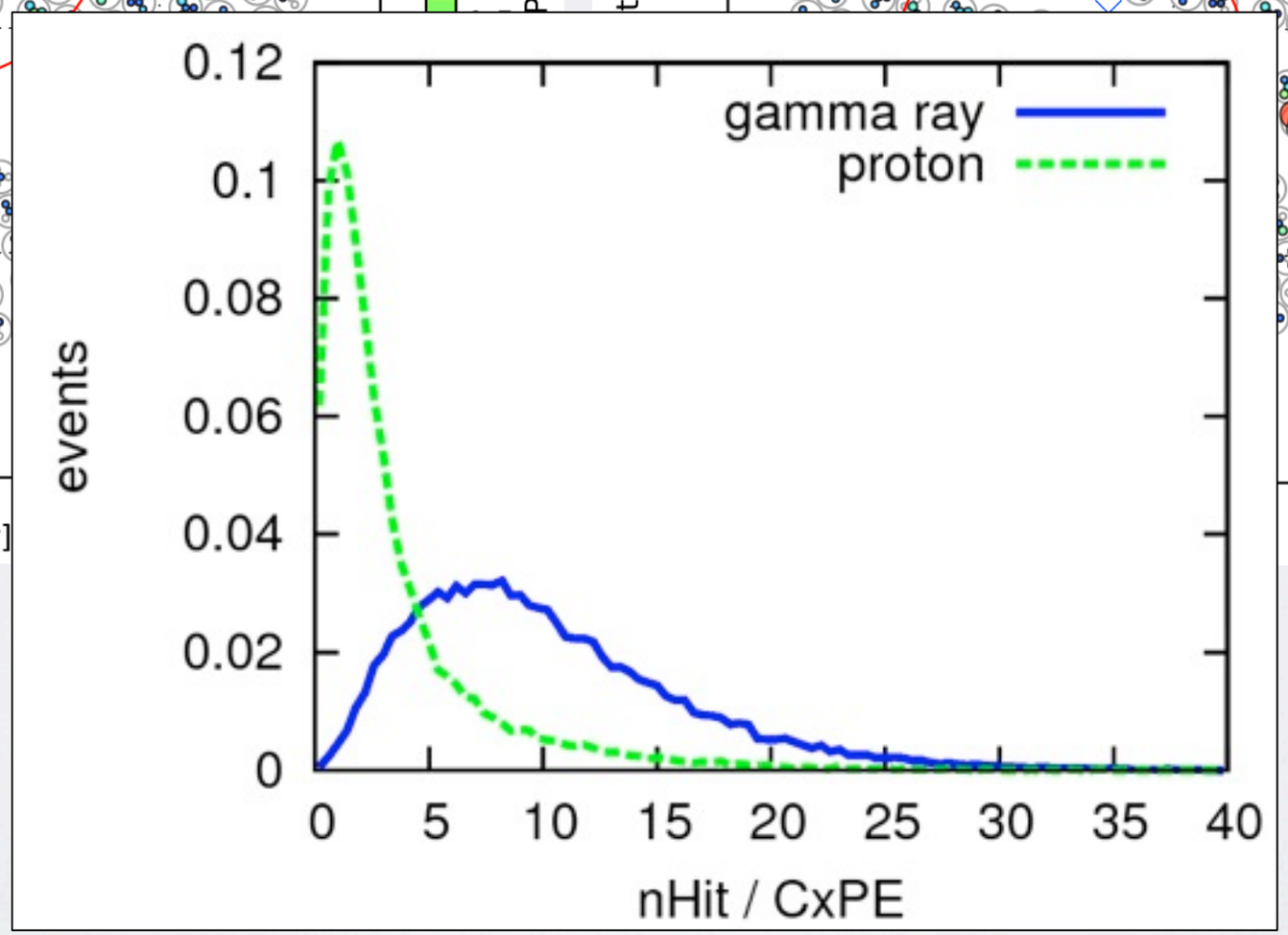
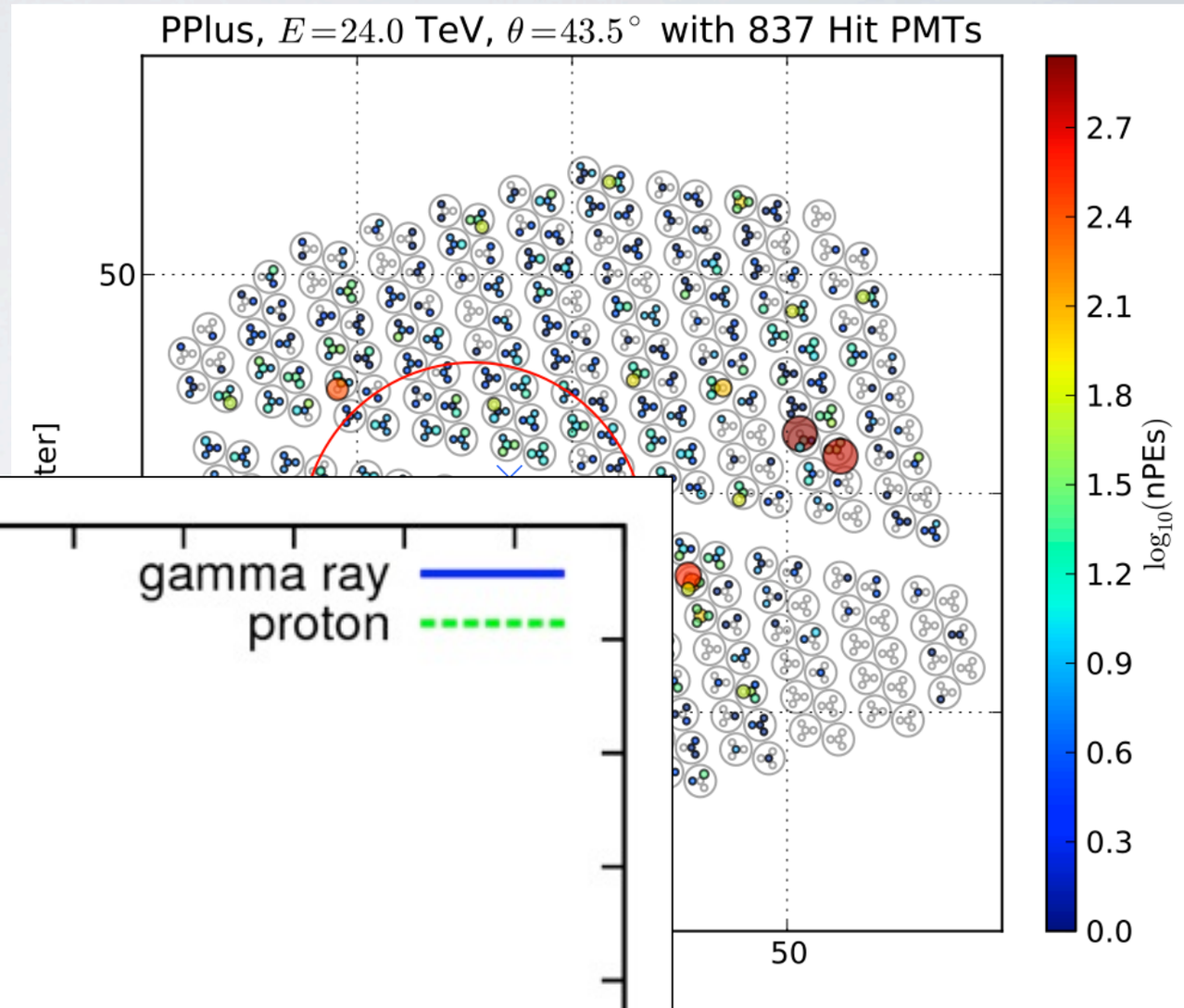


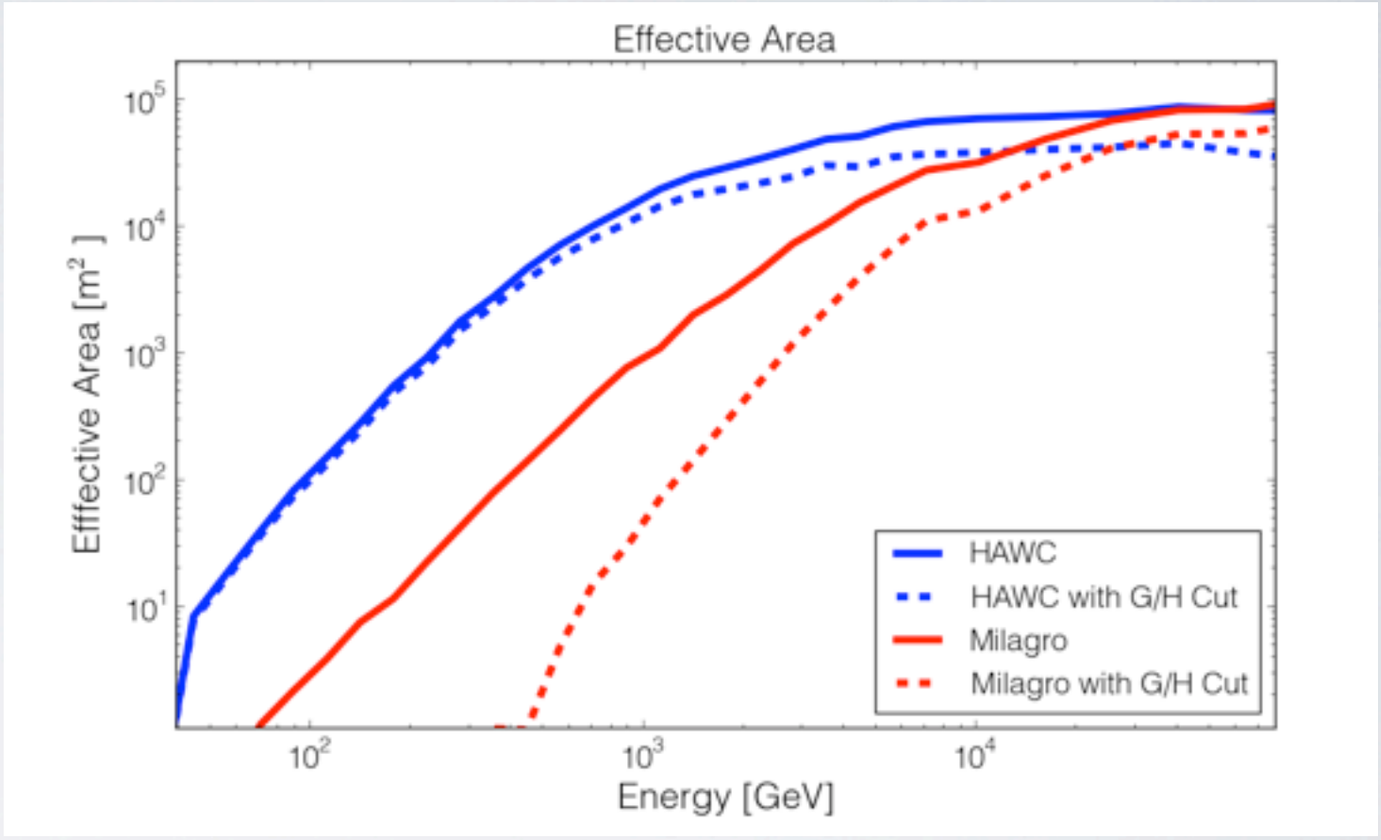




arXiv:1306.5800

Performance

- Larger effective area below 100 GeV
- Much improved hadron rejection.
- Angular resolutions down to 0.1°.



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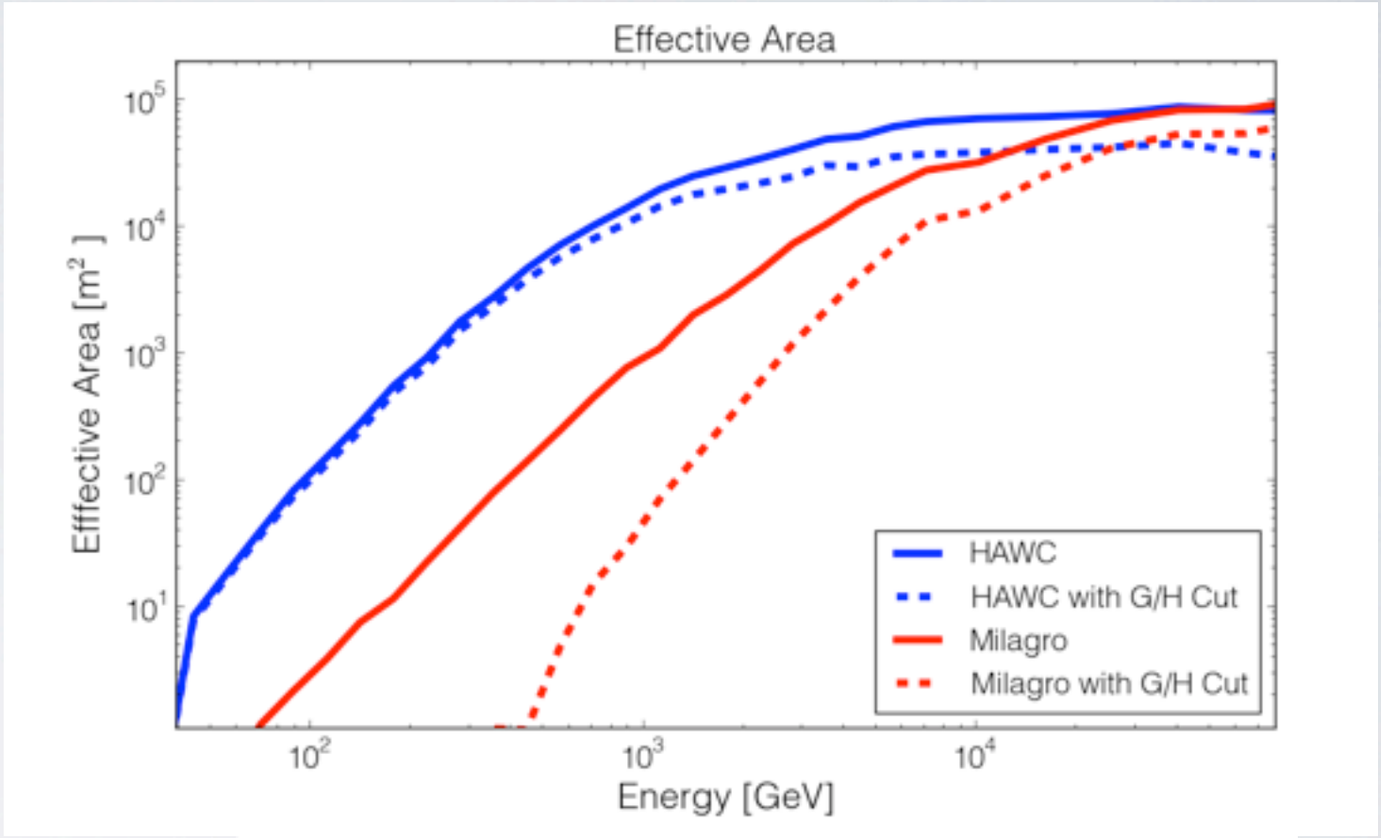

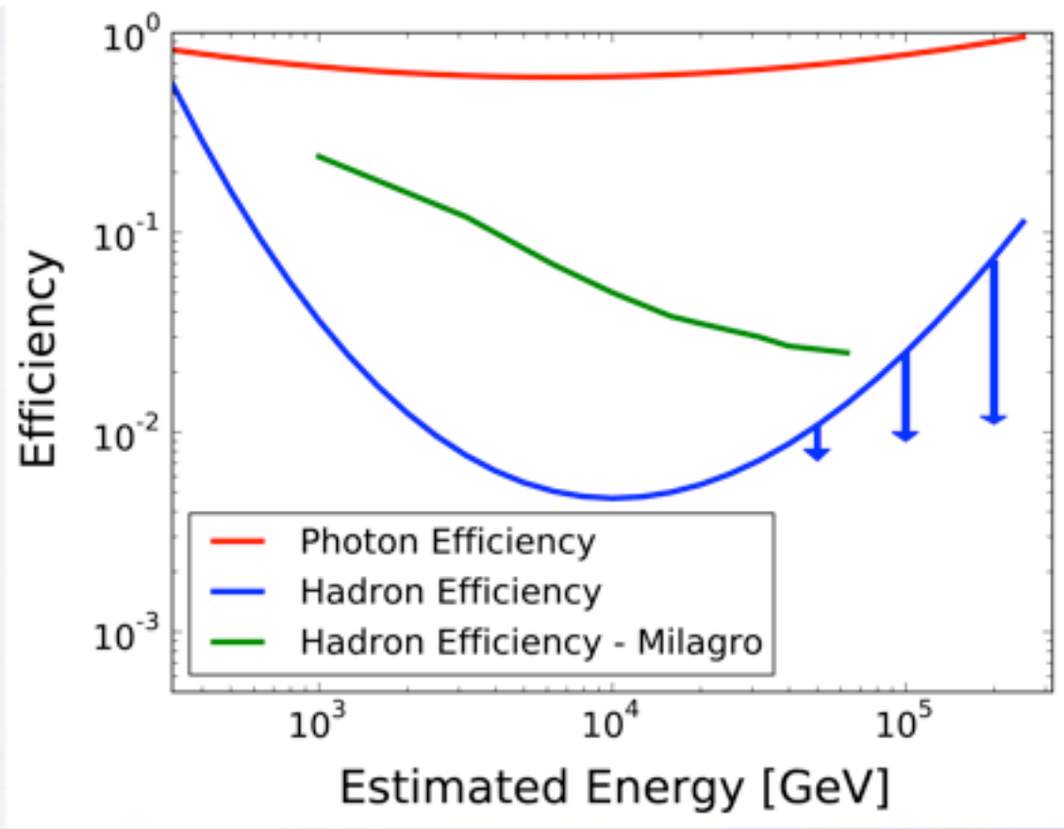

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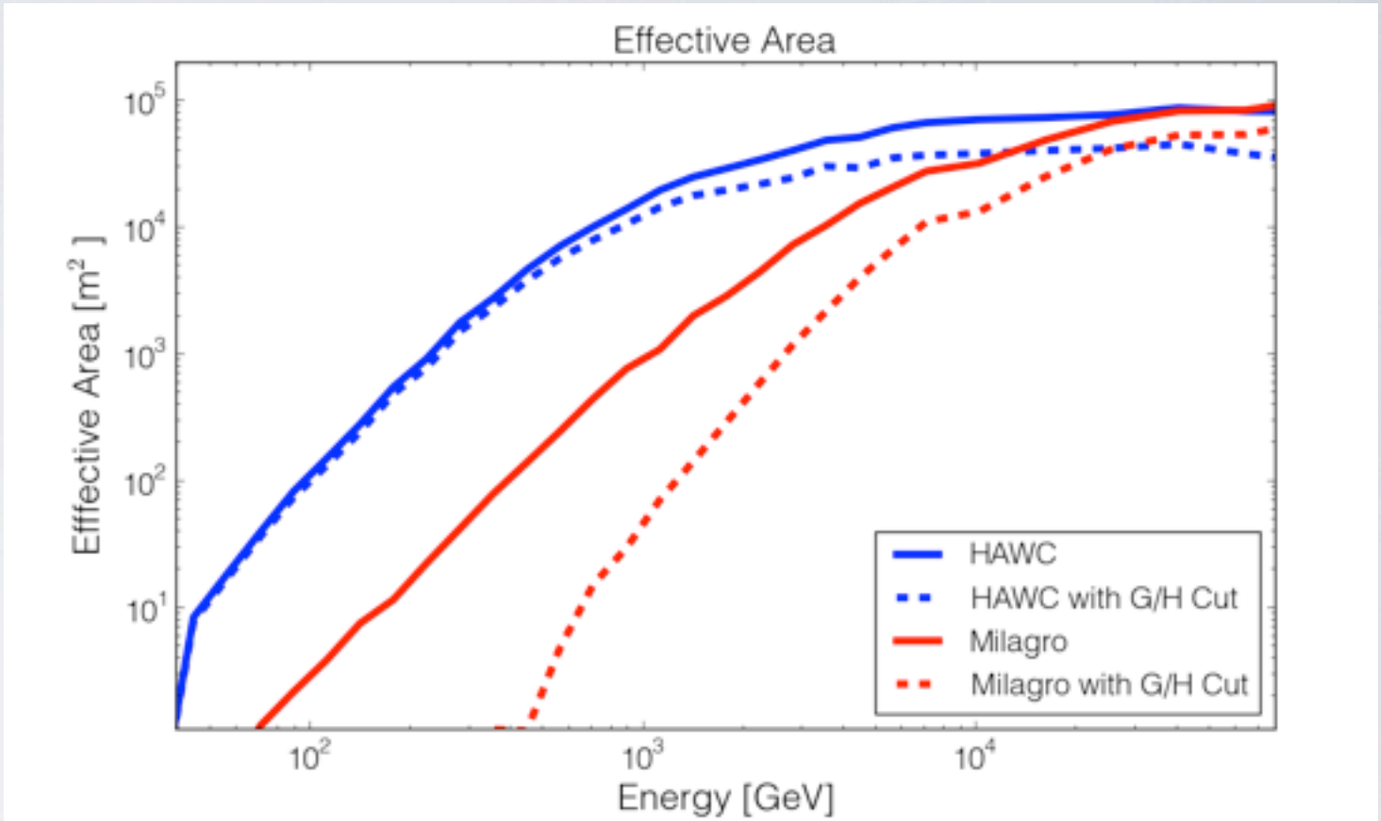
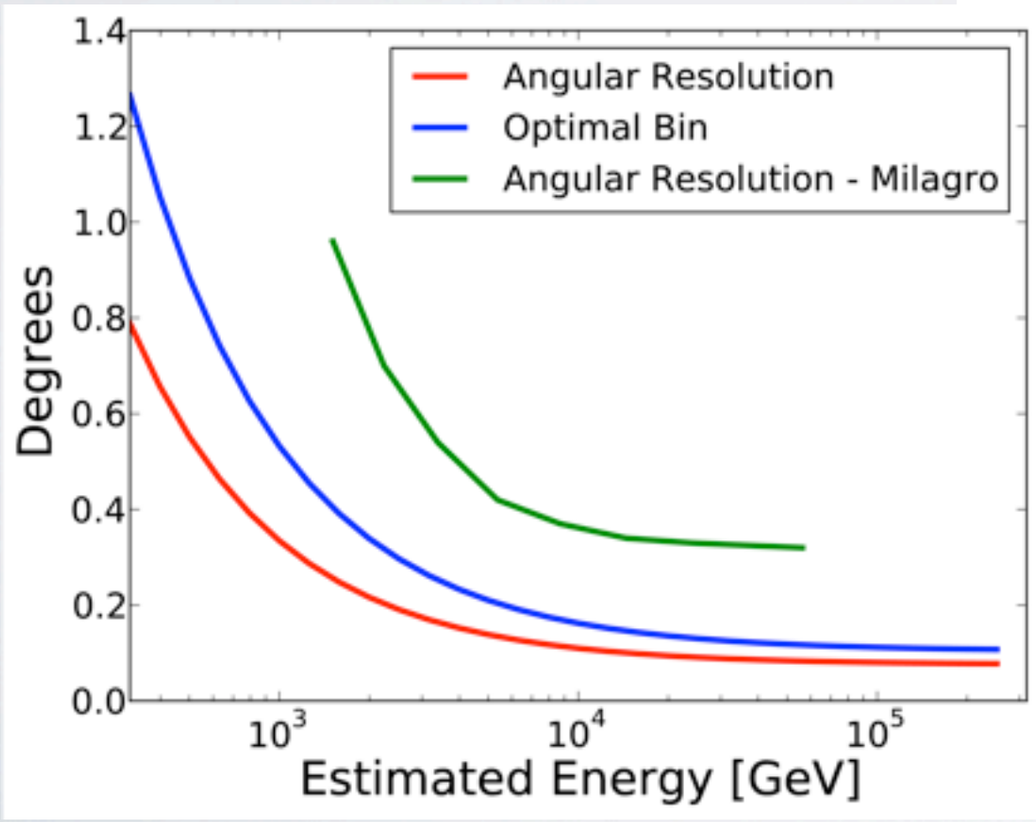
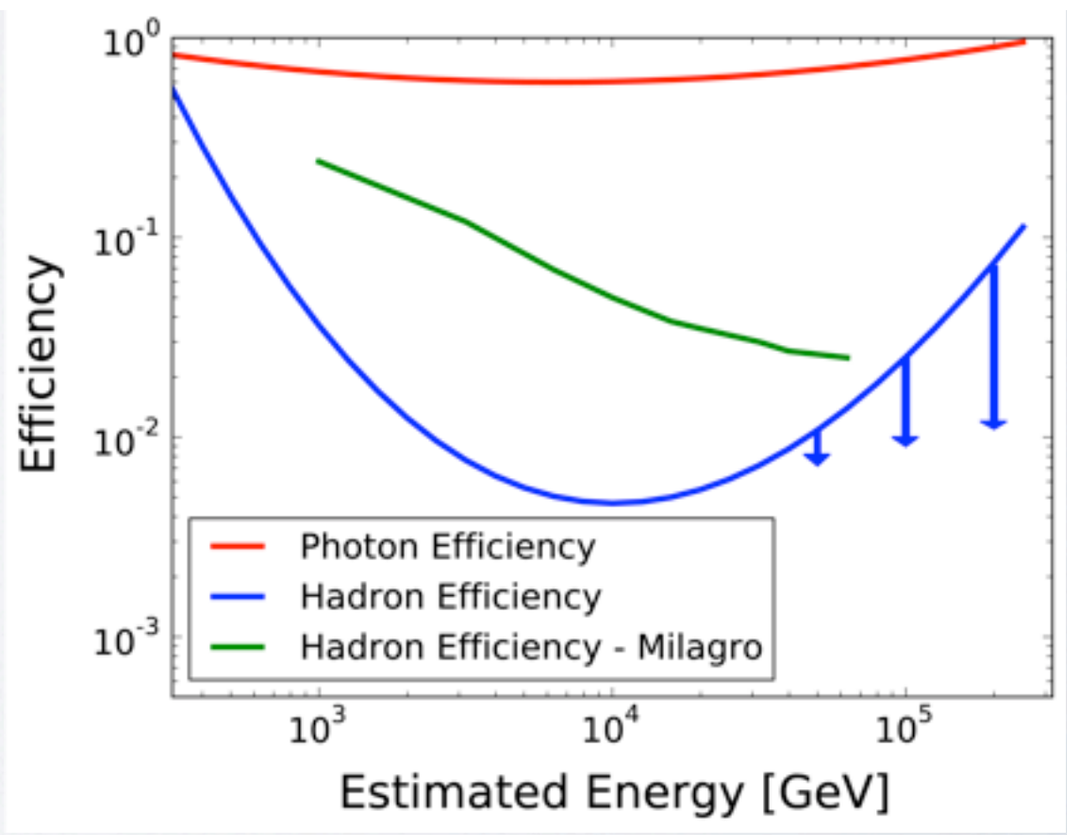
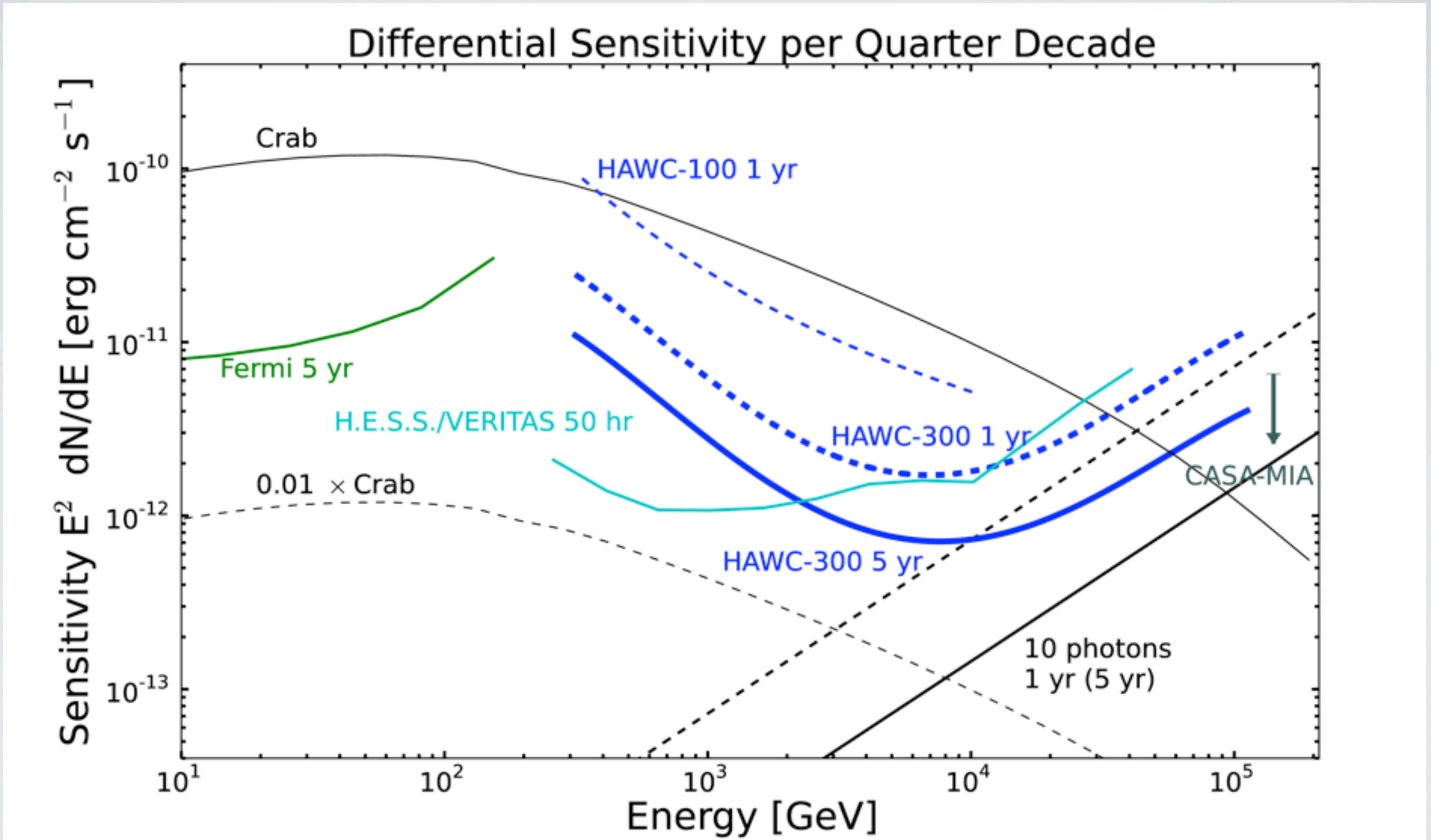






HAWC Sensitivity

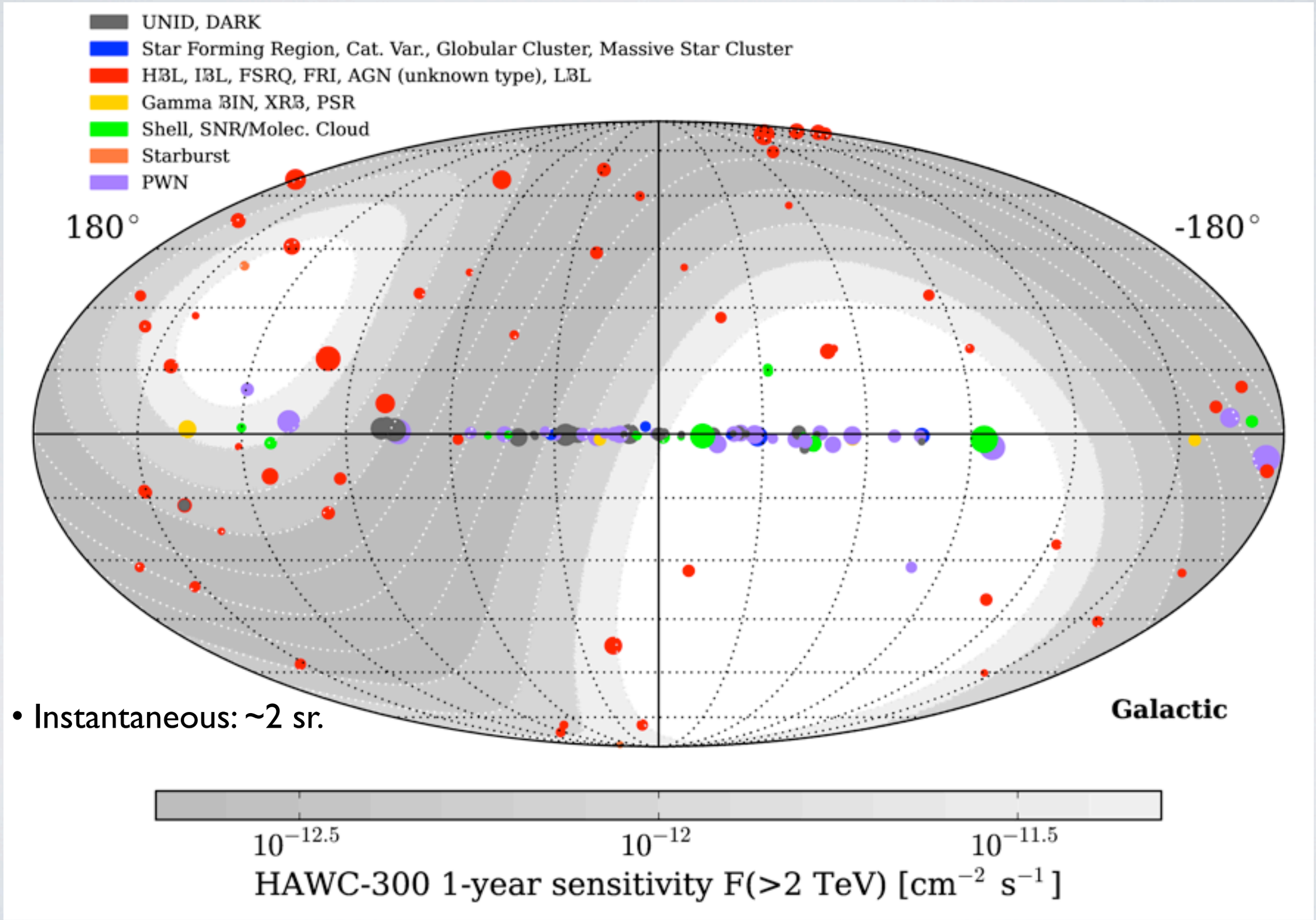
arXiv:1306.5800



Competitive sensitivity to IACTs across the entire sky.

arXiv:1306.5800

Field of View



- Instantaneous: ~2 sr.

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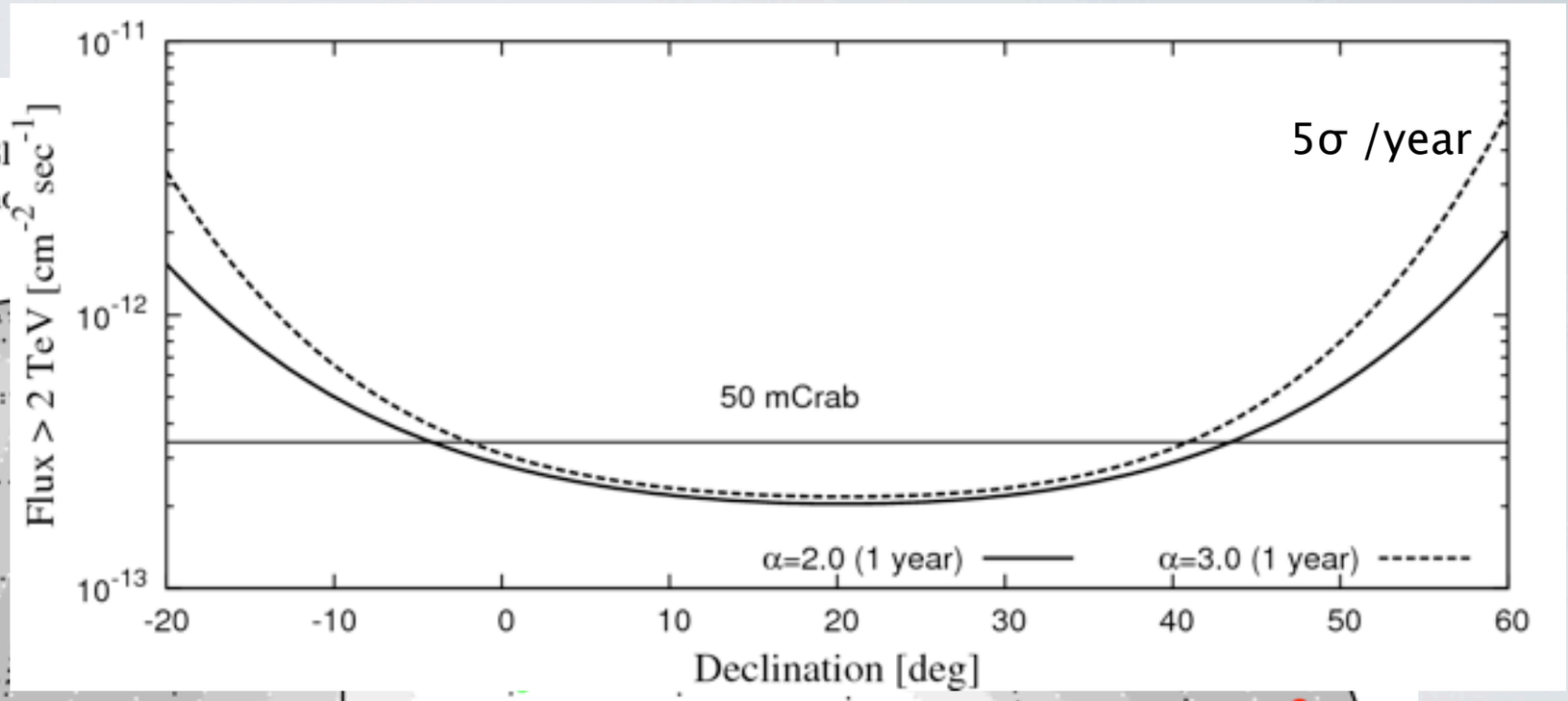

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Current Status

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- Taking data with 30+ since Fall '12.
- Operations formally began Aug 1st.
- Detector to be completed Summer '14.

- Clear evidence of gamma rays from Galactic and extra-Galactic sources.

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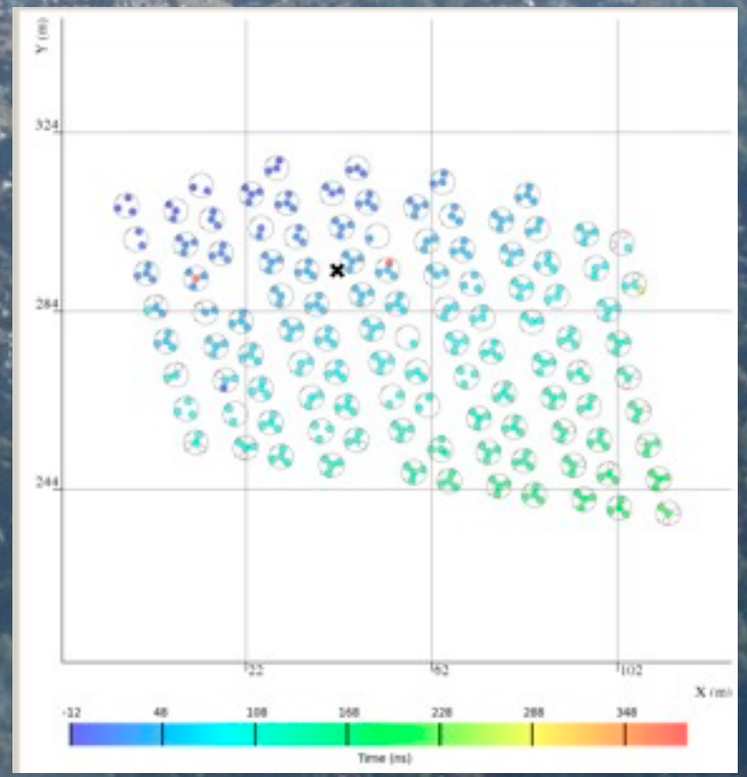
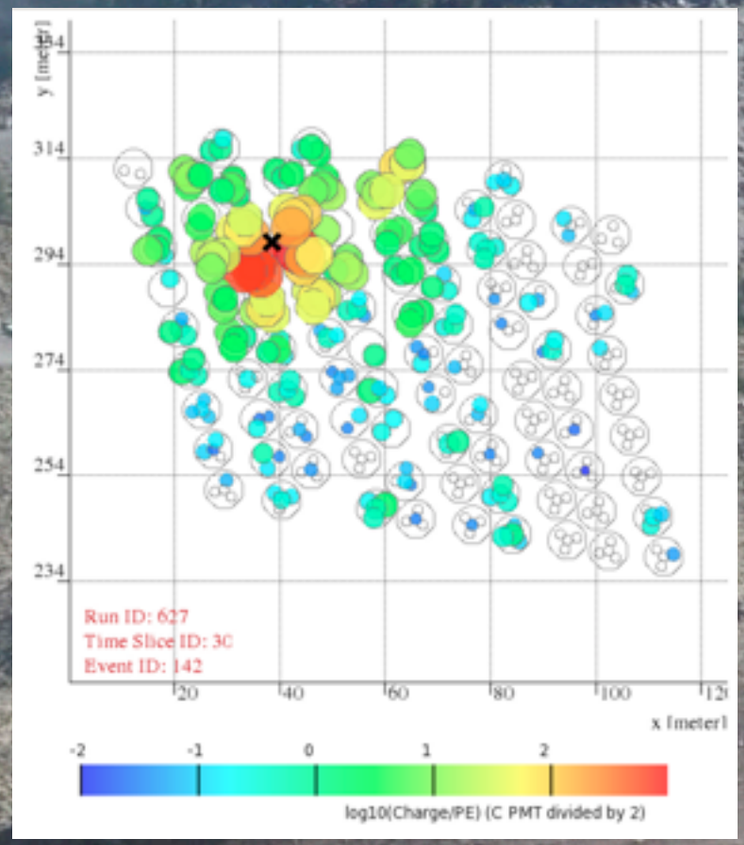
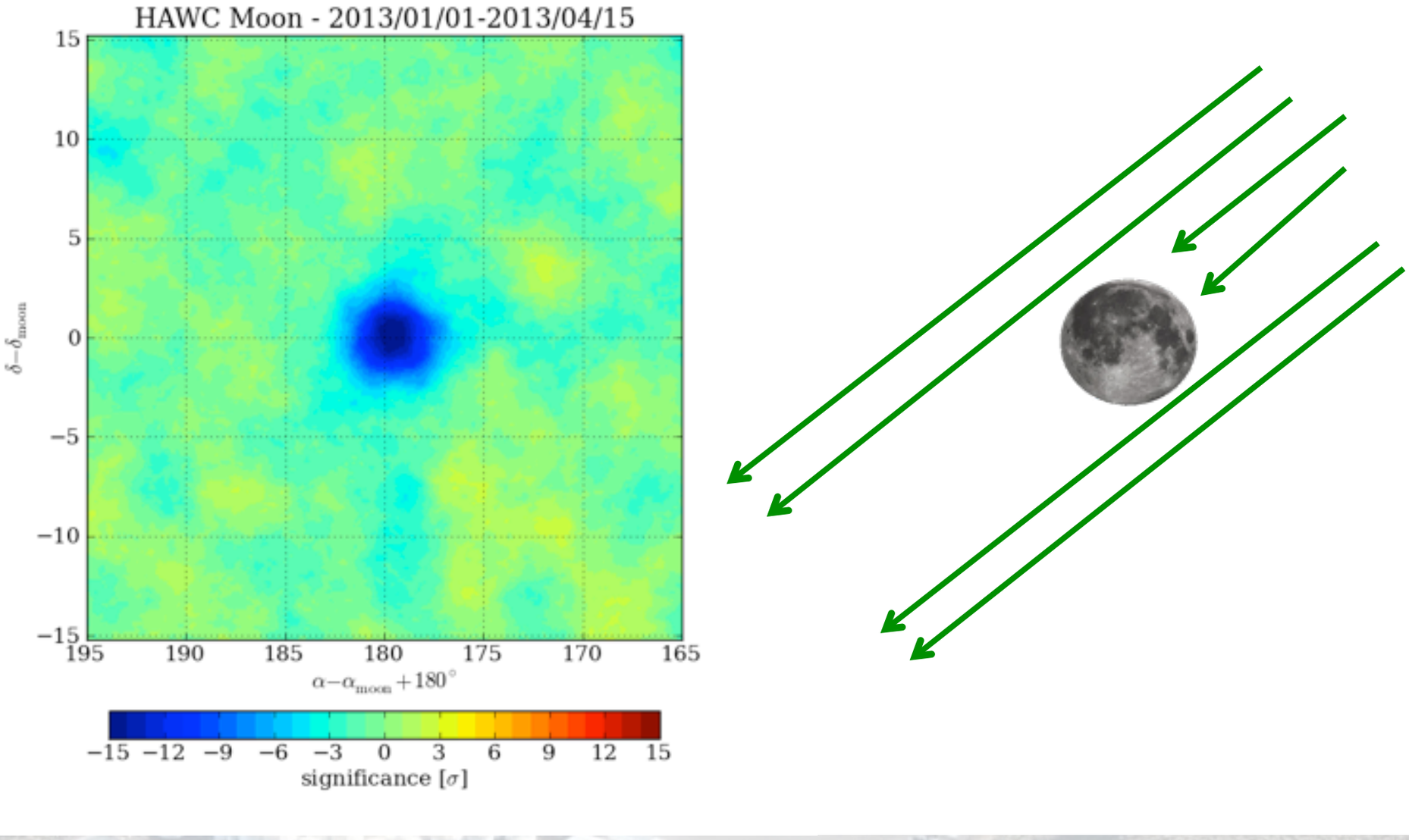


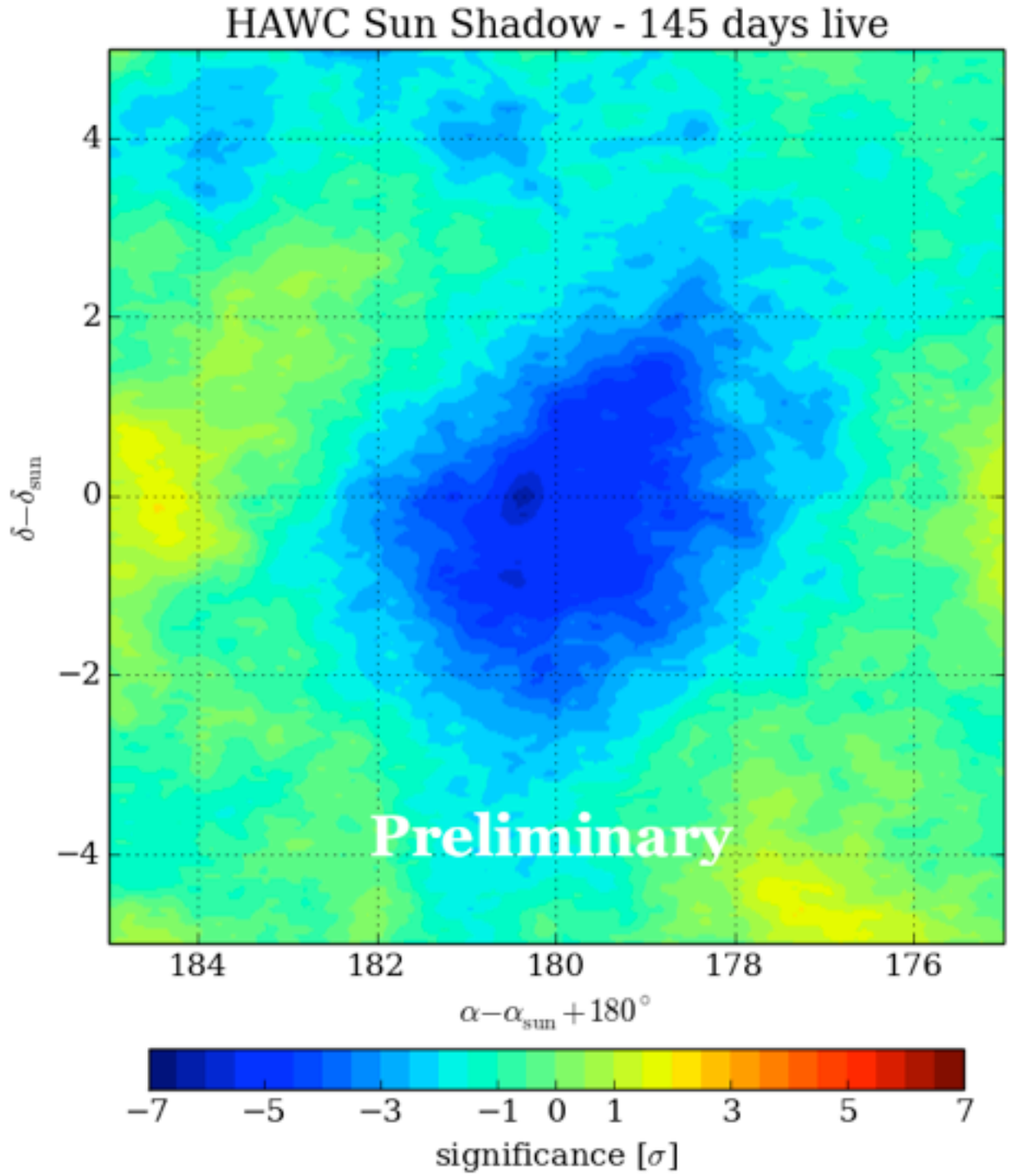


Moon Shadow



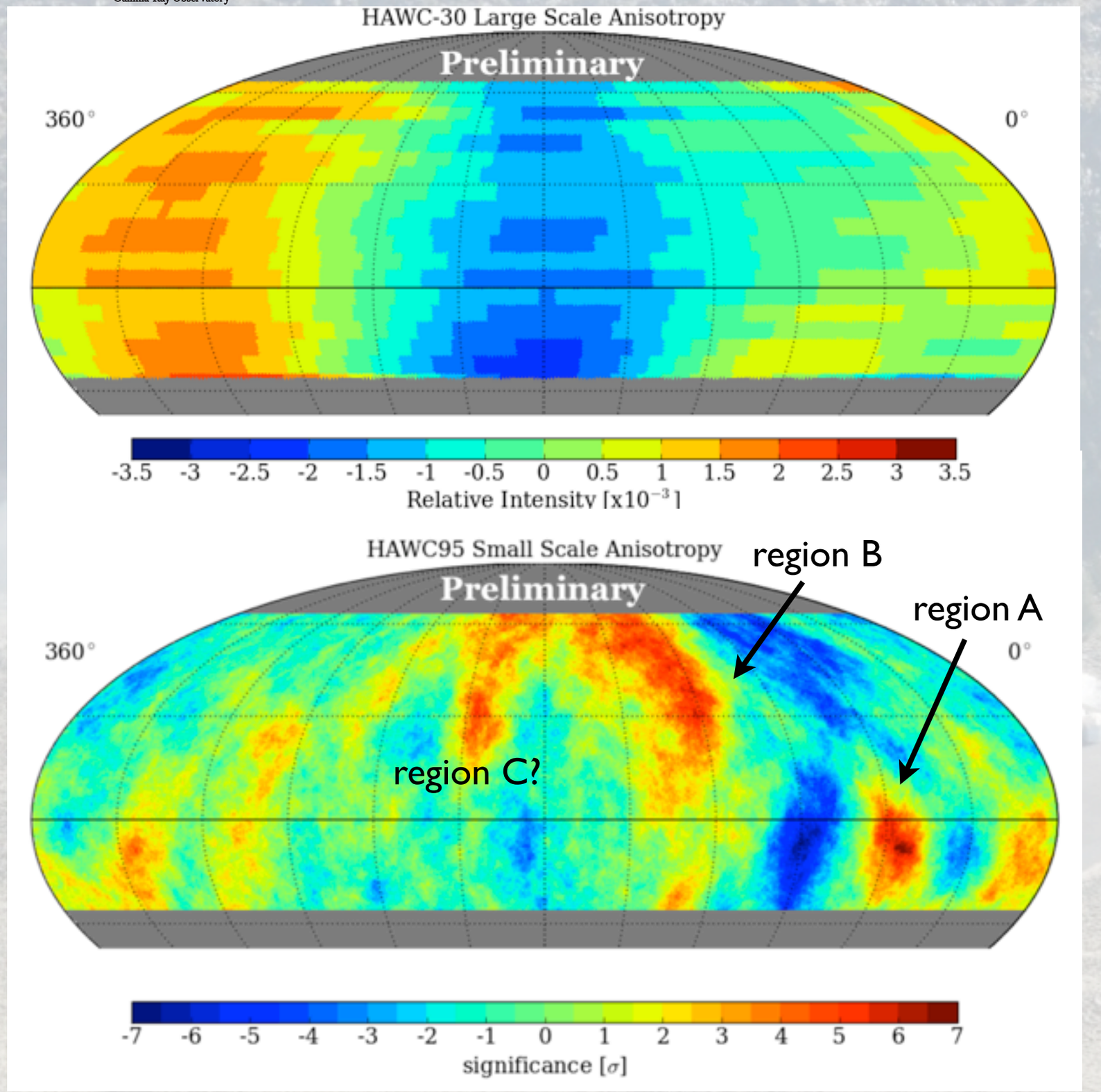
- The Moon & Sun block part of the cosmic-ray flux causing a shadow on Earth.
- Early HAWC data: 1 January - 15 April 2013. 95 live days.
- -15σ deficit, consistent with expectations.
- Position is consistent with geomagnetic deflection.
- End-to-end check for DAQ through reconstruction software and absolute pointing.

Sun Shadow



- Preliminary analysis.
- Modulated by magnetic field of the Sun.
- -6.4σ in 145 days livetime.
- Position is consistent with geomagnetic deflection.
- Amplitude is consistent with current solar cycle.
- Can be used to probe solar activity and solar magnetic field.

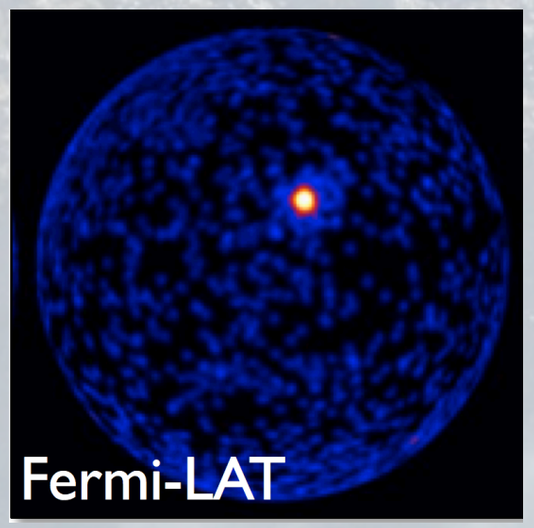
Cosmic-Ray Anisotropy



- Large-scale structure, confirming numerous observations.
- Few parts in 1×10^{-3} anisotropy
- Using the forward-backward technique (Abdo et al. 2009, ApJ, 698, 2121).

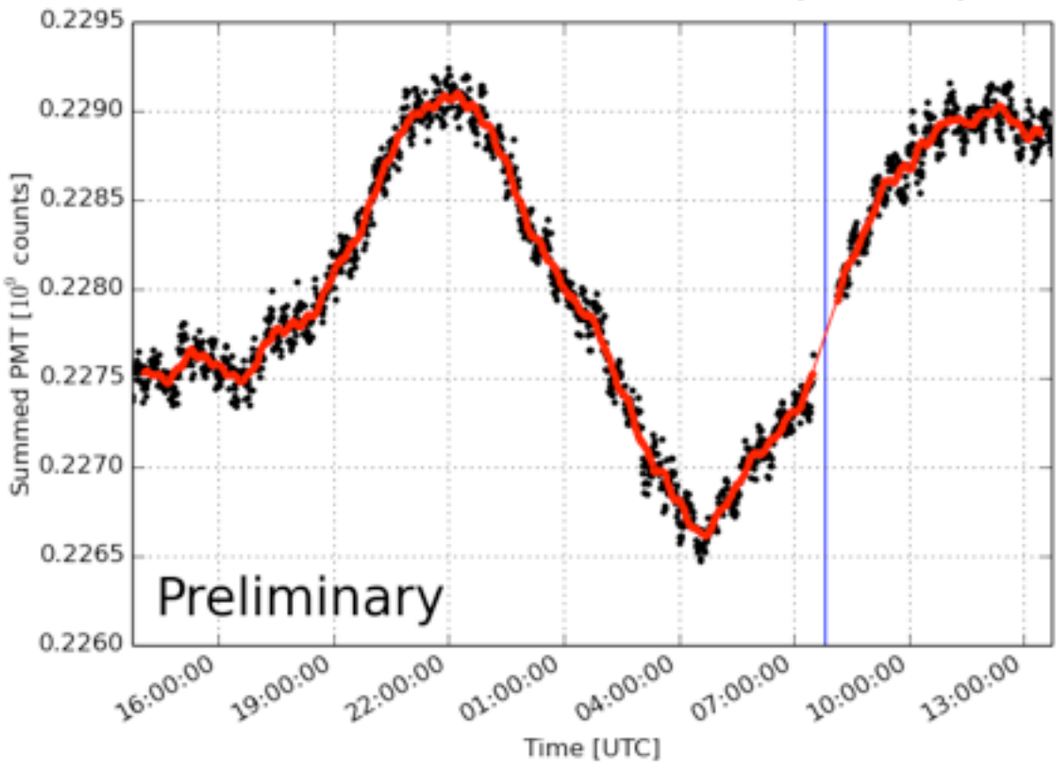
- Small-scale (10°) structure originally discovered by Milagro.
- 1 part in 5×10^{-4} anisotropy.
- One region coincident with heliotail.
- Nearby CR source with magnetic funneling?
- Geminga? (Salvati & Sacco, A&A 2008)
- Dark Matter Annihilation? (Harding, arXiv:1307.6537)

GRB 130427A

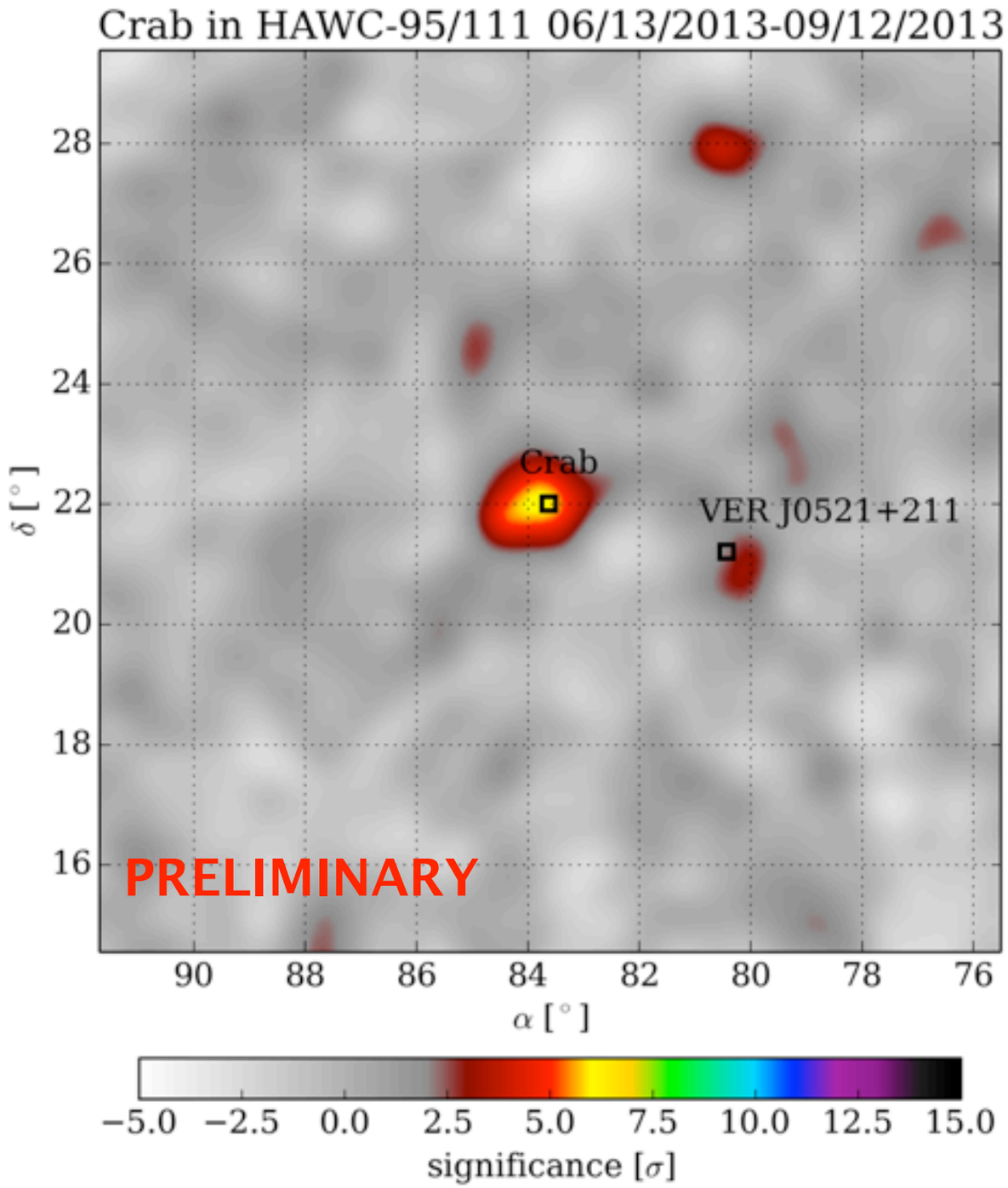


- Brightest GRB detected in 30 years (2×10^{-3} erg/cm^2).
- 94 GeV photon observed.
- Low redshift (z=0.34).
- 57° zenith angle and setting for HAWC.
- HAWC main DAQ was offline, PMT rates recorded by scaler DAQ.
- No excess found in 6 search windows (GCN circular 14549).
- Would be ~5σ if near zenith!

summed PMT rate and moving average



Crab Nebula: First Look

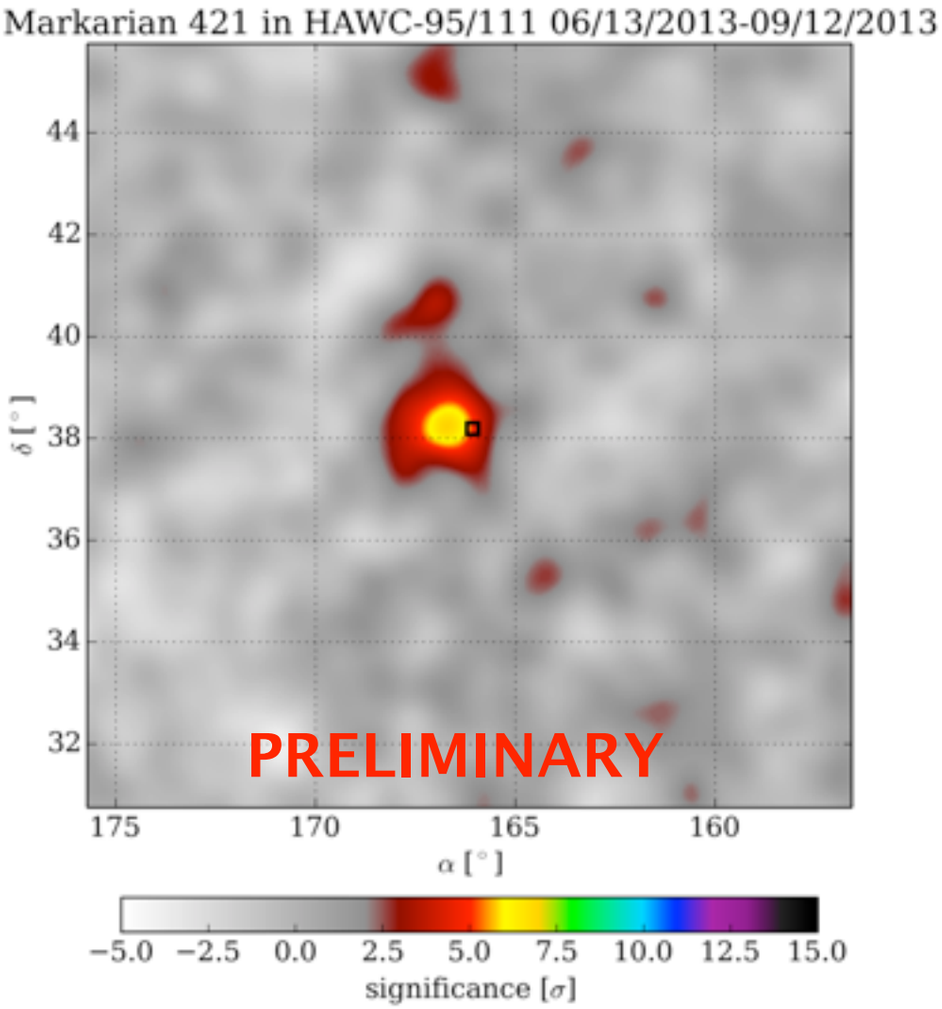


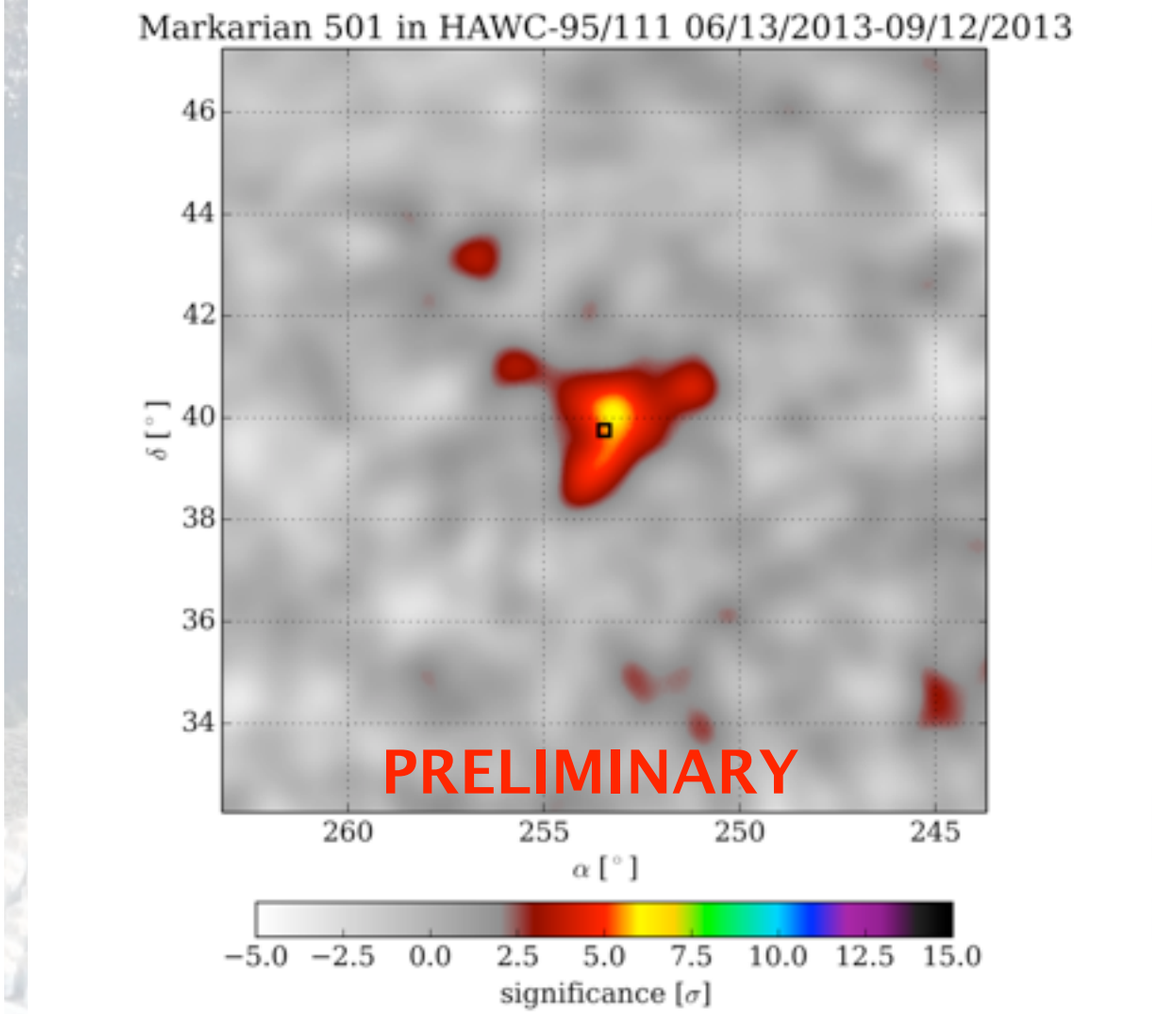
- Crab (Dec +22 deg) transits near zenith and is observed 5-6 hr per day.
- ~2.5 months of HAWC-95 and HAWC-111 exposure over a 3-month period.
- ~6σ at the Crab position.

Caveats:

- Absolute pointing uncertainties.
- Very preliminary calibration.
- Subset of the data reconstructed "online".
- Many small analysis issues TBD yet.

AGN: Mrk 421 and Mrk 501





- Mrk 421: 5.4σ at the source position.
- Mrk 501: 5.5σ at the source location.
- Time dependence under analysis.

Caveats:

- Absolute pointing uncertainties.
- Very preliminary calibration.
- Subset of the data reconstructed "online".
- Many small analysis issues TBD yet.

Summary

- HAWC is a new instrument for multi-TeV astronomy and astrophysics.
- Wide field-of-view: detect rare extremely high-energy photons and continuously monitor the sky for transients.
- Early data analysis underway:
  - Confirmed shadow of the Sun and the Moon.
  - Confirmed cosmic-ray anisotropy.
  - Evidence of gamma rays from the Crab Nebula, Mrk 421, and Mrk 501.
  - Clear signal from the Galactic plane. Analysis underway.
- Full detector to be completed in ~1 year.
- Transient alerts soon.