On Pulsar Wind Nebulae, Supernova Remnants, and Unidentified sources: HAWC observations of the Galactic Plane

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Cosmic Rays, Pulsars & Dark Matter
Santa Fe 2017 Feb 28 — Mar 3

Gamma-Ray Astrophysics

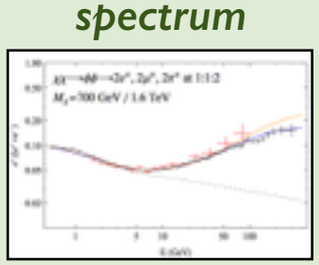
Astrophysics

SNRs, Pulsars, *Binaries*, etc.

AGN Flares

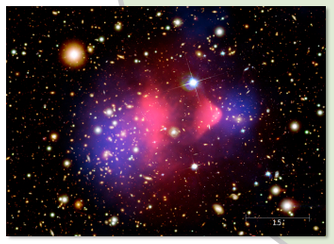
Dark Matter

Cosmic electron spectrum



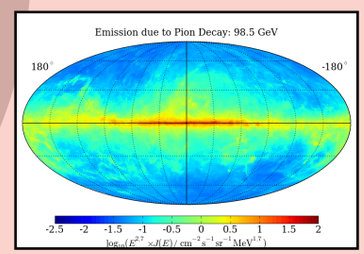
e^+/e^- ratio

Indirect DM Searches

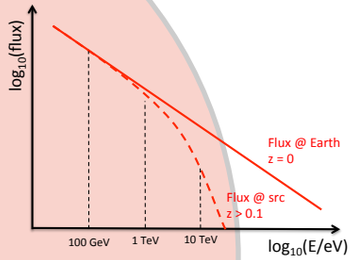


Cosmology

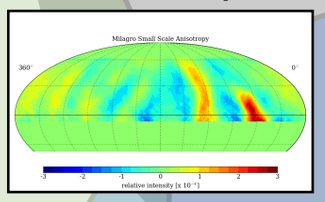
Diffuse Emission



Extragalactic Background Light (IR)

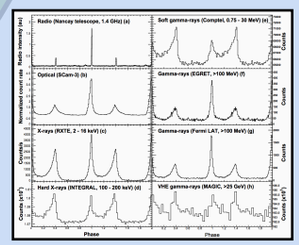


Cosmic Rays



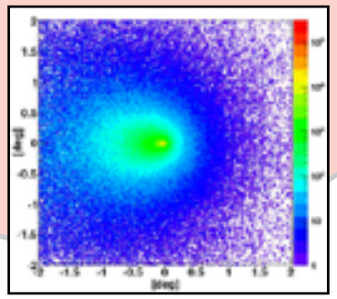
GRBs

Lorentz Invariance Violation



Exotic Particles

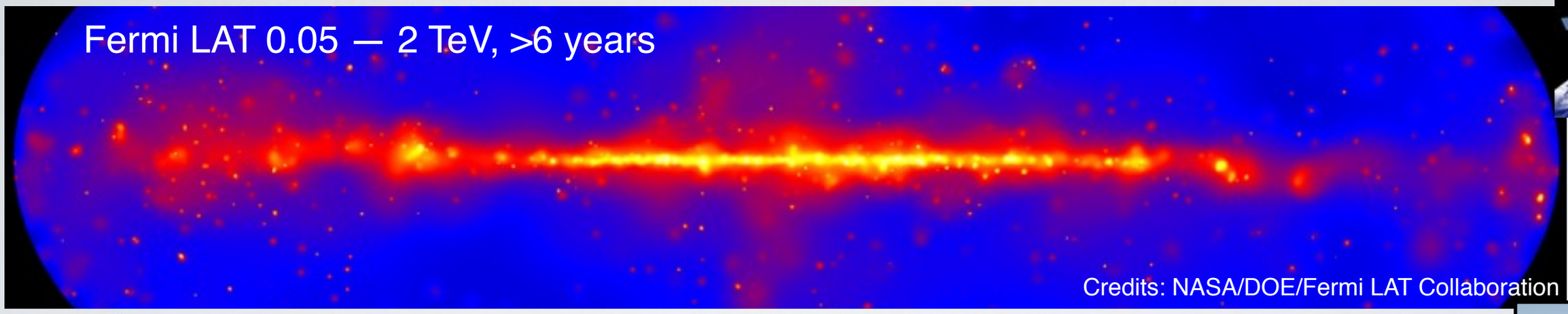
Intergalactic Magnetic Fields



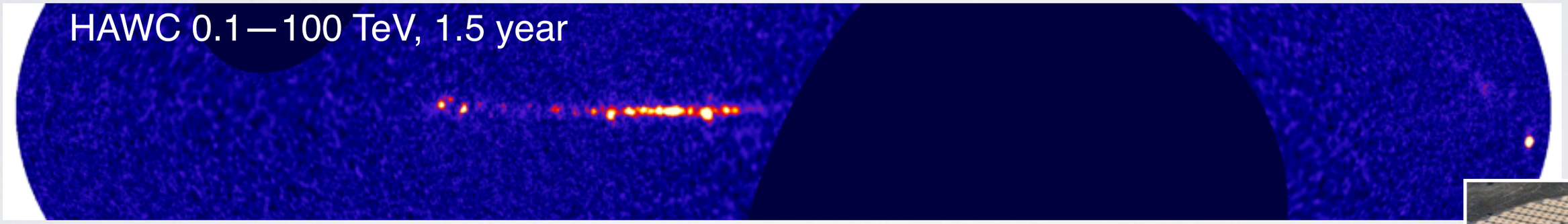
Monopoles, Axions, Q-balls, etc.

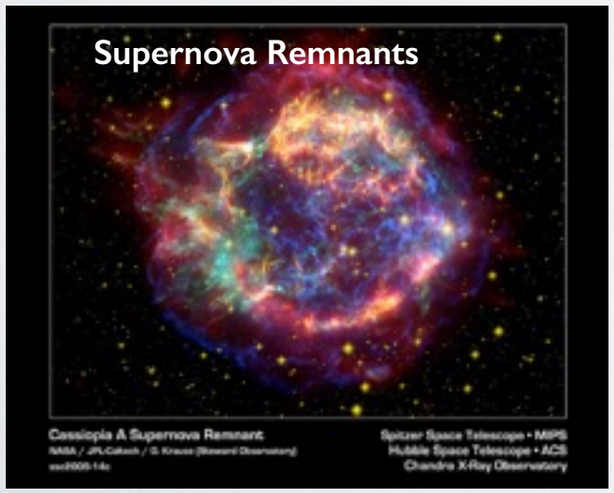
Fundamental Physics

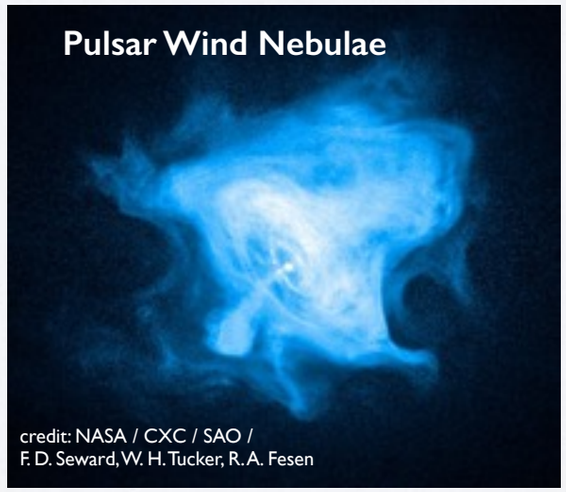
High Energy View of our Galaxy

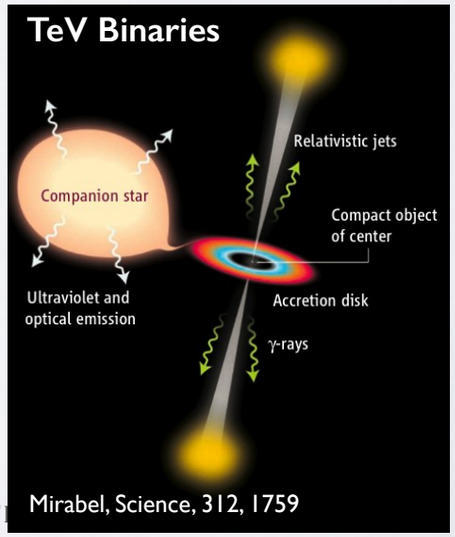


HESS >1TeV, 10 years





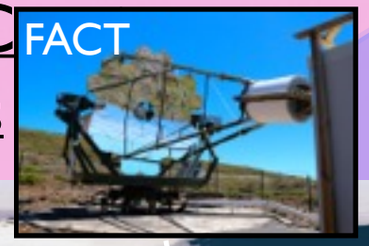




Gamma-Ray Detectors

Wide Field of View, C
Operations

ensitivity



MAGIC
VERITAS

Mapping the Northern Sky in High-Energy Gamma Rays

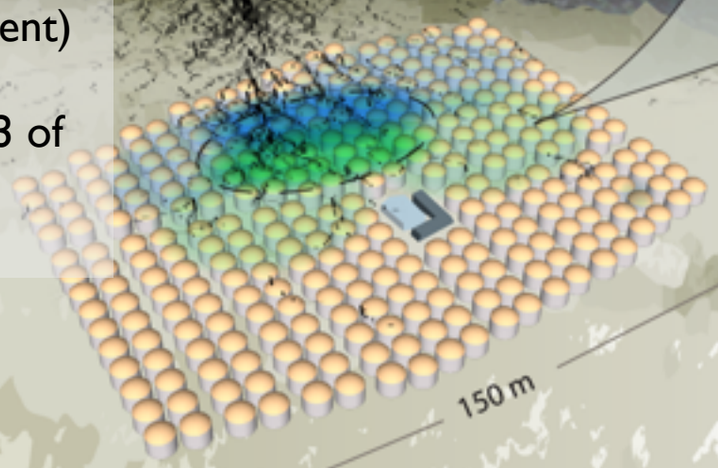
HAWC Observatory

HAWC operates day and night, providing a large field of view for the observation of the highest energy gamma rays.

Pico de Orizaba
(5,626 m)

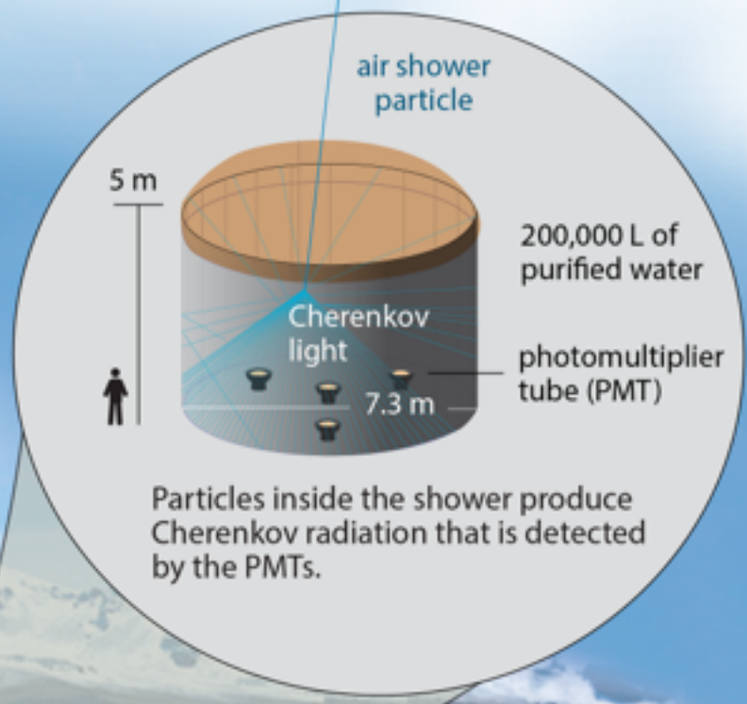
- Sensitive from 100 GeV to 100 TeV.
- Angular resolution (68% containment) 0.2-1.0 degrees.
- 2 sr instantaneous field of view, 2/3 of sky each day.
- >90% duty cycle.

HAWC is located at 4,100 m above sea level, covering an area of 20,000 m².



Water Cherenkov tank

HAWC comprises an array of 300 tanks that record the particles created in gamma-ray and cosmic-ray showers.

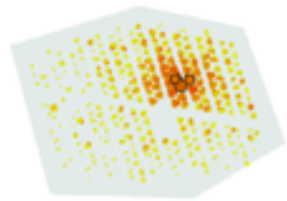


Particles inside the shower produce Cherenkov radiation that is detected by the PMTs.

Gamma rays vs cosmic rays

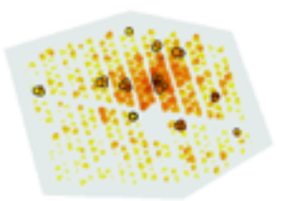
HAWC selects gamma rays from among a much more abundant background of cosmic rays.

gamma-ray shower



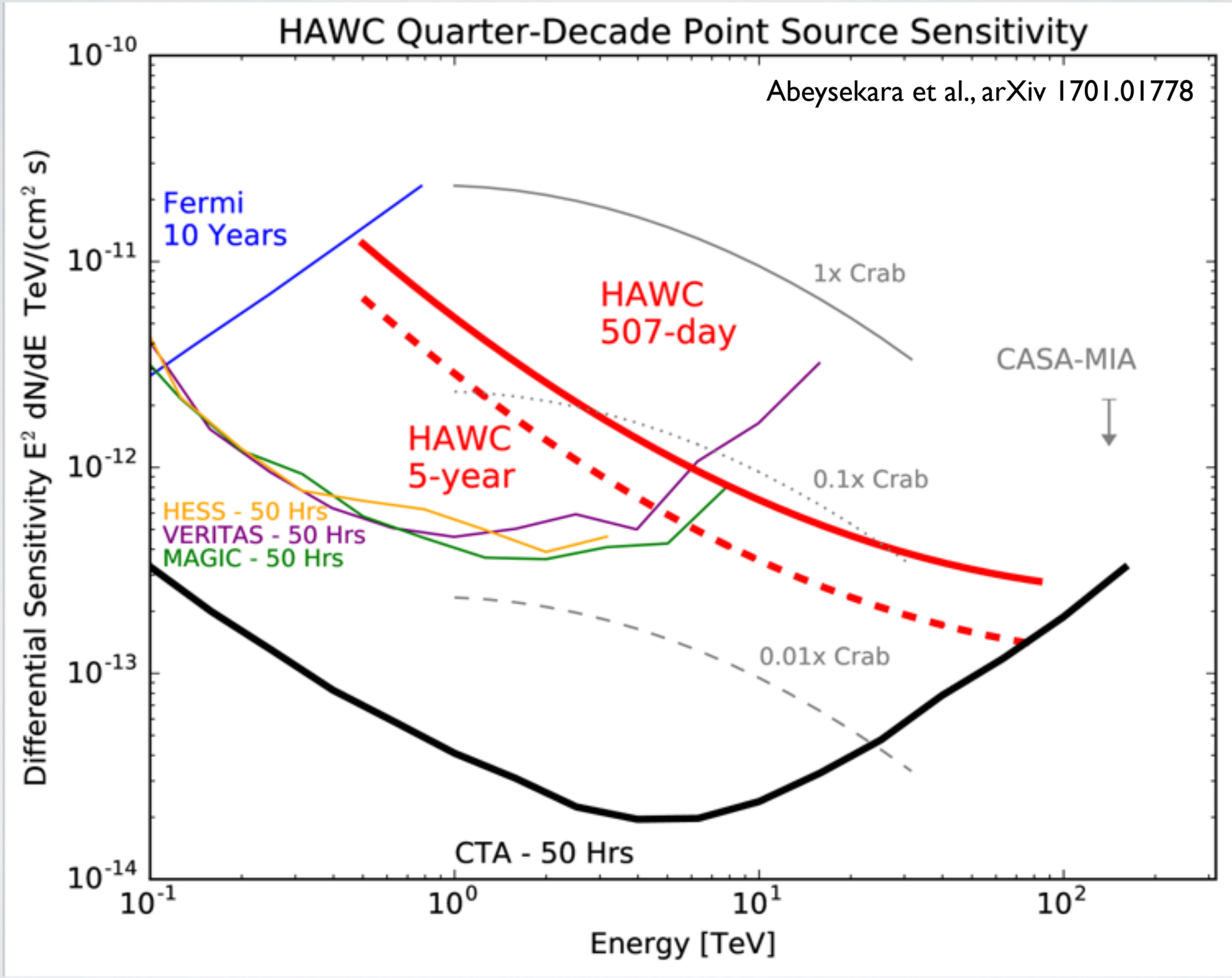
"hot" spots concentrate around the core

cosmic-ray shower



"hot" spots are more dispersed

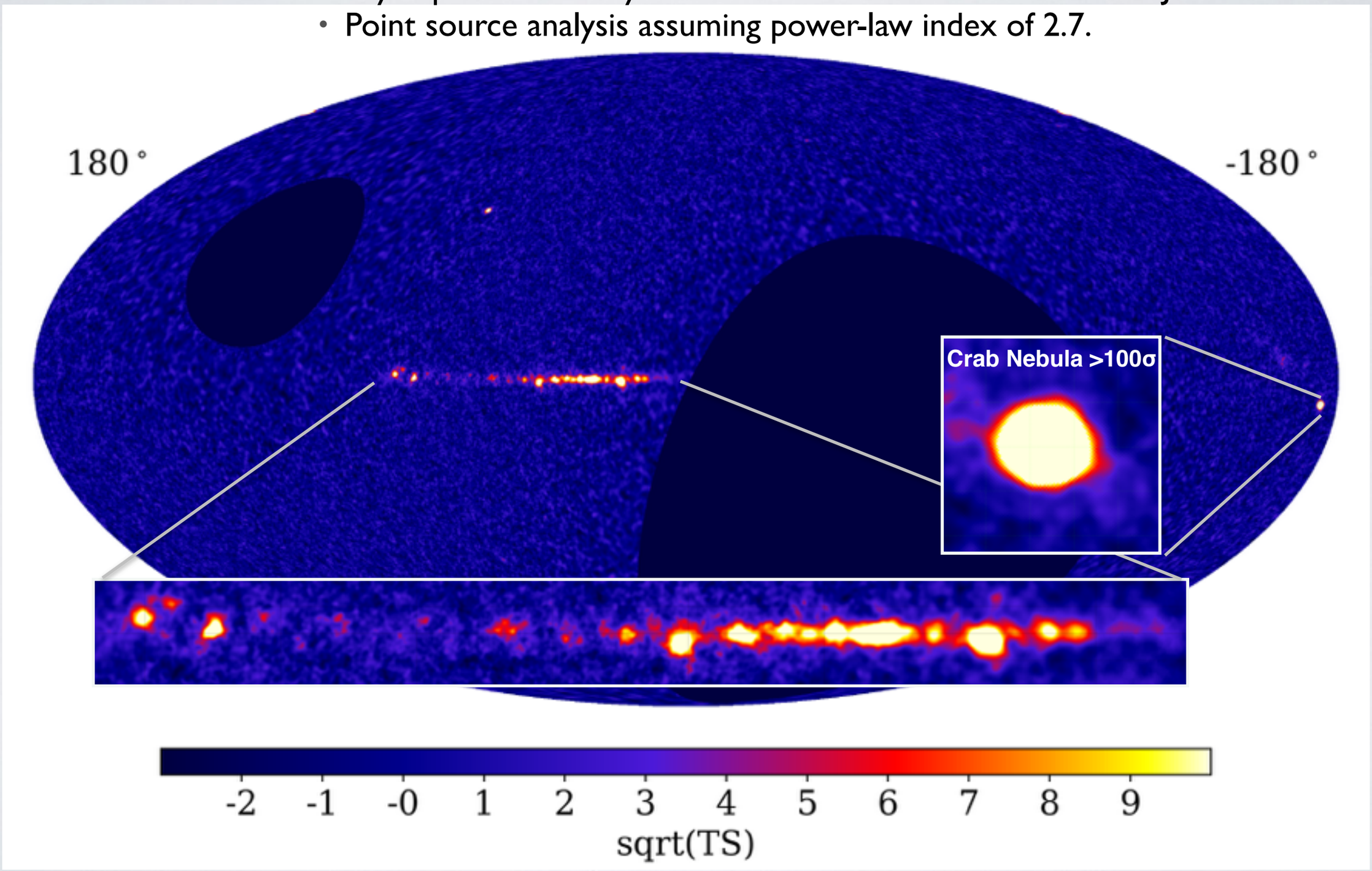
HAWC Sensitivity



HAWC TeV Sky Survey

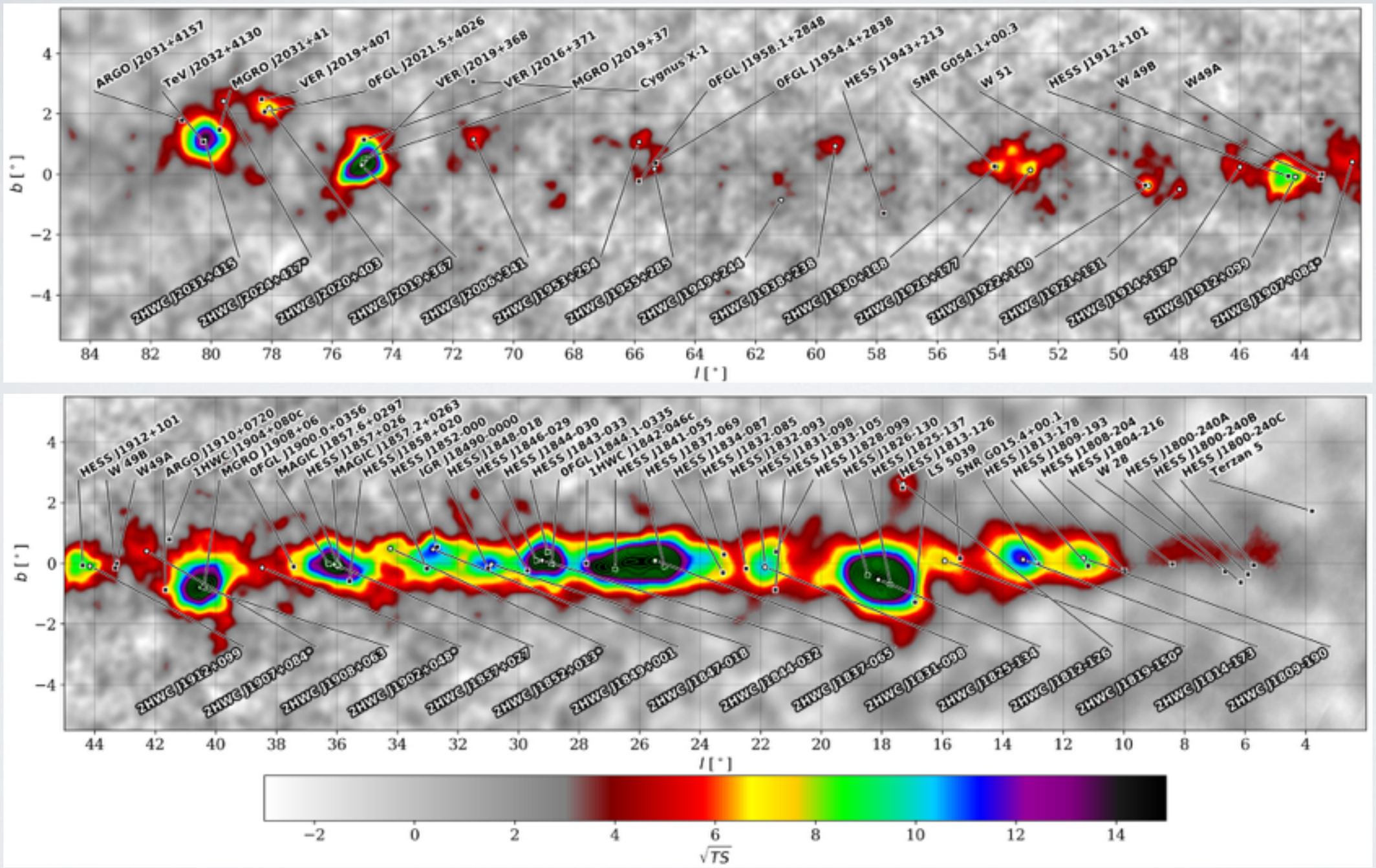
Abeysekara et al., arXiv 1702.02992

- Most sensitive wide-field survey in TeV.
- Skymap from 507 days of data taken between Nov 2014 to Jun 2016.
- Point source analysis assuming power-law index of 2.7.



Galactic Plane

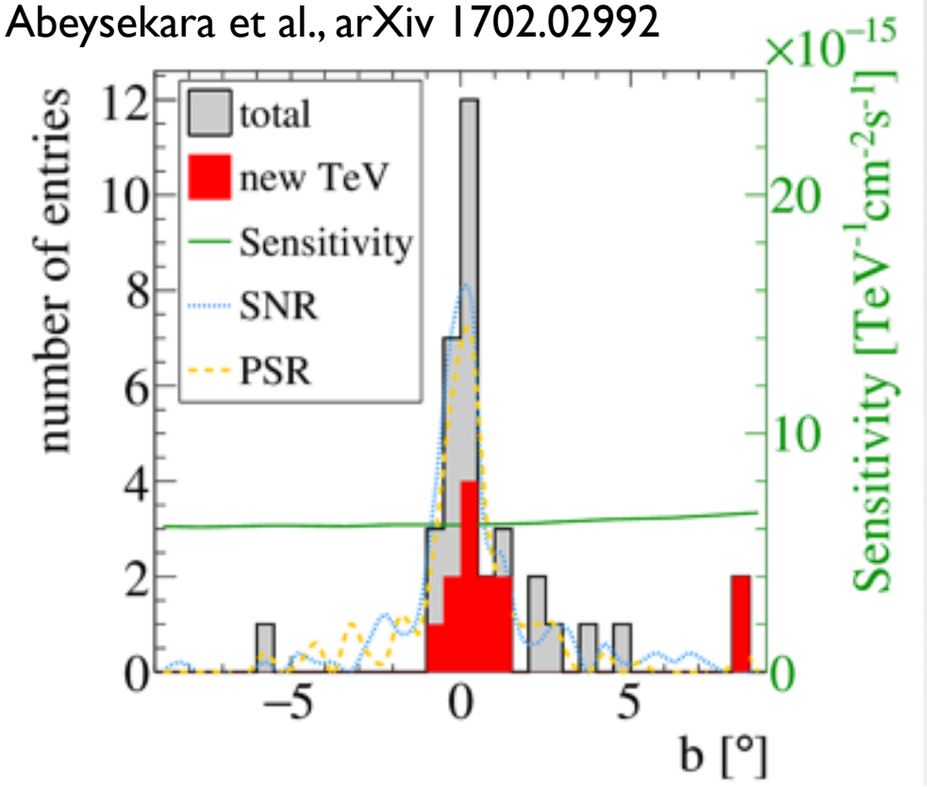
Abeysekara et al., arXiv 1702.02992

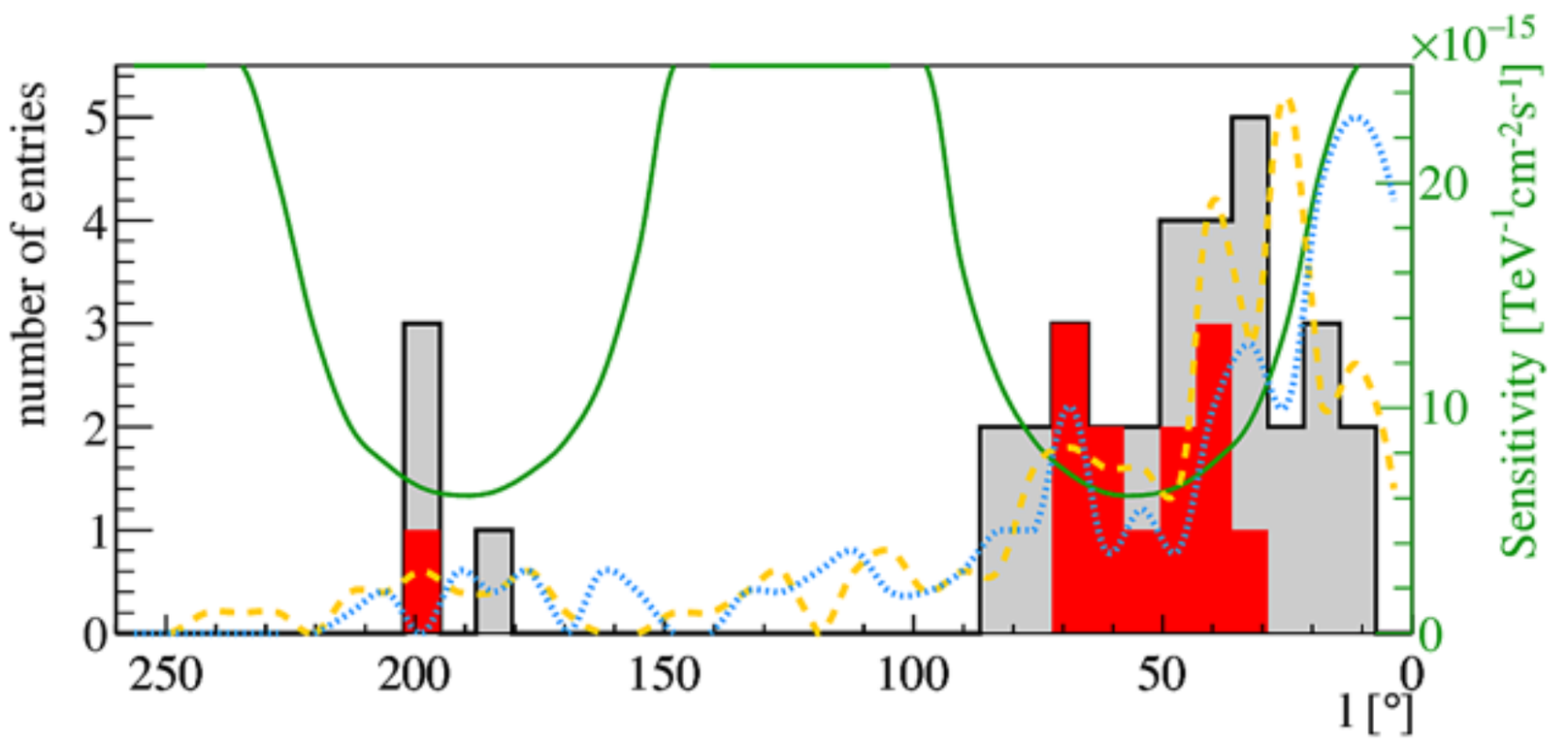


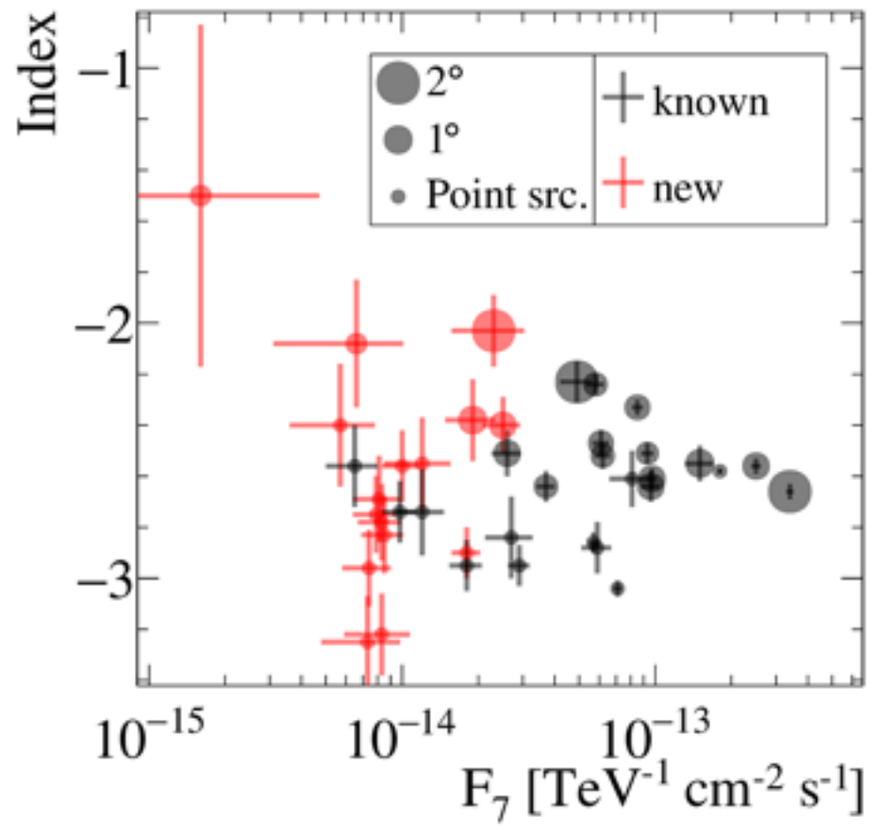
- 30 sources in the Galactic Plane
  - 19 are associated with known TeV sources

Galactic Plane Source Distribution

Abeysekara et al., arXiv 1702.02992







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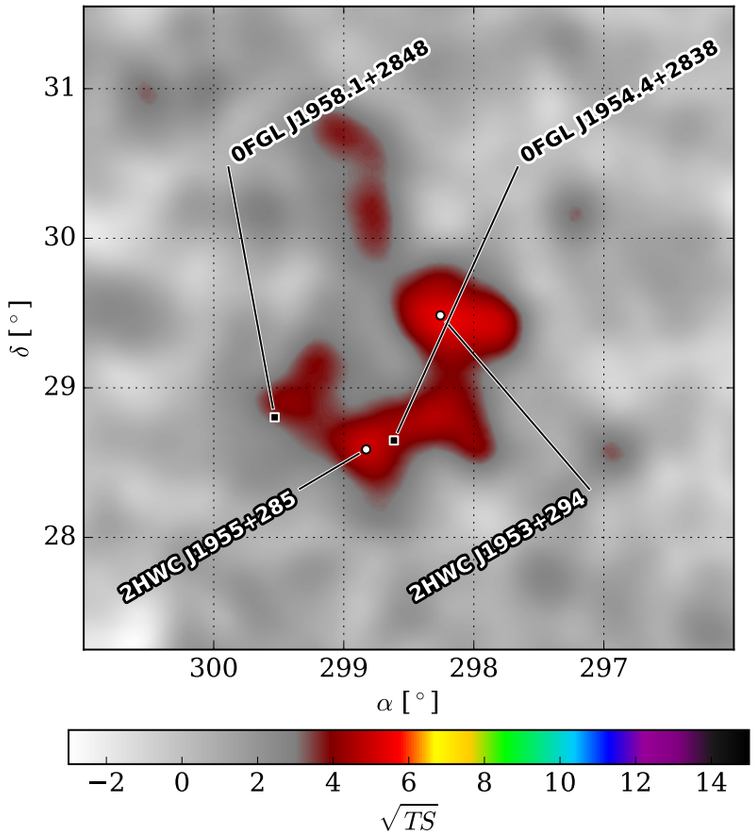
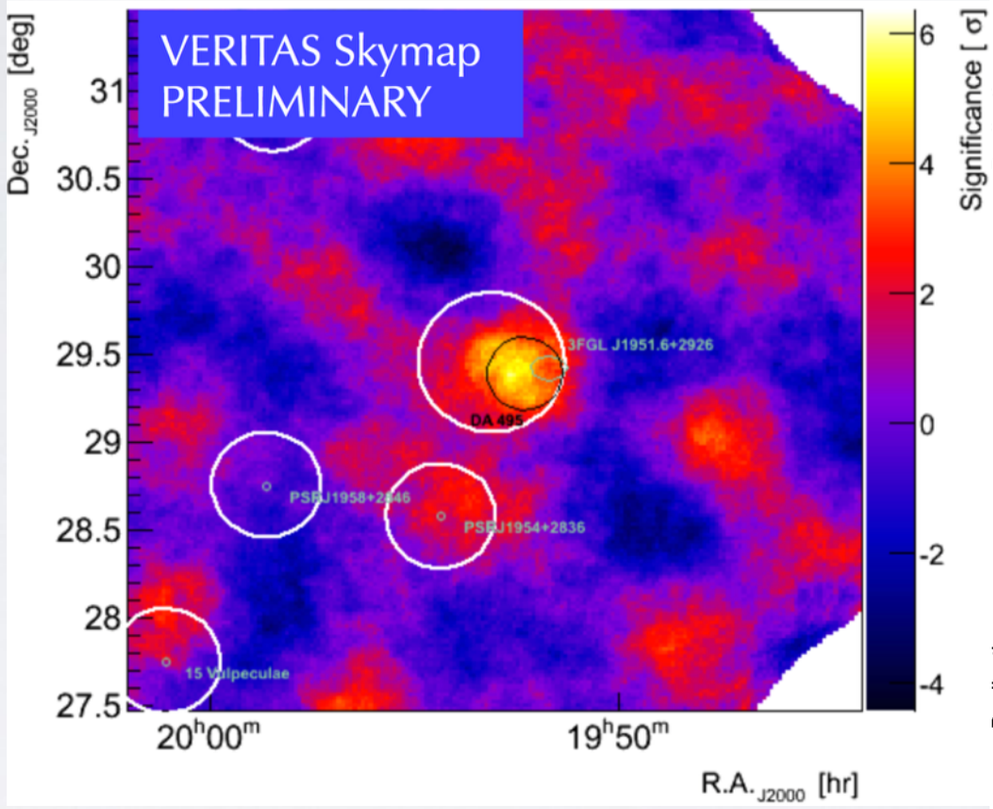
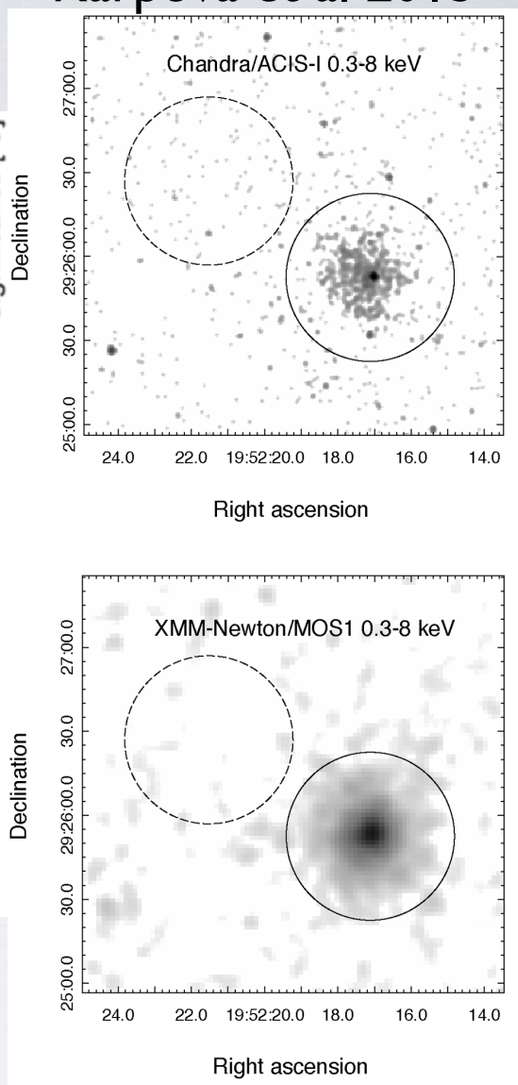
New TeV Sources!

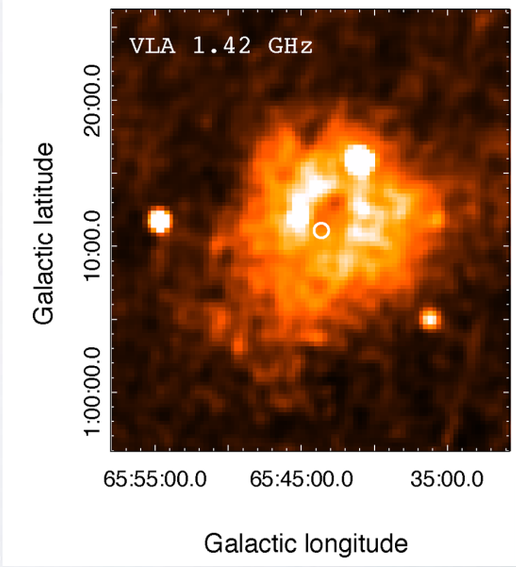
Abeysekara et al., arXiv 1702.02992





Karpova et al 2015



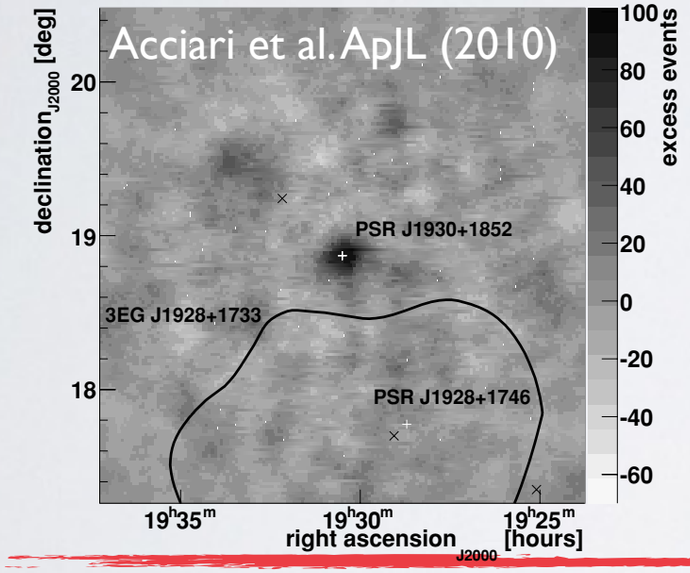


New TeV source
2HWC J1953+294
- confirmed by VERITAS, announced in Gamma16
- potential association:
  - PWN DA 495 seen in X-rays
  - 3FGL J1951.6+2926

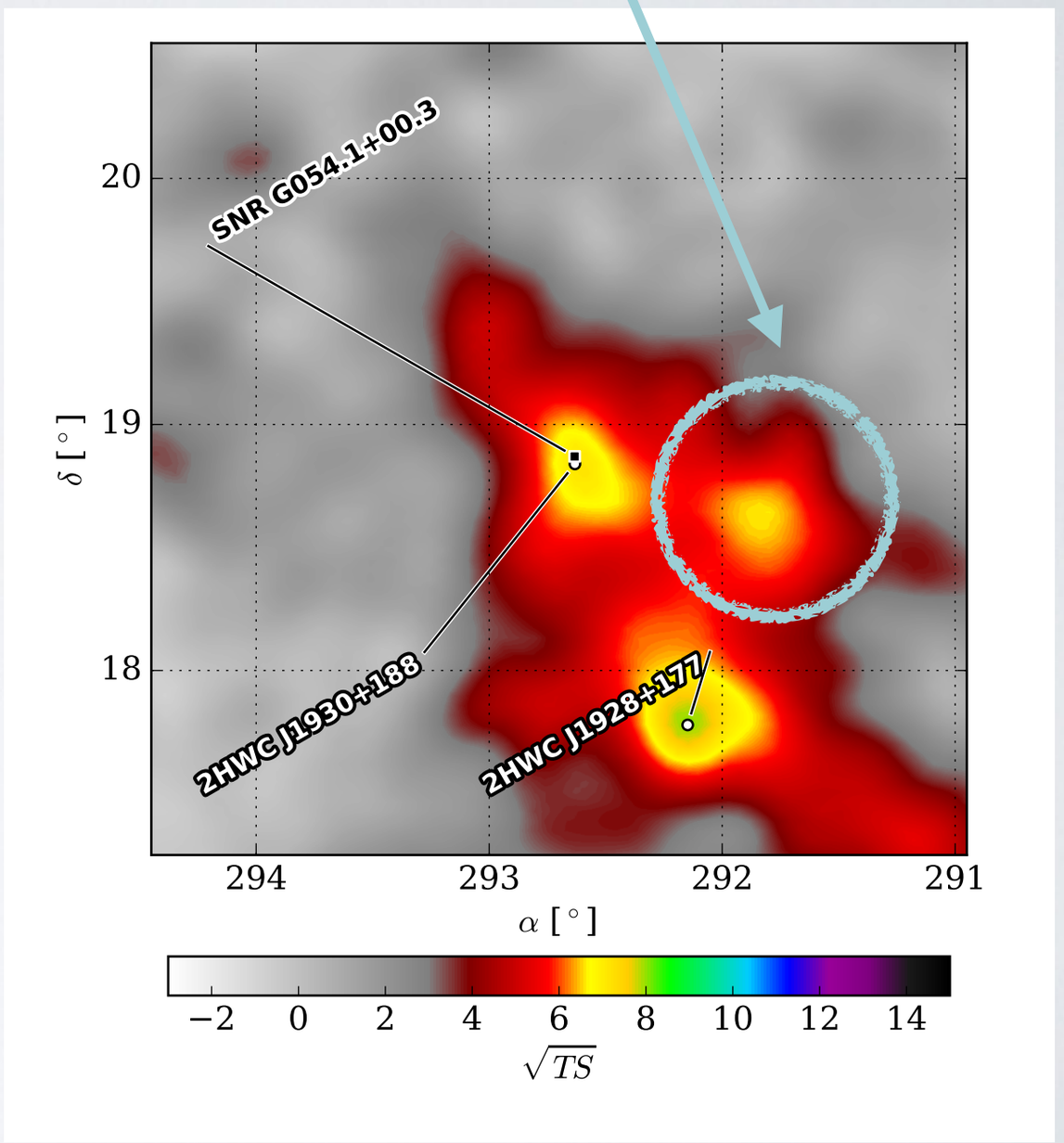
New TeV Sources!

Abeysekara et al., arXiv 1702.02992

2HWC J1930+188
- coincident with VER J1930+188 (SNR G54.1+00.3 / PSR J1930+1852)
- TeV emission was reported to be point-like and likely from PWN
- nearby molecular CO cloud



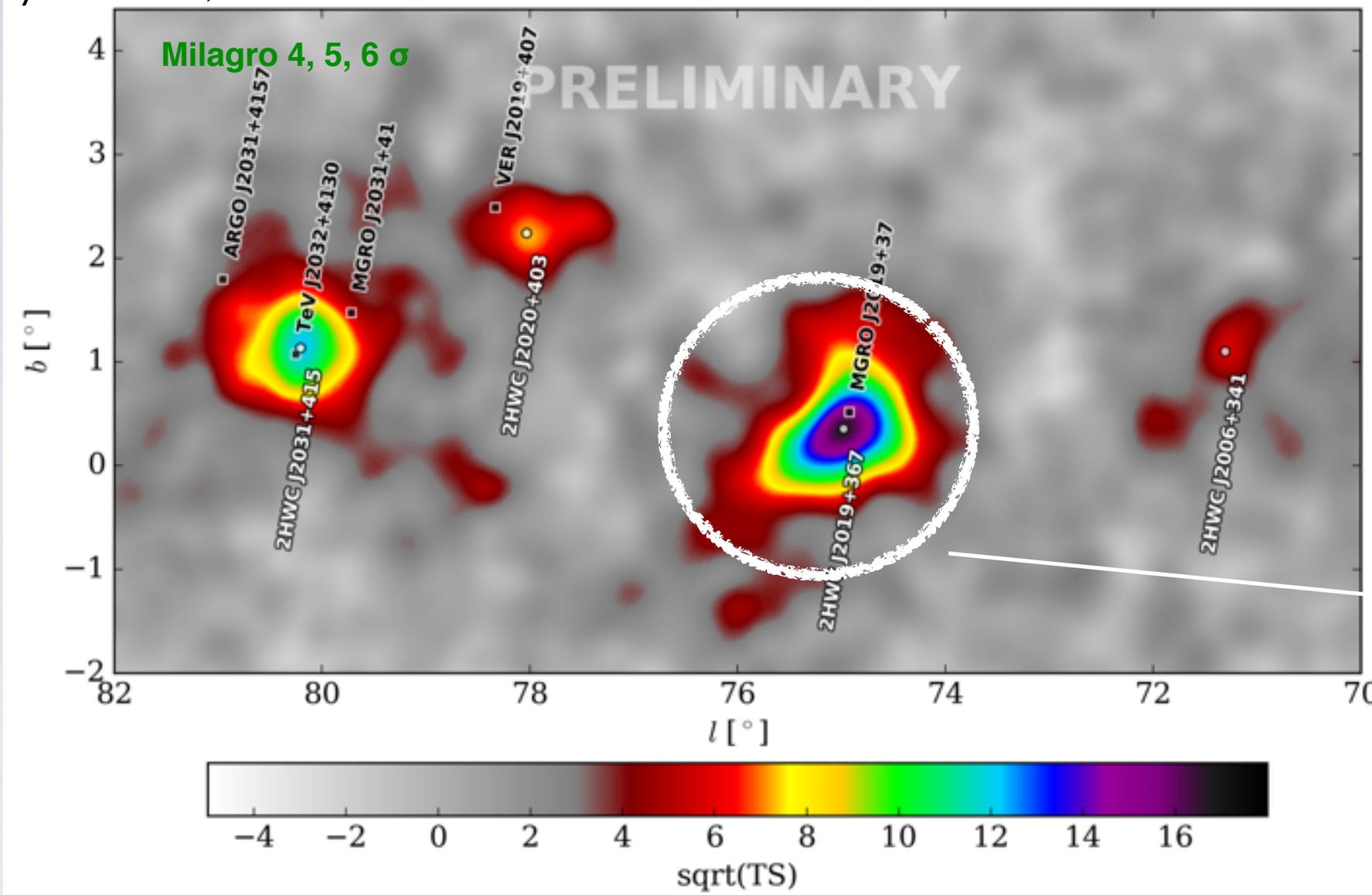
Extended TeV emission region
- several nearby pulsars



New TeV source
2HWC J1928+177
- coincident with PSR J1928+1746
- tail towards unidentified source 3FGL J1925.4+1727
- VERITAS point source upper limit ~1.4% of Crab

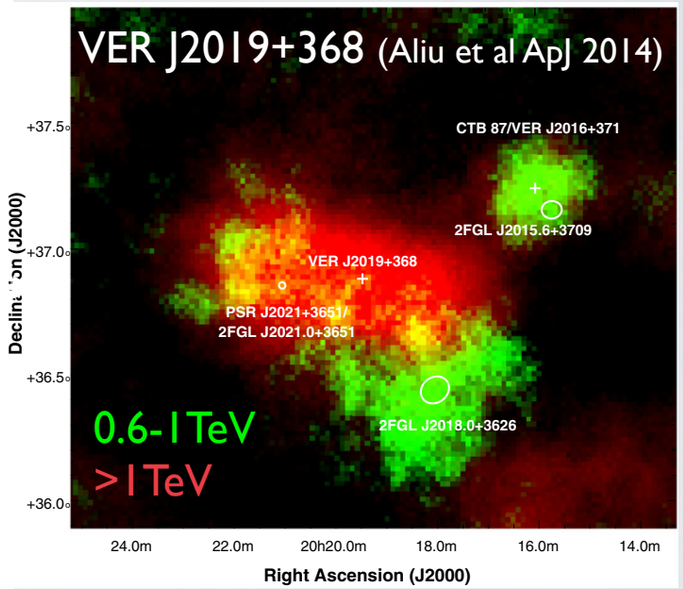
Cygnus Region

Abeysekara et al., arXiv 1702.02992



New TeV source
2HWCJ2006+340:

- >6σ pre-trials
- 0.6° from unidentified source 3FGL J2004.4+3338

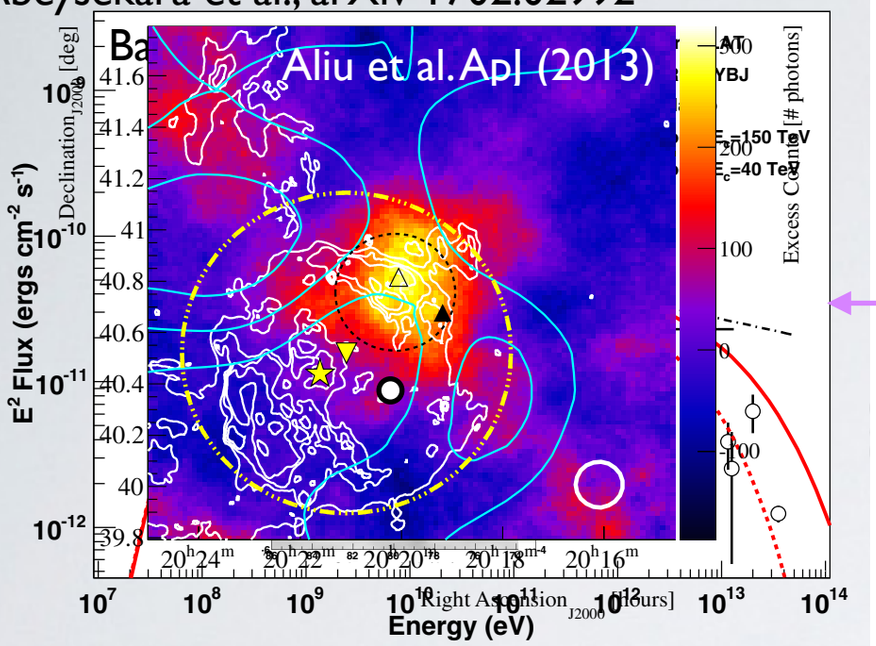


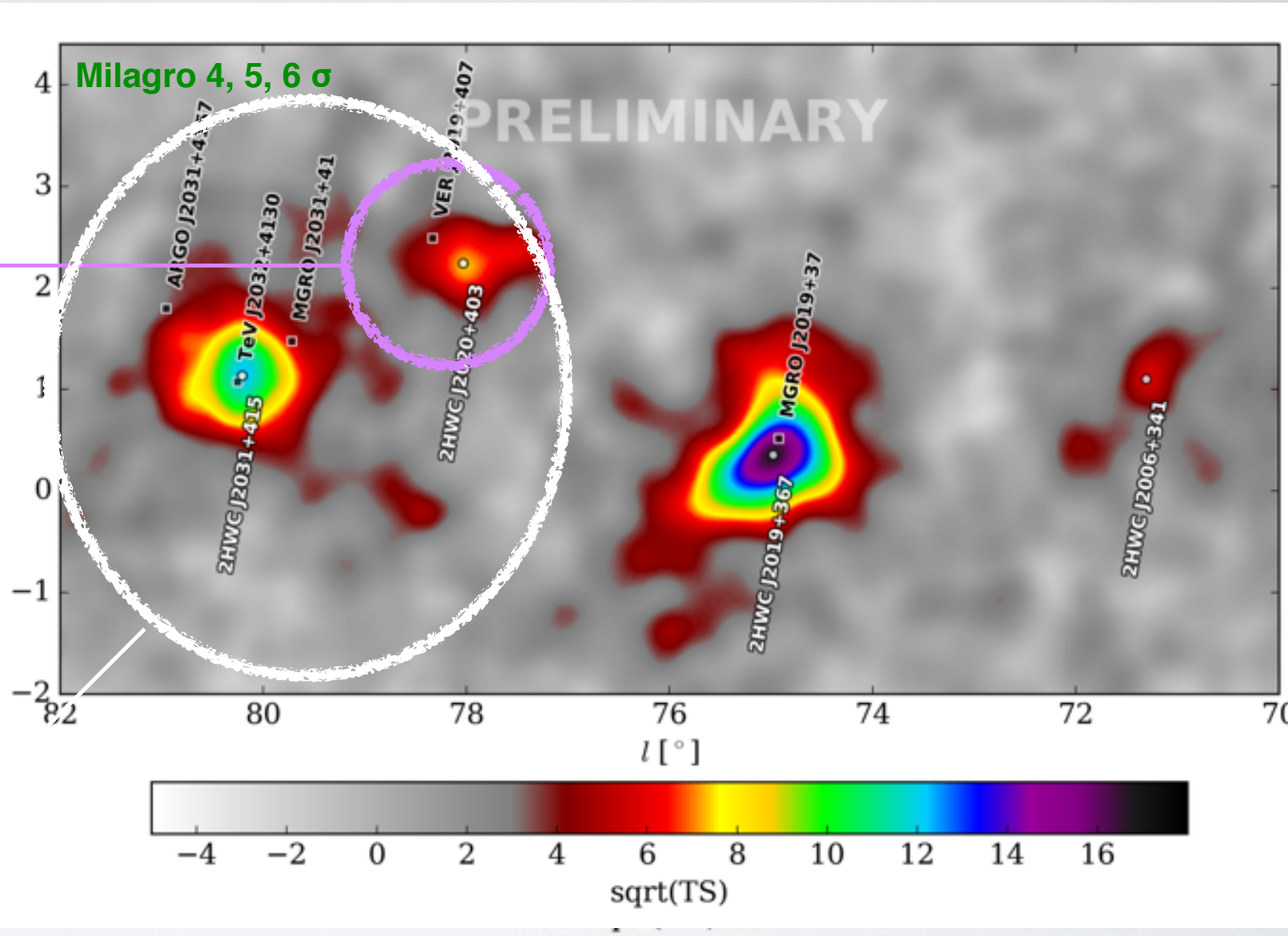
2HWC J2019+368 is coincident with MGRO J2019+37 and VER J2019+368

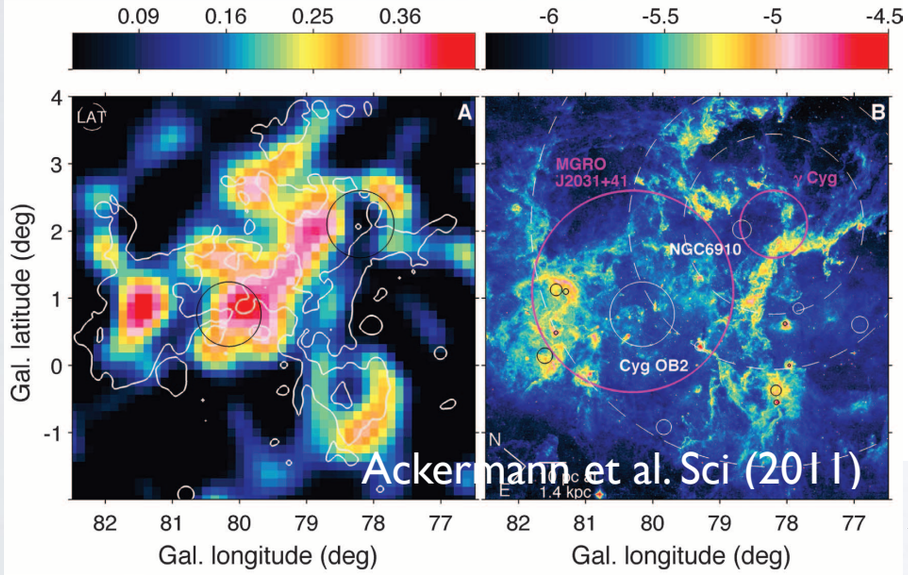
- extended emission including PSR J2021+3651 and HII region Sh 2-104

Cygnus Region

Abeysekara et al., arXiv 1702.02992







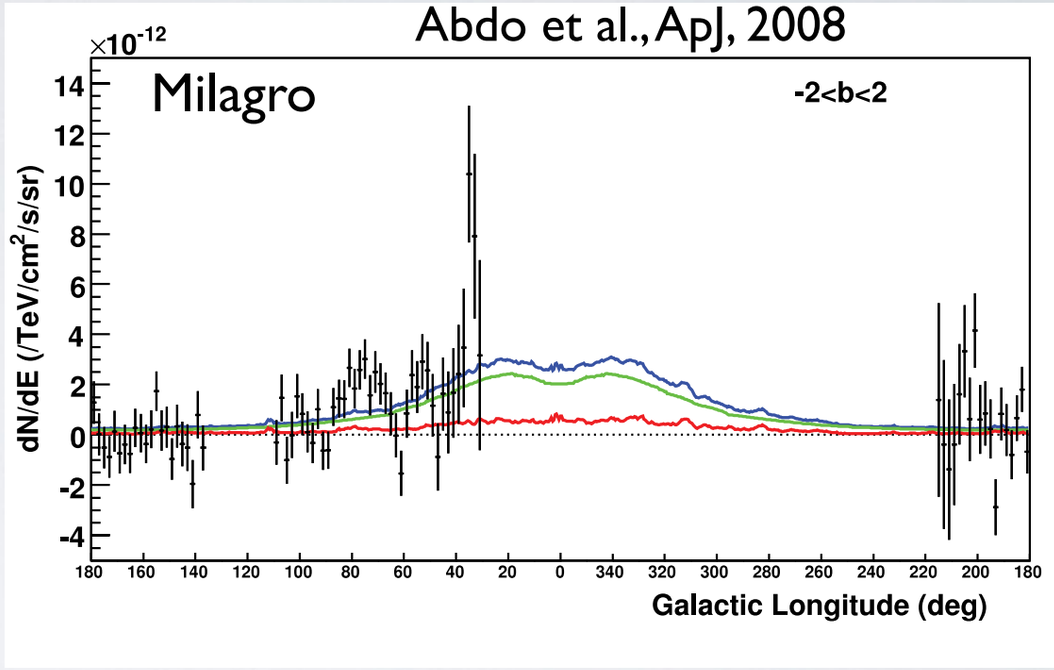
two distinct TeV sources:

- 2HWC J2031+415 — TeV J2032+4130, a PWN
- 2HWC J2020+403 — VER J2019+407, UID encompassing SNR G78.2+2.1 and PSR J2021+4026
- extended emission region 2HWC J2025+410* and 2HWC J2027+403* at Fermi cocoon / ARGO superbubble region

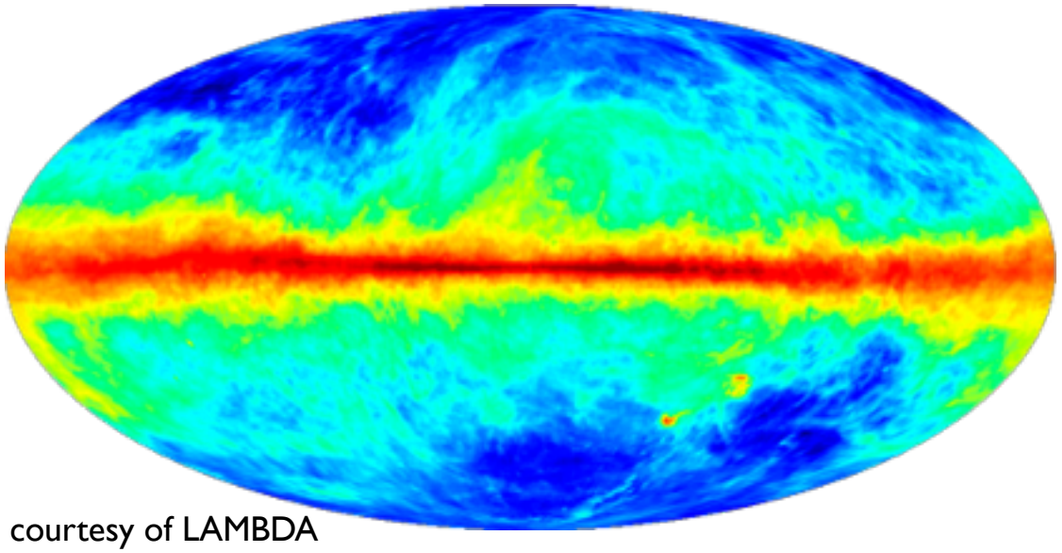
Galactic Diffuse Emission

Diffuse contributions:

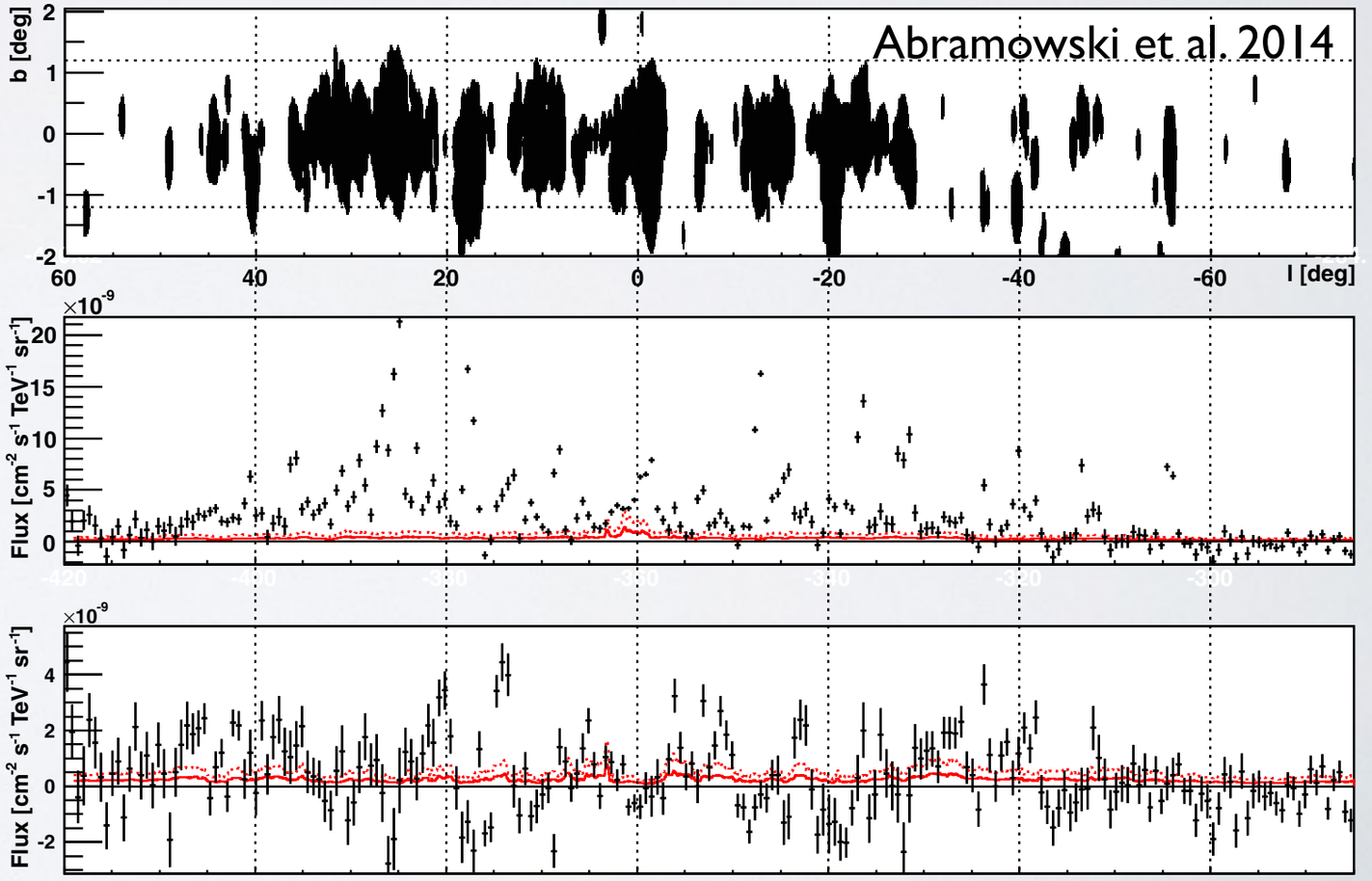
- Cosmic-ray interactions
  - molecular clouds
  - interstellar gas
- Inverse Compton
- Unresolved sources



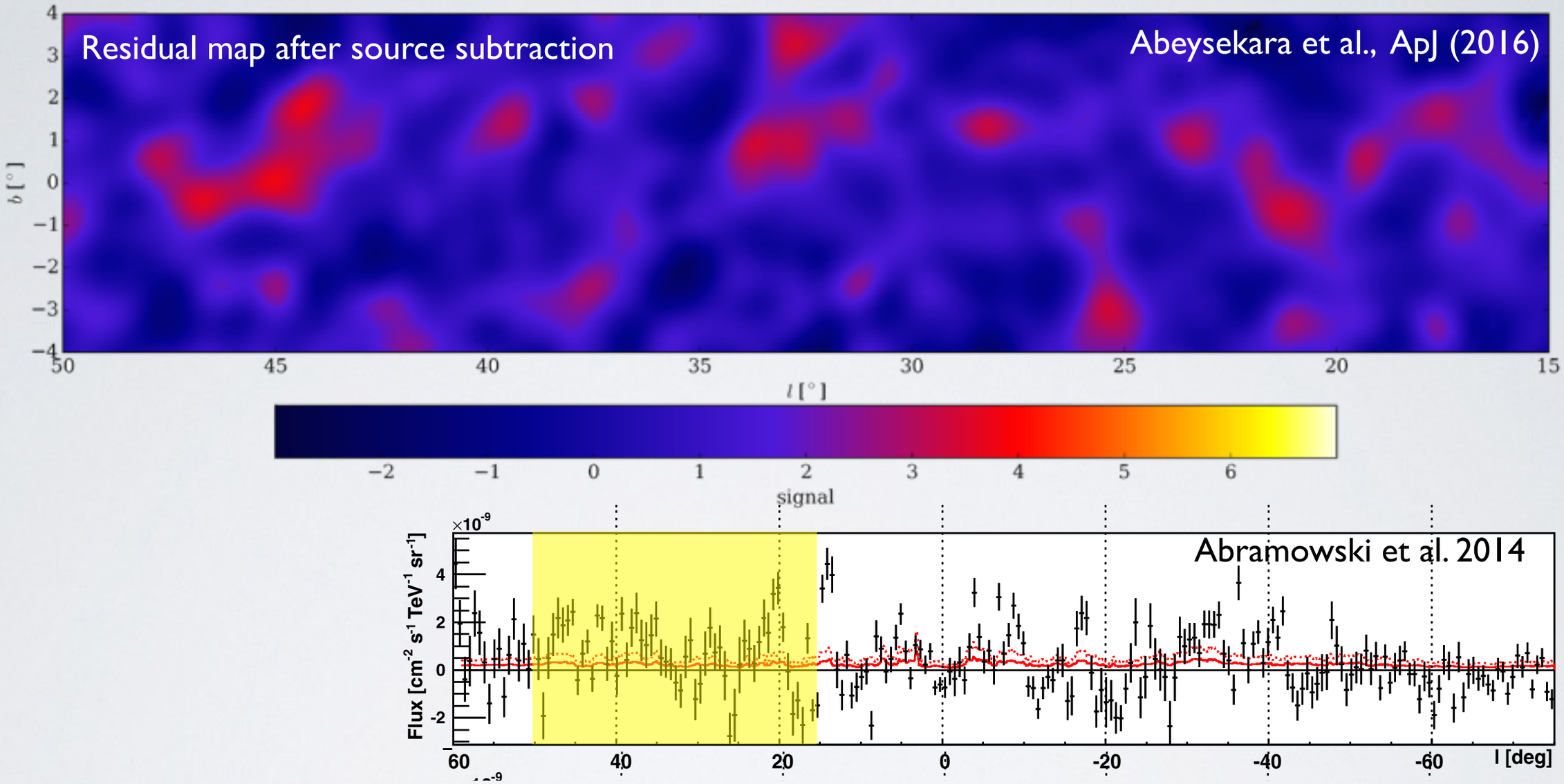
Leiden/Argentine/Bonn (LAB) Survey of Galactic HI



courtesy of LAMBDA



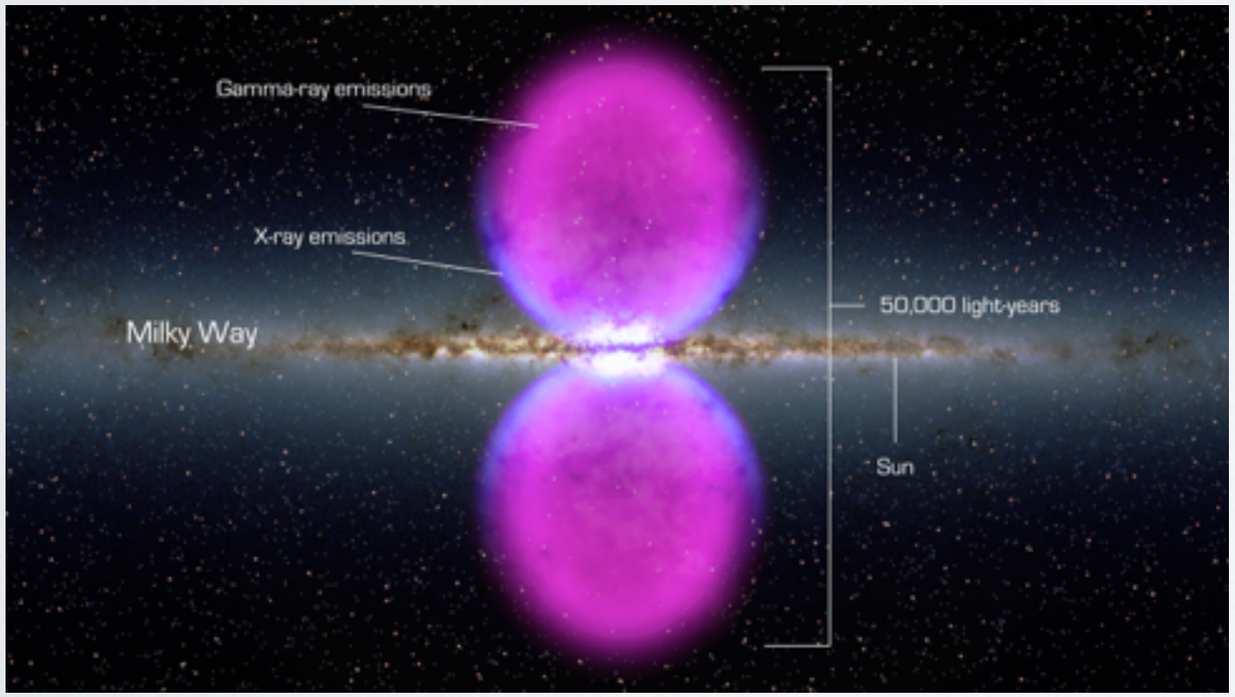
Galactic Diffuse — Limit from Pass 1

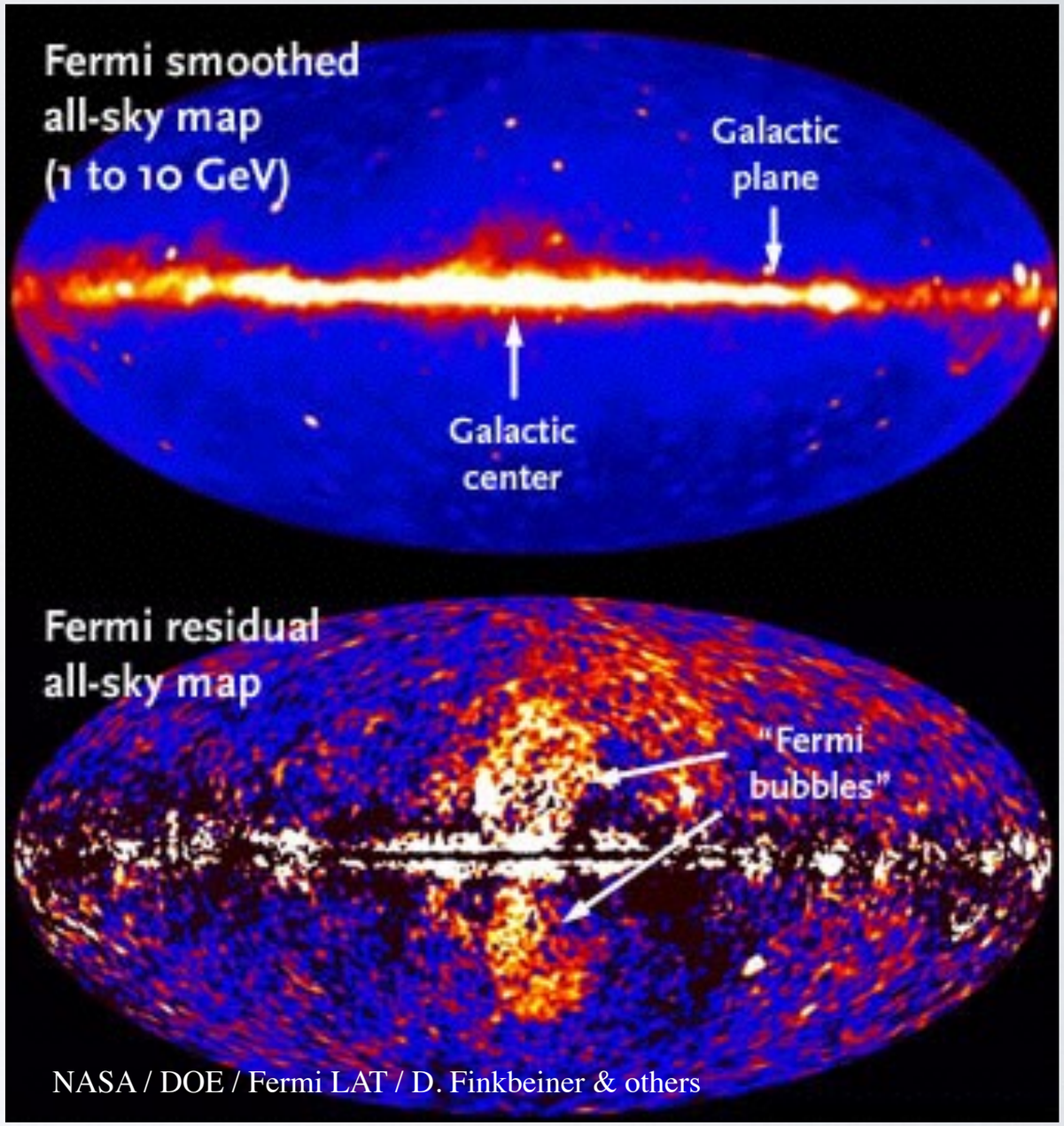


- A uniform surface brightness fit in addition to source model is preferred at **5.7σ**.
- The fitted surface brightness at 5 TeV is 1.6±0.4e-11 TeV^{-1} cm^{-2} s^{-1} sr^{-1}.
- HESS average diffuse extrapolated to 5 TeV is 1.0±0.2e-11 TeV^{-1} cm^{-2} s^{-1} sr^{-1}.
- Current limit from HAWC-111 dataset includes unresolved sources.

Large-scale structures e.g. Fermi Bubbles

- Large scale, non-uniform structures extending above and below the Galactic center.
  - Edges line up with X-ray features.
  - Correlate with microwave excess (WMAP haze)
  - Both hadronic and leptonic model fit Fermi LAT data. Leptonic model can explain both gamma ray and microwave excess.





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  - Edges line up with X-ray features.
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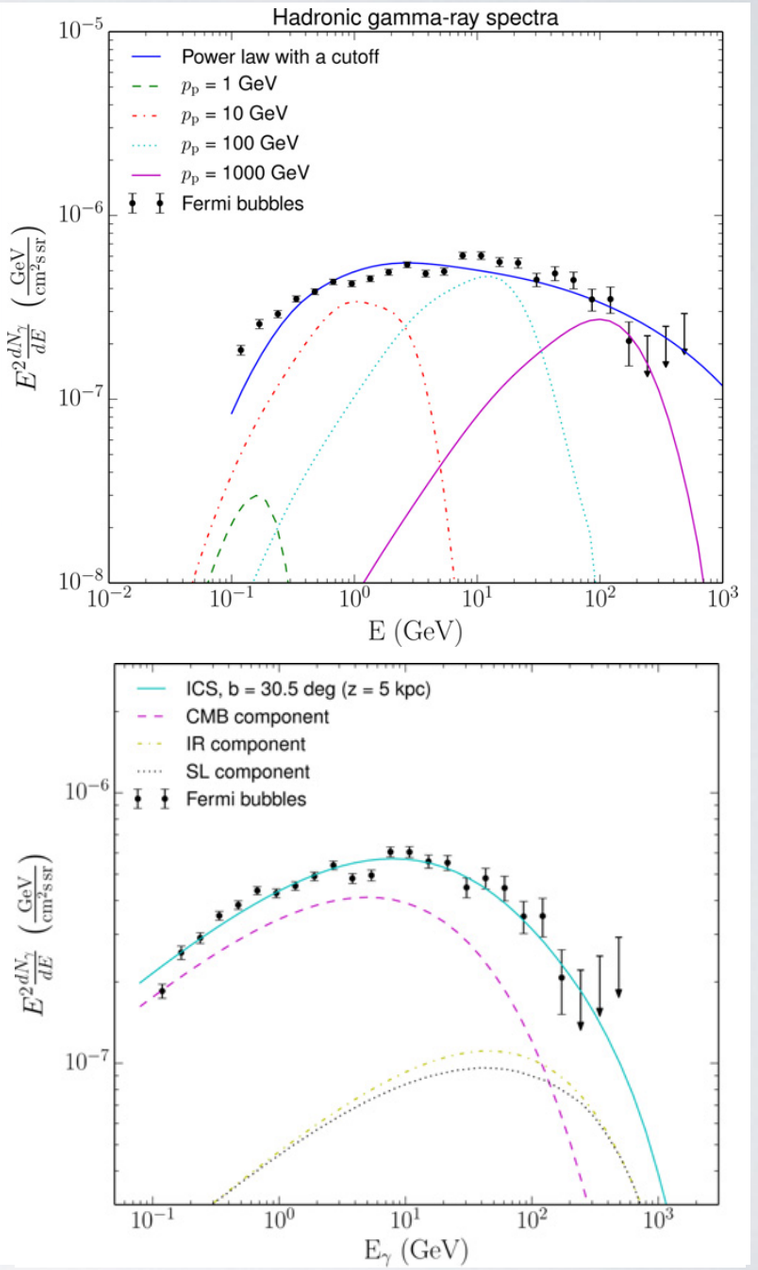
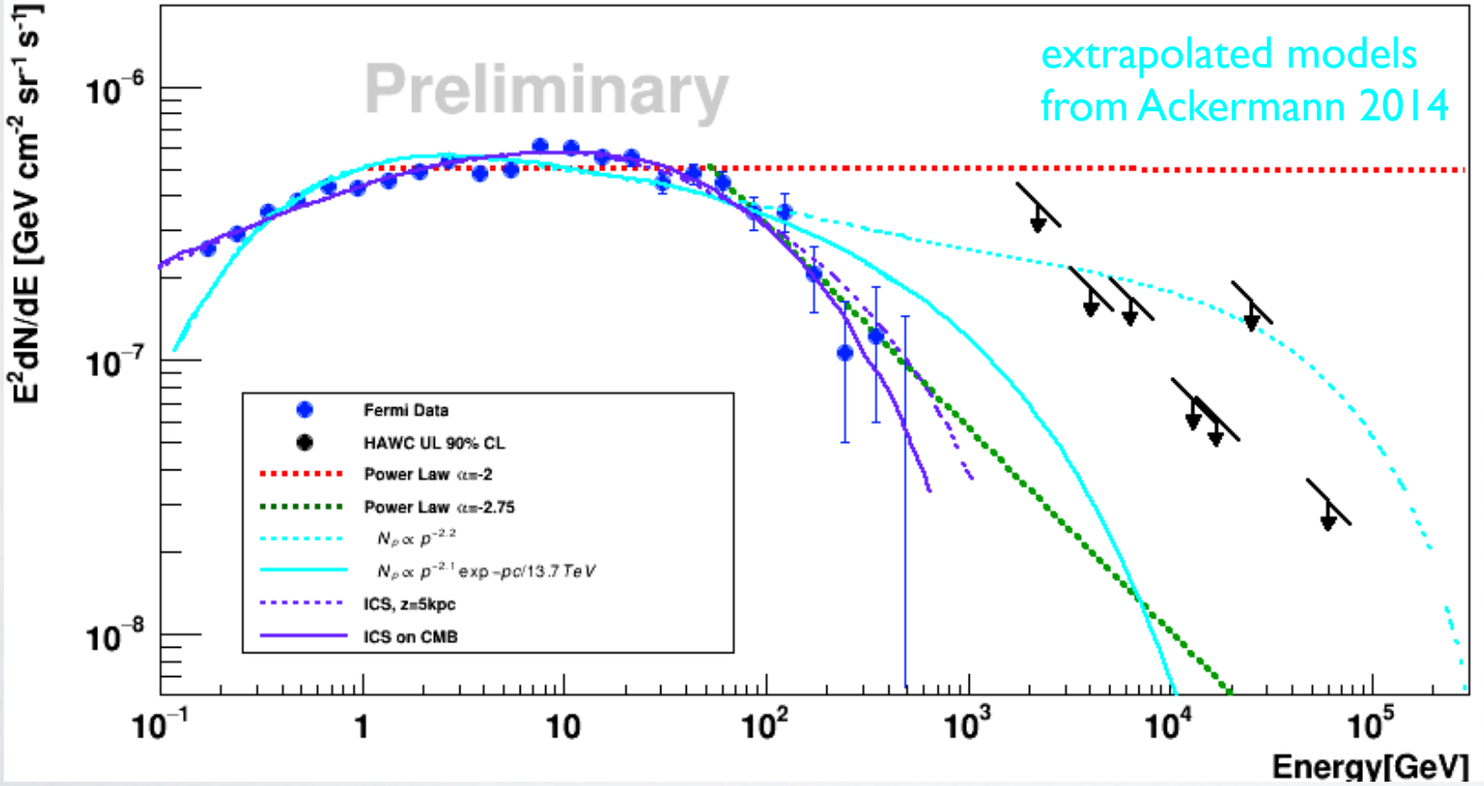
  - Both hadronic and leptonic model fit Fermi LAT data. Leptonic model can explain both gamma ray and microwave excess.
- First limits in TeV, **hard spectrum is highly unlikely.**





Ackermann et al. ApJ (2014)

Multi-wavelength / Multi-messenger

Have follow-up agreement with:

- Swift
- Fermi-LAT
- IACTs
  - FACT
  - HESS
  - MAGIC
  - VERITAS
- AMON
- IceCube
- ANTARES
- LIGO/VIRGO

HAWC-triggered:

- New source candidates lists.
  - immediate follow-up observations by IACTs.
- Flares from known gamma-ray sources.

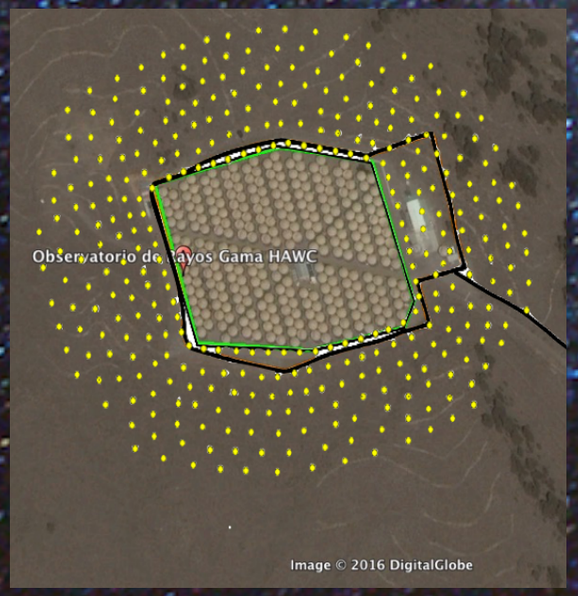
Externally triggered:

- IceCube alert on high confidence neutrino event (highest energy pointed astrophysical track-like).
- Fermi alerts on flaring activities.
- LIGO/VIRGO gravitation wave event follow-up

Results reported in ATels and GCNs.

Outlook

- HAWC is surveying and monitoring the gamma-ray sky, agreement with many instruments ready for follow-up.
- Many instruments from different waveband/messenger (X-rays, neutrinos, gravitational waves) available for simultaneous observation.



- HAWC observatory 2HWC catalog of ~1.5 year full operation is submitted to ApJ and available on arXiv!
- Diverse science results, stay tuned for more papers!
- Upgrade to expand the array to enhance effective area >10 TeV by 3-4x is currently under installation.