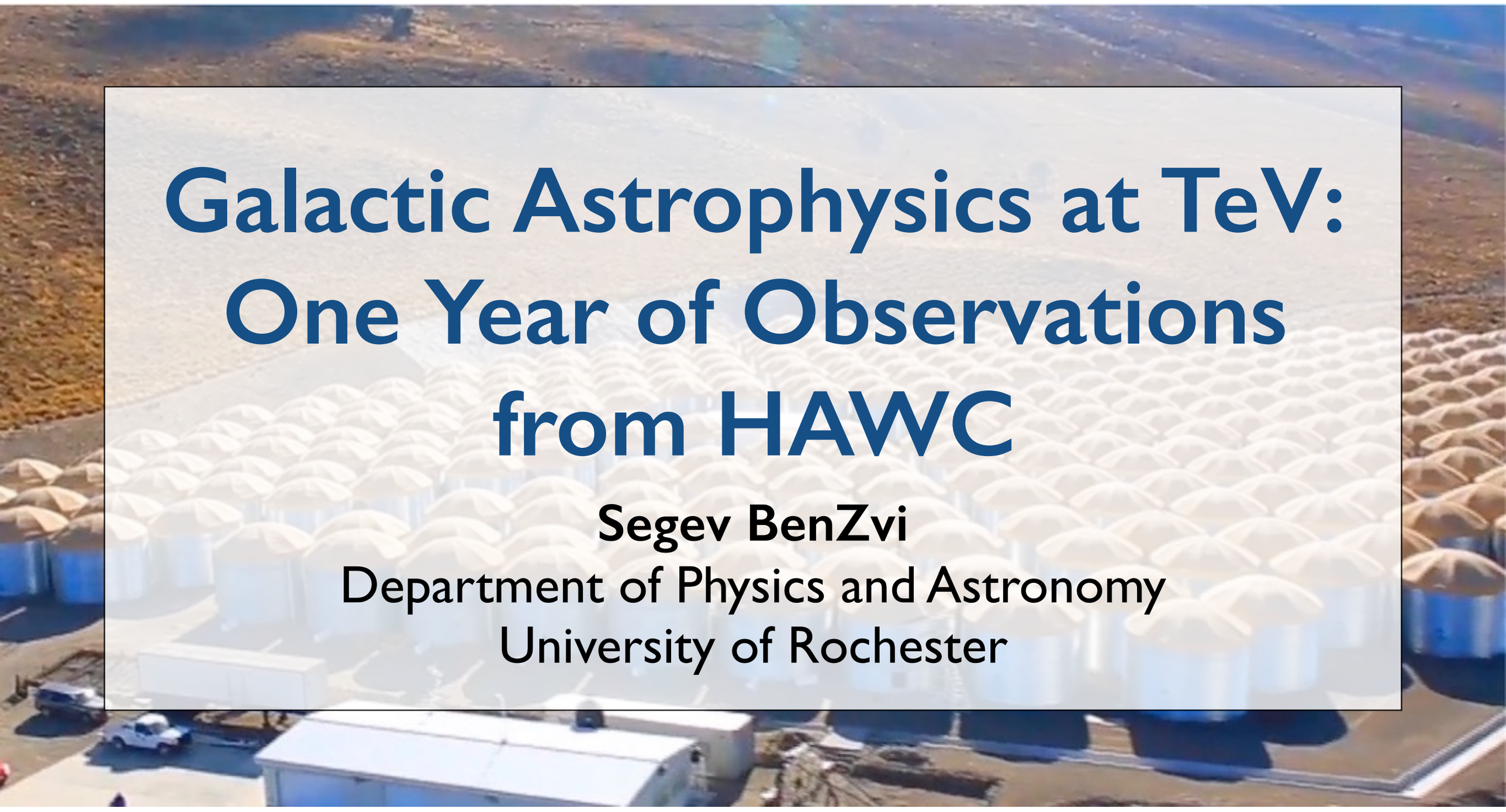
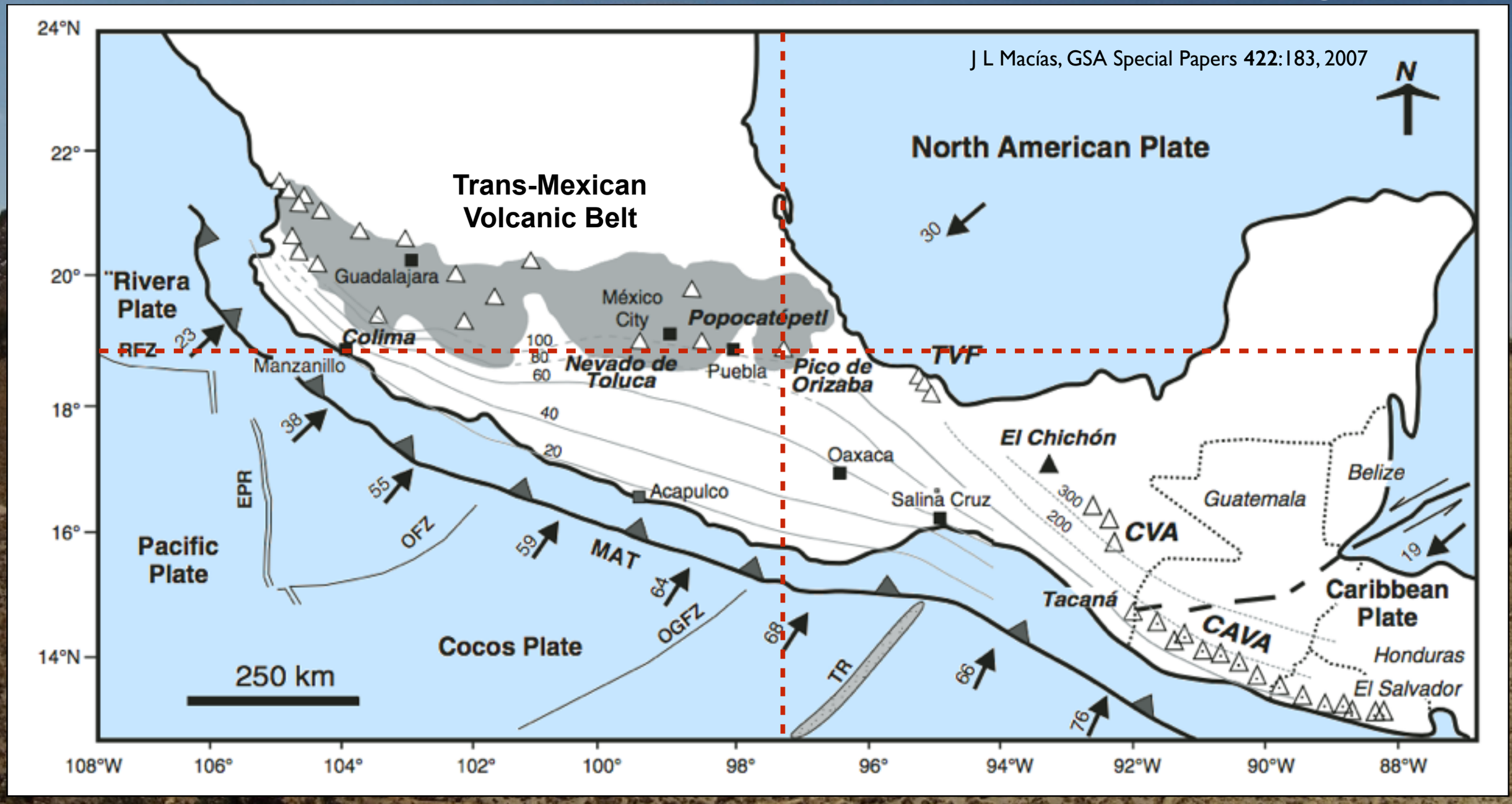


Galactic Astrophysics at TeV: One Year of Observations from HAWC

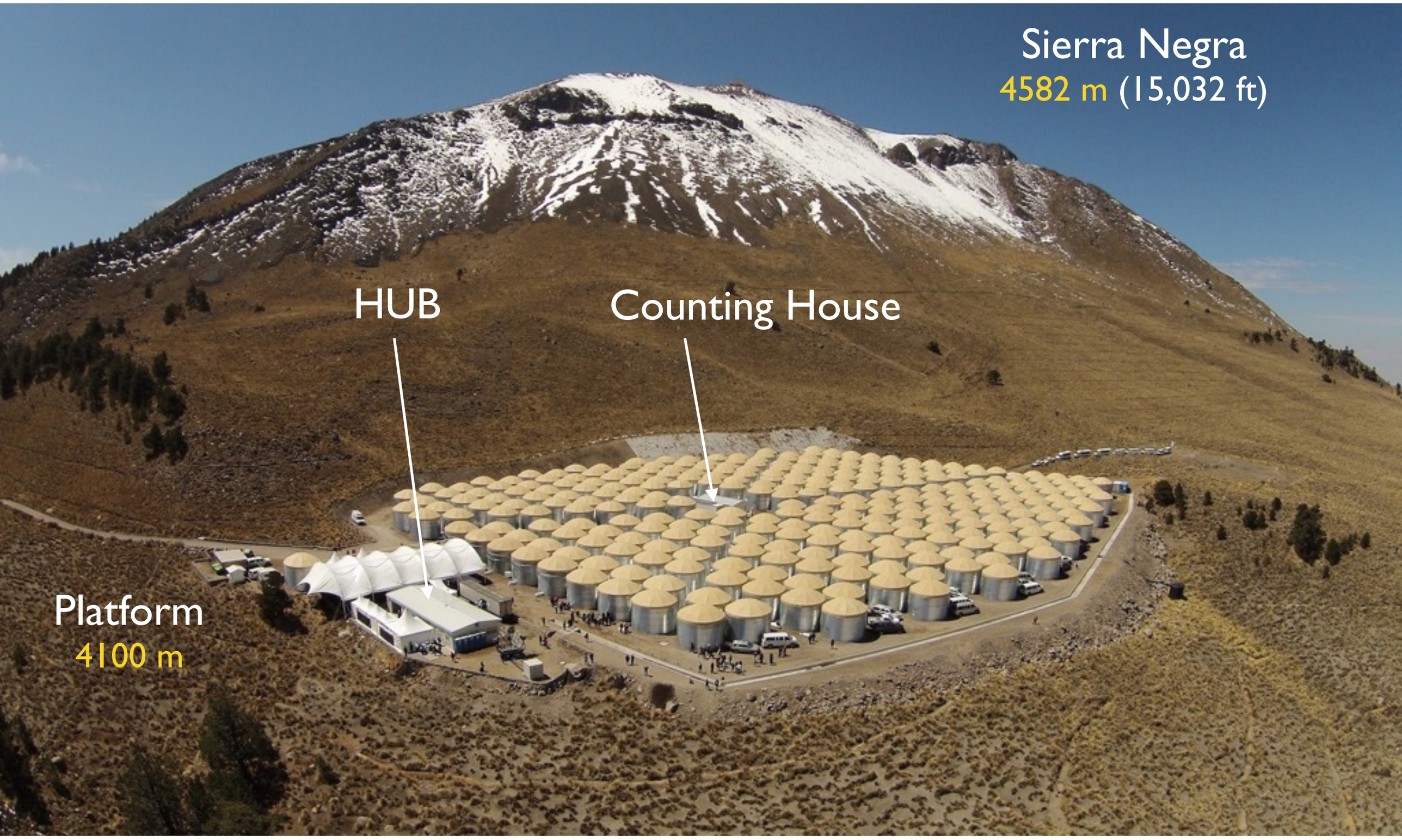
Segev BenZvi
Department of Physics and Astronomy
University of Rochester

High Altitude Water Cherenkov Observatory

Sierra Negra



High Altitude Water Cherenkov Observatory



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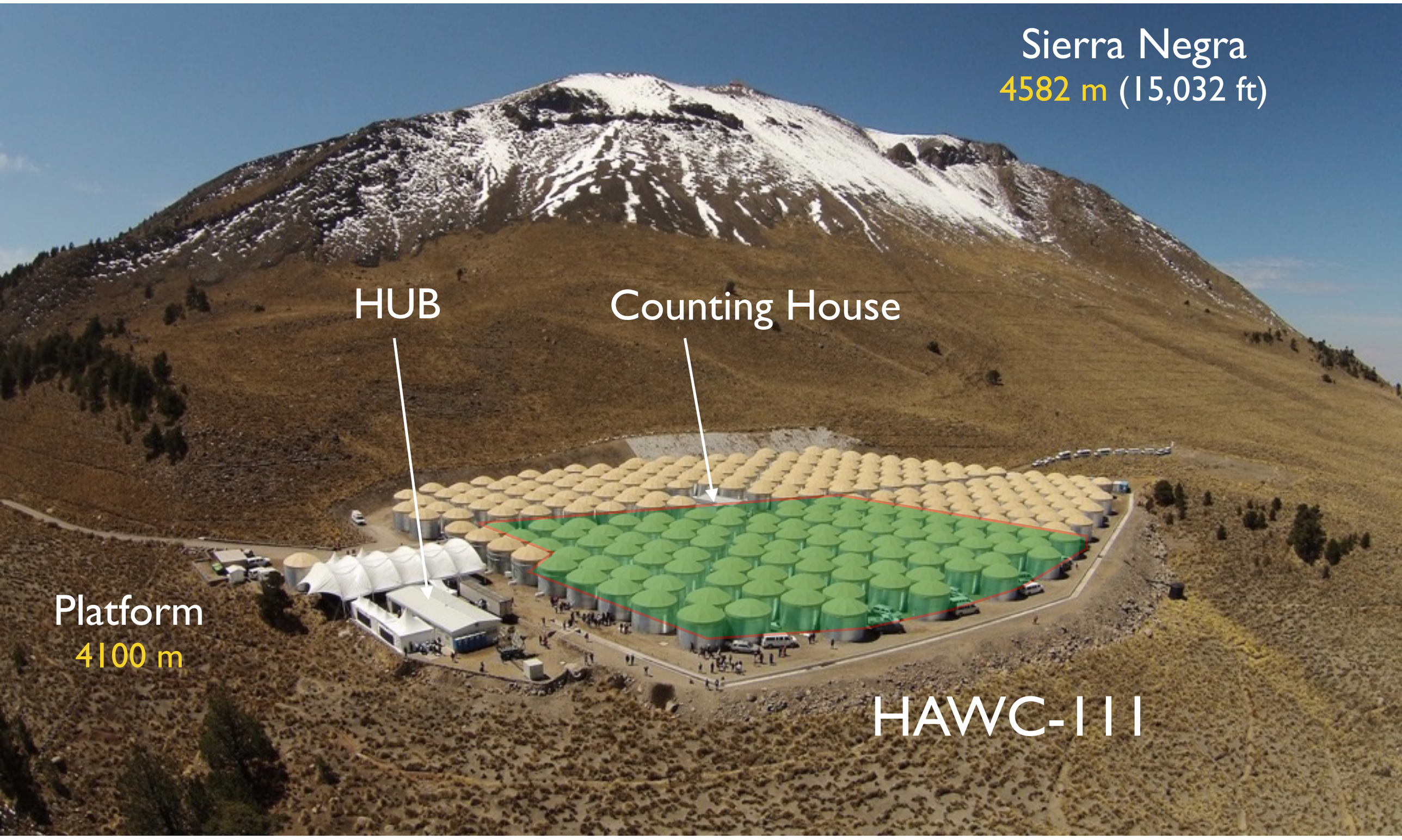
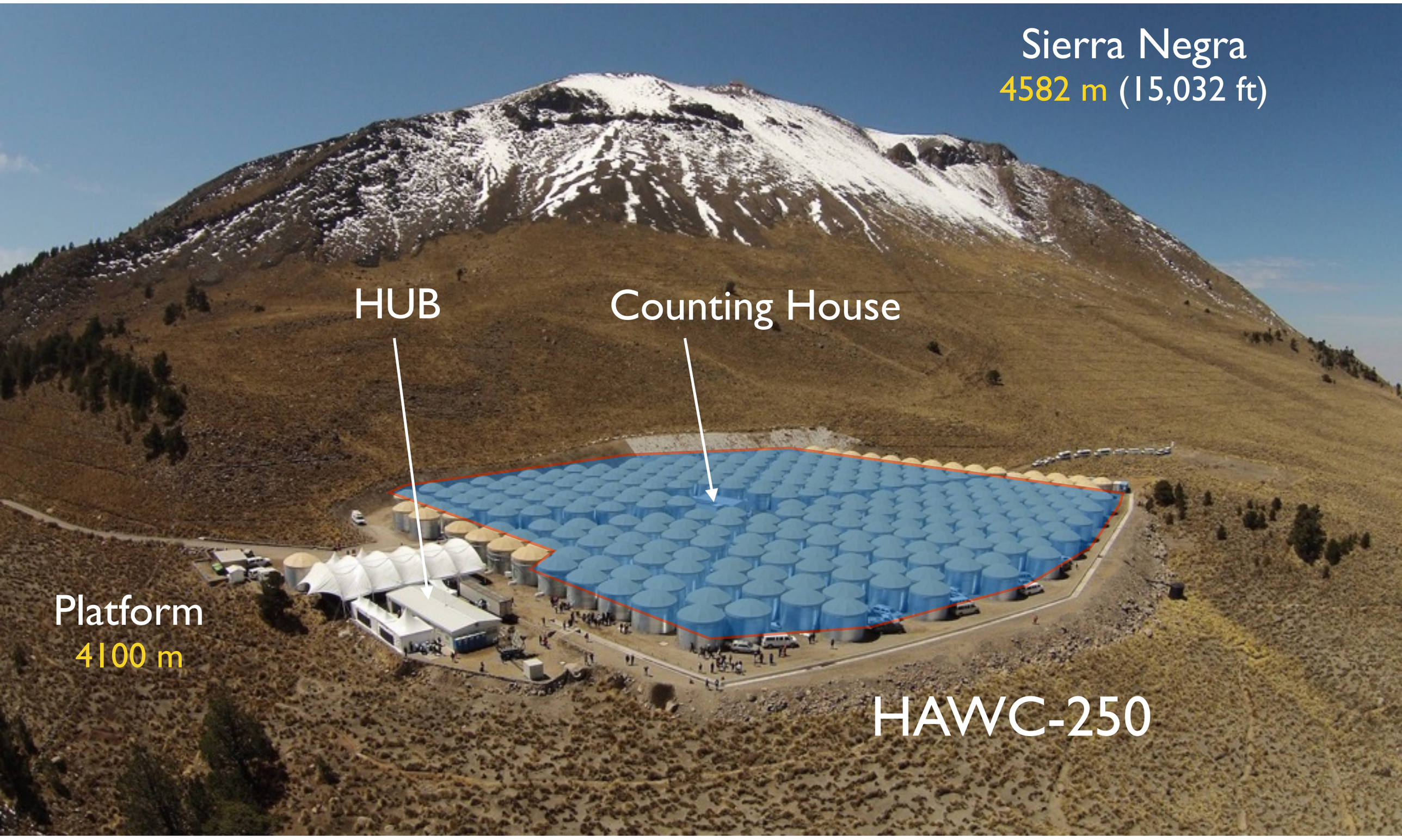
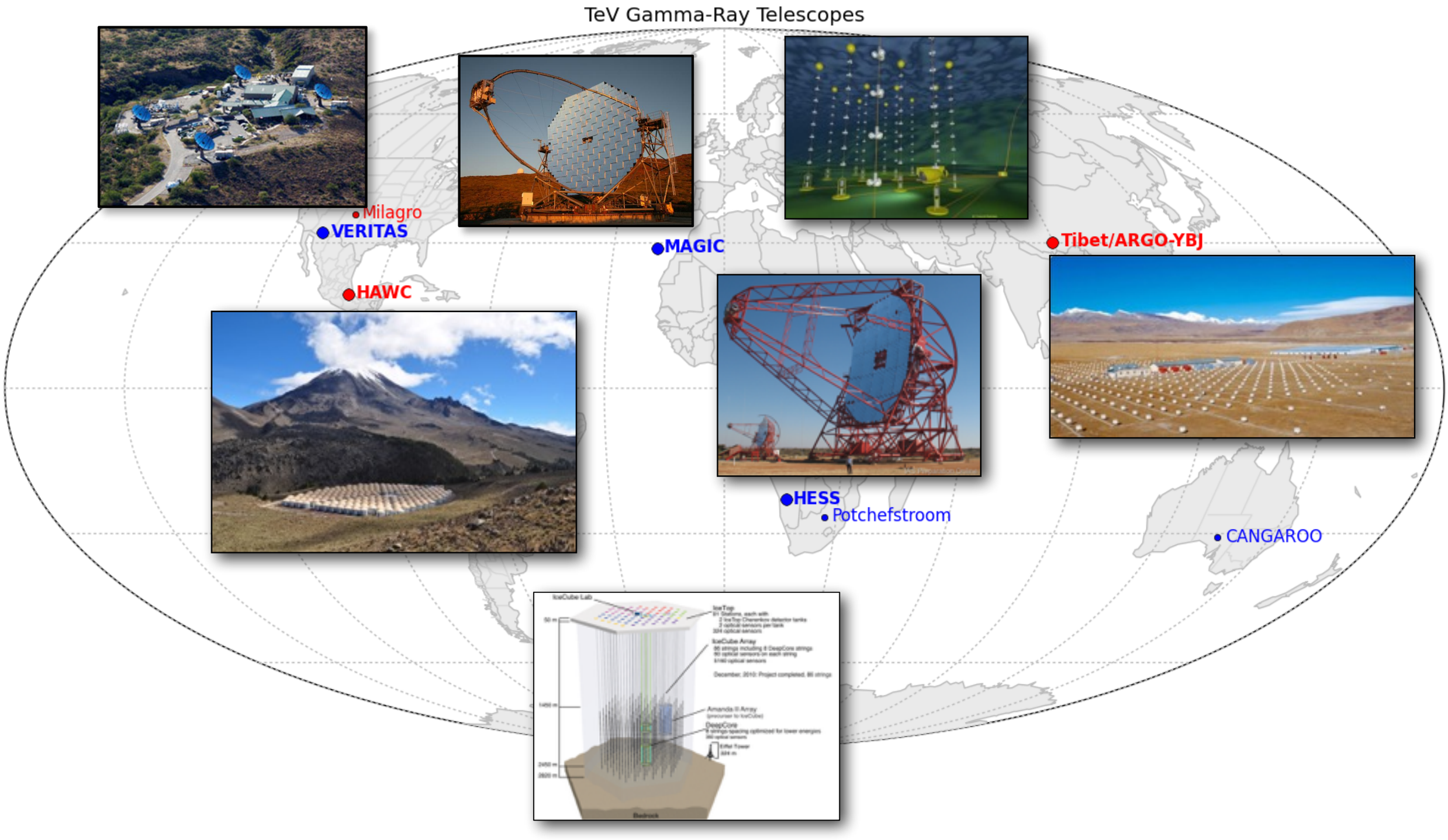


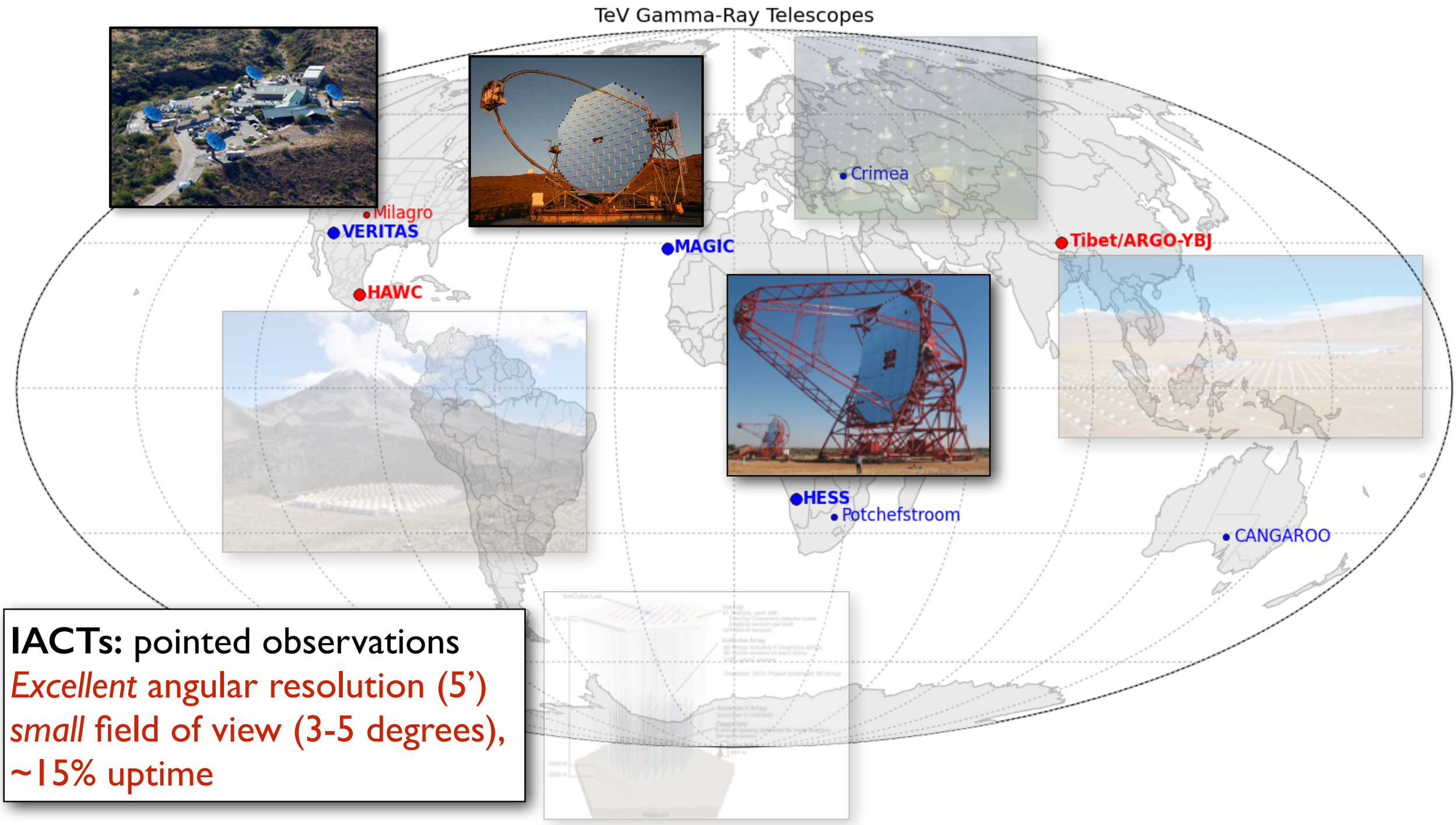
High Altitude Water Cherenkov Observatory



HAWC in Context



HAWC in Context

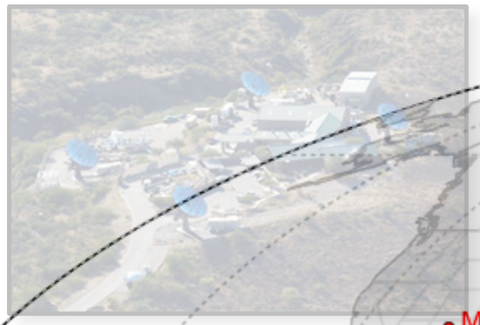


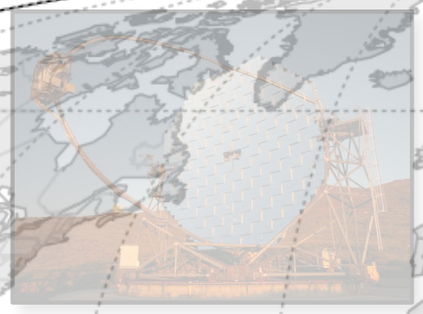
IACTs: pointed observations
Excellent angular resolution (5')
small field of view (3-5 degrees),
~15% uptime

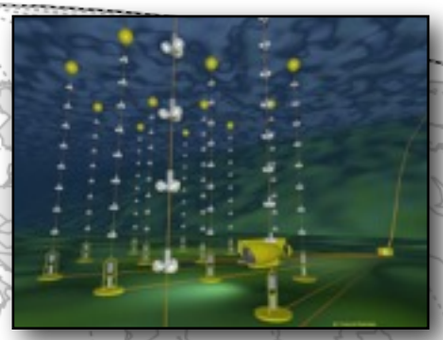
HAWC in Context

EGRET
AGILE
Fermi

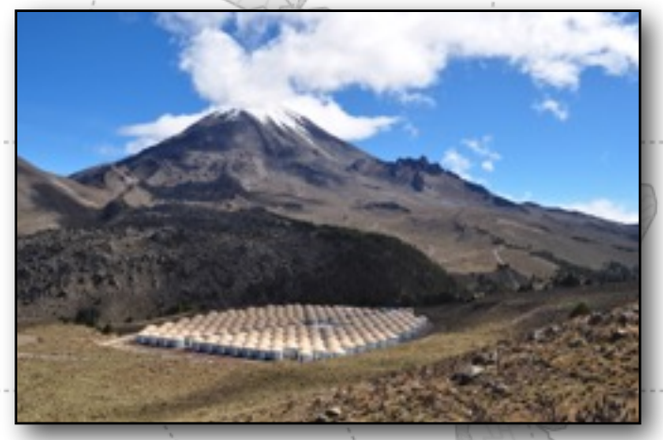
TeV Gamma-Ray Telescopes



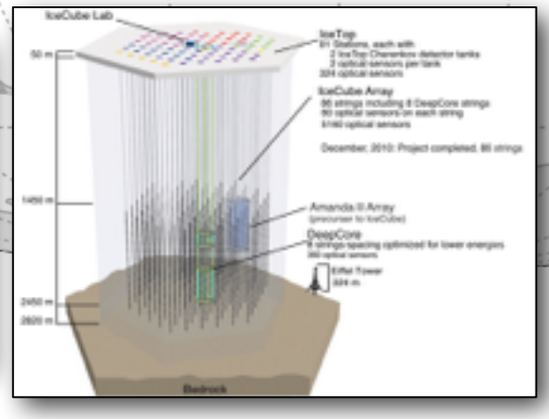




Milagro
VERITAS
MAGIC
HAWC
Tibet/ARGO-YBJ



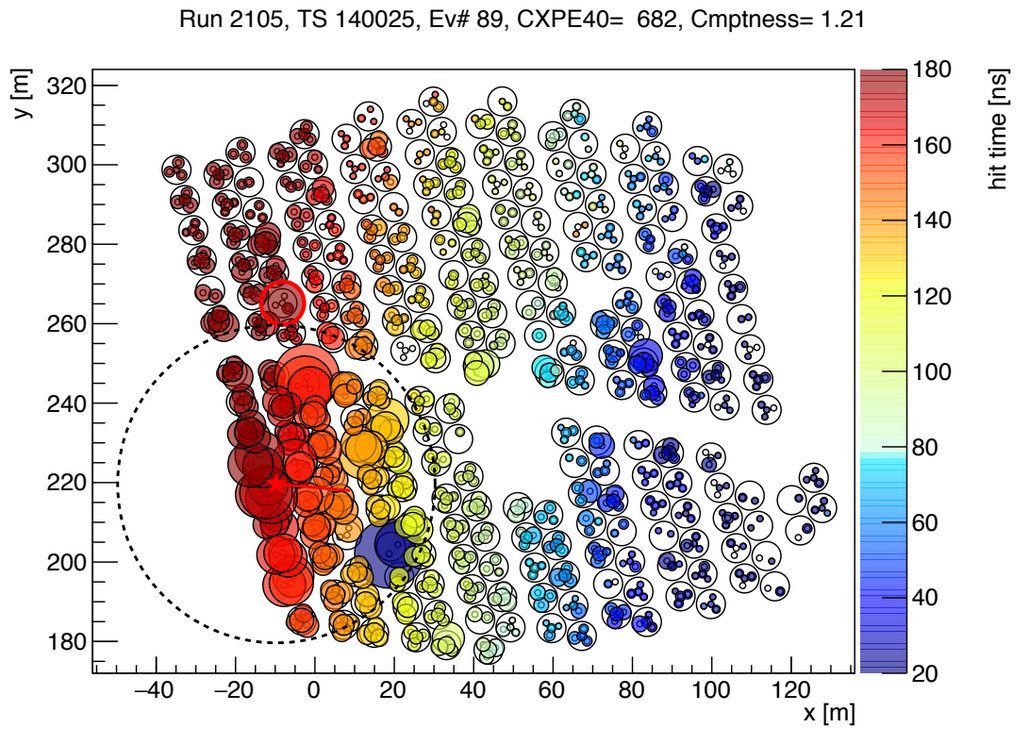
HESS
Potchefstroom
CANGAROO

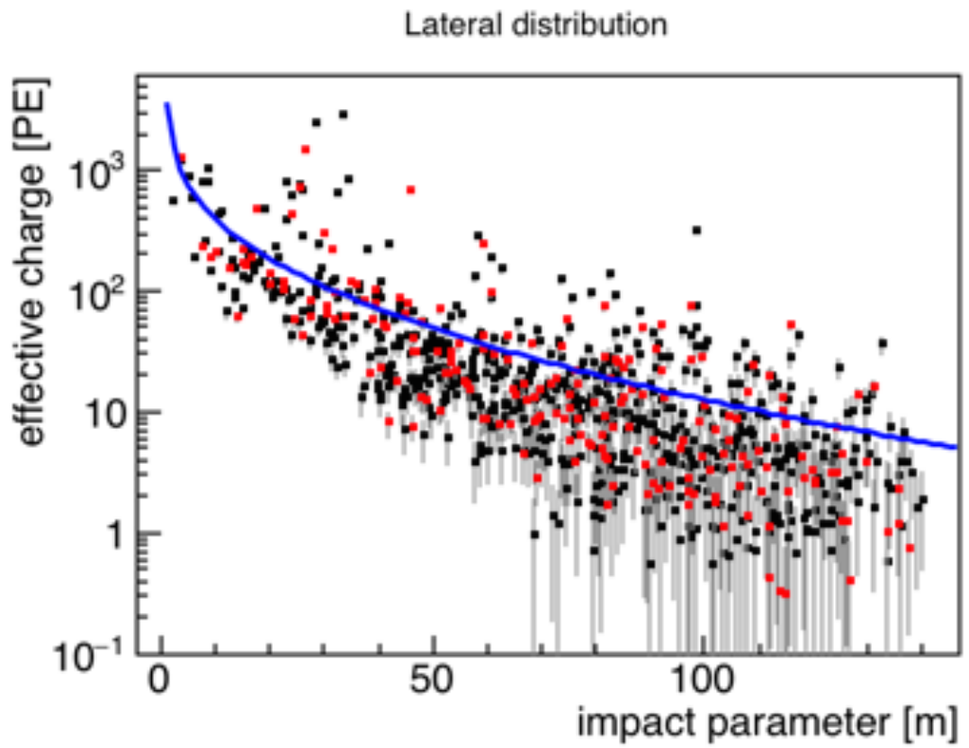


IACTs: pointed observations
Excellent angular resolution (5')
small field of view (3-5 degrees),
~15% uptime

Surface/Volume Detectors: surveys
Moderate angular resolution (10'),
large field of view (partial/all-sky),
continuous monitoring

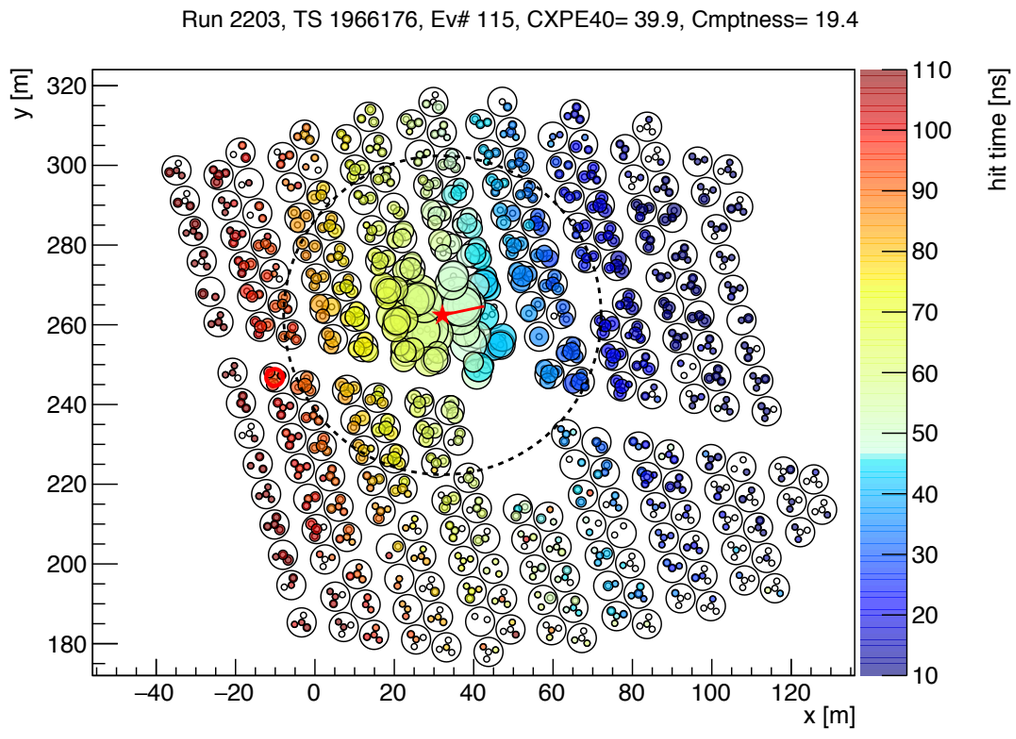
Background Suppression

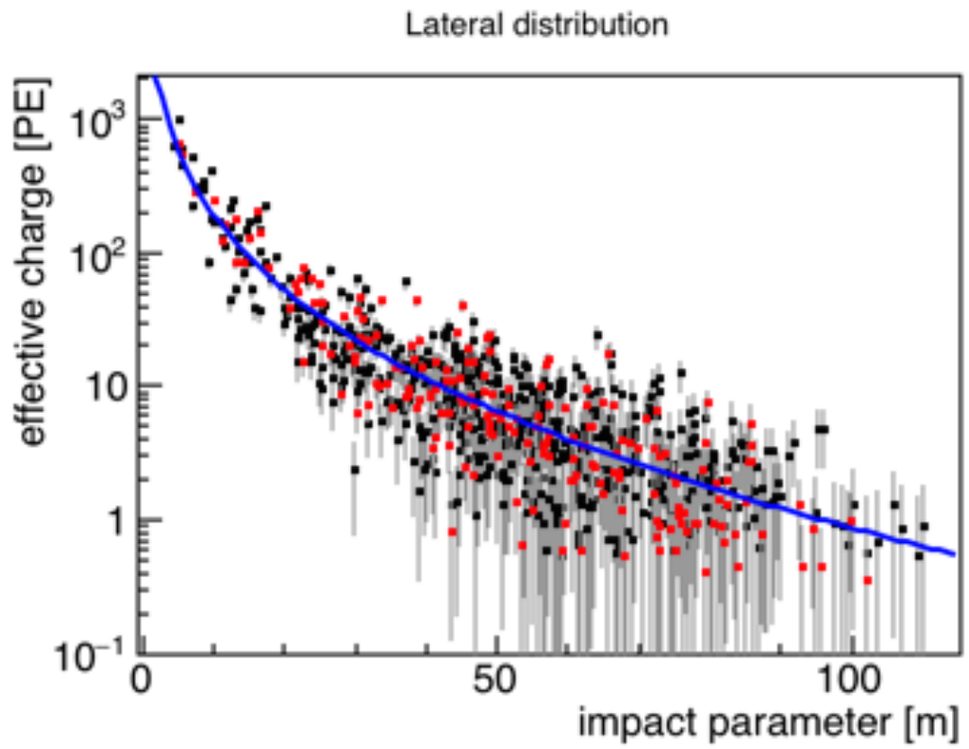




- Cosmic ray background: 25 kHz at trigger level
- Enables high-statistics measurements of cosmic-ray flux and anisotropy (1-100 TeV). Additional solar physics is possible
- Showers characterized by large variance in charge as a function of distance from shower core

Background Suppression





- Gamma ray signal: ~5 mHz from Crab Nebula
- Showers characterized by small variance in deposited charge vs distance from shower core
- 99.9% background suppression at 10 TeV

Spatial/Spectral Analysis

- Events binned by fraction of channels triggered in detector; gamma-hadron and angular cuts (PSF) differ for each bin
- Standard analysis: excess reported using Li-Ma significance
- New: spectral+spatial models forward-folded using Monte Carlo response function and fitted to data in analysis bins

$$\ln \mathcal{L}(\vec{n} \mid \vec{\theta}) = \sum_{i=1}^{N_{\text{bin}}} \sum_{j=1}^{N_{\text{pix}}} n_{ij} \ln \lambda_{ij}(\vec{\theta}) - \lambda_{ij}(\vec{\theta}) - \ln n_{ij}!$$

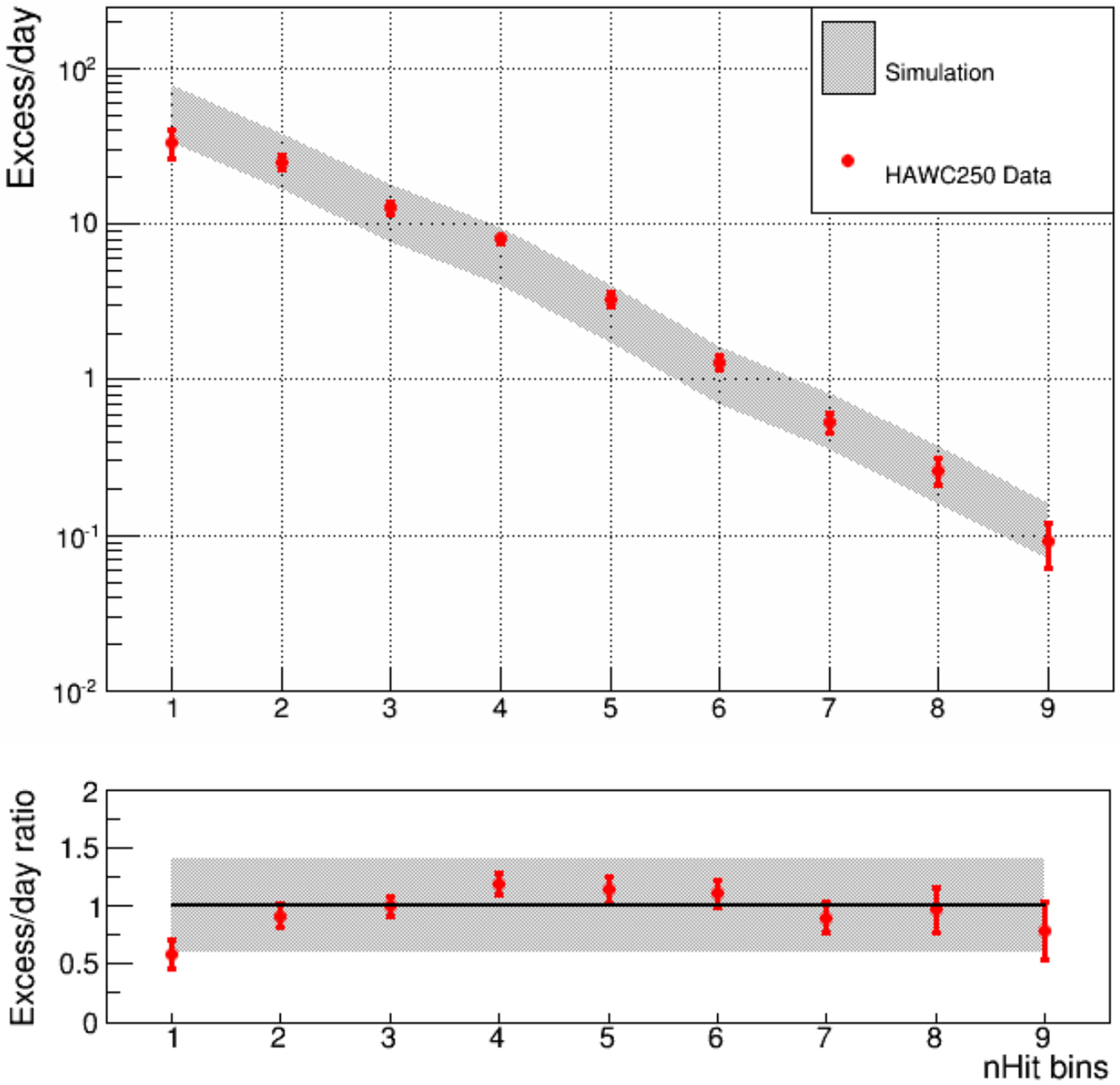
$$\text{TS} = 2\Delta \ln \mathcal{L}$$

$$\text{significance} = \sqrt{\text{TS}}$$

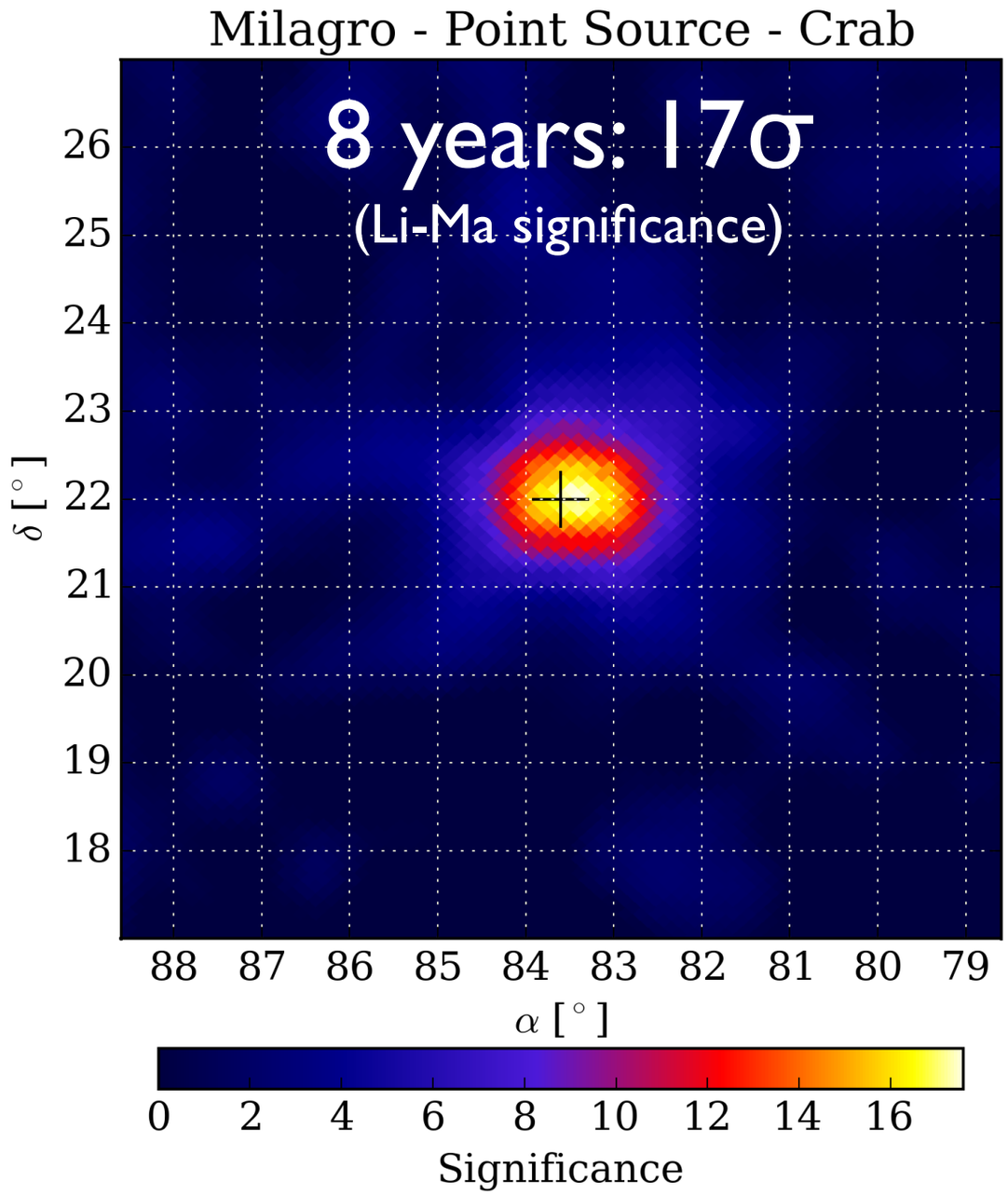
- Model counts: background + signal $\lambda_k = B_k + \Sigma_l f_{kl}(\theta)$

Verification: Crab Nebula

F. Salesa Greus, ICRC 2015

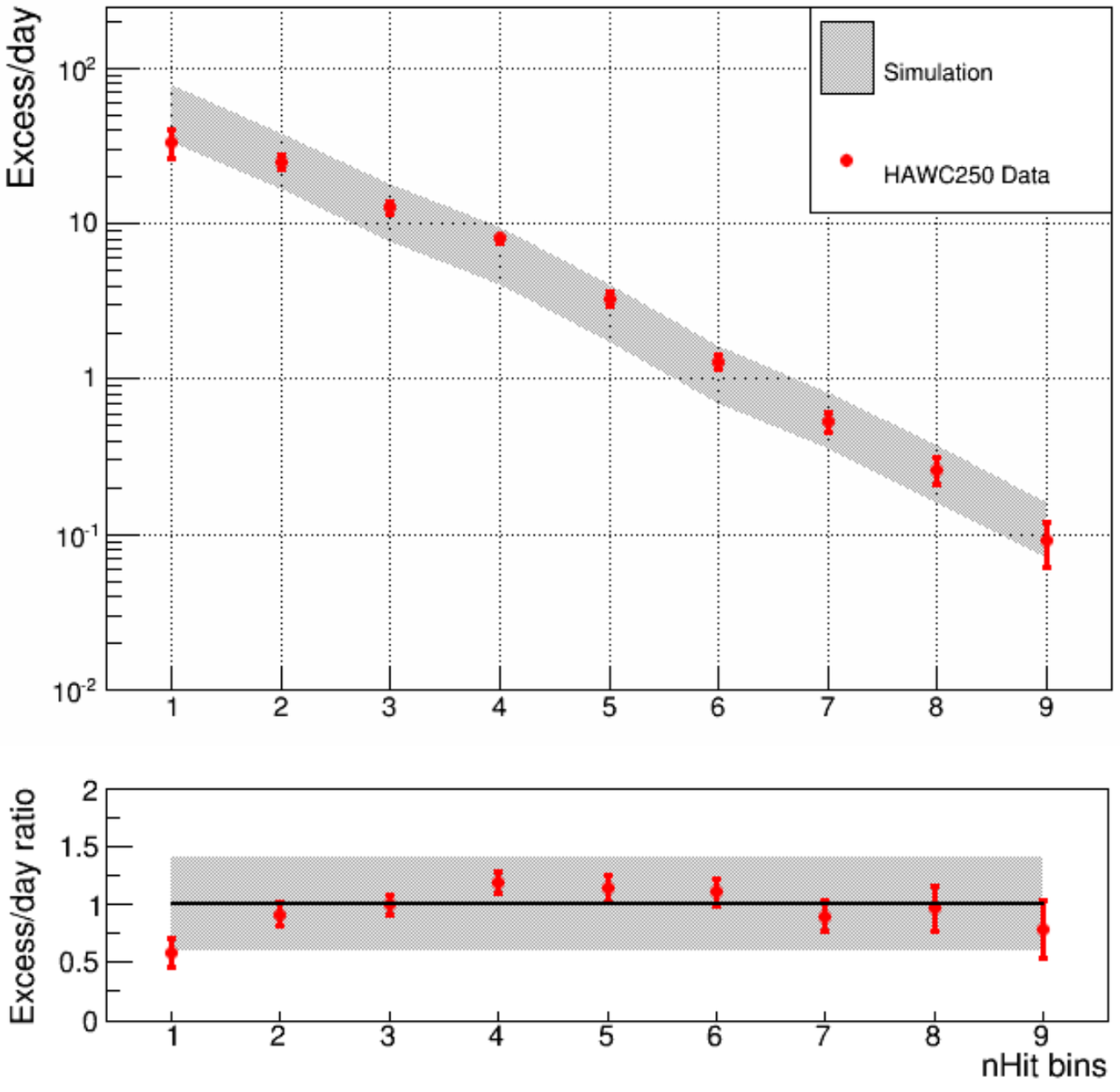


Larger Event:
Higher Energy →

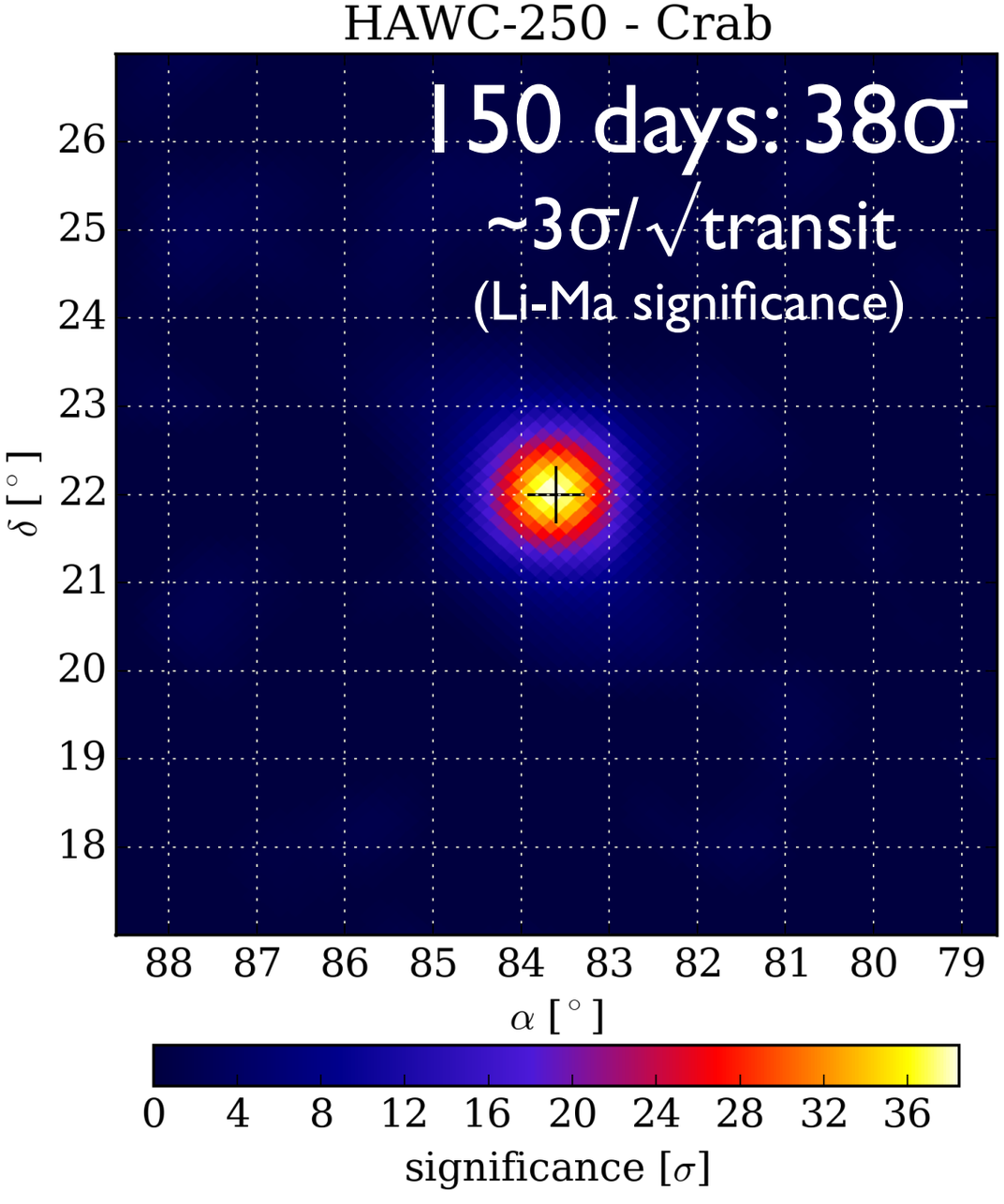


Verification: Crab Nebula

F. Salesa Greus, ICRC 2015



Larger Event:
Higher Energy →



Verification: Crab Nebula

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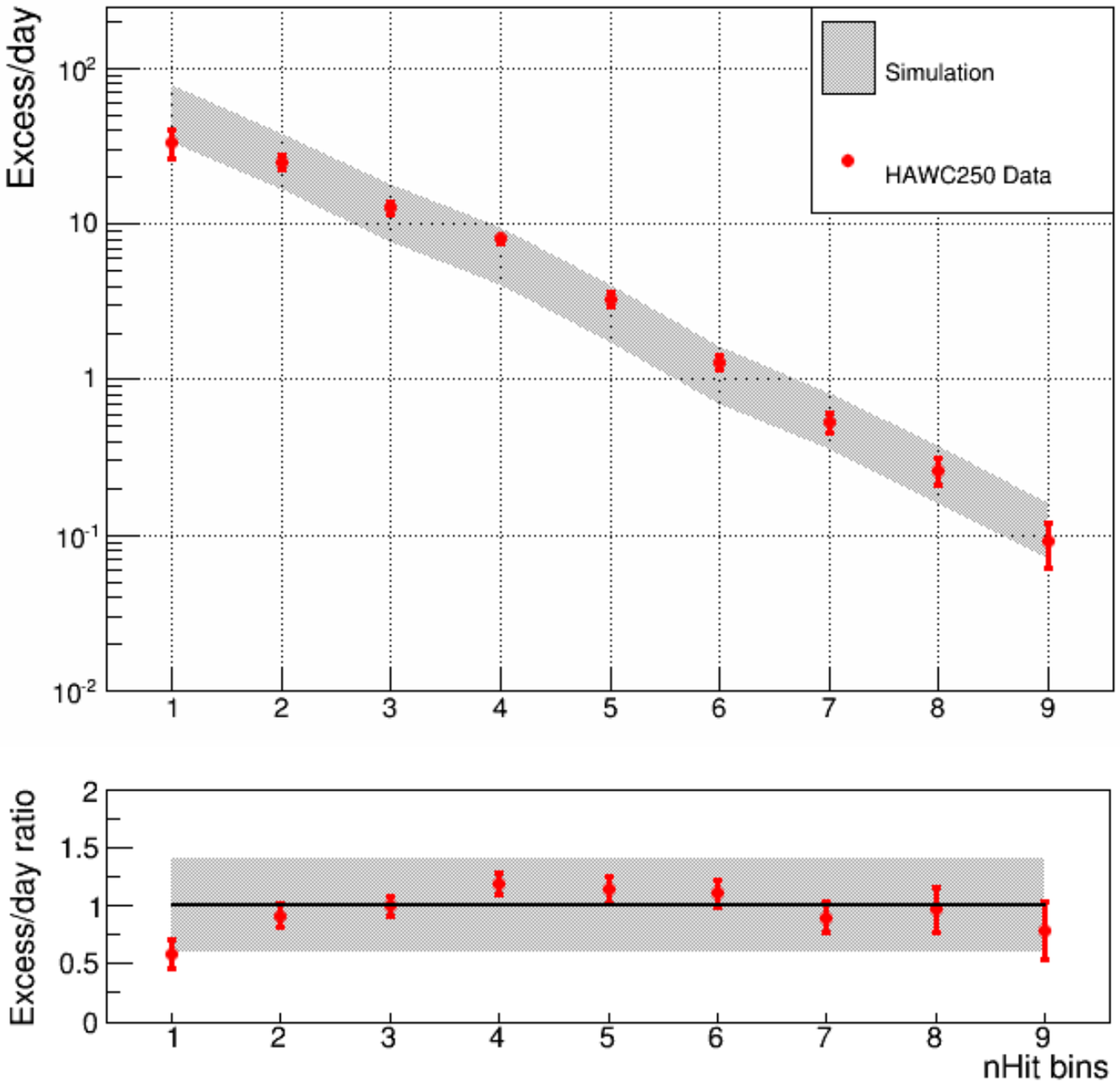
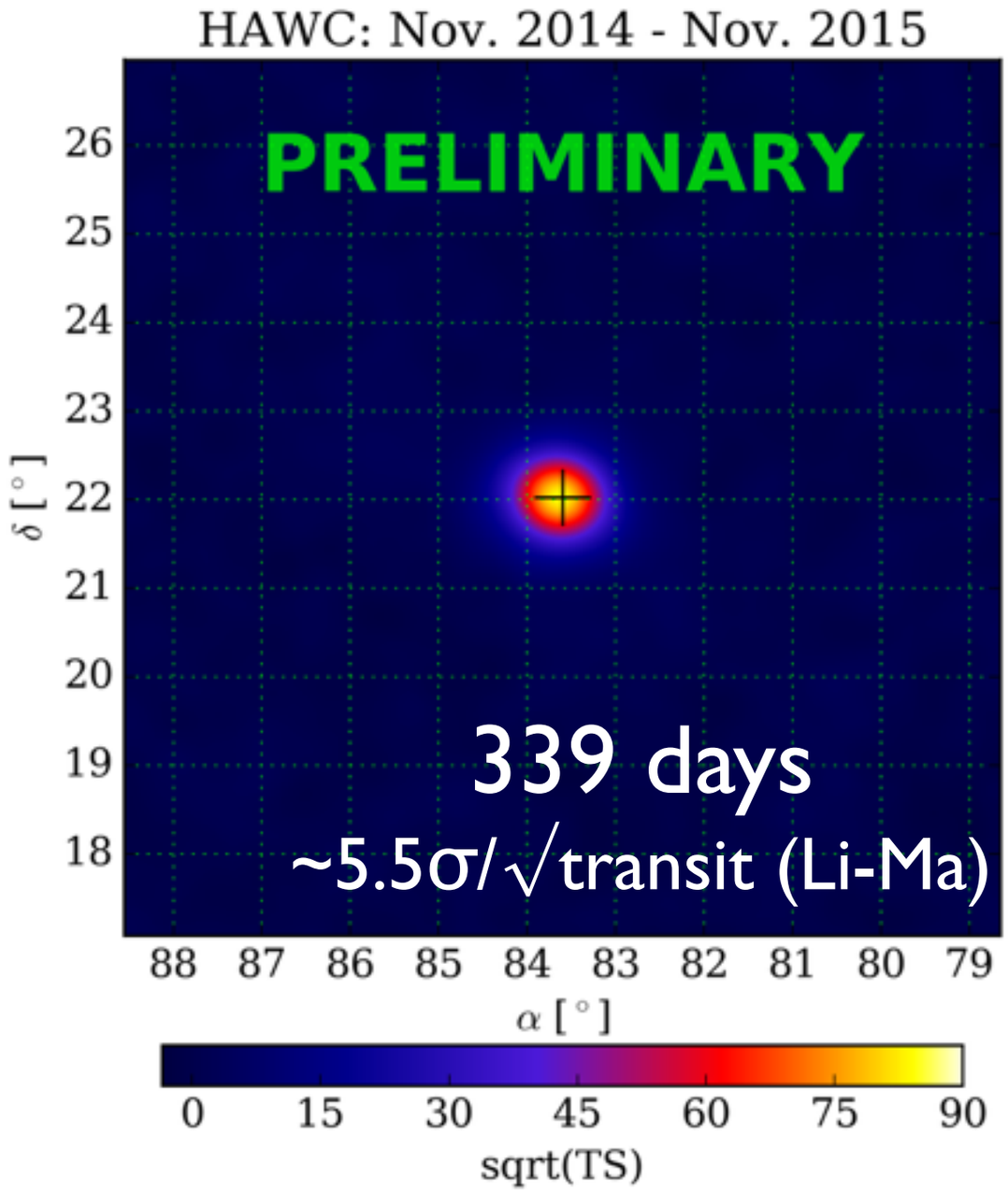
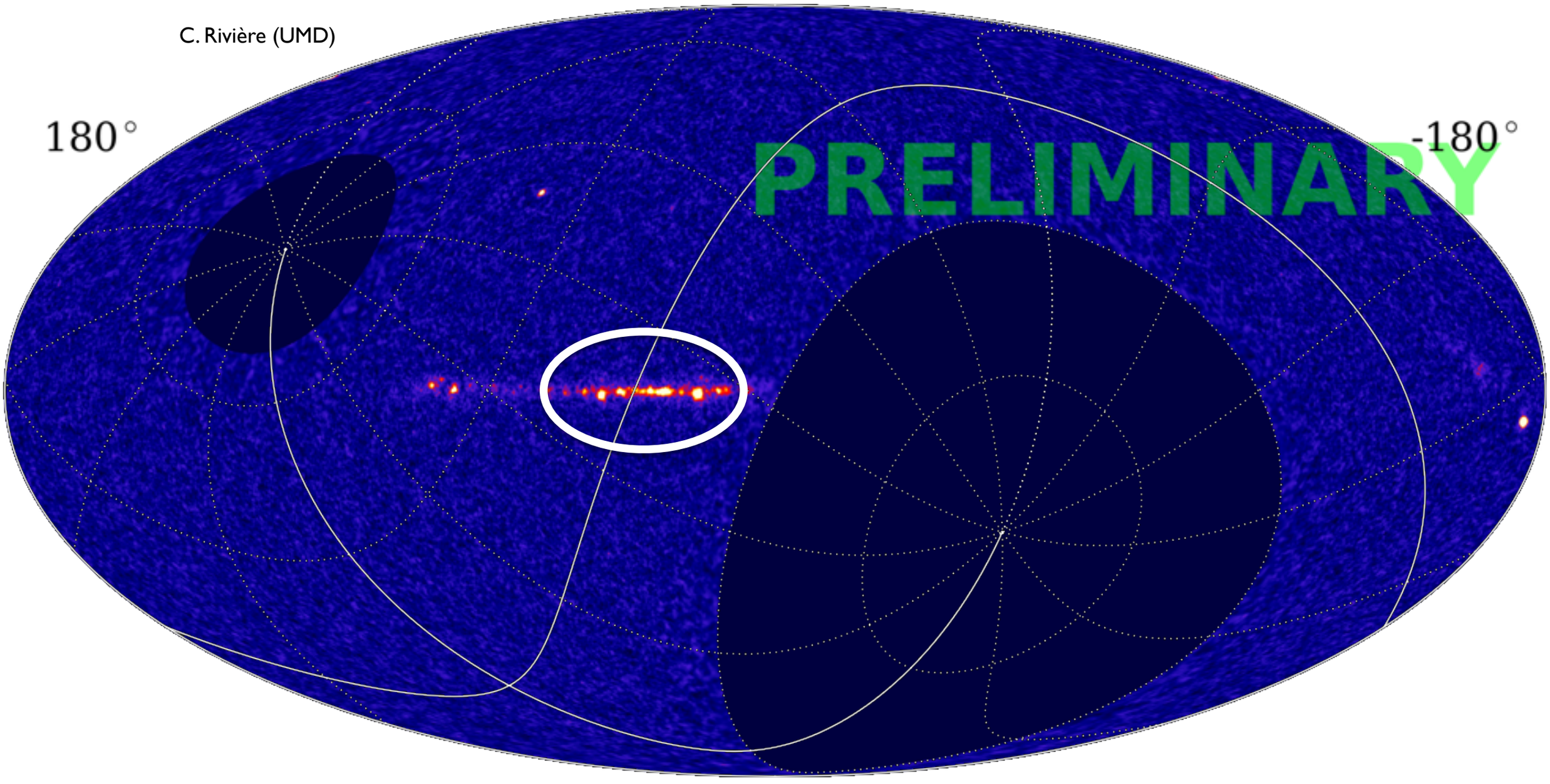


Larger Event:
Higher Energy →



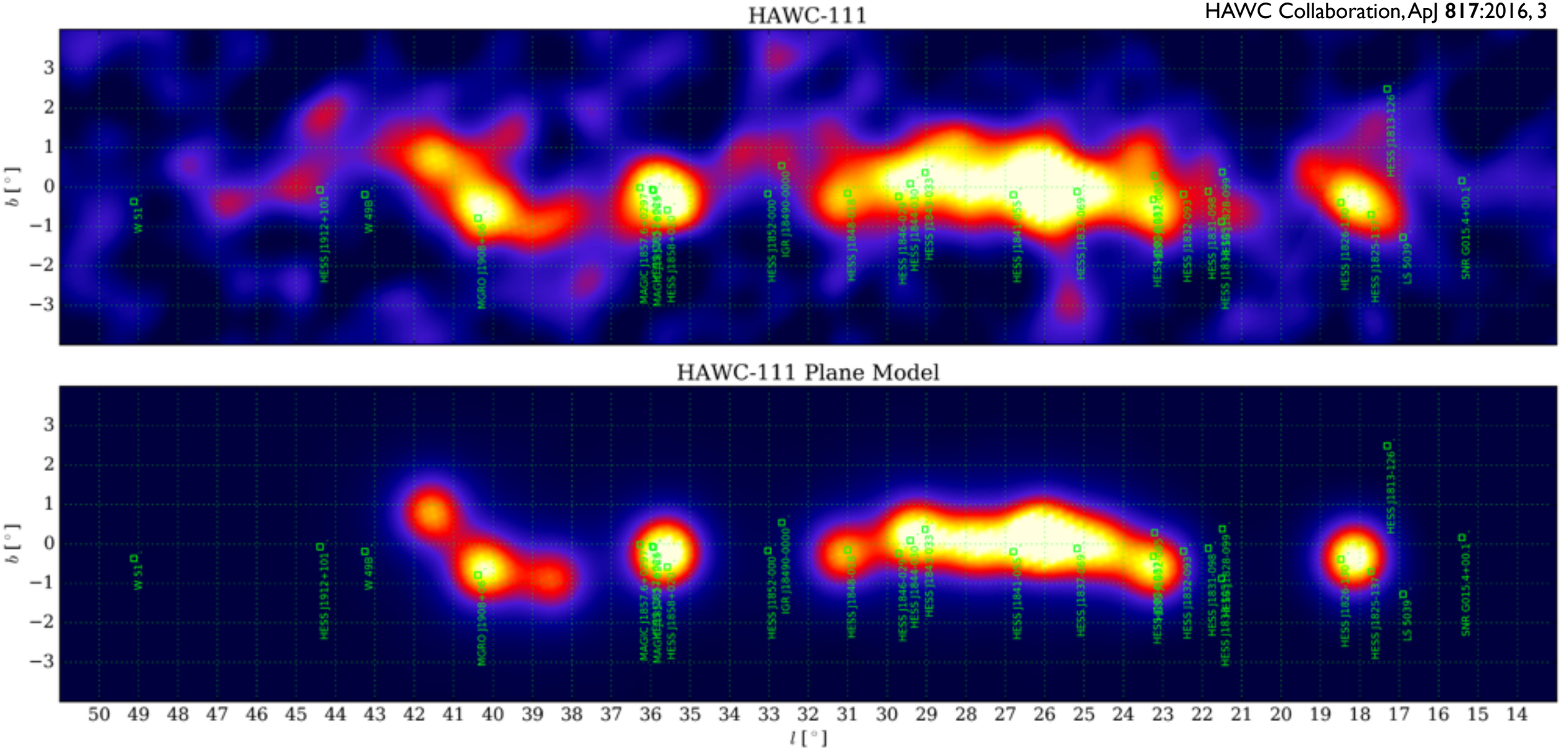
Galactic Plane Survey

C. Rivière (UMD)



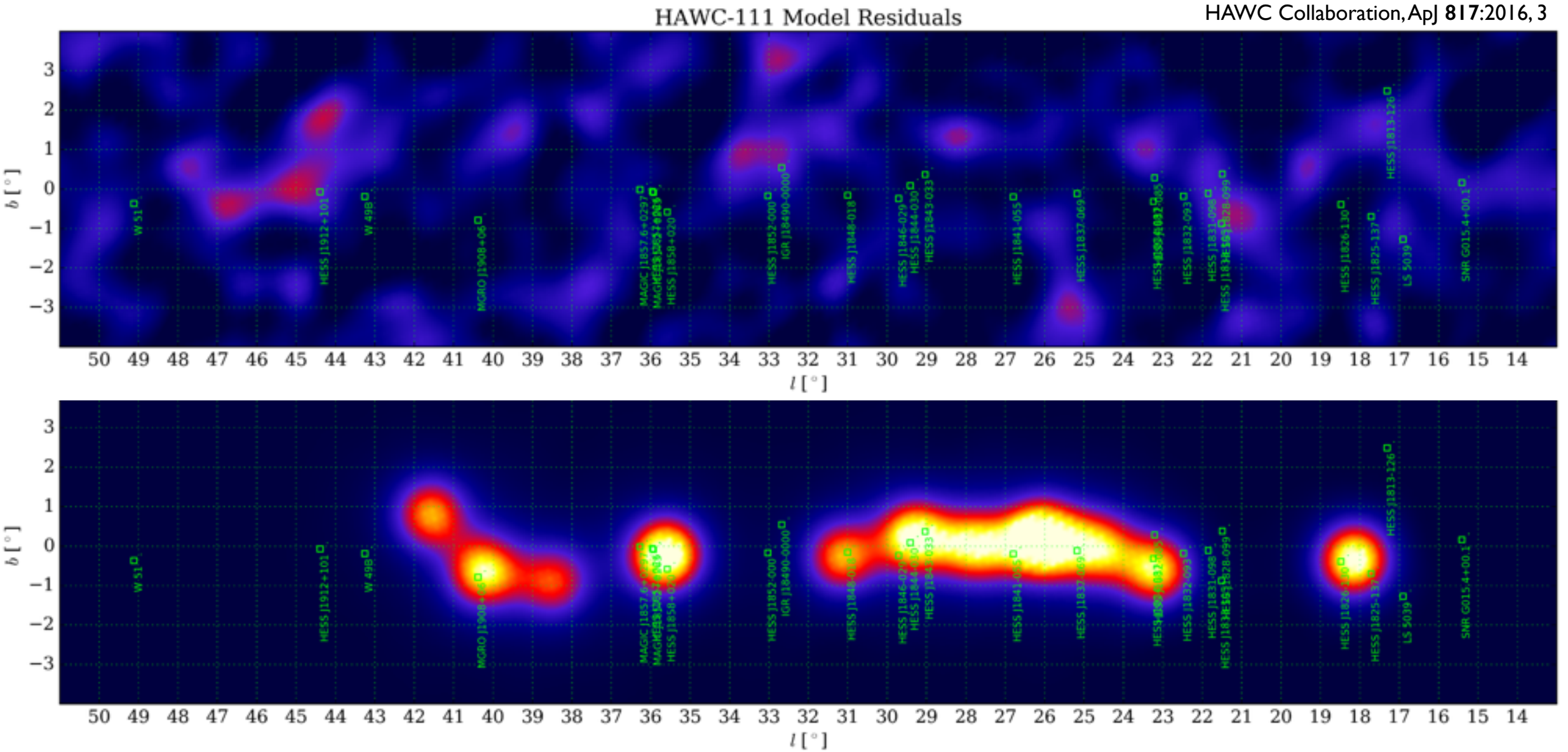
Inner Galaxy: HAWC-111

HAWC Collaboration, ApJ **817**:2016, 3



- Galactic Plane: point sources added to fit until improvement ΔTS < 15 with each additional source (10 src candidates)

Inner Galaxy: HAWC-111

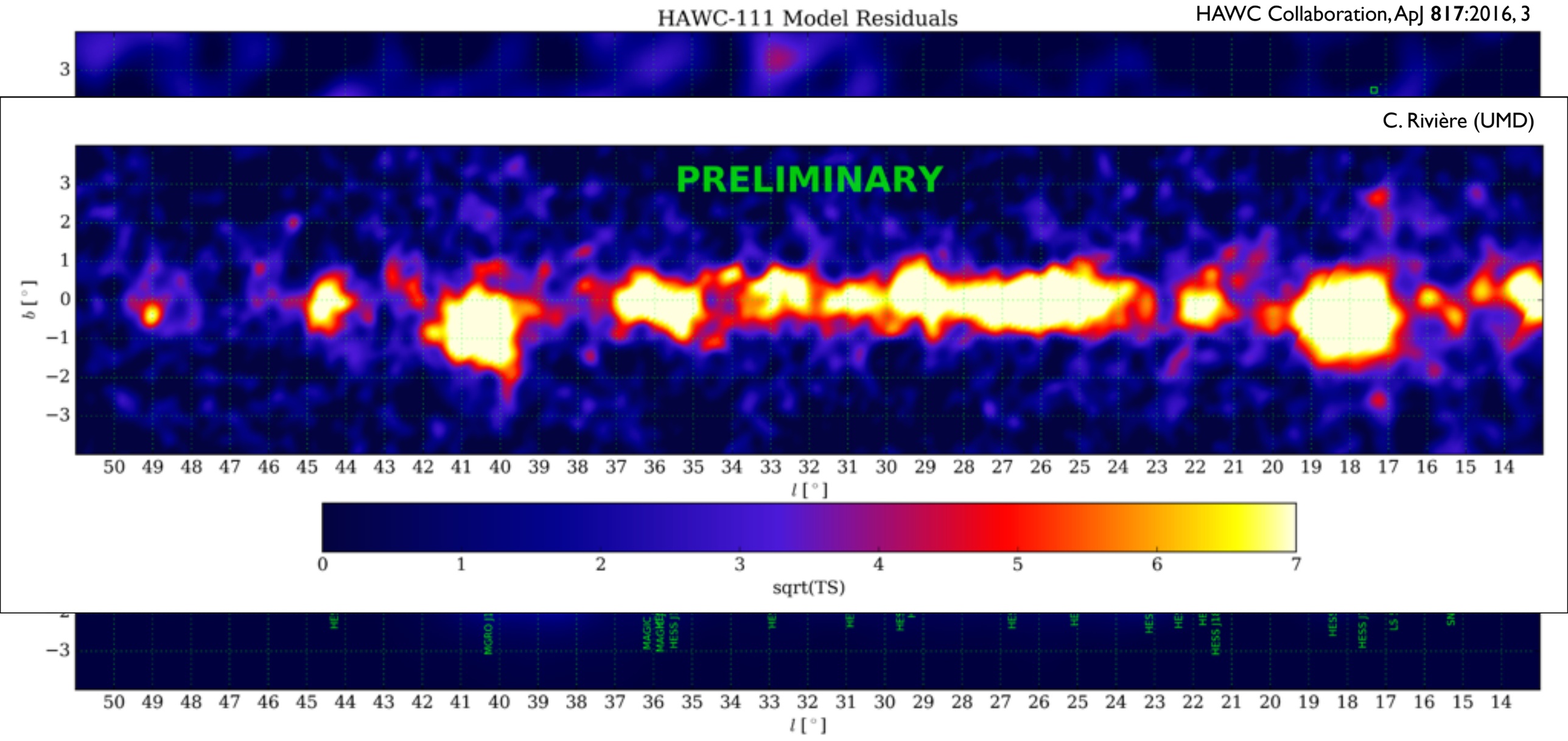


HAWC Collaboration, ApJ **817**:2016, 3

- Galactic Plane: point sources added to fit until improvement ΔTS < 15 with each additional source (10 src candidates)

Inner Galaxy: New Data

HAWC Collaboration, ApJ **817**:2016, 3

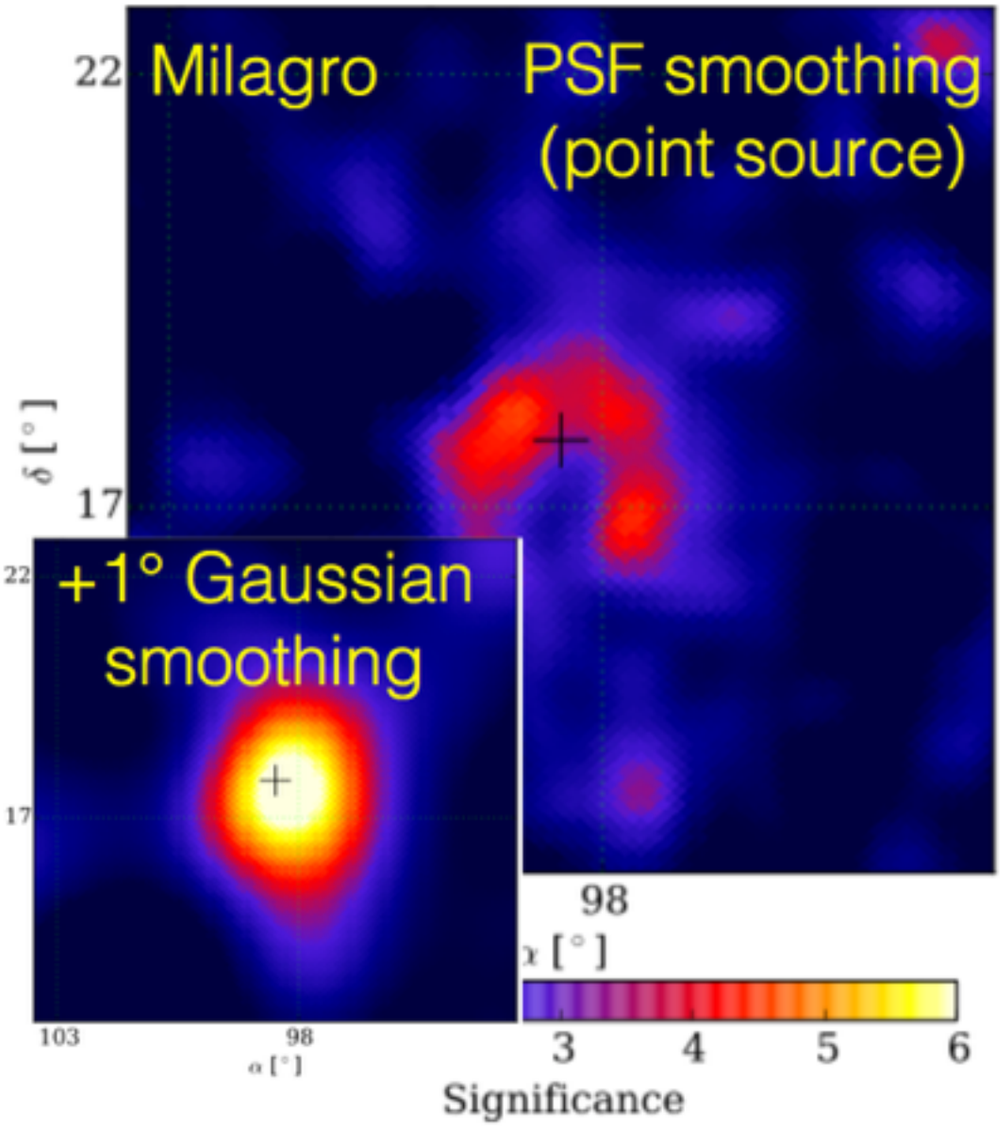


- Upcoming release: ~3x more sources, ~6 not previously measured at TeV. Challenging: src confusion, diffuse emission

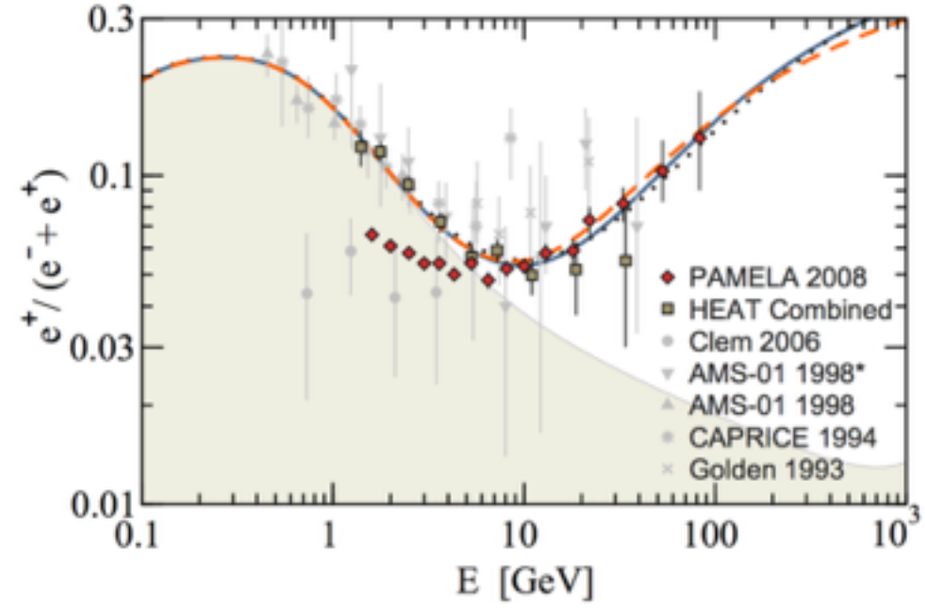
Extended Sources: Geminga

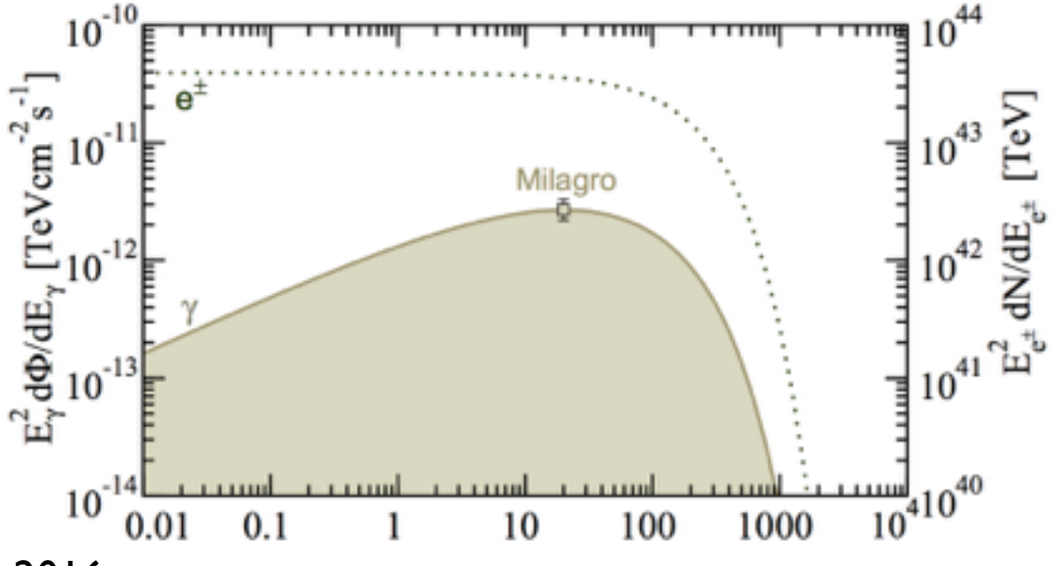
- Positron excess at Earth > 10 GeV; created by nearby pulsar?
- Geminga could be that pulsar. 300 kyr old, ~250 pc distant

Milagro Collaboration: ApJ **700**:2009, L27



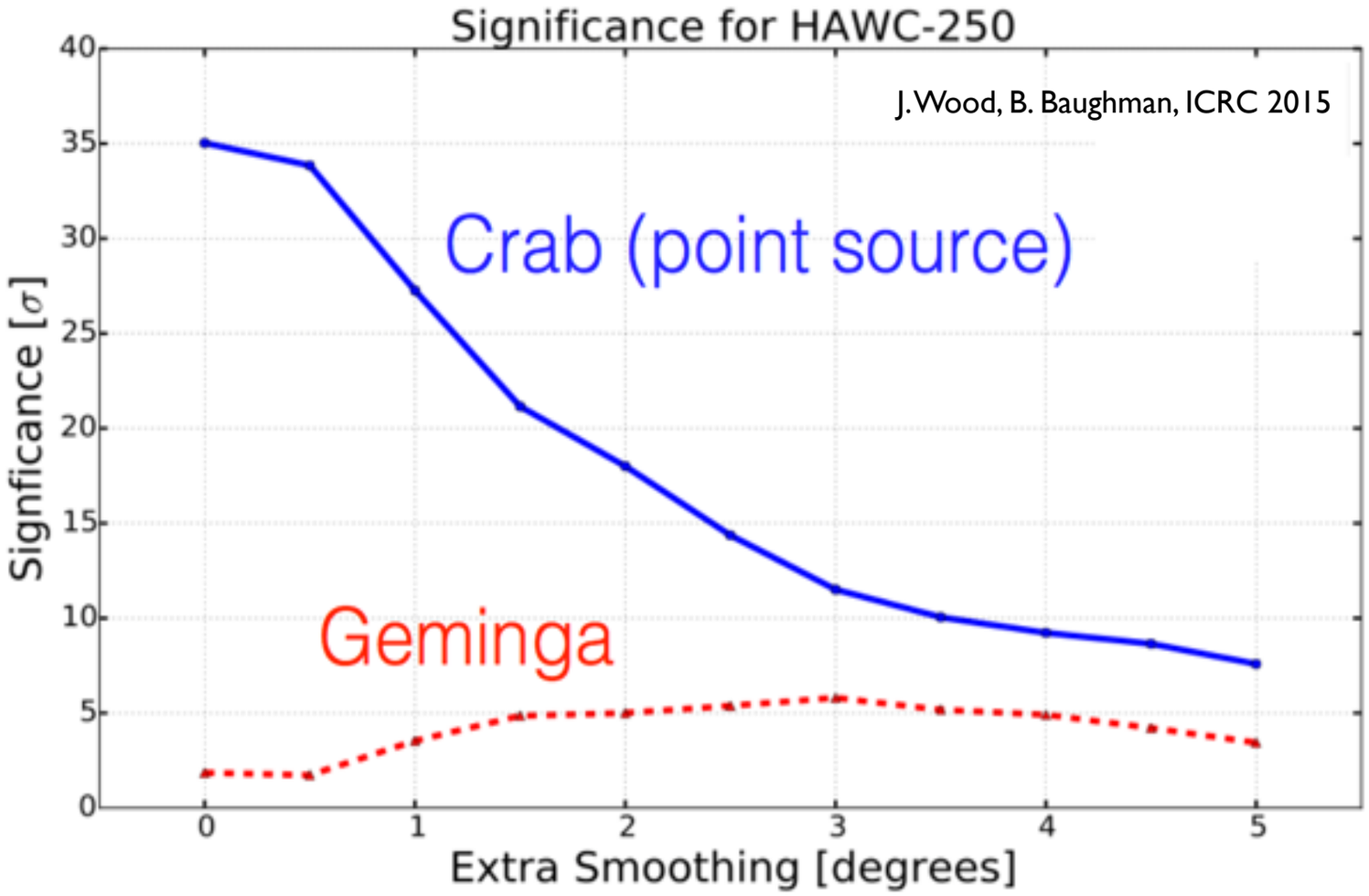
H. Yüksel et al., PRL **103**:0511101, 2009

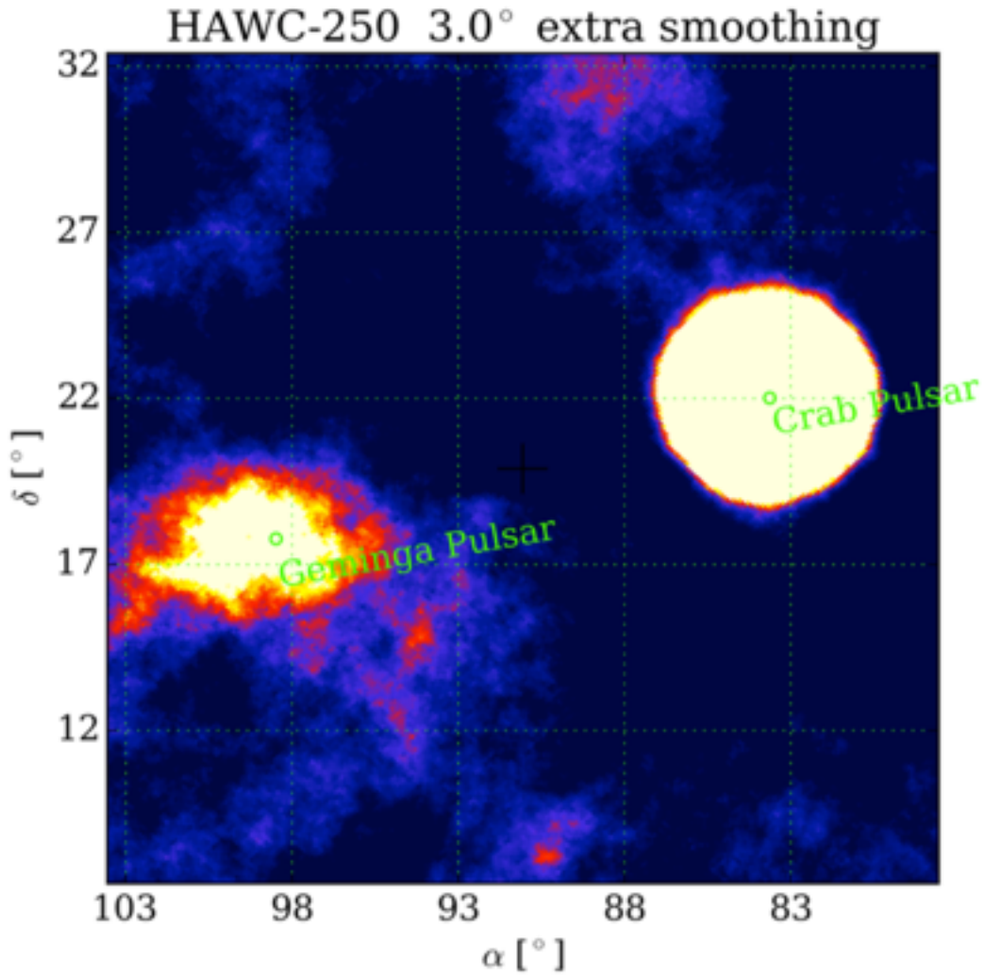




Observation with HAWC

- ICRC 2015: very extended emission, peak at ~3° smoothing
- Significance: ~4σ at location of pulsar
- Spectral index hard relative to the Crab Nebula



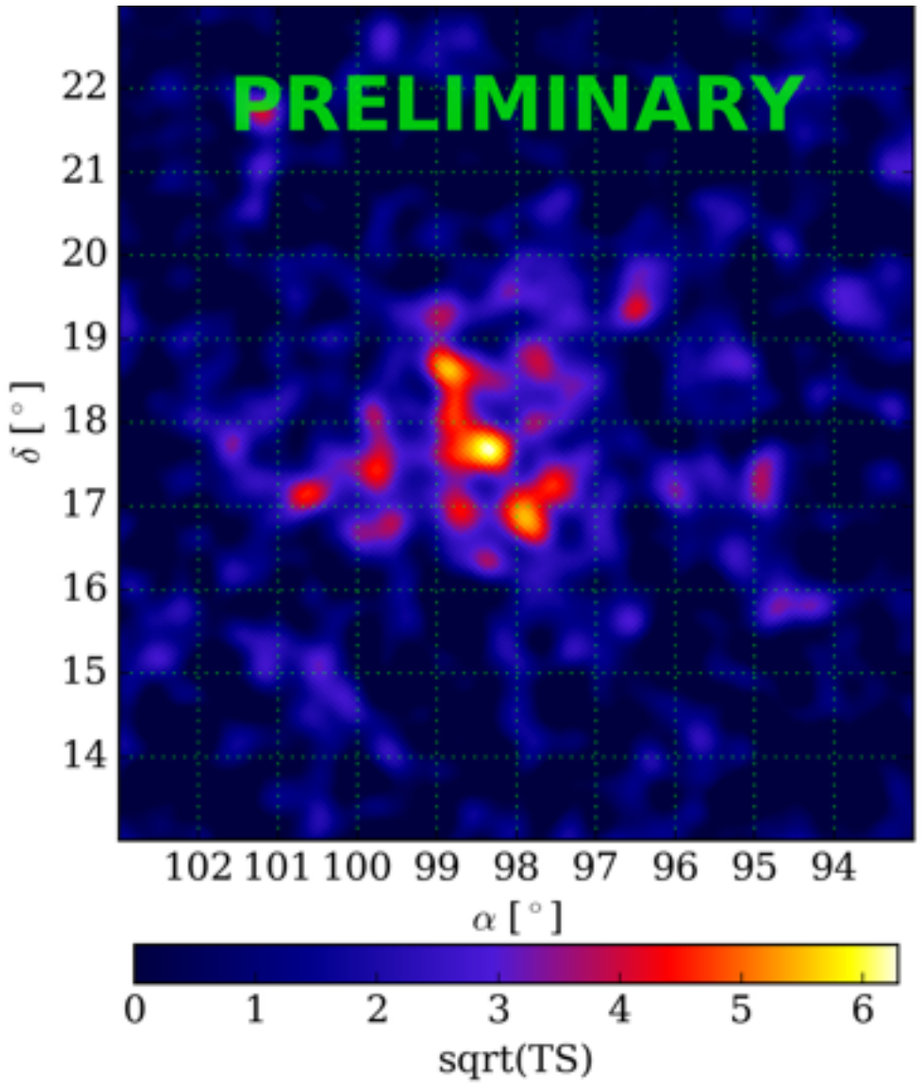


Observation with HAWC

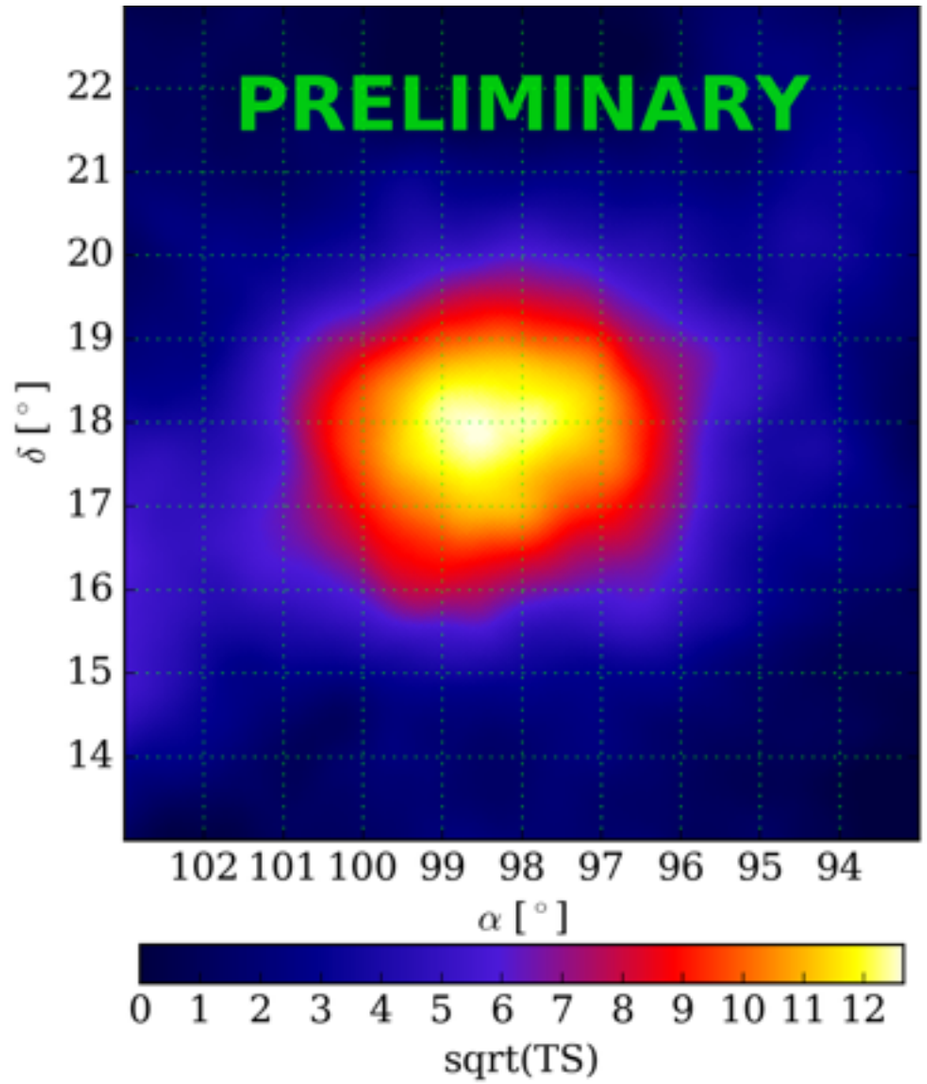
- New data: extended emission from nebula, pulsar not resolved

F. Salesa Greus (IFJ-PAN), H. Zhou (MTU)

Point Source Analysis



2° Top Hat Smoothing

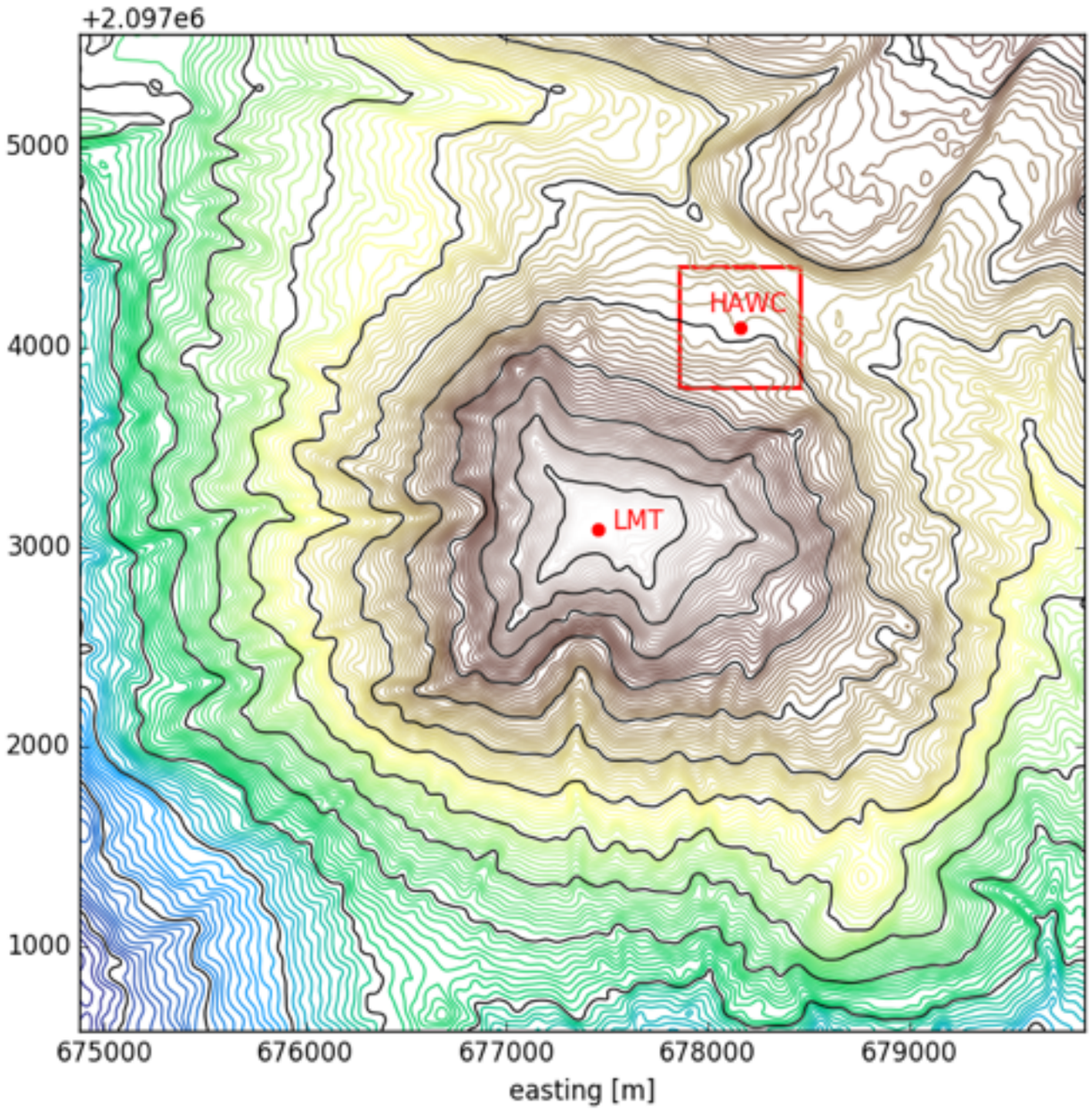


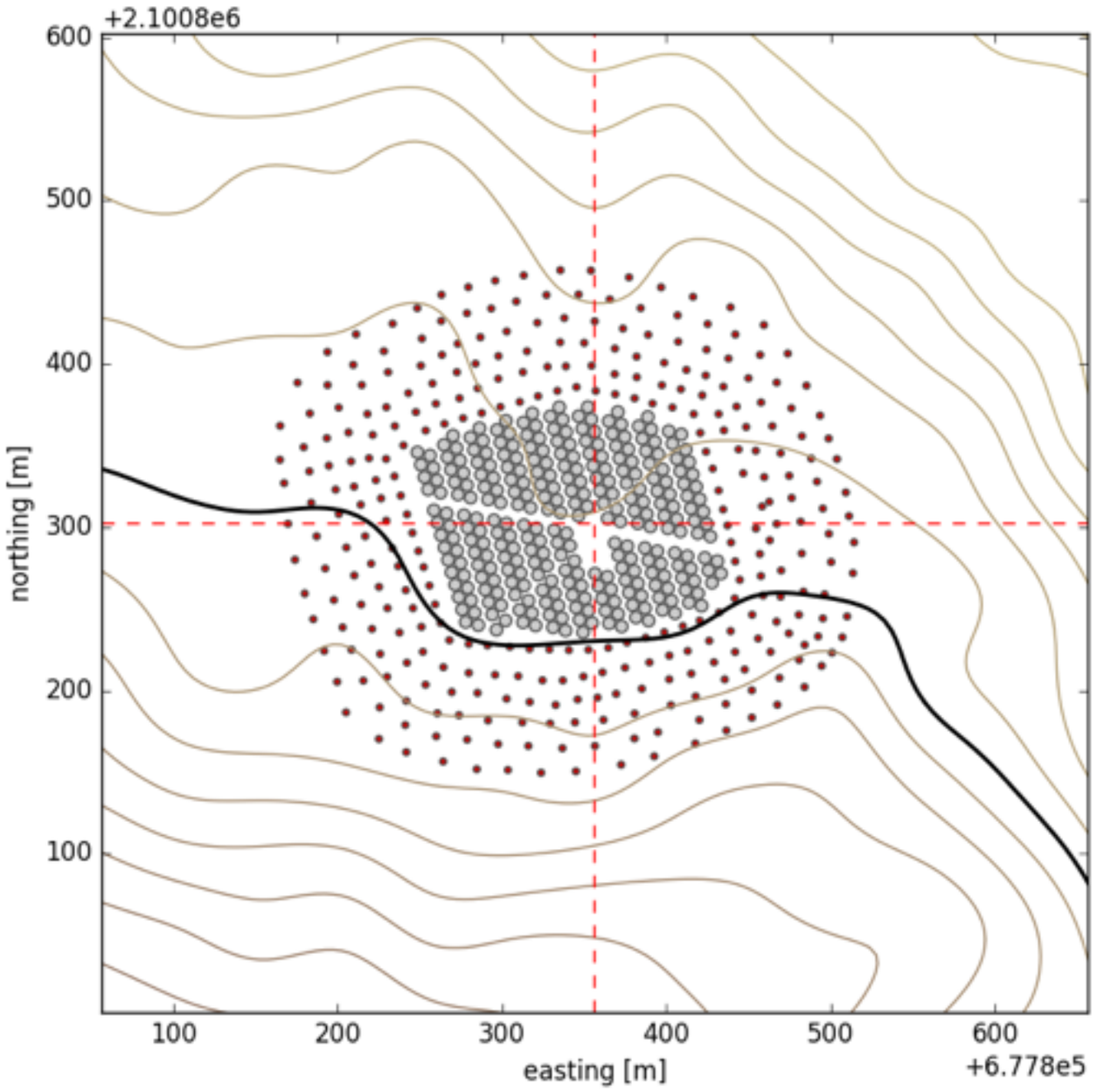
Origin of Local $e^{\pm}$?

- Note: no other TeV observations; limits on emission from the pulsar and surrounding nebula by MAGIC (arXiv:1603.00730). Angular extent makes observations very tough for IACTs
- Note: large nebula is also not observed at other wavelengths (~2' tails seen in X-ray: Caraveo et al., Science **301**:2003, 1345)
- What HAWC provides: estimates of the extent and energy spectrum of TeV gamma rays from the nebula. Questions:
  - Are these IC gamma rays from e+e-? Is the leptonic population consistent with the flux at Earth?
  - Sensitivity to diffusion coefficient
  - Analysis nearing completion…

HAWC Upgrades

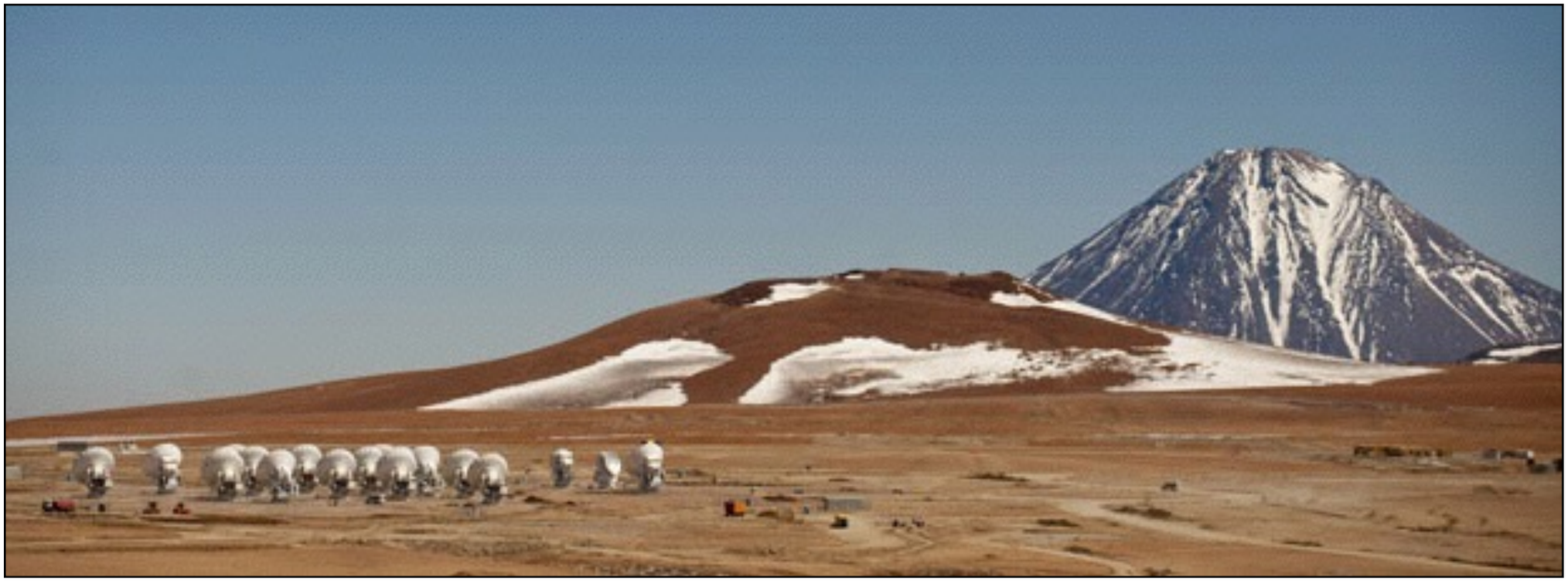
- High-energy extension: outrigger tanks funded (LANL LDRD)
- Rotoplas test tanks deployed and operated over winter 2015-2016





Southern Array?

- A high altitude site in the Southern Hemisphere (e.g., in the Atacama Desert, ~4800 to 5000 m a.s.l.) is under discussion



- Improved sensitivity at and below 1 TeV
- Exposure to Galactic Center, ~8 sr daily sky coverage
- High-uptime early warning system for CTA

Summary

- Construction of HAWC ended in December 2014; stable and reliable operation since
  - Live time exceeds 95%, excluding planned shutdowns
- Preliminary survey of inner Galaxy (excl. Galactic Center) published: ApJ **817**:2016, 3 — arXiv:1509.05401
- New point source list in preparation
- New measurements of very extended regions of TeV emission, not observed at other wavelengths
- Upgrades: high energy extension underway, southern hemisphere site under discussion