HAWC

High Altitude Water Cherenkov
Gamma-Ray Observatory

PennState
Eberly College of Science

NSF

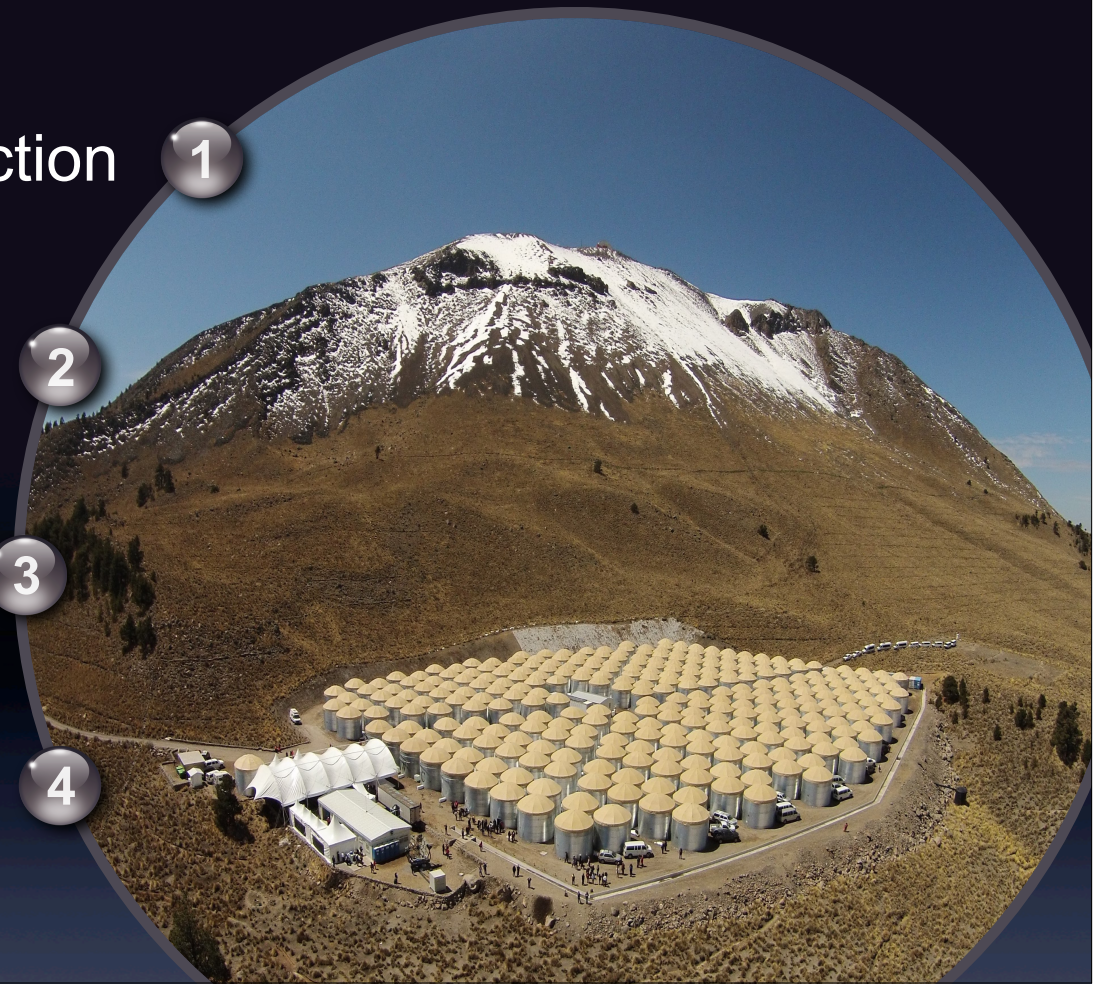
Outline

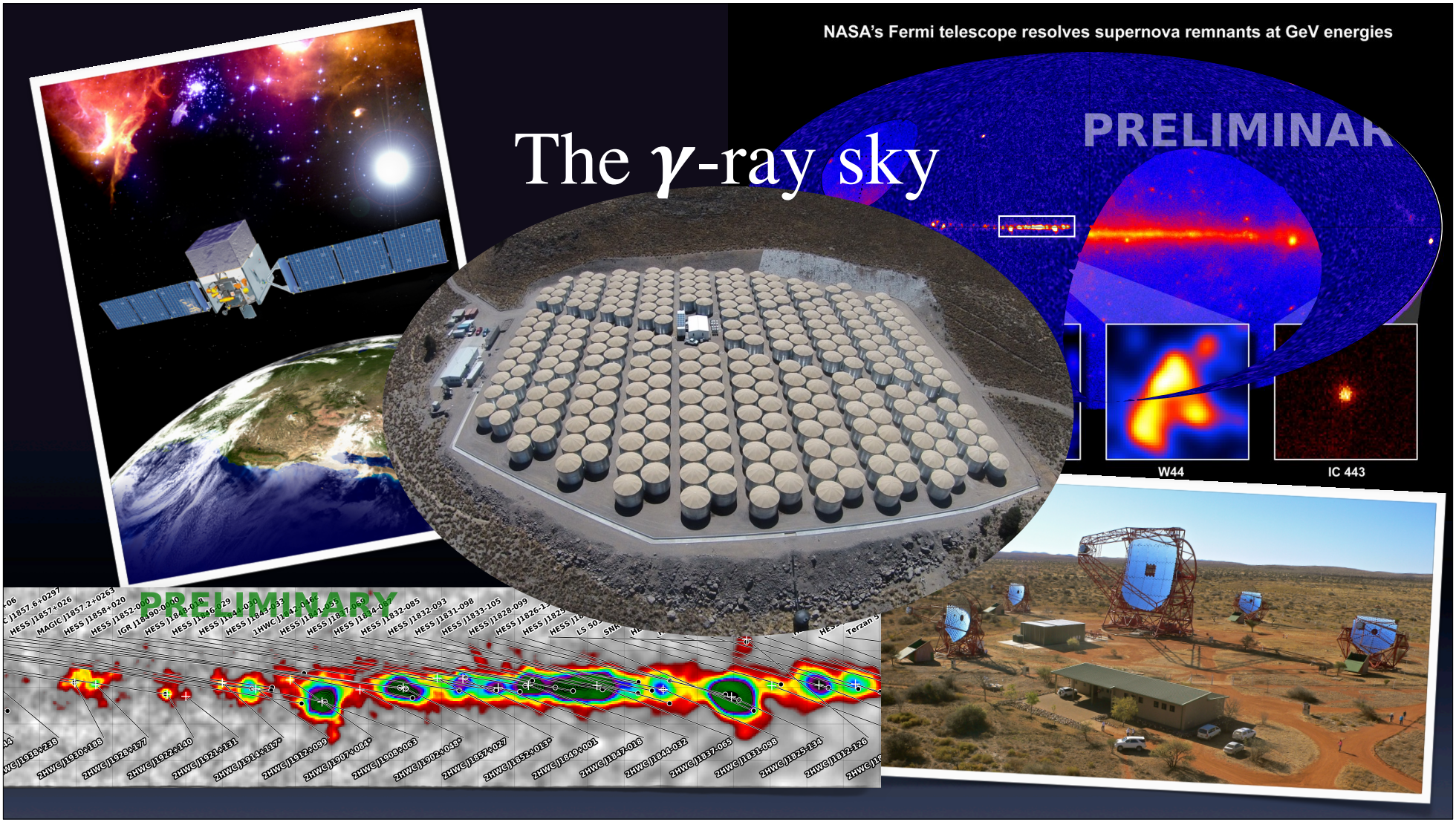
Very brief introduction 1

Selected recent results 2

On-going work 3

Outlook 4




NASA's Fermi telescope resolves supernova remnants at GeV energies
The γ-ray sky
PRELIMINAR
W44
IC 443
PRELIMINARY

Catching Some Rays

A simple but groundbreaking observatory in central Mexico is shedding new light on the workings of cosmic and gamma rays in Earth's atmosphere. Formally opened a year ago, the High-Altitude Water Cherenkov Gamma-Ray Observatory will be used by scientists to gather information on high-energy particle acceleration for 10 years. The observatory is perched on the side of the Sierra Negra volcano, almost 14,000 feet above sea level. Segev BenZvi, an assistant professor of physics, helped to create the observatory and is part of the team now carrying out research there.

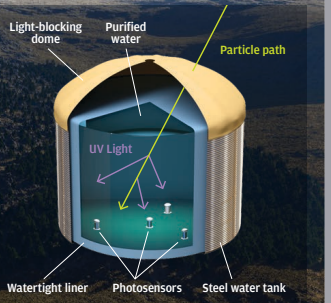
Citlaltépetl (Pico de Orizaba) 18,491 feet

Air Showers

When high-energy gamma rays and cosmic rays interact high in the atmosphere, they create a particle cascade that peaks as it falls to Earth and wanes before it reaches the ground. The cascade, which moves at the speed of light, looks like a pancake that grows wider and wider as it nears ground level.

Gamma Rays

Using the observatory, scientists can distinguish between air showers created by gamma rays and cosmic rays. At ground level, most of the signal from the particle cascade is centered around the direction of the initial gamma ray. But cosmic ray showers are much less orderly, breaking apart as they descend.



Cherenkov Effect

When particles reach the ground, they move through the water tanks, producing ultraviolet light, in a process known as the Cherenkov effect. Photosensors in each tank record the light. By studying when the sensors are triggered, researchers can deduce information about the air shower of particles.

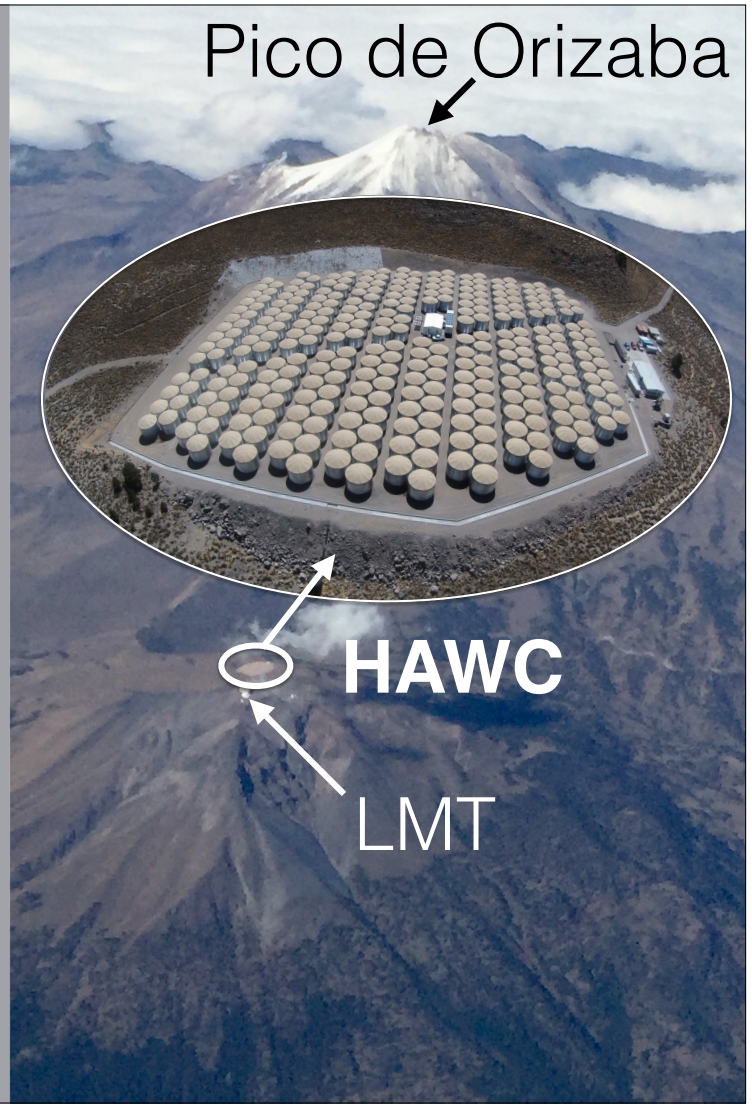
Water Cherenkov Tank Array

Giant water tanks outfitted with photosensors sample air-shower particles by recording the light produced when the particles move through the water.

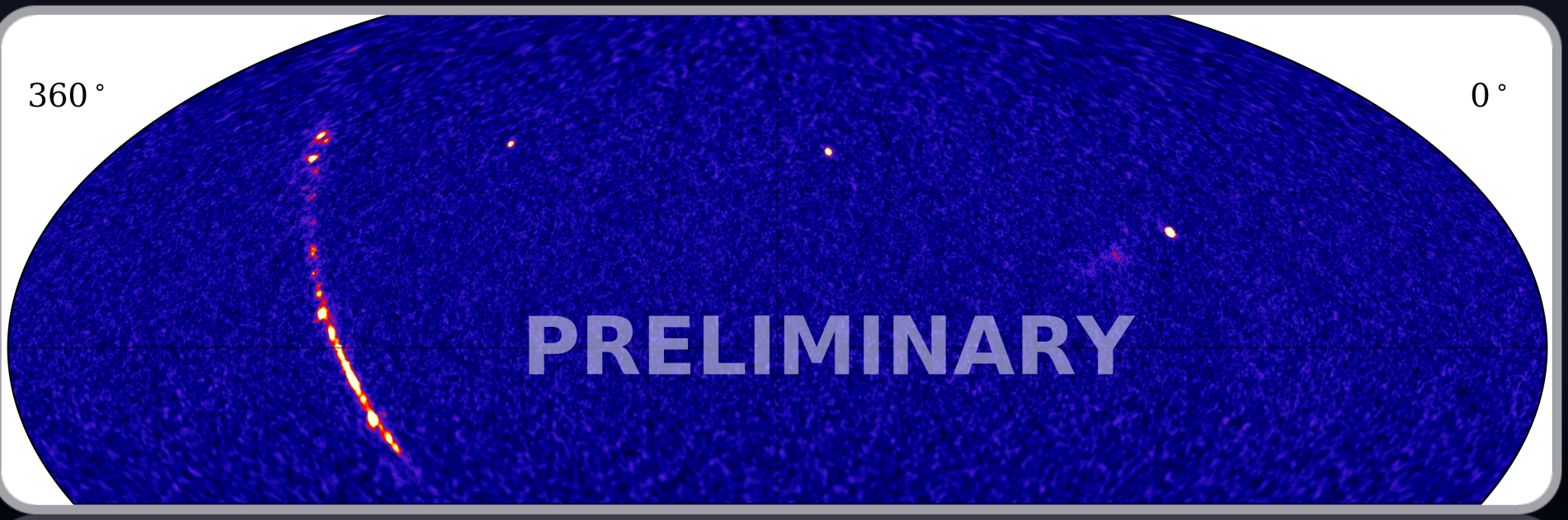
High-Altitude Water Cherenkov Gamma-Ray Observatory

ROCHESTER REVIEW May-June 2016

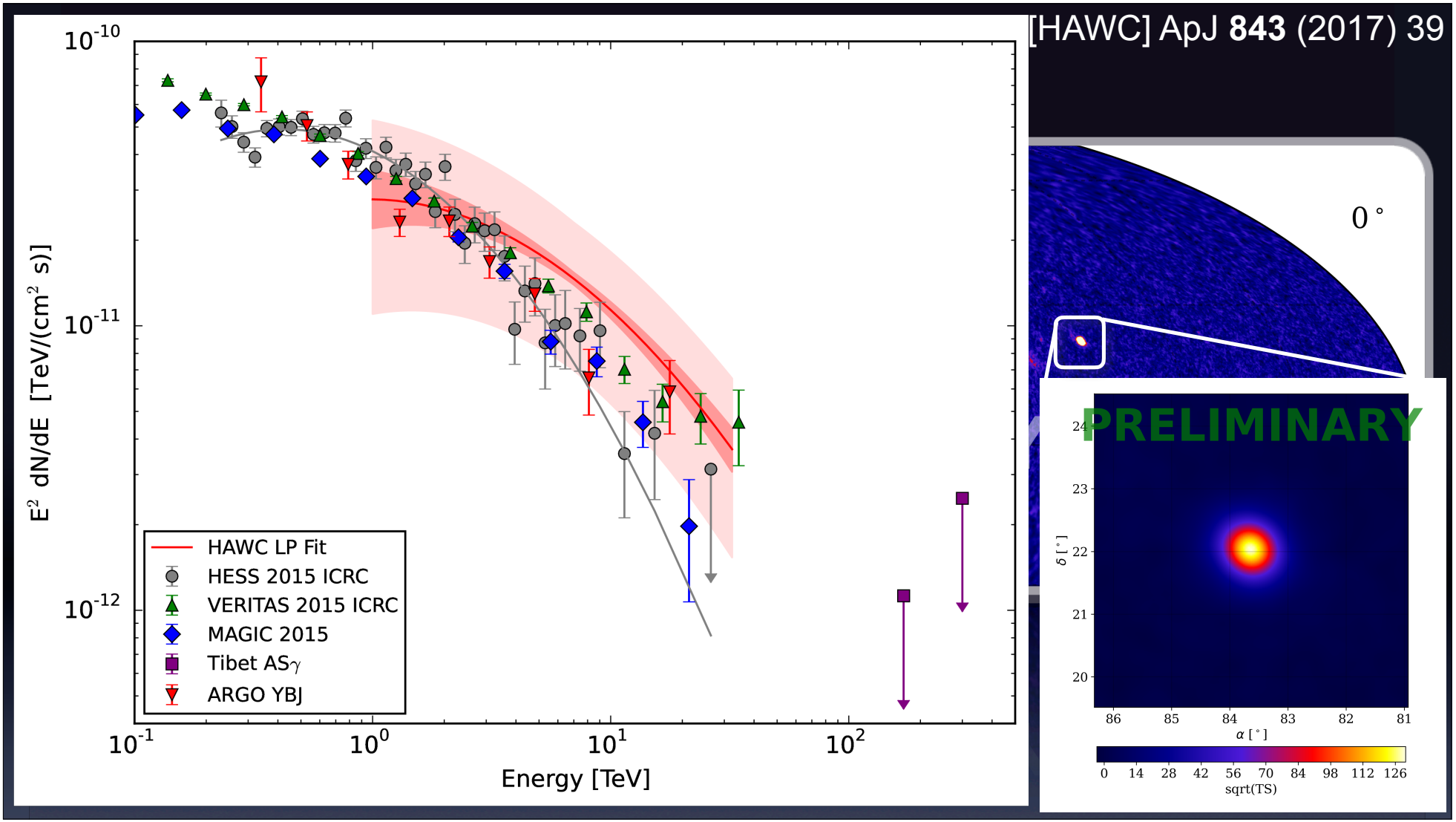
STEVE BOERNER (ILLUSTRATION) /SOURCE: THE HAWC COLLABORATION (WWW.HAWC-OBSERVATORY.ORG)



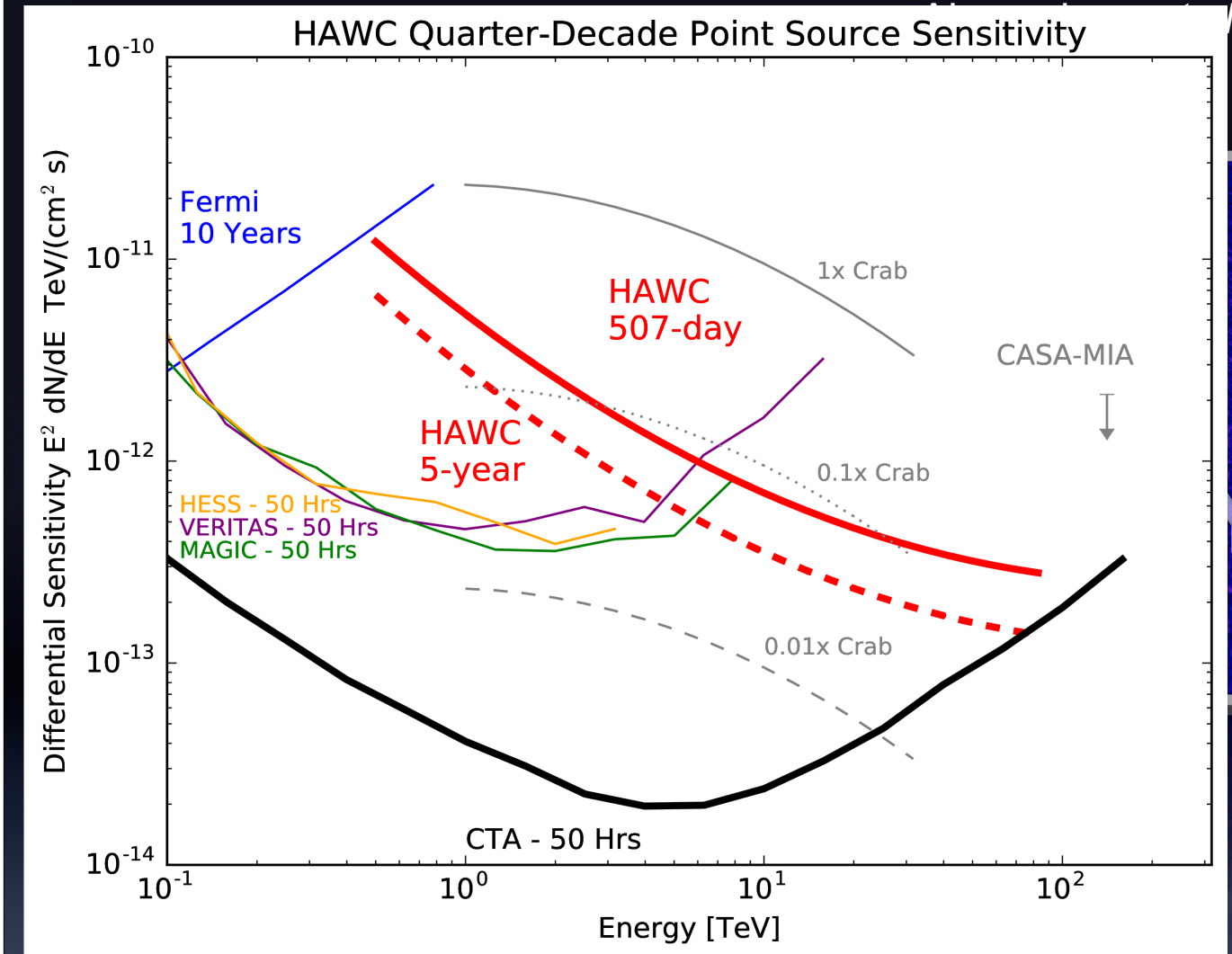
HAWC — 2-year TeV sky

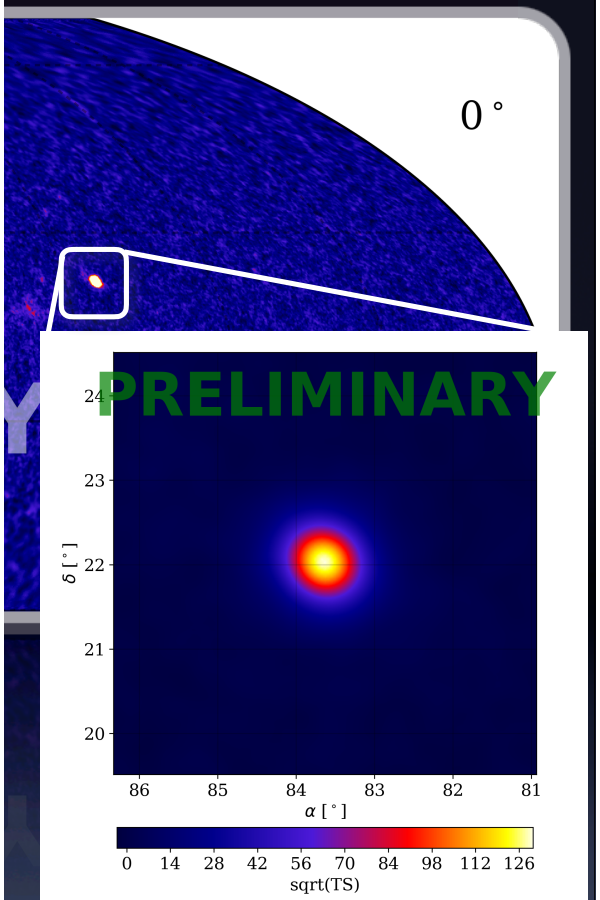


HAWC smoothed map
E > 500 GeV (Pass 4 ~2 years of data)

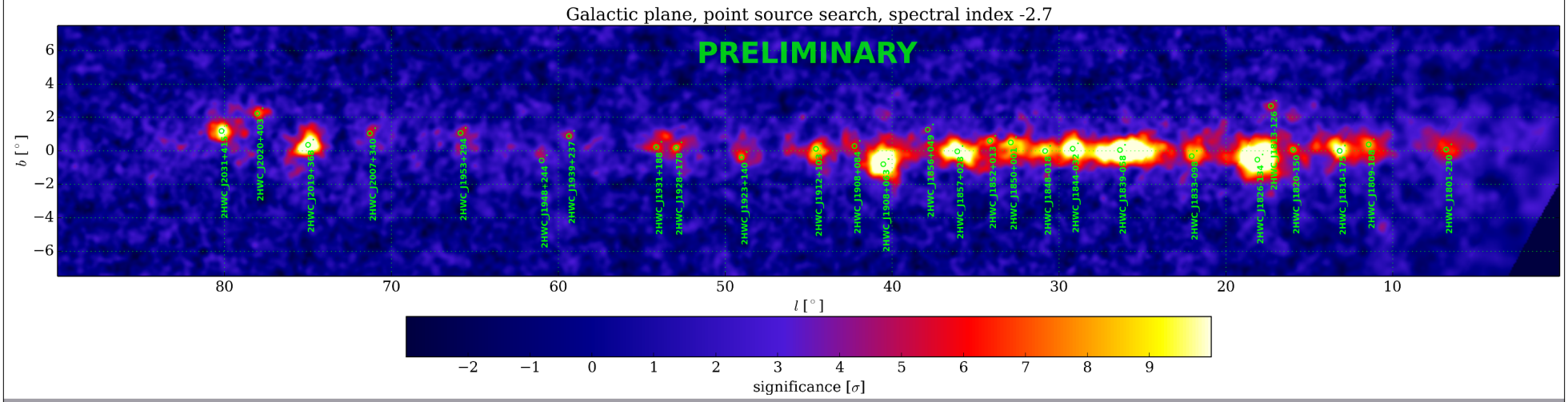

[HAWC] ApJ **843** (2017) 39
10^{-10}
10^{-11}
10^{-12}
E^2 dN/dE [TeV/(cm^2 s)]
HAWC LP Fit
HESS 2015 ICRC
VERITAS 2015 ICRC
MAGIC 2015
Tibet ASγ
ARGO YBJ
10^{-1}
10^{0}
10^{1}
10^{2}
Energy [TeV]
0 °
PRELIMINARY
24
23
22
21
20
δ [°]
86
85
84
83
82
81
α [°]
0
14
28
42
56
70
84
98
112
126
sqrt(TS)

[HAWC] ApJ **843** (2017) 39

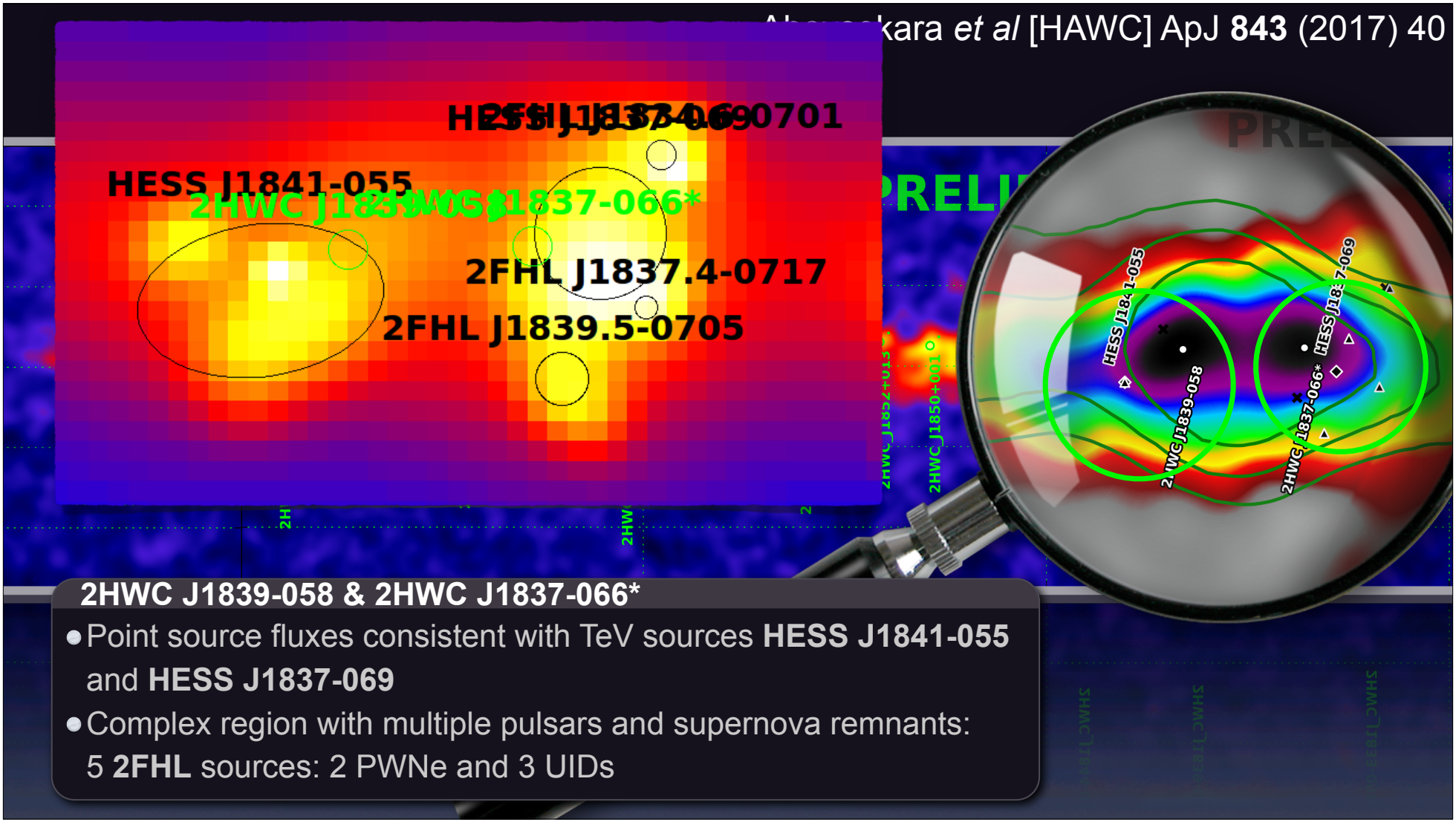




Abeysekara *et al* [HAWC] ApJ **843** (2017) 40

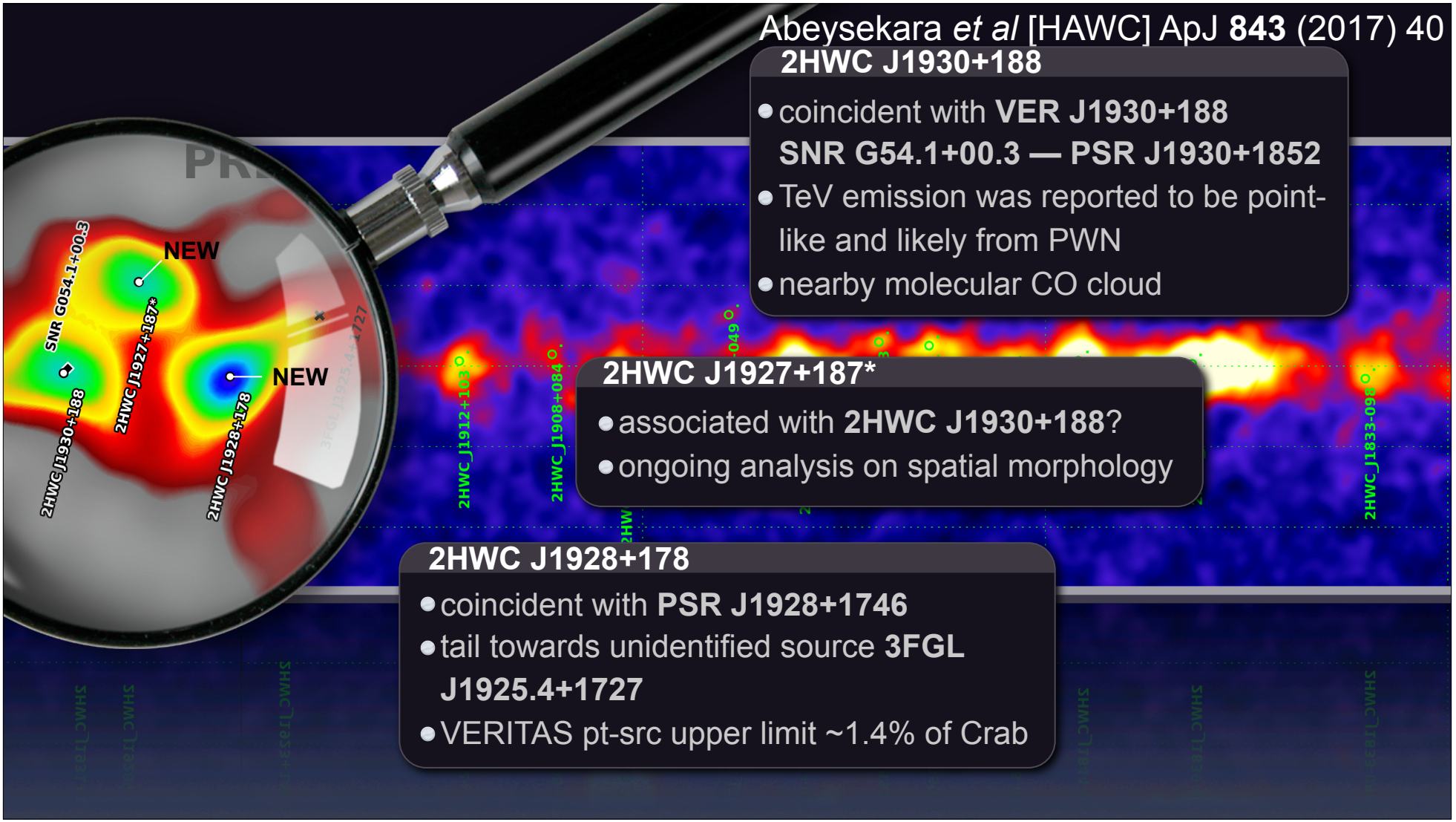


First HAWC catalog

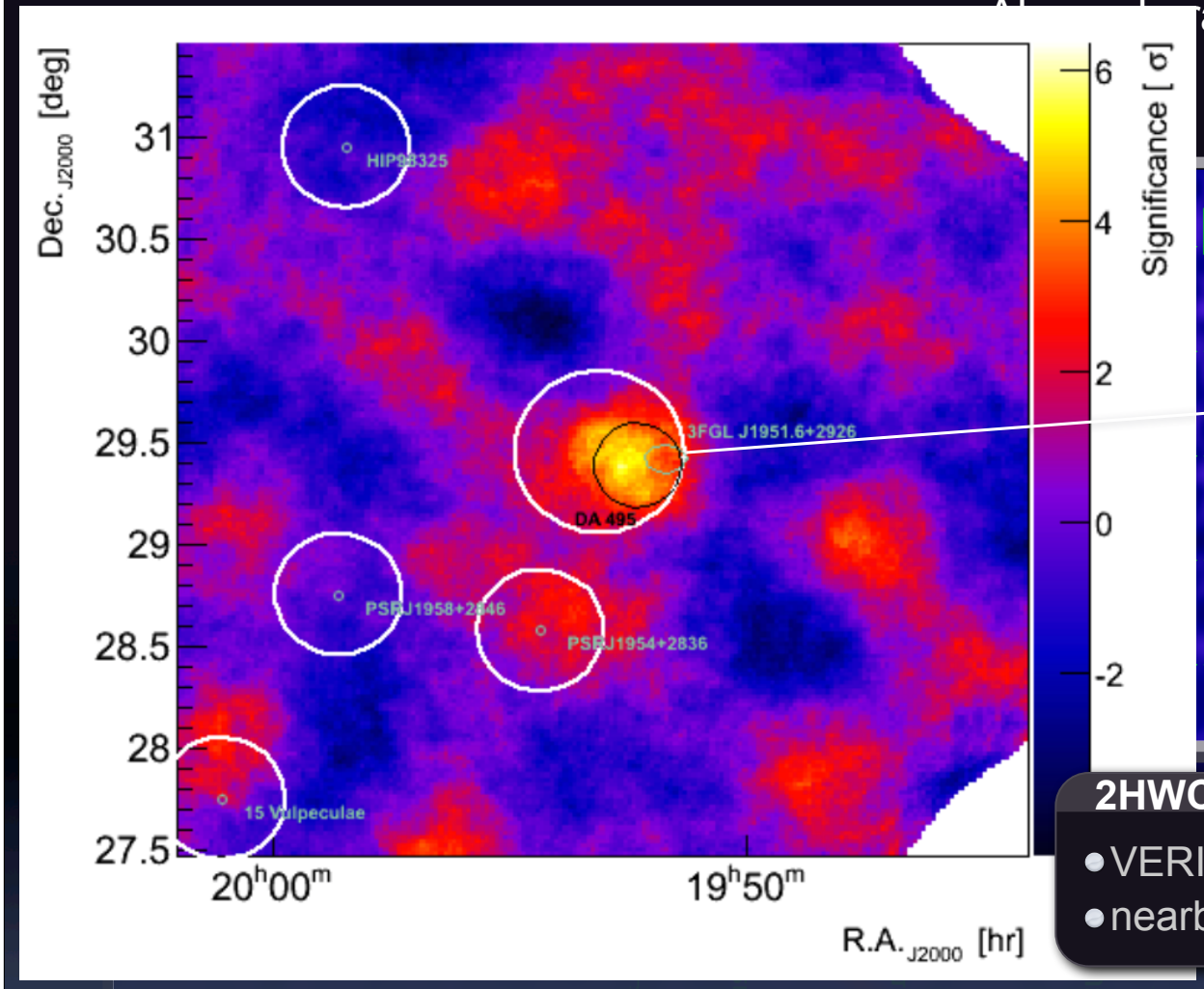


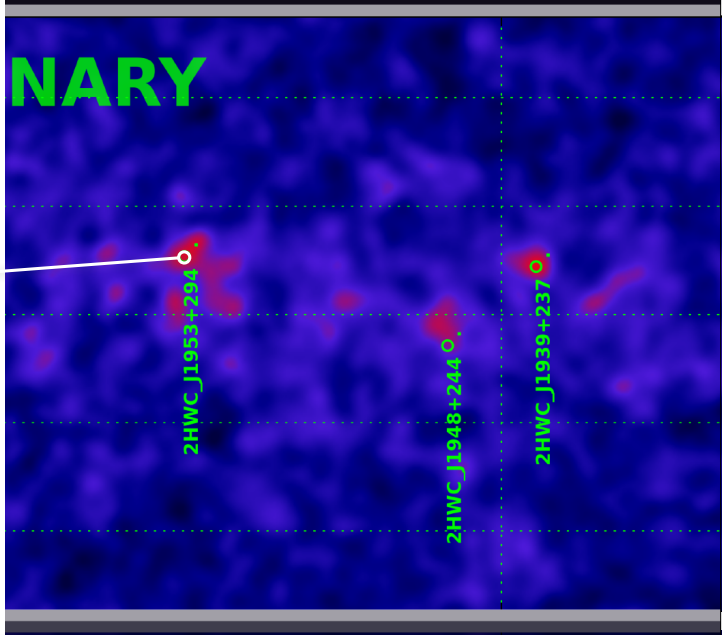
2HWC J1839-058 & 2HWC J1837-066*

- Point source fluxes consistent with TeV sources **HESS J1841-055** and **HESS J1837-069**
- Complex region with multiple pulsars and supernova remnants: 5 **2FHL** sources: 2 PWNe and 3 UIDs


Abeysekara *et al* [HAWC] ApJ **843** (2017) 40
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
2HWC J1927+187*
- associated with **2HWC J1930+188**?
- ongoing analysis on spatial morphology
2HWC J1928+178
- coincident with **PSR J1928+1746**
- tail towards unidentified source **3FGL J1925.4+1727**
- VERITAS pt-src upper limit ~1.4% of Crab
NEW
NEW
SNR G054.1+00.3
2HWC J1927+187*
2HWC J1930+188
2HWC J1928+178
2HWC J1912+103
2HWC J1908+084
2HWC J1833-098

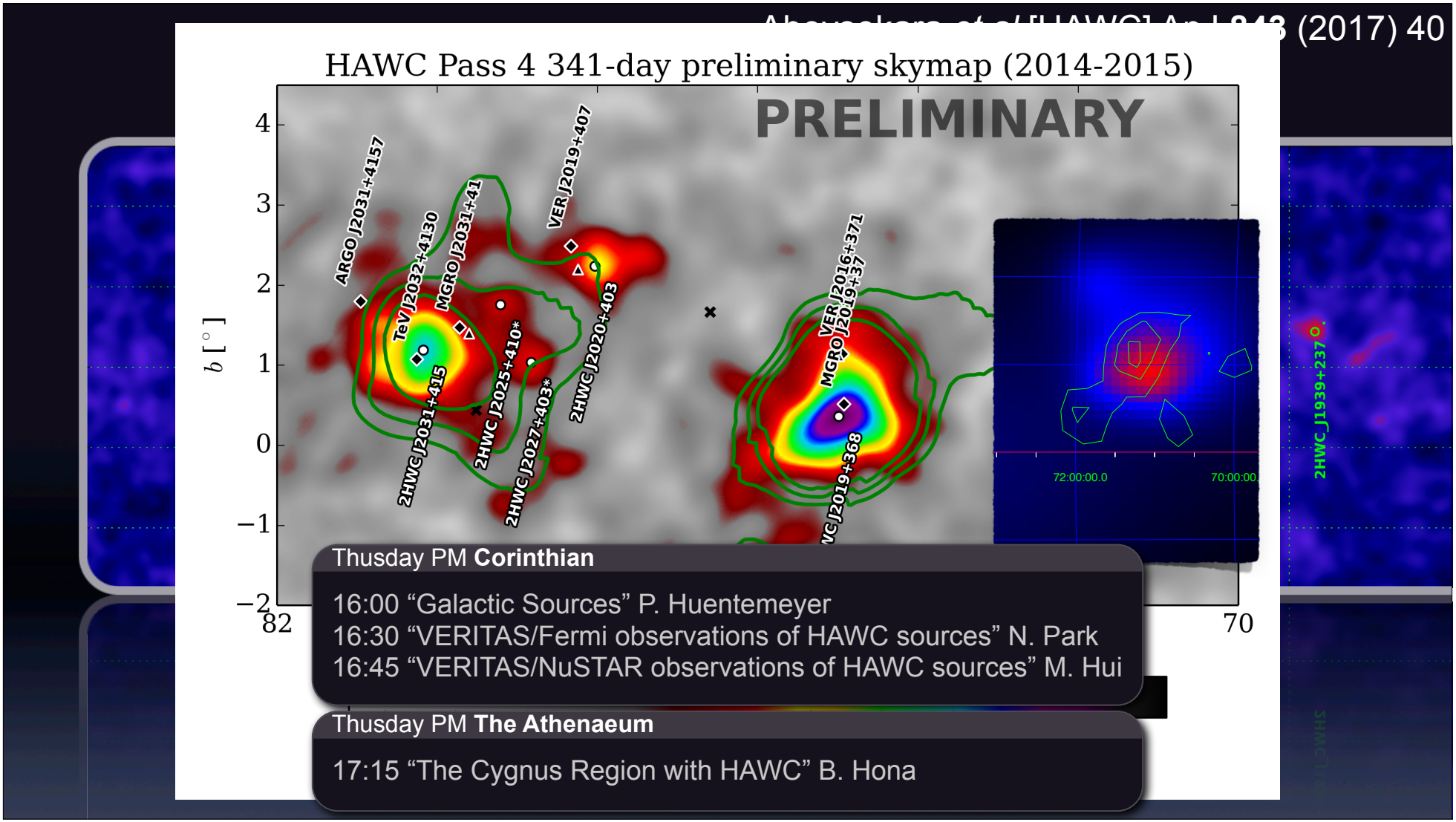
a *et al* [HAWC] ApJ **843** (2017) 40





2HWC J1953+294

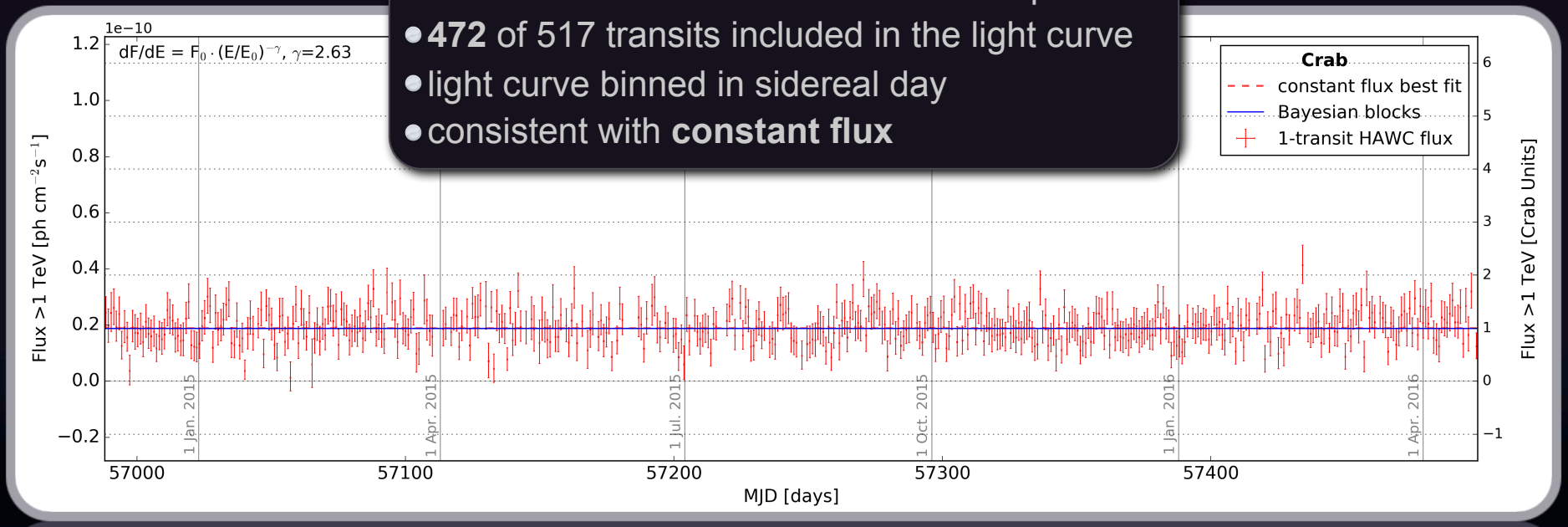
- VERITAS confirms **HAWC detection**
- nearby PWN likely counterpart


HAWC Pass 4 341-day preliminary skymap (2014-2015)
PRELIMINARY
ARGO J2031+4157
TeV J2032+4130
MGRO J2031+41
VER J2019+407
2HWC J2031+415
2HWC J2025+410*
2HWC J2027+403*
2HWC J2020+403
VER J2016+371
MGRO J2019+37
2HWC J2019+368
2HWC J1939+237
72:00:00.0
70:00:00
b [°]
4
3
2
1
0
−1
−2
82
70
Thusday PM Corinthian
16:00 “Galactic Sources” P. Huentemeyer
16:30 “VERITAS/Fermi observations of HAWC sources” N. Park
16:45 “VERITAS/NuSTAR observations of HAWC sources” M. Hui
Thusday PM The Athenaeum
17:15 “The Cygnus Region with HAWC” B. Hona

Abeysekara *et al* [HAWC] ApJ **841** (2017) 100

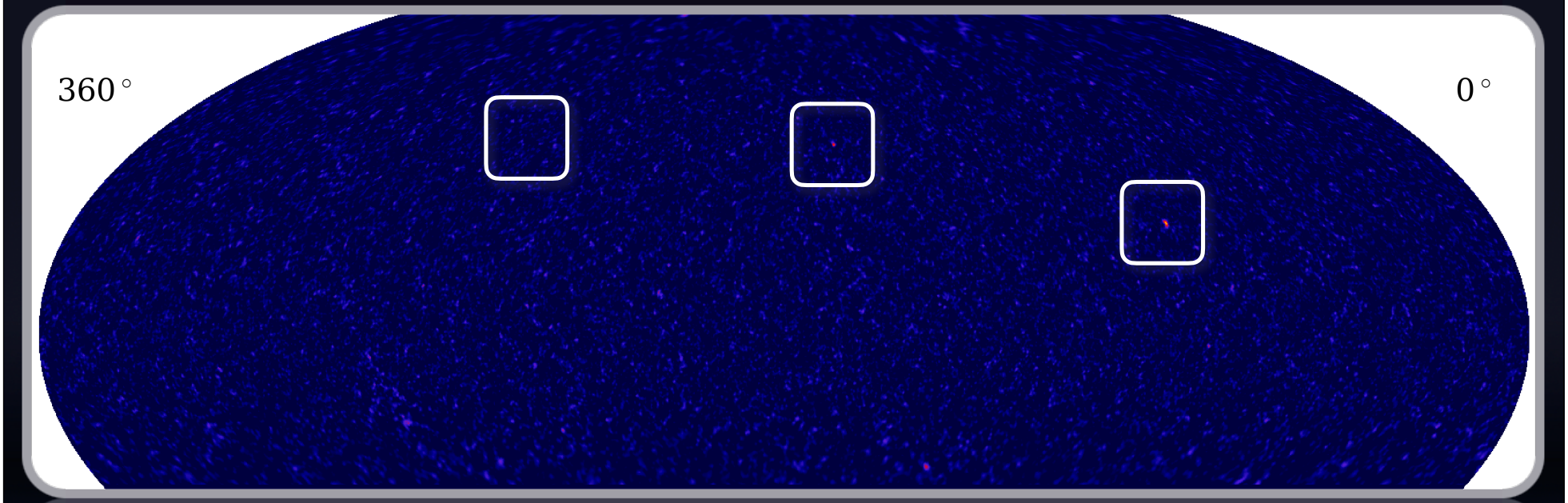
Crab

- Pass 4 data from 26 Nov **2014** to 20 Apr **2016**
- **472** of 517 transits included in the light curve
- light curve binned in sidereal day
- consistent with **constant flux**



Transient searches

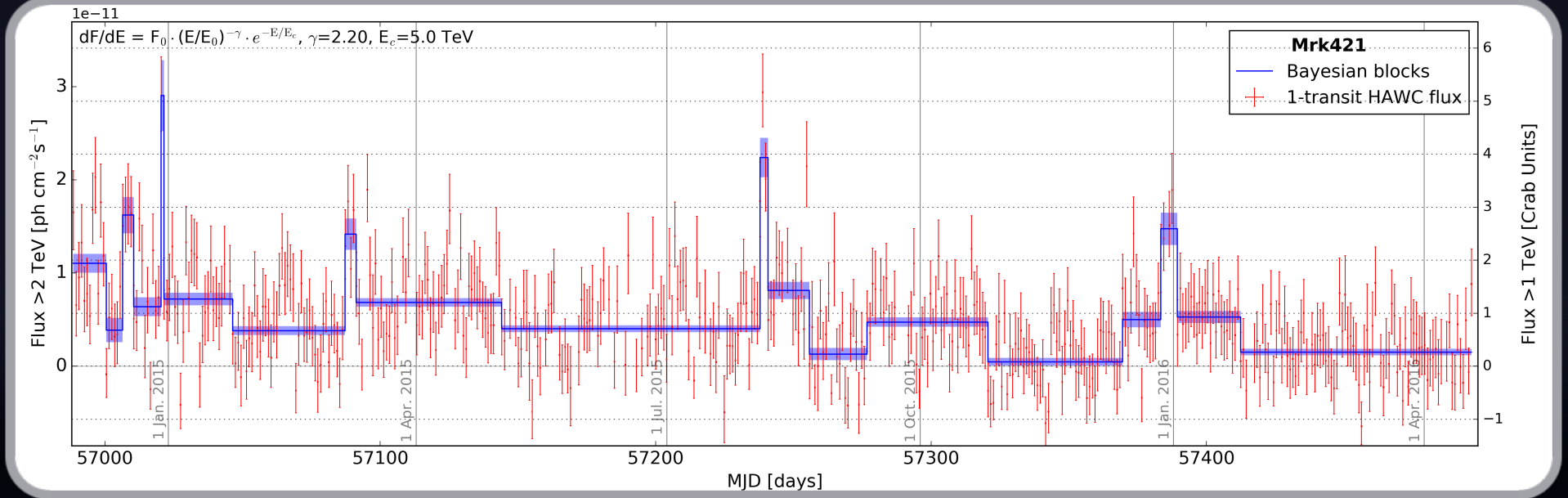
HAWC — daily fluxes in Aug 2015



Transient searches

Abeysekara *et al* [HAWC] ApJ **841** (2017) 100

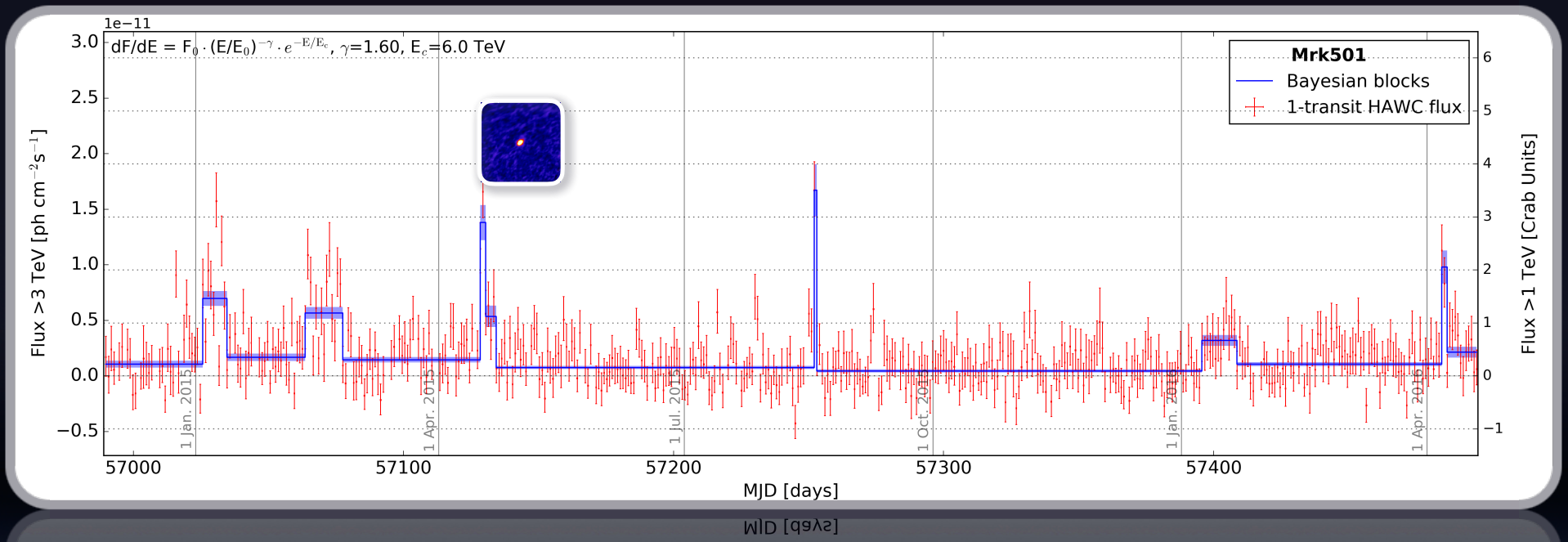
Mrk 421 — light curve



Transient searches

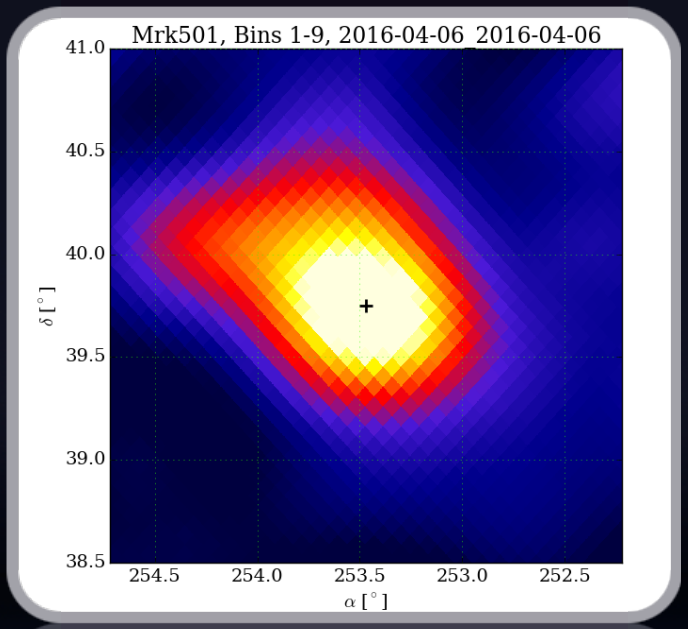
Abeysekara *et al* [HAWC] ApJ **841** (2017) 100

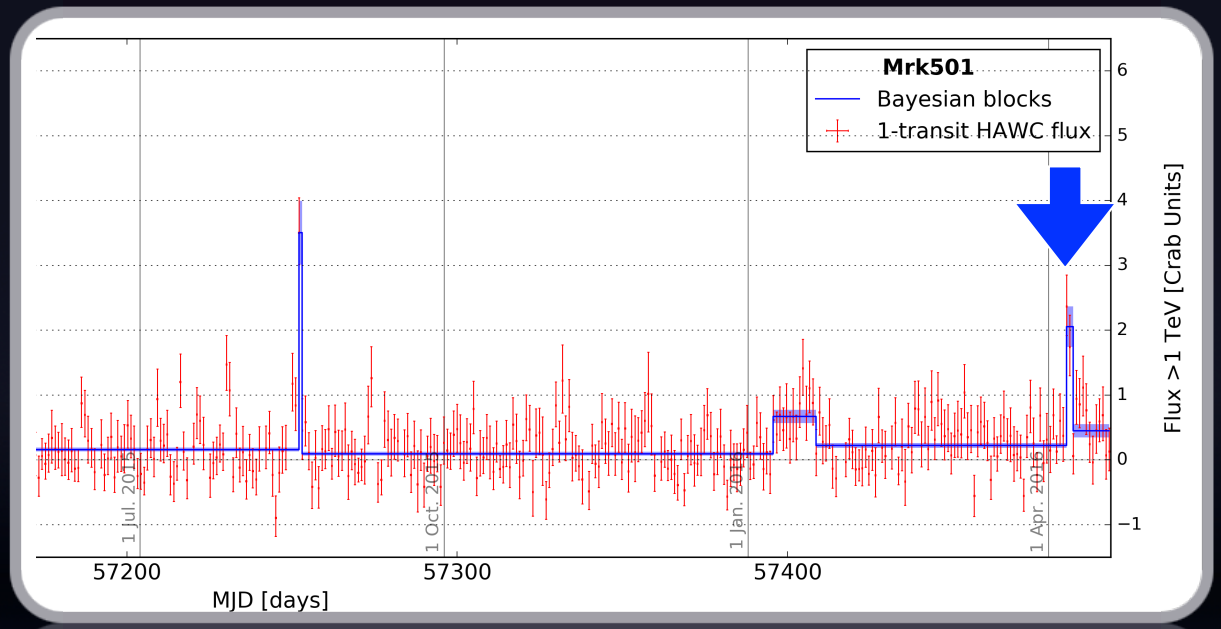
Mrk 501 — light curve



Transient searches

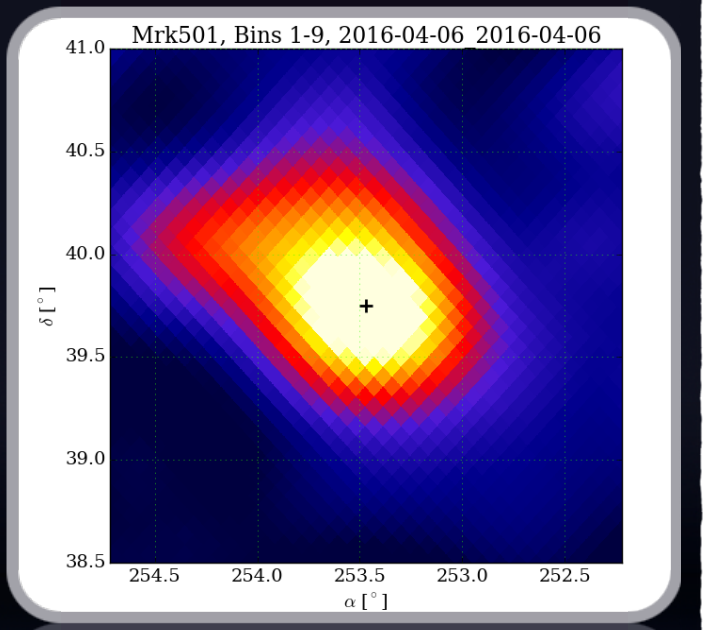
Mrk 501 — light curve





April 6, 2016

AGN flares with HAWC



April 6, 2016

AGN

HAWC detection of increased TeV flux state for Markarian 501

ATel #8922; *Andrés Sandoval (IF-UNAM), Robert Lauer (UNM), Joshua Wood (UMD) on behalf of the HAWC collaboration*
on 7 Apr 2016; 23:38 UT
Credential Certification: C. Michelle Hui (c.m.hui@nasa.gov)

Subjects: Gamma Ray, TeV, VHE, Request for Observations, AGN, Blazar

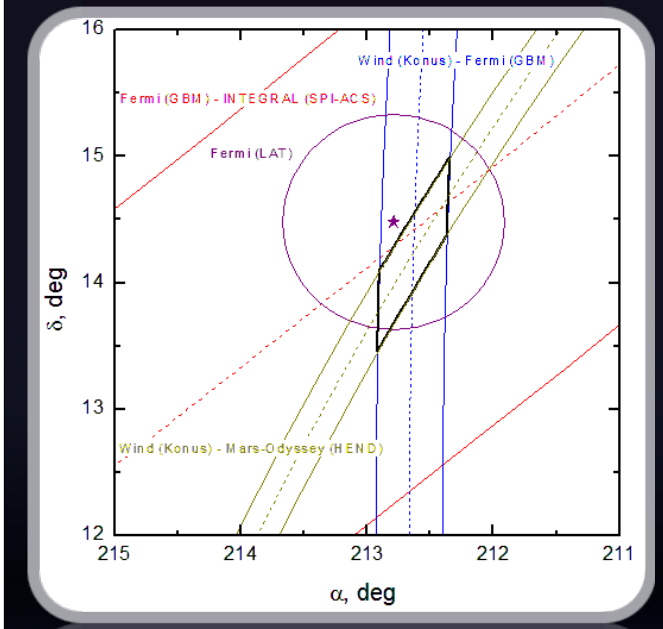
Tweet Recommend 15

The HAWC Observatory measured an increased gamma-ray flux from the direction of the BL Lac Markarian 501 (z=0.033) at the level of (4.88 +/- 1.05) x 10e-11 photons cm^-2 s^-1 above 1 TeV when averaged during the 6 hour transit over HAWC on April 6, 2016 (MJD 57484.31 - 57484.56) which is 2.2 times the average Crab flux observed by HAWC. For the following transit on April 7, 2016 (MJD 57485.30 - 57485.55), a decreased but still above-average flux of (2.78 +/- 0.09) x 10e-11 photons cm^-2 s^-1 was observed, 1.3 times the Crab flux seen by HAWC. The flux on April 6 lies 4 sigma above the average flux of 0.89 x 10e-11 photons cm^-2 s^-1 that was measured for this source by HAWC during the previous year. The flux level on April 7 is 2 sigma above this average and seems to indicate a declining but on-going high flux state. All flux values are obtained from a maximum likelihood fit under the assumption of a fixed spectral shape with power law index of 1.8 and exponential cut-off at 6 TeV. These spectral parameters are the best fit results for HAWC data from Markarian 501 collected between November 2014 and December 2015. HAWC is a TeV gamma ray water Cherenkov array located in the state of Puebla, Mexico that monitors 2/3 of the sky every day with an instantaneous field of view of ~2 sr. The HAWC contact people for this
and Michelle Hui (Mar

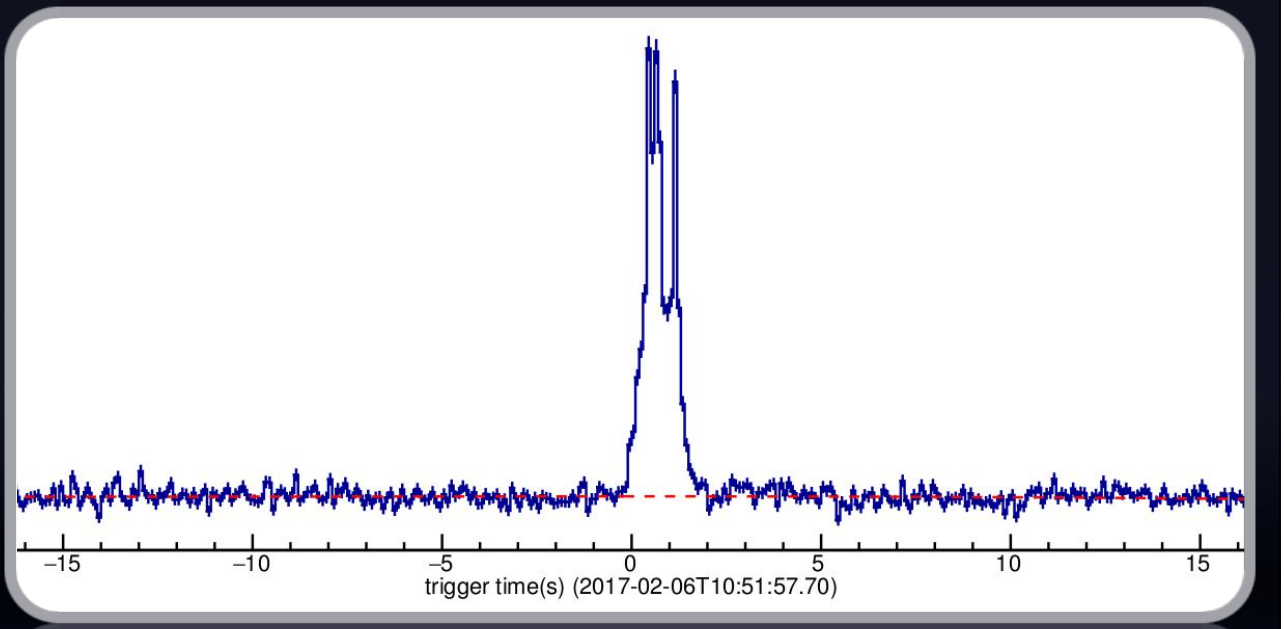
Thusday PM **Macedonian**

16:45 “HAWC real-time flare monitor” T. Weisgarber

IPN triangulation map



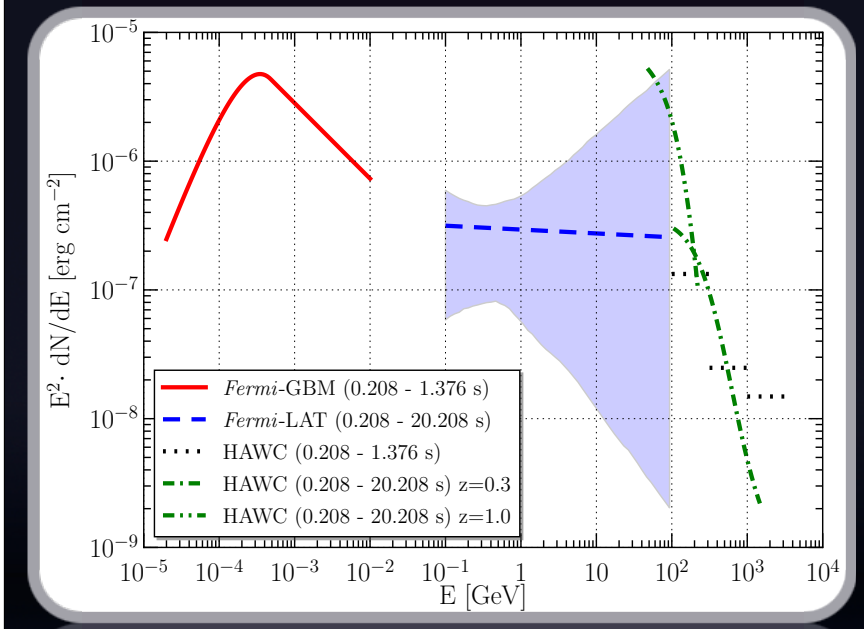
GBM light curve



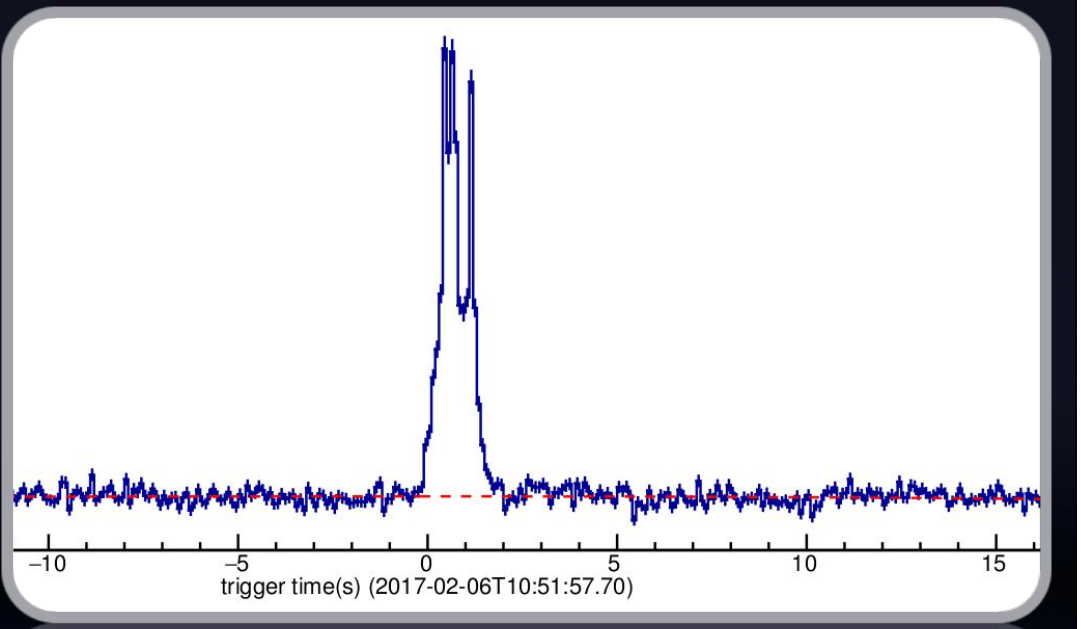
GRB 170206A

Alfaro *et al* [HAWC] ApJ **843** (2017) 88

HAWC limits



GBM light curve



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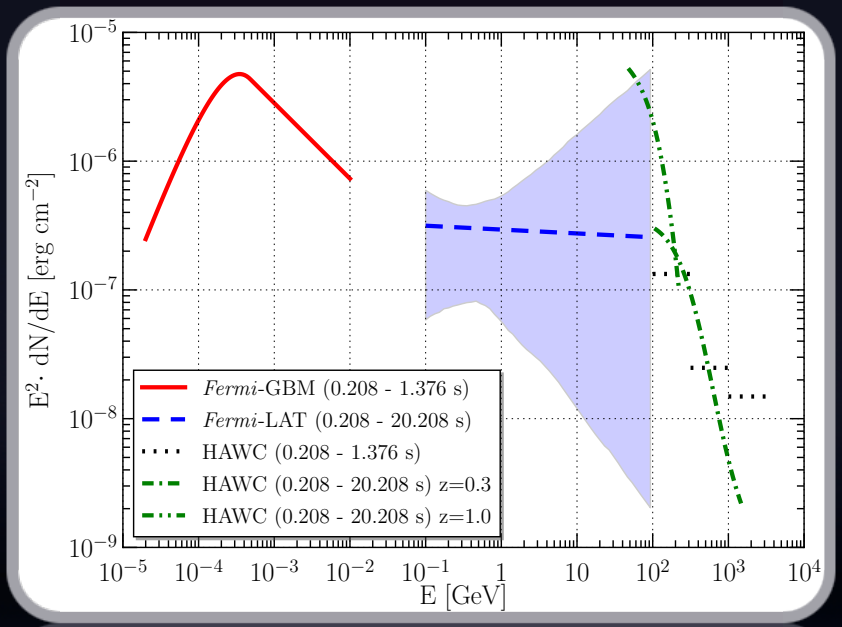
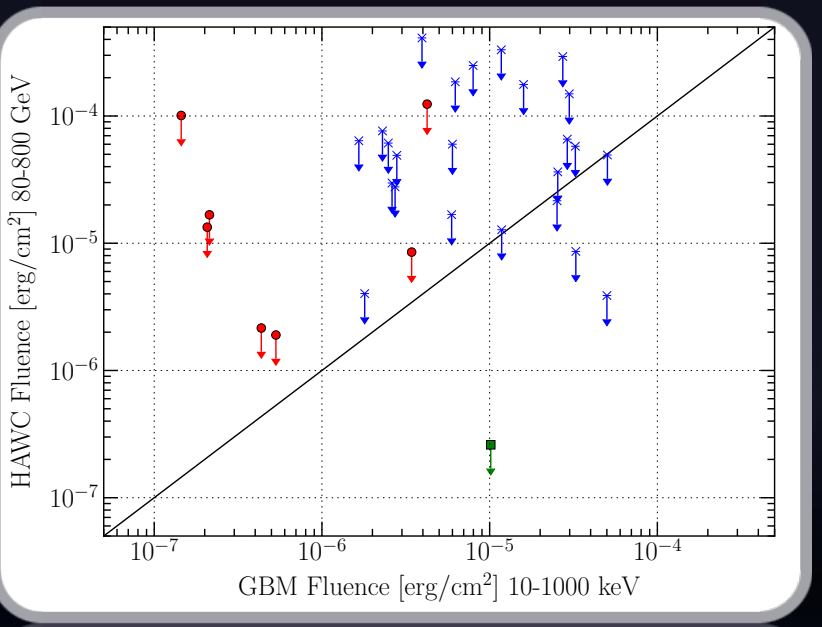
HAWC limits



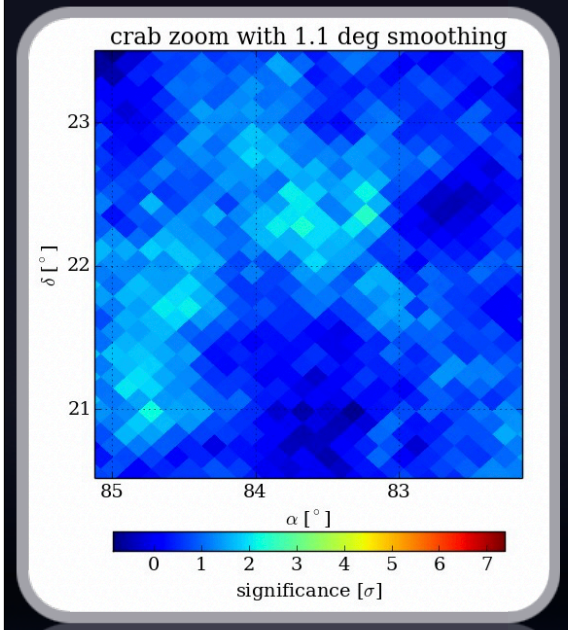
HAWC *vs.* GBM fluence



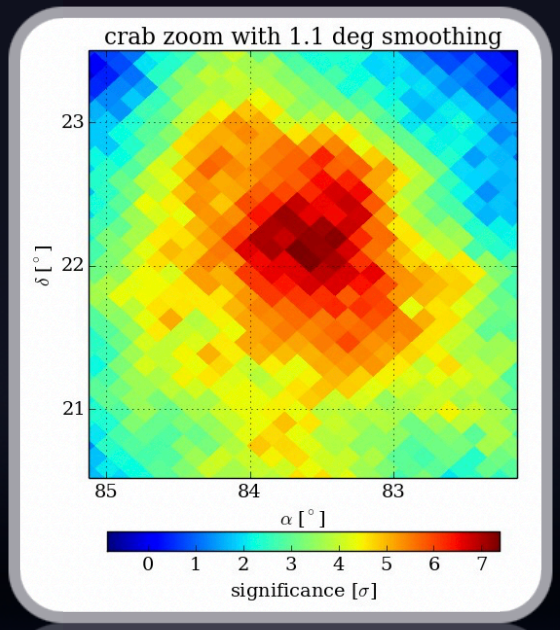
GRB 170206A

Very very preliminary; *i.e.*, work in progress

Crab in bin 0

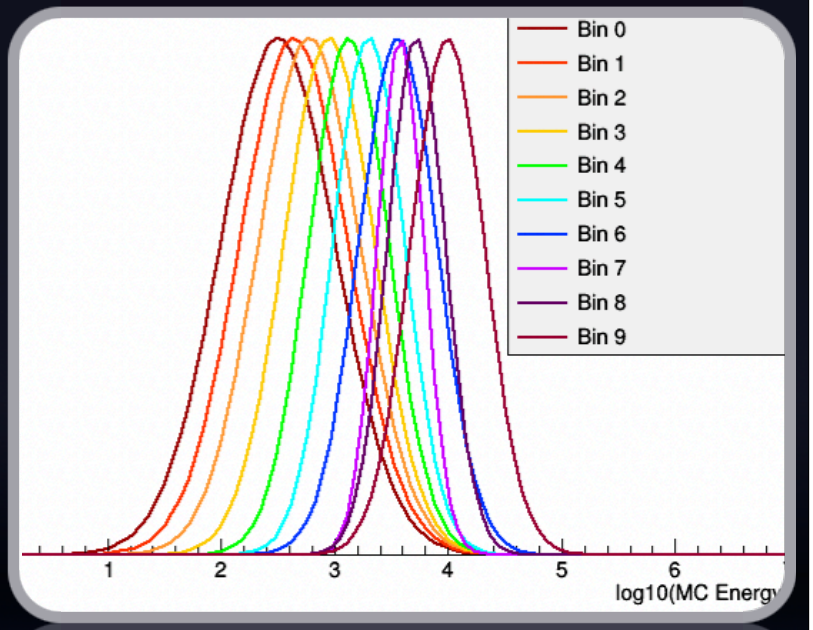


before



after

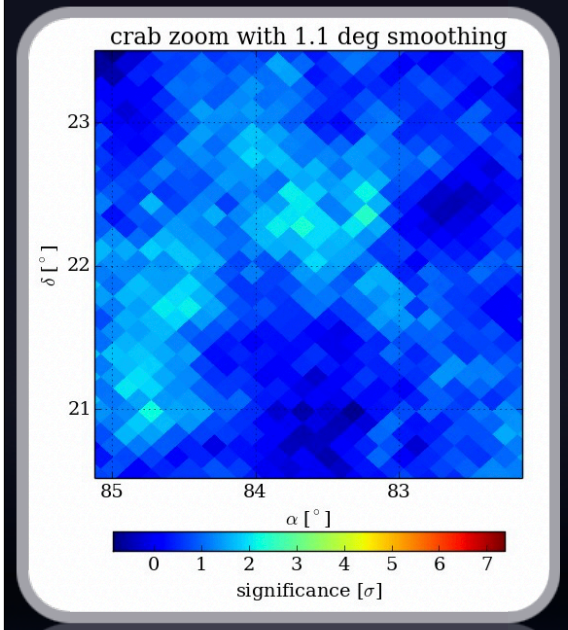
“Size” bins



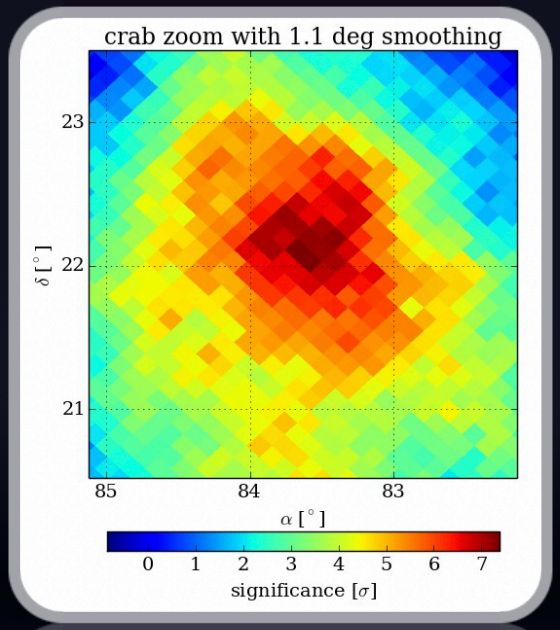
sub-TeV data

Very very preliminary; *i.e.*, work in progress

Crab in bin 0

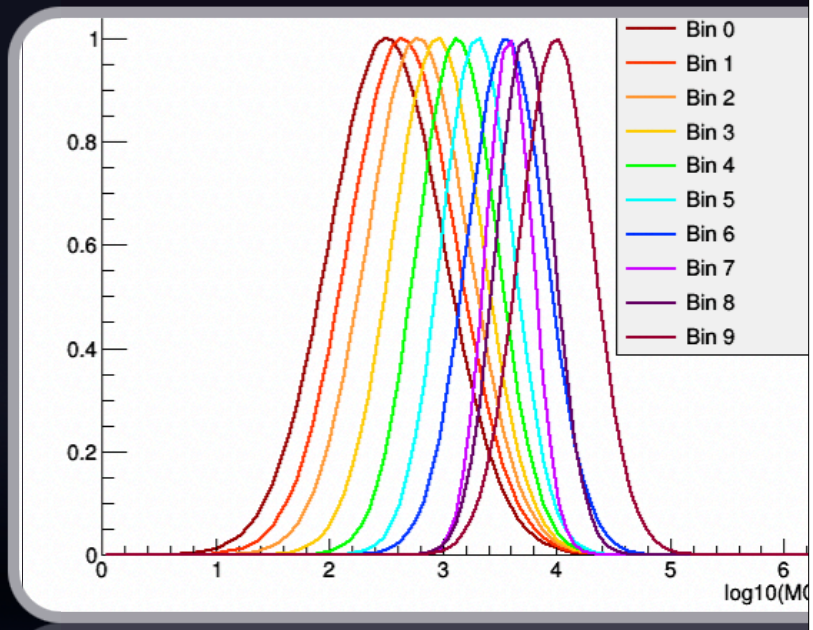


before



after

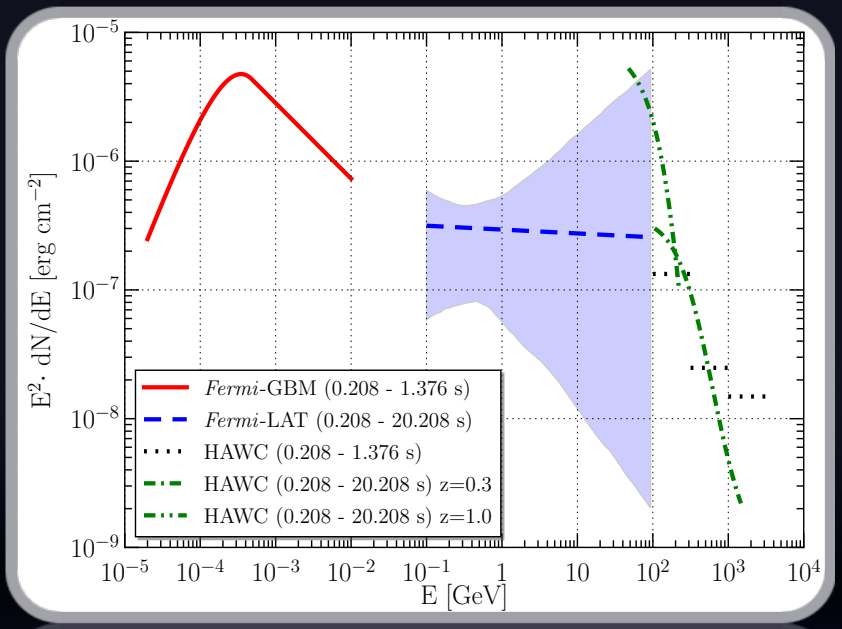
"Size" bins



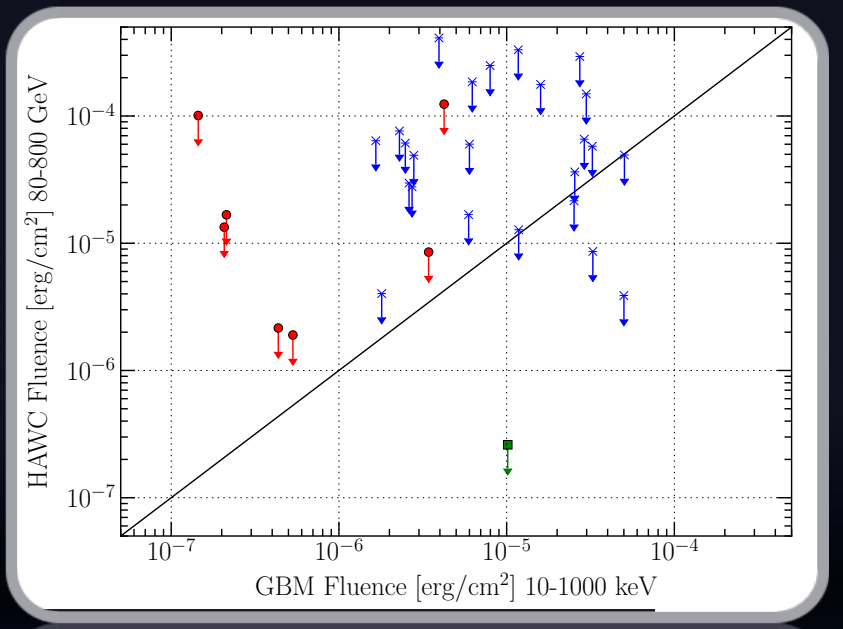
sub-TeV data

Alfaro *et al* [HAWC] ApJ **843** (2017) 88

HAWC limits



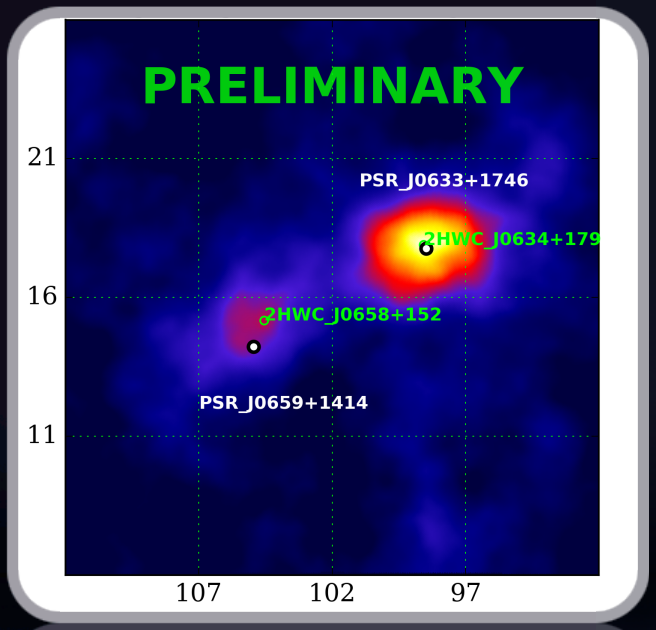
HAWC *vs.* GBM fluence

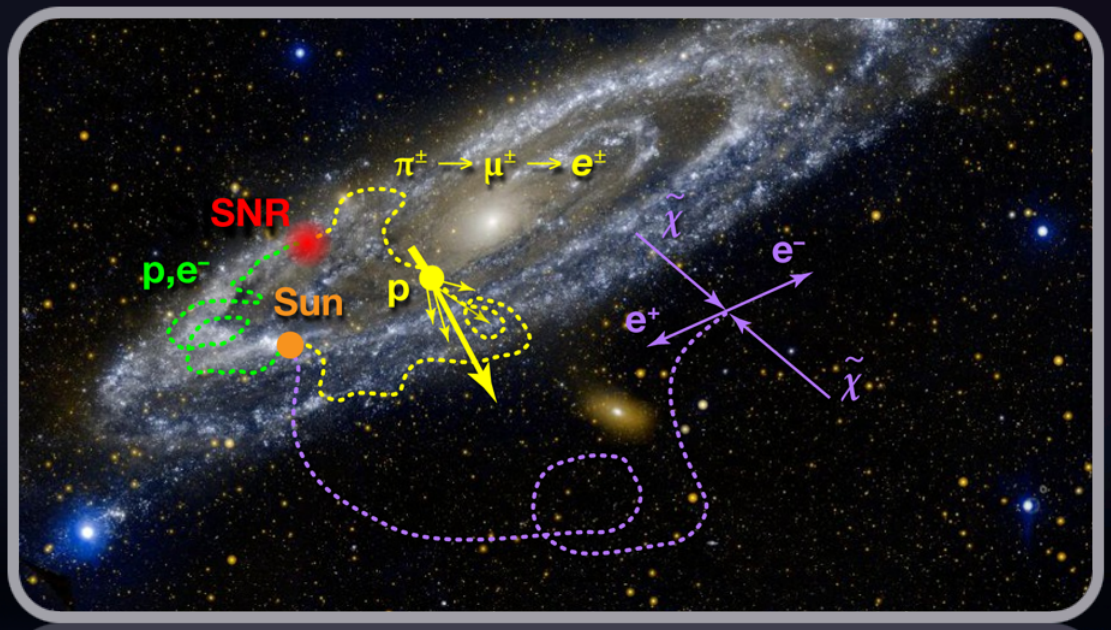


GRB 170206A

Positron excess from nearby pulsars?

Accepted for publication



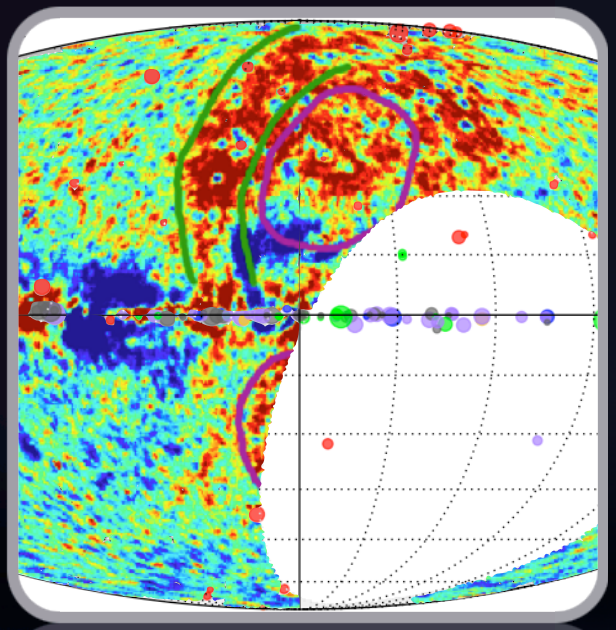


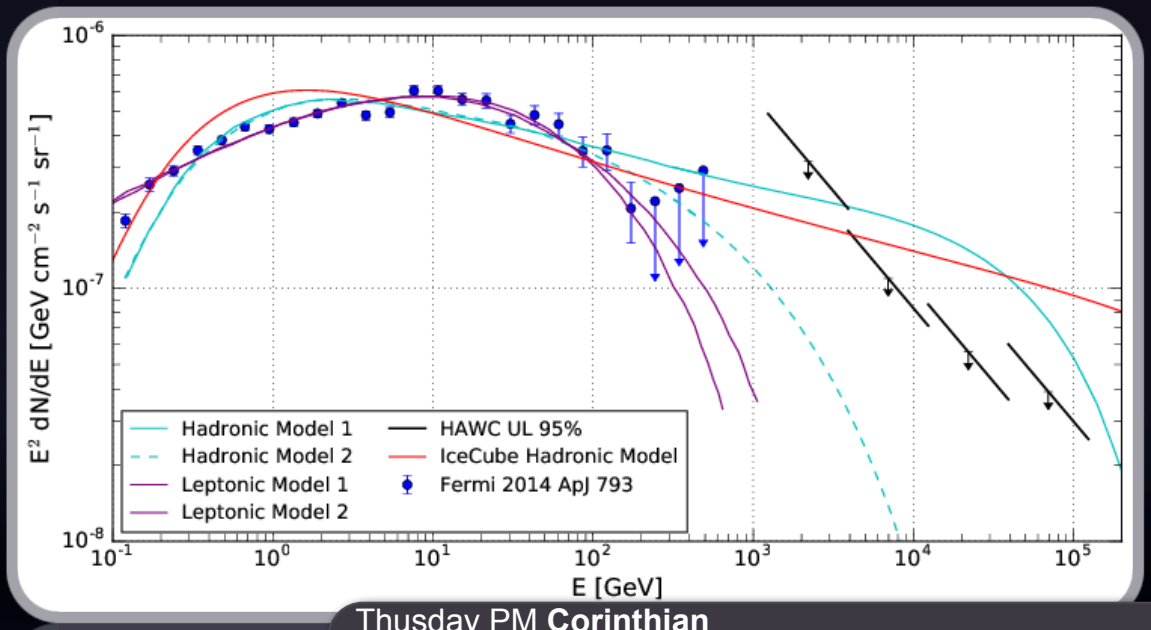
Thusday PM **Corinthian**

17:45 “PBHs and nearby pulsars with HAWC” J. Linnemann

Abeysekara *et al* [HAWC] ApJ **842** (2017) 85

Limits on Fermi bubbles at TeVs





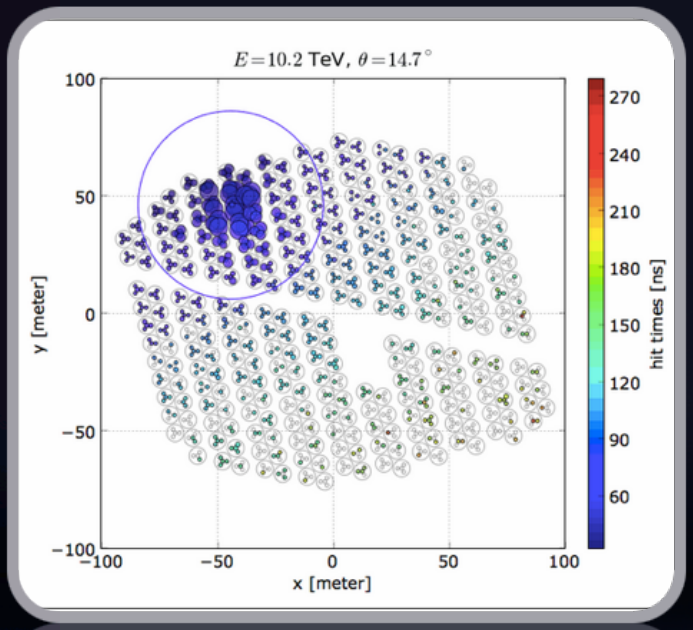
Thusday PM **Corinthian**

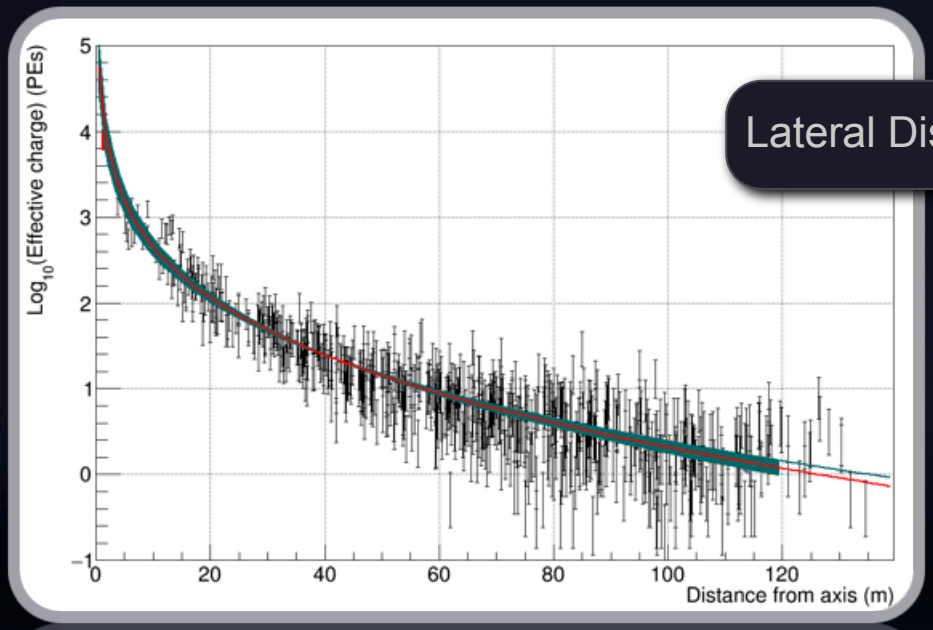
17:30 “Giant molecular clouds with HAWC” H. Ayala

Extended emission

Energy measurement

Number of triggered PMTs is the energy proxy

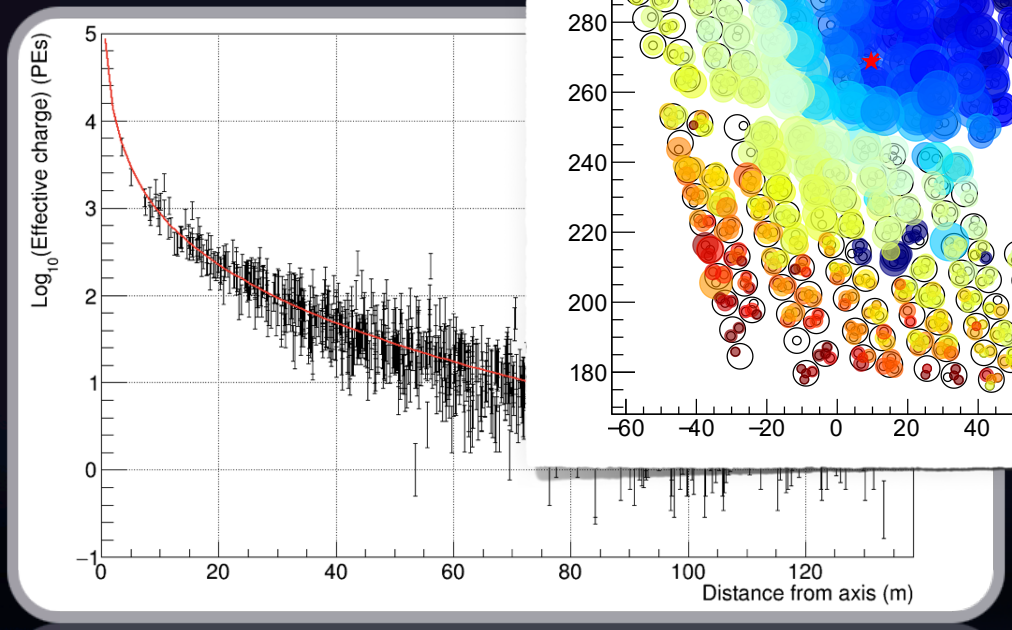


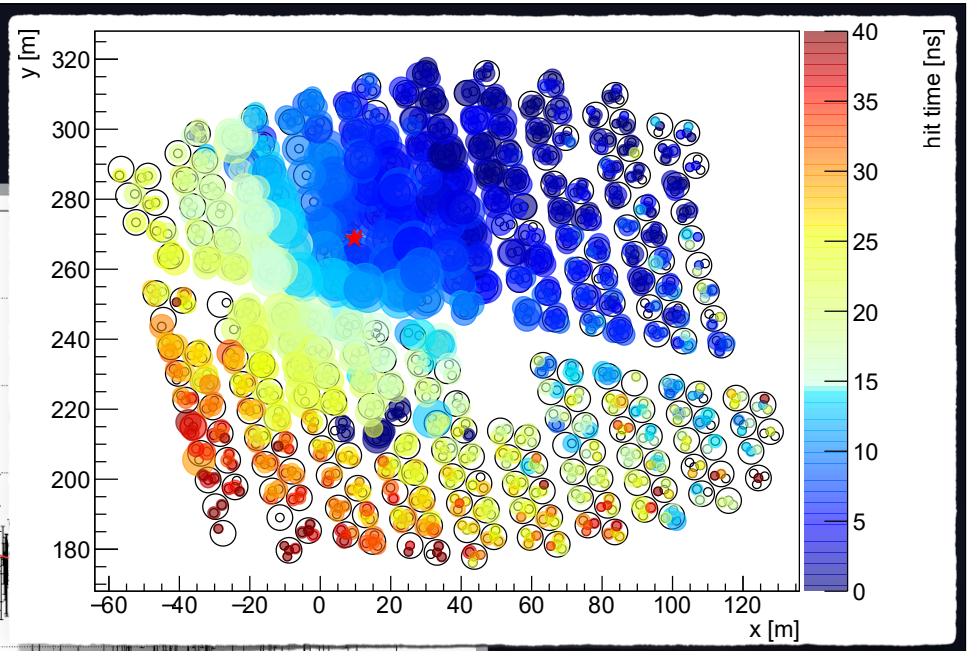


Lateral Distribution Function

Energy measurement

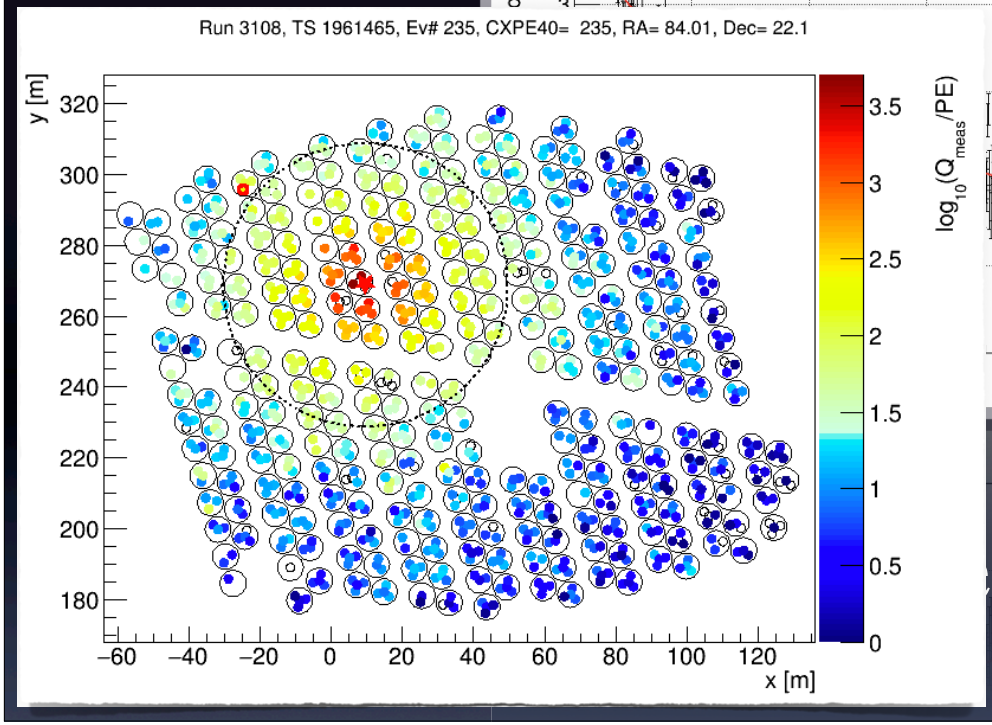
Event from the Crab

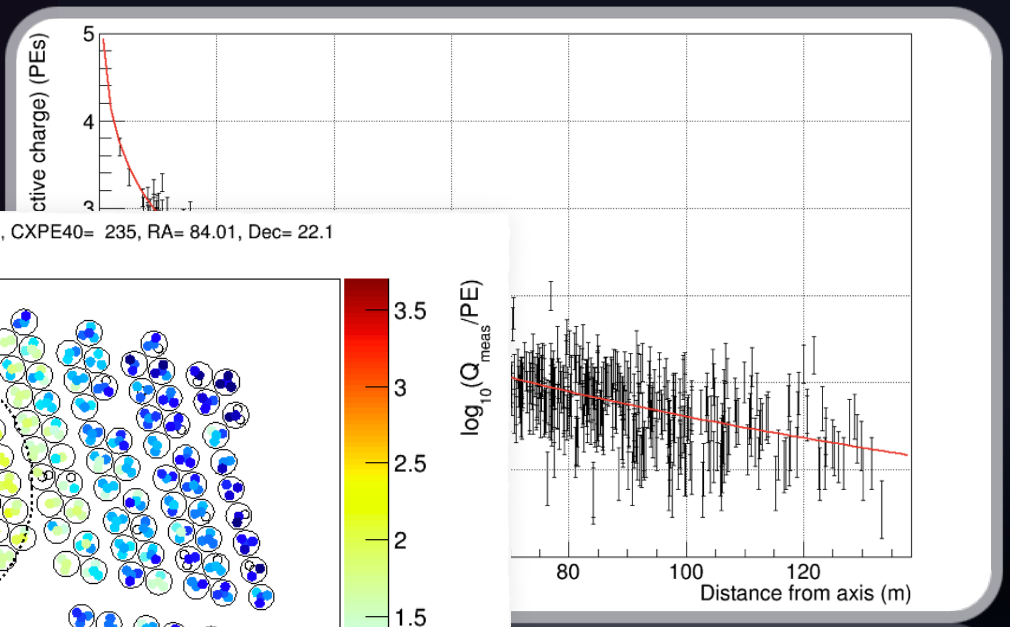




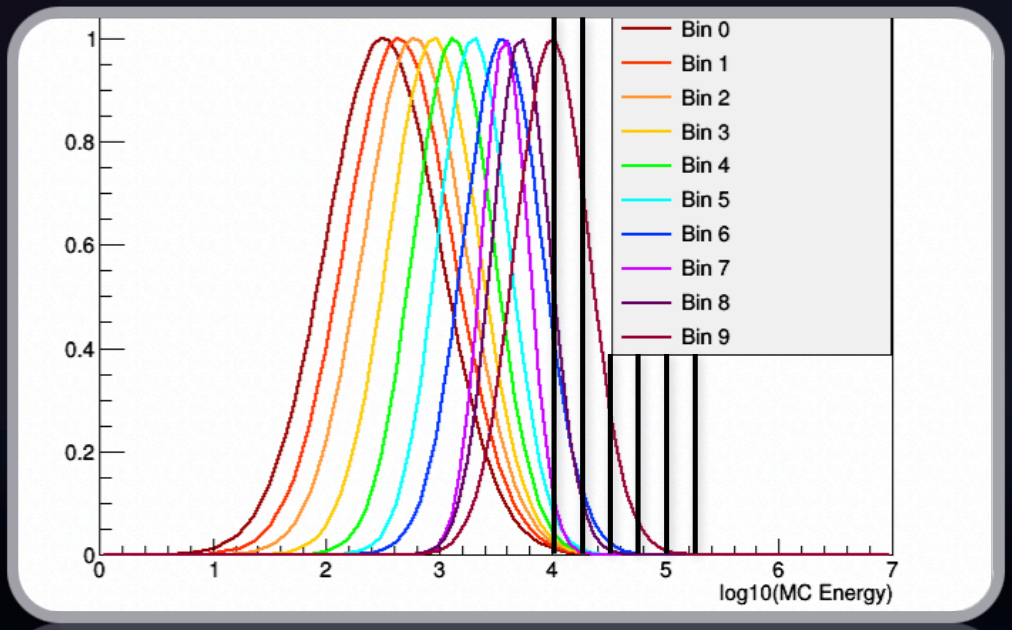
Energy measurement

Event from the Crab



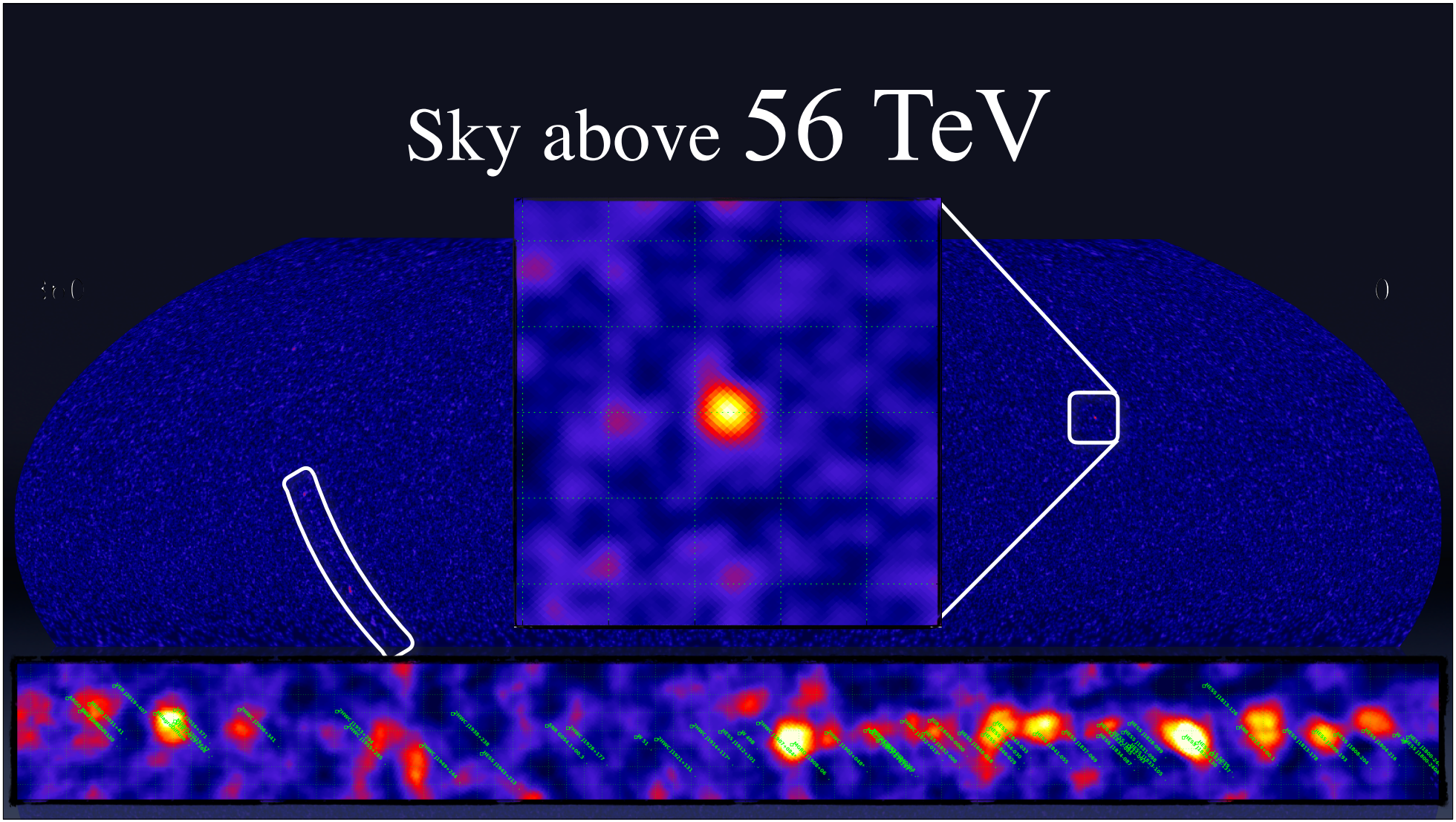


asurement

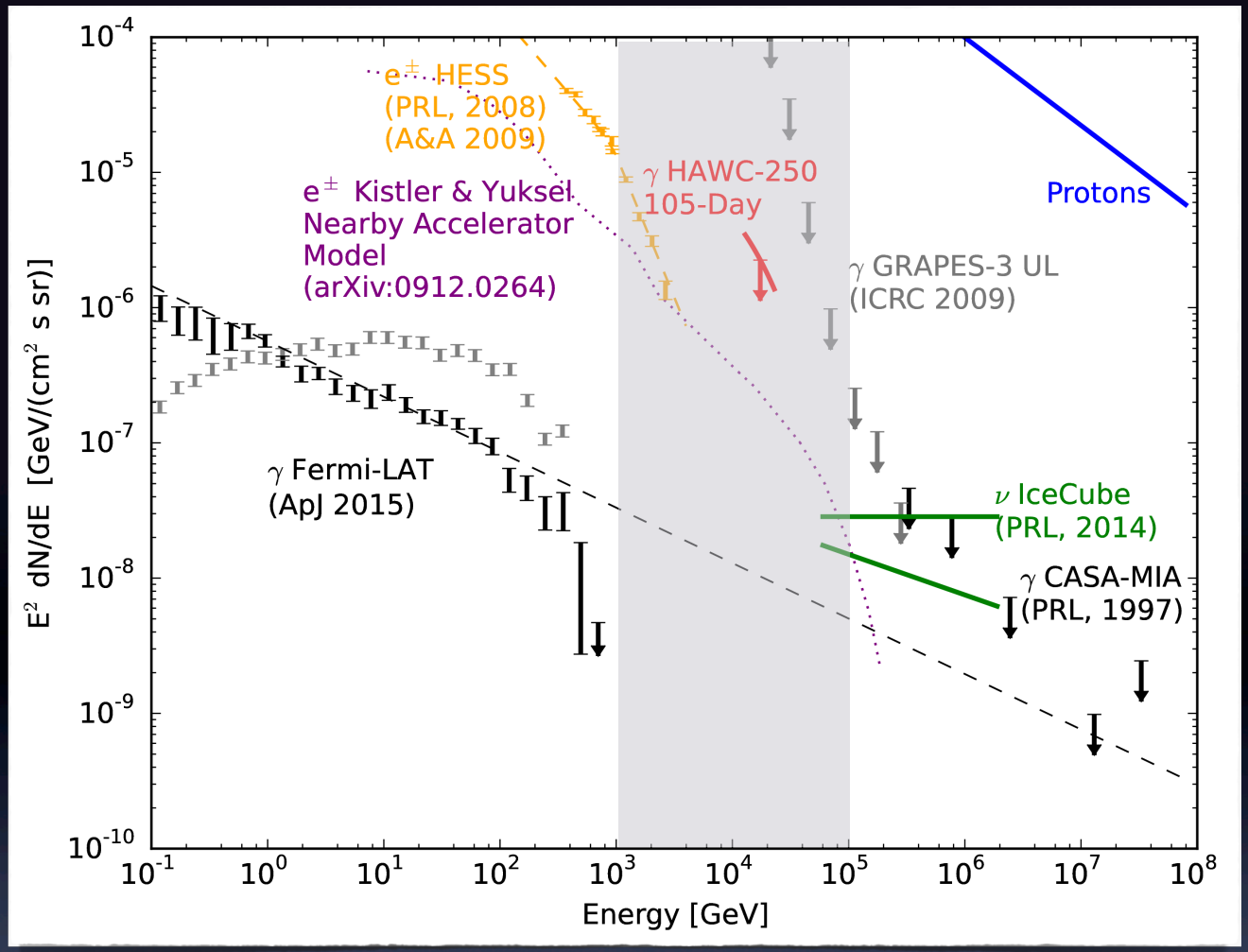


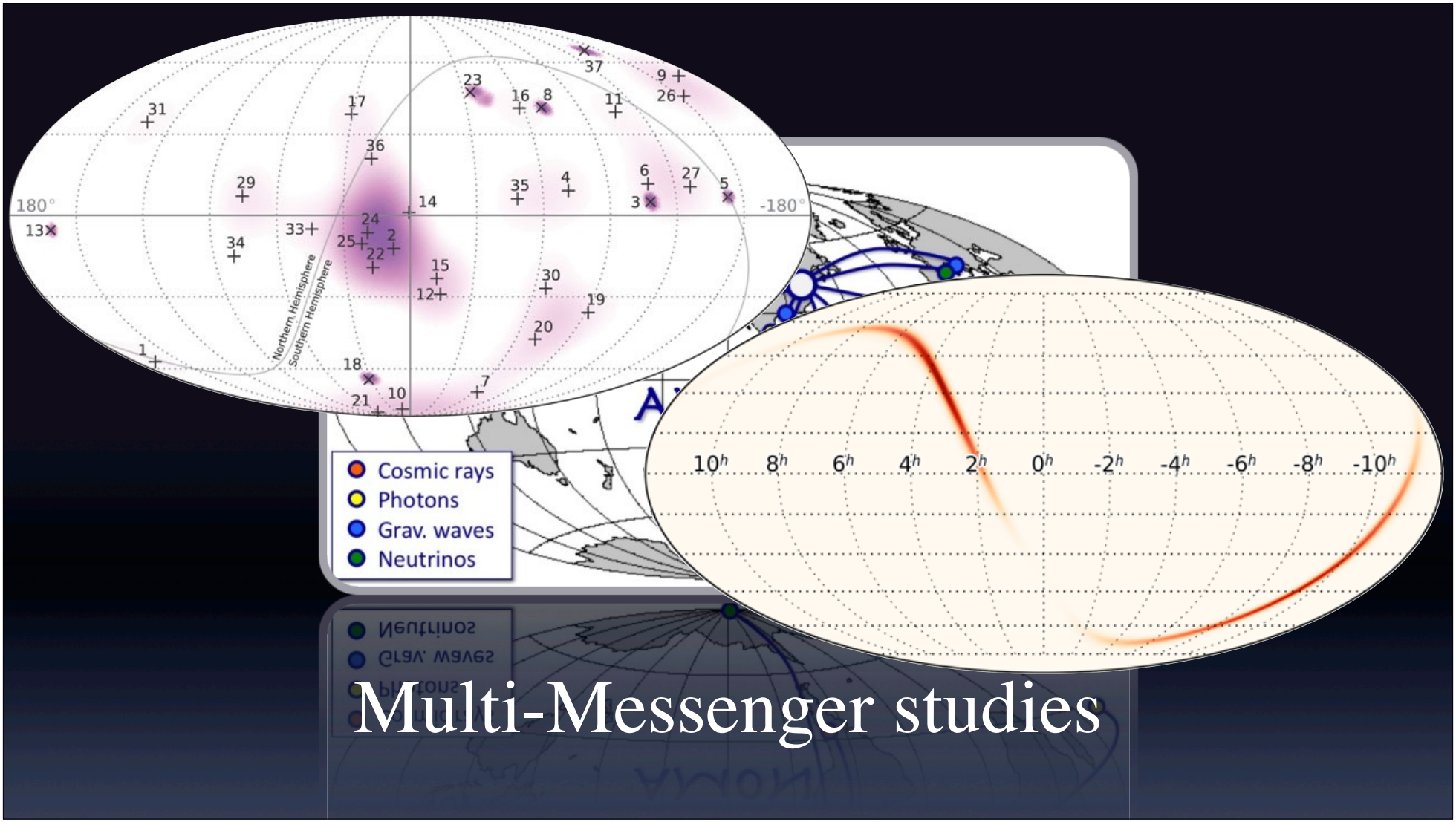
Energy measurement

Sky above 56 TeV

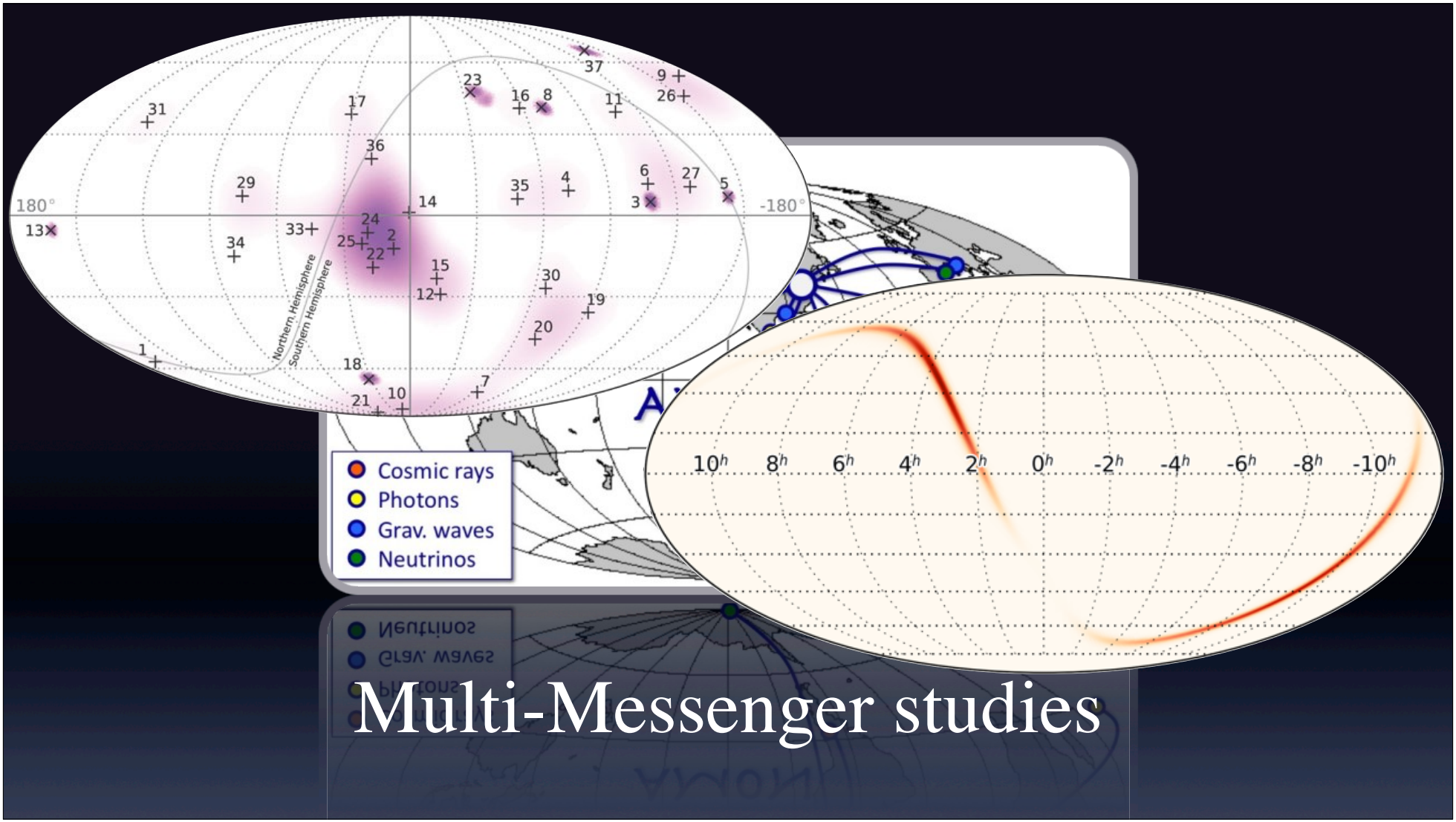


Isotropic Diffuse Emission

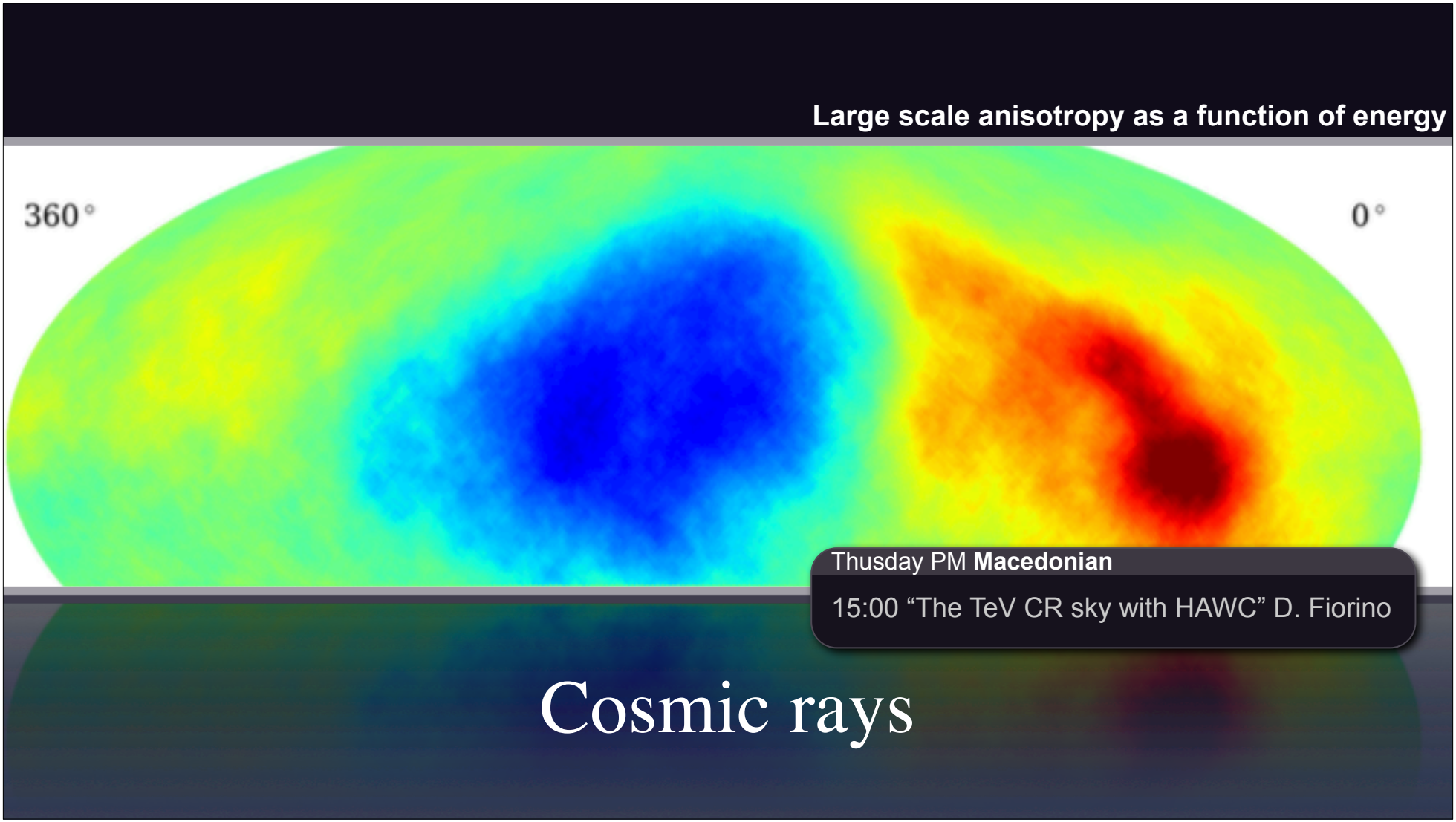


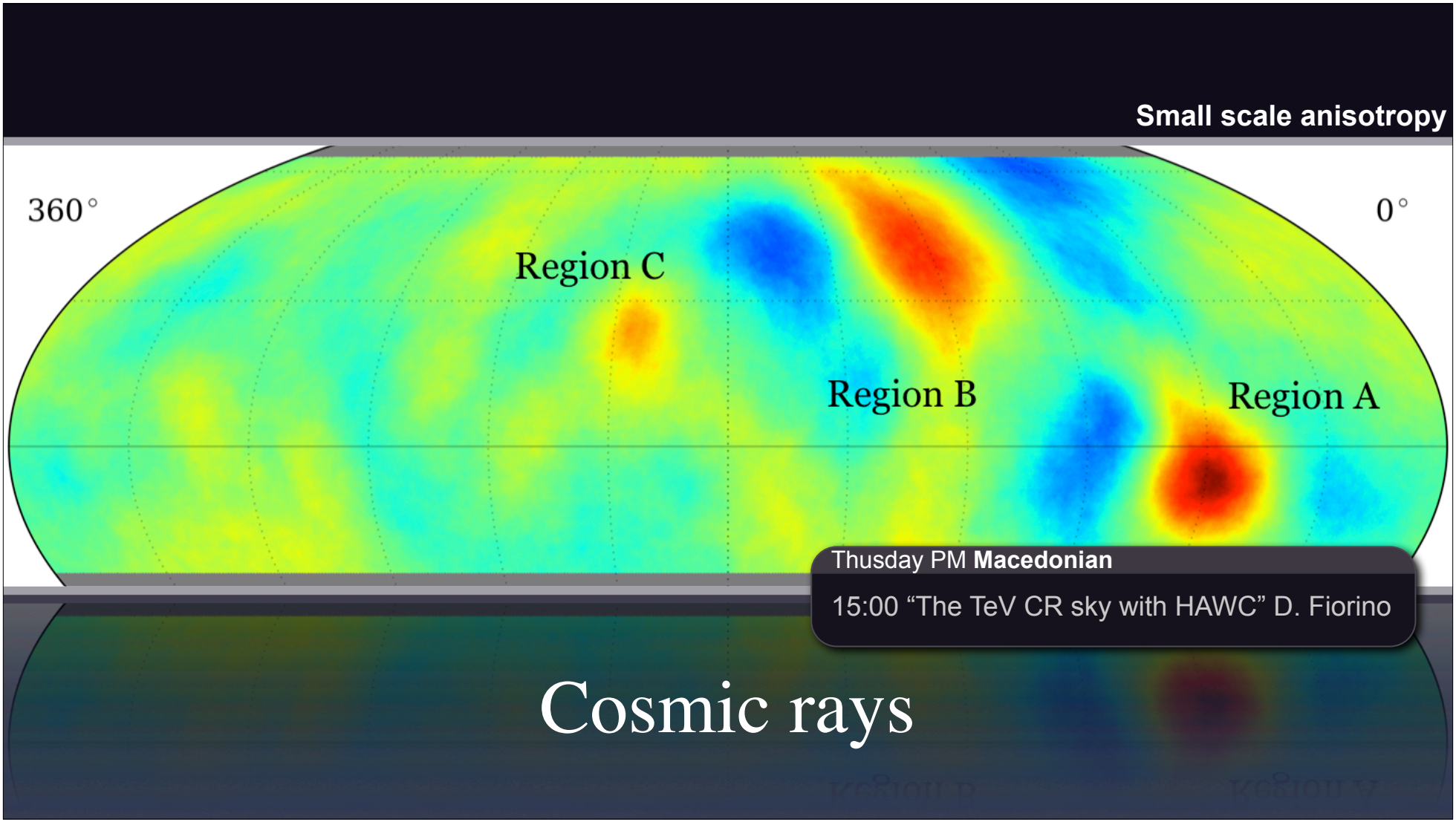


Multi-Messenger studies



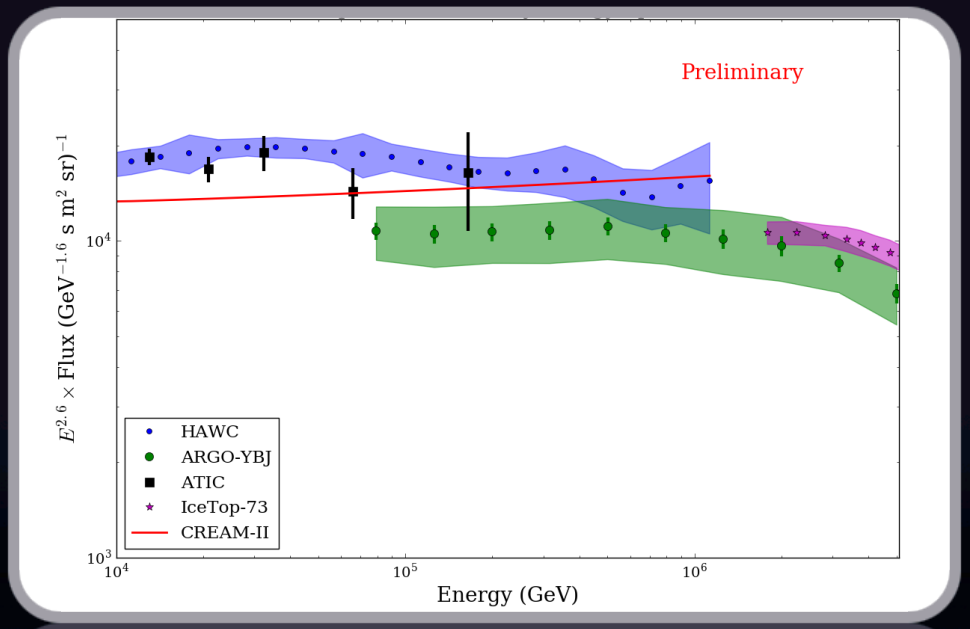
Multi-Messenger studies


Large scale anisotropy as a function of energy
360°
0°
Thusday PM **Macedonian**
15:00 “The TeV CR sky with HAWC” D. Fiorino
Cosmic rays


Small scale anisotropy
360°
0°
Region C
Region B
Region A
Thusday PM **Macedonian**
15:00 “The TeV CR sky with HAWC” D. Fiorino

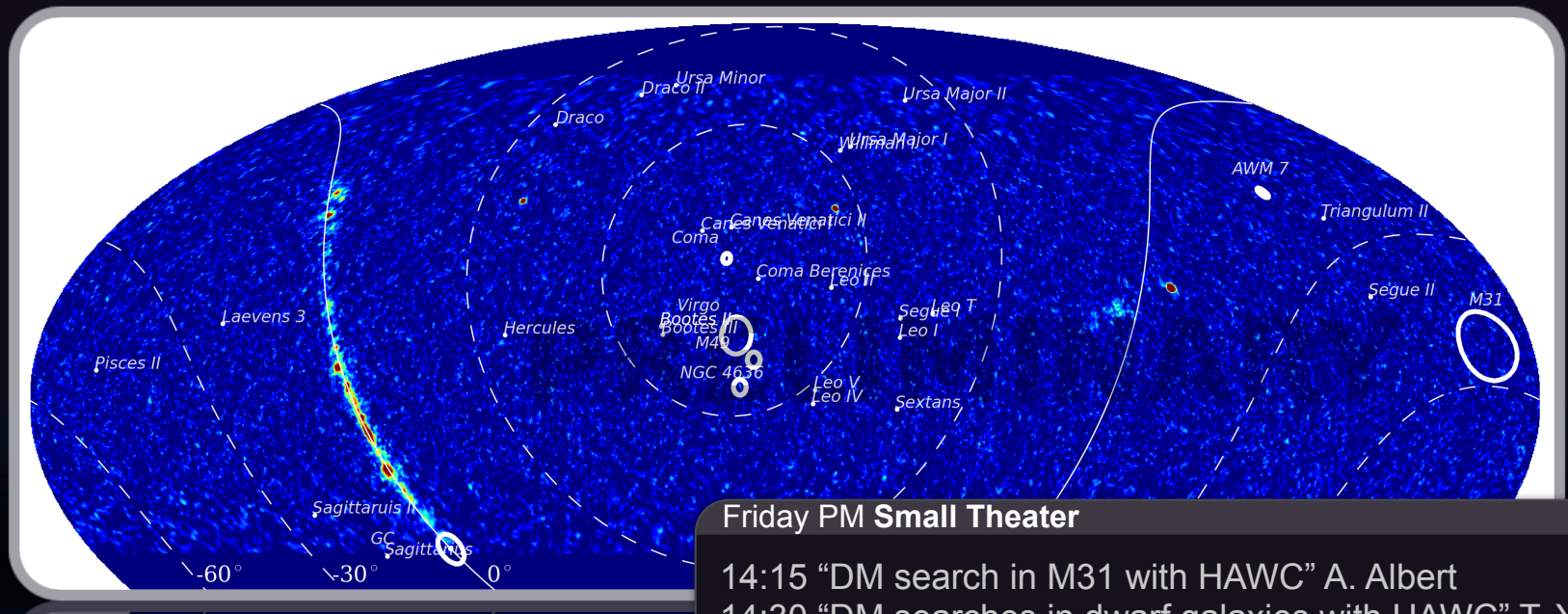
Cosmic rays

All species energy spectrum



Cosmic rays

M31, dwarfs, extended, halos, etc.

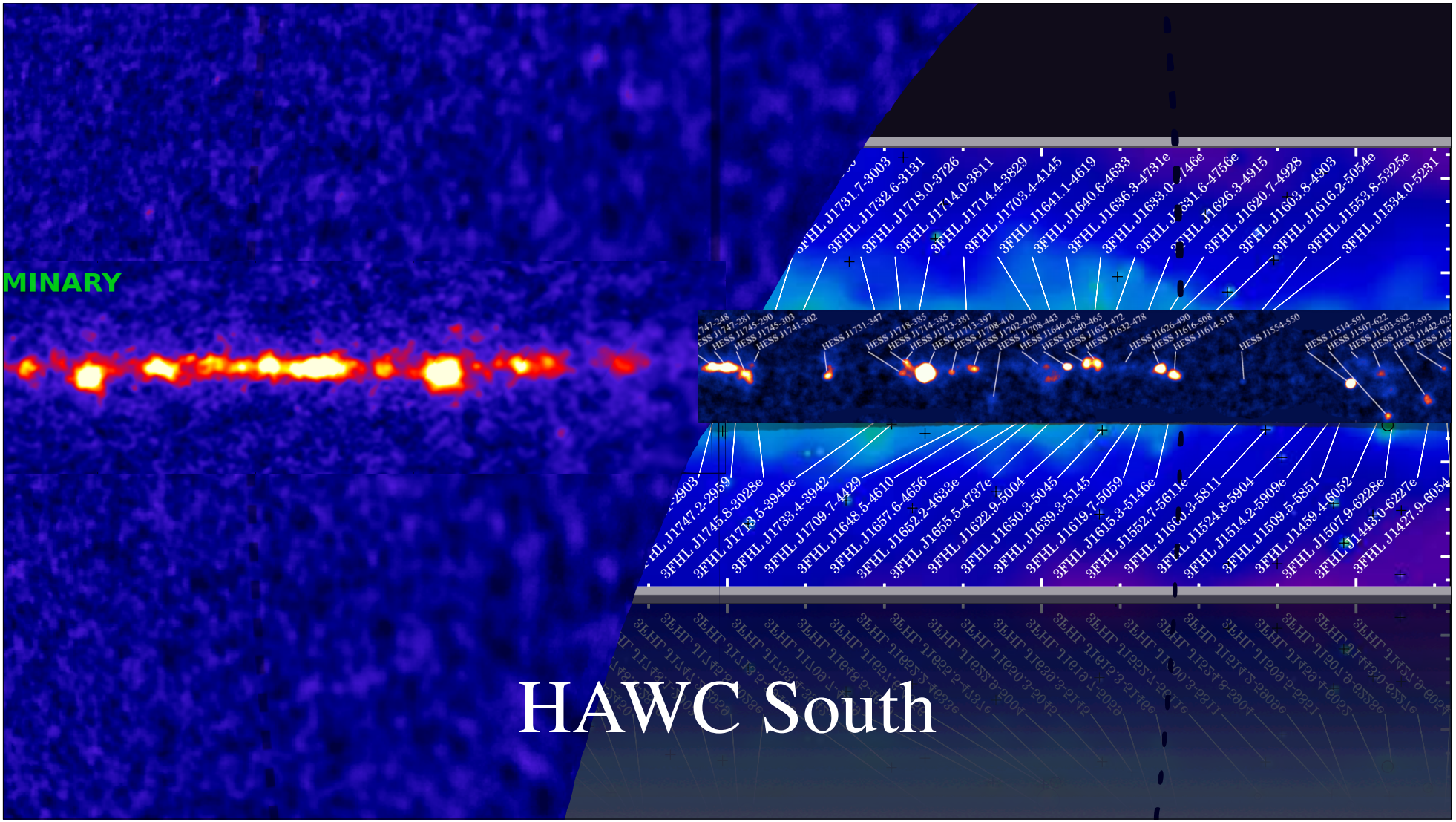


Friday PM **Small Theater**

14:15 “DM search in M31 with HAWC” A. Albert
14:30 “DM searches in dwarf galaxies with HAWC” T. Yapici

Dark matter


One more thing…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HAWC South

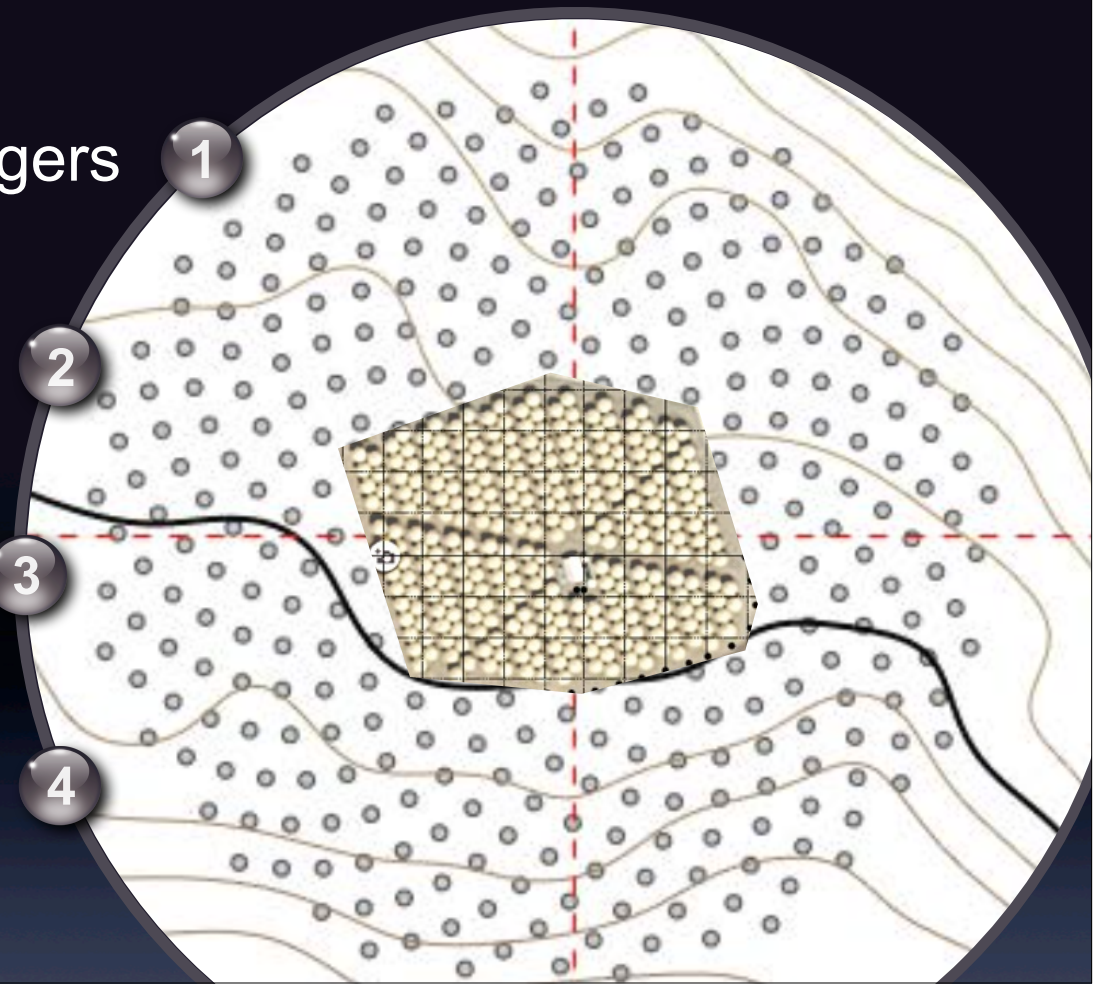
Outlook

Outriggers 1

Galactic Pevatrons 2

Diffuse emission 3

HAWC South 4




Thank you very much

More HAWC talks

Thusday PM **Macedonian**

15:00 “The TeV CR sky with HAWC” D. Fiorino

Thusday PM **Corinthian**

16:00 “Galactic Sources” P. Huentemeyer
16:30 “VERITAS/Fermi observations of HAWC sources” N. Park
16:45 “VERITAS/NuSTAR observations of HAWC sources” M. Hui

Thusday PM **Macedonian**

16:45 “HAWC real-time flare monitor” T. Weisgarber

Thusday PM **The Athenaeum**

17:15 “The Cygnus Region with HAWC” B. Hona

Thusday PM **Corinthian**

17:30 “Giant molecular clouds with HAWC” H. Ayala

Thusday PM **Corinthian**

17:45 “PBHs and nearby pulsars with HAWC” J. Linnemann

Friday PM **Small Theater**

14:15 “DM search in M31 with HAWC” A. Albert
14:30 “DM searches in dwarf galaxies with HAWC” T. Yapici