TeV Particle Astrophysics with the High Altitude Water Cherenkov (HAWC) Gamma-Ray Observatory

Detecting the Highest Energy Light with a Telescope Made of Water

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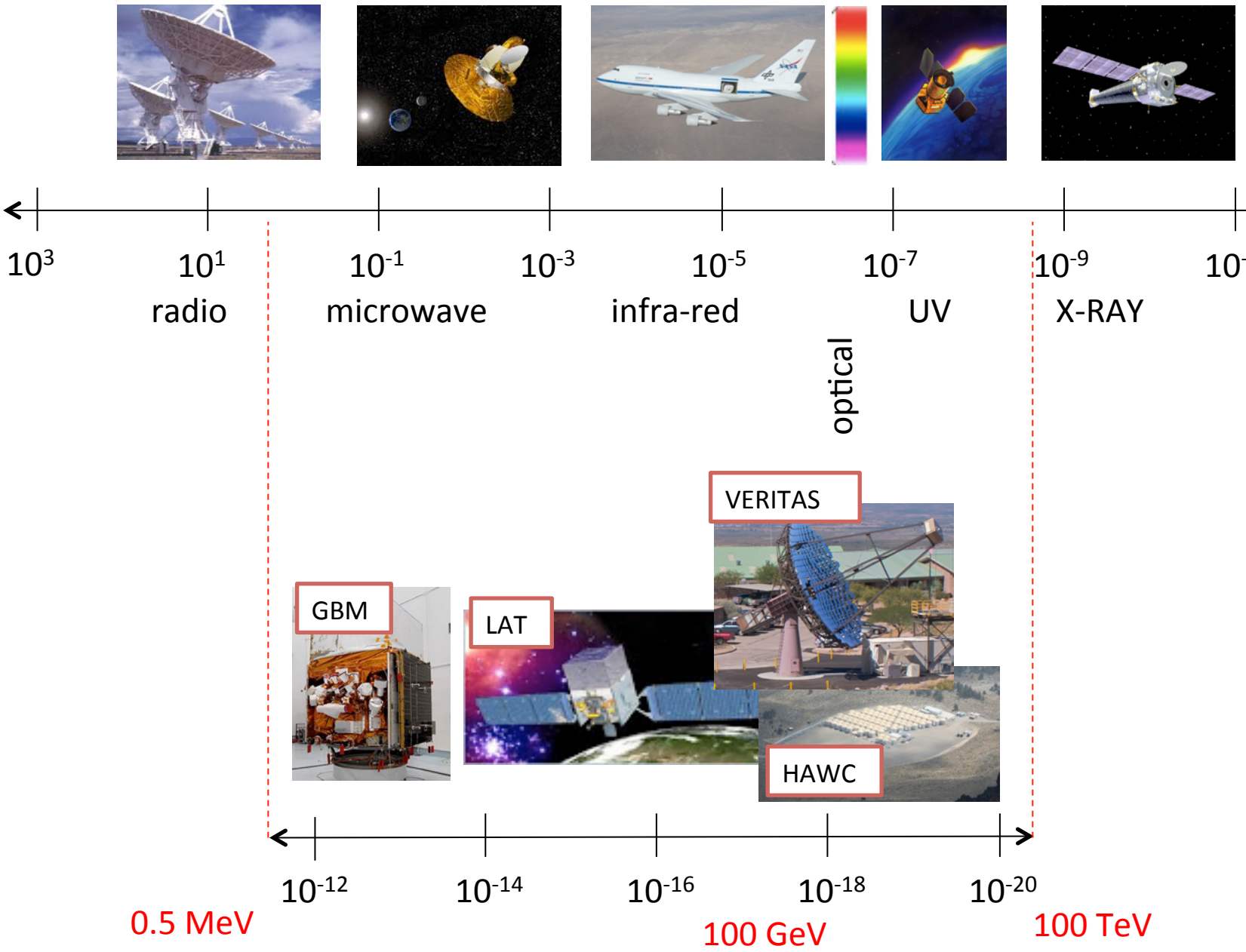
for the HAWC Collaboration

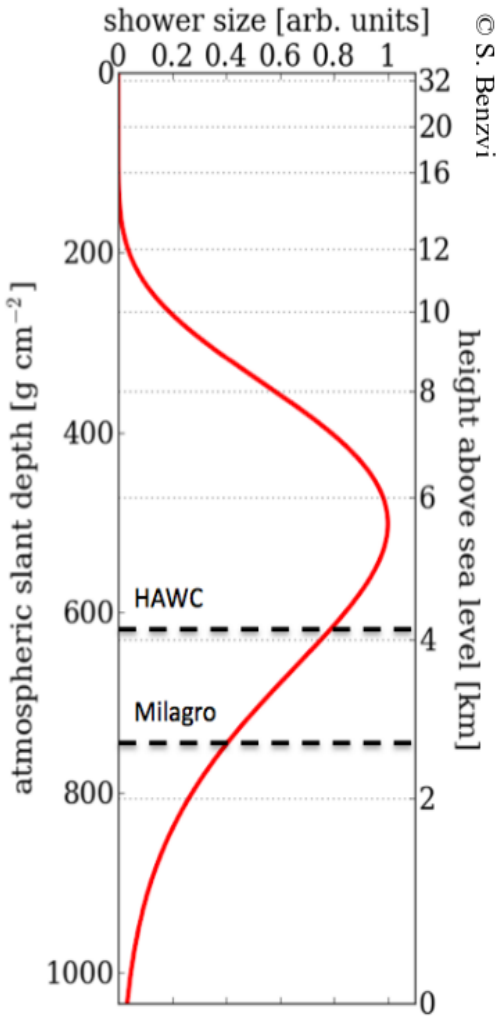
Michigan State University

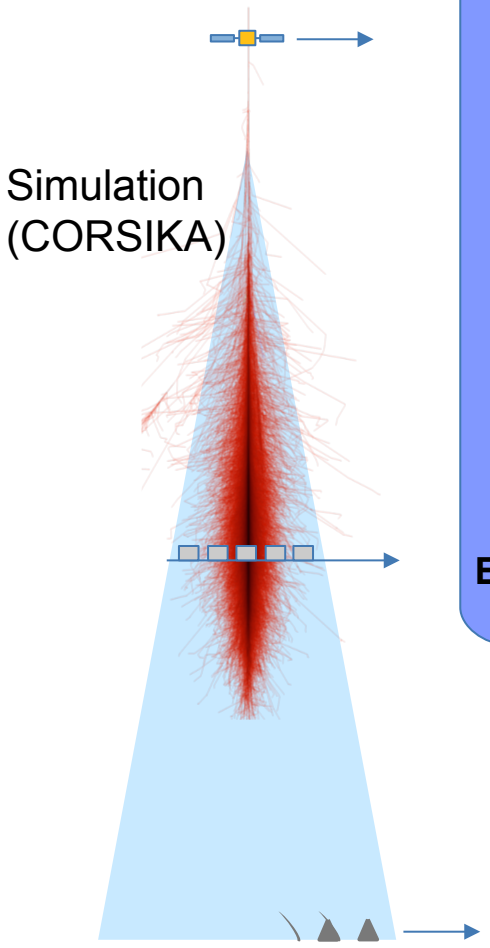
Picture taken July 8, 2015



Courtesy of Jamie Holder

Gamma-Ray Detectors





Satellite Detector
30 MeV – 300 GeV

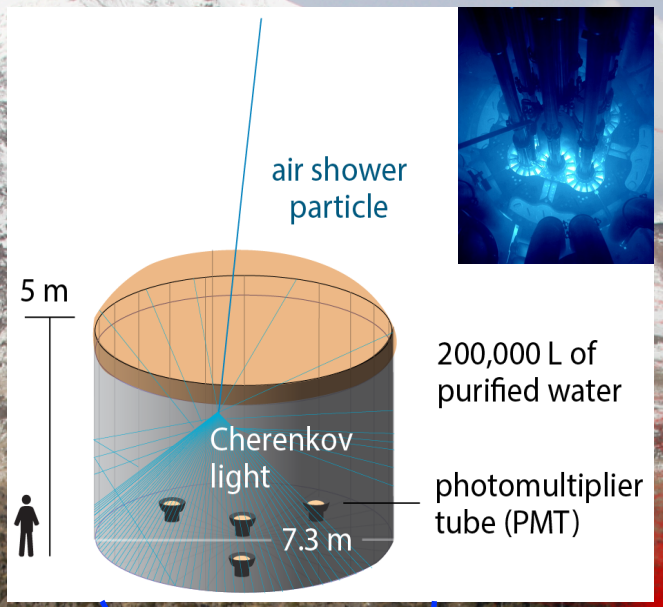
Wide Field of View, Continuous Operations

Extensive Air Shower (EAS) Detector
100 GeV – 100 TeV

Imaging Atmospheric Cherenkov Telescope (IACT)
50 GeV – 20 TeV

TeV Sensitivity

Pico de Orizaba
5610 meters



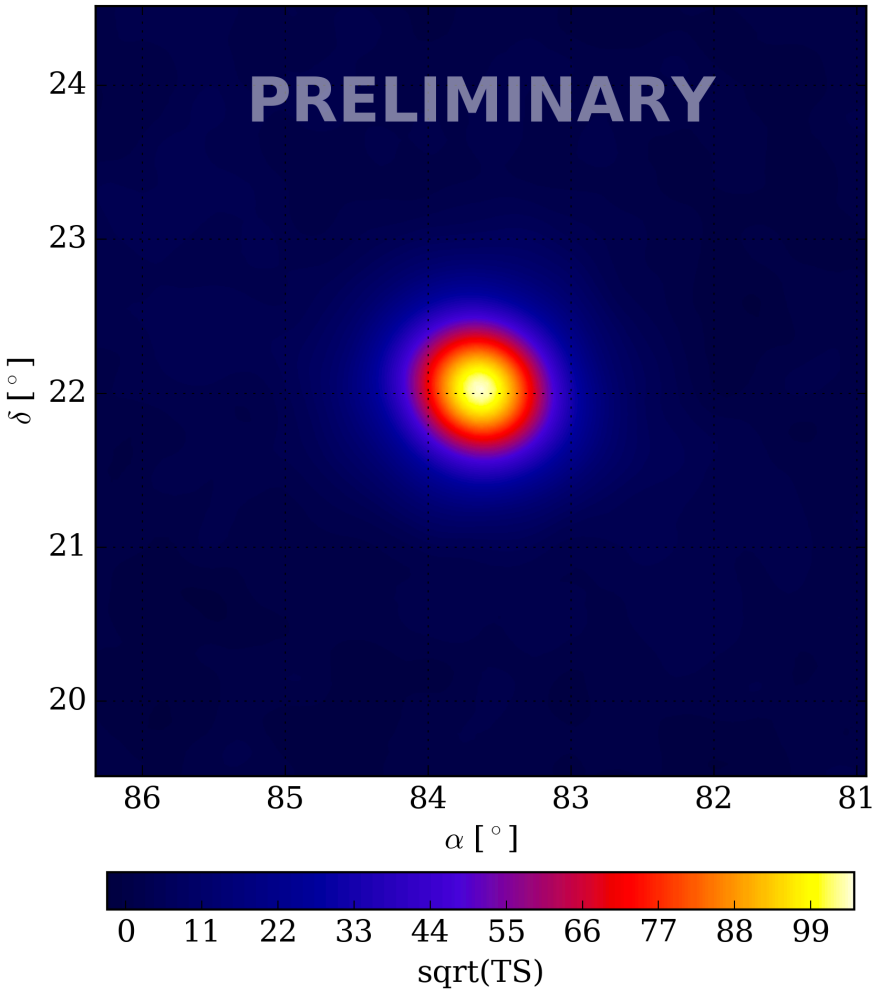
Latitude 19ºN, Longitude = 97ºW.
In the Mexican state of Puebla,
4hr drive East of Mexico City.

HAWC
4100 meters

300 water tanks covering 22,500 m^2

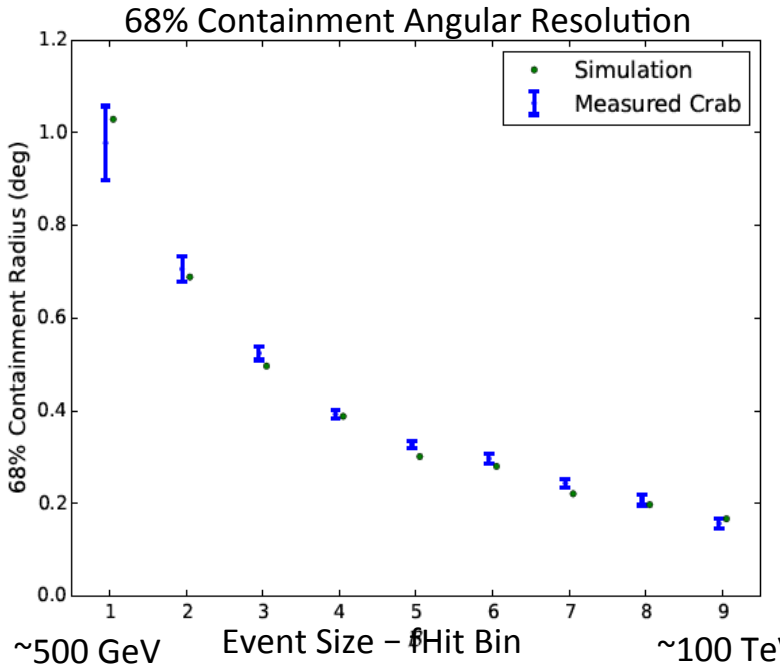
Taken March 18, 2015

Crab Nebula as a Calibration Source



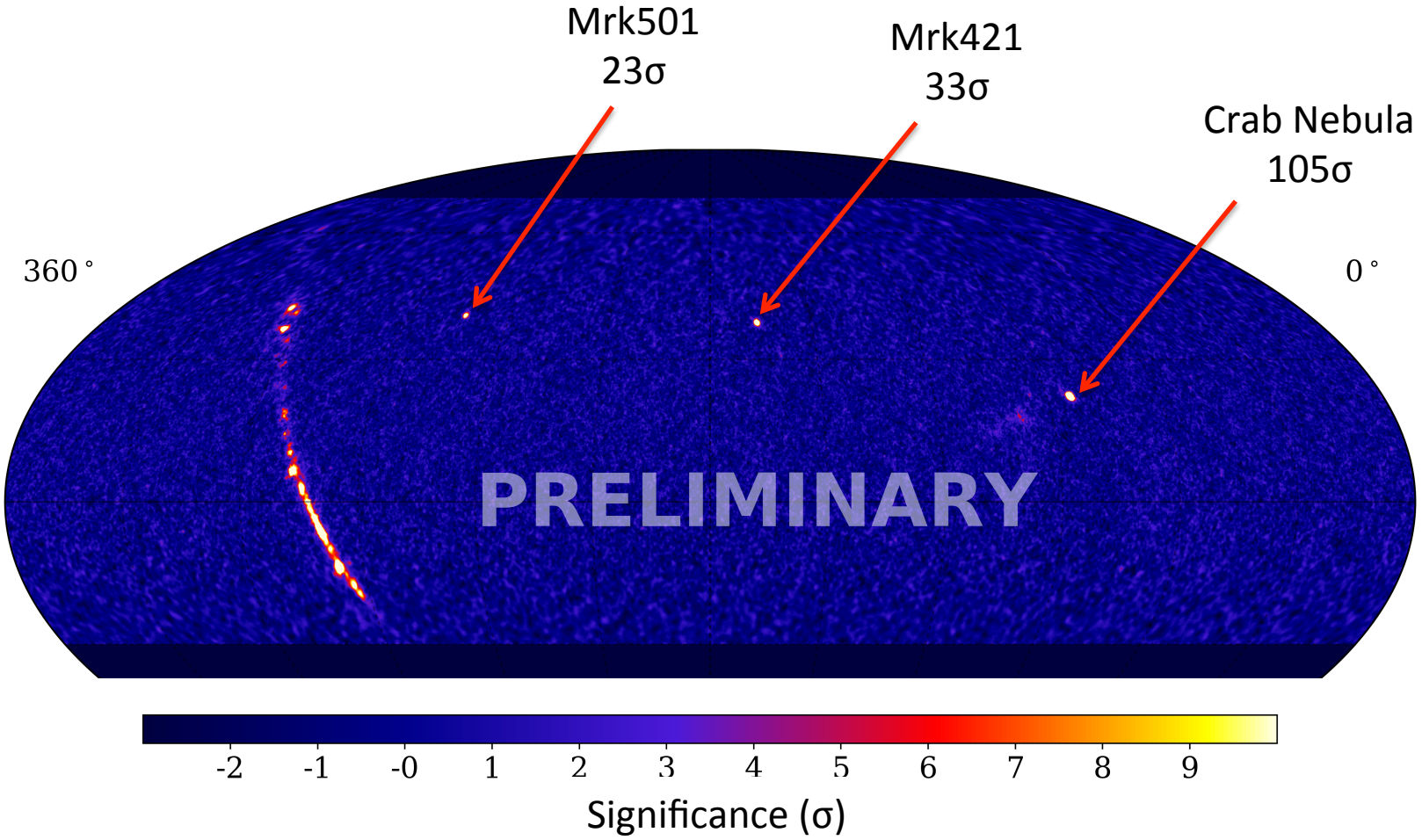
ApJ, 843:39 (July 1, 2017)

- >100σ in 1 year of data
- Observe at >5σ with each transit
- Angular resolution 0.2° at high energies



25 Month Sky Map

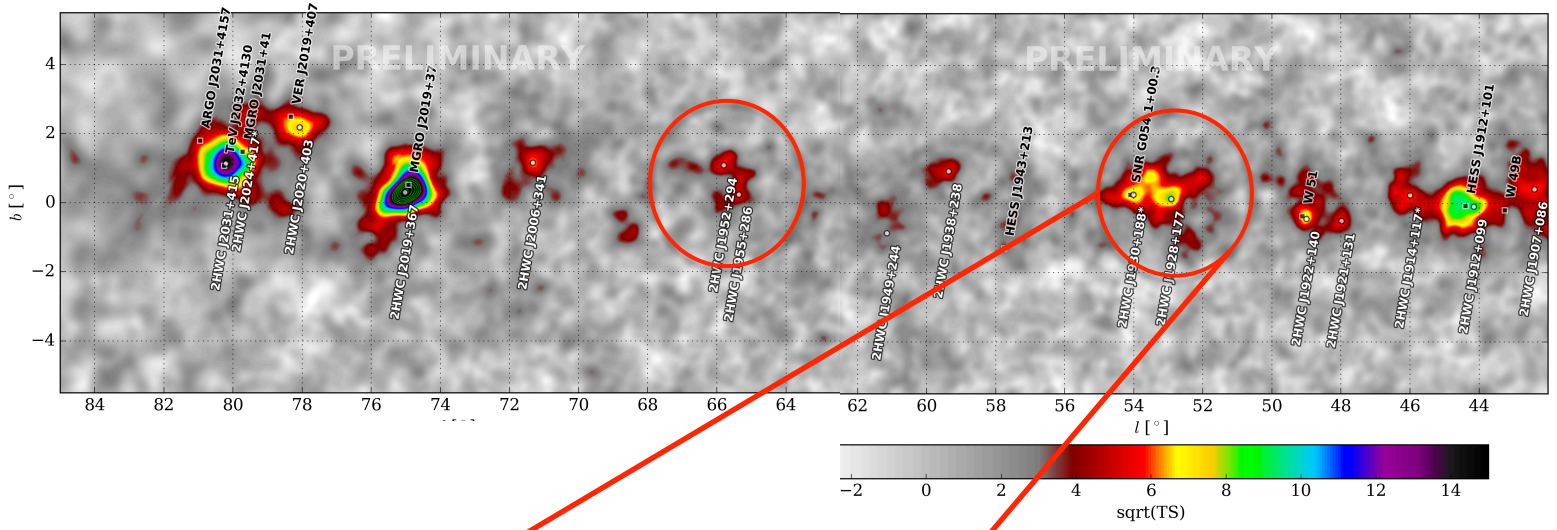
with 100 GeV to 100 TeV Photons

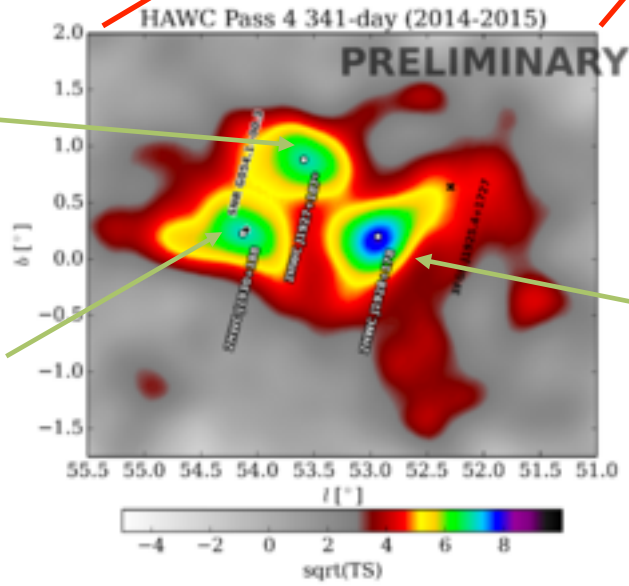


2HWC Catalog (17 months of data) published: ApJ, 843:88 (July 10, 2017)

39 sources found, 10 were new

Known **AND** New TeV Sources



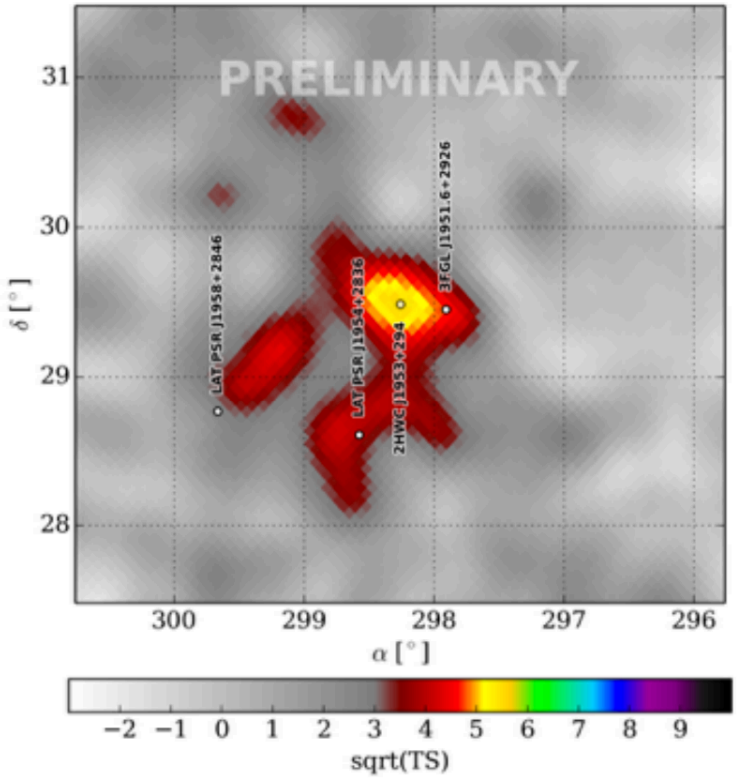


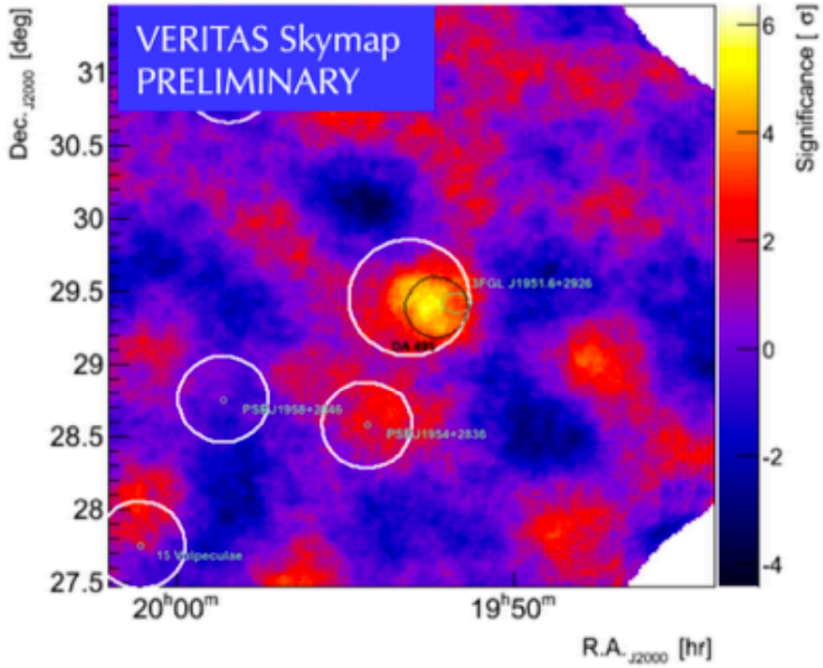
Association unclear

Supernova remnant with very energetic pulsar

Pulsar ~8kpc (26,000 ly) away

VERITAS Confirms HAWC detection

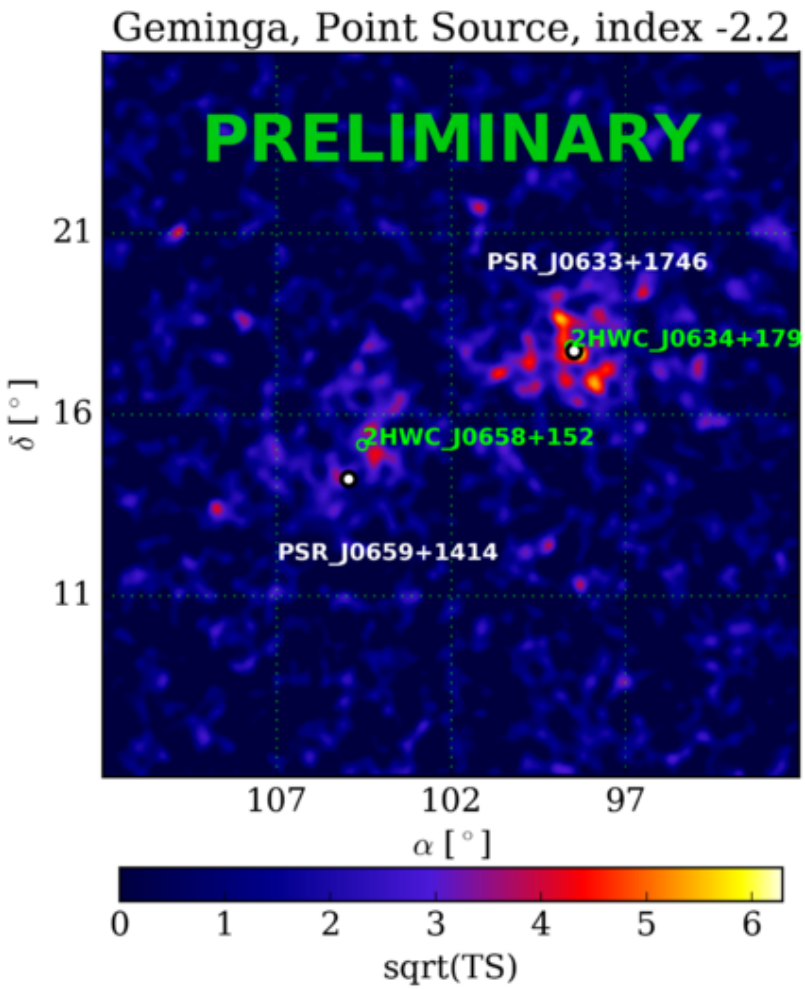




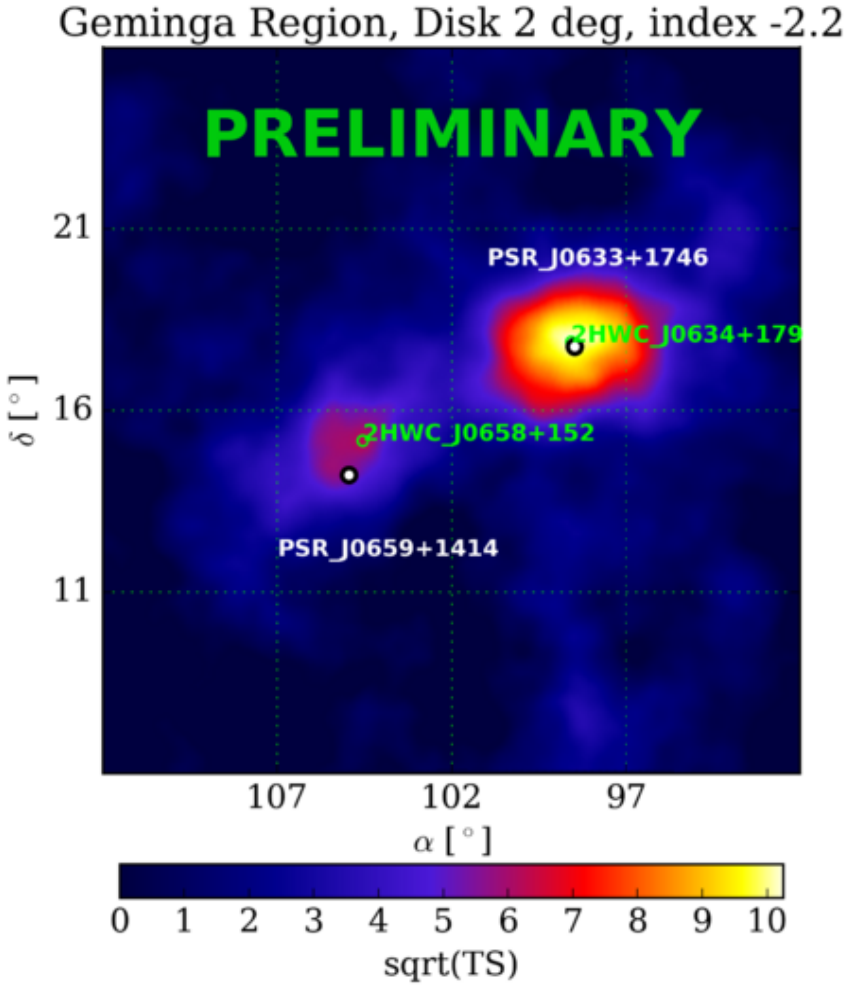
Name	$\sqrt{TS}$	Index	Flux for index at 7 TeV [$\mathrm{TeV^{-1}cm^{-2}s^{-1}}$]
2HWC J1953+294	5.58	-2.76 ± 0.15	1.1e-14 ± 4.2e-15

HAWC Sees Extended Sources

Geminga: Closest known (250 parsecs) middle-aged pulsar



Treated as Point Source

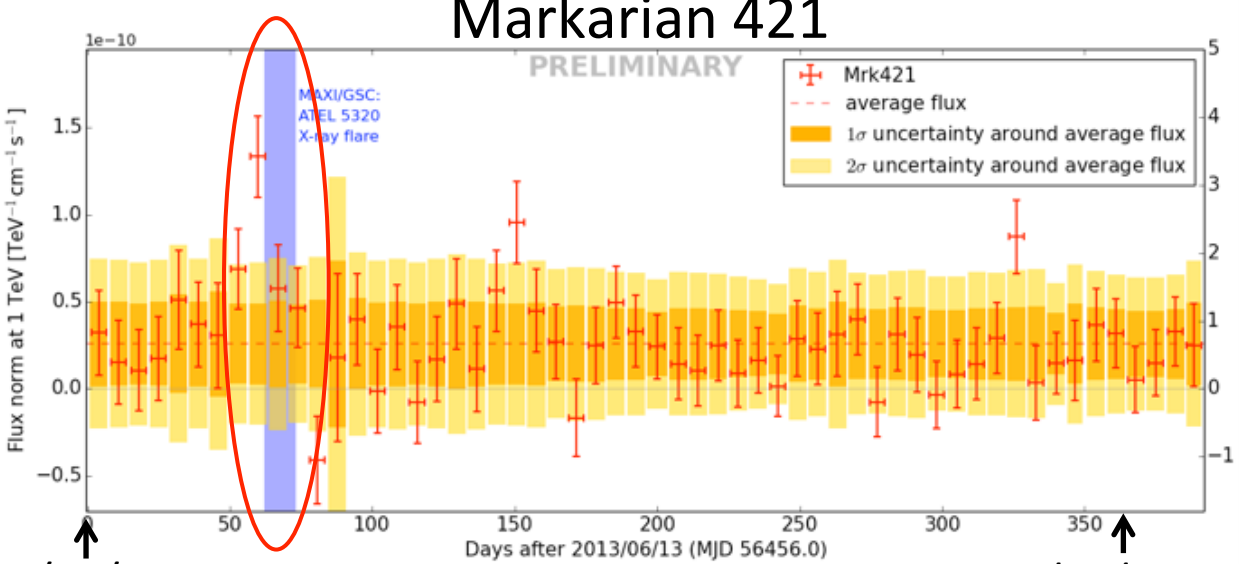


Treated as Extended Source

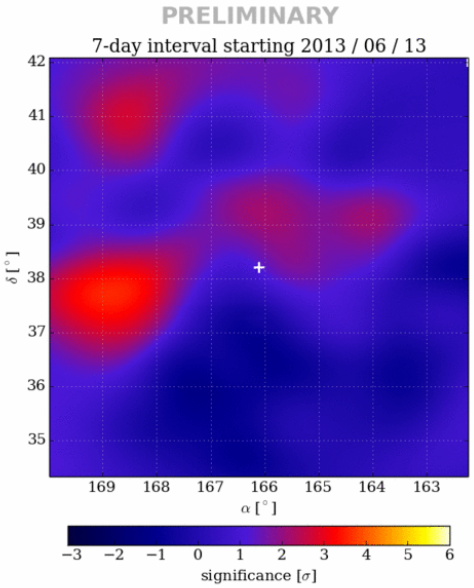
HAWC Sees Flaring Sources

[ApJ, 841:100 (June 1, 2017)]

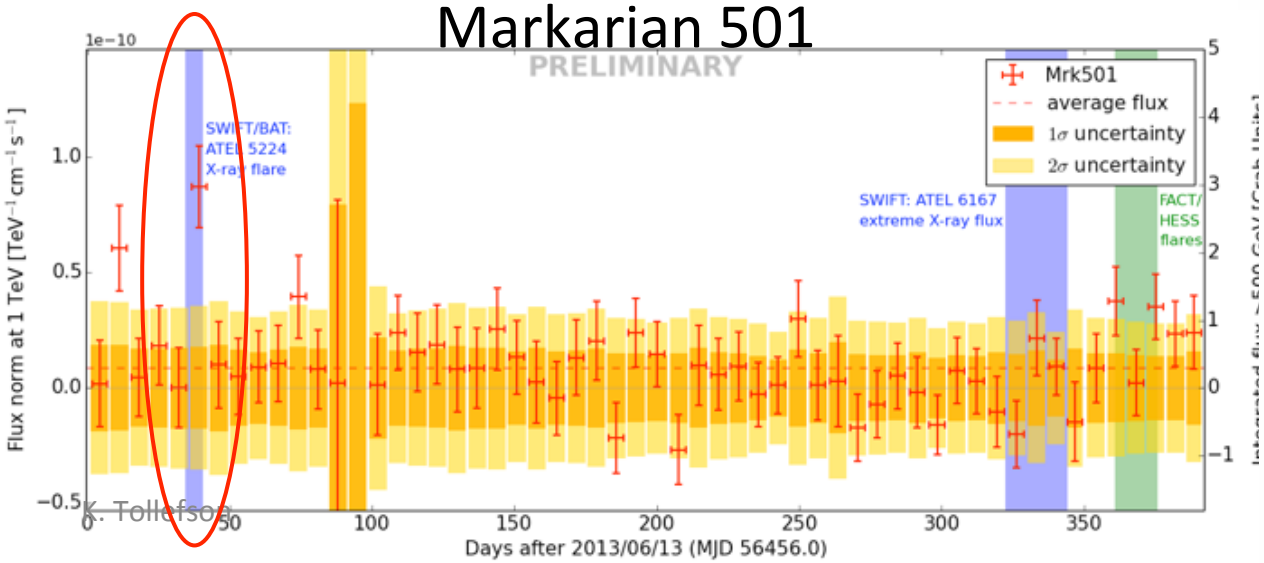
Markarian 421

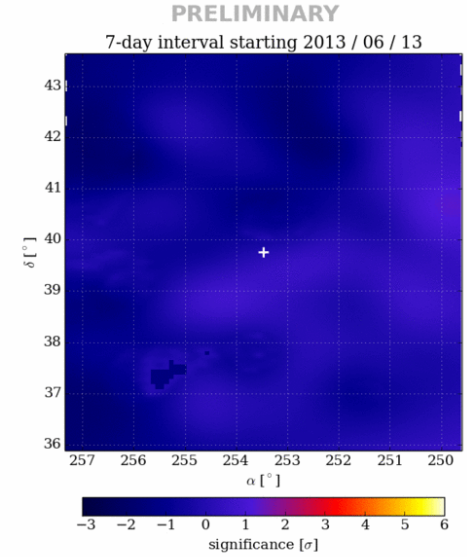


6/13/2013 — 6/13/2014



Markarian 501

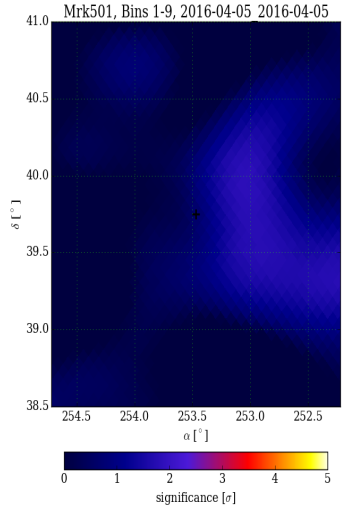




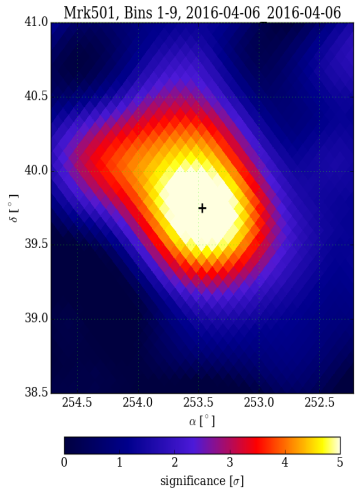
Real-Time Alerts

HAWC monitors all gamma-ray sources visible to it every day.

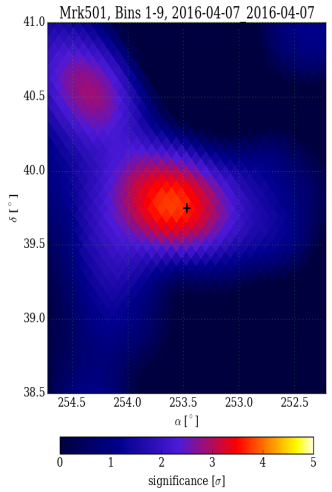
Sends alerts such as Astronomer's Telegram (ATeL)
to immediately alert community of activity.



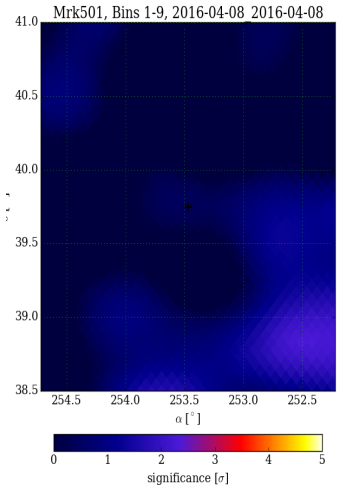
April 5, 2016



April 6, 2016



April 7, 2016



April 8, 2016

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)

Real-time Flare Monitoring published:
ApJ 843:116
(July 10, 2017)

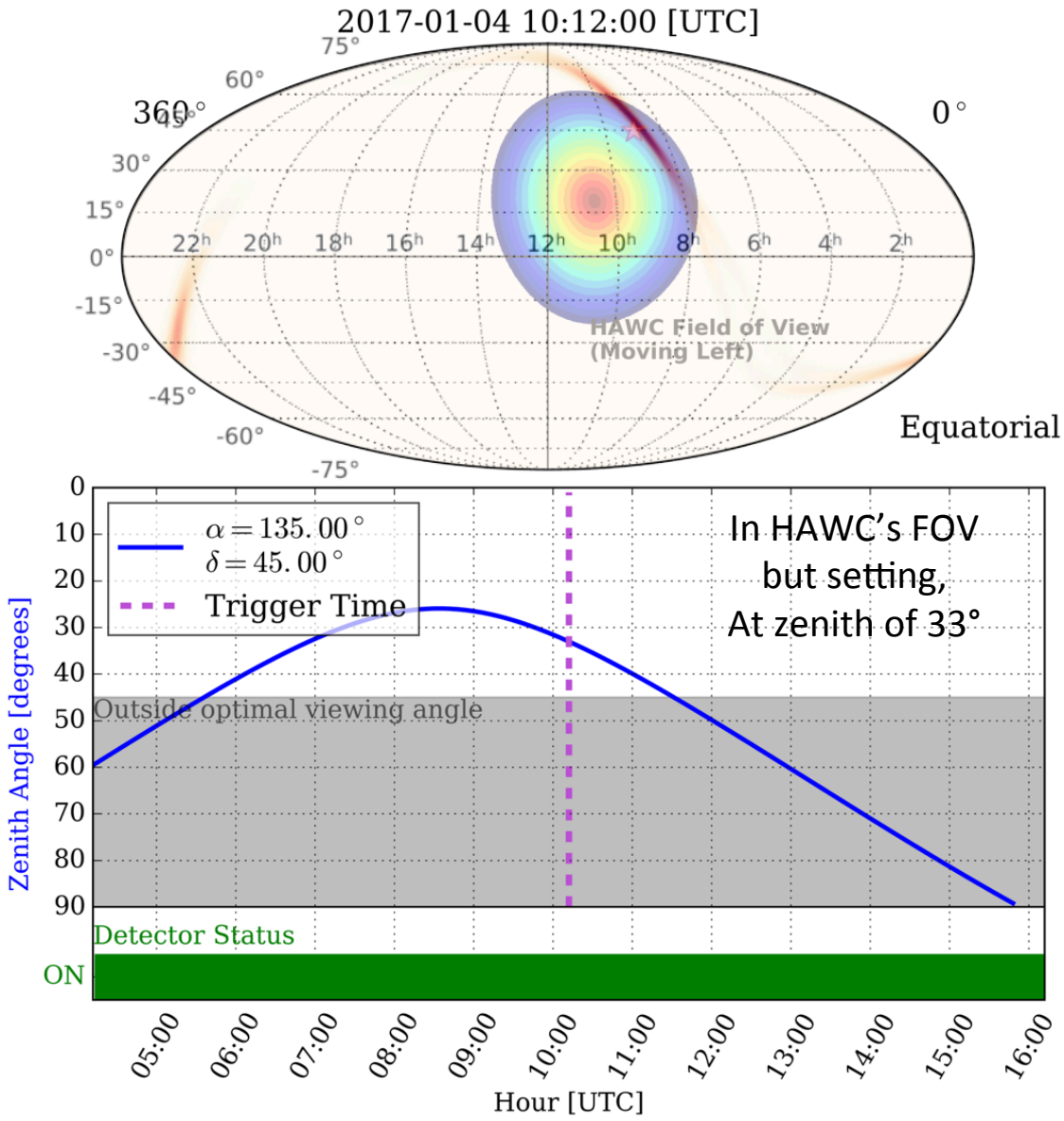
LIGO Gravitational Wave Events

GW170104

- Jan. 4, 2017 at 10:11:58.6 UTC
- BH-BH of 31M⊙ + 19M⊙
- z = 0.18 +/- 0.08
- PRL 118, 221101 (2017)

No transients found in the HAWC data on short (0.1 to 100s) and long (24 hours) time scales in window around the LIGO event.

Results reported promptly to MOU partners.

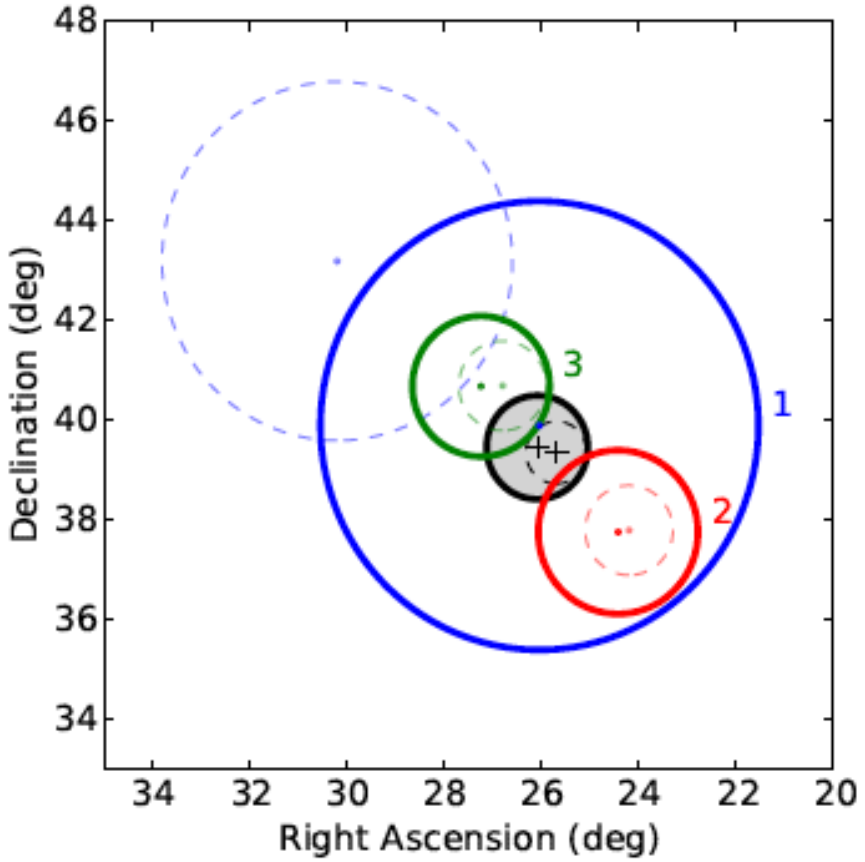


Triplet Event

- 3 ν_μ candidates within 100s consistent with point source origin on Feb. 17, 2016
- Probability to detect at least 1 triplet from atmospheric back-grounds is 32%

$$\pi^0 \rightarrow \gamma\gamma$$

$$\pi^{\pm} \rightarrow \mu^{\pm}\upsilon_\mu \rightarrow \upsilon_\mu\upsilon_e$$



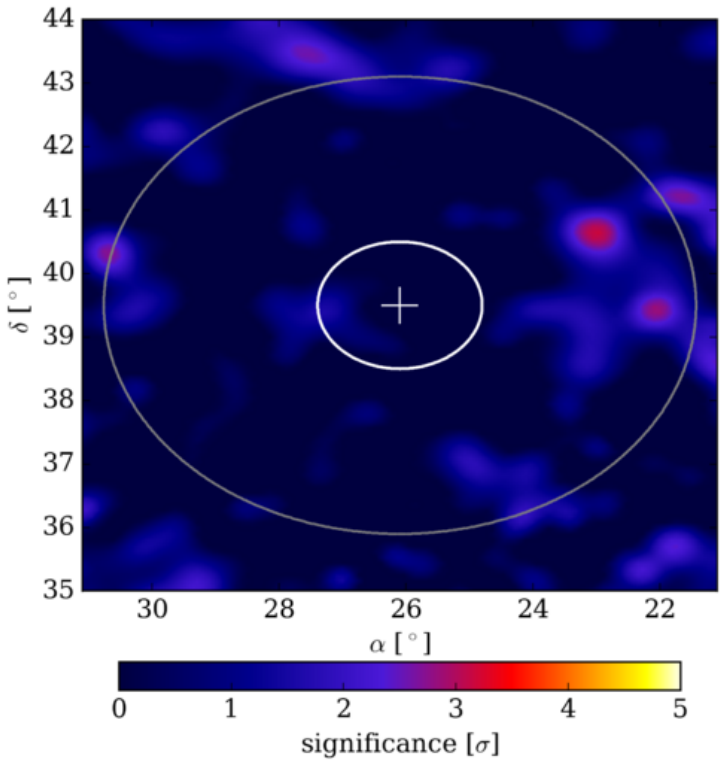
Notified other experiments to search for EM counterpart

IceCube Triplet Event

arXiv:1702.06131

- 8 observatories did follow-ups from visible frequencies up to gamma rays
  - 3 optical: ASAS-SN, LCO, MASTER
  - 2 x-ray: XRT and BAT
  - 3 gamma-ray: FermiLAT, VERITAS, HAWC
- HAWC: Event position had just entered FOV and observed a full transit (~6 hours for zenith <45°)
- **No EM counterparts were observed**

HAWC Sky Map for 1 transit

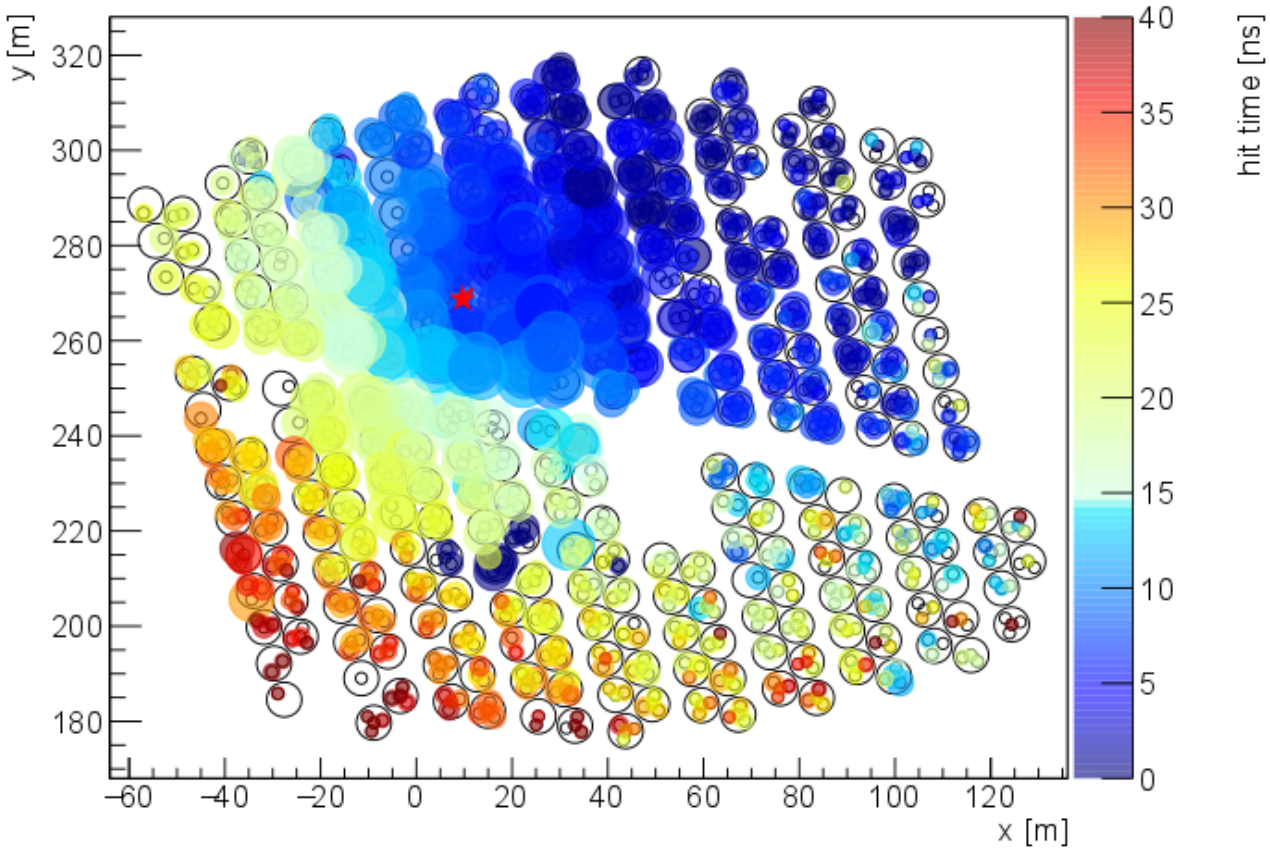


Additional Topics

- **Dark Matter Searches**
  - See **Pat Harding's talk** in Dark Matter session tomorrow at 11:30am in Hornets Nest
  - Dwarf Spheroidal Galaxy limits submitted to ApJ arXiv:1706:01277
- Gamma-ray Burst (GRB) Searches
  - ApJ 843:88 (July 10, 2017) with first 18 months of data
- Many more astrophysics results
  - See ICRC2017 conference proceedings for the latest

    http://www.icrc2017.org/

Highest Energy Event (So Far)



Neural Net Energy = 60 TeV

Ongoing Upgrade

350 **Outrigger** tanks will cover an area 4x HAWC

increasing sensitivity 3-4x above 10 TeV

Summary

- HAWC started full operations in March 2015 and is performing great!
  - Most sensitive gamma-ray experiment above 10 TeV
  - Several publications using first 1.5 years of data, more expected soon
  - Sending real-time alerts, following-up on alerts, doing multi-wavelength and multi-messenger analyses with other experiments
- Upcoming Attractions:
  - Analysis improvements, including better energy estimators
  - Outriggers will improve resolution at highest energies
  - Joint Fermi/VERITAS/HAWC working groups are standardizing and combining results