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

Detecting the Highest Energy Light with a Telescope Made of Water

Kirsten Tollefson
for the HAWC Collaboration
Michigan State University

Picture taken July 8, 2015
Radio, microwave, infra-red, optical, UV, X-RAY

0.5 MeV, 100 GeV, 100 TeV

GBM, LAT, HAWC, VERITAS

Courtesy of Jamie Holder
Gamma-Ray Detectors

Simulation (CORSIKA)

Wide Field of View, Continuous Operations
- Satellite Detector
  - 30 MeV – 300 GeV

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

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

K. Tollefson
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 m²

Taken March 18, 2015
Crab Nebula as a Calibration Source

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


K. Tollefson
25 Month Sky Map with 100 GeV to 100 TeV Photons

Mrk501 23σ
Mrk421 33σ
Crab Nebula 105σ

39 sources found, 10 were new

Known AND New TeV Sources

Supernova remnant with very energetic pulsar

Pulsar ~8kpc (26,000 ly) away

Association unclear
VERITAS Confirms HAWC detection

<table>
<thead>
<tr>
<th>Name</th>
<th>$\sqrt{S}$</th>
<th>Index</th>
<th>Flux for index at 7 TeV [TeV$^{-1}$cm$^{-2}$s$^{-1}$]</th>
</tr>
</thead>
<tbody>
<tr>
<td>2HWC J1953+294</td>
<td>5.58</td>
<td>-2.76 ± 0.15</td>
<td>1.1e-14 ± 4.2e-15</td>
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</tbody>
</table>
**Geminga**: Closest known (250 parsecs) middle-aged pulsar
HAWC Sees Flaring Sources

Markarian 421

6/13/2013

Markarian 501

6/13/2014

ApJ, 841:100 (June 1, 2017)
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.

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)
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.

K. Tollefson
• 3 $\nu_\mu$ candidates within 100s consistent with point source origin on Feb. 17, 2016
• Probability to detect at least 1 triplet from atmospheric backgrounds is 32%

\[
\begin{align*}
\pi^0 & \rightarrow \gamma\gamma \\
\pi^\pm & \rightarrow \mu^\pm \nu_\mu \rightarrow \nu_\mu \nu_e
\end{align*}
\]

Notified other experiments to search for EM counterpart
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
Additional Topics

• Dark Matter Searches
  – See Pat Harding’s talk in Dark Matter session tomorrow at 11:30am in Hornets Nest

• Gamma-ray Burst (GRB) Searches

• Many more astrophysics results
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