Recent Results from the HAWC Gamma-ray Observatory

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The HAWC Observatory

HAWC Observatory

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

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.

“hot” spots concentrate around the core

“hot” spots are more dispersed
Observing Air Showers with Water Cherenkov Detectors

arXiv:1701.01778

Timing of when each PMT was hit → direction  
Charge of each PMT → energy
Wide Field of View TeV Observatory

Wide-field/Continuous Operation

- Fermi-LAT (GeV)

TeV Sensitivity

- HAWC
- ARGO-YBJ
- LHASSO (future)
- VERITAS, HESS, MAGIC, FACT, CTA (future)
HAWC Publications

- 14 papers published in 2017 & 2018
- Too many results for just 20 min!
- Find all HAWC publications online https://www.hawc-observatory.org/publications/

Constraining the $\pi^+$/\pi$^0$ Ratio in TeV Cosmic Rays with Observations of the Moon Shadow by HAWC

A Search for Dark Matter in the Galactic Halo with HAWC
HAWC Collaboration: A.U. Abeysekara et al., JCAP 02 (2018), 049.

Data Acquisition Architecture and Online Processing System for the HAWC gamma-ray observatory

Dark Matter Limits from Dwarf Spheroidal Galaxies with the HAWC Gamma-Ray Observatory

Extended gamma-ray sources around pulsars constrain the origin of the positron flux at Earth

Multi-messenger Observations of a Binary Neutron Star Merger

All-particle cosmic ray energy spectrum measured by the HAWC experiment from 10 to 500 TeV

The HAWC real-time flare monitor for rapid detection of transient events

Search for very-high-energy emission from Gamma-ray Bursts using the first 18 months of data from the HAWC Gamma-ray Observatory

The 2HWC HAWC Observatory Gamma-Ray Catalog

Observation of the Crab Nebula with the HAWC Gamma-Ray Observatory
HAWC 3 year Sky Map

HAWC 3 year skymap -- 1017d livetime: 2014-11 to 2017-12

Mrk 501

Mrk 421

Inner galactic plane

Geminga & Monogem

Crab

PRELIMINARY
HAWC 3 year Sky Map
Inner Galactic Plane
HAWC 3 year Sky Map
Inner Galactic Plane

2HWC catalog (ApJ 2017) was 507 days and found 39 sources, 19 of which were new
• AMS-02 on board the International Space Station observes local cosmic rays since 2011
  ○ excellent charge resolution and particle species discrimination
• TeV $e^-e^+$ lose energy quickly and therefore must be produced locally ($d < \sim 100$ pc)
  ○ secondaries produced by cosmic ray interactions with ISM (spallation)
  ○ primaries produced by local source
    ■ local cosmic accelerator (e.g. Geminga)? local dark matter interactions?
• Larger positron flux observed above $\sim 10$ GeV than expected from secondaries
  ○ First observed by Pamela in 2009, since confirmed by Fermi LAT and AMS-02
  ○ Are they from a local cosmic accelerator or dark matter?
    ■ If they are from dark matter, other annihilation products should be produced
Geminga and Monogem

- HAWC observes extended emission from both the Geminga and Monogem (PSR B0656+14) pulsars
- These are both nearby, middle-aged pulsars that could be producing the observed local positrons

<table>
<thead>
<tr>
<th></th>
<th>Geminga</th>
<th>Monogem</th>
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<tbody>
<tr>
<td>( \dot{E} ) [erg/s]</td>
<td>( 3.2 \times 10^{34} )</td>
<td>( 3.8 \times 10^{34} )</td>
</tr>
<tr>
<td>Age [yr]</td>
<td>( 3.42 \times 10^5 )</td>
<td>( 1.1 \times 10^5 )</td>
</tr>
<tr>
<td>Dist. [pc]</td>
<td>250</td>
<td>288</td>
</tr>
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Science 358 (2017) no.6365, 911-914
Electron/Positron Diffusion Coefficient

- TeV radial profile → direct measurement of electron/positron diffusion around the source
- Measured diffusion is ~100 times smaller than the ISM diffusion derived from the B/C ratio
  - $D_{100 \text{TeV}} = 4.5 \pm 1.2 \times 10^{27} \text{ cm}^2/\text{s}$
- Using the measured diffusion coefficient, $e^+/e^-$ cannot reach Earth and Geminga/Monogem do not explain the positron excess

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- But, if you use a variable diffusion coefficient, the positrons can reach earth and explain the positron excess
  - D. Hooper et al., PRD 96, 103013 (2017); K. Fang et al., arXiv:1803.02640; S. Profumo et al., arXiv:1803.09731
HAWC Dark Matter Targets

• HAWC has a wide field of view making it sensitive to extended objects
• HAWC surveys $\frac{2}{3}$ of the sky every day, including several DM targets
No gamma-ray excess detected in any target
Limits set on DM annihilation cross section and decay lifetime
What are the sources of high-energy cosmic rays?

- Cosmic rays below the “knee” are hypothesized to be from the Milky Way Galaxy, while higher energy cosmic rays are hypothesized to be extragalactic.
- We know some sources of cosmic rays, but the highest energy Galactic sources (PeVatrons) are still not well characterized:
  - PeVatrons make 10’s to 100’s of TeV gamma rays
  - H.E.S.S. observations of the Galactic Center suggest it is a PeVatron (Nature 2016)
  - Are other Galactic sources PeVatron candidates?

http://www.physics.utah.edu/~whanlon/spectrum.html
HAWC PeVatron Candidates

Galactic Plane, > 56 TeV (0.5 degree extended source assumed)

- HAWC is observing the highest energy photons ever detected (>50 TeV)
- Preliminary analysis has found high-energy (>56 TeV) sources
  - PeVatron candidates
  - High-energy sources are coincident with pulsars
  - Spectral fits are forthcoming, which will help determine emission mechanisms and if they are PeVatrons
Upgrade to HAWC Array

- Upgrade to HAWC array is underway
  - add larger, sparse array of small tanks
- Provide better measure of high energy showers
  - expect gain in sensitivity > 10 TeV of about 3-4
Summary

- The full HAWC Observatory has been observing the TeV gamma-ray sky since March 2015
  - Wide field of view, works day and night
- 2 year catalog discovered 10 new sources
- Observations from Geminga and Monogem pulsars constrain origin of local positrons
- HAWC sets competitive limits on dark matter annihilation and decay
- HAWC is observing the highest energy photons ever detected
  - Have found a new PeVatron candidate
  - Outrigger array will extend our high energy reach