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Recent results from the High Altitude Water Cherenkov Observatory

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High energy γ-ray observations are an essential probe of cosmic-ray acceleration mechanisms. The detection of the highest energy γ rays and the shortest timescales of variability are the key to improve our understanding of the acceleration processes and the environment of the cosmic accelerators. The High Altitude Water Cherenkov (HAWC) experiment is a large field-of-view, multi-TeV, γ-ray observatory continuously operating at 4100 m a.s.l. since March, 2015. The HAWC observatory has an order of magnitude better sensitivity, angular resolution, and background rejection than the previous generation of water-Cherenkov arrays. The improved performance allows us to discover new TeV sources, to detect transient events, to study the Galactic diffuse emission at TeV energies, to measure or constrain the TeV spectra of GeV γ-ray sources, to search for Galactic Pevatrons, and to improve the upper limits on indirect searches for dark matter and the constrains on Lorentz invariance violation. In this contribution I summarize the most recent results from the HAWC observatory using the latest reconstruction algorithm (Pass 5 production) and I discuss their implications for cosmic-ray acceleration and propagation.

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1. The High Altitude Water Cherenkov Observatory

The High Altitude Water Cherenkov (HAWC) Observatory has a main array of 300 water-Cherenkov detectors over an area of ~22,000 m^2 at 4,100 m a.s.l. in Mexico. The instantaneous field of view is ~2 sr; i.e., we observe more than 70% of the sky every day. The HAWC Observatory was designed to study γ rays and cosmic rays in the multi-TeV energy range. We started operating with the full main array in March, 2015. The most notable features are the high duty cycle (>95%) and the large field of view. A detailed description of the HAWC Observatory can be found in Ref. [1].

In this proceedings I highlight a selection of the published analyses since the last ICRC.

2. Selected recent results

2.1 Searching for TeV Dark Matter in Irregular Dwarf Galaxies

The mentioned features of HAWC allow us, for example, to perform indirect searches for dark matter (DM) from relatively large halos or to set limits on new proposed targets using the whole data set. In the most recent analysis [2], we show the capabilities of the HAWC Observatory to perform indirect searches and to constrain DM models using a sample of 31 dwarf irregular galaxies. The exclusion limits for annihilation cross-section and decay lifetime for WIMP candidates with masses between 1 and 100 TeV in Ref. [2] are comparable to the limits obtained for classical dwarf Spheroidal galaxies. Thus, we will perform a combined analysis with both populations in future studies that will allow us to improve the constraints on the different properties of the DM candidates.

2.2 Search for Gamma-Ray and Neutrino Coincidences

The same key features that I mentioned in the introduction make HAWC an ideal instrument to observe transient events [3]. A flare monitor was designed to detect VHE transient events and to produce real-time alerts to facilitate multi-wavelength and multi-messenger studies. These alerts are sent in real time to the Astrophysical Multimessenger Observatory Network (AMON) [4] to be distributed as VHE γ-ray flares **and** to correlate them with data streams from other messengers, such as gravitational waves and neutrinos. In Ref. [5], we present the coincidence analyses between high-energy γ rays detected with the HAWC Observatory and high-energy neutrino data from the Neutrino Telescope and Abyss environmental RESearch (ANTARES) neutrino telescope [6]. We performed an archival search first and we then established an online analysis that sent γ-ν coincidences in real time until ANTARES ceased operations. The analysis method applied in this work is the same as the one developed for the HAWC and IceCube detectors in Ref. [7], which is still running in real time. In fact, these are the only truly multi-messenger alerts in the world.

2.3 New TeV Gamma-Ray Sources

2.3.1 Unassociated sources

Another important capability of the HAWC Observatory is the discovery of new TeV sources. For example, we recently reported two new sources in the region of the Galactic plane at galactic longitude 52°$<\ell<$55° [8]. The first new source, 3HWC J1928+178, was discovered by HAWC and coincident with the pulsar PSR J1928+1746. But it was not initially detected by any IACT despite their long exposure on the region, until a recent new analysis of H.E.S.S. data was able to confirm it. (Moreover, no X-ray counterpart has been detected from this pulsar.) In Ref. [8], we presented a detailed description and multi-wavelength overview of this complex region that revealed an additional new source, HAWC J1932+192, which is potentially associated with the pulsar PSR J1932+1916.

2.3.2 TeV Halos

In Ref. [9] we reported the detection of a new TeV halo around the pulsar PSR J0359+5414. This pulsar was detected in the MeV-GeV energy range by Fermi-LAT [10], and was later classified as radio-quiet. The TeV emission we observe with HAWC presents similar features as the other TeV halo candidates; e.g., the derived acceleration efficiency and a diffusion coefficient much lower than the average value of the ISM.

Our observation of the TeV halo features associated with the pulsar PSR J0359+5414 suggests the existence of a VHE electron population outside the region where the nebula is energetically dominant.

2.4 Gamma-Ray Emission from the Classical Nova V392 Per

Galactic novae have been detected in the GeV energy range. They are among the newest candidates for VHE γ-ray sources assuming that the same shocks are able to produce photons in the TeV energy range. We studied the γ-ray properties of the 2018 eruption of the Galactic nova V392 Per in Ref. [11]. This analysis spanned photon energies from ~0.1 GeV up to 100 TeV by combining observations from the Fermi-LAT and the HAWC Observatory. The HAWC flux upper limits disfavor an extension of the Fermi-LAT spectrum to photon energies above 10 TeV.

2.5 Extragalactic Science

Using data from the first three years of observations, we reported the significant (above 10 σ) detection of VHE γ radiation from Markarian 421 (Mrk 421) and Markarian 501 (Mrk 501) [13]. In Ref. [13], we report the time-averaged spectral analyses for both sources above 0.5 TeV. The maximum energies at which the signals from Mrk 421 and Mrk 501 are detected are 9 and 12 TeV, respectively. These values are some of the highest energy detections reported to date for spectra averaged over long periods of time. The study of the spectral energy distributions of these blazars provides information about the physical processes that take place in their relativistic jets.

The direct measurement of the Extragalactic Background Light (EBL) is challenging, particularly in the infrared waveband, due to foreground photon contamination from the Sun. VHE γ rays coming from blazars travel cosmic distances through the intergalactic space and interact with diffuse photons from the EBL in the mid to far-infrared region through pair production. By studying this absorption effect in blazar spectra we can infer properties about the IR region of the EBL. In Ref. [12], we use HAWC and Fermi-LAT observations from Markarian 421 and Markarian 501 to analyze the different EBL absorption scenarios. The EBL intensity measurements and containment bands are calculated from 1 to 100 μm, probing higher wavelength values than previous measurements. This method has the advantage of being independent of any particular EBL shape and the assumed intrinsic spectra of the blazars. The results for both sources are in agreement with current upper limits from direct IR observations and lower limits from galaxy counts. Other features observed in these measurements might be related to intrinsic spectral properties of the sources.

2.6 Ultra High Energy Sources

Last, but not least, is the fact that ground arrays of particle counters have the potential to identify the highest energy sources. For example, we reported new observations of the source MGRO J1908+06 in Ref. [14]. MGRO J1908+06 is one of the highest energy γ-ray sources ever detected, with emission extending past 200 TeV. This extremely bright source, located in the Galactic plane, is an intriguing source to study. Previously, the origins of the emission were unclear because there is a supernova remnant, molecular clouds, and multiple pulsars in the region. Evidence of hadronic emission could identify this source as a "PeVatron." In Ref. [14], our model favors a predominantly leptonic emission that originates from the extremely energetic pulsar PSR J1907+0602. However, there is a possible hadronic component above 50 TeV. This result highlights the importance of multi-wavelength and multi-messenger studies to pinpoint the emission mechanisms.

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