

Latest news from the High Altitude Water Cherenkov Observatory

A González Muñoz for the HAWC Collaboration

Instituto de Física, Universidad Nacional Autónoma de México, Apartado Postal 20-364,
México D.F. 01000, México

E-mail: adiv.gonzalez@fisica.unam.mx

Abstract. The High Altitude Water Cherenkov Observatory is an air shower detector designed to study very-high-energy gamma rays (~ 100 GeV to ~ 100 TeV). It is located in the Pico de Orizaba National Park, Mexico, at an elevation of 4100 m. HAWC started operations since August 2013 with 111 tanks and in April of 2015 the 300 tanks array was completed. HAWC's unique capabilities, with a field of view of ~ 2 sr and a high duty cycle of 5%, allow it to survey $2/3$ of the sky every day. These features makes HAWC an excellent instrument for searching new TeV sources and for the detection of transient events, like gamma-ray bursts. Moreover, HAWC provides almost continuous monitoring of already known sources with variable gamma-ray fluxes in most of the northern and part of the southern sky. These observations will bring new information about the acceleration processes that take place in astrophysical environments. In this contribution, some of the latest scientific results of the observatory will be presented.

1. Introduction

The direct detection of high energy gamma rays is only possible with instruments installed in satellites orbiting the Earth (like Fermi-LAT [1]). However, the effective area of these instruments is limited, mainly due to the high costs of delivering payloads into orbit, which makes quite challenging to detect gamma rays of higher energies. However, very-high energy (VHE) gamma rays (as well as cosmic rays) upon interaction with the Earth atmosphere will produce cascades of secondary particles called Extensive Air Showers (EAS). Most of these secondary particles will lose all of its energy crossing the atmosphere but some of them will reach the ground. The EAS, being composed by particles traveling at relativistic speeds, will produce Cherenkov light in the air. This Cherenkov light can be collected and concentrated by reflectors into sensitive cameras, from which and “image” of the shower can be extracted. From this image the energy and direction of the primary gamma ray can be estimated. Instruments that use this technique for the observations of VHE gamma rays are called Imaging Atmospheric Cherenkov Telescopes (IACTS). The other main technique to indirectly observe VHE gamma rays is by detecting the particles from the EAS that hit the ground. A relatively cheap way to do it is by measuring the Cherenkov light that these particles produce in water. The pioneer of this technique for the detection of VHE gamma rays was *Milagro* [2], which operated from 2000 to 2008. It consisted of a rectangular pond of 80 m long, 60 m wide and 8 m deep, located at 2630 m above sea level in the Jemez Mountains, New Mexico, U.S.A. Inside the pond there were 723 photomultiplier tubes (PMTs) arranged in a grid. By registering the time in which the particles hit the pond and the intensity of the Cherenkov light that they produced it was possible



to estimate the direction and the energy of the primary gamma ray. In order to achieve better sensitivity with this technique, the detector has to be as close as possible to the maximum of the EAS and cover a big area. With these principles in mind the High Altitude Water Cherenkov (HAWC) observatory was constructed.

2. HAWC Observatory

The HAWC observatory was inaugurated on March 20th, 2015. It was designed to be sensitive to gamma rays and cosmic rays between the energies of 100 GeV and 100 TeV [3]. The facility consists of an array of 300 water Cherenkov detectors (WCDs) deployed in a surface of ~ 22000 m² at 4100 m above sea level, in a valley between the volcanoes Pico de Orizaba and Sierra Negra, in Mexico. Each WCD consist of a cylindrical structure of steel with 7.3 m of diameter and 4.5 m high. Inside of the steel cylinder there is a light-tight bladder where 200 000 l of highly purified water are stored. Each WCD is instrumented with four photomultiplier tubes (PMTs) installed at the bottom of the bladder, facing upward. Three of these PMTs (8-in photocathode) are deployed forming an equilateral triangle (side length 3.2 m), centered around the forth one (10-in photocathode) located at the centre of the WCD.

The secondary particles in an EAS are distributed around the shower axis in what is called the “shower front”. These particles hit the WCDs of HAWC at different times, depending on the orientation of the shower axis. Additionally, the Cherenkov light produced in the WCDs depends on the flux intensity of the shower. With this information (time and charge) the direction and energy of the primary gamma ray is possible to be reconstructed. HAWC has an instantaneous field of view of 2 sr, allowing it to scan 2/3 of the sky per day.

3. HAWC’s first scientific results

One of the first and most interesting scientific results from the HAWC observatory, is the detection of a small-scale anisotropy in the arrival direction of TeV cosmic rays. The data used for this study was gathered between June 16, 2013 and February 27, 2014 [4]. In order to find the small-scale anisotropy, first, a reference map is created in which asymmetries due to diurnal changes coming from changes in the cosmic-ray rate and the asymmetric shape are taken into account. Then, a relative intensity map is created computing the amplitude of deviations from the isotropic expectation (see Eq. 2 in [4]). Then, to see structures of scales smaller than 60° , the dipole, quadrupole and octupole terms are removed from this map, creating the maps shown in Fig. 1. Three regions are clearly visible, labeled as region A, B and C. These regions are largely in agreement with other anisotropy measurements by Milagro [2], Tibet AS γ [5] and ARGO-YBJ [6], in the same regions scanned by HAWC. For a more detailed explanation of the methods used and discussion of the results please see [4].

Another important result from HAWC is the identification of sources and candidate sources in the inner galactic plane (longitude $[+15^\circ, +50^\circ]$ and latitude $[-4^\circ, +4^\circ]$ in galactic coordinates) using data from August 2, 2013 to July 9, 2014 [7]. A skymap was created in the region of interest containing all the excess events over a normalized background. Then, to identify the number of sources needed to model the excess events, a likelihood ratio test is performed, first with only 1 source, then with 2 and so on, in a iterative process. The model for the source spectrum is assumed to follow a simple power-law function, with a fixed index of 2.3. Fig. 2 shows the significance skymap and the model for 11 sources. Three sources have been identified with more than 5σ of significance and another seven candidates with more than 3σ . For a more detailed discussion please see [7].

4. HAWC monitoring of the gamma-ray sky

One of the most notorious capabilities of the HAWC observatory is its high duty cycle ($\sim 95\%$). Together with its large field of view, makes it the best instrument in current operation for an

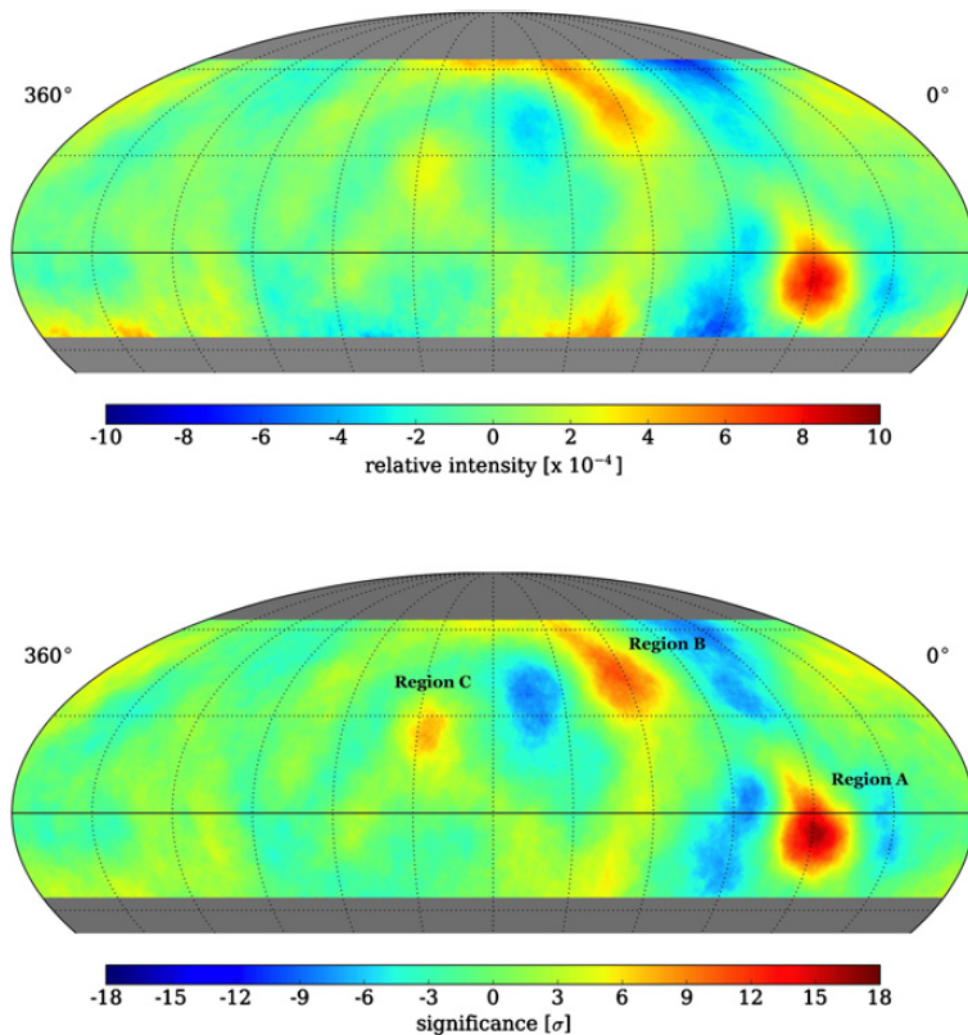


Figure 1. Relative intensity (top) and pre-trial significance (bottom) of the cosmic-ray flux after fit and subtraction of the dipole, quadrupole and octupole term. The coordinates are equatorial. Right ascension runs from 0° to 360° from right to left. The solid horizontal line denotes a declination of 0° [4].

almost continuous monitoring of known gamma-ray sources and the detection of transient events at VHE. These transient events include the possible detection of gamma-ray bursts (GRBs). Extrapolating data from GRB observations by Fermi-LAT, it is expected that HAWC observes 1 or 2 GRBs per year [9]. Another interesting kind of transient events are the high activity states (flares) of the active galactic nuclei (AGNs). These flares by themselves are interesting to study acceleration mechanisms inside the jets of AGNs. These flares usually produce large fluxes from which good quality spectra and skymaps can be produced, and be used to study the interaction of the gamma rays with the extragalactic background light and the presence of intergalactic magnetic fields. The large field of view of HAWC also makes it an optimal instrument for the study of large portions of the sky, searching for extended gamma-ray sources that could be originated by the self-annihilation of dark matter [10].

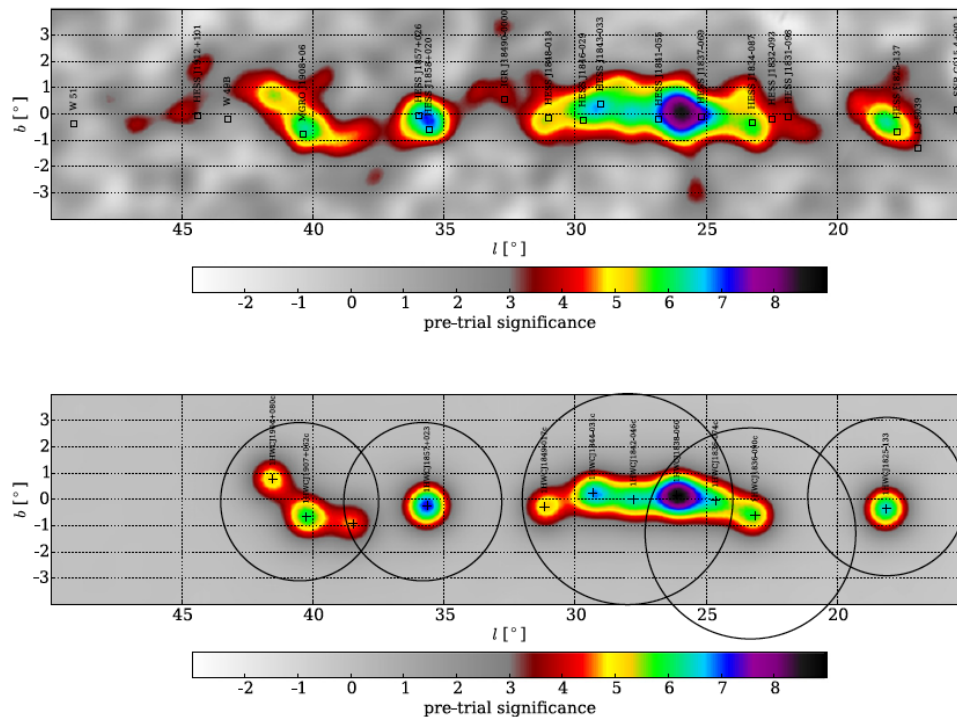


Figure 2. Top: significance map of the inner galactic plane; Bottom: model with 111 seed sources (crosses). The Black circles indicate the five regions of interest [7]. Open squares mark TeV sources in [8]

5. Ongoing HAWC developments

The software and hardware of the HAWC observatory are in continuous development and improvement. Each improvement on the software, once fully tested, is integrated in the on-line analysis of the HAWC observatory. This also means that all the previous data from the observatory is reprocessed. These improvements include changes in the algorithms for the reconstruction of events that improve the angular resolution and increase the sensitivity of the instrument.

On the side of the hardware, a major improvement will be the installation of the outriggers. For the reconstruction of events, it is critical to have a good determination of the “core” of the shower. Most of the large EAS detected by HAWC had their cores falling outside of the detector. To overcome this problem, 300 smaller WCDs (1.6 m diameter, 1.6 m high) will be installed around the main array, equipped with a single PMT each. With this outrigger array it is expected a gain of a factor of 3-4 in sensitivity for gamma rays above 10 TeV over what is presently achieved. The deployment will follow the geometry shown in Fig. 3, in which the inhomogeneities come from the conditions of the terrain. The commissioning of the outrigger array will be in spring 2017 [11].

Acknowledgments

We acknowledge the support from: US National Science Foundation (NSF); US Department of Energy Office of High-Energy Physics; The Laboratory Directed Research and Development (LDRD) program of Los Alamos National Laboratory; Consejo Nacional de Ciencia y Tecnología (CONACyT), Mexico; Red de Física de Altas Energías, Mexico; DGAPA-UNAM; VIEP-BUAP; the University of Wisconsin Alumni Research Foundation; the Institute of Geophysics, Planetary

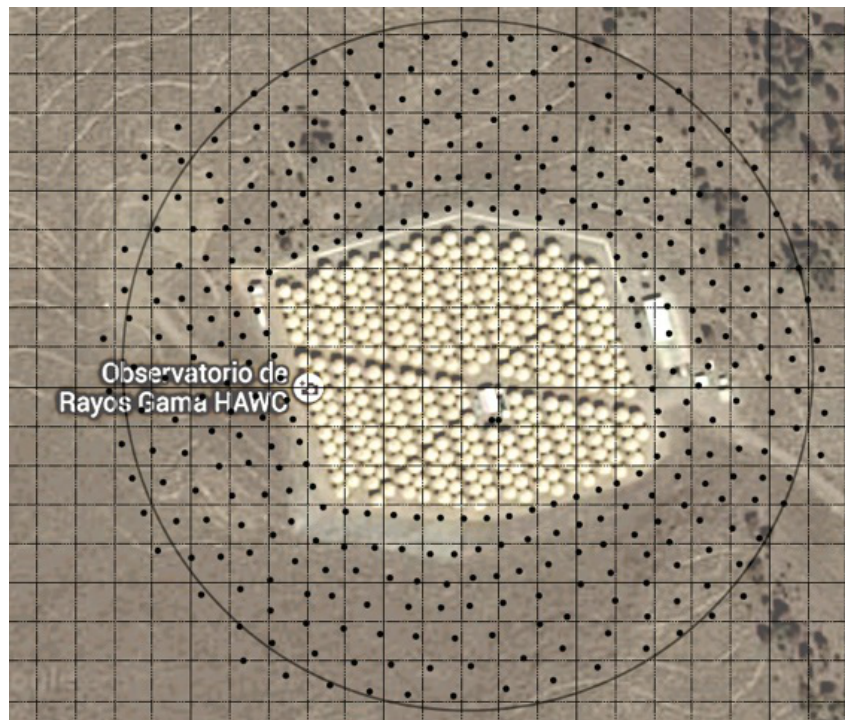


Figure 3. HAWC site with the current HAWC array and the layout of the outrigger array (black points) [11]

Physics, and Signatures at Los Alamos National Laboratory.

References

- [1] Atwood W B *et al.* 2009 *Astrophys. J* **697** 1071
- [2] Abdo A A *et al.* 2009 *Astrophys. J* **698** 2121
- [3] Abeysekara A *et al.* 2013 *Astroparticle Phys.* **50-52** 26
- [4] Abeysekara A *et al.* 2014 *Astrophys. J* **796** 108
- [5] Amenomori M *et al.* 2005 *Astrophys. J* **626** L29
- [6] Bartoli B *et al.* 2013 *Phys. Rev. D* **88** 082001
- [7] Abeysekara A *et al.* 2016 *Astrophys. J* **817** 3
- [8] Wakely S P and Horan D 2008 *ICRC* **3** 1341
- [9] Taboada I and Gilmore R 2013 *Nucl. Instrum. Meth. A* **742** 276
- [10] Abeysekara A *et al.* 2014 *Phys. Rev. D* **90** 122002
- [11] Sandoval A 2015 *ICRC* arXiv:1509.04269 [astro-ph.IM]