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The Boomerang PWN and its SNR G106.3+2.7 Viewed in the Very-High-Energy Gamma-Ray Regime by the HAWC Observatory

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Supernova remnant (SNR) G106.3+2.7, home to the Boomerang pulsar wind nebula (PWN), has long been thought to be a cosmic-ray PeVatron. However, its close proximity to the Boomerang PWN and the lack of gamma-ray (GR) observations above 30 TeV have made it difficult to model the nature of the emission mechanism. Recently, both the head (containing the PWN) and the tail (containing diffuse ejecta from the SN event) of the SNR have been separated by the MAGIC and Fermi-LAT observatories, giving us a glimpse into the very-high-energy (VHE) GR regime for both regions. With $>6\sigma$ detections for both the head and tail regions, the HAWC observatory is now able to extend these energy ranges past 50 TeV using new reconstruction algorithms on more than 2000 days of data. We present the multi-wavelength modeling of both the head and the tail regions, which supports a leptonic nature for the head and a lepto-hadronic nature for the tail, as well as possible sources for CR acceleration.

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1. Introduction

The search for galactic PeV cosmic-ray (CR) accelerators, or galactic PeVatrons, has led us to believe that supernova remnants (SNRs), where CRs can be accelerated to PeV energies in the shock fronts of the explosions, are the dominant type of galactic PeVatron [9]. Detecting a gamma-ray (GR) source above 100 TeV coincident with an SNR would strengthen the case for SNRs being PeVatrons.

SNR G106.3+2.7 contains a compact head region and an extended tail region. The head consists of the pulsar (PSR) J2229+6114 and its Boomerang pulsar wind nebula (PWN) and the tail contains SN ejecta from the SNR. Since the SNR's first detection by the Dominion Radio Astrophysical Observatory [13], five different GR observatories have detected significant emissions coming from the region. HAWC [5], Tibet ASγ [6], and LHAASO [7, 8] have seen emissions above 100 TeV, making the SNR a prime PeVatron candidate. However, the production mechanism for these GRs remains a mystery since the emission from the head and the tail of the SNR have only been distinguished in the high-energy GR regime and not the VHE regime [1, 10].

Since HAWC's last detection of SNR G106.3+2.7 in 2020 [5], HAWC has developed a new reconstruction algorithm on more than 2000 days of data that has allowed HAWC to detect the head and tail of the SNR above 6σ (figure 1). The HAWC observatory is located in Sierra Negra, Mexico, and is made up of 300 water Cherenkov detectors (WCDs) that cover 22,000 m^2. It has a >95% duty cycle and an angular resolution of $\geq$0.1 degrees [3].

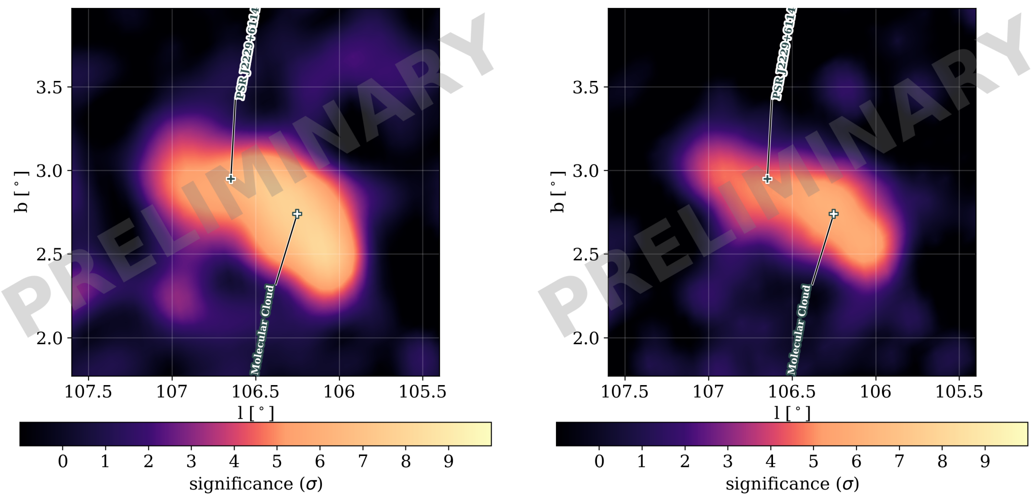

Figure 1: The HAWC significance map of the region for the neural net (left) and ground parameter (right) data maps. The PSR J2229+6114 and the nearby molecular cloud are shown for reference.

2. Analysis

This analysis was carried out on HAWC's data maps that are first binned in the fractional hit of the PMT's on HAWC's main array and second in reconstructed energy. Two algorithms are used for energy reconstruction, a neural net (NN) and an algorithm based on the lateral distribution of extensive air showers called ground parameter (GP). Figure 1 shows the maps for each algorithm. A multi-source fitting method using the HAL plugin [2] for the Multi-Mission Maximum Likelihood (3ML) framework [14] to find the most statistically preferred model. Both point and extended source assumptions, along with power-law and log-parabola spectra, are tested for this region.

3. Discussion

The head of the SNR is most likely powered by PSR J2229+6114 and its PWN. The radio [12, 13] and X-ray [11] observations of the head, which are relevant for the GR production mechanisms, would be produced by non-thermal synchrotron radiation. The high- and VHE GR observations would most likely be produced by Inverse Compton scattering from electrons in the PWN [1].

Similarly, the radio [12, 13] and X-ray [11] observations of the tail would be produced by non-thermal synchrotron radiation. The tail of the SNR is co-located with a nearby molecular cloud, making hadronic GR production through pion decay in the tail possible. Protons would be accelerated in the shocks of the SNR and, after some time, escape to interact with the molecular cloud. However, leptonic GR production cannot be ruled out at this time [1, 4–6, 10].

In this contribution, we discuss the best-fit morphological and spectral models of the region as seen in HAWC's newest data set. We also explore the possible CR acceleration mechanisms and GR production mechanisms for both the head and tail regions of SNR G106.3+2.7.

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