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Limits on Diffuse Dark Matter with HAWC

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In addition to dense regions of dark matter, such as galaxy clusters and dwarf galaxies, dark matter annihilation and decay are also expected to have a nearly isotropic distribution across the sky. This isotropic component is less model-dependent than the flux from isolated dark matter targets, and would produce galactic contributions to the Diffuse Gamma-Ray Background (DGRB). With its continuous monitoring of the gamma-ray sky from a few hundred GeV to several hundred TeV and its wide field-of-view, the High Altitude Water Cherenkov (HAWC) observatory is well-suited to search for dark matter contributions in the DGRB. In this work, 535 days of HAWC data and Monte Carlo simulations were studied to set limits on annihilating or decaying diffuse dark matter at TeV energies. With this data, we consider both leptonic and hadronic dark matter channels and are able to constrain dark matter up to masses >100 TeV.

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1. Motivation and Detector

Isotropic emission of gamma rays uncorrelated with any known sources are expected to be the main provenance of the Diffuse Gamma-Ray Background (DGRB). However, if dark matter were to annihilate or decay to produce gamma rays, due to the Earth's location near the middle of the galactic dark matter halo, a diffuse gamma-ray emission would be observed in all directions. This is particularly true if the DGRB is observed at multi-TeV energies where extra-galactic emission is attenuated via pair-production on the extra-galactic background light, making dark matter a more likely candidate for any observed high-energy DGRB emission.

In this work we use 535 days of data from the High Altitude Water Cherenkov (HAWC) gamma-ray observatory, taken from November 2014 to June 2016. With its 300 water Cherenkov detectors, HAWC was built to detect gamma rays in the energy range between 300 GeV to more than 100 TeV. For ground-based detectors, such as HAWC, hadronic Cosmic Rays (CRs) are the main source of background to high-energy photon observation. Fortunately, above several TeV, the air showers produced by high-energy CRs and gamma rays differ in shape. By quantifying the smoothness of the lateral charge distribution function of air showers [4] most of the cosmic ray contamination can be removed.

2. Analysis

We implement a 2D binning scheme [1] focusing on high energy events with reconstructed energies above 10 TeV and where more than 61.8% of the PMTs available were hit. Although this analysis does not include more recent HAWC data, the characteristics of the dataset used are very well known. A parallel work in this conference [1] relies on the same data and contains more details on the methodology.

Previous studies have been performed using the HAWC observatory to set limits on the DGRB [5–7]. In this work, the DGRB region of interest is a strip centered on the Crab nebula's location. Within the strip, bright known γ-ray sources – i.e. the Crab, Geminga and the Galactic Plane – have been removed to avoid contamination. The resulting DGRB strip has an area of 0.57 sr and is shown in Figure 1.

As we apply tighter gamma/hadron separation cuts, few events remain and we must rely on Poisson statistics. For a binned likelihood analysis, the log-likelihood is calculated as the sum of the log of the Poisson probability to observe N^{obs} events in a bin given that the model predicts N^{pred}

$$\ln\mathcal{L} = \sum_{i}^{\text{bins}} N_i^{obs} \log(N_i^{pred}) - \sum_{i}^{\text{bins}} N_i^{pred} \tag{1}$$

where N^{obs} is set as the number of events in our DGRB strip and N^{pred} depends on the number of Monte Carlo simulated events. We inject the latter with isotropic and spatial-model independent gamma-ray emissions from galactic dark matter interactions into tau leptons and bottom quarks [8]. However we do not perform a joint likelihood; in order to calculate the best estimate for the overall scale of the spectrum, the bins are not summed but treated as separate independent "experiments".

[1] https://pos.sissa.it/395/829

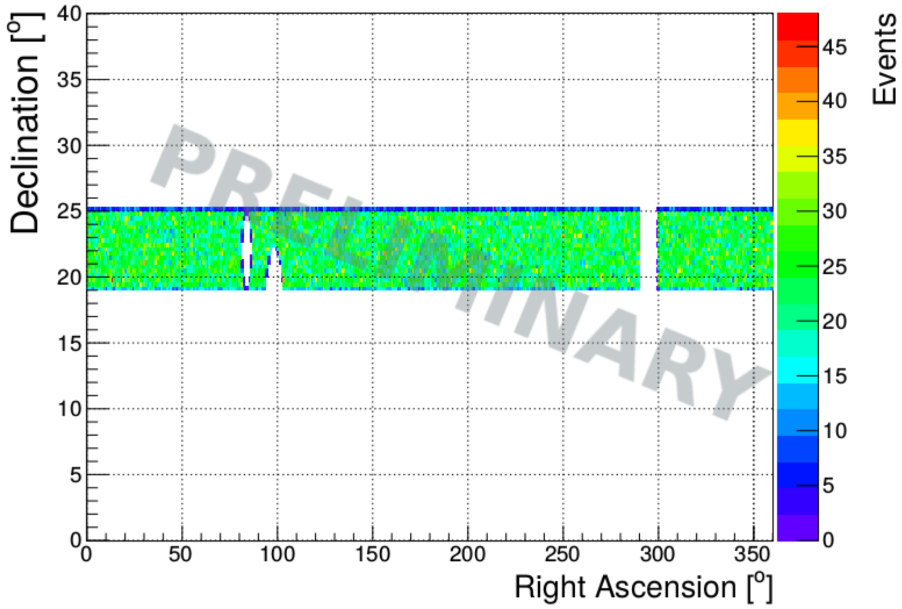

Figure 1: Map of the Diffuse Gamma-Ray Background strip

The 95% containment level of the maximum likelihood best estimate is calculated in each bin and the one with the lowest value is selected, as it would be the one with the most expansive limit.

3. Results

There are a few candidates which can be evaluated when it comes to dark matter masses and dark matter annihilation or decay spectra. We explore the more conventional channels for dark matter annihilation and decay interactions, which are the $b\bar{b}$ and $\tau^+\tau^-$ channels. Both of these processes would lead to the creation of gamma rays. By injecting the spectra of chosen dark matter masses in our Monte Carlo simulation we can calculate the 95% containment level of the best estimate of the overall scale of said spectra, which is referred to as $\beta_{95\%}$. We then chose the best $\beta_{95\%}$ to calculate $\beta_{95\%} \times \langle\sigma v\rangle$ for annihilation upper limits and the best $\beta_{95\%}$ to calculate $lifetime \div \beta_{95\%}$ for decay lower limits. The results are shown in Figure 2.

4. Discussion and Prospects

It is possible that diffuse γ-ray emissions originate from annihilating or decaying dark matter in the extended halo around the Galaxy. Gamma rays would then be observed in all directions, as a background to all other γ-ray observations. The limits obtained here are pushing into an energy range higher than the Fermi-LAT Isotropic Gamma-Ray Background and the HAWC Andromeda Galaxy constraints, nonetheless we can observe better limits for interactions involving tau leptons when compared to the HAWC Burkert Galactic Halo limits.

With the addition of more years of data, upcoming improvements to the HAWC reconstruction algorithms and analytical methods, and the deployment of the outrigger array in 2018, stronger

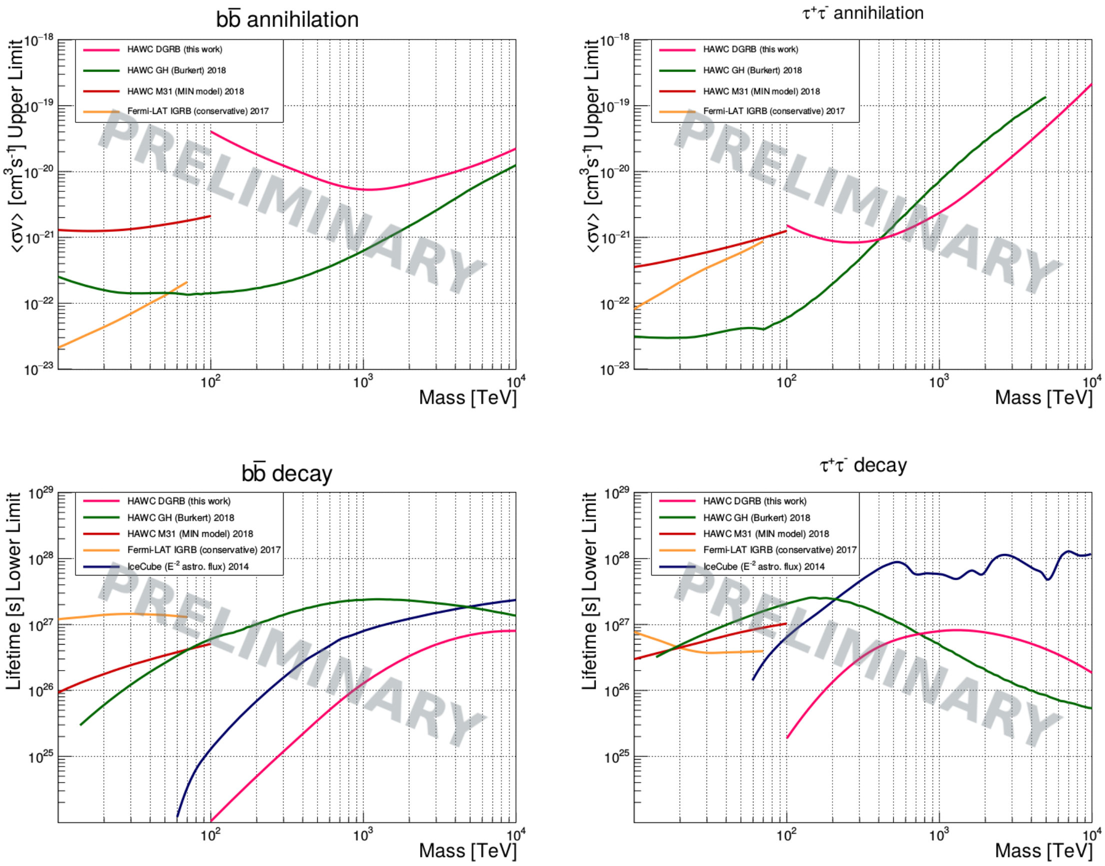

Figure 2: 95% confidence level limits on diffuse dark matter compared to recent dark matter searches with HAWC [9][10] and other experiments such as IceCube [11] and Fermi-LAT [12].

constraints on the previous results are expected. Furthermore, a next-generation Southern Wide-field Gamma-ray Observatory (SWGO) [2] is being considered for the Southern Hemisphere which will extend sensitivity to energies above the tens of PeV.

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[2]www.swgo.org

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