VERITAS Observations of a "Forbidden Velocity Wing"

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†see R.A. Ong et al. (these proceedings) or http://veritas.sao.arizona.edu/conferences/authors/icrc2009

Abstract. The H.E.S.S. extended Galactic plane survey [1] revealed the presence of a new extended TeV gamma-ray source, HESSJ1503-582, with no obvious counterpart at other wavelengths. The source is, however, coincident with an H I structure with a velocity significantly different from that of galactic rotation - a so-called "Forbidden Velocity Wing" [2]. These structures have been suggested as the fast moving shells and filaments associated with the oldest supernova remnants in our galaxy. The detection of TeV gamma-ray emission from these structures might indicate that supernova remnants remain efficient particle accelerators for much longer than is commonly believed. Here we report on recent VERITAS observations of one of these structures, FVW 190.2+1.1, which shows a clear shell-like morphology in the H I maps.

Keywords: Forbidden velocity wing, VERITAS, Gamma-ray observations.

I. INTRODUCTION

At the Heidelberg Gamma 2008 Symposium, the H.E.S.S. collaboration reported the results of their extended galactic plane survey, including the detection of a new extended source (≈ 45° diameter) with an integrated flux above 1 TeV of 6 × 10^{-12} erg cm^{-2}s^{-1}, well-fit by a smooth power law spectrum with photon index Γ = 2.4 ± 0.4stat ± 0.2sys [1, 2]. The source, labelled HESS J1503-582, has no clear counterpart at other wavelengths; however, Renaud et al. noted the interesting coincidence with an H I structure; a so-called "Forbidden Velocity Wing". This motivates an investigation of similar structures with VERITAS in the Northern hemisphere.

The term "Forbidden Velocity Wing" (hereafter FVW) is given to structures identified through their anomalous velocities, derived from doppler shifting of H I line emission. In a plot of velocity (v) against galactic longitude (l), these structures appear as spatially limited (≤ 2°) "wings" extending from the bulk of the galactic H I emission (Figure 1), with positive or negative velocity extensions greater than ≈ 20 km s^{-1}. FVWs are believed to be sites where kinetic energy has been injected into the interstellar medium through some violent event. Kang & Koo [3] have compiled a catalog of 87 FVWs using the Leiden/Dwingeloo H I survey data [4] and the H I Southern Galactic Plane Survey data [5], which they rank according to the clarity of the structures in the l − v and b − v velocity diagrams. 33 of the 87 are given the highest rank, one of which, FVW 319.8+0.3 is located with HESS J1503-582.

Kang & Koo discuss a number of potential progenitors for the FVW structures, among them stellar winds and supernova remnants (SNRs), both of which are potential TeV gamma-ray sources. In its final stages, an SNR consists of a rapidly expanding H I shell, which might persist after the remnant is too faint to be observed at radio wavelengths. The number of detected SNR shells in the galaxy is much lower than the number expected from the supernova rate, presumably because of these observational limitations. The H I emission from another of the highest ranked FVW objects, FVW 190.2+1.1, has been mapped by Koo et al. with high resolution (3.4") using the 305 m Arecibo telescope [6]. Their results reveal a rapidly expanding (~ 80 km s^{-1}) shell structure, invisible at other wavelengths, which they suggest is consistent with being the shell of an SNR with an age of ~ 3 × 10^5 years (Figure 2). In these proceedings we report on a search for counterpart TeV emission from FVW 190.2+1.1 using the VERITAS array.

II. OBSERVATIONS

VERITAS [7, 8] is an array of four imaging atmospheric Cherenkov telescopes located at the basecamp of the Fred Lawrence Whipple Observatory near Tucson, Arizona. The array has been fully operational since mid-2007 and has sensitivity sufficient to detect a point-
like source with 1% of the steady Crab Nebula flux in < 50 hours. Observations cover the energy range from 100 GeV to > 30 TeV with an energy resolution of 15-20% above 300 GeV, and an angular resolution per gamma-ray photon of 0.1° at 1 TeV.

Observations of FVW 190.2+1.1 were made on clear nights between October 26th and December 28th 2008, at a mean source elevation of 68°. The HI source is extended, with an HI velocity-dependent diameter of ~ 1°. The centre of the shell was offset from the centre of the field-of-view by 0.7° (80% of the observations) or 0.5° (20% of the observations) to allow simultaneous background estimation (wobble mode [9]). The physical camera field-of-view of VERITAS is 3.5° in diameter; wobble-mode observations allow us to map a somewhat larger field-of-view with long exposures. Observations taken under poor weather conditions were rejected from the analysis. The final exposure consists of 18.4 hours of good quality data, with all four telescopes operational.

III. RESULTS

The data were analysed using standard VERITAS analysis tools [10]. Cherenkov images were first calibrated and cleaned, then parameterized according to their first and second moments [11]. The air shower impact position and arrival direction were then reconstructed using all events wherein at least 3 telescopes recorded a Cherenkov image. The mean-reduced-scaled width and mean-reduced-scaled length parameters were calculated (e.g. [12]) and used for gamma-hadron separation. A further cut was applied on the arrival direction of the incoming gamma-ray relative to the test position on the sky (θ). Since the angular extent and spectrum of the putative TeV source is not well defined, four different sets of gamma-ray selection cuts were applied, to provide best sensitivity for both point-like (θ < 0.122°) and moderately extended (θ < 0.235°) sources, and for sources with a Crab-like spectrum (standard cuts) and for significantly harder spectra (hard cuts). Standard and hard cuts differ only in the minimum number of photo-electrons required (~ 75 and ~ 225 respectively) for a Cherenkov image to be used in the event reconstruction. This approach is similar to that typically used in the analysis of survey data for imaging atmospheric Cherenkov telescopes [13], [14]. The background in each test source region was estimated using the “ring-background” method [15]. All results have been verified using two independent analysis chains.

TABLE I: 99% Confidence Upper Limits

<table>
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<tr>
<th>Analysis Cuts</th>
<th>Upper Limit (Φ&gt;500 GeV) (ph cm⁻² s⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard spectrum, point source</td>
<td>3.6 x 10⁻¹³</td>
</tr>
<tr>
<td>Standard spectrum, extended source</td>
<td>4.3 x 10⁻¹³</td>
</tr>
<tr>
<td>Hard spectrum, point source</td>
<td>3.9 x 10⁻¹³</td>
</tr>
<tr>
<td>Hard spectrum, extended source</td>
<td>3.5 x 10⁻¹³</td>
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</table>
The resulting sky maps are shown in Figure 3. No significant excess is observed at any position for any of the four analyses; all positive excesses are consistent with the expectation for fluctuations in the absence of any gamma ray source. Table I shows the derived upper limits (calculated using the method of Helene [16]) at the centre of the field-of-view for each cut.

IV. DISCUSSION

FVW structures are clearly among the more speculative candidates as counterparts to the unidentified TeV sources. Assuming its identification as an SNR is correct, Koo et al. estimate a distance to FVW 190.2+1.1 of 8 kpc and a dynamical age of \( t = 3.4 \times 10^5 \) years. TeV emission from an isolated old remnant such as this is not expected under conventional models, although Yamazaki et al. [17] predict that the TeV/X-ray flux ratio might increase significantly as remnants age. Old remnants have already been detected at TeV energies, for example in the case of W28 [18], with an estimated age of between 0.4 – 1.5 \( \times 10^5 \) years. In this case the emission is likely enhanced by interaction with surrounding molecular clouds. Another, originally unidentified, H.E.S.S. source, HESS J1713-347 [19] is now believed to be associated with a newly identified shell-type SNR, G353.6-0.7, with an estimated age of 0.27 \( \times 10^5 \) years at a distance of 3.2 \( \pm 0.8 \) kpc [20].

In summary, we have observed a Forbidden Velocity Wing HI structure, FVW 190.2+1.1, that is most likely associated with a supernova remnant. We see no evidence for TeV gamma-ray emission from this region, and set upper flux limits at the level of \(< 1\%\) of the steady Crab Nebula flux.

V. ACKNOWLEDGEMENTS

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REFERENCES

Fig. 3: Sky maps of the excess significance for each test position in the field around FVW 190.2+1.1. The dashed ellipse indicates the derived angular extent of the expanding shell in Koo et al. Maps for each of the four different gamma-ray selection cuts are shown as labelled. The results are consistent with the expectation for background fluctuations in the absence of a gamma-ray source.