

Recent Results from VERITAS

David Hanna (for the VERITAS Collaboration)¹

Physics Department , McGill University, Montreal, Canada

E-mail: hanna@physics.mcgill.ca

Abstract. The Very Energetic Radiation Imaging Telescope Array System (VERITAS) [1] is a ground-based gamma-ray observatory used for a variety of observations at energies between 100 GeV and 30 TeV. This contribution reports on detections of two active galactic nuclei, W-Comae and 3C 66A, of the IBL class and discusses some features of their detection within the context of astroparticle physics, one of the central themes of the TAUP conference series.

1. Introduction

TeV gamma-ray astronomy plays an important role in astroparticle physics, one of the two themes of the TAUP conference series. Some gamma-ray observations have direct links to fundamental physics while others are concerned more with astrophysical phenomena that involve subatomic particles. Searching for evidence of Lorentz invariance violation by measuring the arrival times and energies of photons from the flares of distant sources [2, 3, 4] is an example of the first kind of study. An example of the second is the search for the origin of cosmic rays by studying the gamma-ray emission from supernova remnants within our galaxy, or from the more distant active galactic nuclei (AGNs). Dark matter is topical in both astrophysics, where evidence for its existence was first obtained, and particle physics, which supplies one of the leading candidates for dark matter. Searching for high energy gamma rays from annihilation of dark matter particles in places such as dwarf galaxies is one of the activities of TeV gamma-ray groups.

VERITAS [1], as one of the new generation of TeV instruments, is pursuing an active program in particle astrophysics. In this contribution I will highlight some recent results which bear on the broader program, namely discoveries of TeV emission from two AGNs. I will describe the VERITAS instrument and observing details and describe our results. Space limitations preclude a more comprehensive review; readers are invited to refer to the proceedings of the 31st International Cosmic Ray Conference [5] for more details.

2. VERITAS Instrument and Observational Details

The VERITAS detector comprises an array of four imaging atmospheric Cherenkov telescopes (IACTs) located at the Whipple Base Camp on Mount Hopkins in southern Arizona. Each telescope consists of a reflector, 12 metres in diameter, which collects Cherenkov light from extensive air showers and directs it onto a ‘camera’ made from 499 photomultiplier tubes (PMTs). Each camera has a field of view 3.5° in diameter. The array was built in stages between 2003 and 2007 with four-telescope observations beginning in September, 2007.

¹ see <http://veritas.sao.arizona.edu/conferences/authors?taup2009> for a list of collaboration members

VERITAS covers the energy range from approximately 100 GeV to beyond 30 TeV with an energy resolution of between 15 and 20% and single-event angular resolution (68% containment) of 0.1° . It can make a five-sigma detection of a source with a flux of 1% of that of the Crab Nebula in less than 50 hours. More details can be found in [6].

During the first years of observations we have concentrated on four key science projects: blazars, galactic sources, dark matter and a sky survey of the Cygnus region. Additional observing campaigns proposed by members of the collaboration and approved by a time-allocation committee have also been carried out.

3. Active Galactic Nuclei

TeV gamma-rays from beyond our galaxy have been detected from a limited set of astrophysical objects, the majority of which belong to the *blazar* class of AGNs. According to the standard blazar paradigm, gamma rays are produced in relativistic jets powered by accretion onto a super-massive black hole at the centre of the AGN. An AGN with one of its jets oriented towards the Earth is a blazar. The spectral energy distributions of blazars display a double-peaked structure with the low-energy peak likely due to synchrotron radiation from high energy electrons in the jet and the high-energy peak due to inverse-Compton scattering from these electrons, or perhaps arising from other processes like synchrotron radiation from protons. Blazars can be classified according to the mean energy of the synchrotron peak. Low-frequency-peaked BL Lac objects (LBLs) have this peak at infra-red and optical wavelengths and the corresponding high energy peak at X-ray energies. For HBLs the synchrotron peak occurs in X-rays and the high energy peak in the TeV range. Until recently, no intermediate-frequency-peaked BL Lac objects (IBLs) had been detected.

3.1. W-Comae

VERITAS has detected three IBLs so far; the first was W-Comae [7]. A 4.9σ detection was made using a 40-hour data set acquired between January and April 2008, using all four telescopes. The sky map generated from these observations is shown in figure 1. Approximately 70% of the signal resulted from a four-night flare [8] which occurred in mid March, as shown in the light curve displayed in figure 2. The energy spectrum from the two flare nights with the highest flux can be fit with a power law with index of $\Gamma = 3.8 \pm 0.4$. The integral flux above 200 GeV is approximately 9% of the Crab Nebula flux above that energy. The soft energy spectrum is likely due to absorption of high-energy photons in pair-production collisions with the extra-galactic background light (EBL [9]) since the source lies at $z=0.102$. It is also consistent with the notion that the mean of the high-frequency peak of this source is in the GeV region and we are observing its rapidly falling upper side. The spectral energy distribution (SED) can be modeled using a one-zone synchrotron-self-Compton scenario but this needs an unnaturally low magnetic field value (0.007 G). A more natural fit can be obtained with an external-Compton (EC) model.

3.2. 3C 66A

The second IBL to be detected by VERITAS was 3C 66A. A detection of this variable source at very high flux levels was reported by the Crimean group [11] in 2002 and VERITAS detected it during a flaring episode [12] in 2008. Although data were acquired over the 2007-08 (4.7 hours after quality cuts) and 2008-09 (28.1 hours) observing seasons, 80% of the signal comes from the period from MJD54740 through MJD54749. The sky map made with the entire data set is shown in figure 3 and the corresponding energy spectrum in figure 4. The sky map shows that the TeV source detected by VERITAS is very close to the nominal position of 3C66A and is definitely not (at a significance level of 4.8σ) associated with the nearby radio galaxy 3C 66B. This is an important feature of our measurement since it contrasts with an earlier TeV detection by the MAGIC [13] collaboration which favours 3C 66B as the source. The energy

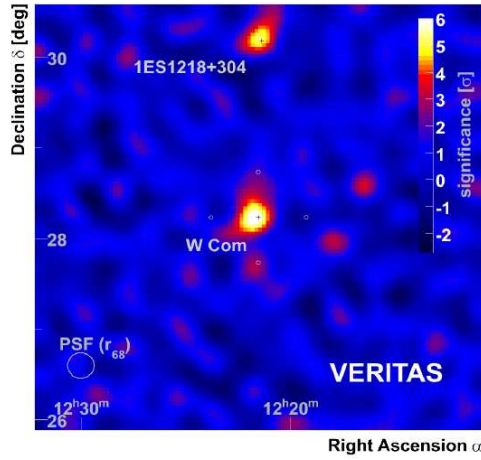


Figure 1. Sky map for the region around W-Comae. Note the presence of a signal from the blazar 1ES 1218+30.4, demonstrating VERITAS' off axis sensitivity.

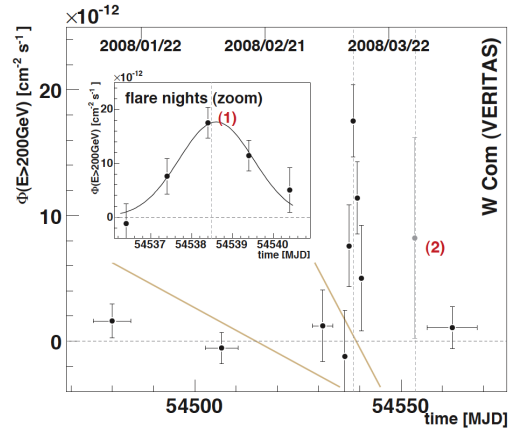


Figure 2. Light curve for the W-Comae measurements made during 2008. The flare centred on March 13 (MJD 5438), which contributed most of the detected flux, is shown in the inset.

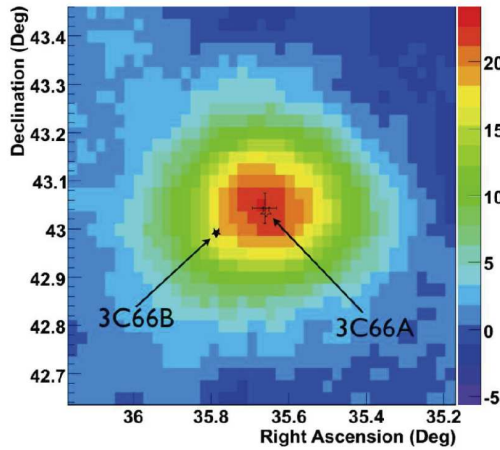


Figure 3. Sky map for the region around 3C 66A indicating that the VERITAS measurement strongly disfavours 3C 66B as the source of the gamma-ray signal.

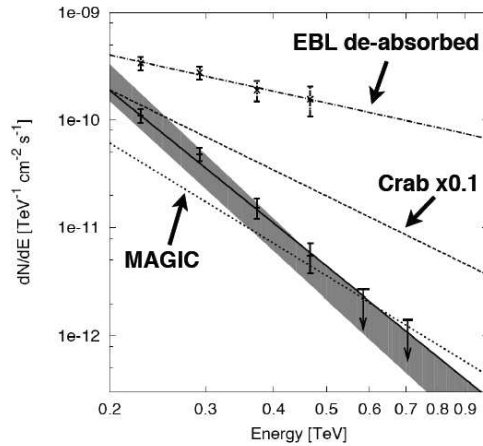


Figure 4. Energy spectrum for 3C 66A as measured by VERITAS, along with its possible intrinsic spectrum as calculated using a model of extra-galactic background light [10] and assuming $z=0.444$. The MAGIC [13] spectrum, from their detection of 3C 66B, is also shown.

spectrum of 3C 66A is very soft; a power-law fit results in an index of $\Gamma = 4.1 \pm 0.4_{stat} \pm 0.6_{syst}$. One expects absorption by EBL photons to steepen the spectrum of distant blazars but using a leading model [10] to correct for this effect yields an anomalously hard intrinsic spectrum ($\Gamma = 1.1 \pm 0.4_{stat}$). It is possible that this is due to the use of an erroneous value for the distance; the redshift for 3C66A ($z = 0.444$) is not well measured [16, 17, 18].

4. Discussion and Conclusions

VERITAS has detected TeV gamma-ray emission from two AGNs which are members of the IBL class. The catalog of these objects will surely grow now that the *Fermi* Gamma-ray Space Telescope is in orbit since the high-energy peaks of these objects lie in the range where the *Fermi* Large Area Telescope [19] has good sensitivity. The measurements presented here are very much astronomical but they are part of a body of knowledge that must be increased and consolidated to improve our understanding of the basics of AGNs. Only by understanding the physics of gamma-ray emission from AGNs, especially any energy-dependent timing issues, will we be able to make confident statements about apparent Lorentz-invariance violation effects. The modeling uncertainties associated with the W-Comae observations show that much is left to be done. Similarly, the uncertainties in source red-shifts, highlighted in the 3C 66A observation need to be reduced. Finally, a detailed understanding of AGN particle production in general, accessible through high-quality gamma-ray observations, is critical for determining whether AGNs are the sources of ultra high energy cosmic rays [20], another topic of current interest. High-energy gamma-ray astronomy will continue to have much to offer astroparticle physics in the future.

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