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VERITAS: STATUS AND EARLY RESULTS*

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A new generation of observatories have revolutionized the study of the very high energy gamma-ray sky. The recently-commissioned VERITAS observatory, an array of four 12 m diameter imaging atmospheric Cherenkov telescopes designed to search for gamma-ray sources in the energy band between 100 GeV and 50 TeV, is one of these new instruments. VERITAS has been taking scientific data with three or more telescopes since November 2006. We discuss the thrust of the VERITAS observation program and present results from these early observations, including new results on the sources IC433, LSI+61 303, 1ES 1218+304 and M87.

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1. Introduction

The field of VHE (very high energy) gamma-ray astronomy is young (the first confirmed VHE gamma-ray source detection, that of the Crab Nebula, was made in the late 1980s [18]), but it is one with the potential to shed light on a variety of subjects, from the origin of cosmic rays to the nature of dark matter. From its inception the field has relied heavily on the atmospheric Cherenkov technique, with imaging atmospheric Cherenkov telescopes (IACTs) providing many of the field's greatest successes. The latest generation of IACT instruments, including the HESS array in Namibia [11] and the MAGIC detector in the Canary Islands [13], has led to an explosion in both the number and type of known VHE gamma-ray sources.

VERITAS, an array of four IACTs installed at the base camp of the Fred Lawrence Whipple Observatory, is the most recently commissioned of these third-generation instruments. Each of the four identical telescopes employs a 12 m diameter tessellated mirror with a 499-pixel photomultiplier tube (PMT) camera installed at the focal plane. Further details on the VERITAS instrument can be found in [14]. The VERITAS telescopes were commissioned over a several year period; two-telescope array observations began in early 2006 and the full array was completed in early 2007. Results reported in this paper derive primarily from observations made with the two- and three-telescope array configurations.

In the first two years of the VERITAS program, half the available observing time is devoted to four key science projects: a two-year survey of the Cygnus region of our galaxy, begun in April 2007 and covering the region between $52 < l < 82$ in galactic latitude and $-1 < b < 4$ in galactic longitude, a search for (neutralino) dark matter annihilation signatures, a study of supernova remnants, and a study of active galactic nuclei. At the time of writing, the first year's observations for the Cygnus region survey have just concluded, and analysis of both the survey data and the dark matter search observations is underway. Many of the results discussed in the following sections come under the mandate of the other key projects.

2. Early results

2.1. Supernova remnants

Supernova remnants (SNRs) are thought to be responsible for the acceleration of cosmic rays up to energies of about 10^{15} eV. Particle acceleration is believed to take place at either the shock front between the expanding remnant and the interstellar medium (shell-type remnants) or at the termination shock created by the collision of the pulsar wind with the surrounding medium (plerionic remnants or pulsar wind nebulae). It remains in question whether the gamma-ray emission is produced by inverse Compton scattering of accelerated electrons or is the result of pion decay subsequent to hadronic interactions.

As not only the most established, but the strongest, non-variable source of VHE gamma-ray emission, the Crab pulsar wind nebula is an invaluable calibration source for any new VHE gamma-ray observatory. VERITAS observed the Crab Nebula for a total of 38.5 hours with two- and three-telescope array configurations [6]. The data were used to validate a number of performance benchmarks, as predicted by Monte Carlo simulations. We find that the instrument has a single-event angular resolution of $< 0.14°$ and an energy resolution of 10–20% and that a source with 10% of the Crab flux will give a 5σ detection in $\simeq 1$ hour. The measured Crab flux and spectral shape (between 250 GeV and 6 TeV) are consistent with those measured at other observatories.

The detection of supernova remnant IC443 is the highlight of the early VERITAS observations of SNR and PWN. This shell-type supernova remnant, initially detected in VHE gamma-rays by MAGIC [3], has been observed in other wavelengths to interact with a molecular cloud along the line of sight. VERITAS observations in spring 2007 [12] resulted in a source detection of 7.1σ pre-trials and 6σ post-trials. The source excess is point-like and the centroid position is consistent with that of the original MAGIC detection. The source flux is roughly 3–4% of the Crab Nebula above 200 GeV. The coincidence of the gamma-ray source with the densest region of the molecular cloud suggests hadronic cosmic-ray acceleration, with the cloud acting as a target medium to amplify both pion production and the associated gamma-ray emission.

2.2. High-mass X-ray binaries

At this time, three high-mass X-ray binaries have been detected as gamma-ray sources at TeV energies. LSI+61 303, first detected by MAGIC [2] is the only source in the northern hemisphere. LSI+61 303 consists of a Be-type star with a dense circumstellar disk, orbited once every 26.5 days by either a neutron star or black hole. The system is thought by some

(a) (b)

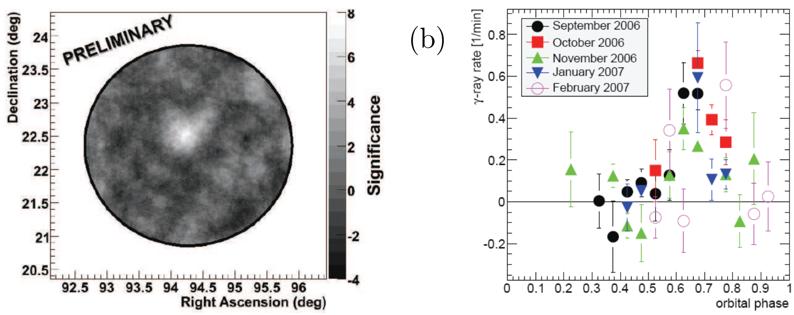

Fig. 1. (a) Significance map for the VERITAS IC443 detection [12]. (b) Raw excess event rates *versus* orbital phase for five orbits of the LS I +61 303 system [15].

to be a *microquasar*, in which accretion of material from the star onto the compact object powers relativistic jets that are the sites of gamma-ray production [4, 17]. However, it is equally possible that the gamma-rays are produced by shocks formed by collision of the relativistic pulsar wind with that of the star [16]. LSI+61 303 was detected by VERITAS over several orbital periods, using both the two- and three-telescope array configurations. The gamma-ray emission was observed to be strongly modulated by the 26.5 day orbital period (as shown in Fig. 1(b)), with the maximum flux for each orbital cycle appearing at apastron and corresponding to $\simeq 10\%$ of the flux of the Crab Nebula.

2.3. Active Galactic Nuclei

Active Galactic Nuclei (AGN) are galaxies in which broadband emission from the core region dominates over the combined luminosity of the galaxy's stars. The emission (in the form of collimated jets) is thought to be powered by accretion onto the supermassive black hole at the AGN's core. The majority of VHE gamma-ray sources known to be AGN are *blazars*, AGN for which the jets are aligned with our line of sight. VHE emission from these sources is strongly variable; in an active, or flaring, state, their fluxes can exceed that of the Crab Nebula. Distant VHE blazars are of particular interest since they are an important source of information on the attenuation of gamma-rays by the extragalactic background light (EBL) [8].

The well-known TeV blazar Mrk421 was detected, while in a high state, at 35σ in 17 hours of observation (corresponding to a gamma-ray rate of 5.7 γs/min); more notable is the 16σ detection of the relatively quiescent (and equally well-known) TeV blazar Mrk501 [9]. The more distant (at $z = 0.182$) blazar 1ES1218+304 was detected at 8.9σ with 17.4 hours of two- and three-telescope VERITAS observations [10], confirming the original

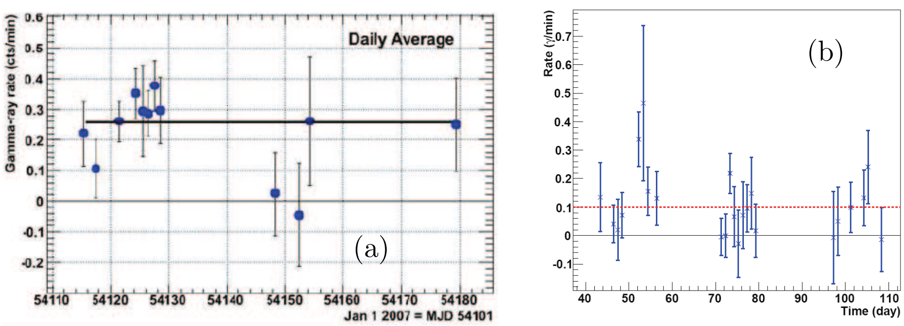

Fig. 2. (a) Raw flux levels *versus* observation time for 1ES1218+304 [10]. (b) Light curve of the VERITAS M87 observations [7].

MAGIC discovery [1]. The light curve shown in Fig. 2(a) is statistically consistent with a constant source flux over the period of observation. Further observations on this source are planned.

M87 is currently the only extragalactic non-blazar object seen in VHE gamma-rays; it is believed to be a nearby AGN similar to the blazars just discussed, but with the jet displaced from the line of sight. 2005 HESS observations [5] of M87, while the source was in a high state, show variability on a few-day time scale, which suggests a compact gamma-ray production region, which could either be located in the M87 core or correspond to compact structures in the jet itself. 51 hours of VERITAS three-telescope array observations of M87 [7] yielded a 5.1σ significance detection with an approximate energy threshold of 250 GeV. The gamma-ray flux, as estimated from the time-averaged excess rate, corresponds to 1.7% of the Crab Nebula. Fig. 2(b) shows the night-by-night M87 light curve over the three-month observation period; no statistically significant short-timescale variability was observed.

3. Conclusions

Observations made during the commissioning of the VERITAS observatory have yielded a promising crop of early results. We start the 2007–2008 observing season with a completed telescope array and anticipate a productive future.

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