The VERITAS Prototype and the Upcoming VERITAS Array

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Abstract. The prototype for the VERITAS imaging atmospheric Cherenkov telescope array was successfully operated in southern Arizona between September 2003 and April 2004. The prototype consisted of 86 mirror facets mounted centrally on a 12-meter dish, which was built to accommodate up to 350 facets when converted to a complete VERITAS telescope. The camera consisted of half of the full 499 pixel camera. The signal and trigger electronics were nearly identical to those that will be used for the individual VERITAS array telescopes. By observing the Crab and Mrk421, as well as performing a variety of tests, the characteristics of the instrument were evaluated. The prototype met all performance expectations and served as a valuable test bed for the current design, as well as for the construction and operation of VERITAS. This prototype instrument is now being upgraded to a complete VERITAS telescope that will be operated during the construction of the full VERITAS array. The array is expected to be operational by November 2006.

INTRODUCTION

The successful use of Imaging Atmospheric Cherenkov Telescopes (IACTs) was pioneered at the Whipple Observatory using a single 10-meter reflector with an imaging camera ([6]). The breakthrough of using an imaging camera to greatly reduce cosmic ray background led to the detection of the background dominated very high energy (VHE) gamma rays (energy $>$300 GeV). The stereo technique, which images showers from

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multiple angles using several telescopes, was then utilized by several groups, thus further reducing background. We have now entered the next generation of VHE gamma-ray astronomy, which uses very large diameter IACTs and/or stereoscopic arrays, such as CANGAROO-III, HESS, MAGIC, and VERITAS [4, 2, 5, 3].

THE VERITAS ARRAY

VERITAS will be a stereoscopic array of 7 IACTs, four of which are currently under construction, arranged with 80 meter spacing, as shown in Figure 1. The telescopes are currently being constructed at Horseshoe Canyon on Kitt Peak, in southern Arizona, at approximately 5800 ft elevation and 31° latitude.

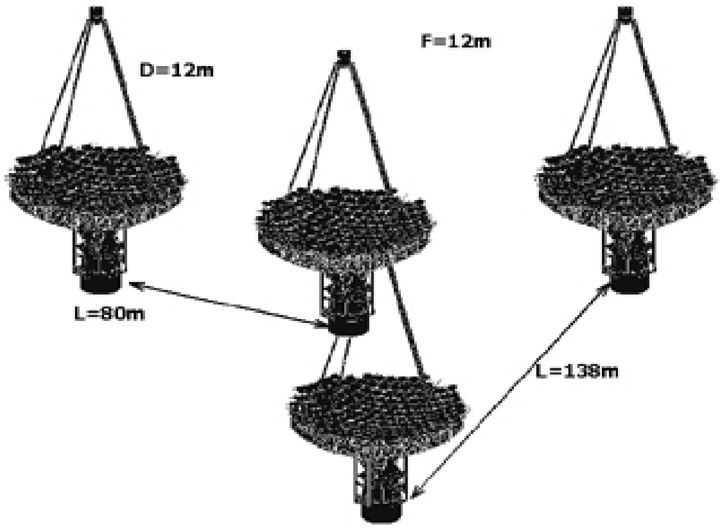

FIGURE 1. Layout of the VERITAS 4 telescope array

Each of the telescopes in the array will be an f/1.0 reflector, with a 12 meter focal length and a 12 meter diameter. The telescopes use the Davies-Cotton design [1], which incorporates 350 hexagonal mirrors, each having a 24 meter radius of curvature, mounted on a spherical optical support structure. The radius of curvature of each glass mirror blank is held to a tolerance of $\pm 1\%$. Anodized aluminum coatings are applied at the Whipple Observatory. The point spread function of each telescope is expected to be less than 0.05°. The telescope is capable of smoothly tracking a position in the sky with an accuracy of $<0.02°$. The slew speed has been demonstrated to be $>0.5° sec^{-1}$, and the possibility of achieving faster slew speeds is being explored.

Each telescope has a 499 channel camera in the focal plane of the reflector. The front-end of each channel consists of a 28mm Photonis XP2970/02 photomultiplier tube (PMT) and a preamplifier located in the camera. Reflective light cones are placed in front of the PMTs to reduce dead spaces and gather more light. The spacing between pixel centers is 0.15^o, and the entire camera has a 3.5° field of view. The signals from each of these channels then proceed through RG-59 coaxial cable to the counting house, which contains the processing electronics. The signals are read by dual-gain, 8-bit 500 MHz flash analog-digital converter (FADC) boards. These boards, and the associated data acquisition (DAQ) system, record the entire time structure of the pulse from each channel, thus facilitating a measurement of the total charge in a pulse, as well as timing characteristics of individual pulses. There are three trigger levels, which combine to produce a trigger for the DAQ system to read an event. The first level is a constant fraction discriminator to determine if a single channel is above a pre-defined threshold; the second trigger level requires a pattern of neighboring channels to fire within a fixed period of time (for instance: 3 neighboring tubes must pass the first trigger level together); the third trigger level is an array trigger, which requires multiple telescopes to meet the criteria of the level two trigger. Once the trigger conditions are satisfied, an event is read by the DAQ system, and subsequently stored to disk. The data is saved to a database, which is mirrored in at least two locations.

TABLE 1. Expected performance of VERITAS array, based upon simulations

	VERITAS 4 telescopes	**VERITAS 7 telescopes**
Peak Energy (GeV)	110	90
Crab Rate ($\gamma\ min^{-1}$)	35	50
Effective Area at 10 TeV ($10^8 cm^2$)	30	36
Effective Area at 100 GeV ($10^8 cm^2$)	3.3	6.3
Flux Sensitivity at 10 TeV* ($10^{-11} erg\ cm^{-2} s^{-1}$)	0.37	0.36
Flux Sensitivity at 100 GeV† ($10^{-11} erg\ cm^{-2} s^{-1}$)	1.4	1.0

* 50 hours, 5σ
† 50 hours, 5σ

The expected sensitivity, based on simulations, of the VERITAS array is shown in Table 1. This sensitivity is more than a factor of 20 greater than the sensitivity of the Whipple 10 meter telescope, and the peak energy response is much lower. A significant improvement in spectral resolution is also expected, as a result of the improved ability to determine the impact parameter with a stereoscopic array. The predicted spectral resolution is $\Delta E/E = 0.15$ to 0.20.

THE PROTOTYPE

During the Winter and Spring of 2004, the VERITAS prototype was operated at the Whipple Observatory (Figure 2). The prototype was a full-sized telescope structure, but contained only a fraction of the mirror area and camera channels. Only 87 mirrors (full telescope has 350 mirrors) were mounted on the 12-meter optical support structure, and less than half of the camera channels were installed in the camera. The DAQ electronics were nearly identical to that of the VERITAS array.

FIGURE 2. The VERITAS prototype telescope operating at its site at the base of Mt Hopkins

The prototype performed as expected. It verified the efficacy of the VERITAS design, while providing valuable feedback that led to several improvements in both hardware and software. Some data on Mrk 421 was obtained with the prototype, as shown in Figure 3. While these data are not particularly interesting from a scientific point of view, due to the engineering mode of the prototype, they validate the operability of the VERITAS electronics and telescope hardware.

Although many things were learned during operation of the prototype, resulting in various modifications to details of each subsystem, all VERITAS systems performed well enough to be included in the next stage of construction. The optical support structure and the mirror characteristics matched specifications, and produced a point spread function that was measured to be $<0.04^\circ$. The telescope tracked smoothly, with a pointing accuracy $<0.02^\circ$. All components of the trigger and DAQ system were capable of handling event rates as high as 1 kHz. The FADC system recorded the pulses from each

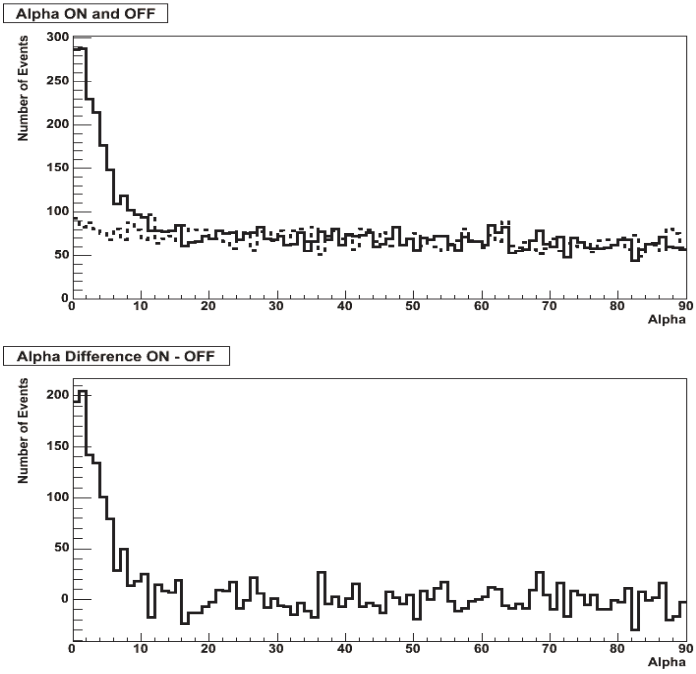

FIGURE 3. Alpha plot of of 19 hours of Mrk 421 data taken with the prototype telescope, during April 2004. A significance of 20σ was obtained from these data, which were not optimized since we were operating the telescope in various engineering modes during this time period.

PMT in every event with time bins that were 2 ns wide. This facilitated a calculation of the pedestal directly from the event data by looking at a time region with no signal, and it showed distinct time structure as some events progressed across the camera.

STATUS OF VERITAS

VERITAS is fully funded and due to be completely operational by November 2006. Two phases of construction are proceeding simultaneously. The prototype is being converted into a full telescope, (referred to as Telescope 1). The completed Telescope 1 is expected to produce engineering data by November 2004, with scientific data following within a few months. This telescope will operate independently as a scientific instrument until the rest of the array is nearly complete at Horseshoe Canyon, at which time Telescope 1 will be moved. Construction of the full array has also begun at this time. Site preparation is expected to be complete by December 2004, and many parts, including positioner, PMTs, mirrors, etc., have been ordered. The 4-telescope array is expected to be complete by November 2006.

CONCLUSIONS

The new generation of IACTs is poised to strengthen and diversify the role played by VHE gamma-ray astronomy within the wider field of astronomy and astrophysics. Due to the dramatic increase in sensitivity provided by VERITAS, and other next generation instruments, much dimmer and hence more numerous sources can be detected. This should include nearby sources that are intrinsically dimmer, as well as sources at higher redshifts. As a result of this expanded catalog, population studies of VHE gamma-ray sources will now be possible, and the extragalactic infrared background can be more easily studied with the higher redshift sources that should be detected. It is also expected that there will be new types of sources detected since this relatively unexplored wavelength region will be probed at lower flux levels. All of the new objects, as well as the currently known VHE emitters, will be studied in unprecedented detail due to the ability of VERITAS to detect sources with much shorter exposures and to more accurately resolve energy spectra.

For updates and more information on VERITAS, please see `http://veritas.sao.arizona.edu`.

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