The VERITAS Project

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Abstract

VERITAS is a new, major ground-based γ-ray observatory designed to significantly advance our understanding of extreme astrophysical processes in the universe. The observatory comprises seven large-aperture (12 m diameter) Cherenkov telescopes, each equipped with an imaging camera. The first phase of VERITAS (consisting of four telescopes) is currently under construction. Here we outline the key features of VERITAS and provide an update on its status.

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1. Introduction

Ground-based γ-ray astronomy came of age in the last decade. The discovery of numerous sources by telescopes using the imaging atmospheric Cherenkov technique proved that very high energy (VHE) astronomy can be done from the ground. Roughly one dozen VHE sources have now been detected with varying levels of significance [1]. The established sources include pulsar-powered nebulae, active galaxies of the BL Lac type, and shell type supernova remnants.

These exciting discoveries strongly motivate the construction of new instruments to substantially increase the VHE source catalog and to enable much more detailed studies of individual sources. VERITAS combines the successful features of the Whipple Observatory (large-aperture reflector, imaging camera) with those of HEGRA (array of reflectors). Relative to current operating imaging telescopes, VERITAS will have substantially *better flux sensitivity* (factor of five to ten improvement, depending on energy), *reduced energy threshold* (peak energy near 100 GeV), *improved energy resolution* (resolution of 10-15% over a broad energy range), and *improved angular resolution* (4.3 arc-min at 1 TeV).

2. VERITAS Design

Serious consideration of VERITAS started in 1996, and its design was developed and finalized over the next several years. The design uses modular construction and proven technology to a large degree, but it also encompasses new technical innovations where appropriate. VERITAS will be an array of seven telescopes, each employing a 12 m diameter optical reflector. Each telescope has a camera of 499 photomultiplier tube elements, covering a field of view of 3.5° diameter. The photomultiplier tubes are read out through high-bandwidth electronics by a Flash ADC (FADC) system sampling at 500 MSps. The FADC sampling, a flexible trigger system, and extensive electronic and optical calibration systems are among the important new capabilities of VERITAS. Details on the design and expected performance of VERITAS have been published earlier [2,3]. This report provides an update on the key developments that have happened recently.

VERITAS will be sited on Mt. Hopkins in southern Arizona, USA, near the Basecamp of the Whipple Observatory (1350 m altitude). The site will be well protected from light pollution (within 20% of the darkest sites available in the U.S.). The construction will be carried out in two phases. During the first phase (VERITAS-4), four telescopes will be constructed and deployed as shown in Figure 1. In the second phase, three additional telescopes will be added to complete the hexagonal array.

Table 1. VERITAS-4 Performance

Characteristic	E	Value
Peak Energy [a]		110 GeV
Flux sensitivity	100 GeV	3.4×10^{-11}cm^{-2}s^{-1}
	1 TeV	6.5×10^{-13}cm^{-2}s^{-1}
	10 TeV	2.1×10^{-13}cm^{-2}s^{-1}
Angular resolution	100 GeV	7.5 arc min
	1 TeV	4.3 arc min
	10 TeV	1.6 arc min
Collection area	100 GeV	3.3×10^{8}cm^{2}
	1 TeV	2.2×10^{9}cm^{2}
Crab Nebula	$>$100 GeV	40/minute
γ-ray rates	$>$300 GeV	15/minute
	$>$1 TeV	4/minute
Energy resolution[b]		$<$15%

[a]Maximal differential rate for Crab Nebula-like spectrum. The trigger requirement is three adjacent pixels per telescope, each with more than 5.6 p.e. and three out of four telescopes.
[b]RMS $\Delta E/E$.

3. VERITAS-4 Performance

We have carried out detailed simulation studies to estimate the expected performance of the four telescope array, VERITAS-4 – some key results are shown in Table 1. In quoting sensitivity, we make the conservative requirement of at least a five standard deviation γ-ray excess in each energy bin, of width one-quarter decade.

4. Technical Progress

A great deal of technical progress has been made on VERITAS, and we are well on our way towards the construction of a prototype telescope encompassing all important design elements. Here we describe the salient features of the VERITAS design and recent progress made on the construction of the prototype that will become operational in mid-2003.

4.1. Telescope, Optical Support Structure, and Mirrors

The VERITAS telescopes consist of a tubular-steel, space-frame optical support structure (OSS) mounted on a commercial positioner. In the OSS design, as shown in Figure 1, quadrapod arms penetrate the mirror surface to hold up the camera. We expect excellent optical performance from the OSS – the blur will be well less than

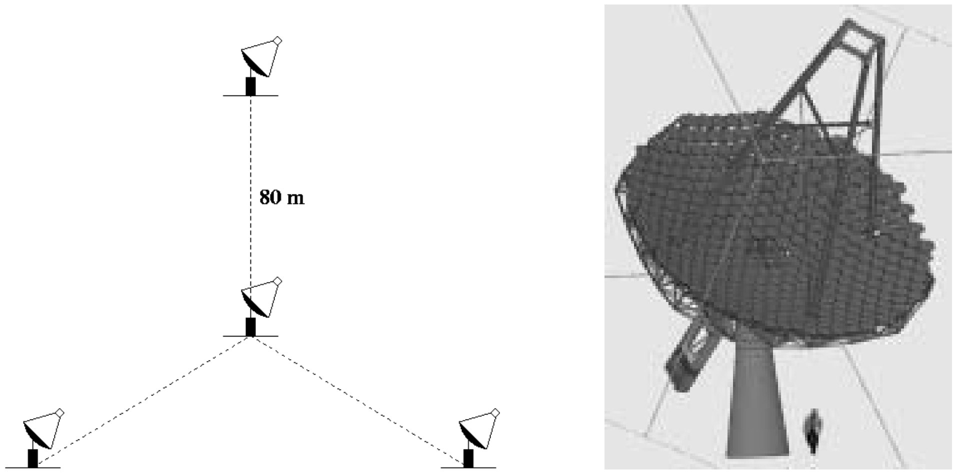

Fig. 1. Layout of telescopes for VERITAS-4 (left). Three additonal reflectors will be added to complete the full array of seven telescopes. Design of optical support structure for each 12 m telescope (right).

$0.01°$ over the usable elevation range of the telescope, and the de-centering will be less than $0.002°$. The positioner for the prototype telescope will be delivered in April 2003.

We use the Davies-Cotton optical design in which the telescope reflecting surface is spherical and the mirror facets are identical in shape. Each 12 m diameter (f/1.0) mirror is made from 350 hexagonal facets and has a total mirror area of $110\,\mathrm{m}^2$. The facets are made of float glass that has been slumped and polished by the manufacturer (DOTI Technologies). They are aluminized and anodized in a dedicated facility near the Whipple Observatory Basecamp. All the facets for the prototype telescope have been received; mirror coating is in progress. Laser measurements indicate that the optical quality of the facets is better than originally specified: 1) the tolerance of the radius of curvature is better than 0.4% (as opposed to 1.0% specified), and 2) the average blur is less than 0.5 cm (as opposed to 1.0 cm specified).

4.2. Camera, Cables, & High Voltage

The cameras for VERITAS comprise 499 photomultiplier tubes (PMTs), arranged in a close-packed hexagonal pattern with an angular separation between PMTs of $0.15°$. Light cones increase the photon collection efficiency and protect the PMT's from stray light pollution. A high-speed, custom-made amplifier is used to boost the signal before transmission through 40 m of high-bandwidth 75Ω coaxial cable. The high voltage level for each PMT can be individually programmed, and custom-designed electronics monitor individual PMT anode currents.

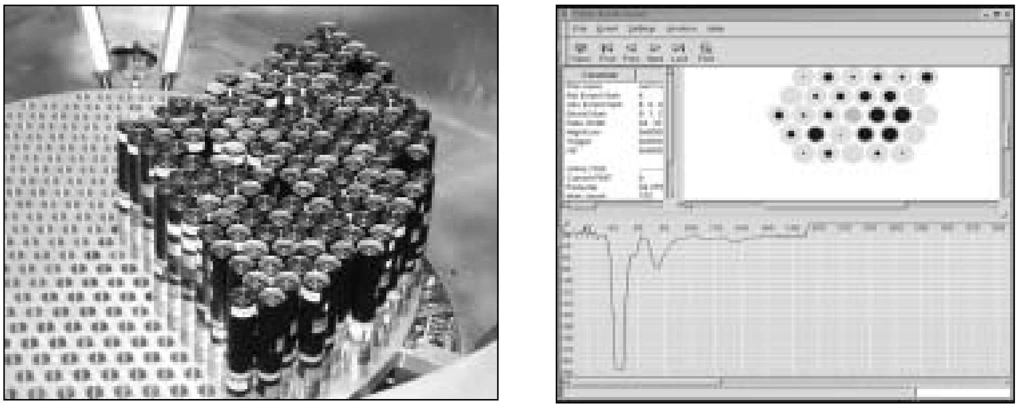

Fig. 2. Camera integration for prototype VERITAS telescope, partially completed (left). Display from FADC sampling of Cherenkov pulse (right). The second peak corresponds to a delayed copy of the pulse with lower gain.

All of the key camera components were tested in November 2001 when thirty PMT channels were installed in the focus box of the Whipple 10m telescope. Performance characteristics (e.g. linearity, rise time, noise levels, etc.) of the full electronics chain of VERITAS were verified. The assembly of the camera for the prototype telescope is currently in progress at the University of Chicago. The integrated camera will be shipped to Mt. Hopkins in spring 2003. Figure 2 shows the camera box during assembly and an FADC trace for a Cherenkov pulse.

4.3. Flash ADCs (FADCs) and Data Acquisition

The custom-built FADCs digitize the Cherenkov pulse waveform at a rate of 500 MSps to provide the maximum possible information about the shape and time structure of the pulse. Each PMT signal is sampled by a separate FADC with an effective dynamic range of 11 bits and a memory depth of 64 μs. The FADCs are packaged in 9U VME boards with 10 channels/board. The data acquisition is based around standard VME architecture, comprising a fast VME backplane and crate Single Board Computers (SBC's) connected to a local event-building workstation via the fast SCI protocol. The FADC design has been finalized, and the boards for the prototype telescope are being built. The VME readout for the FADC system is also near completion; crate-to-crate transfer speeds of 100 MB/s have been achieved.

4.4. Trigger Electronics and Calibration

VERITAS employs a three level trigger system to select Cherenkov events at the lowest possible energy threshold. Level 1 consists of constant fraction discriminators

(CFDs) to determine when a PMT pulse exceeds a given threshold. The CFDs are mounted directly on the main FADC board to minimize noise and signal delay. Level 2 comprises a hardware pattern trigger designed to select compact Cherenkov events, as opposed to night sky background overlaps. Level 3 uses the Level 2 telescope triggers to determine when the array has triggered. The designs for all three trigger levels are well advanced and complete systems for the prototype telescope are now being integrated with the other electronics.

The calibration system is designed to calibrate and monitor the performance of each telescope and the combined array. There are three major calibration components: charge injection, optical injection, and atmospheric monitoring. The charge injection system distributes a calibrated amount of charge to the front-end electronics. The initial optical system uses a dye laser to simultaneously flash all PMTs in the camera.

4.5. Software

The online software can be divided into a number of components: 1) FADC and VME data acquisition, 2) Telescope acquisition (event building), 3) Array acquisition/online analysis (Quicklook), and 4) Array Control and Database. The software uses object-oriented (C++) programs running on Intel-based Linux computers. Reliance is made on widely available software packages (e.g. CORBA, SQL, Qt, etc.) for database and graphic user interface tasks and for inter-process communication and control. The majority of the online code for the prototype telescope has been written, and now the major task is integration. Initial software systems for offline analysis and simulation are also in place; these will be augmented and refined in the future.

5. Schedule & Summary

VERITAS is a new state-of-the-art ground-based γ-ray observatory for VHE astronomy. An initial phase (VERITAS-4) consists of four atmospheric Cherenov telescopes. A prototype telescope will begin operating in summer 2003, and funding permitting, first light for the VERITAS-4 array is expected in late 2005, well before the launch of the Gamma-ray Large Area Space Telescope (GLAST).

6. References

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