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VERITAS: the Very Energetic Radiation Imaging Telescope Array System

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Abstract

The Very Energetic Radiation Imaging Telescope Array System (VERITAS) is the major next generation imaging atmospheric Cherenkov γ-ray telescope in the western hemisphere and will be located in southern Arizona nearby Kitt Peak National Observatory. The VERITAS observatory will provide unprecedented sensitivity to photon energies between 50 GeV and 50 TeV. The first stage is an array of four telescopes to be fully operational in early 2006, with an expansion to seven telescopes envisioned for 2008. The construction of a prototype telescope is underway, for which first light is expected in Fall 2003. The technical concept is outlined and a progress report is given.

Keywords: γ-ray astronomy; TeV energies; Atmospheric Cherenkov detectors

1. Introduction

The Very Energetic Radiation Imaging Telescope Array System (VERITAS) proposal is to build an array of seven (VERITAS-7) imaging atmospheric Cherenkov telescopes (IACTs) of 12 m aperture. The individual telescopes are based on the proven design of the Whipple observatory 10 m telescope, however, with significant improvements in the reflector optics, light collection efficiency, signal chain and recording electronics. Fig. 1 shows the layout of the VERITAS detector with its two staged approach showing VERITAS-4 and the final stage VERITAS-7.

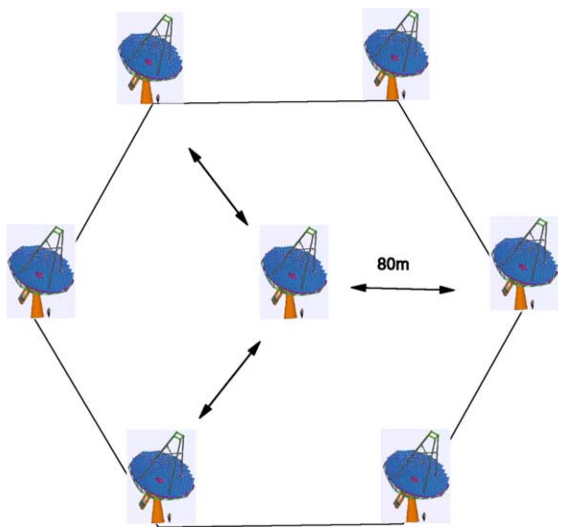


Fig. 1. The layout of VERITAS-7. VERITAS-4 will consist of the central telescope and the three outer telescopes as indicated in the figure above by the three connecting arrows.

The most significant step in improving the sensitivity of the imaging atmospheric technique over previous generation instruments such as Whipple (Finley et al., 2001), HEGRA (Konopelko et al., 1999), and CAT (Barrau et al., 1998) can be achieved by combining the advances of moderately larger reflectors with the stereoscopic technique (HEGRA) and fast electronics (CAT). Together, these improvements will provide an order of magnitude better sensitivity, larger effective area, significantly reduced energy threshold, better energy resolution and angular resolution.

The individual telescope design is based on a commercial positioner, a custom built optical support structure (OSS), slumped glass mirrors, a focal plane camera, new front-end and data acquisition electronics/readout system (for more details of the instrument design see (Weekes et al., 2002)). A prototype combining the individual elements is currently under construction at the basecamp of Whipple observatory. Once the specifications have been verified with the telescope detecting cosmic-ray induced showers, single muons and also γ-ray events from the Crab Nebula, the prototype will be completed and deployed at the final VERITAS site (Horseshoe Canyon at Kitt Peak National Observatory) to become the first element of the array. The VERITAS prototype is nearing the stage at which all detector subsystems are merged at the test site in Arizona. In the following we give a short status report of the individual components.

2. Telescope mount and OSS

The telescope mount is fabricated by RPM/PSI (Los Angeles) and is based on a standard industrial product. Fig. 2(a) shows a conceptual drawing of the mechanical structure of the telescope. Fig. 2(b) we show the assembly of the OSS (trussed steel) and the positioner at the test site at the Whipple observatory basecamp. The telescope optics are based on the Davies–Cotton design (Davies and Cotton, 1957) with the mirror facets arranged on a spherical surface with 12 m radius and the individual mirrors shaped with 24 m radius of curvature. The Davies–Cotton design has off-axis aberrations smaller than a parabolic reflector, showing good image quality out to a few degrees off-axis. The aspect ratio of focal length to telescope diameter is described by the f-number, which is $f/1.0$ for the VERITAS telescope. Although the Davies–Cotton design is not isochronous, the intrinsic time spread of the reflector is less than $\approx$4 ns as a result of a large f-number. Each reflector carries 315 mirrors providing a mirror area $\sim$100 m^2 per telescope. The mirrors are made from glass, are slumped and polished and then coated with aluminum and anodized at a dedicated facility on-site. Approximately one third of the necessary mirrors have been manufactured and coated on-site and are ready to be mounted on the reflector.

3. Camera and electronics

The focal plane instruments will consist of 499 photomultipliers per camera with 0.15° angular spacing, corresponding to a FOV of 3.5°. For maximum light collection efficiency in the focal plane light concentrators are employed to funnel the Cherenkov light onto the photocathodes of the photomultipliers and to limit the acceptance of the light detectors to the aperture of the reflector.

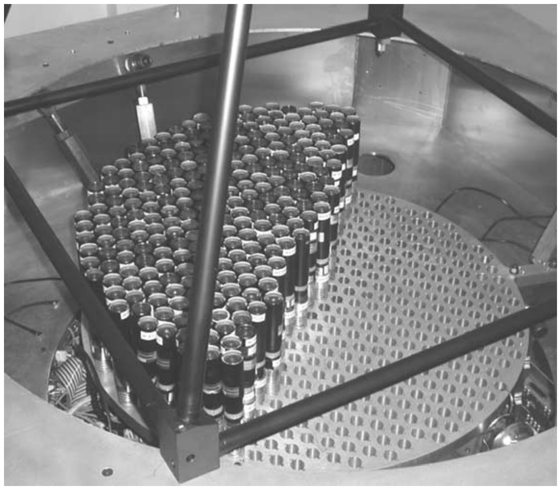
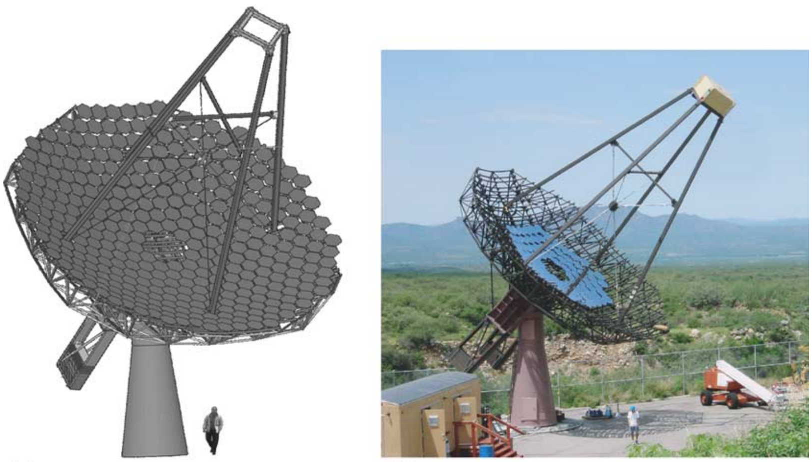


Fig. 3. The VERITAS prototype camera, during integration. The black frame is a mount for the optical calibration pulser for laboratory tests of the camera.



(a) (b)

Fig. 2. (a) The design of the 12 m telescope and optical support structure. (b) Assembly of the first VERITAS telescope at the base camp of Whipple observatory with the positioner, the OSS, inner mirror section, the quadra-pod arms and the camera.

The signals from each photomultiplier are amplified by a high-bandwidth preamplifier integrated into the photomultiplier base mounts. This circuit also allows the PMT anode currents to be monitored and the injection of charge pulses for calibration of the electronic signal chain to be enabled.

To date, all the components required for the prototype focal plane instrument, the camera frame, 250 pixels and high-voltage hardware, have been constructed at the collaborating universities and are currently being integrated at a central place (University of Chicago) together with the data acquisition electronics. Fig. 3 shows the camera of the prototype telescope partially completed.

4. Data acquisition systems

The centerpiece of the data acquisition (DACQ) is a custom-built 500 MS per second flash-ADC system. Each PMT signal is digitized by a flash-ADC with a dynamic range of 11 bits and a memory depth of ~ 8 μs. The flash-ADCs for each telescope are deployed in four custom VME crates, where they are read out by local single board computers. Buffered events from the local computers are transferred via Scaleable Coherent Interface to an event-building computer, where they are integrated, tested, and passed on to the online analysis system.

All of the components required for the prototype DACQ system have been manufactured and are currently undergoing integration and characterization. A successful full-chain stress-test performed in April, 2003 has recently confirmed the underlying design of the entire DACQ system. A test of the entire signal chain including 210 flash-ADC channels using optical light pulses has been successfully completed in June 2003.

5. Trigger and calibration systems

The trigger of VERITAS is formed in a sequence using three different levels in the electronic chain. Level 1 consists of a constant fraction discriminator with a programmable threshold located on the FADC modules. Level 2 consists of a pattern trigger (Bradbury et al., 1999) and is used to form local coincidences at each telescope to reduce accidental triggers from night sky background fluctuations. The local trigger decisions (Level 2) from each telescope are transmitted by digital optical fiber cable to a central location and are delayed individually to account for the orientation of the shower front. This allows formation of array coincidences in real time and subsequent triggering of the readout of the flash-ADCs.

All of the trigger electronics for the VERITAS prototype have been manufactured and are currently being integrated into the telescope systems. The basic operational principles of all the components were verified in a successful end-to-end trigger test performed in the laboratory. A full test under realistic sky conditions will be carried out on-site with the prototype telescope in Fall 2003.

The calibration systems for VERITAS include a charge injection system, a nitrogen dye laser flasher and atmospheric monitoring stations. Both the charge-injection and optical flasher systems have been installed and are presently operational. They currently comprise an important component of the overall camera testing procedures.

6. Performance of VERITAS-4 and VERITAS-7

Detailed simulations have been used to determine the peak energy, the flux sensitivity, angular resolution and collection area of VERITAS-4. For the performance of the final stage of the instrument VERITAS-7 and a detailed description of the strategy and details of the simulations see (Weekes et al., 2002; Vassiliev et al., 1999).

A summary of the VERITAS-4 performance is given in Table 1. VERITAS-4 has a moderately higher peak energy than VERITAS-7 (Vassiliev et al., 1999), but still has substantial sensitivity at 50 GeV. At energies above 110 GeV VERITAS-4 has comparable sensitivity to VERITAS-7. The full seven telescope array has the capability of enhancing the scientific output significantly by operating subarrays in various combinations, hence providing great versatility for carrying out ascientifically broad and efficient observing program.

Table 1
Performance of VERITAS-4

Characteristic	E	Value
Peak energy[a]		110 GeV
Flux sensitivity[b]	>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	0.13°
	1 TeV	0.07°
	10 TeV	0.03°
Effective area	100 GeV	3.3×10^4 m^2
	1 TeV	2.2×10^5 m^2
Crab Nebula γ-ray rate	>100 GeV	40/min
Energy resolution[c]		21% @ 100 GeV; 18% @ 300 GeV; 10% @ 10 TeV

[a] Energy at which the rate of photons per unit energy interval from the Crab Nebula is highest for a 5.6 photoelectron trigger threshold.

[b] At least five standard deviations excess in each energy bin, of width one-quarter decade.

[c] RMS $\Delta E/E$.

7. Conclusions

The VERITAS project is well on its way and the construction and testing of a prototype telescope is nearing completion. The individual sub-systems of the prototype have been constructed at the various collaborating universities and have been tested together at the camera integration site. The telescope positioner and optical support structure are currently being assembled at the Whipple Observatory basecamp. The prototype telescope is scheduled to see first light in Fall 2003, first operation of the completed VERITAS-4 array is targeted for early 2006.

Acknowledgements

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