The VERITAS Atmospheric Čerenkov Telescopes: Positioner, Optics and Associated Components

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Abstract

The Very Energetic Radiation Imaging Telescope Array System (VERITAS)[1,2] is a next generation ground-based TeV gamma-ray detector. VERITAS will consist of seven 12 m aperture atmospheric Čerenkov telescopes. The design of these telescopes builds on three decades of experience with the Whipple 10-m. Significant improvements have been made in their optical and tracking performance, and hence, in their ability to exploit the VERITAS high-resolution cameras and stereo imaging capability.

1. Introduction

This paper will discuss the telescope performance requirements necessary to meet the scientific goals of VERITAS, the design of the telescope's components (i.e., positioner, optical support structure (OSS), and mirror segments), their measured and/or anticipated performance, and the positioner control system (M/PCS).

2. Performance Requirements and the Telescope Design

Among the performance goals of VERITAS are a low energy threshold and excellent angular resolution (see Table 1). These goals imply an increase in aperture and an improvement in optical performance beyond that of the Whipple 10-m (or any existing ground-based gamma-ray detector). Neither necessitates a radical rethink in design. Thus, superficially, the VERITAS telescopes bear a strong resemblance to the 10-m. The basic optical and mechanical configuration have not changed: a Davies-Cotton segmented reflector atop an altitude-over-azimuth positioner and fabricated as a steel space-frame.

During the design phase, a conceptual study was performed with the goals of maximizing the aperture, while maintaining excellent optical performance and pointing capability, and controlling the cost. The results, together with vendor input, strongly supported the acquisition of an "off the shelf" positioner; a modest

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Table 1. A summary of the Telescope performance requirements.

Threshold:	<100 GeV w/sensitivity to $\sim$50 GeV
Angular Resolution:	<0.05° for showers, <0.005° for sources
Energy Resolution:	δE/E $\sim$ 0.15%
Image Blur/Decentering	<0.02° RMS / ±0.02°
Energy Concentration:	>90% within a 10mm diameter circle
Reflectance:	≥90% at 320 nm, ≥85% from 280 to 450 nm

increase in aperture to $\sim$11 m was also indicated. For the positioner, a number of bid proposals were received. RPM-PSI's model PG-4000 (see Figure 1) was selected. This positioner exceeds VERITAS' requirements (e.g., vertical load) by a wide margin.

The VERITAS camera will record shower images with high resolution. However, its effective utilization requires considerably better optical performance than that of the 10-m. Achieving this performance level was one of the primary goals of the design study. Due to its simplicity, the Davies-Cotton configuration was adopted as a baseline. The advantages: e.g. fixed segment focal length, ease of alignment, etc. outweigh its principal shortcoming, of being non-isochronous. To reduce optical aberration, the f-number, f/0.7 for the 10-m, was increased to f/1.2 (subsequently reduced to f/1.0 when the aperture was increased to 12 m).

Given the weight of the OSS, the mirror segments and the focal-plane instrument (≤350 kg), it is impractical to design the OSS as a rigid body; some deformation is inevitable. Analysis using a finite-element model (FEM) indicated that the points where the Quadrapod joined the OSS produced the greatest optical distortion. Subsequent modeling led to the adoption of a top-quad bypass option wherein the load imposed by the uppermost quadrapod is brought through the OSS to the rear yoke structure. Even so, conventional alignment at the horizon leads to unacceptable optical performance at high altitudes necessitating "bias-alignment" (see below).

The OSS (designed by M3 Engineering of Tucson AZ and fabricated by Amber Steel of Chandler AZ) is scheduled for delivery in mid-May.

3. Mirror Facets

Each telescope is fitted with 315 hexagonal mirror facets of $\sim$0.322 m^2 area each, for a total collecting area of $\sim$100 m^2. The mirror facets are float-glass, slumped and polished with a radius-of-curvature of 24 m±1%. One hundred facets have been delivered by the vendor (DOTI of Round Rock, TX), to the Whipple Observatory. There they are cleaned, aluminized, anodized and then undergo acceptance testing. Their performance exceeds the VERITAS requirements: >90% of the reflected light from a point source falls in a circle of diameter 5.7±1.9 mm.

Fig. 1. The PG-4000 altitude/azimuth positioner and the pedestal on which it will be installed (left). A large yoke (not shown) provides the interface between the OSS, the positioner and the counterweights. The OSS during initial "fit-up" at the manufacturer's facility (right).

Reflectance exceeds 90% at 320 nm and is >85% from 280 to 450 nm.

Like the 10-m, mirror facets are attached to the OSS via a triangular frame which isolates the facets from OSS flexure. However, significant improvements have been made in the support's design (much of the blur observed in the 10-m is believed to originate from the "cantilever" design of its facet support). Adjustment screws allow each facet to be aligned to within 0.02°.

4. Blur, Decentering & Bias-Alignment

Optical distortion due to flexure takes two forms: blur and decentering. Blur is the RMS width of the the image formed by all facets; decentering is the movement of the mean of the image centroid with respect to the center of the focal-plane. Both are largely repeatable functions of the telescope's altitude.

Here, experience gained on the 10-m, together with the FEM analysis, suggest a solution. By using "bias-alignment" the VERITAS optical performance goals can be obtained. In bias-alignment individual mirror segments are aligned such that at observing altitudes (40–80°) blur and decentering are minimized (both are reasonably pronounced in the horizon pointing position). Results from the 10-m are encouraging and those using the FEM for VERITAS are as indicated in Figure 2. It is notable that even without bias-alignment the FEM models predict that the OSS meets or exceeds the VERITAS requirements.

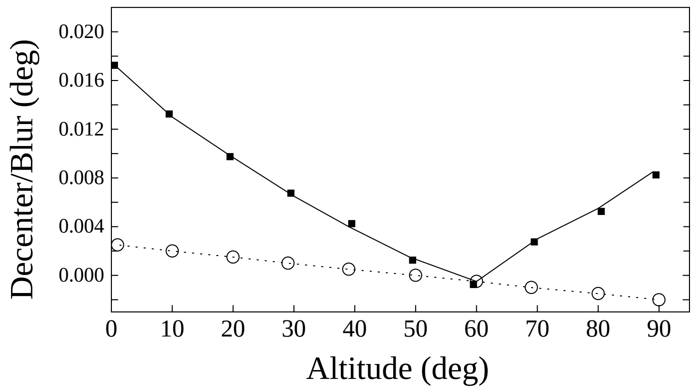

Fig. 2. The expected blur and decentering for VERITAS (assumes perfect facets, i.e., no contribution from individual facet aberrations).

5. Positioner Control System

Each VERITAS telescope is controlled by a dedicated Positioner Control System (PCS). These are "slaved" to the Master Positioner Control System (MPCS) which is commanded by the ARRAY-Controller. The PCS provides a set of methods to control the positioner (isolating the vendor supplied interface (PIU)). The PCS generates tracking input to the PIU, protects the positioner from "harmful" inputs and handle errors.. The MPCS allows multiple telescopes to be controlled as a unit and provides summary status information to the ARRAY-Controller. Communications between the ARRAY-Controller and the MPCS, and between the MPCS and the PCSs, is via CORBA remote method calls. Multiple threads within the MPCS and PCS communicate via a shared object model.

6. Conclusion

The VERITAS telescopes will provide significant improvements in optical and tracking performance. The first telescope will be delivered in May 2003 and commissioned in June. Results will be reported at the conference.

7. Acknowledgments

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8. References

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