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Bias Alignment of the VERITAS Telescopes

J. A. TONER[14], V. ACCIARI[24], A. CESARINI[14] G. H. GILLANDERS[1], D. HANNA[3], G. E. KENNY[1], J. KILDEA[4], A. MCCANN[3], M. MCCUTCHEON[3], M. J. LANG[1], P. T. REYNOLDS[5], M. SCHROEDTER[6], A. SMITH[47], J. E. WARD[8], T. C. WEEKES[4], B. ZITZER[9]
[1]*Dept. of Experimental Physics, National University of Ireland, Galway, Ireland*
[2]*Dept. of Physical and Life Sciences, Galway-Mayo Institute of Technology, Galway, Ireland*
[3]*Physics Dept., McGill University, Montreal, Quebec, H3A 2T8, Canada*
[4]*FLWO, Harvard-Smithsonian Center for Astrophysics, Amado, AZ 85645, USA*
[5]*Dept. of Applied Physics and Instrumentation, Cork Institute of Technology, Bishopstown, Cork, Ireland*
[6]*Dept. of Physics and Astronomy, Iowa State University, Ames, IA 50011, USA*
[7]*School of Physics and Astronomy, University of Leeds, Leeds, LS2 9JT, England*
[8]*School of Physics, University College Dublin, Belfield, Dublin 4, Ireland*
[9]*Dept. of Physics, Purdue University, West Lafayette, IN 47907, USA*
john.toner@nuigalway.ie

Abstract: The mirror facets on the VERITAS telescopes, which are of Davies-Cotton design, are aligned in the horizontal stow position using a laser projector at the radius of curvature. The instrument used will be described. The mechanical design of the optical support structure undergoes some gravitational slumping with elevation which can be counteracted by bias alignment (deliberate misalignment at 0° elevation). In practice this allows the optimum point spread function (PSF) to be attained over an elevation range from 50° to 85°.

Introduction

VERITAS (Very Energetic Radiation Imaging Telescope Array System) is an array of four identical imaging atmospheric Cherenkov telescopes (IACTs), currently located at the base of Mt. Hopkins in southern Arizona (altitude=1275m). The telescopes are of Davies-Cotton design [1], with 12m aperture and a focal distance of 12m.

Each telescope's reflector is made up of 345 identical, individually mounted aluminized and anodized mirror facets of area $0.322\,\mathrm{m}^2$ [4], giving a total reflective area of $110\ \mathrm{m}^2$ per telescope. The facets are hexagonal in shape to permit close packing. They are sections of a sphere with a 24m radius of curvature. The optics are modeled on those of the Whipple 10m telescope [3]. The mirror facets are mounted on 3-point adjustable brackets to allow manual alignment from the front of the facet.

When imaging extensive air showers, the width of the image is the most important criterion, both in regard to gamma-hadron separation and the angular resolution of the instrument [2]. Any image formed on the telescope's camera is a convolution of the ideal image with the response of the optics. As such, the optical response of the telescope should be optimised.

Instrumentation

A purpose-built, semi-automated alignment system (see Figure 1) has been developed at NUI, Galway. Using this system, each mirror facet can be individually aligned, thus bringing the entire reflector into correct alignment. It comprises:

- A computer-controlled pan-tilt unit (PTU)
- A laser and beam-splitter assembly
- A SBIG ST-237A CCD camera

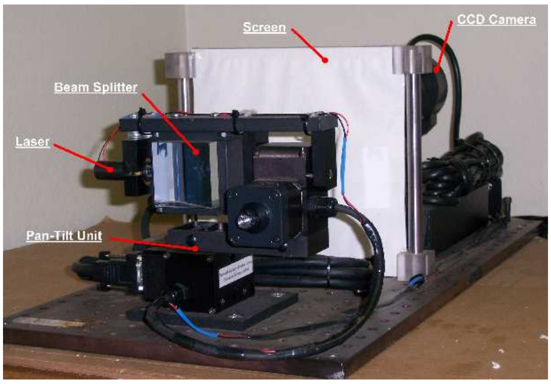

Figure 1: The VERITAS Semi-Automated Alignment System (Cover removed for clarity)

- A translucent plastic screen

With the telescope at an elevation of 0°, the system is set up on a platform (or alignment tower — see Figure 2) located at twice the focal distance from the center of the reflector along the optic axis. We refer to this location as the “*2f*” point.

The PTU, controlled by a custom computer program, is used to direct the outgoing laser beam onto each mirror facet in turn. Due to the Davies-Cotton optics employed by the telescope reflector, the beam reflected from the mirror should then return along its own outgoing path when the mirror is correctly aligned. With all mirrors aligned in this manner, light from a source at infinity should converge to a point at the focal plane of the telescope.

Part of the laser beam is backscattered by the beam-splitter onto the screen (*i.e.* the reference beam). This gives a reference point on the screen for the desired position of the reflected beam when the facet is aligned correctly. Using an image of the screen obtained by the CCD, the program can find the centroid locations of both the backscattered and the reflected beams. These positions are used to determine how far the reflected beam is from the reference position on the screen and thus calculate what adjustments must to be made to the facet mounting bracket in order to align the mirror correctly. This is then repeated for all mirror facets on the reflector. Once aligned, it is not necessary to re-align the facets more frequently than once a year.

Figure 2: Purpose-built alignment towers have been constructed and placed at the “*2f*” point for each telescope. In this image, the telescope is stowed (pointing north) and is not pointing at the tower.

Gravitational Slump

When the telescope moves in elevation, the optical support structure (OSS) is subject to some slumping. As the OSS slumps, each of the mirror facets moves by a small amount due to gravity. This puts the telescope’s optics increasingly out of alignment as the elevation is increased, degrading the PSF at typical observing elevations. However, this happens in a reproducible way and can be corrected for.

Measurements of the movement experienced by each mirror facet are made by attaching a small, light-weight laser unit to each facet. The laser beam is directed onto the focal plane of the telescope. A CCD image of the focal plane is then obtained. The telescope is raised to an elevation of 65° (the desired elevation of best focus) and another image of the focal plane is obtained.

The amount by which the laser spot moves on the focal plane is measured by comparing the images from the two different telescope positions. The movement of the laser beam corresponds to the movement of the mirror facet due to slumping of the OSS. This is repeated for all mirror facets on the reflector. A file containing information about the movement of each mirror (*i.e.* bias file) is generated for use by the alignment program so that the slumping effect can be negated.

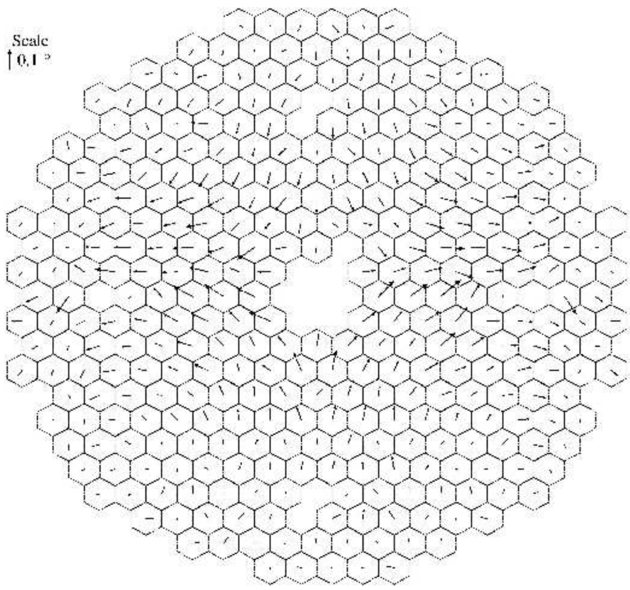

Figure 3: Gravitational slumping effects for Telescope 1 reflector. Mirror deflection is seen to be similar in the other telescopes.

Bias Alignment

Once the movement of the mirrors with elevation is known (see Figure 3), each mirror is then deliberately misaligned while the telescope is at 0° elevation. The amount by which each mirror is misaligned is equal in magnitude to the movement due to gravitation slumping, but in the opposite direction. This intentional misalignment of all mirrors is known as bias alignment. The technique was pioneered on the Whipple 10m telescope [5] [6].

The bias file, generated earlier, can now be used by the alignment program. Once again, the backscattered beam is used to define a reference point on the screen for each mirror. The program then uses the bias file to calculate where the reflected beam should be on the screen in relation to the reference point when the mirror has been moved to counteract gravitational slumping effects. This point will be offset from the reference point by an amount which relates to the movement of the mirror due to the slumping of the OSS when the telescope was moved to an elevation of 65°. The program outputs the mounting bracket adjustments required to bring the reflected beam to the new offset point on the screen. When completed for all mirror facets the telescope's optics fall into optimum and correct alignment at an elevation of 65°.

Results

In order to test the alignment, a CCD image of the focal plane is obtained while the telescope is tracking a bright star. This is done at a succession of elevations. This is done both before and after the telescopes are bias aligned. Qualitative results may be seen in Figure 4.

Figure 5 shows the PSF[1] attained at a range of elevations, both before and after bias alignment.

Before bias alignment, the PSF is seen to have its best value (0.06°) at an elevation of 0°. The value then deteriorates as the elevation increases to a maximum of 0.10° at around 70° elevation. This is what is to be expected from gravitational effects before bias alignment is applied.

1. Full-width-half-maximum of a fitted 2-D gaussian.

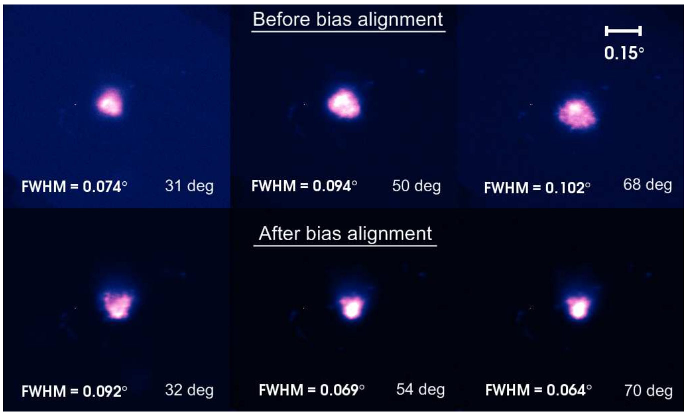

Figure 4: PSF before and after bias alignment. The line labeled 0.15° shows the angular size of the photomultiplier tubes which comprise the camera on the VERITAS telescopes.

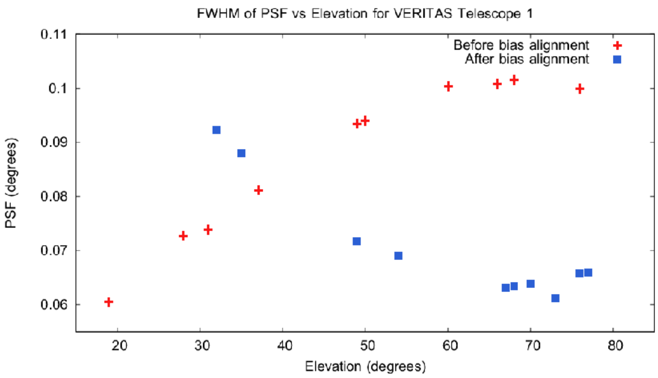

Figure 5: FWHM of Telesope 1 PSF vs. elevation, before and after bias alignment.

After bias alignment, the value for the PSF is optimized at around 65° elevation, to a value of 0.06°. Either side of this, the value only deteriorates slightly in the region where most observations are taken. In the elevation range from 50° - 85°, the PSF is always less than 0.075°, or about half the width of one PMT pixel in the Cherenkov imaging camera.

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