Development of a New Mirror Alignment System for the VERITAS Observatory

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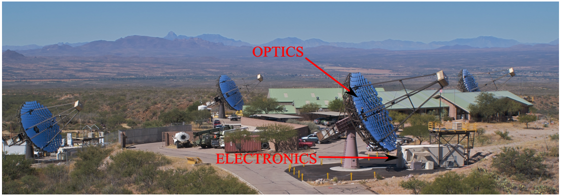
Background

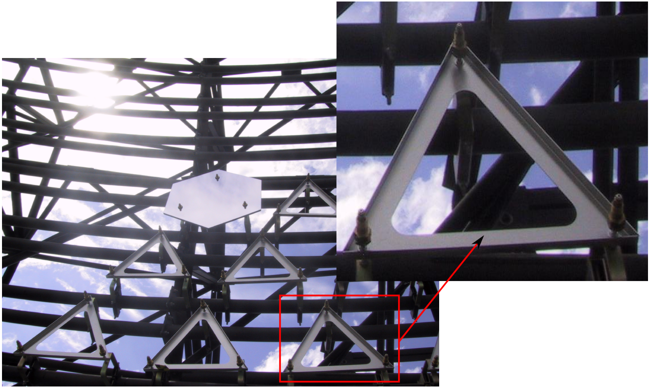
- Imaging Atmospheric Cherenkov Telescope Array
- First Light in Spring 2007 at the Fred Lawrence Whipple Observatory
- Solar Concentrator + Fast Recording Electronics
- Cost, Cost, Cost

The Telescopes



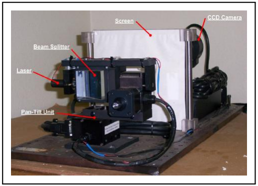
- Four 12 Meter Davies-Cotton Telescopes
- Steel space frame on an alt-az mount
- 342 mirror facets per telescope (61 cm. flat to flat)
- 499 pixel PMT camera with FADC recording electronics

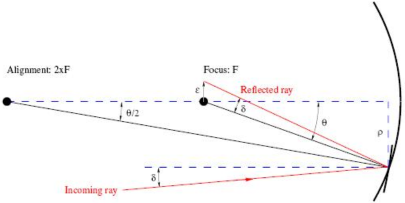
The Mirrors



- Slumped and polished float glass with 24 meter radius of curvature
- Front coated aluminum with $\frac{\lambda}{4}$ Al_2O_3 protective layer
- 400 mirrors re-coated per year (about 1.3 telescopes)
- Mirrors are bolted on telescope through triangle mounting brackets
- Castle nuts on mounting triangles allow adjustment of mirror pointing

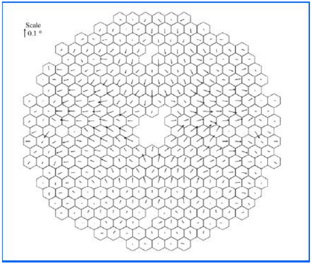
Mirror Alignment - Geometrical Method

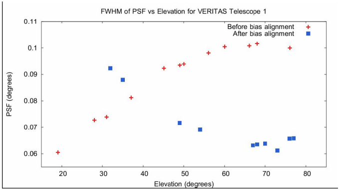




- Laser PTU placed on alignment tower at the 2f point
- Laser retro-reflects when mirror is geometrically aligned
- Poor repeatability due to equipment setup
- Time and labor intensive (2 Nights, 2+ people)
- Can only be aligned at stow position

Mirror Alignment - Geometrical Method



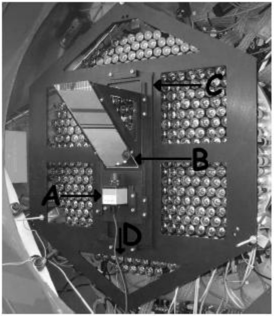


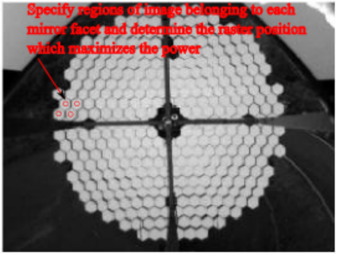
- The telescope OSS deflects under loading as it is pointed
- Mirrors are coupled to the OSS and become mis-aligned
- Motion of the mirror pointing is repeatable and measurable
- Offsets can be applied to each mirror at 0° so that they become correctly aligned at a nominal elevation (Bias-alignment)

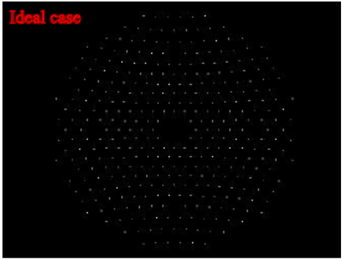
Mirror Alignment - Raster Scan Method

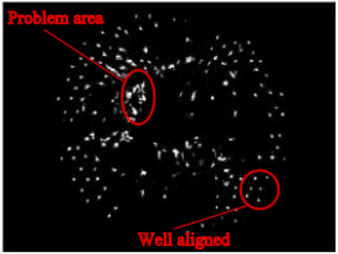
- Place an imaging camera near the focus of the telescope (Daytime)
- Image the telescope dish and allocate a zone in the image for each mirror facet (Daytime)
- Image the mirror spots for each raster position of the telescope (Nighttime, 2 hours)
- Post-process data to determine optimum facet adjustment (Daytime)
- Adjust facets (daytime) and measure PSF (nighttime), *repeat above with new grid finesse if necessary*

Mirror Alignment - Raster Scan Method



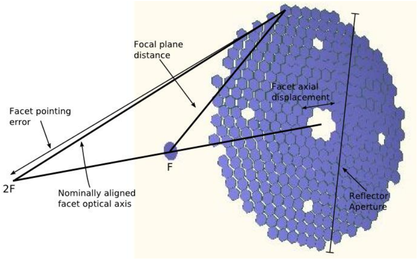






Optical Simulation of Mirror Alignment

- What performance can we expect from the raster scan method?
- Simulate the geometrical alignment method as verification
- Model raster scan method by optimizing on the irradiance distribution from each facet
- All model parameters correspond to measured values

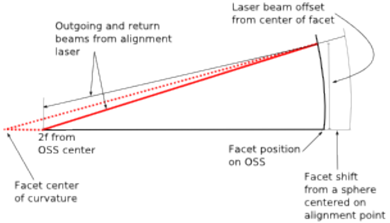


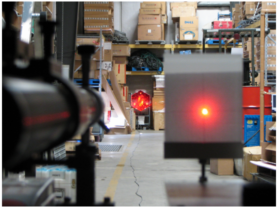
Simulation Parameters

Parameter	Nominal Value	Tolerance
Reflector Aperture	1247 cm	1247 cm
Reflector ROC	1200 cm	1200 cm
Focal Plane Distance	1200 cm	1196 cm – 1202 cm
Alignment Point Distance	2400 cm	2400 cm
Inter-facet Spacing	1 cm	1 cm
Facet Pointing Error	0°	0° – 0.01°
Facet ROC	2400 cm	2400 cm $\pm 1\%$
Facet Spot Size	0 cm	0.2 cm – 1.0 cm
Number of Facets	344	344

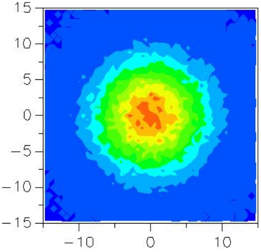
Simulation Parameters

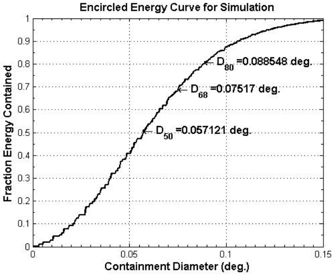
- Focal plane distance: Measured with a surveyor's tape from center of camera to each facet. Small variation.
- Alignment point distance: Fixed relative to center of OSS only.
- Facet pointing error: Contribution by laser beam offset from PTU and sag difference between mirror ROC and OSS ROC. Systematic.
- Mirror spot size and ROC: Measured in the lab. Spot size can be simulated using Harvey-Shack scatter. Very well characterized.





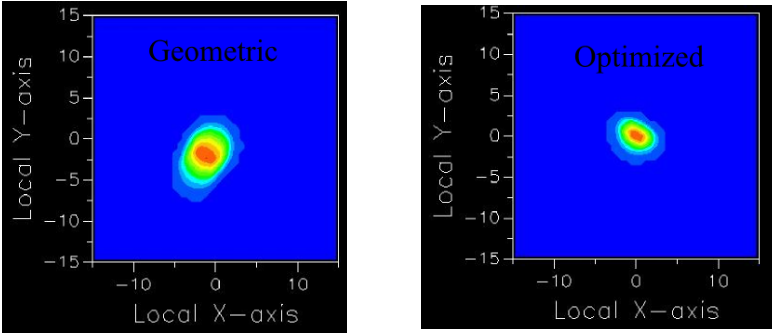
Geometrical Simulation Results





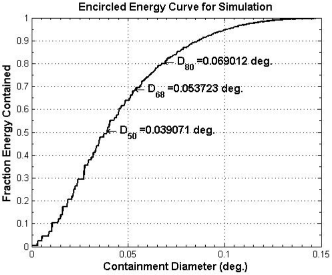
Dataset	FWHM	D_{68}	D_{80}
Simulation	0.057°	0.075°	0.089°
Measurement	0.060°	0.084°	0.130°

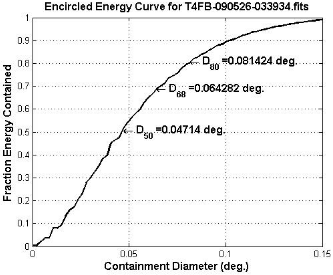
Raster Scan Optimization



- Loop over each facet irradiance distribution at the focal plane
- Calculate and apply new mirror tilt for peak irradiance
- Re-calculate telescope PSF and encircled energy
- Compare results with measured data

Raster Scan Optimization





Dataset	FWHM	D_{50}	D_{68}	D_{80}
Simulation	0.035°	0.039°	0.054°	0.069°
Measurement	0.036°	0.047°	0.064°	0.081°

- Simulation is noiseless
- Facet adjustments are still made by hand
- Raster scan has discrete grid spacing

Conclusions

- Telescope point spread function FWHM reduced from 0.06° to 0.036° on axis using the raster scan method
- Significant reduction in dark sky engineering hours needed
- Smaller raster grid may be needed to reduce containment diameter further
- Raster scan method is much less susceptible to human error