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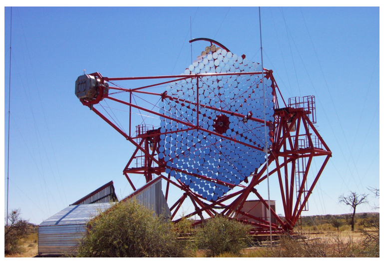

Mirror Alignment and Optical Quality of the H.E.S.S. Imaging Atmospheric Cherenkov Telescopes

The Universe viewed in Gamma-Rays
Univ. Tokyo Workshop 2002, Kashiwa, Chiba, Japan

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Abstract

H.E.S.S. is a stereoscopic system of large imaging atmospheric Cherenkov telescopes currently under construction in the Khomas Highland of Namibia with the first telescope already in operation. The reflector of each telescope consists of 380 mirror facets with a total area of 107 m^2. The alignment of the facets is performed by a fully automated alignment system using stars imaged onto the lid of the PMT camera. In order to be adjustable, the mirror facets are mounted onto supports which are equipped with two motor-driven actuators while optical feedback is provided by a CCD camera viewing the lid. The alignment procedure, implying the automatic analysis of CCD images and control of the mirror alignment actuators, has been proven to work reliably. On-axis, 80% of the reflected light is contained in a circle of less than 1 mrad diameter (1 mrad corresponds to 1.5 cm in the focal plane), well below specifications.

Mirror Alignment Technique

The mirror alignment is based on a fully automated scheme:

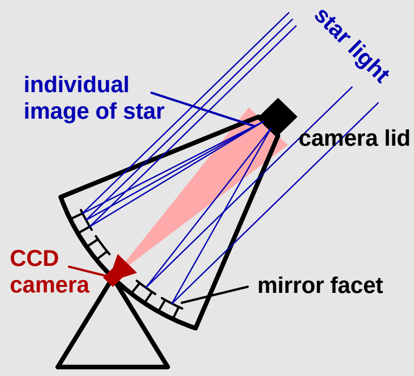
- Mirror supports with motor-driven actuators.
- Sophisticated control electronics.
- CCD camera for optical feedback.
- **Alignment completely computer controlled.**

Major advantages of alignment technique:

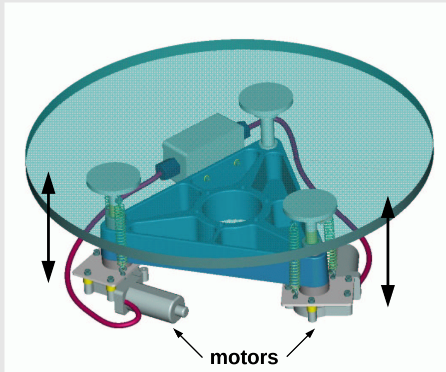
- Point-source at infinite distance.
- **Alignment of mirror factes at optimum elevation (55° – 75°).**

Duration of mirror alignment:

- Initial alignment (only once): 2 weeks
- **Realignment of all mirror facets (if required): 1–2 nights**

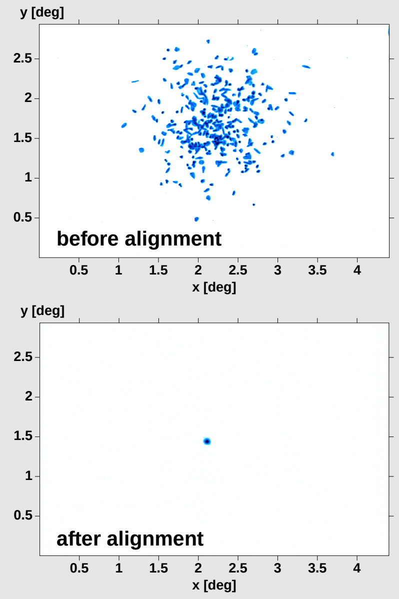


Mirror alignment technique: The telescope is pointed towards an appropriate star whereupon all mirror facets generate individual images of the alignment star in the focal plane. Actuator movements change the location of the corresponding image which is observerd by a CCD camera.



Mirror facet with adjustable support:

- Mirror held by special joints to avoid stress.
- Two motor-driven actuators with two Hall sensors on each motor shaft for recording of movement.
- Resolution of actuator movement: 3.4 μm corresp. to 0.013 mrad. Range of adjustment: $\pm$ 1.4 cm corresp. to $\pm$ 52 mrad.



Light spots before and after the mirror alignment as seen by the CCD camera (log. scale).

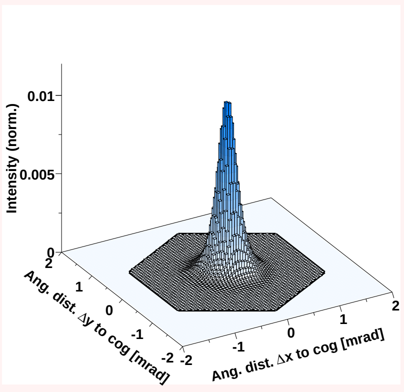
Point Spread Function

The mirror facets of the first H.E.S.S. telescope have been aligned in Jan/Feb 2002.
The resulting point spread function of the whole reflector is well below specifications:

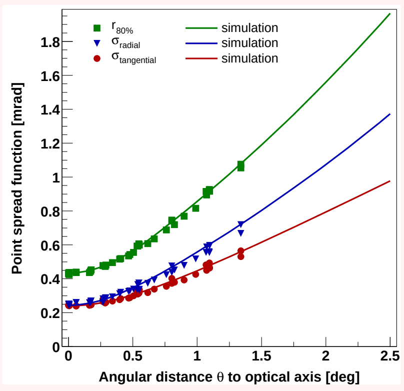
width of psf	result	requirement
σ_{proj}	0.24 mrad	$\leq$ 0.50 mrad
σ_{2D}	0.34 mrad	$\leq$ 0.71 mrad
$r_{80\%}$	0.42 mrad	$\leq$ 0.90 mrad
$r_{80\%}$ for individual mirrors		$\leq$ 0.50 mrad

σ_{proj}: rms of projected intensity distribution
σ_{2D}: rms of two-dimensional distribution
$r_{80\%}$: 80% containment radius

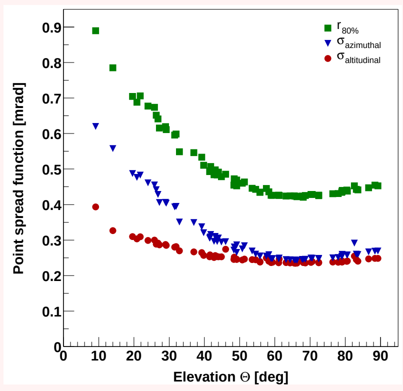
⟹ **Very good average mirror quality.**
⟹ **Excellent alignment accuracy.**



Intensity distribution in the focal plane of an imaged star in comparison with the hexagonal shape of a pixel of the PMT Cherenkov camera. **The complete amount of light is well within one pixel.**



Off-axis behaviour of the point spread function. The measurements are in excellent agreement with simulations.

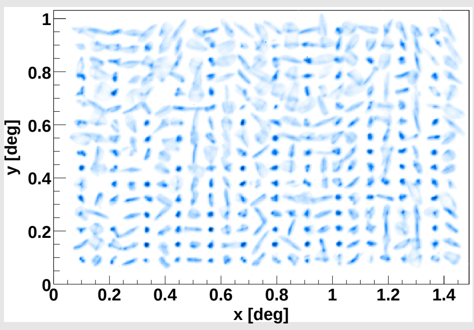


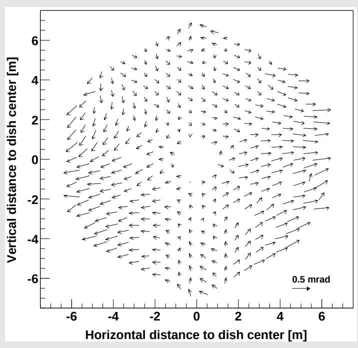
Point spread function with varying elevation. The curves are nearly flat in the usual working range between 45° and 90° elevation, indicating a **good stability of the support structure.**

Dish Deformation

The alignment system allows to study the deformation of the support structure in detail: Rather than combining all individual spots to a uniform main spot, the spots can be arranged in arbitrary patterns.

Spot matrix: Each spot corresponds to an individual mirror facet at a certain location in the dish.





CCD images of spot matrix at different elevations ⟶ relative movement of spots ⟶ deflection of mirror facets ⟶ deformation of dish structure.

Left: Mirror deflections at 29° elevation with respect to 65° (mean alignment elevation), arrows scaled by sqrt(deflection).

Conclusion

The mirror alignment of the first H.E.S.S. telescope was a proof of concept and a fairly decent test of all technologies involved: mechanics, electronics, software, algorithms and the alignment technique itself. All components work as expected and the resulting point spread function exceeds the specifications by a significant margin. The widening of the spot with increasing angle to the telescope axis is in accordance with the expected behaviour based on simulations and the variation of spot size with elevation due to deformations of the support structure is completely uncritical over the working range.

References

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Acknowledgements: This work was supported by the German Ministry for Education and Research, BMBF.