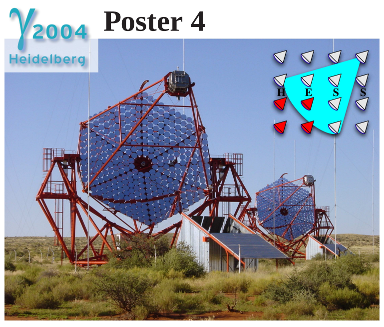

Poster 4

Point spread function and long-term stability of the H.E.S.S. reflectors

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Abstract

H.E.S.S. is a stereoscopic system of four large imaging atmospheric Cherenkov telescopes in the Khomas Highland of Namibia. The 107 m² reflector of each telescope consists of 380 mirror facets with 60 cm diameter which are aligned by a fully automated system using stars imaged onto the lid of the Cherenkov camera. The alignment procedure, implying the automatic analysis of CCD images and control of the mirror actuators, has been proven to work reliably. On-axis, 80% of the reflected light is contained in a circle of less than 1 mrad (0.057° or 1.5 cm in the focal plane) diameter, well below specifications. The widening of the spot with increasing angle to the optical axis is in accordance with the expected behaviour based on simulations, and variations of spot size with elevation are uncritical. Deterioration of the point spread function over time is of no concern; recurrent monitoring proved the width to be stable and thus the support structure to be very stiff.

Mirror Alignment Technique

The mirror alignment is based on a fully automated scheme:

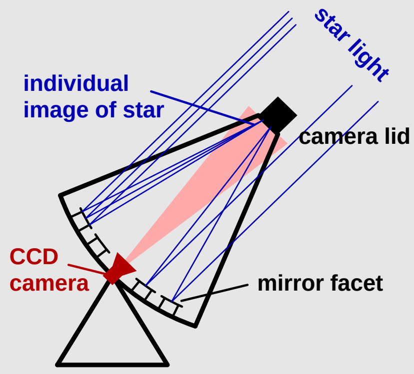
- Mirror supports with motor-driven actuators.
- Sophisticated control electronics.
- CCD camera for optical feedback.
- **Completely computer controlled.**

Major advantages of alignment technique:

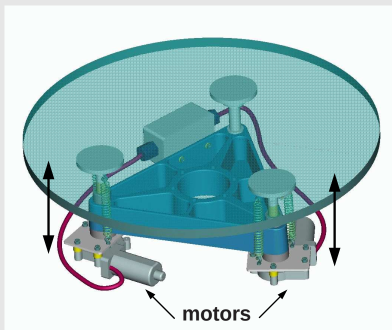
- Natural point-like source at infinite distance.
- Direct imaging in the focal plane.
- **Alignment of mirror facets at optimum elevation (55° – 75°).**

Duration of mirror alignment:

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

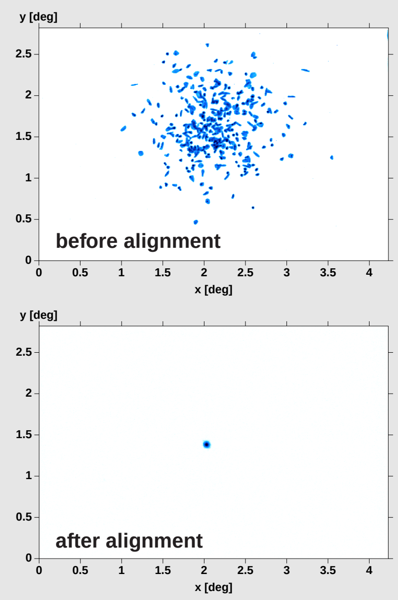


Mirror alignment technique: The telescope is pointed towards an appropriate star whereupon all mirror facets generate individual images of the alignment star in the focal plane (closed lid of the Cherenkov camera). Actuator movements change the location of the corresponding image which is observed by a CCD camera at the center of the dish.



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: ± 1.4 cm corresp. to ± 52 mrad.



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

Point Spread Function

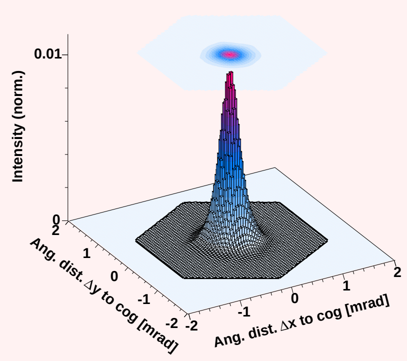
On-axis widths (all values in mrad):

width	CT01	CT02	CT03	CT04	specs
σ_{proj}	0.23	0.23	0.23	0.23	≤ 0.50
$r_{80\%}$	0.40	0.41	0.40	0.40	≤ 0.90
$r_{80\%}$ for individual mirrors					≤ 0.50

σ_{proj}: rms of projected intensity distribution
$r_{80\%}$: 80% containment radius

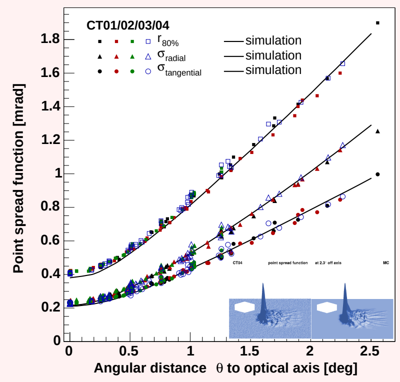
Overall alignment results:

$\Longrightarrow$ **very good average mirror quality**
$\Longrightarrow$ **excellent alignment accuracy**



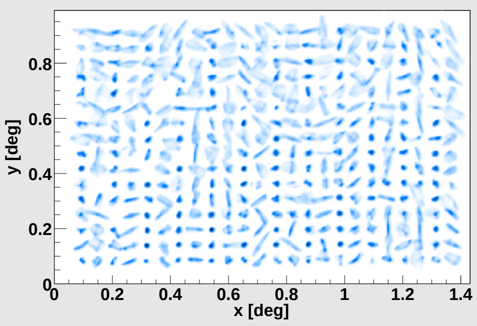
***Left:* On-axis intensity distribution of a star image on the lid** (CT04). The hexagonal border indicates the size of a photomultiplier pixel.

***Right:* Off-axis behaviour of the point spread function.** The measurements are in good agreement with Monte Carlo simulations of the whole reflector.
Inset: Measured spot shape (left, CT04) in comparison with a Monte Carlo generated image (right) at 2.3° off axis. Even sub-structural details (knots and ribs) in the tails of the intensity distributions are reproduced.



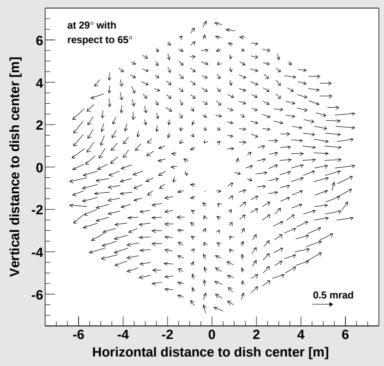
Reflector Stability

To study the deformation of the support structure in detail, individual spots (i.e. mirror facets) can be arranged in arbitrary patterns.

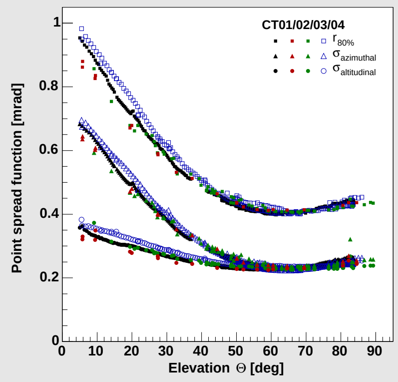


Spot matrix: Each star image corresponds to an individual mirror facet at a certain location in the dish (facets of CT03).

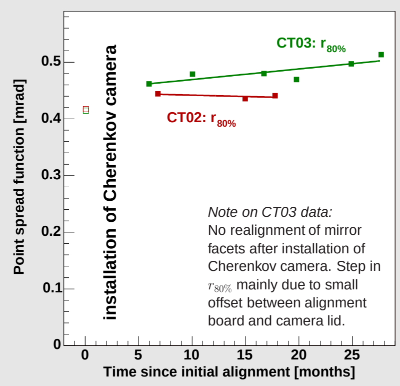
By taking matrix images at different elevations, the deflection of mirror facets (i.e. deformation of the dish structure) can be inferred from the relative movement of the corresponding spots.



Mirror deflections at 29° elevation with respect to 65° (CT03, scaled by $\sqrt{\text{deflection}}$).



Effect of the elevation-dependent deformation on the PSF. The curves are nearly flat in the usual working range (45°–90°), indicating a **good stability of the support structure**. In addition, **all reflectors behave very similar.**



Evolution of the point spread function at 65° elevation. Only a small increase of 0.022 mrad or 6% per year for $r_{80\%}$ is observed (CT03, the first telescope), indicating an **outstanding long-term stability of the telescope structure.**

Conclusion

The alignment of the four H.E.S.S. reflectors was a proof of concept and a 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 significantly exceeds the requirements. The four reflectors behave very similar which demonstrates the high accuracy of the support structure and the reproducibility of the alignment process. This is complemented by an excellent long-term stability of the telescope structures; only a small increase in spot size is observed over a period of two years. To conclude: H.E.S.S. successfully pioneered star-based automated mirror alignments in air-Cherenkov astronomy.

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