Telescopes for the High Energy Section of the CTA

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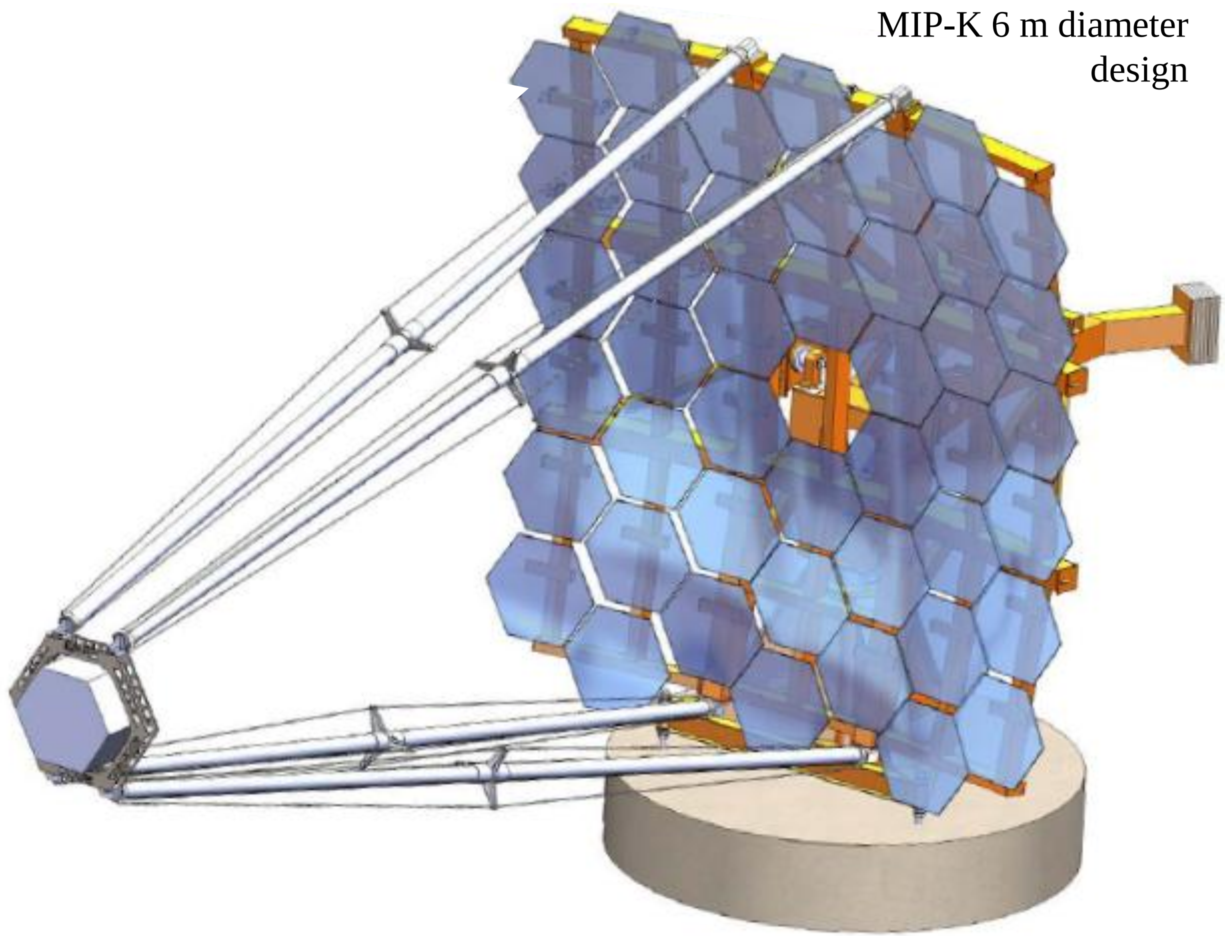
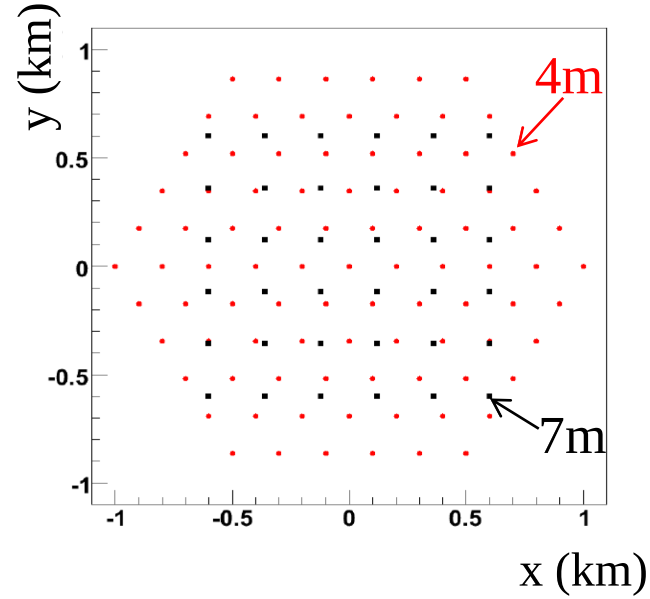
- Summary.



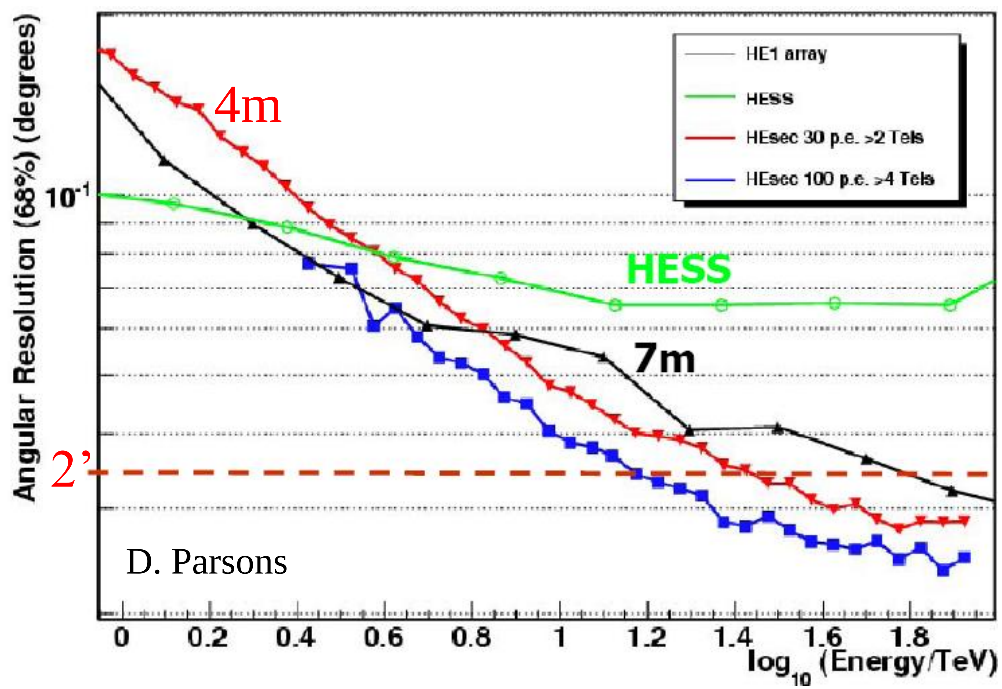
MIP-K 6 m diameter design

Introduction

- Flux of highest energy photons small, need to cover large area.
- Two approaches possible:
  - Lots of cheap telescopes with moderate field of view separated by ~ 150 m.
  - Fewer expensive telescopes with very large field of view allowing separations up to ~ 500m.
- Latter approach leads to smaller multiplicity, poorer angular resolution: use many small telescopes.
- Possibilities include:
  - D-C with ~ 7 m diameter mirror.
  - Dual mirror, primary ~ 4 m.

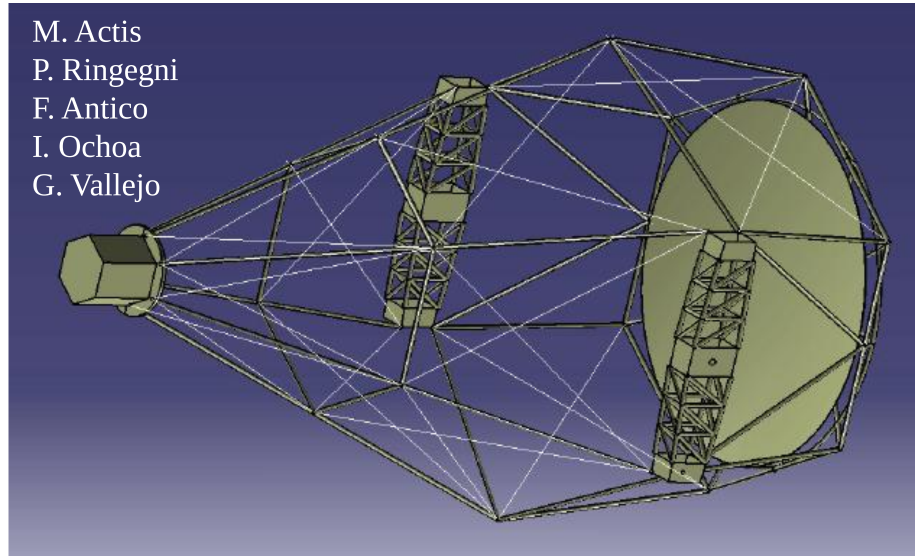


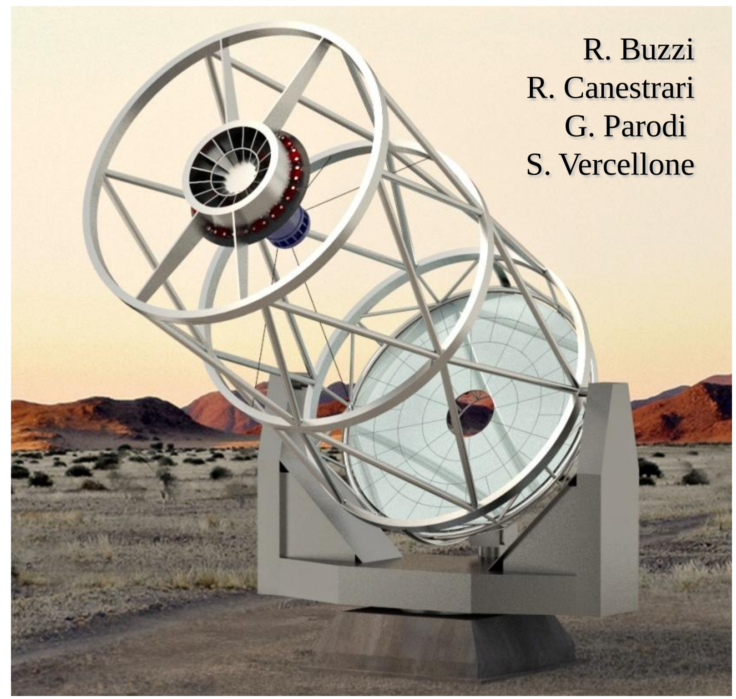
- Multiplicity and angular resolution.



Introduction

- Typical requirements for telescopes:
  - Field of view of 8...10°.
  - Pixel size of around 0.2...0.3°.
- Davies-Cotton design, F ~ 12 m, mirror diameter ~ 7 m (F/D ~ 1.5), pixels ~ 40 mm, PM-based camera.
- Dual-mirror design, F ~ 2.3 m, primary diameter ~ 4 m (F/D ~ 0.6), secondary diameter ~ 2 m, pixels ~ 8 mm, MAPM- or GAPD-based camera.
- Single mirror design using (solid) Winston Cones and GAPDs.
- Here describe progress with optical design of a dual mirror telescope.

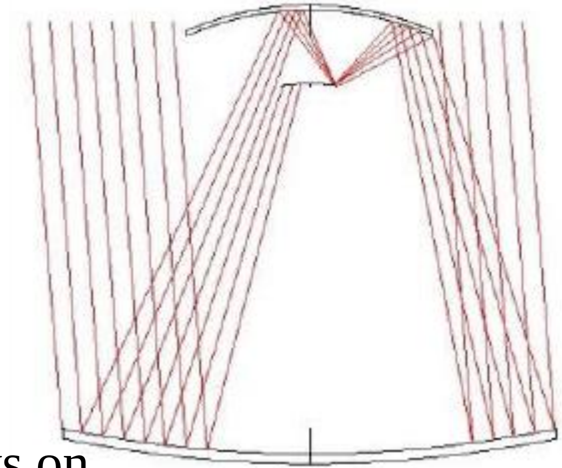




Dual mirror optics

- Two optical design studies.
- Commercial package ZEMAX[1] (CfAI, Durham).
- "Exact Optics"[2] (Liverpool).
- Both approaches give PSFs consistent with pixel sizes of a few mm.
- Concern due to steep angle of rays on camera, particularly for "Exact Optics" solution, of up to 75°.
- Further optimisation (V11) using ZEMAX allowed reduction of max angle to below 60°.
- Results reported in Zeuthen.

- Ray tracing with $\delta = 4.5°$:



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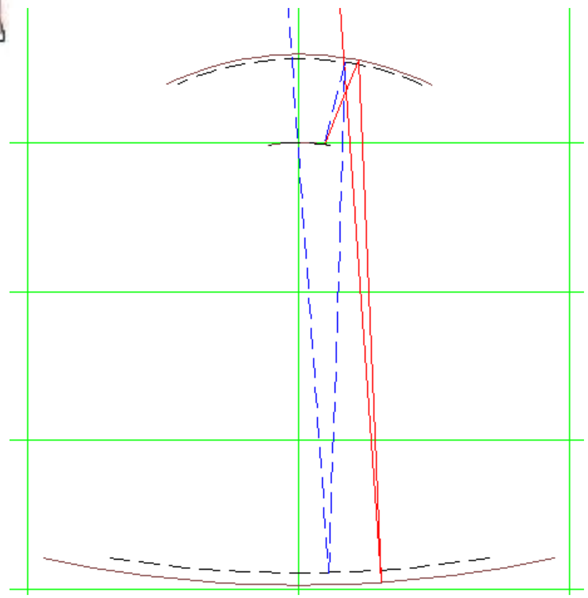


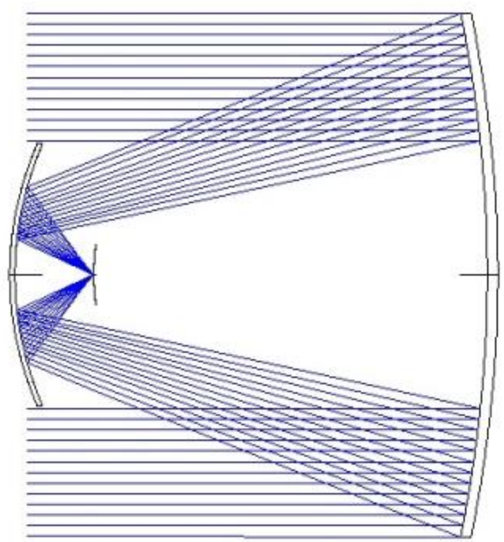
1 http://www.zemax.com/

2 Lynden-Bell, Mon. Not. R. Astron. Soc. **334**, 787-796 (2002).

V17 parameters

- Further ZEMAX optimisation.
- In particular plate scale corrected and additional weight given to PSFs at large field angles in optimisation.
- Result (V17) is plate scale of 39.6 mm/° and increased uniformity of PSFs across field of view.
- Telescope parameters:
  - F = 2.283 m.
  - D_p = 4 m.
  - D_s = 2 m.
  - D_{cam} = 0.36 cm.
  - Dist. Prim. to Sec. 3.56 m.
  - Dist. Sec to Cam. 0.51 m.
  - Camera convex, ρ_{cam} = 1 m.

- V13 (top) and V17 (bottom):



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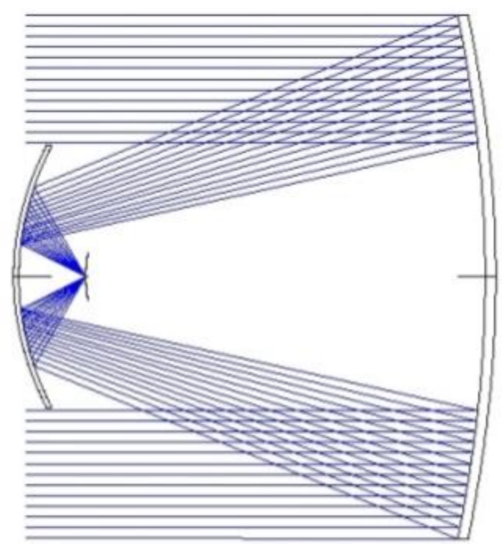
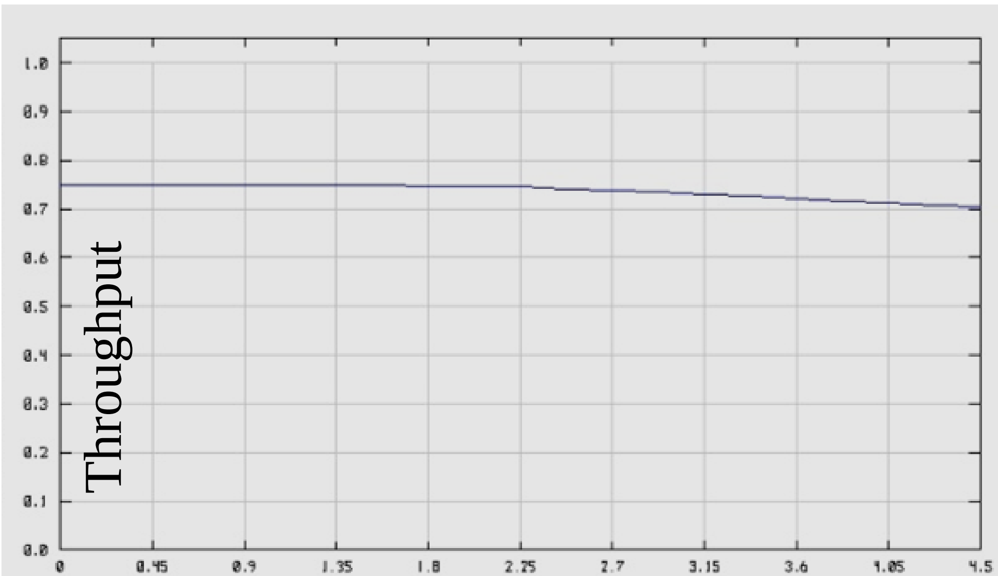


Light throughput

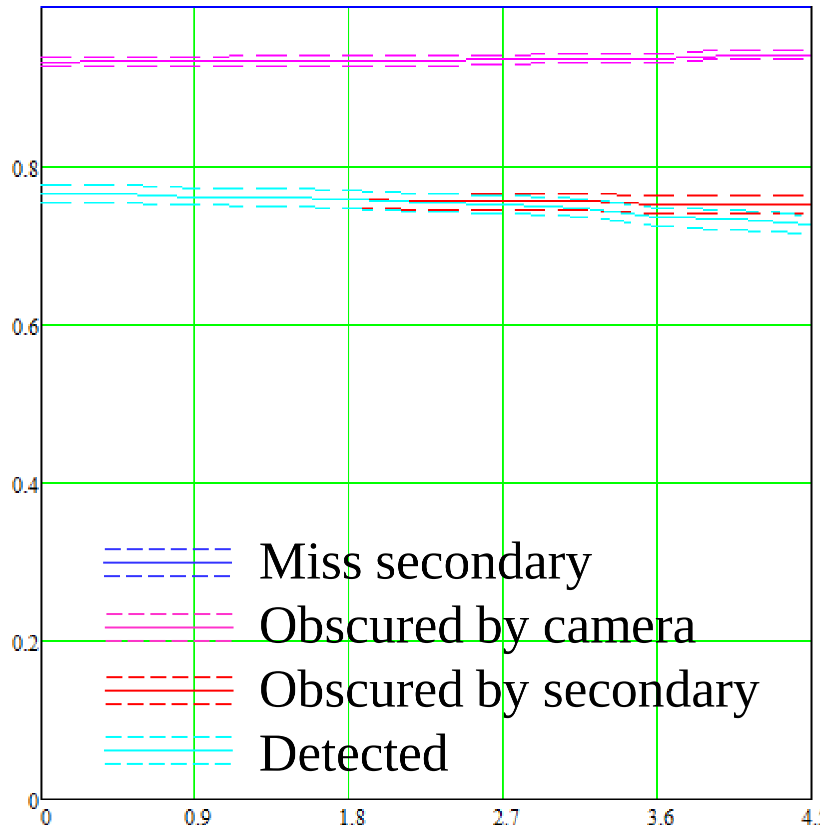
- Geometrical throughput:



δ (°)

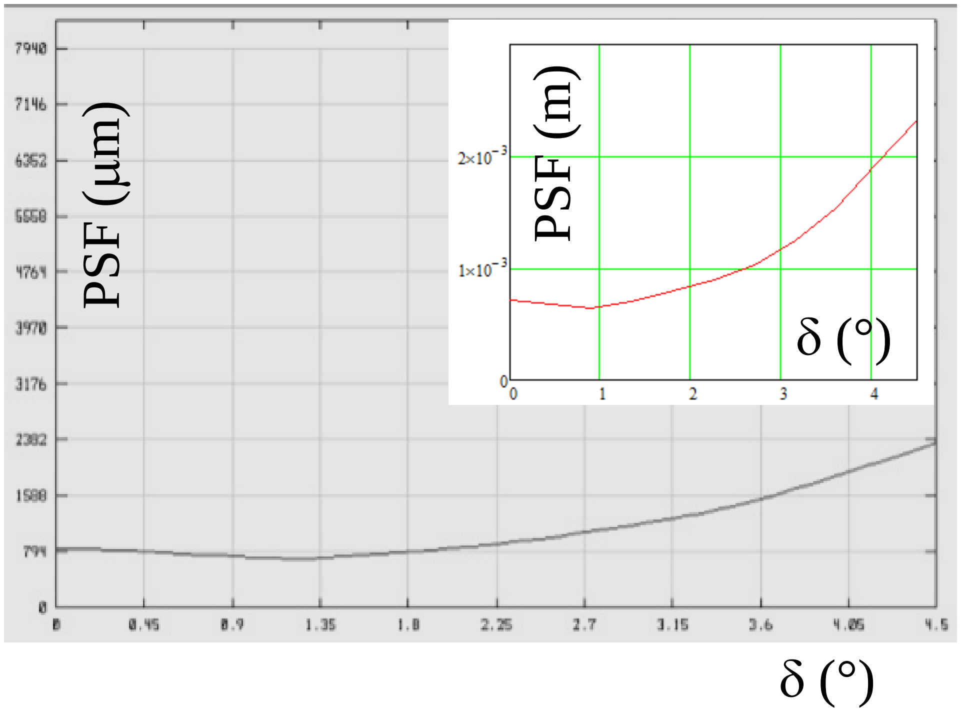
- Throughput varies from 75% to 71% (effective area 9.4 m^2 to 8.9 m^2).

- Results independently checked.



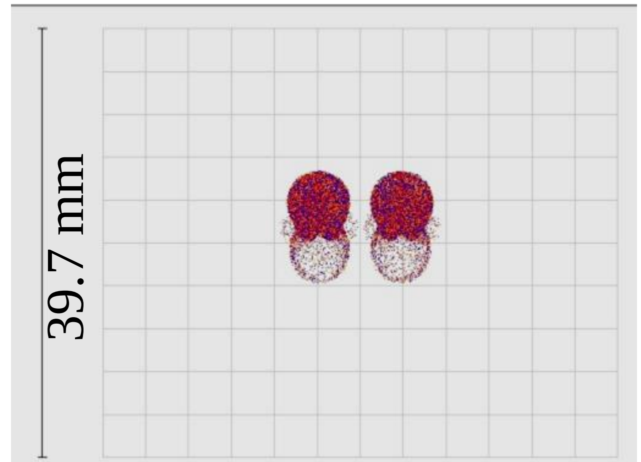
PSFs and resolution

- PSFs (enclosed energy 70%):

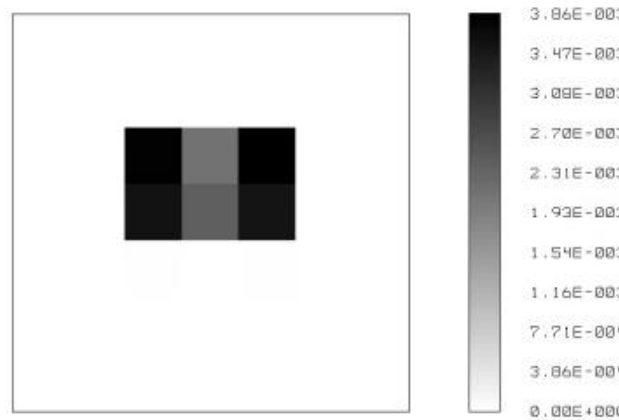


- 7940 mm = 0.2°.

- Resolution (images at 0.2° separation)...

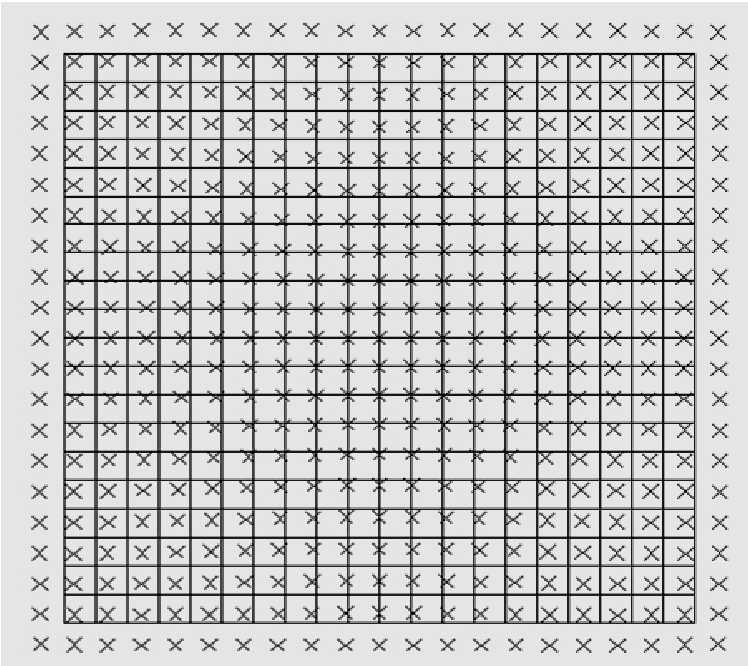


- ...dominated by pixel size (6.5 mm), not optical performance of telescope.



Distortion and tolerances

- Distortion:



- Maximum -2.5% at largest field angles.
- Isochronous.

- Tolerances (monolithic mirrors):

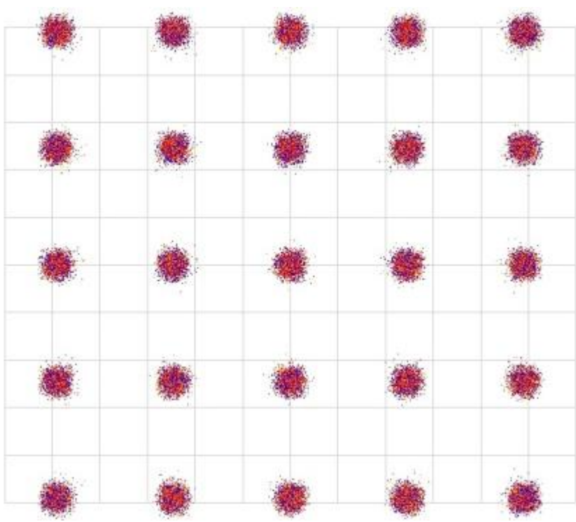
Error	Surface	Tolerance
Distance deviation	M1 to M2	+/- 5 mm
	M2 to detector array	(+/- 5 mm) (*)
Surface irregularity	M1	20 µm rms
	M2	50 µm rms
Surface roughness	M1	1 µm rms
	M2	1 µm rms
Radius deviation	M1	+/- 10 mm
	M2	+/- 3 mm
	detector array	+/- 3 mm
Element decenter	M1	+/- 5 mm
	M2	+/- 5 mm
	detector array	+/- 5 mm
Element tilt	M1	+/- 0.14°
	M2	+/- 0.14°
	detector array	+/- 0.14°

- Above modifications result in less than 10% increase in PSFs.
- Change of focus (M2 to camera) allowed as compensation, max 3.7 mm(*).

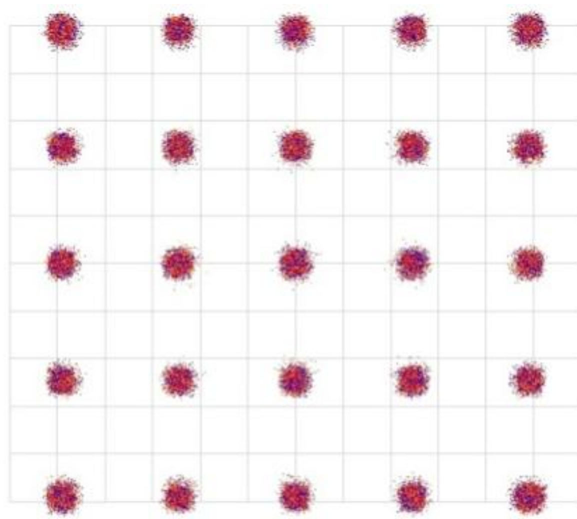
Tolerances cont. and effect of flat camera elements

- Allowed error in position and angle of mirror segments (resulting in shift of image of less than 2.15 mm).

Element decentre	M1	± 2 mm
	M2	± 2 mm
Element tilt	M1	± 0.17°
	M2	± 0.5°
	Focal plane	± 0.83°

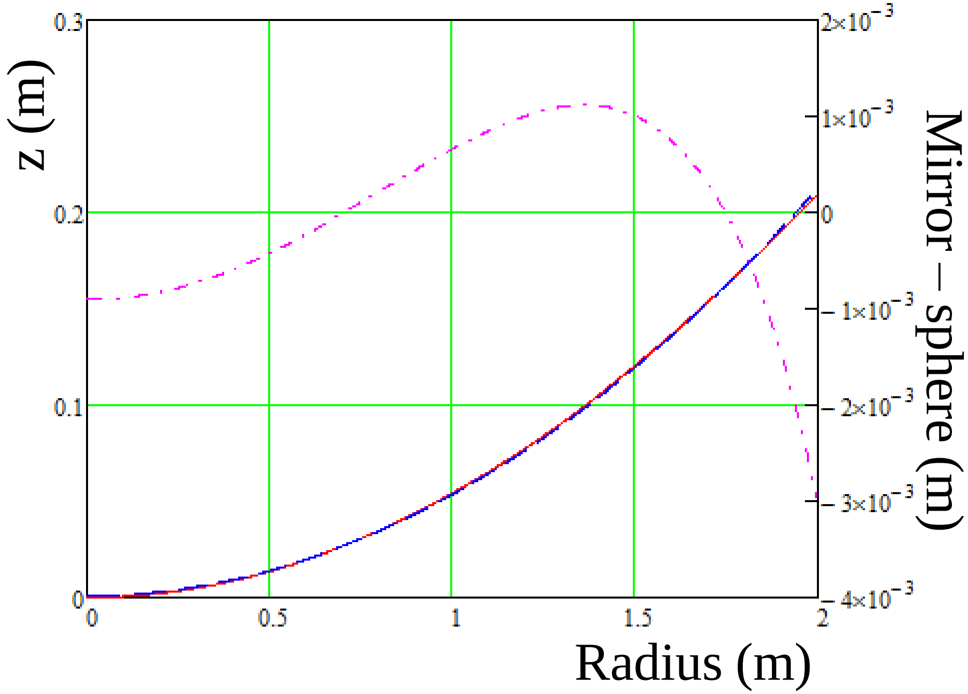


- Effects of constructing camera using flat tiles (e.g. of MAPMs) rather than curved surface investigated.
- Tile size 52 × 52 mm^2.
- No appreciable difference between images on curved (left) and flat (right) surfaces:

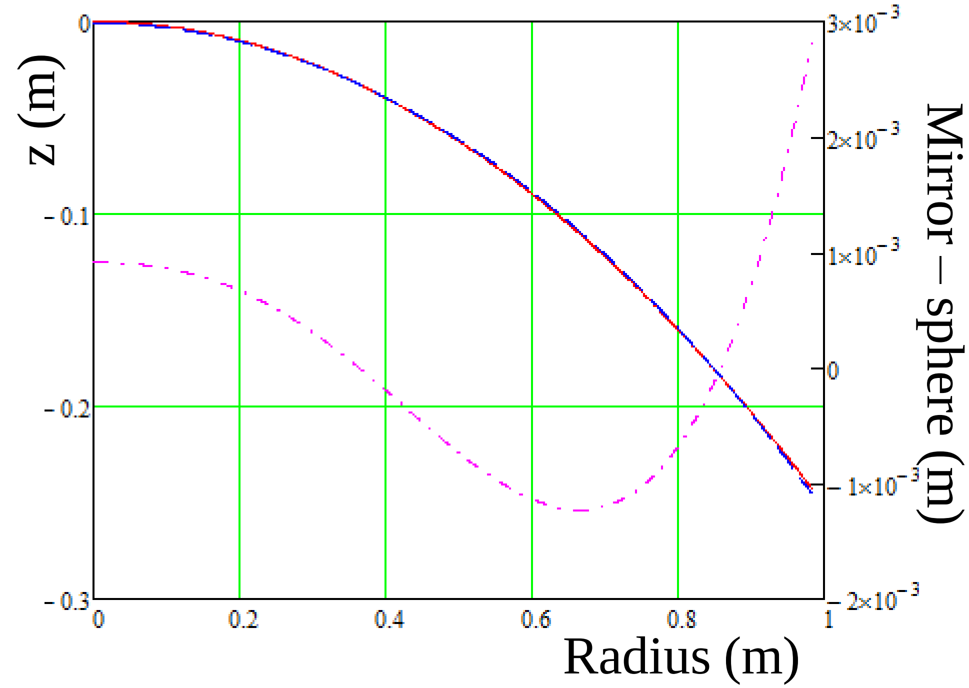


Mirror shapes

- Mirrors aspherical, shape and deviation from closest sphere (R = 9.55 m) for primary...



- ...and secondary (R = 2.10 m).



Summary

- Optical design of dual mirror telescope has been further developed.
- PSFs (70% enclosed energy) below 2.5 mm (0.1°) achieved for field angles up to 4.5°.
- Geometrical throughput ~ 75%: primary diameter 4 m implies effective area of around 9 m^2.
- Tolerances reasonable.
- Investigation of mirror construction techniques required.
- Studies of sensors appropriate for camera needed.