OWL Phase A Review - Garching - 2nd to 4th Nov 2005

Telescope Optics

(Presented by P. Dierickx)

European Southern Observatory

Telescope Optics

- Requirements
- Baseline design
- Properties
- Optical fabrication
- Conclusions

Requirements

- Top Level +

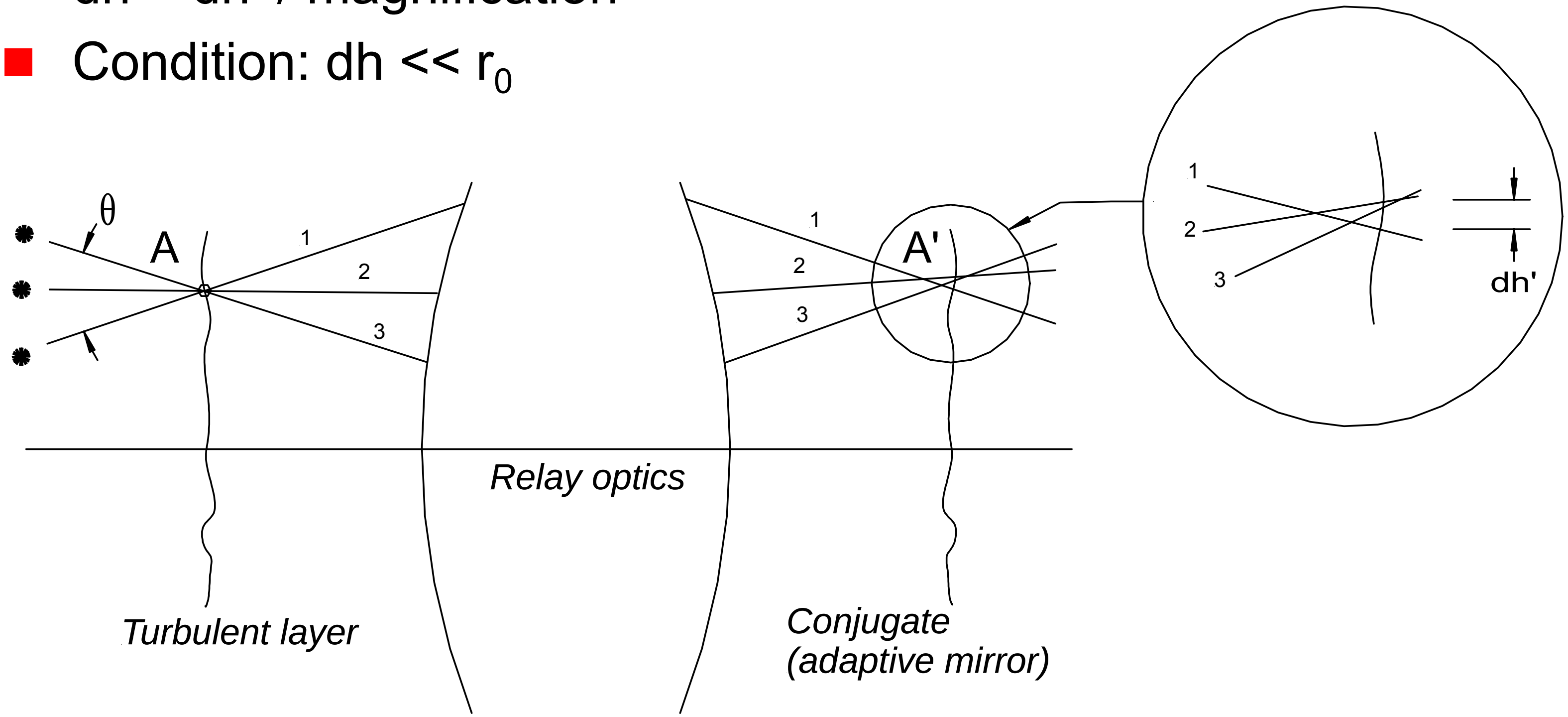
➢ Diffraction-limited FOV ~ AO patrol field	No AO offset
➢ Linear FOV < ~ 2-m	Metrology (flexures)
➢ Surfaces for wavefront control incl. AO	Functionality
➢ Total FOV > 6 arc minutes	On-sky metrology
➢ Monolithic surfaces ≤ 8-m	Feasibility
➢ Identical segments a major advantage	Cost
➢ Compactness	Performance, cost
➢ Etc.	

- Functionality ⇨ **at least 4 surfaces**
- 4 surfaces ⇨ **spherical M1 is an option**
- FOV 10 arc minutes (wavefront control) ⇨ **f/D ~6-7**

Optical design must incorporate re-imaging of atmospheric layers

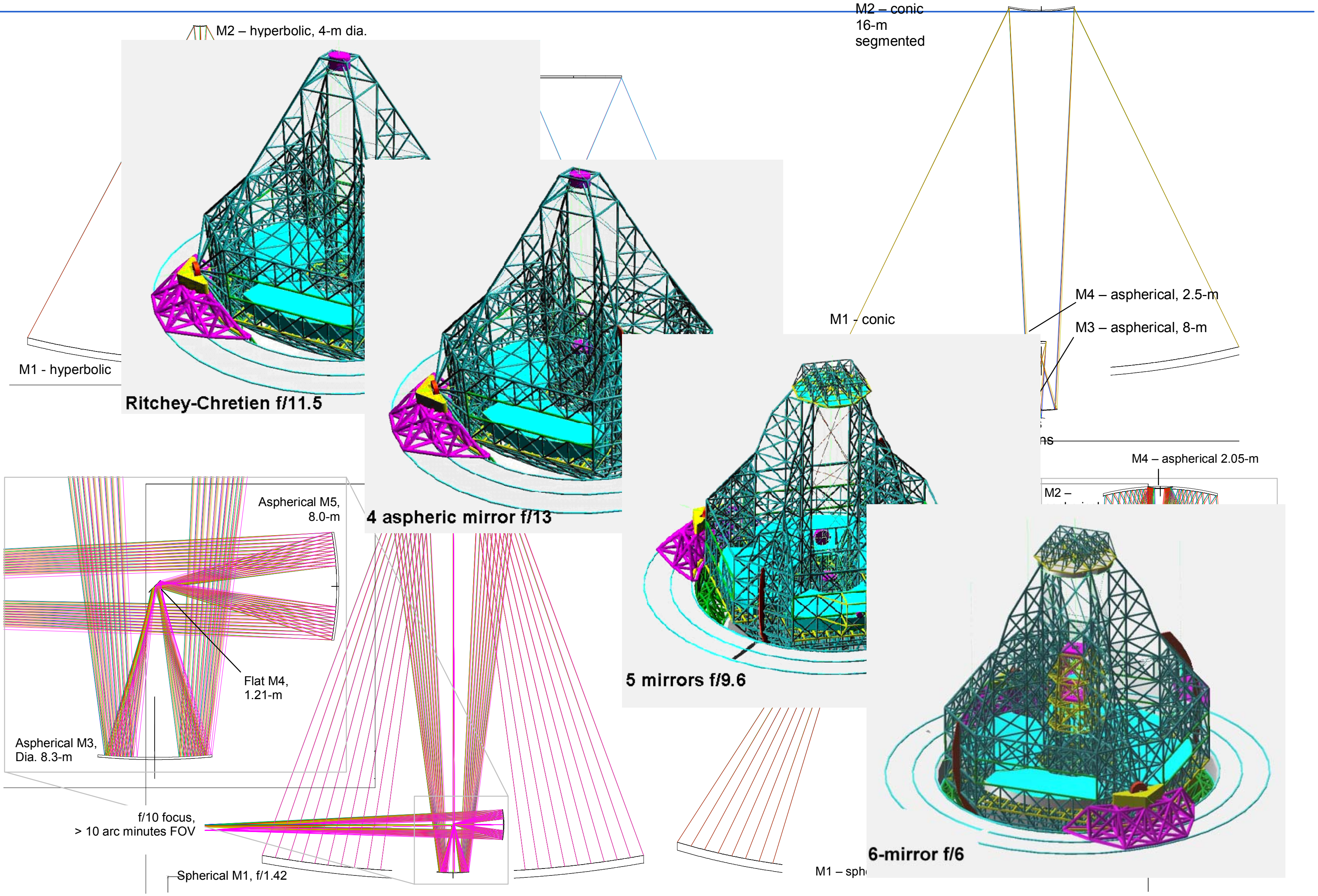
Imaging of atmospheric layers

- Phase error $\sigma^2 = 6.88 (dh / r_0)^{5/3}$
- $dh = dh' / \text{magnification}$
- Condition: $dh << r_0$



- Only affects “large” FOV AO (but number of references helps)

Design prospection

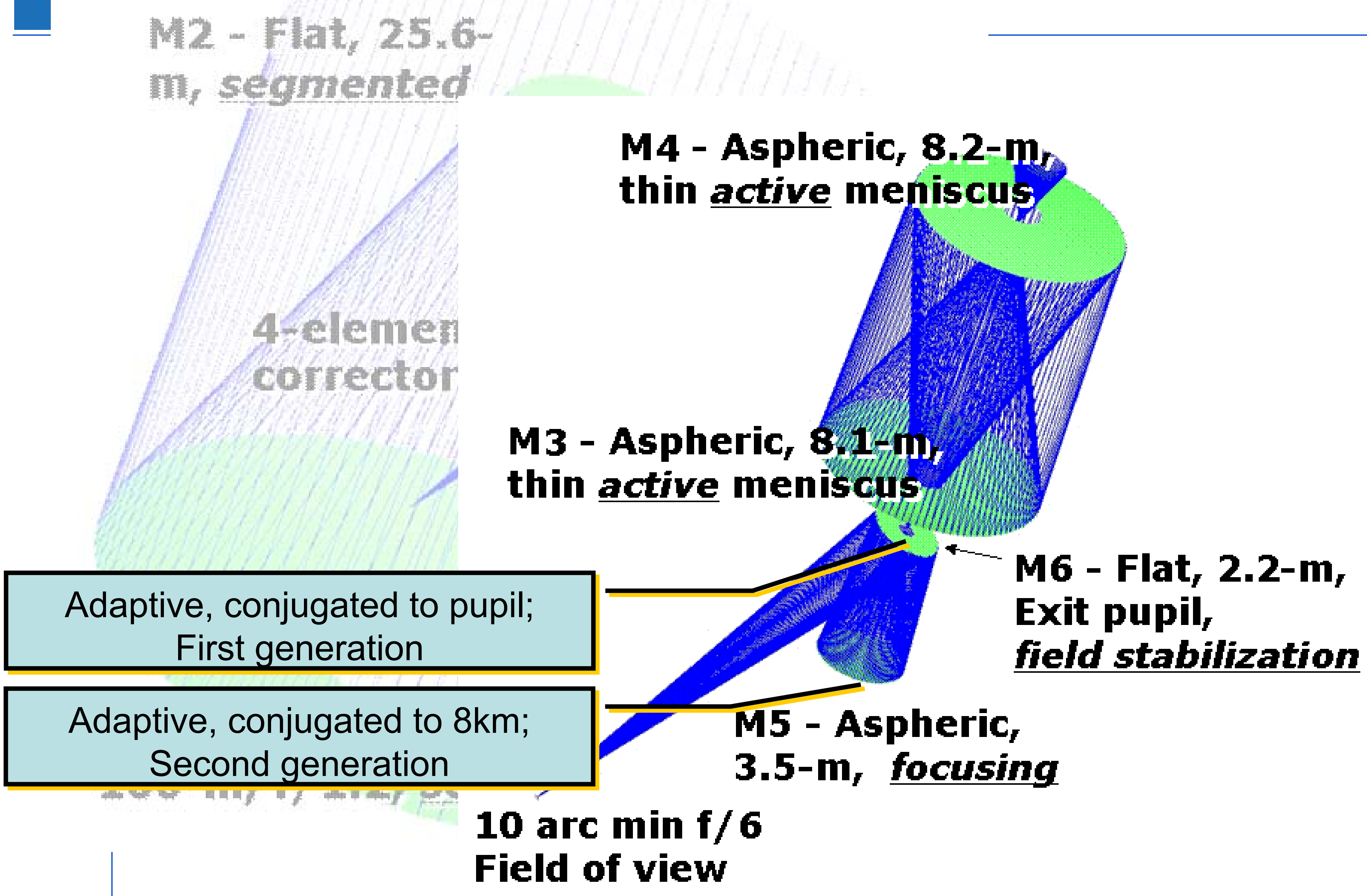


Baseline selection

- Function of merit
  - 7 mandatory requirements (FOV, quality, functions, etc.)
  - 33 relevant characteristics (from vignetting to fabrication)
  - NOT rigorous, only for trends
- Result is a *compromise* (i.e. nobody is happy)

Mandatory requirements	
1	Field aberrations over science field (3 arc min.) axisymmetrical or negligible.
2	Diffraction-limited (Strehl Ratio = 0.80, λ=0.5μm) $\geq$ 1 arc minute.
3	Field of view (dia.) for adaptive optics wavefront sensing $\geq$ 6 arc minutes.
4	The design shall provide suitable surfaces for active optics, including deformable mirror(s), active centring, focusing, and field stabilization
5	Monolithic mirrors shall be less than 8.3m in diameter
6	Field stabilization shall be done in a pupil image
7	The design shall provide a suitably located surface for single-conjugate IR SCAO and GLAO.

Baseline optical design



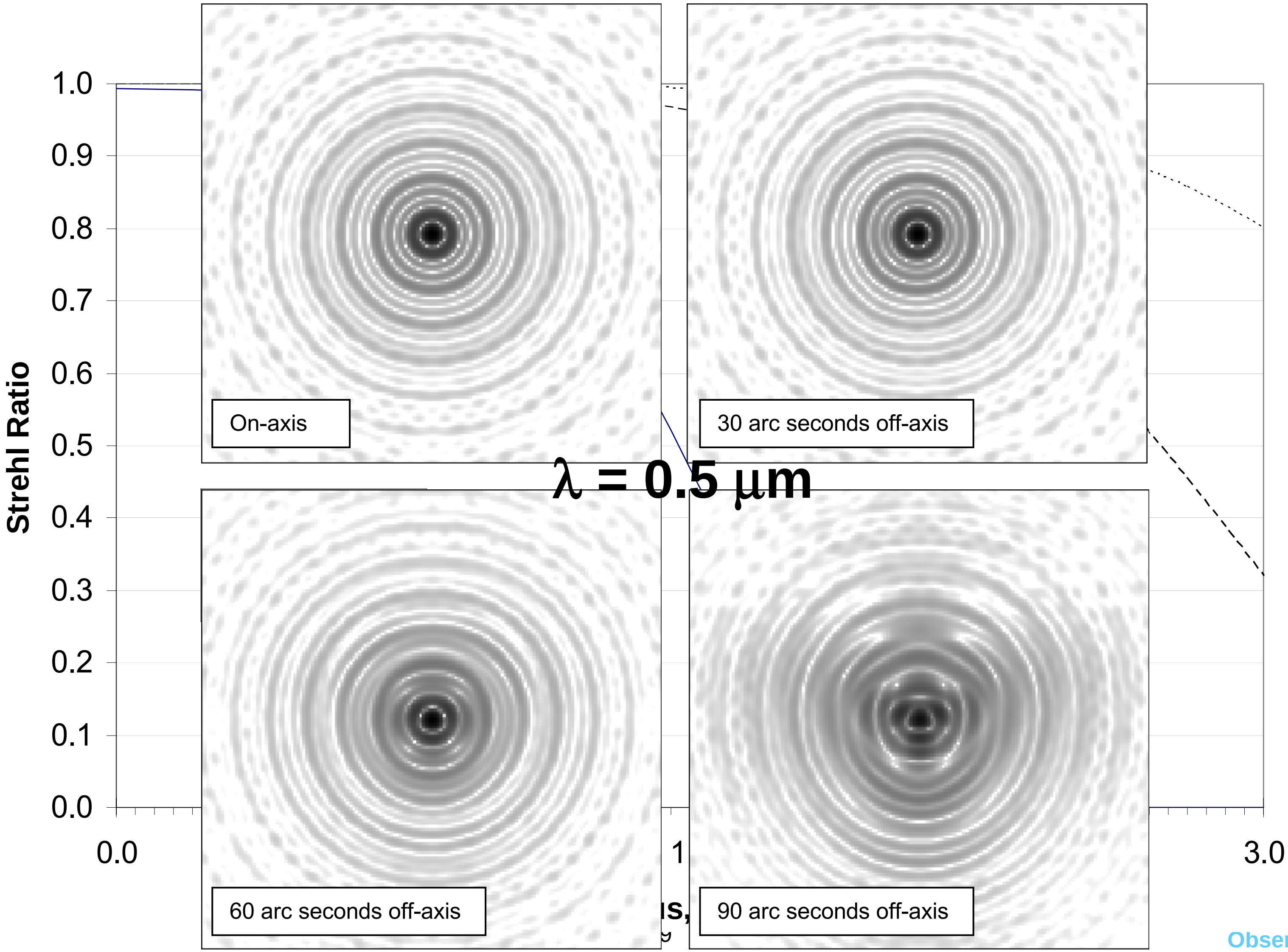
Overall properties

Characteristic	
Telescope diameter	100m
Focal ratio	6
Primary mirror focal ratio	1.25
Total field of view (diameter)	10 arc minutes
Unvignetted field of view (diameter)	6 arc minutes
Optical quality at the edge of the curved field	0.056 arc seconds RMS
Diffraction-limited field of view[1] (diameter, curved field)	
Visible (0.5 μm)	2.37 arc mins
IR (2.2 μm)	4.08 arc mins
IR (5.0 μm)	6.00 arc mins
Secondary mirror diameter	25.6m
Central obscuration (linear)	35%

[1] Strehl Ratio ≥ 0.80, curved field.

Optical quality

About 4 times better than Ritchey-Chretien



Sensitivity to decentres

- M2, M6 lateral decenters innocuous (flat mirrors)
- Effect of M2 tilt relatively small (low angular magnification)
- Effect of M1 + M2 decentres fully cancelled by Corrector decentres
- Critical: M2 piston (fast M1 !), lateral decentres inside corrector
- Passive compensation (to a large extent)
- Active alignment
  - Coarse refocus with M2 (segments actuators have sufficient range) or corrector, fine refocus with M5
  - Coarse tip-tilt with M2 or corrector, fine correction with M6 mount, diffraction-limited with adaptive shell
  - Decentring aberrations: TBD, several options possible inside the corrector (but must take 5^{th} order aberrations into account)
- Need to take into account prescription (i.e. plate scale)

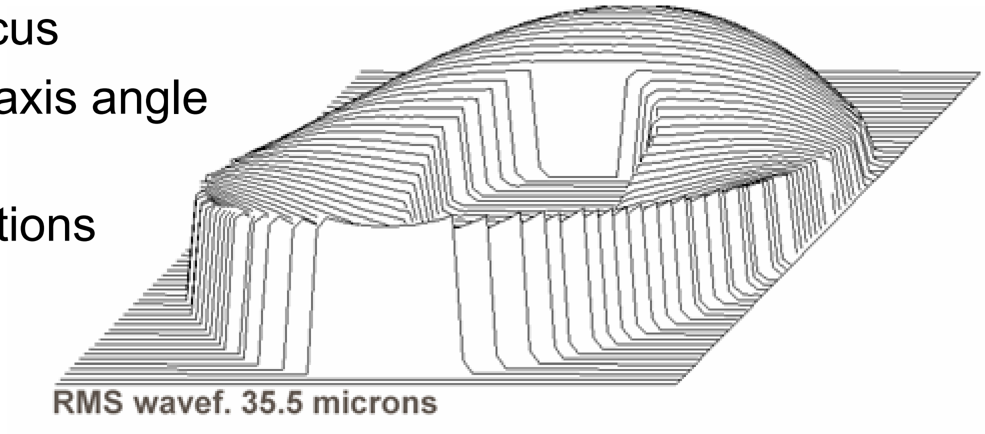
Imaging of Atmospheric layers, LGS

- Imaging of atmospheric layers: OWL M6 tilted
  ⇨ Phase error RMS $\sigma < \lambda/3\sqrt{N}$ for 3 arc minutes
  (**very** conservative, worst location on M6)

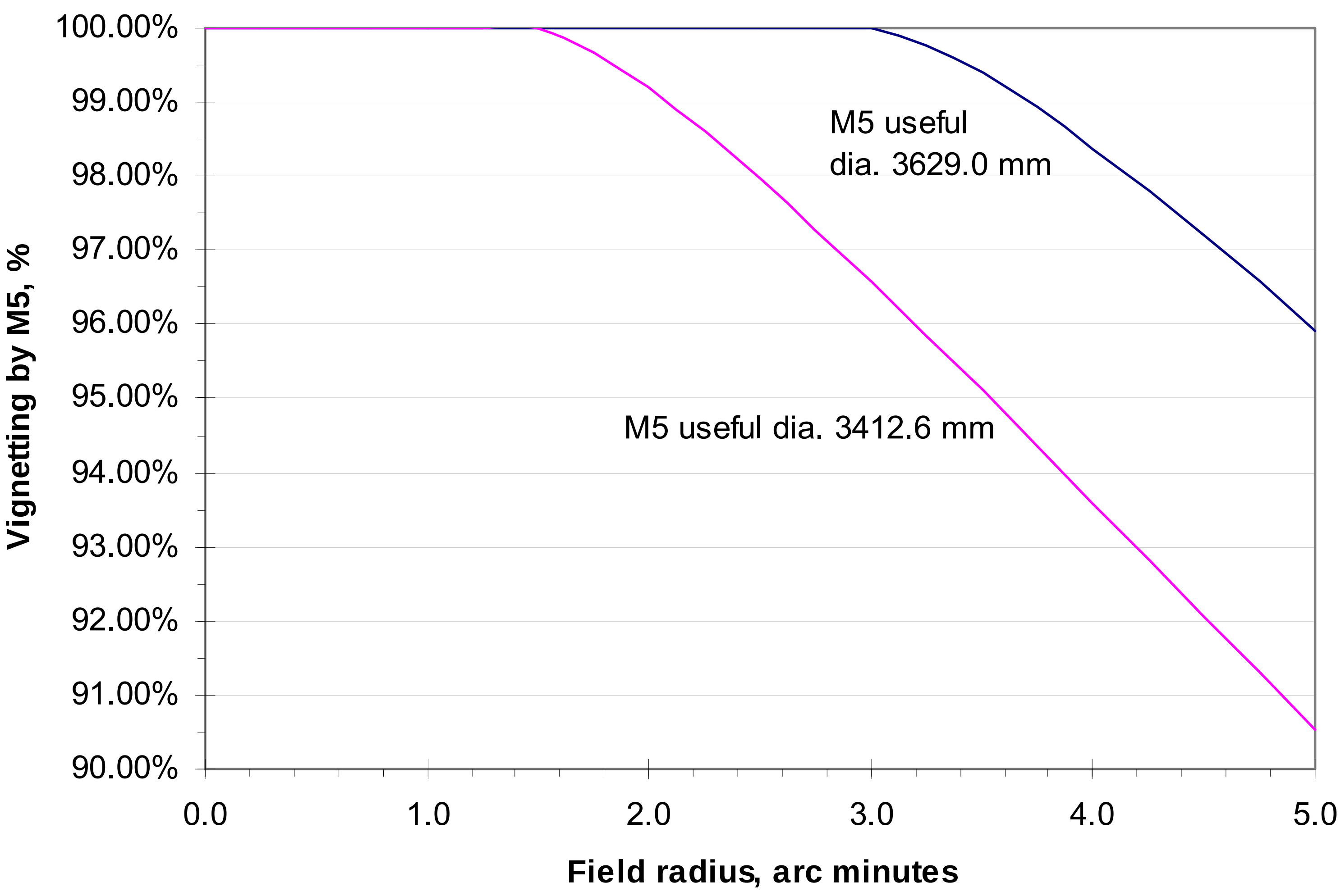
- Imaging of Laser Guide Stars
  - First order: defocus ~ D^2
  - Aberrated image after refocus

    Aberrations depend on off-axis angle and Focal Ratio

    Third and fifth order aberrations not controllable, need NGS
  - Novel AO concepts in ELT Design Study (PIGS, SPLASH, etc.)

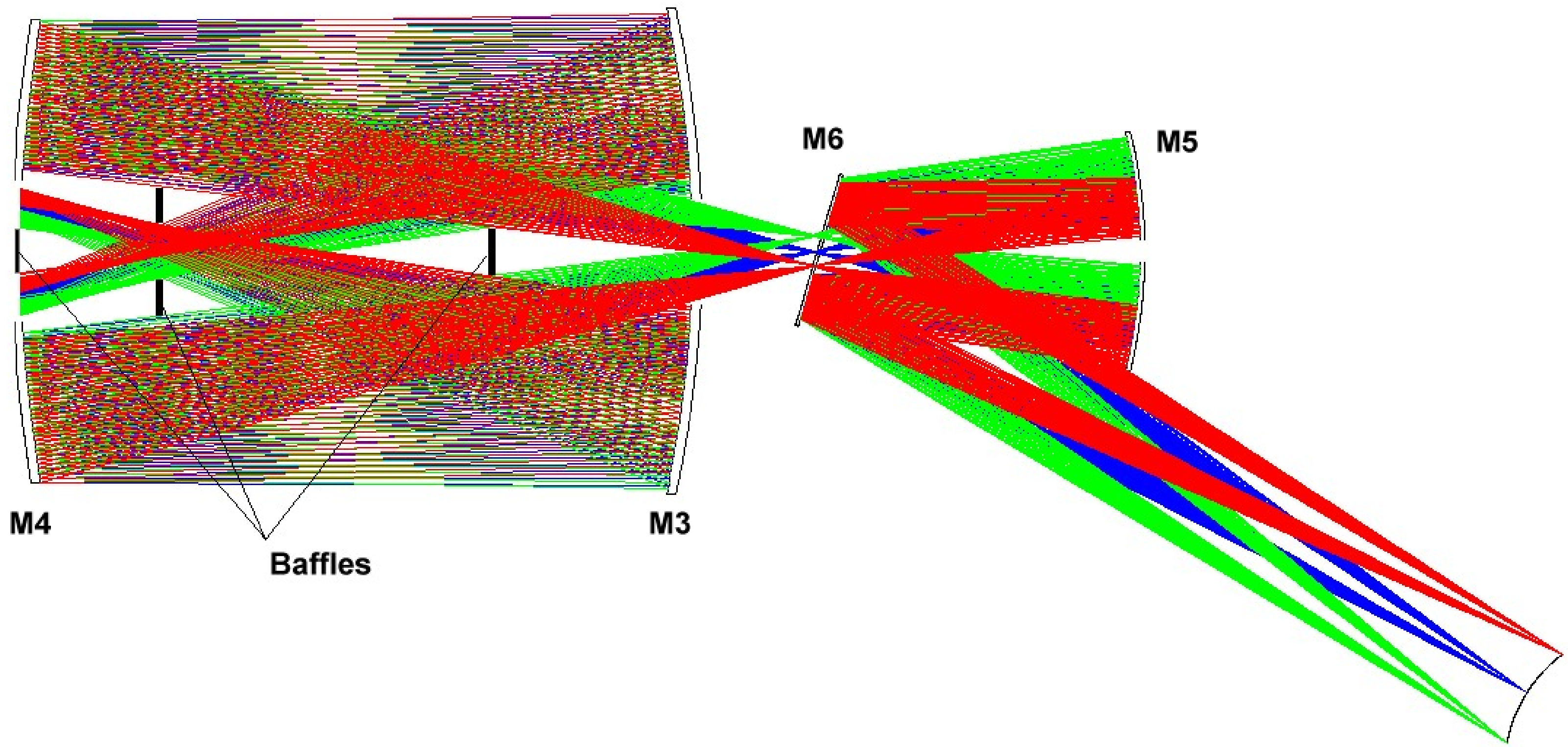


Vignetting

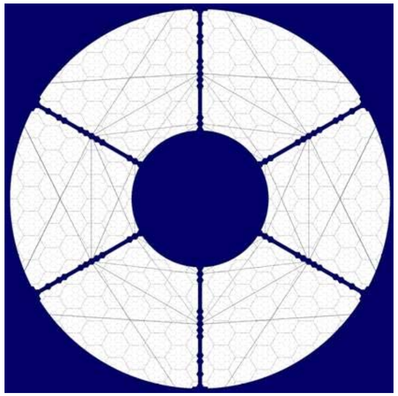

100.00%
99.00%
98.00%
97.00%
96.00%
95.00%
94.00%
93.00%
92.00%
91.00%
90.00%
Vignetting by M5, %
M5 useful
dia. 3629.0 mm
M5 useful dia. 3412.6 mm
0.0
1.0
2.0
3.0
4.0
5.0
Field radius, arc minutes

Baffling

- Open air
- Extensive baffling options

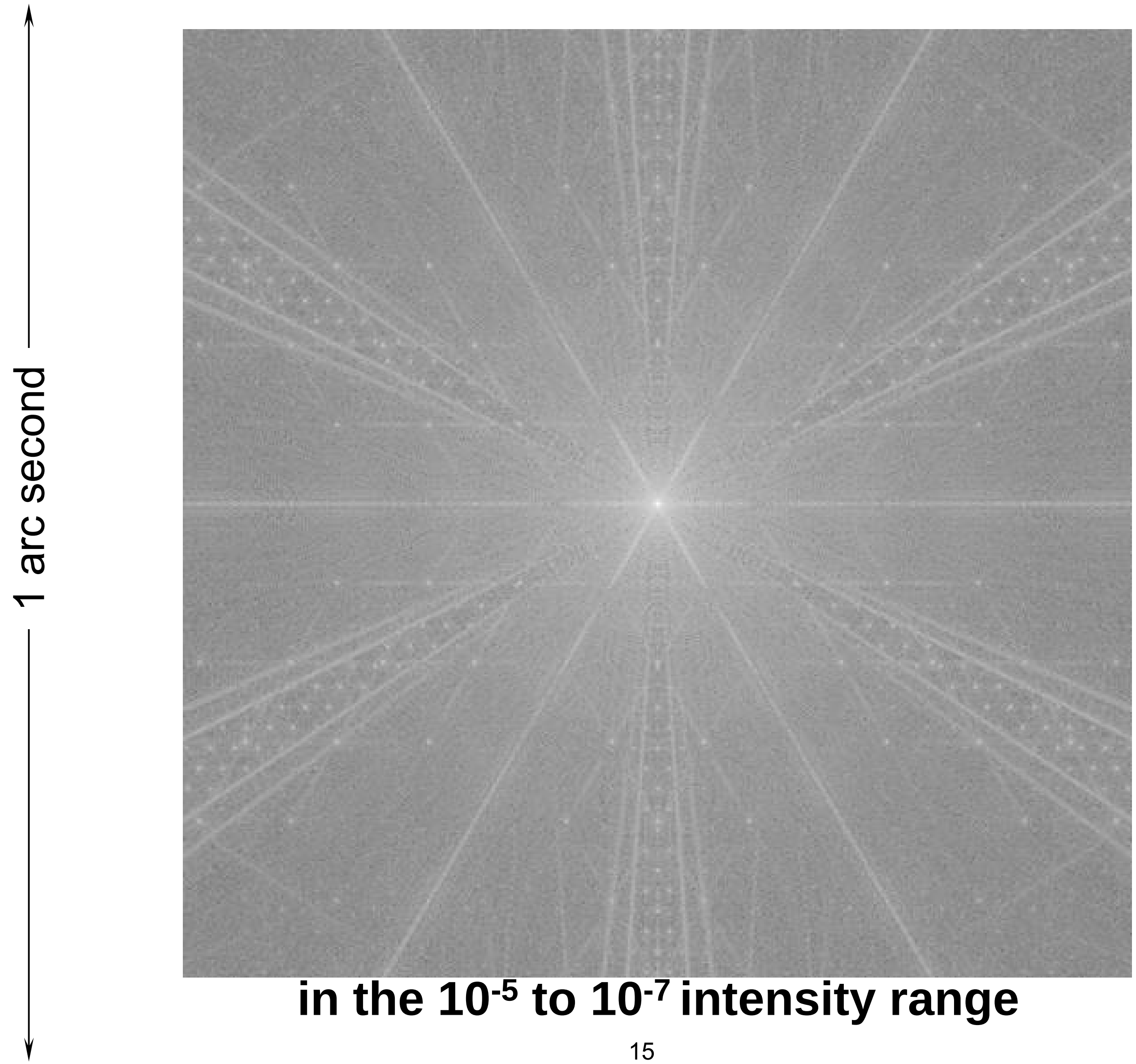


Emissivity (Gemini coatings)

Source	w/o pupil mask	with pupil mask	Pupil mask + Optional corrector
M1 	1.5%	1.5%	1.5%
M2	1.5%	1.5%	1.5%
M3	1.5%	1.5%	1.5%
M4	1.5%	1.5%	1.5%
M5	1.5%	1.5%	
M6	1.5%	1.5%	
M1+M2 gaps	1.2%	1.2%	1.2%
Ropes	1.1%	1.1%	1.1%
Spiders + missing segments	6.1%		
Central obscuration	11.9%		
Subtotal w/o ADC	**29.3%**	**11.3%**	**8.3%**

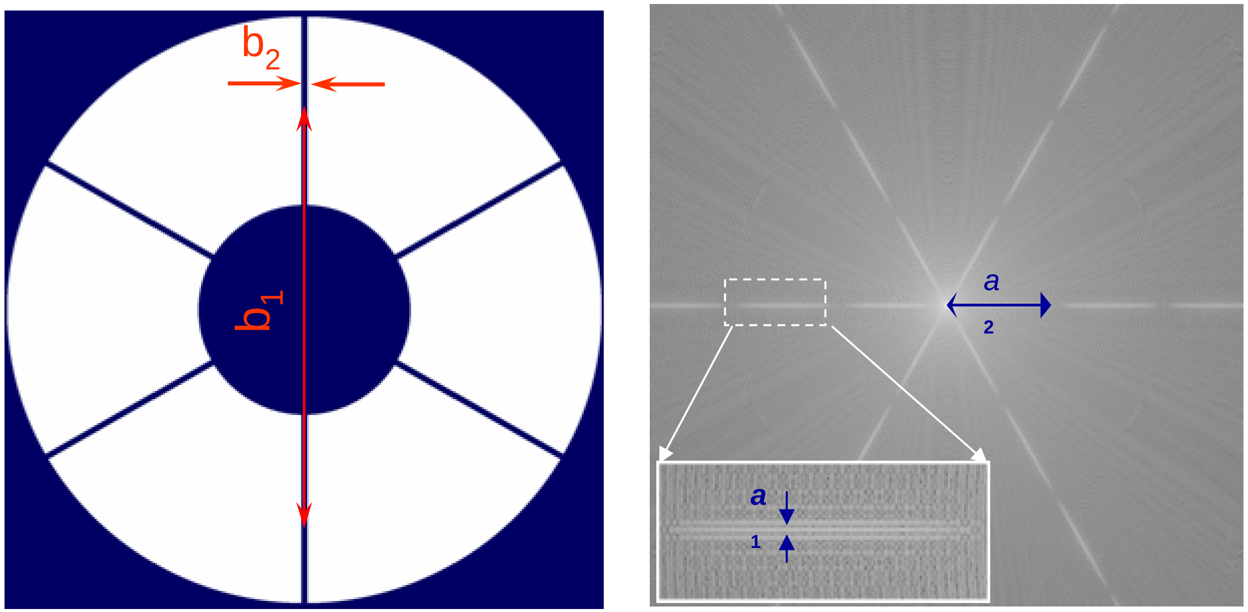
Optimistic: on-axis, assumes perfect pupil re-imaging

Diffraction (log scale)



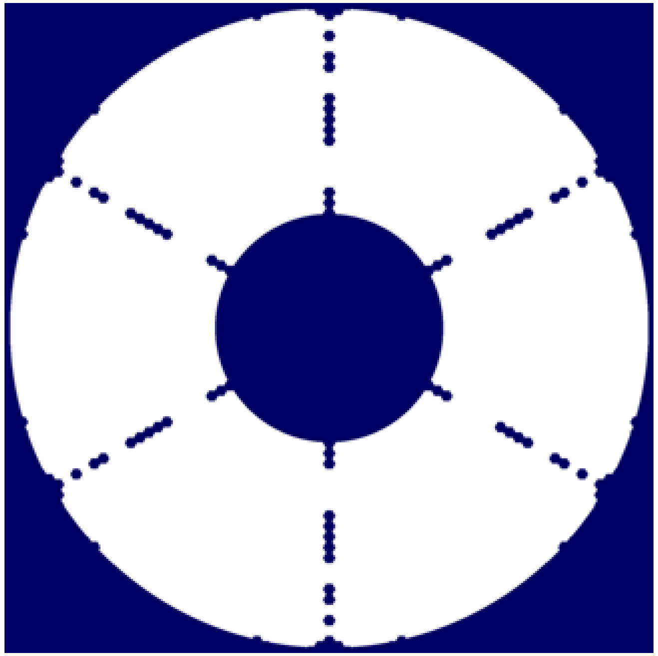
in the 10^{-5} to 10^{-7} intensity range

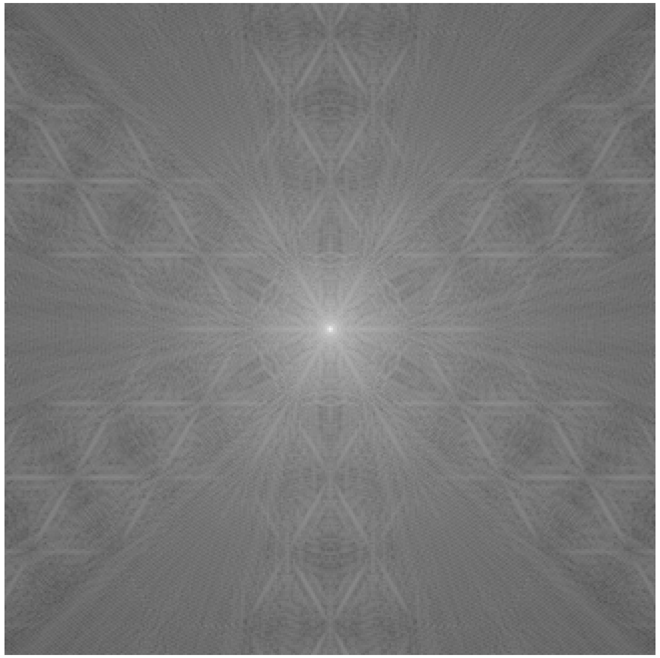
Diffraction



Diffraction by the "spiders". PSF box size 0.72"

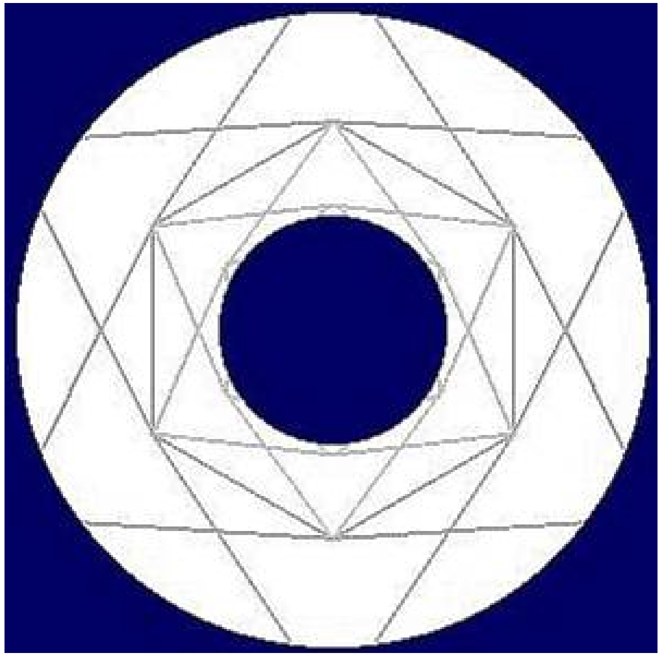
Diffraction

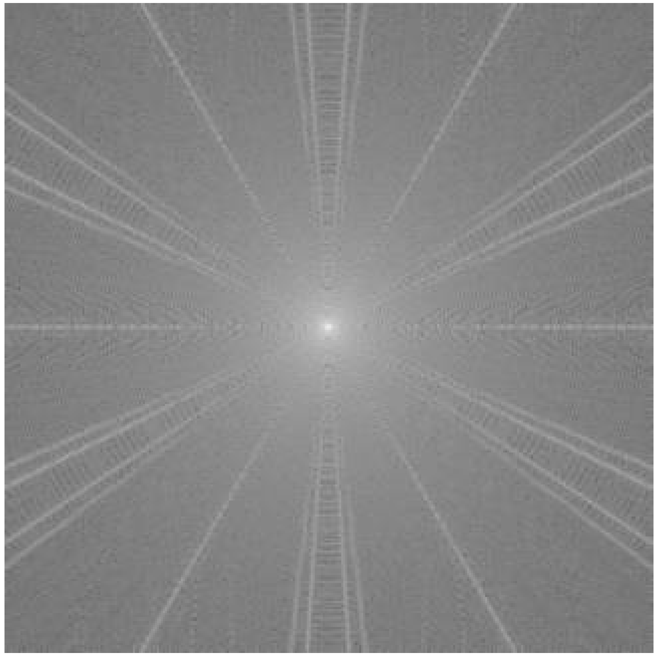




Diffraction by "missing" segments. PSF box size 0.72"

Diffraction

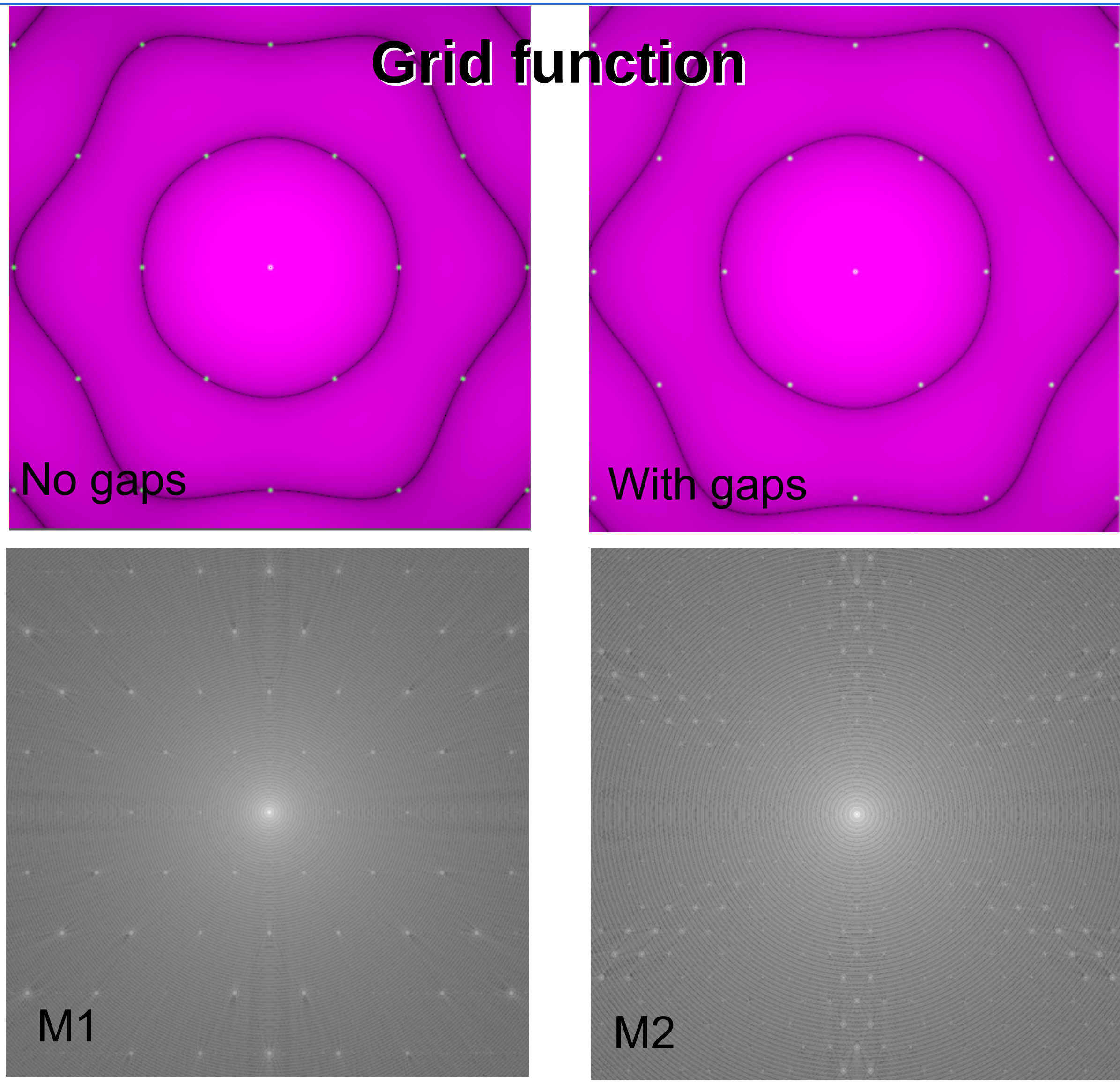




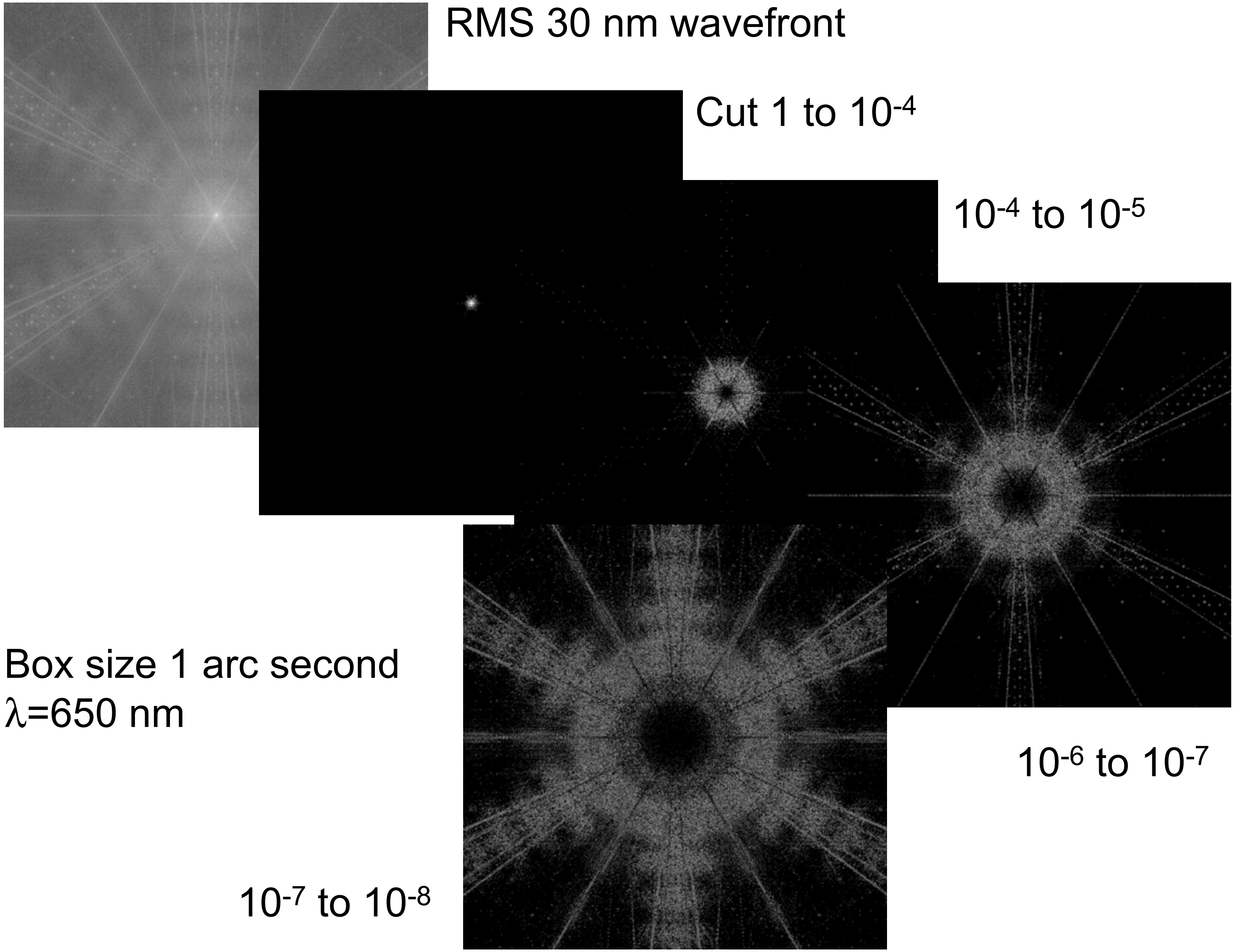
Diffraction by the ropes. PSF box size 0.72”

Diffraction

Grid function



Phasing errors



RMS 30 nm wavefront

Cut 1 to 10^{-4}

10^{-4} to 10^{-5}

10^{-6} to 10^{-7}

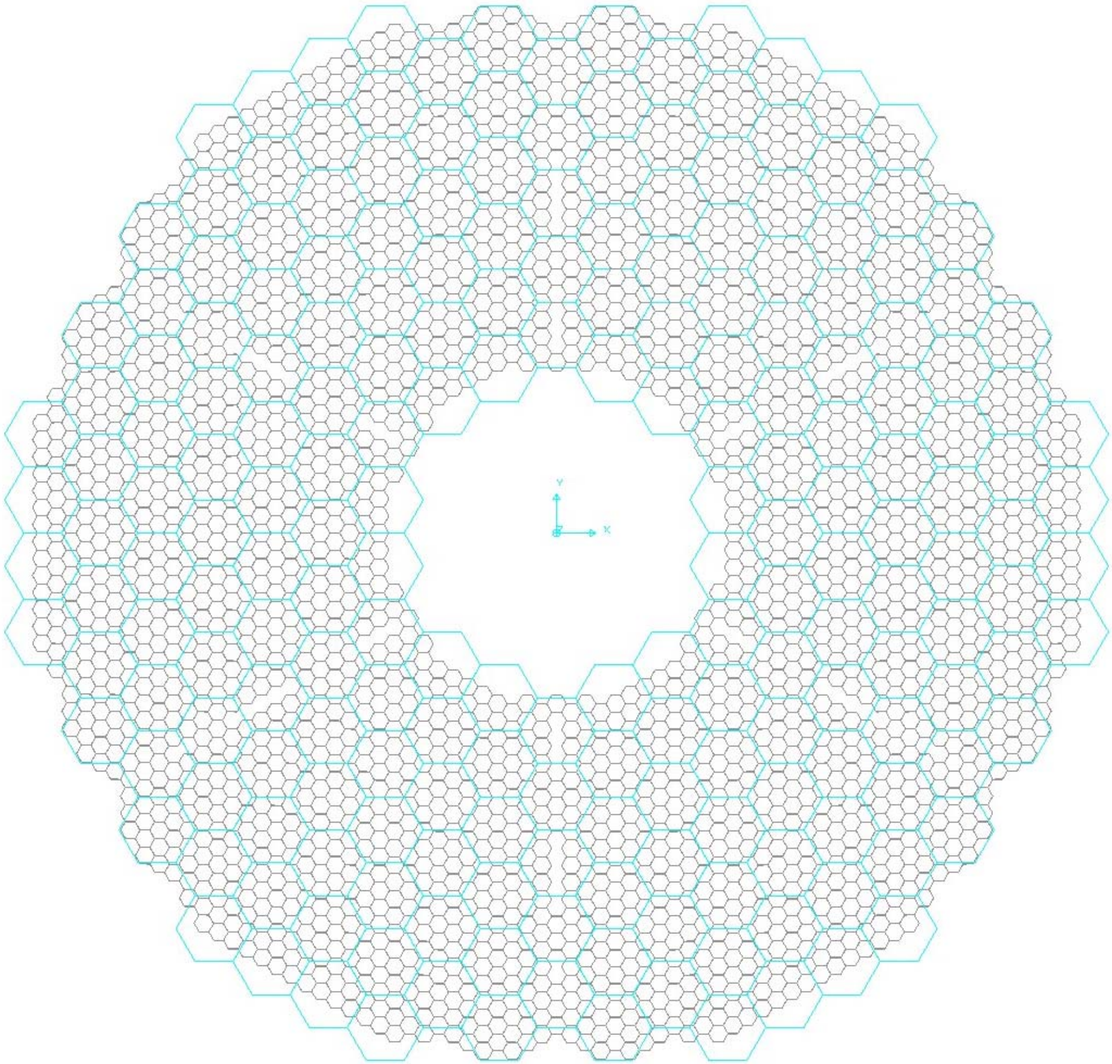
Box size 1 arc second
λ=650 nm

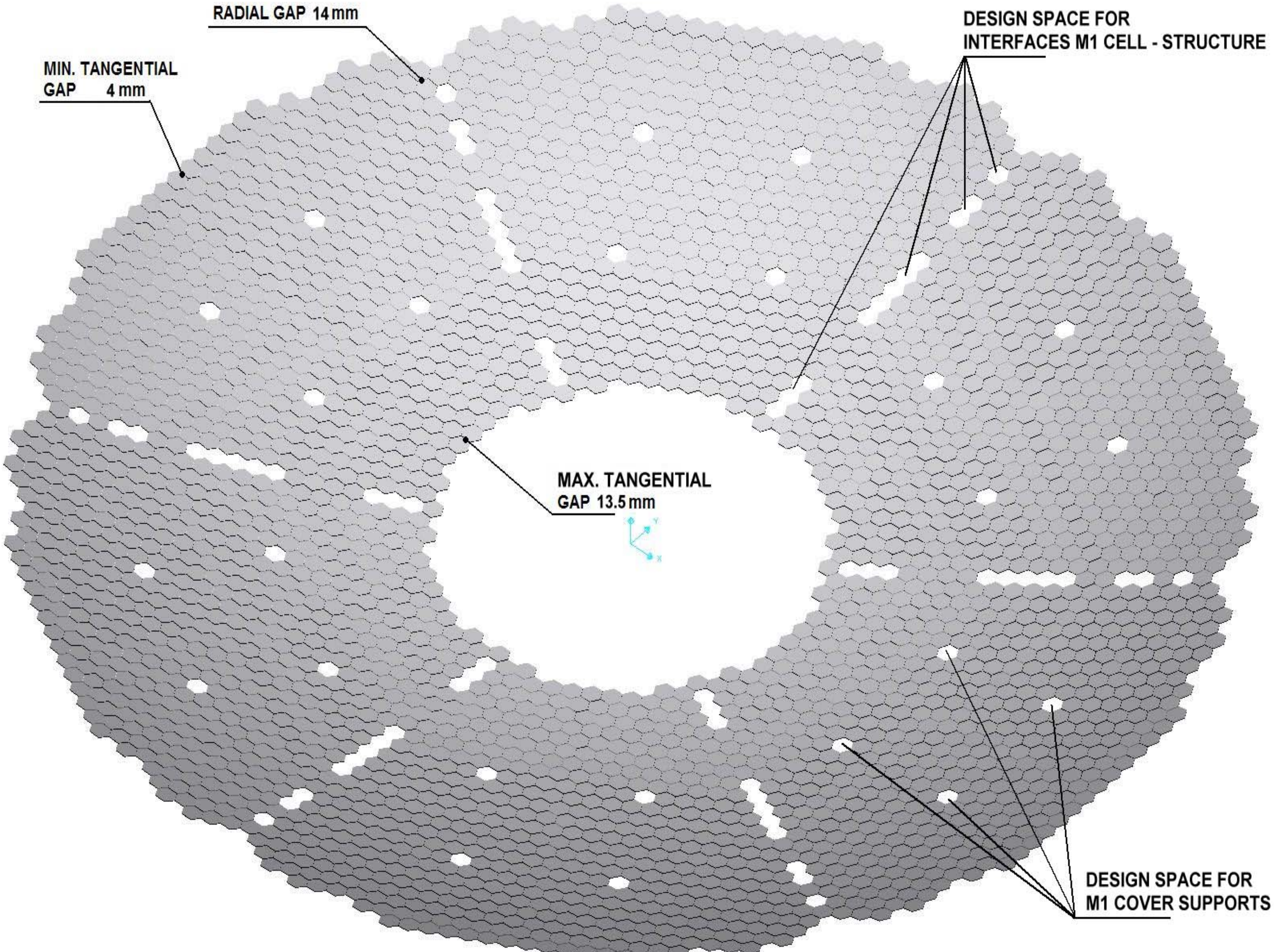
10^{-7} to 10^{-8}

Segments characteristics

Characteristic		Value
Substrate		Zerodur, ULE or Astro-Sital
Shape / type		Hexagonal / solid
Dimensions	Flat-to-flat Thickness	1.6-m 70-mm
Radius of curvature	Primary mirror Secondary mirror	250-m Flat
Support	Axial Lateral	18 points whiffle-tree 1 central support
Quantity	Primary mirror Secondary mirror	3048 216

Segments distribution





RADIAL GAP 14 mm
MIN. TANGENTIAL GAP 4 mm
DESIGN SPACE FOR INTERFACES M1 CELL - STRUCTURE
MAX. TANGENTIAL GAP 13.5 mm
DESIGN SPACE FOR M1 COVER SUPPORTS

Industrial studies

- Segments blanks
  - Corning — ULE
  - Zeiss (LZOS) — Astrosital
  - SCHOTT — Zerodur
  - Boostec — SiC
  - ECM — CESIC
- Polishing
  - SAGEM
  - SESO
- … Eager to start !


SCHOTT
glass made of ideas

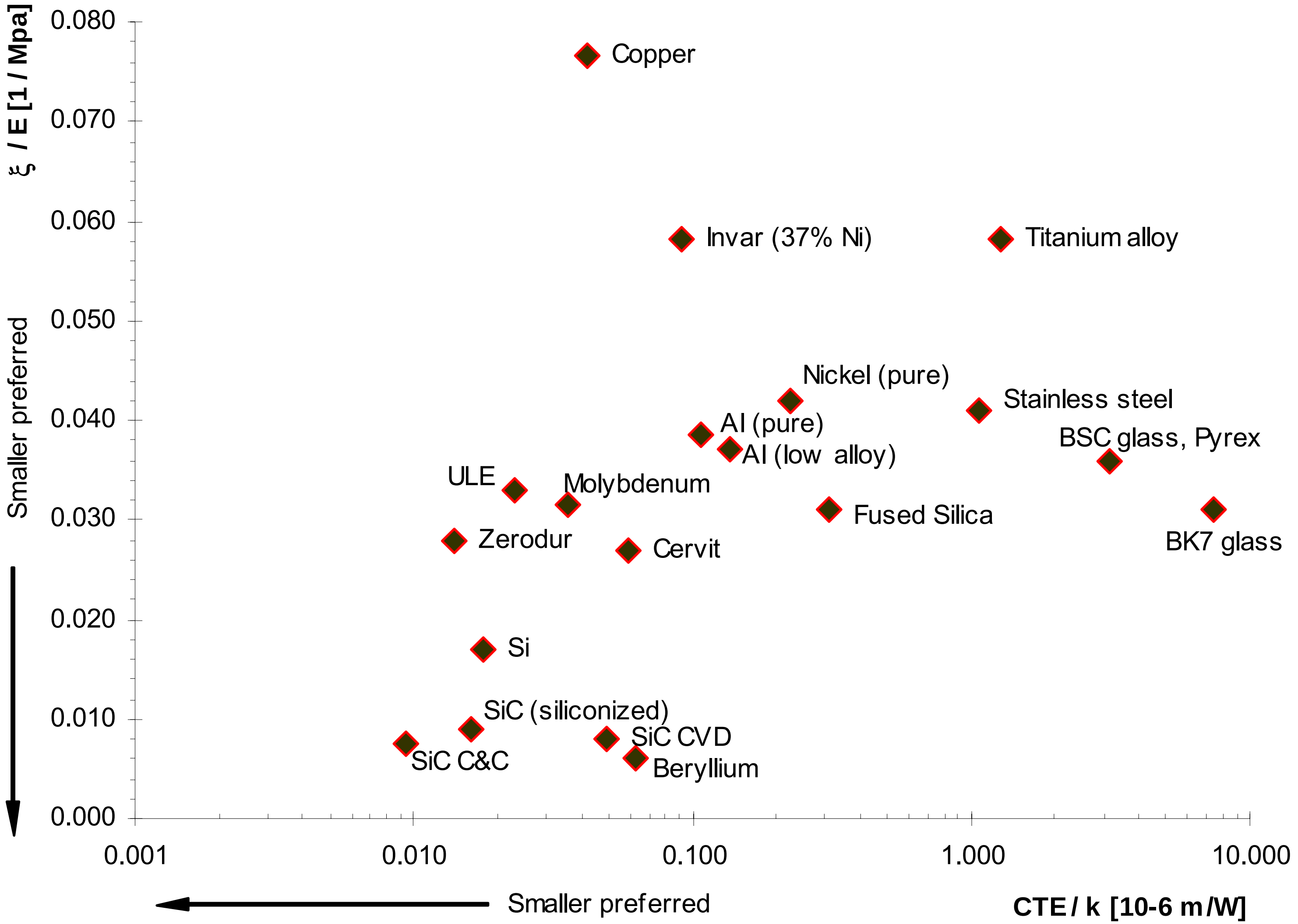

SCHOTT
glass made of ideas


CoorsTek and Boostec –
BOOSTEC


ECM
Helios

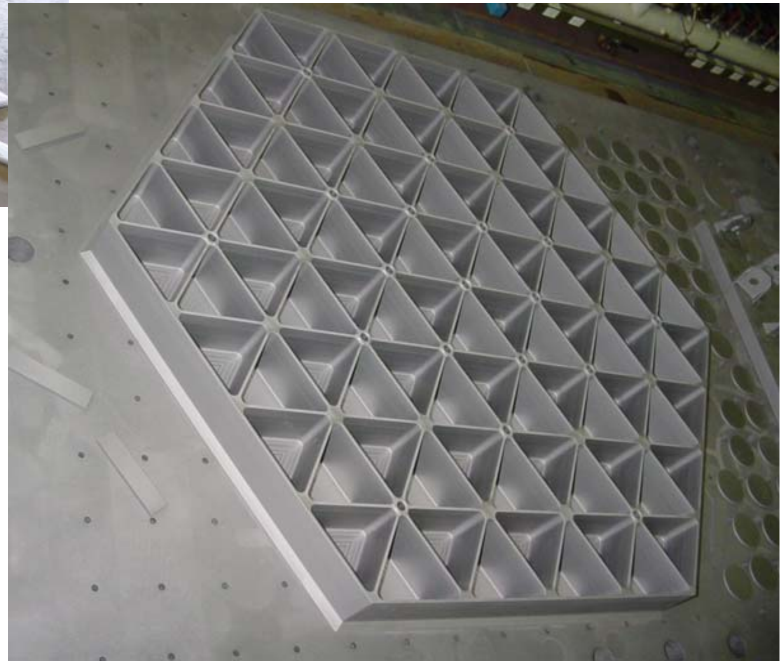

Snecma Propulsion Solide
groupe snecma

Silicon Carbide



Silicon Carbide

(Courtesy Boostec)



Total mass ~1/4th of glass
Fast thermal equilibrium
Less expensive substrate

BUT
Requires polishable overcoating
Grinding / polishing potentially very expensive

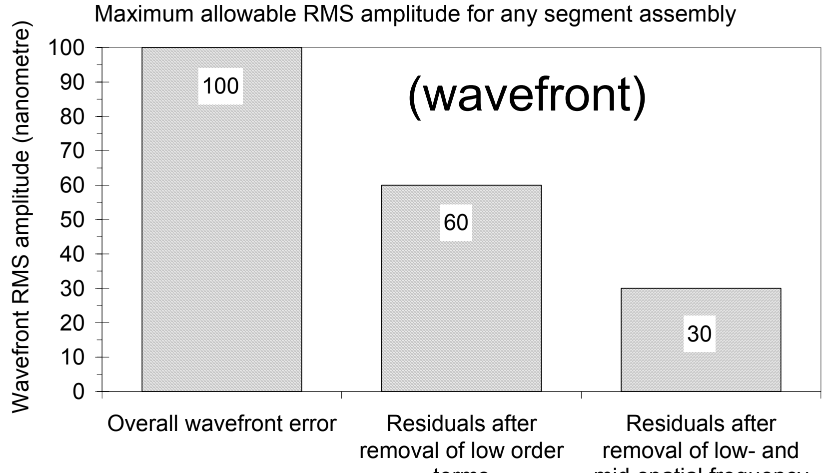
Optical Specifications

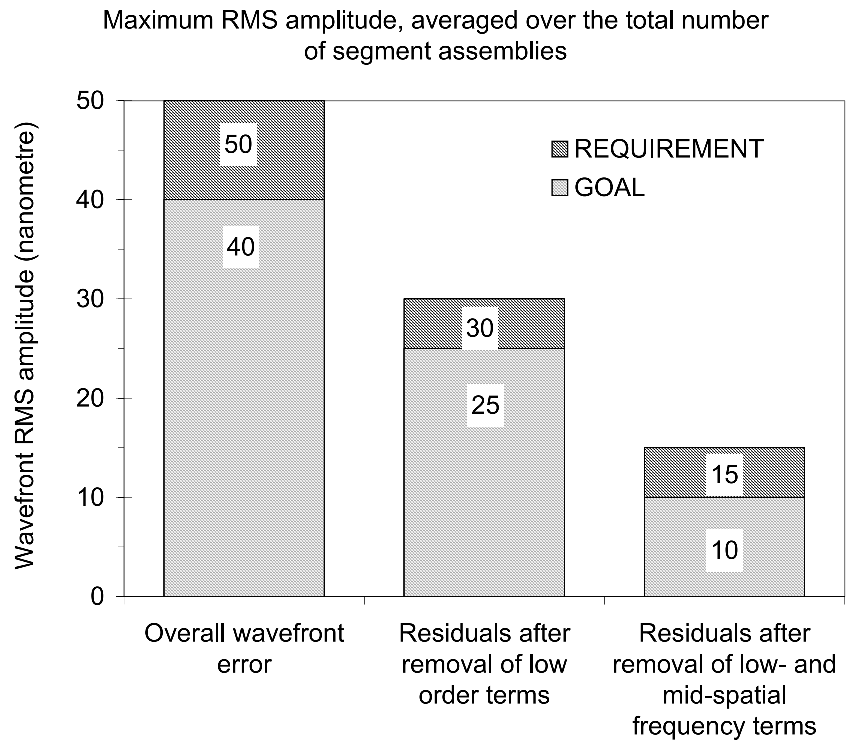
Takes into account AO correction

M1 segments: 3rd order aberrations

M2 segments: 3rd and 5th order aberrations

Edge misfigure critical (spherical shape helps)



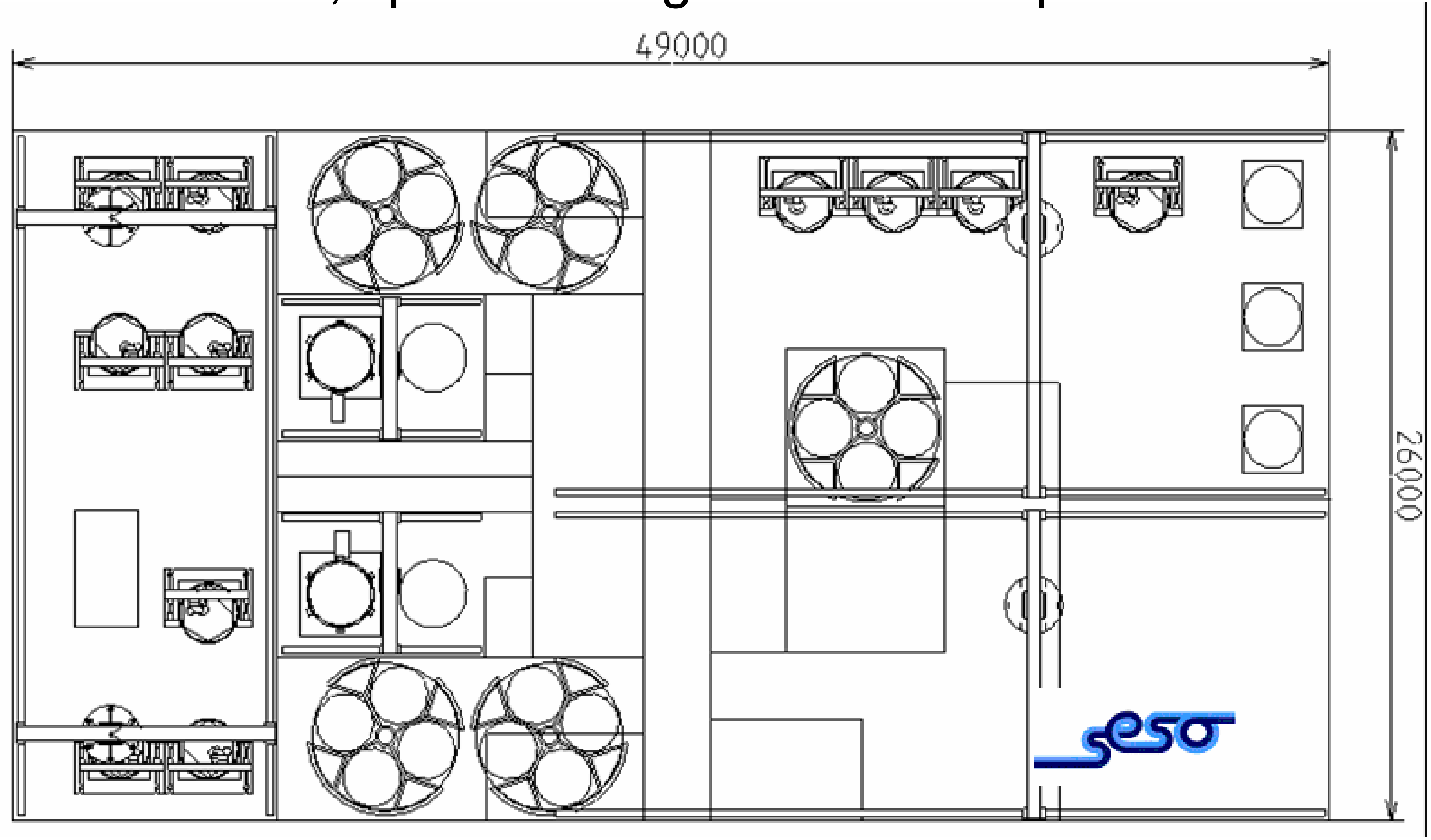


Spherical vs. Aspherical primary (fabrication)

	SPHERICAL	**ASPHERICAL**
Testing		
	➢ Simple and reliable optical test (**unique** matrix)	➢ Optical test TBD (GTC procedure not applicable beyond 36 seg.)
Polishing		
	➢ Planetary polishers unproven above ~1.3-m (machine ?) ➢ OR Classical machine, large stiff tools • Low high-frequency residuals • Better for edge misfigure • Fast & proven process (tool area !) • Reliable • SiC or lightweight glass possible • Final finish with Ion-Beam or computer-controlled small tools	➢ Stressed polishing (Keck, warping harness) • Requires smaller segments • Back surface polished (time, cost) • Tight substrate tolerances (cost !) • Only classical substrates • No lightweight blanks ➢ OR CC polishing (GTC) • Superb quality achieved • Long development time • Difficulty to control edge • SiC probably not possible • Inherently longer processing (tool area !)
	➢ **SERIAL PRODUCTION**	➢ **SERIAL ONLY WITHIN A FAMILY**

Polishing: factory implementation

All identical, spherical segments ⇨ fast production



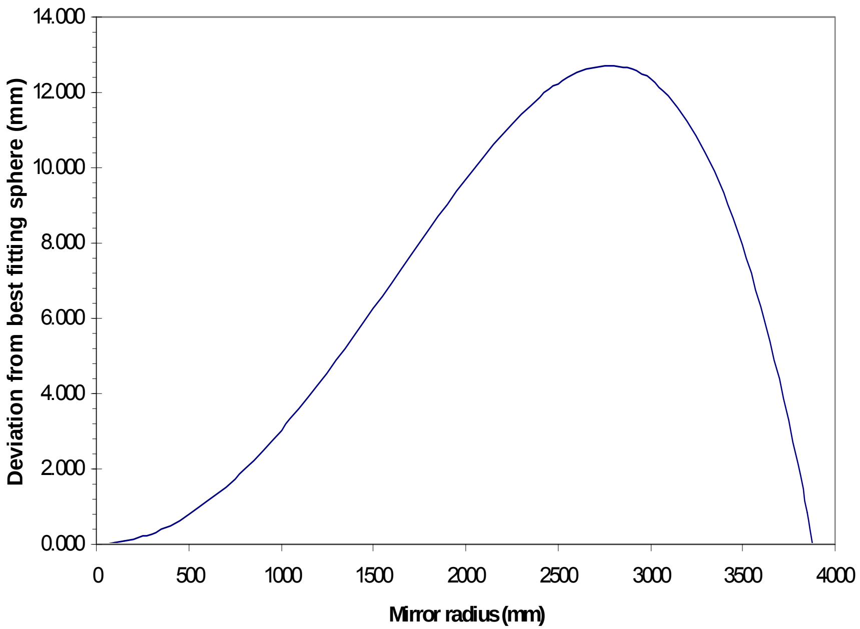
Size (area) comparable to VLT 8-m production facility

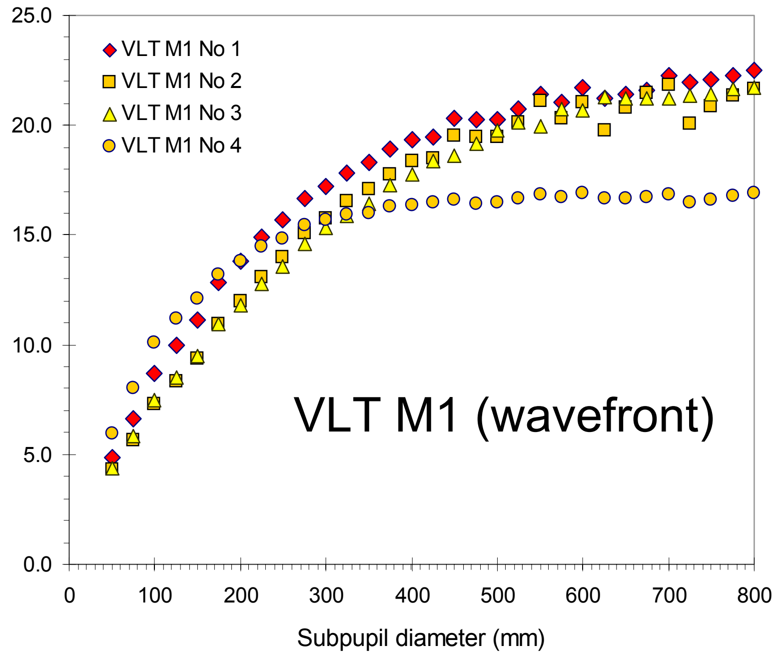
Corrector optics

- M3, M4 blanks: ULE or Zerodur (one 8-m blank available at SCHOTT; would require thinning to 135 mm)
- M3 figure comparable to VLT M1
- M4 figure a tough challenge
- M5 adaptive, aspherical concave (size ~3.5-m)
  - Provision for a temporary, non-adaptive unit
  - Early start of science (SCAO with M6)
- M6 adaptive, flat (size ~2.5-m)
  - Provision for a temporary, non-adaptive unit
  - ~6 months engineering time before SCAO first light

M4

- Extreme aspherization
- BUT
  - Slopes comparable to SALT equivalent mirror
  - Active AND adaptive optics
  - Active forces could be ~5 times larger than with VLT M1



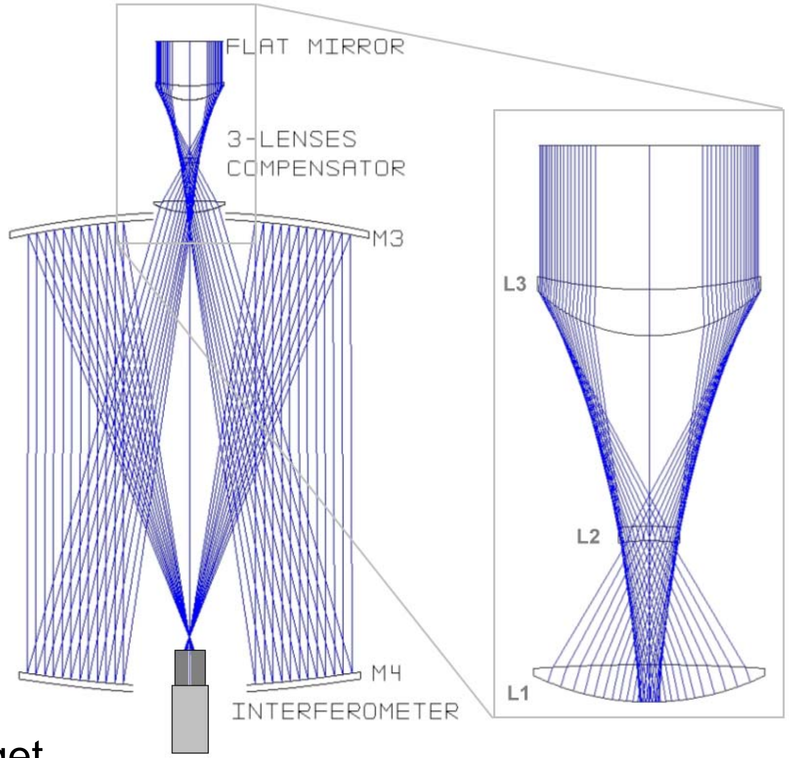


M4 optical test setup

- CGH (Computer-Generated Hologram) or combination lenses-hologram
- All-spherical (zerodur) lenses (max. dia. 1.6-m) theoretically possible
- Centring tolerances
  - Extremely demanding

  BUT – relaxation possible

  - Masks in the caustic
  - Rotation of M4, rotation of null-lens
  - Active mirror ! Generous force budget
- Provision for ~2.5 times longer polishing than VLT M1



Strengths & weaknesses

Strengths

- Excellent image quality in the field of view;
- Low sensitivity to M2 (flat) lateral decenters;
- **Availability of 2 surfaces for AO**;
- Availability of 2 surfaces, M3 and M4, for active optics;
- Availability of all wavefront control functions, including field stabilization, with no more than 6 surfaces.
- **FLAT M6 (1^{st} gen. AO)**
- Compatibility with serially produced segments (spherical primary, flat secondary);
- Baffling opportunities.

Weaknesses

- Tilted AO mirror, limiting performance with GLAO;
- Fairly short focal ratio;
- Fairly strong field curvature, concave in the direction of propagation of light.
- Large, segmented M2;
- Design space for M6 AO unit;
- No gravity-stable instrument location;
- Extreme aspherization of M4.

Provision for 2 design iterations (feedback from instrumentation, AO studies)

Summary

- An optical solution for an active & adaptive telescope with "only" 6 surfaces
- Excellent optical quality
- Compatible with serial production for the most expensive subsystem (M1)
- Tailored to minimize fabrication risks (segments, 1st generation AO mirror; M4 an exception)
- Tailored to structural constraints
  - Telescope tube, stiffness, impact of decenters
  - Requires demanding stiffness where it is easier to achieve
- Demanding on instrumentation
  - But this might be inevitable – short focal ratio required
  - Gravity-stable focal station may have to be provided by active instrument racks (budgeted)