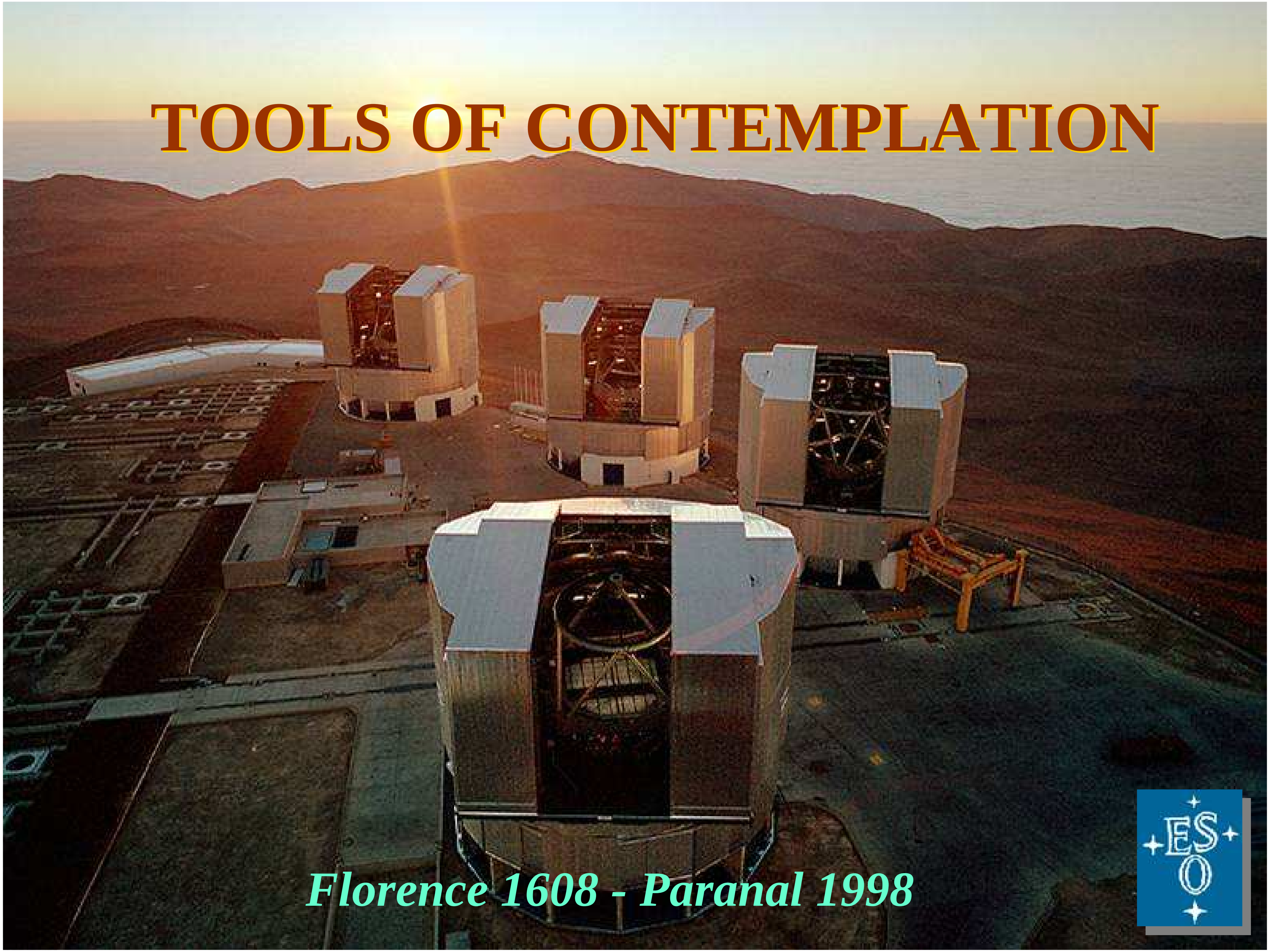
From Galileo to OWL: Telescopes of the past, present, and future

P. Dierickx

The NEON Archive Observing School

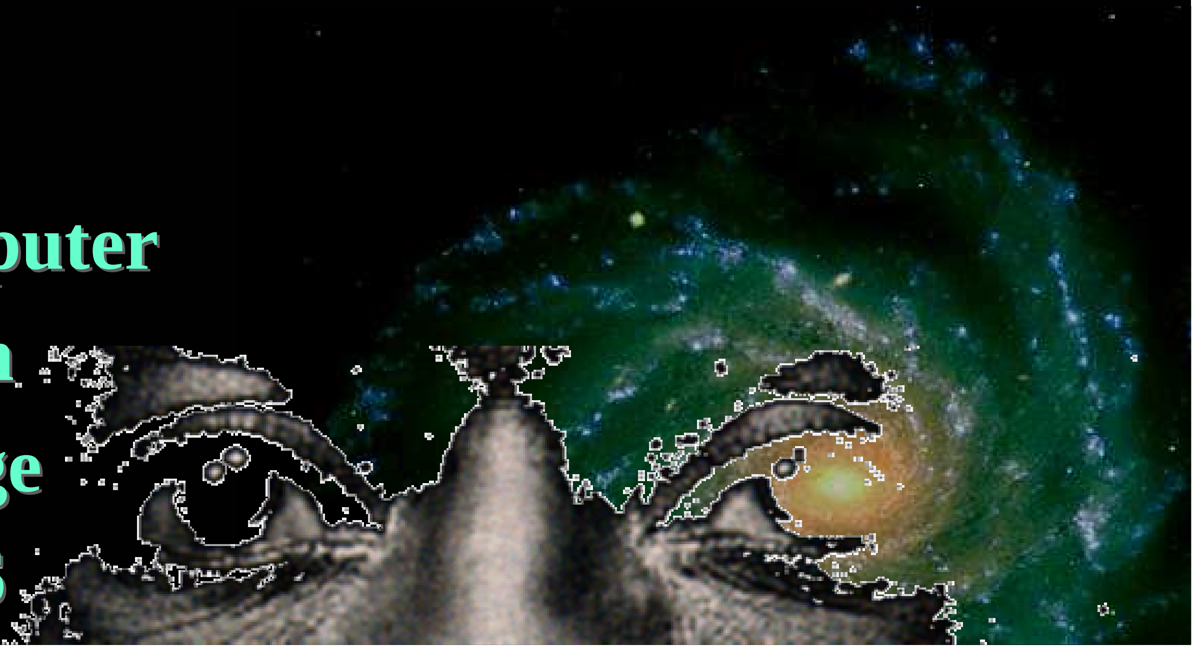
ESO, Garching, July 14-24, 2004

TOOLS OF CONTEMPLATION



Florence 1608 - Paranal 1998

TOOLS OF CONTEMPLATION



The human eye.

7 mm and a supercomputer

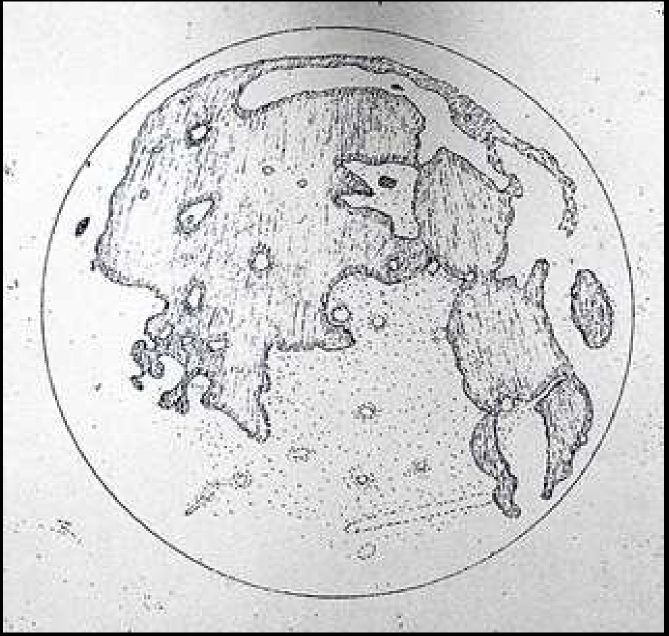
1 arc minute resolution

Extreme dynamic range

Limiting magnitude ~6

Galileo’s telescope

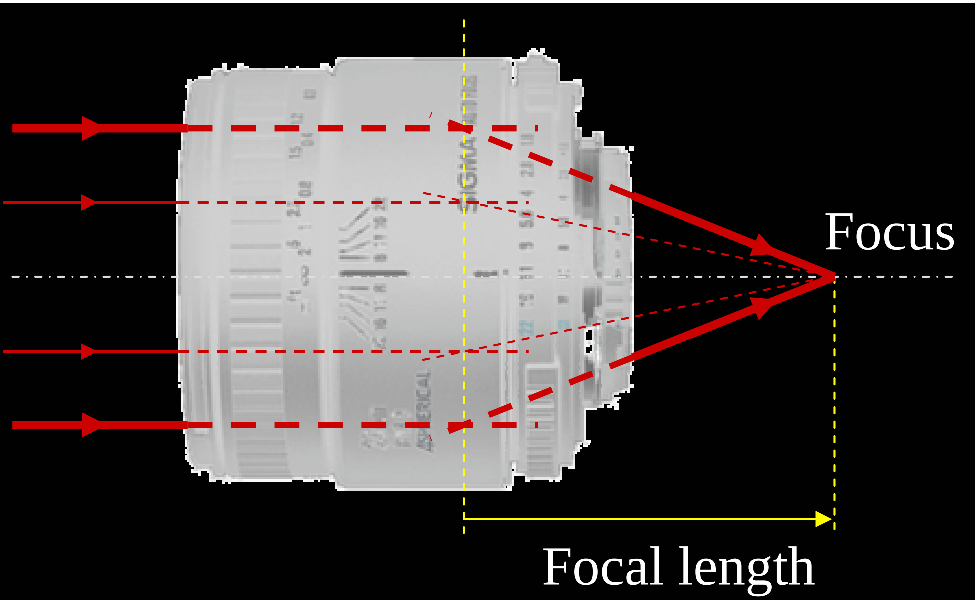
Diameter 30 mm

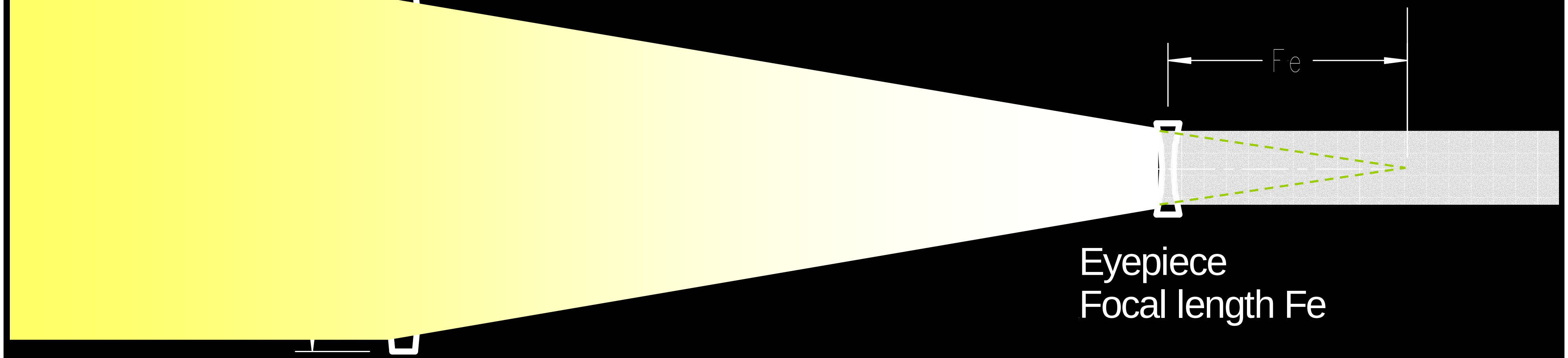


Thomas Harriot
1609

Venise, 1609.

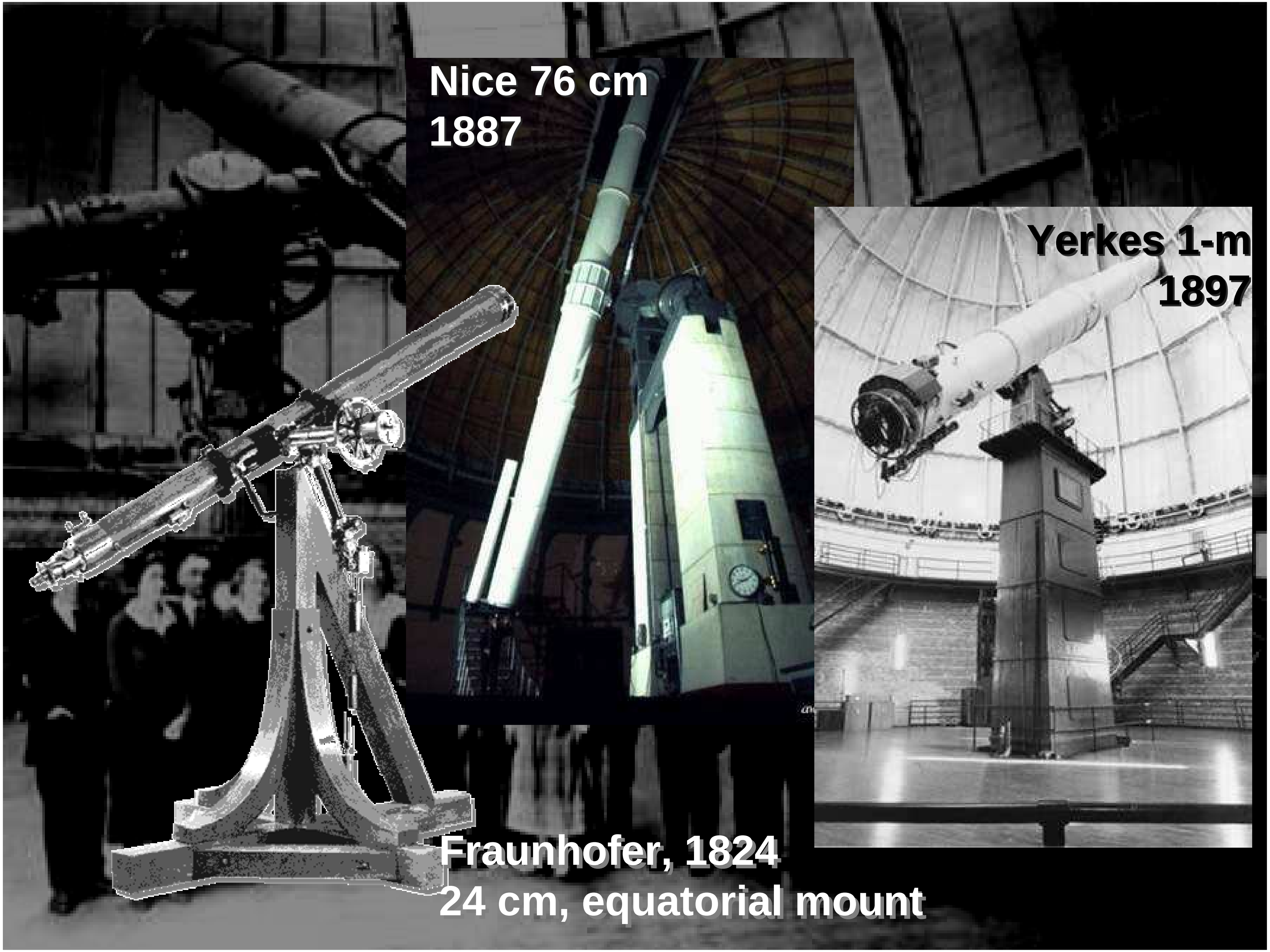
Galileo’s telescope





Angular magnification G=Fo / Fe

Focal ratio N=Fo / D



Nice 76 cm
1887

Yerkes 1-m
1897

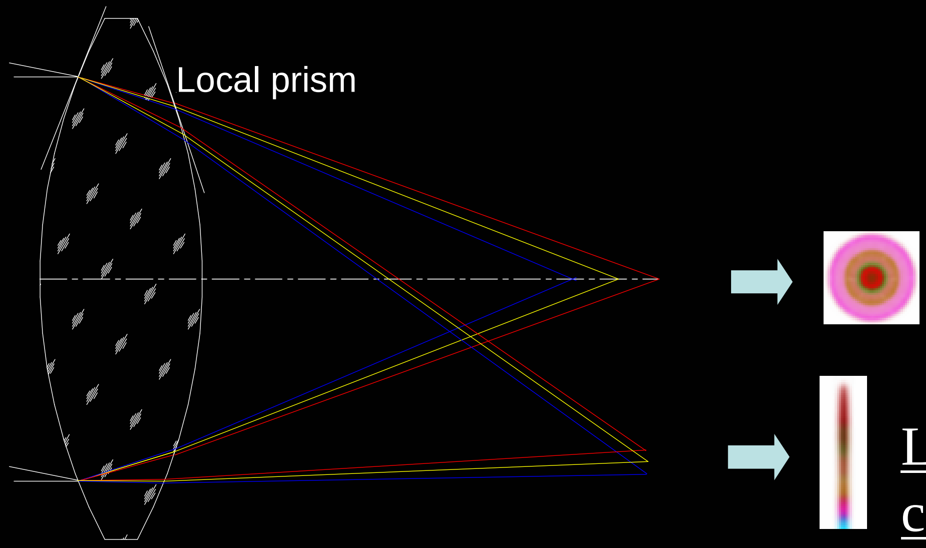
Fraunhofer, 1824
24 cm, equatorial mount

Refracting

- Chromatic aberrations
- Spherical & field aberrations

Reflecting

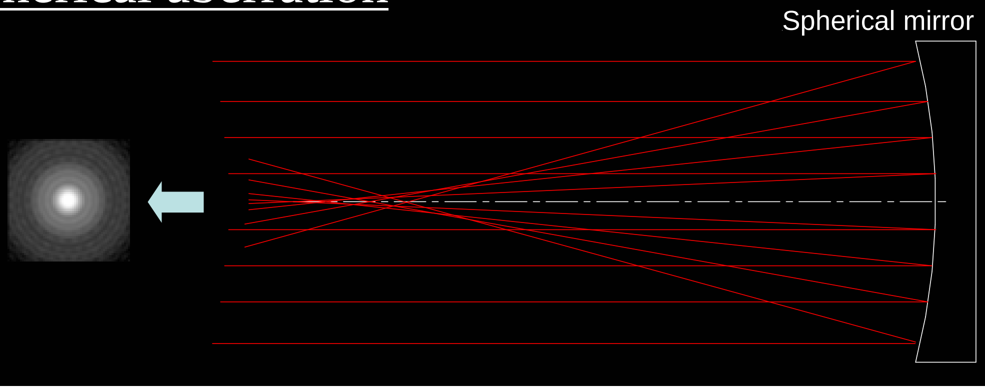
- Spherical & field aberrations
- 4 times tighter manufacturing tolerances



Axial chromatism

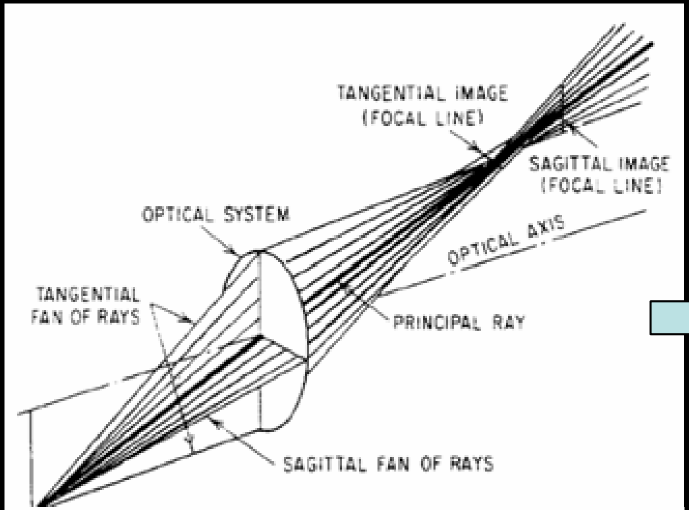
Lateral chromatism

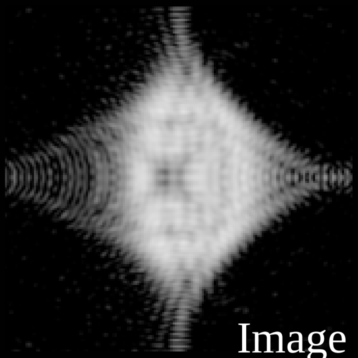
Spherical aberration



Field aberrations

Astigmatism





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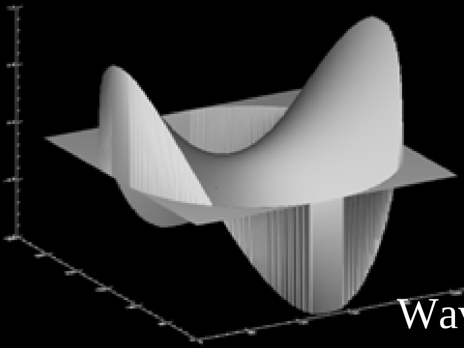
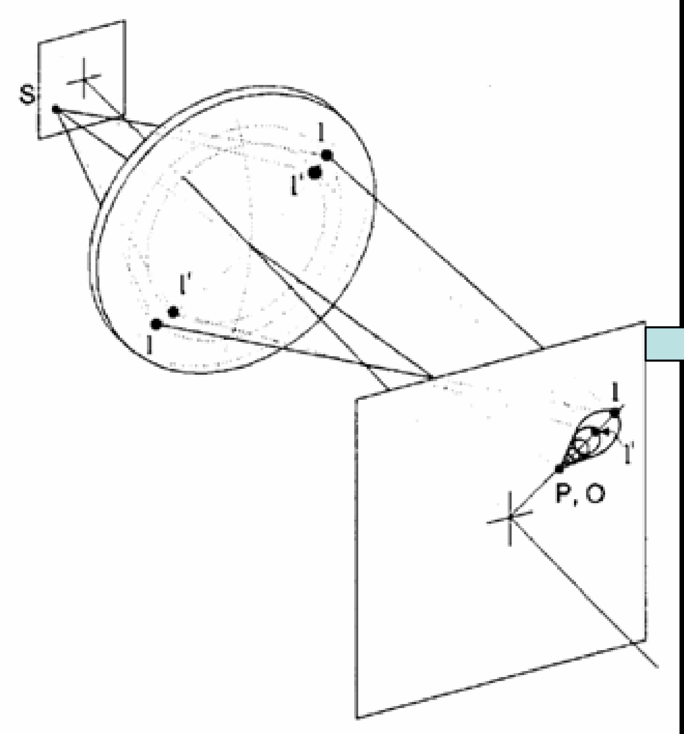
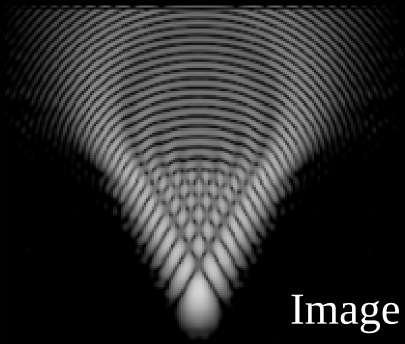


Wavefront

Coma





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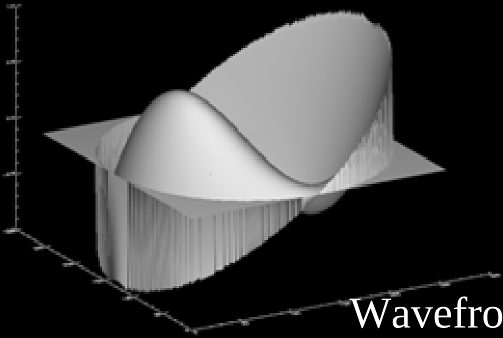
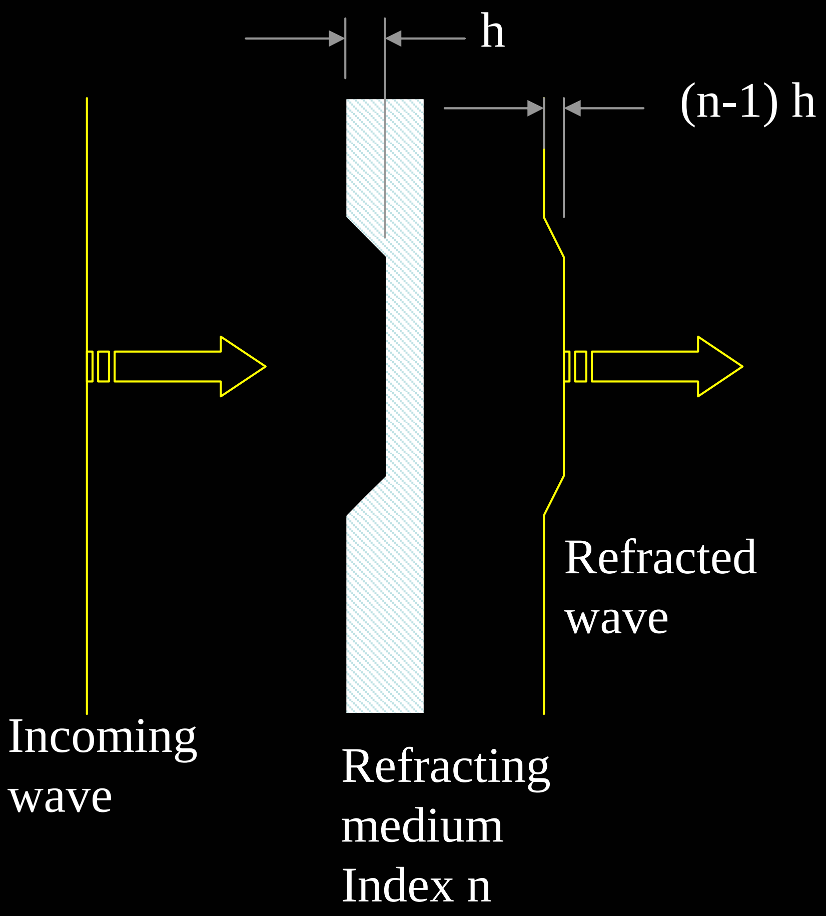
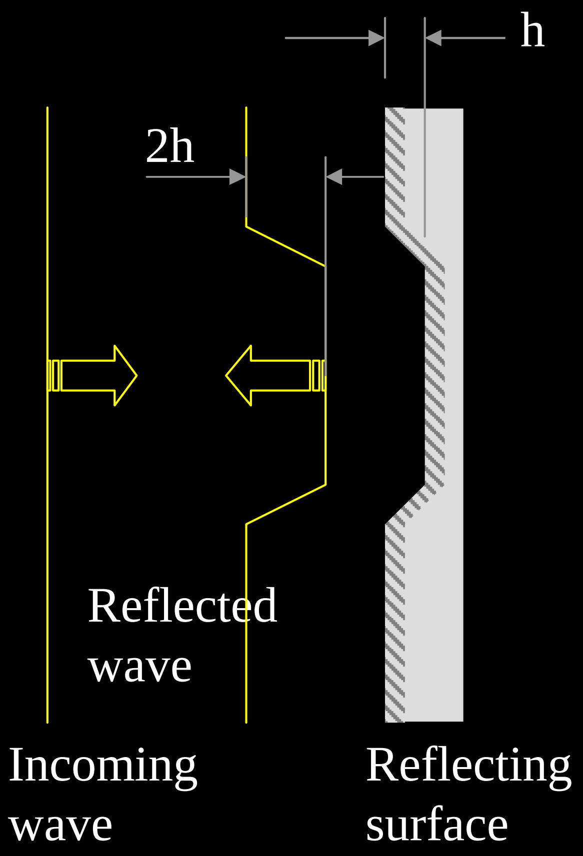


Wavefront

- Refractors



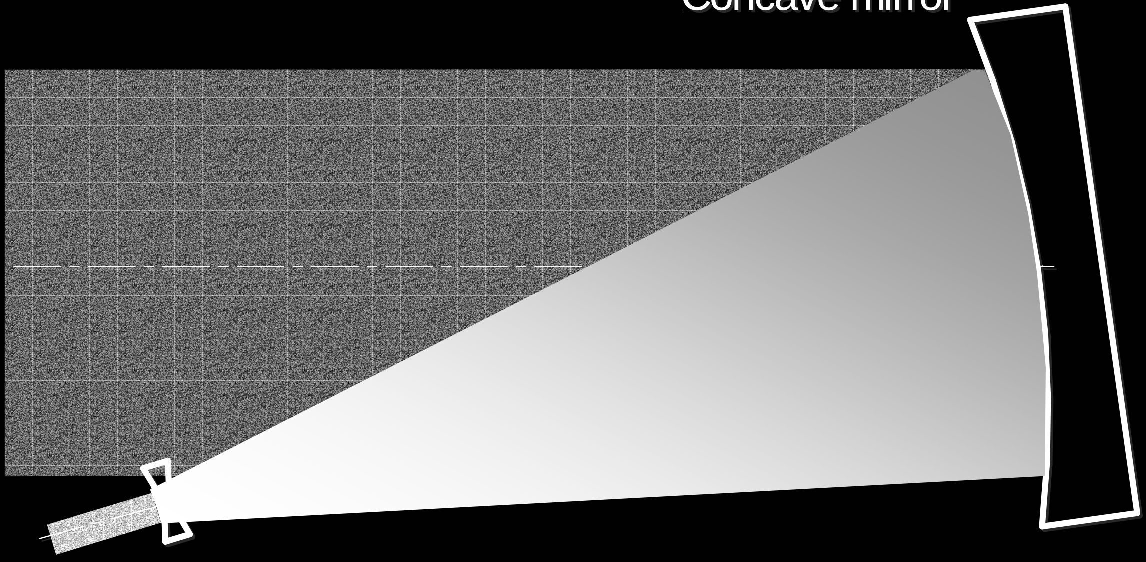
- Reflectors

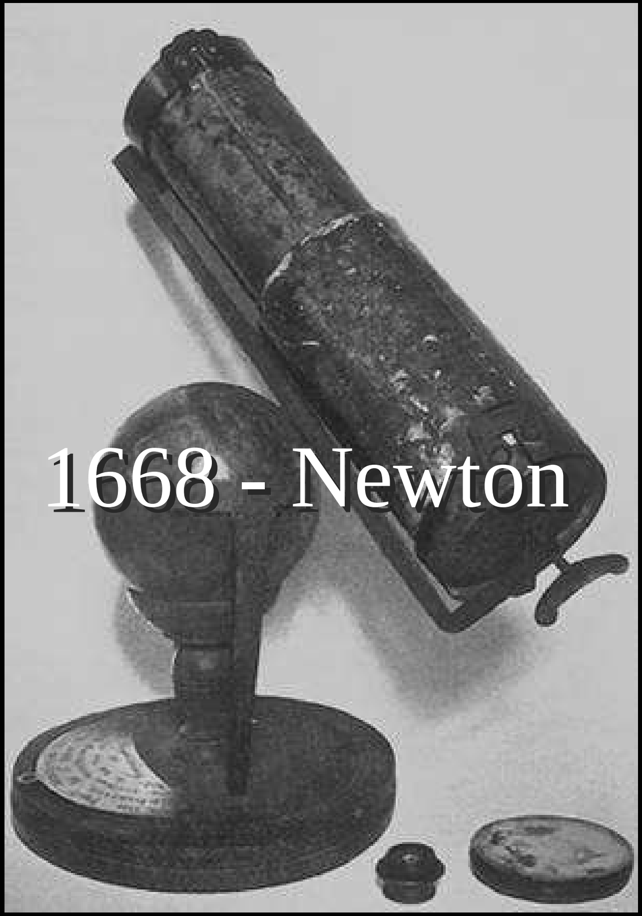


Surface quality requirement for a reflecting surface ~ 1/4th of surface quality requirement for a refracting one

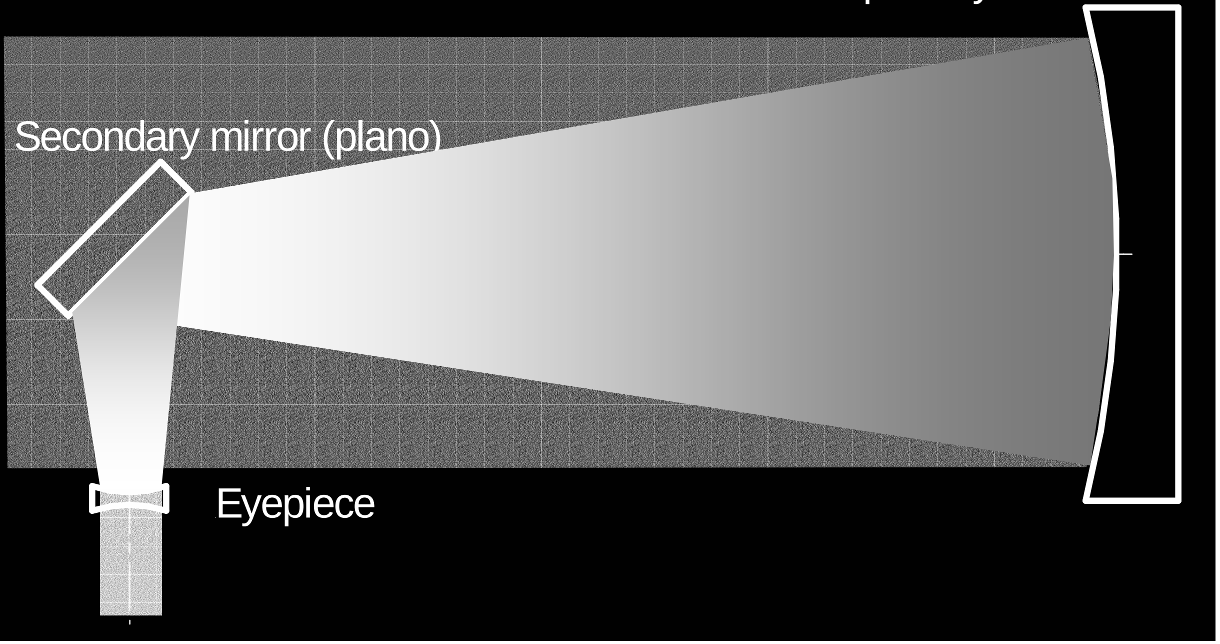
Reflecting telescopes – the early years 1608-1672

1616 - Zucchi



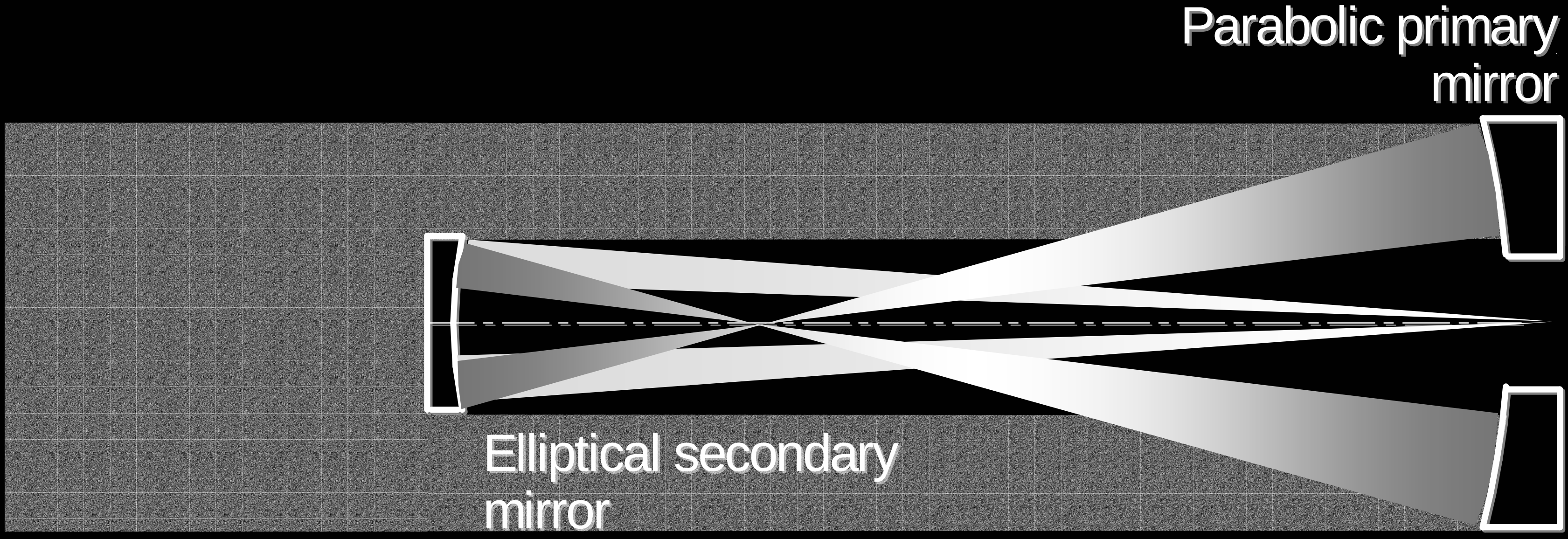


1668 - Newton

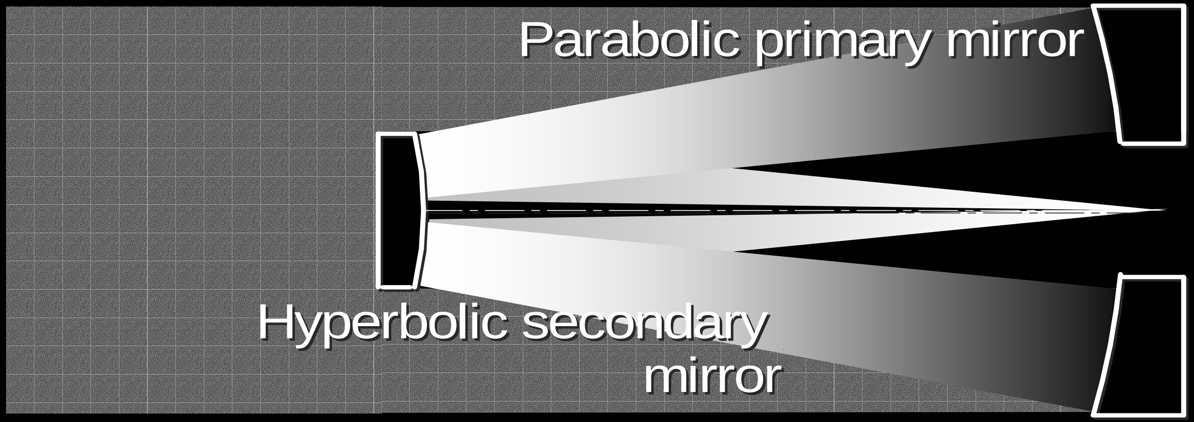


The early years 1608-1672

Gregorian



The early years 1608-1672
Cassegrain



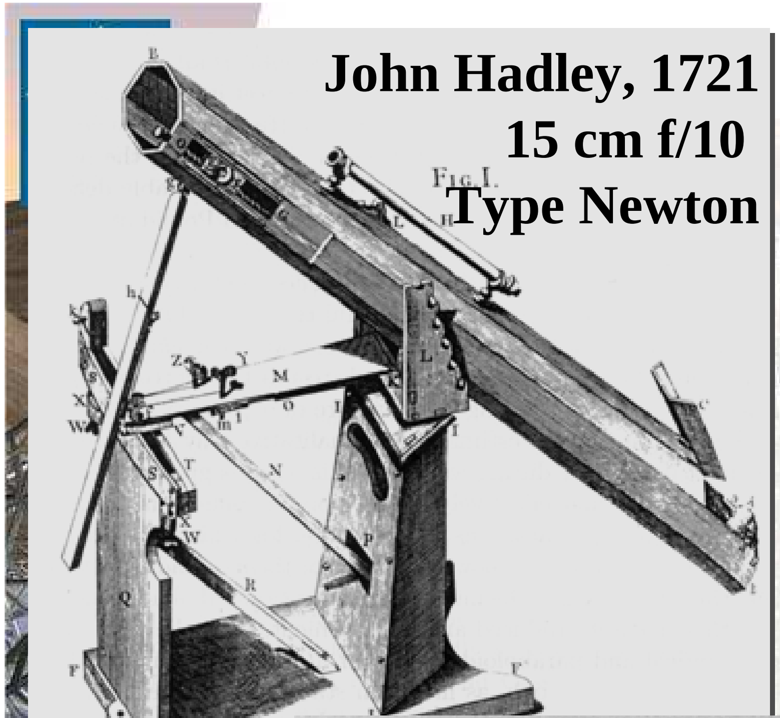
The theory of the reflecting telescope

(mirrors shape)

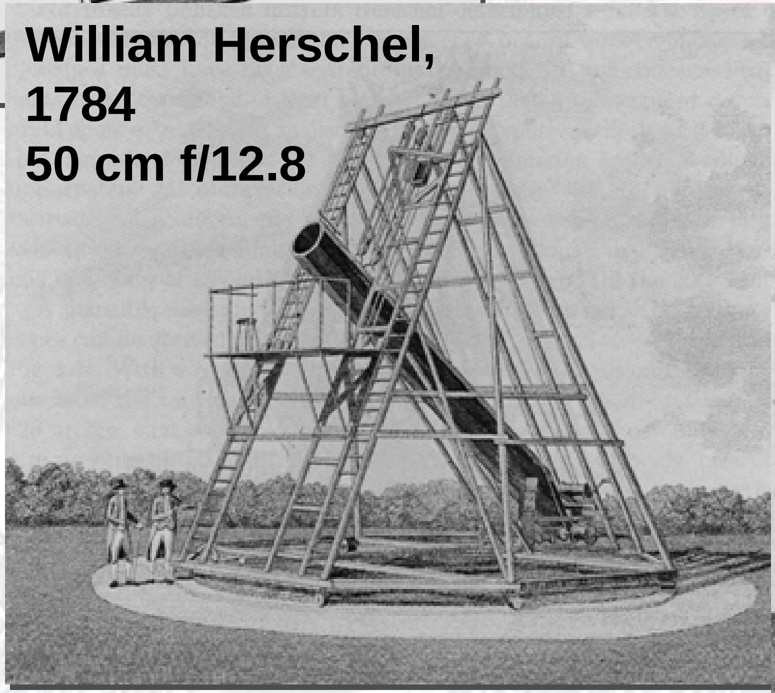
will remain unchanged until 1905.

Réflecting telescopes after 1672

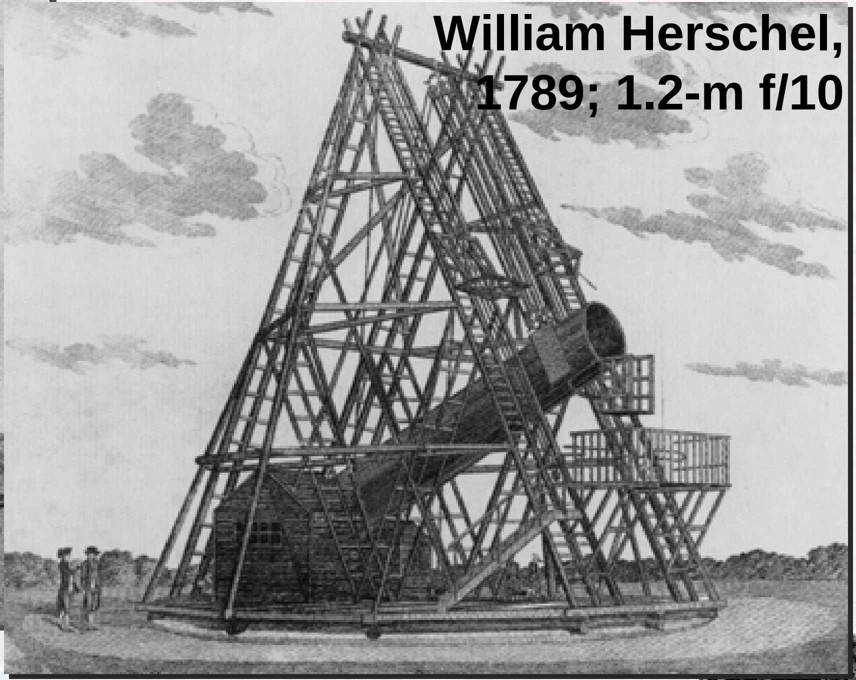
- Speculum mirrors
- Low efficiency
- Needs periodic re-polishing
- Large collecting area



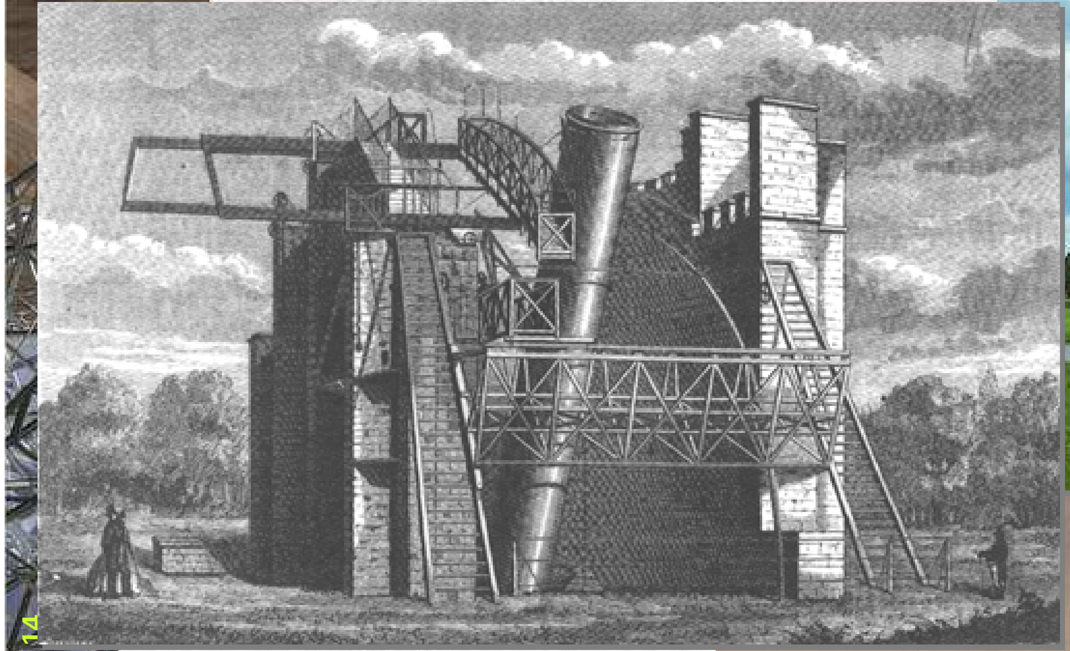
John Hadley, 1721
15 cm f/10
Type Newton



William Herschel, 1784
50 cm f/12.8

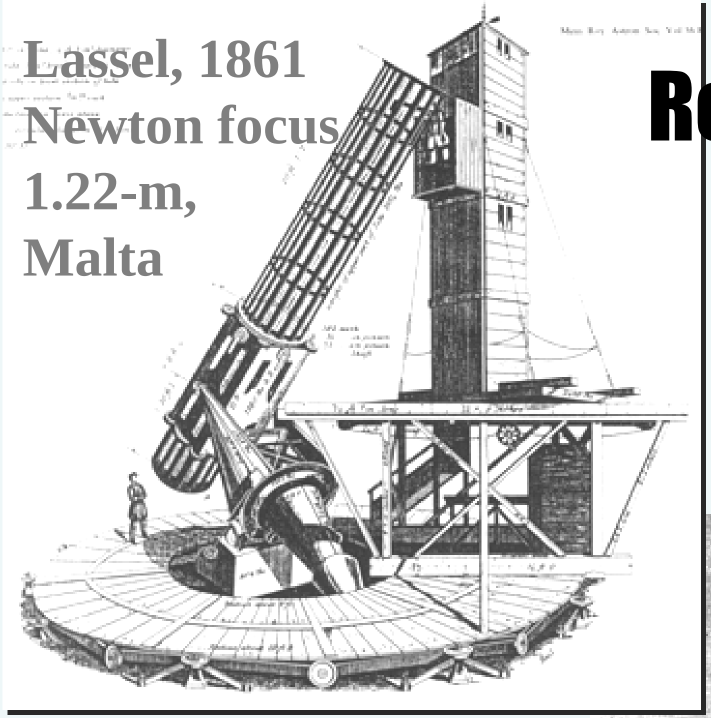


William Herschel, 1789; 1.2-m f/10

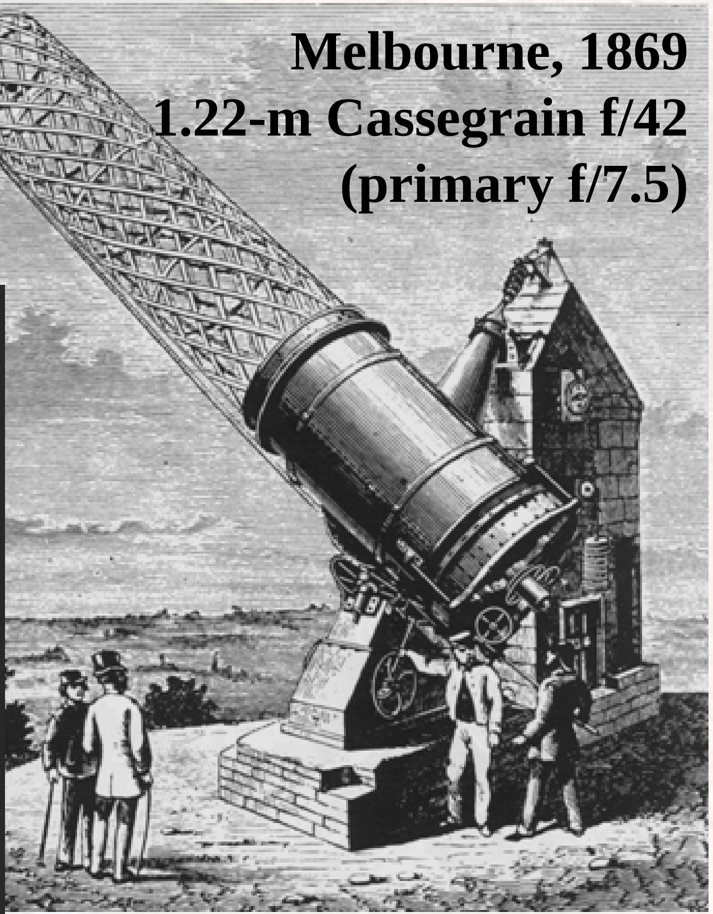


Lord Rosse 1.82-m, 1845
F/9 Newton focus
Astatic supports
Byrr Castle, Ireland

Reflecting telescopes after 1672



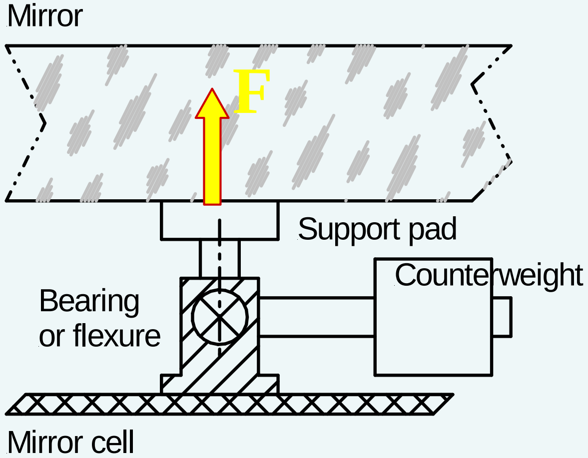
Lassel, 1861
Newton focus
1.22-m,
Malta



Melbourne, 1869
1.22-m Cassegrain f/42
(primary f/7.5)

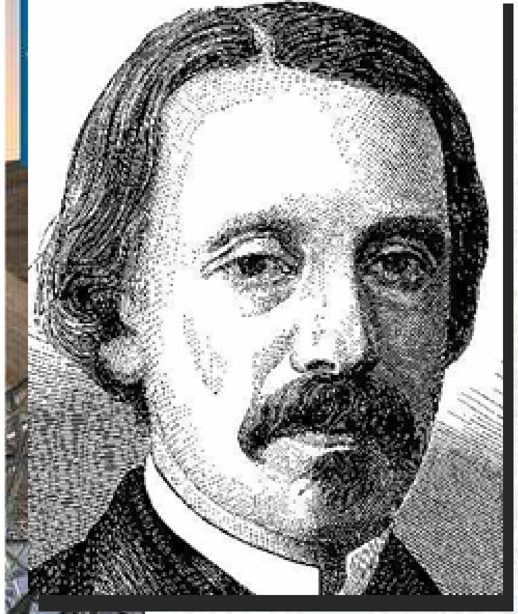
Nasmyth, 1845
50-cm

Counterweight support



$F \propto \cos z$

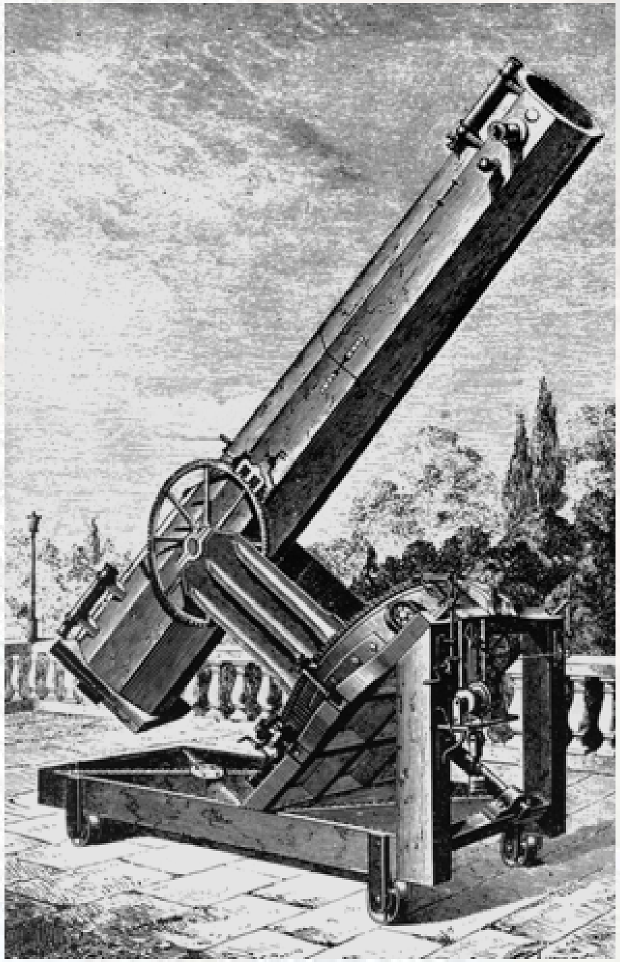
Glass mirrors



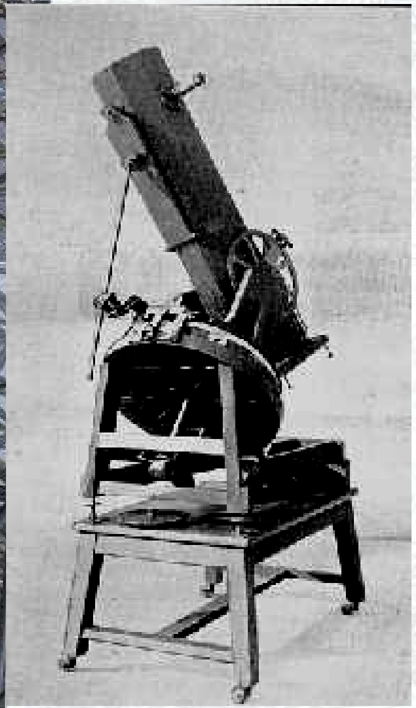
Foucault

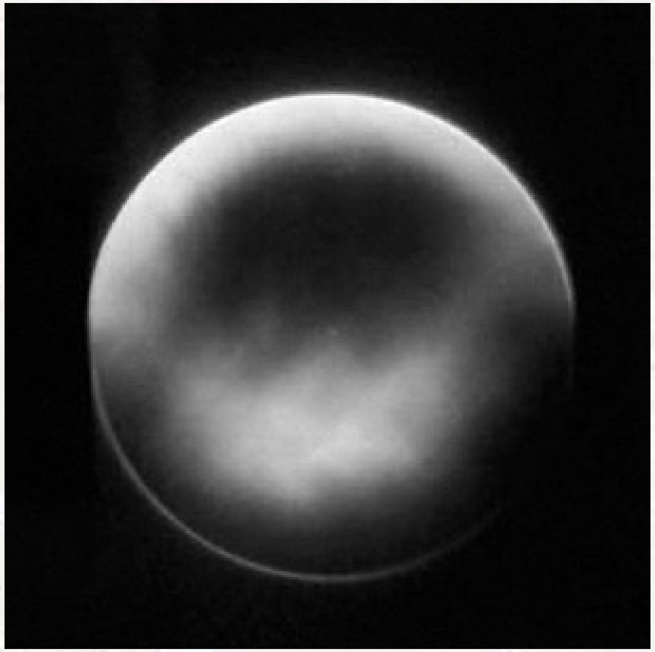
1857: silver on glass

1859: Foucault test

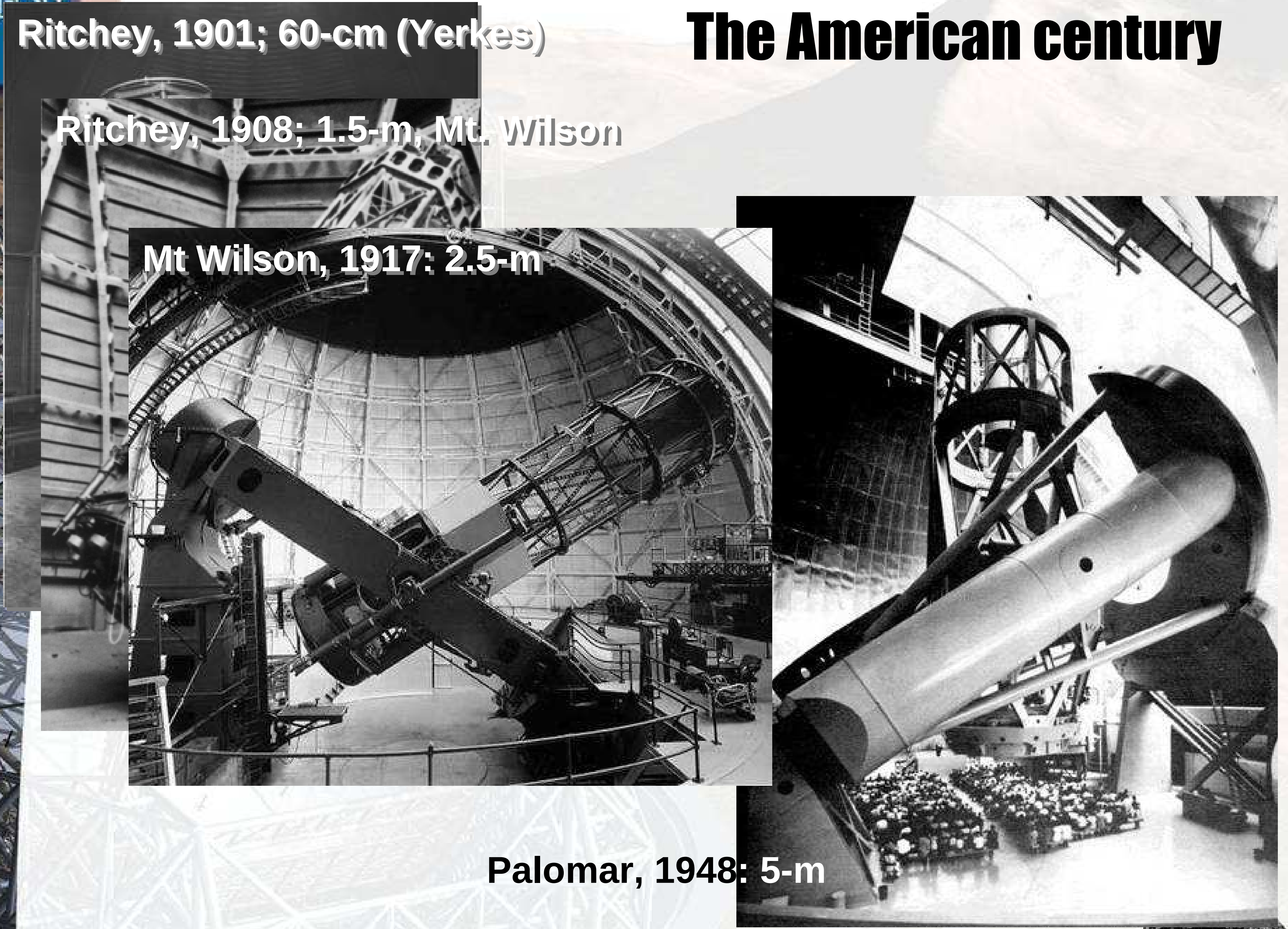


1862, 80 cm,
Silvered glass mirror





The American century



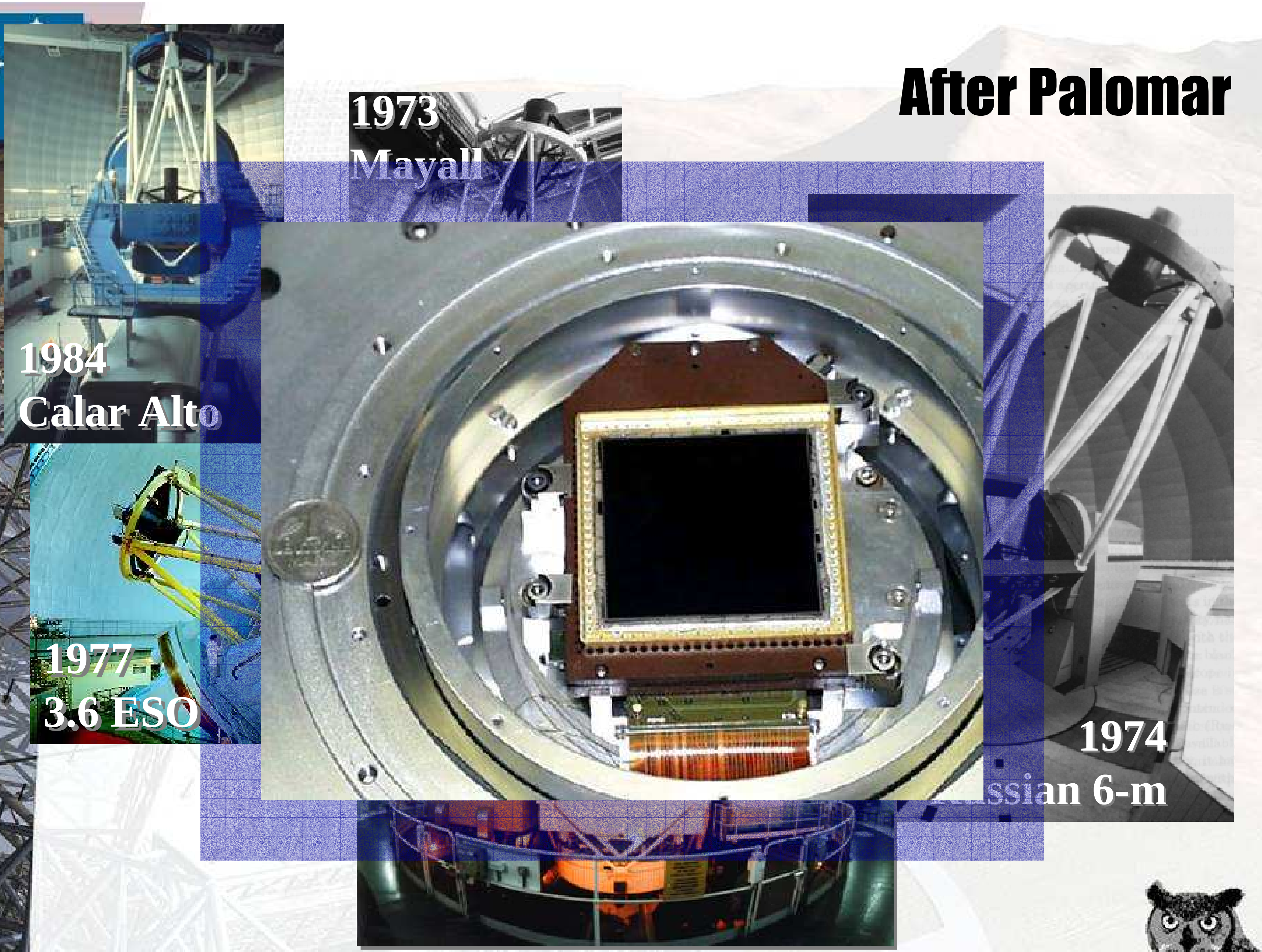
Ritchey, 1901; 60-cm (Yerkes)

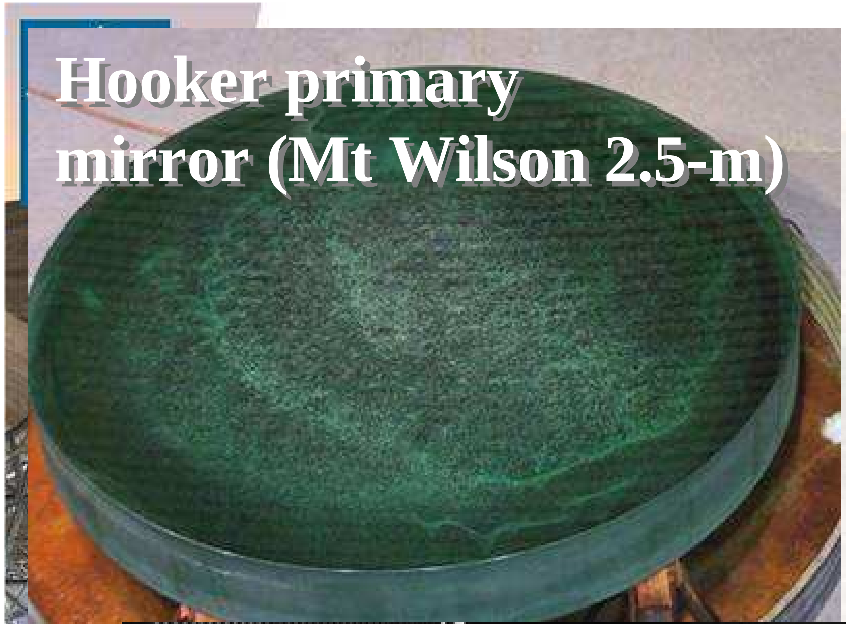
Ritchey, 1908; 1.5-m, Mt. Wilson

Mt Wilson, 1917: 2.5-m

Palomar, 1948: 5-m

After Palomar

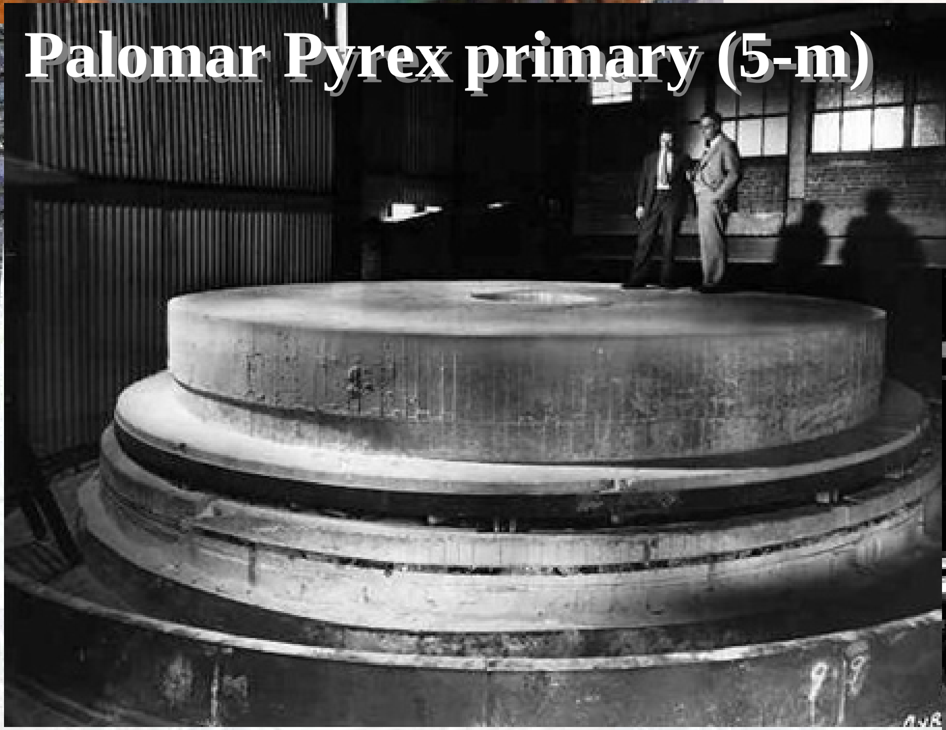




Hooker primary mirror (Mt Wilson 2.5-m)

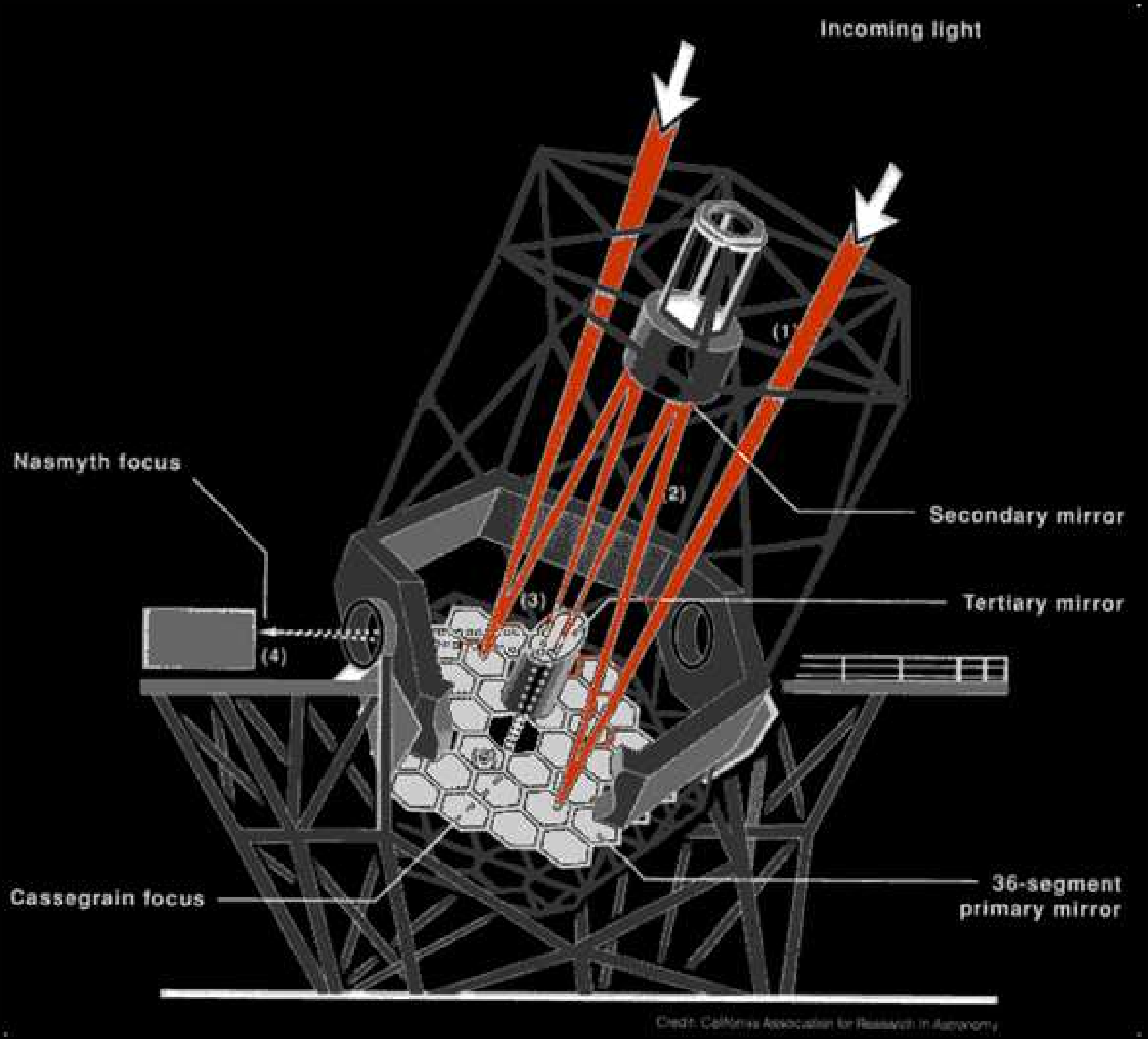
Slow progress

- Casting large homogeneous slabs,
- Polishing incl. metrology
- Support systems

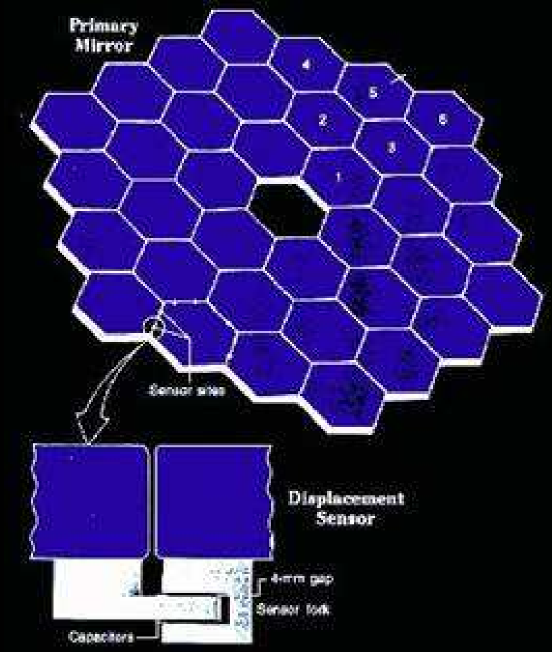


Palomar Pyrex primary (5-m)

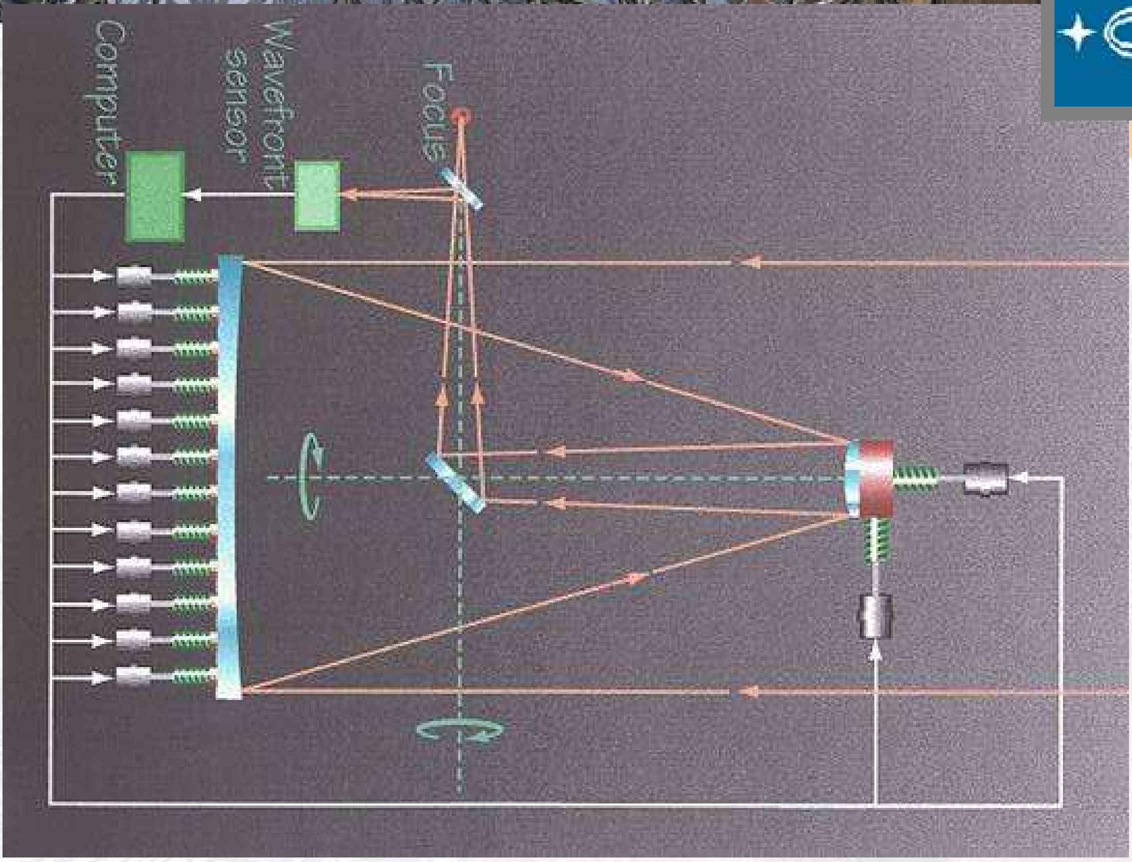
ESO's 3.6-m
Fused silica

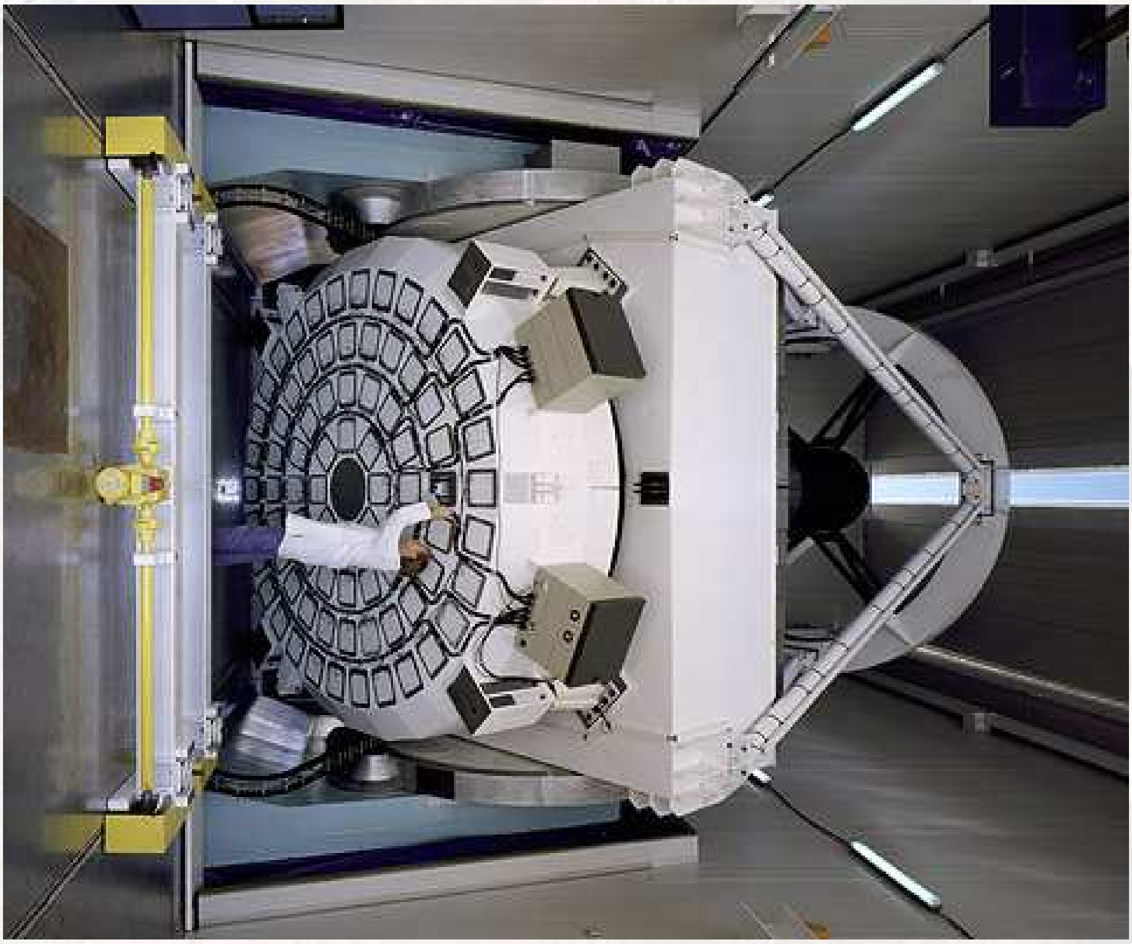


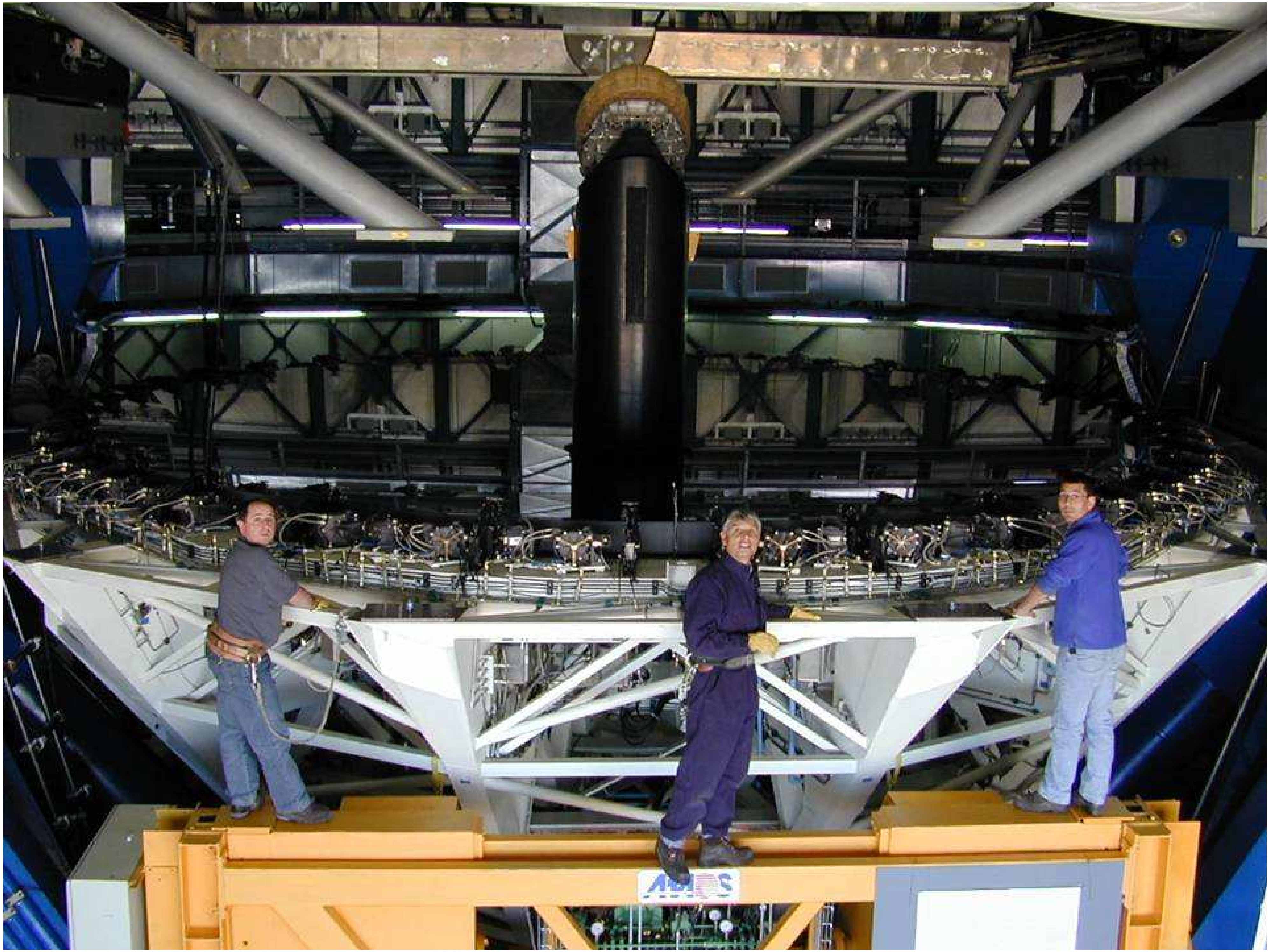
Credit: California Association for Research in Astronomy

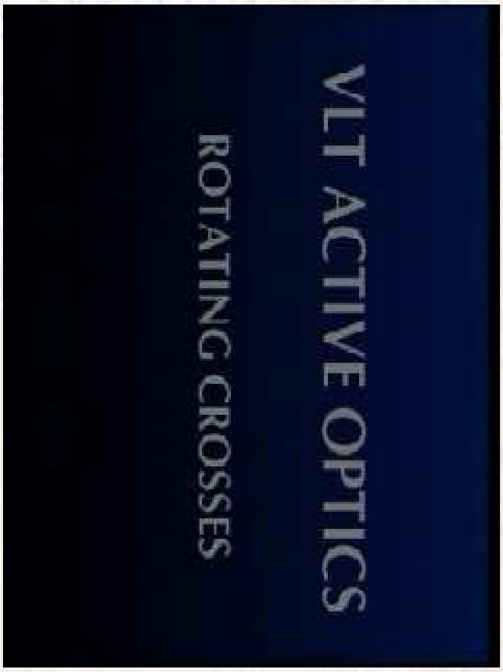


Segmentation – Keck 10-m telescopes


Focus
Wavefront sensor
Computer

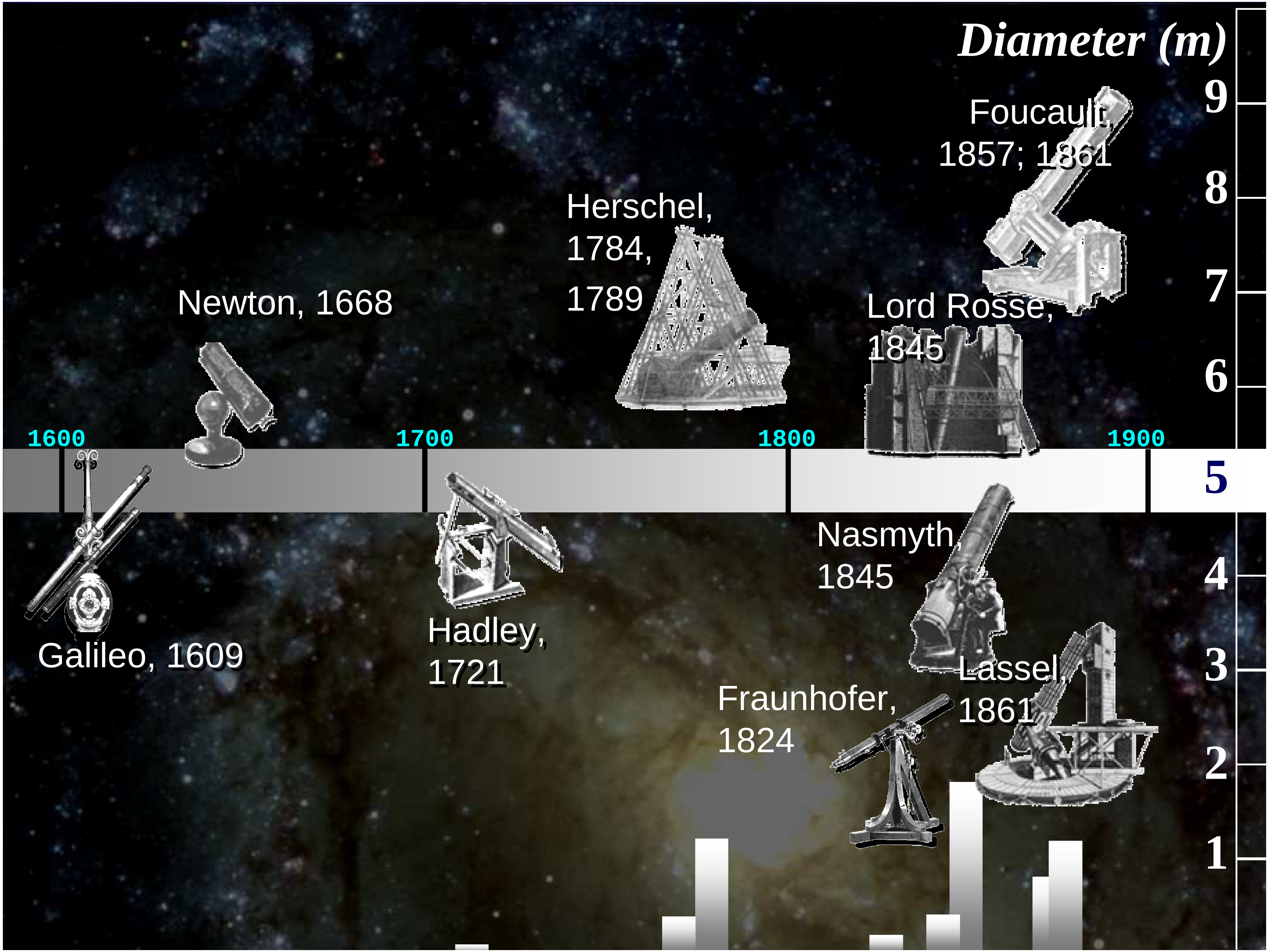


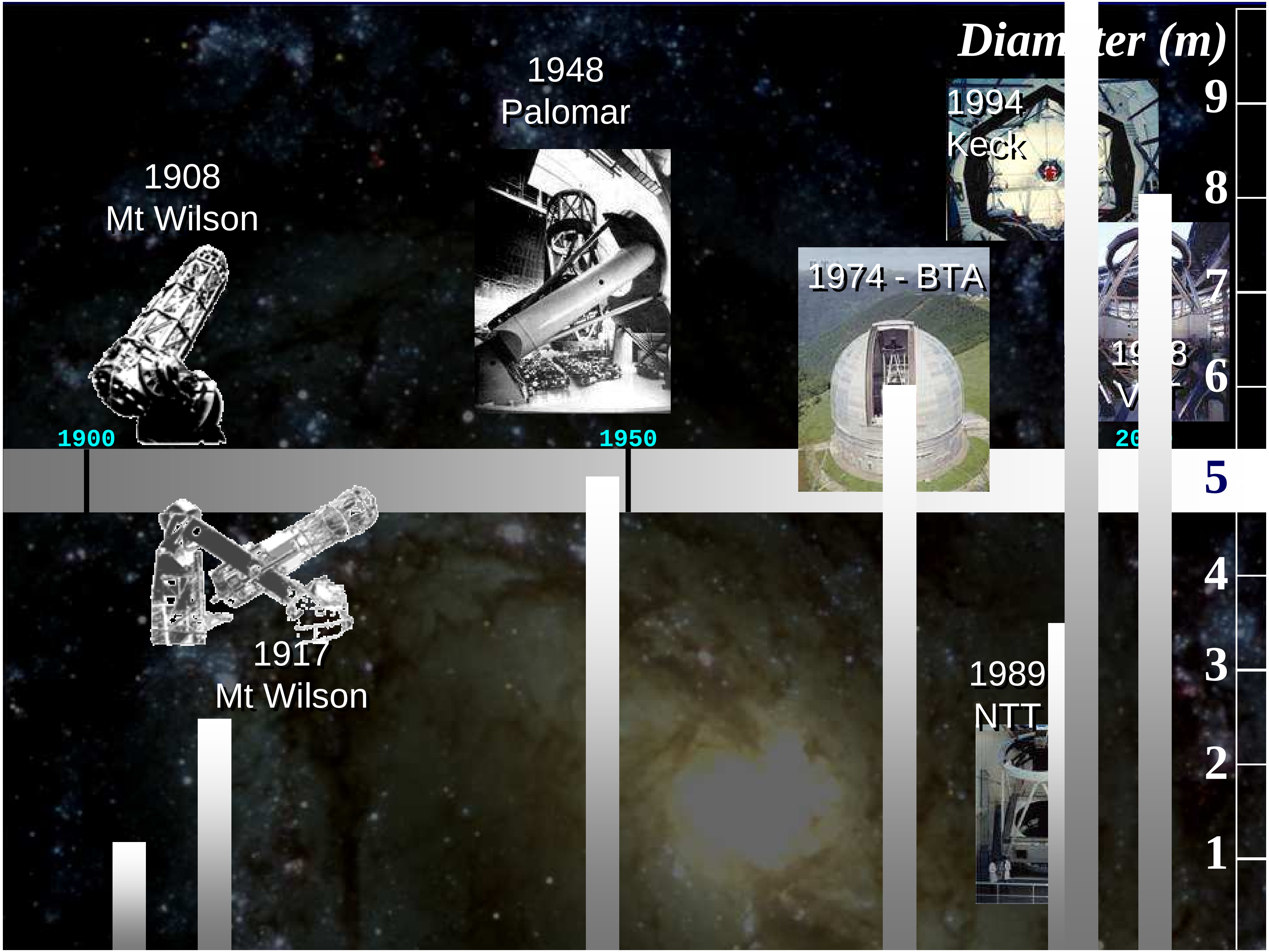




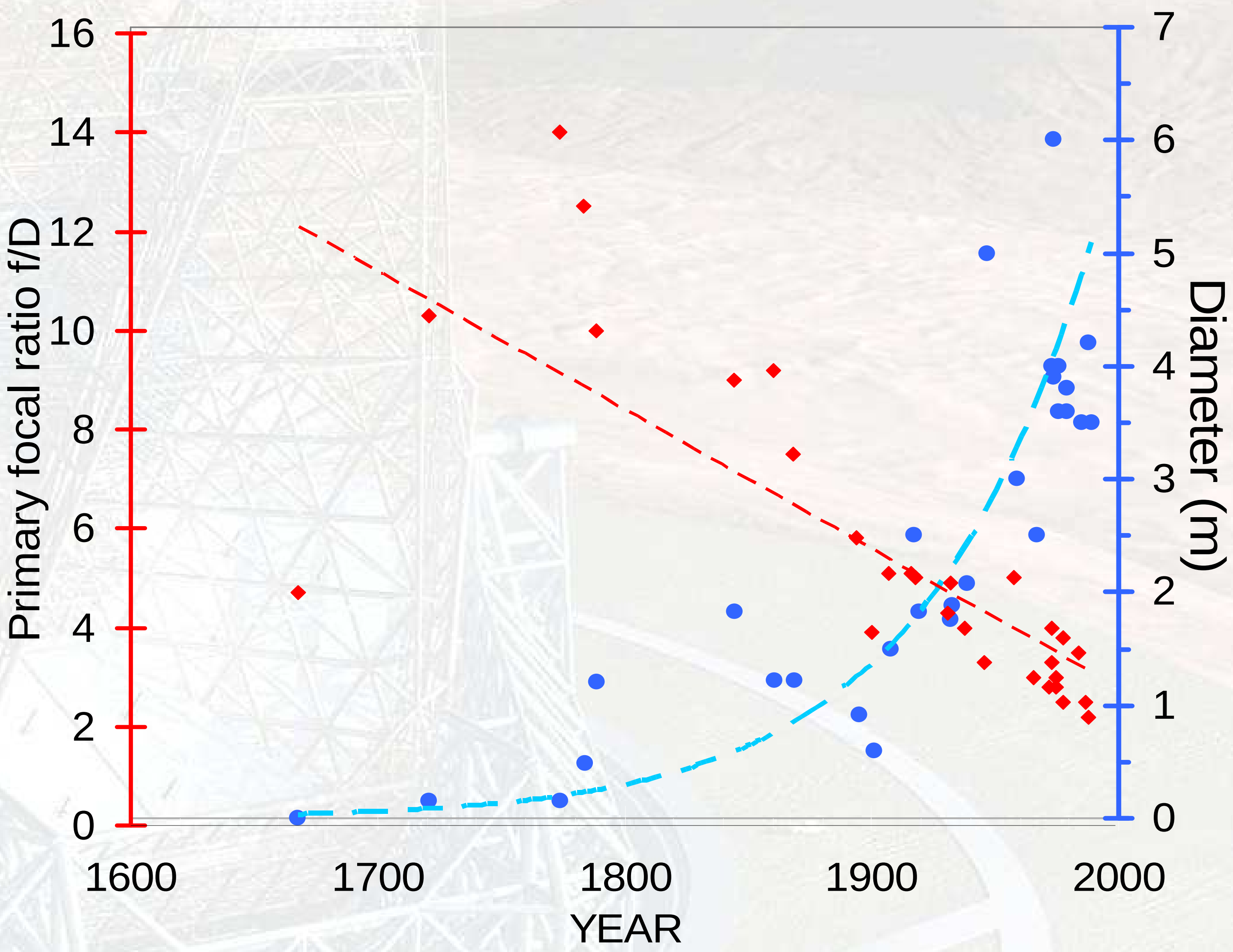
VLT ACTIVE OPTICS

ROTATING CROSSES

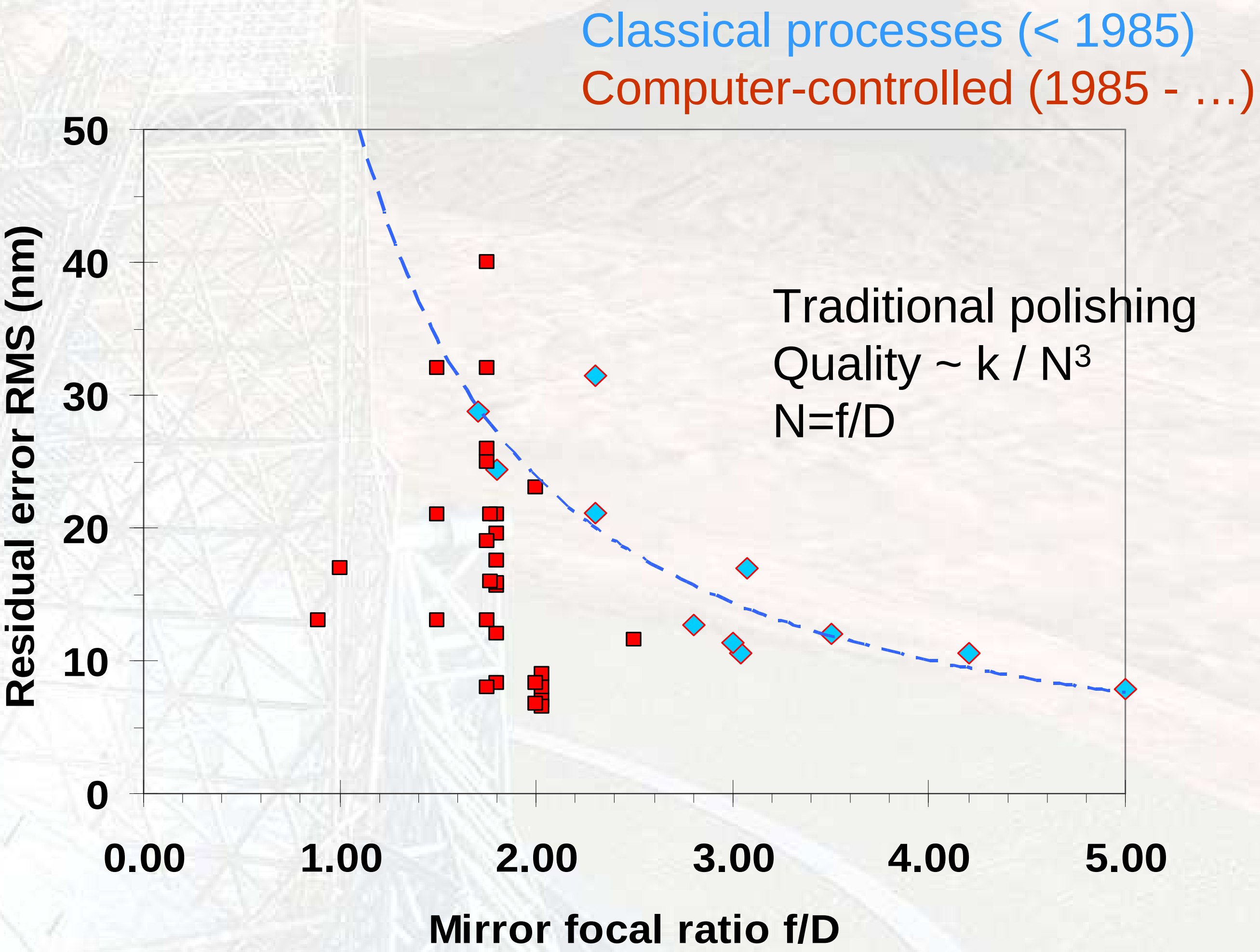

Diameter (m)
9
8
7
6
5
4
3
2
1
1600
1700
1800
1900
Galileo, 1609
Newton, 1668
Hadley, 1721
Herschel, 1784, 1789
Fraunhofer, 1824
Lord Rosse, 1845
Nasmyth, 1845
Foucault, 1857; 1861
Lassel, 1861


Diam ter (m)
9
8
7
6
5
4
3
2
1
1908
Mt Wilson
1948
Palomar
1994
Keck
1974 - BTA
19 8
V
1900
1950
20
1917
Mt Wilson
1989
NTT

Larger and shorter

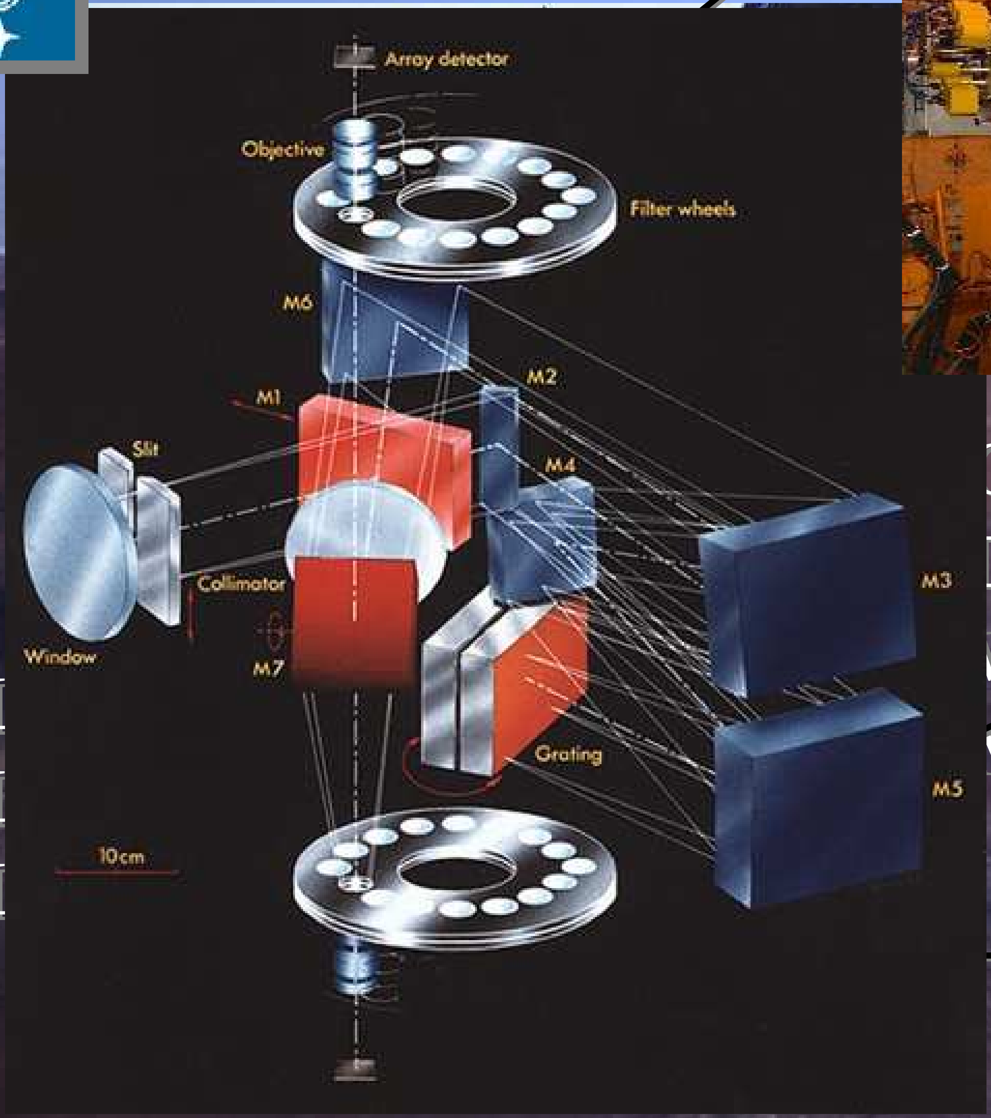


Shorter is more difficult



TODAY: IF YOU CAN MEASURE IT, YOU CAN DO IT
(BUT YOU MAY HAVE TO PAY A LOT …)

Paranal, a modern observatory



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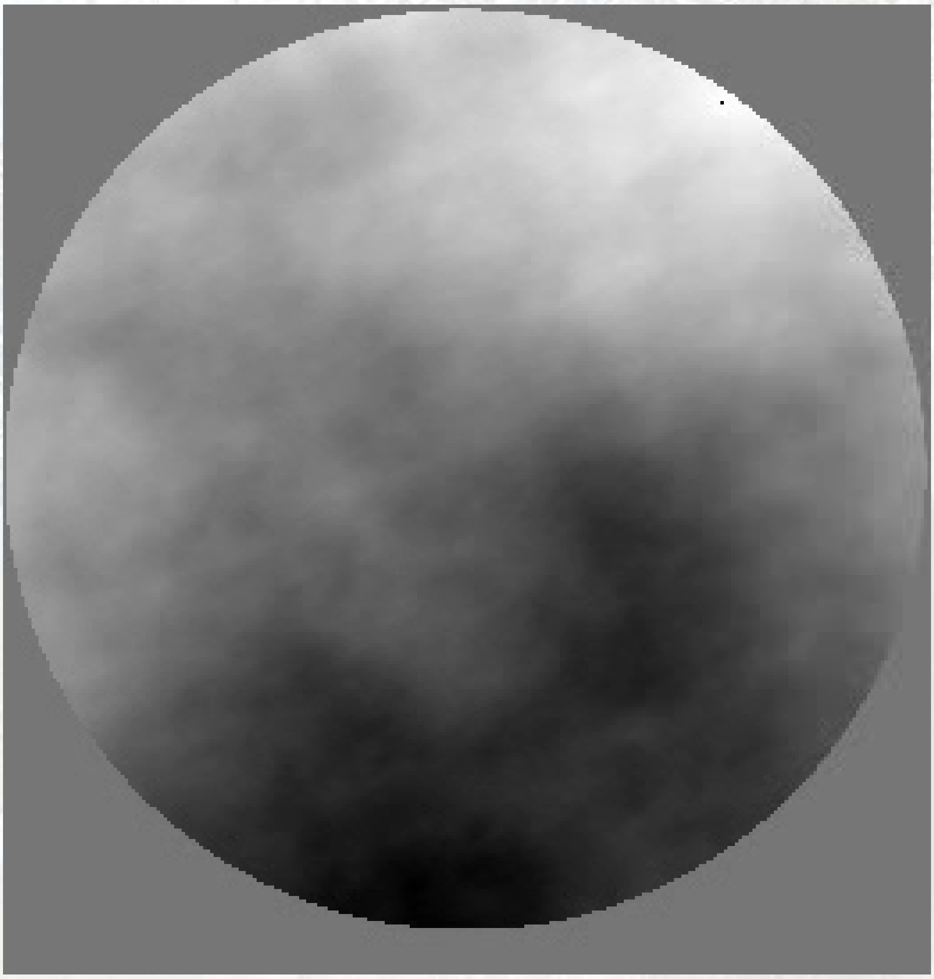
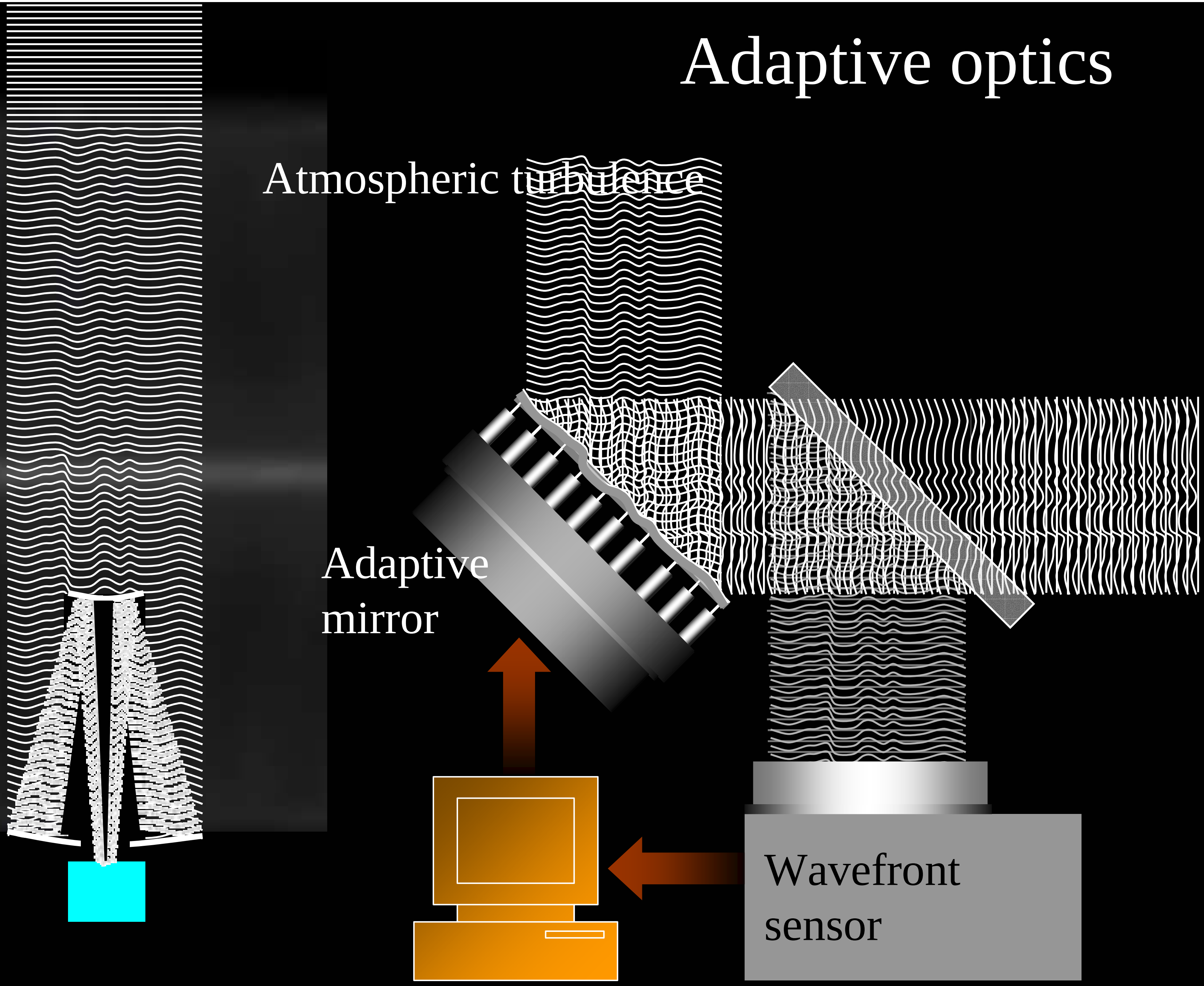
Active, deformable
primary mirror

Industry as a key partner

Atmospheric turbulence



Adaptive optics



Atmospheric turbulence

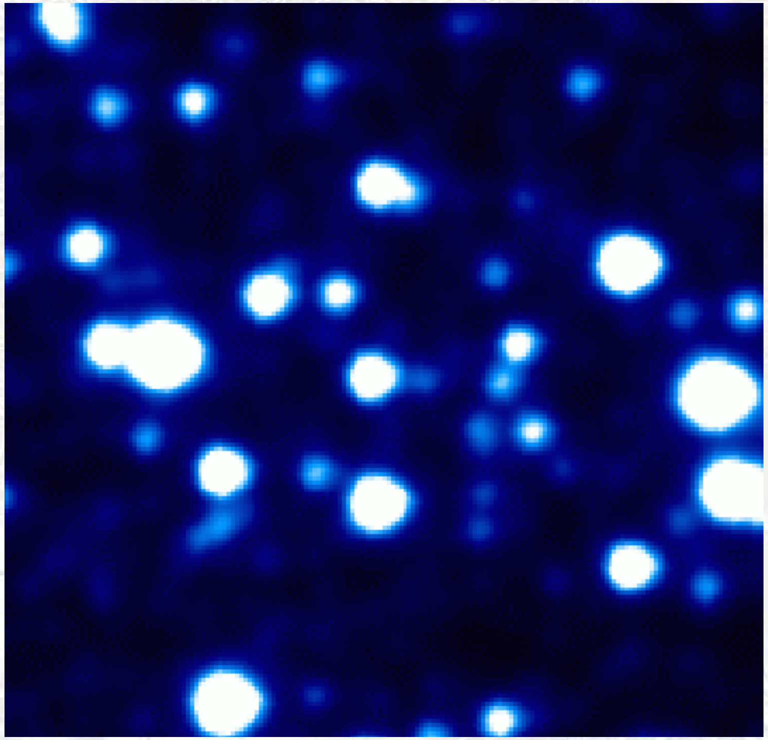
Adaptive mirror

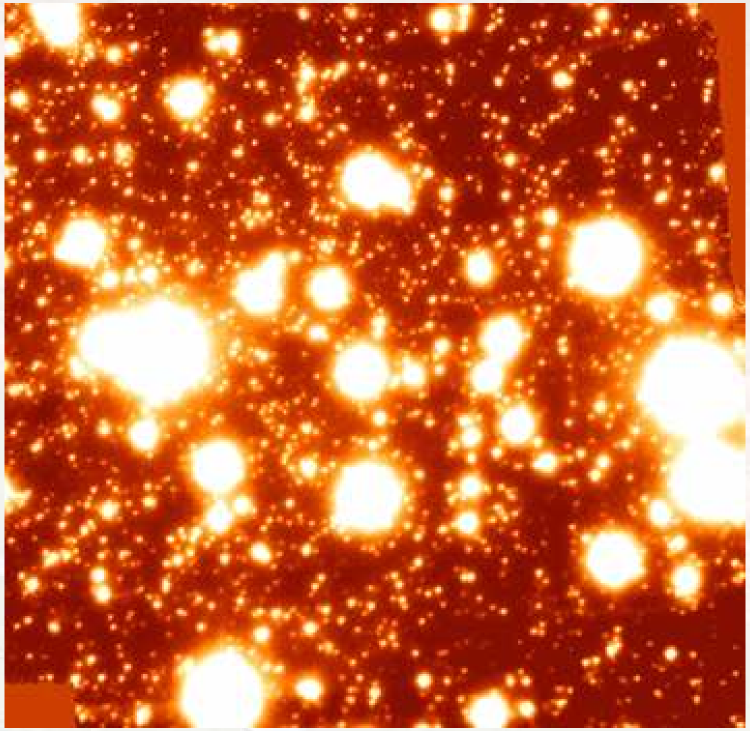
Wavefront sensor

Increase in resolution <u>and</u> sensitivity

Seeing-limited
(0.85 arc seconds)

Hokupa'a+Quirc
0.092 arc seconds

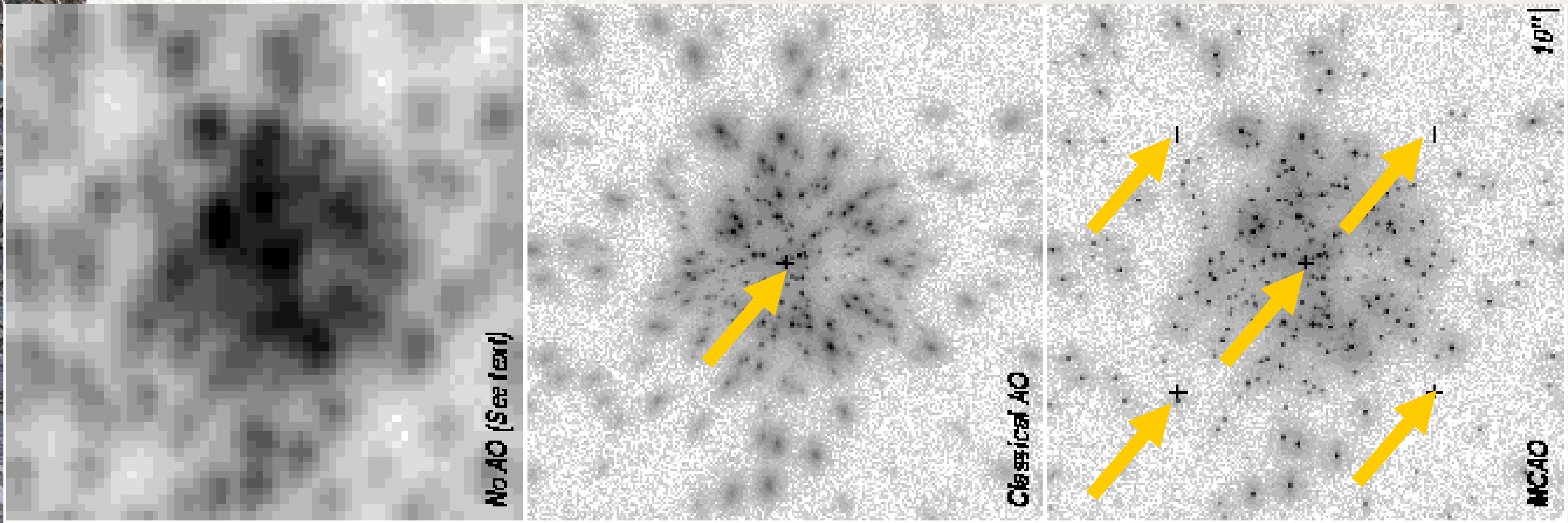




Images: Gemini Observatory, Mauna Kea

Field limitations

Uncorrected Single conjugate AO Multi-conjugate AO



1 adaptive mirror
1 guide star

2 adaptive mirrors
5 guide stars

F. Rigaut, Gemini 1999

Key atmospheric parameters

- r_0 : atmospheric coherence length ⇨ angular resolution
- σ : wavefront rms phase distortion
- θ : free atmosphere seeing, FWHM ⇨ angular resolution
- Θ : isoplanatic angle ⇨ field of view
- C_n^2 , C_n^2 (h): Index structure coeff. ⇨ turbulence strength
- τ_0 : Greenwood time delay ⇨ AO bandwidth
- λ : wavelength
- R : Strehl ratio ⇨ resolution
- D : telescope diameter
- L_0 : outer scale of turbulence

Key atmospheric parameters (con't)

$C_n^2 = \int C_n^2(h)\,dh$

$r_0 = [0.423\, k^2 (\cos z)^{-1} C_n^2]^{-3/5}$ z: zenithal dist., h: altitude

$\sigma^2 = 1.03\, (D/\, r_0)^{5/3}$ warning: Kolmogorov !

phase error ~1 rad ~ $\lambda/6$ rms over aperture with dia. = r_0

$\tau_0 = 0.314\, r_0 / v$ v : mean propagation velocity

control loop delay such that phase error ~1 rad ~ $\lambda/6$ rms

$\theta \approx 0.98\, \lambda / r_0$ (without ao correction !)

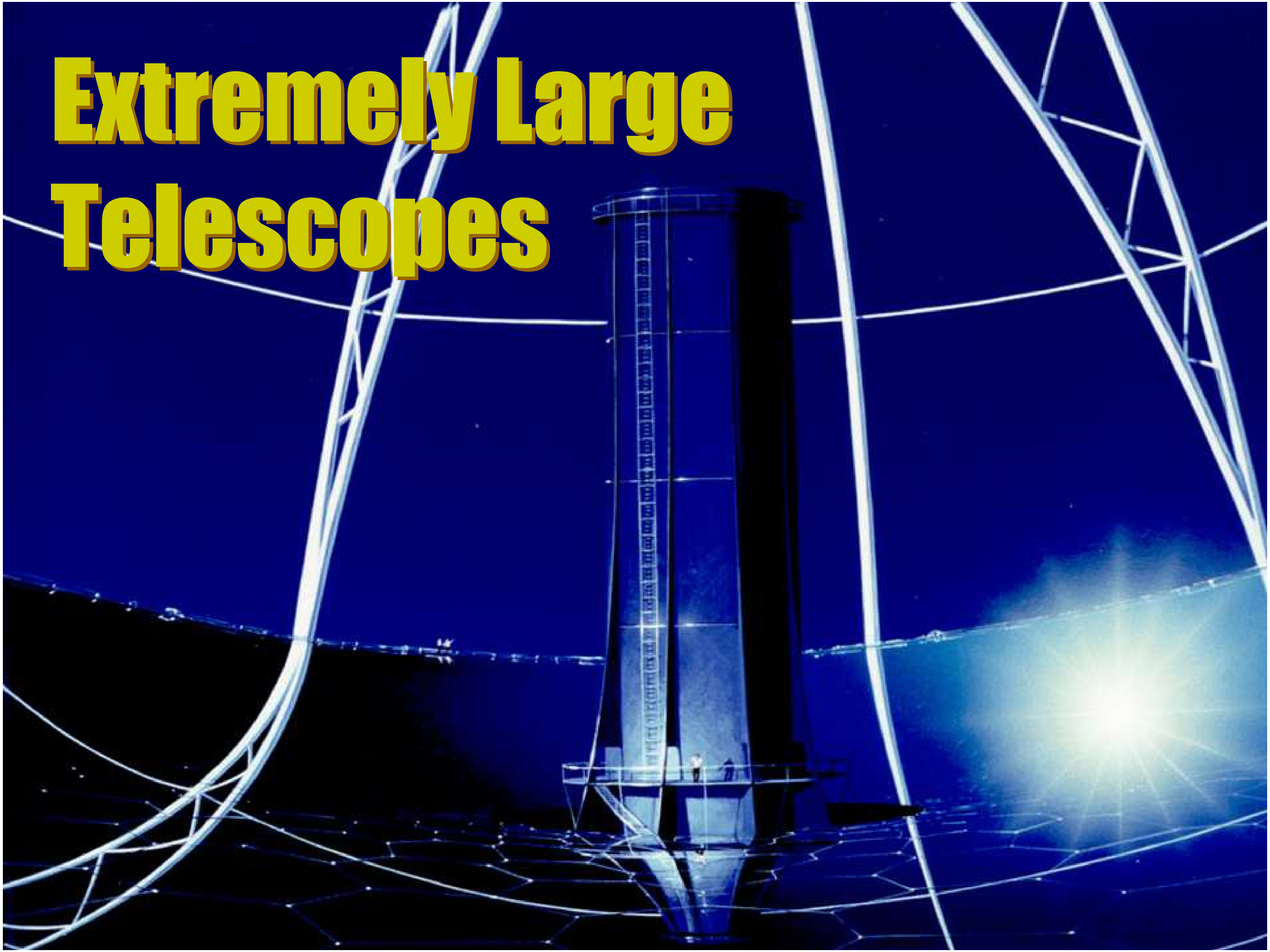
$\Theta = 0.314\, r_0 \cos z / \boldsymbol{h}$ ***h*** weighted average, layers alt.

angular distance such that phase error ~1 rad ~ $\lambda/6$ rms

$r_0(\lambda') = r_0(\lambda)\, .\, (\lambda'/\lambda)^{1.2}$

$R \approx (r_0 / D)^2$ $(D >>> r_0)$;

Extremely Large Telescopes



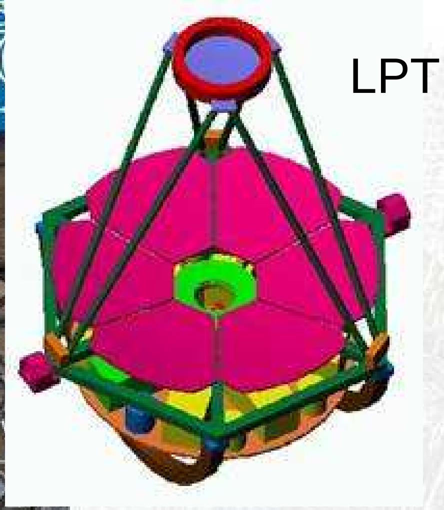
Extremely Large Telescopes

- A brief history …
  - 1977: Meinel et al, 25-m feasible (but not very useful …)
  - 1989 … 25-m … 50-m concept proposed by Lund university
    Personal opinion: mostly an academic exercise
  - 1996: Mountain et al; HDF spectroscopy ⇨ 50-m MAXAT
  - 1998, Gilmozzi et al: is a 100-m telescope possible ? ⇨ OWL
  - 2000: ELT, GSMT, CELT, EURO-50, etc.; OWL phase A funded

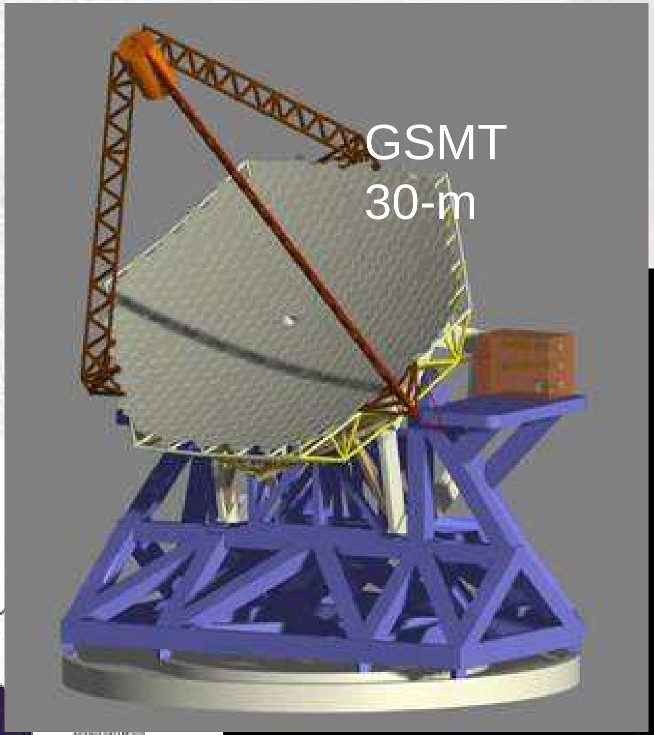
- 2004 status:
  - OWL nearing phase A completion
  - GSMT (Aura), CELT (Caltech), HDRT (Canada) merge into TMT
  - EURO-50 proposal released (2003)
  - GMT Phase A started
  - European technology development programme approved by EC

- NO LIGHT BUCKETS ! Adaptive optics essential !!!

Extremely Large Telescopes

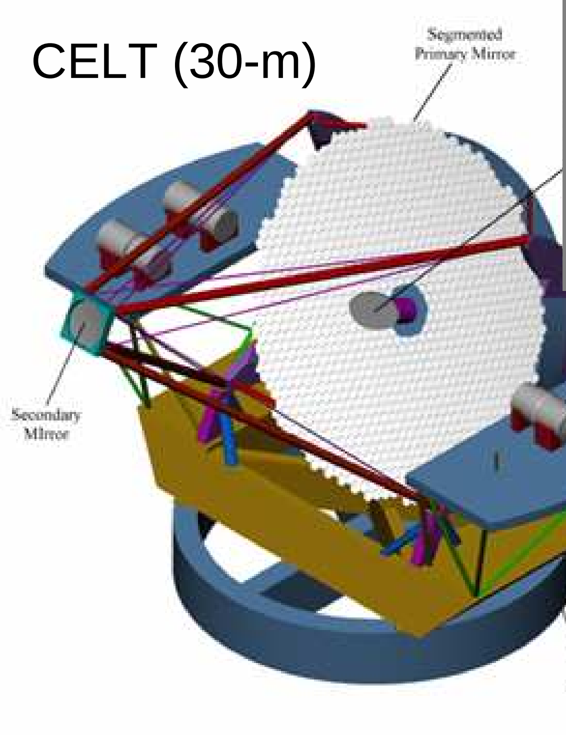


LPT (20-m)

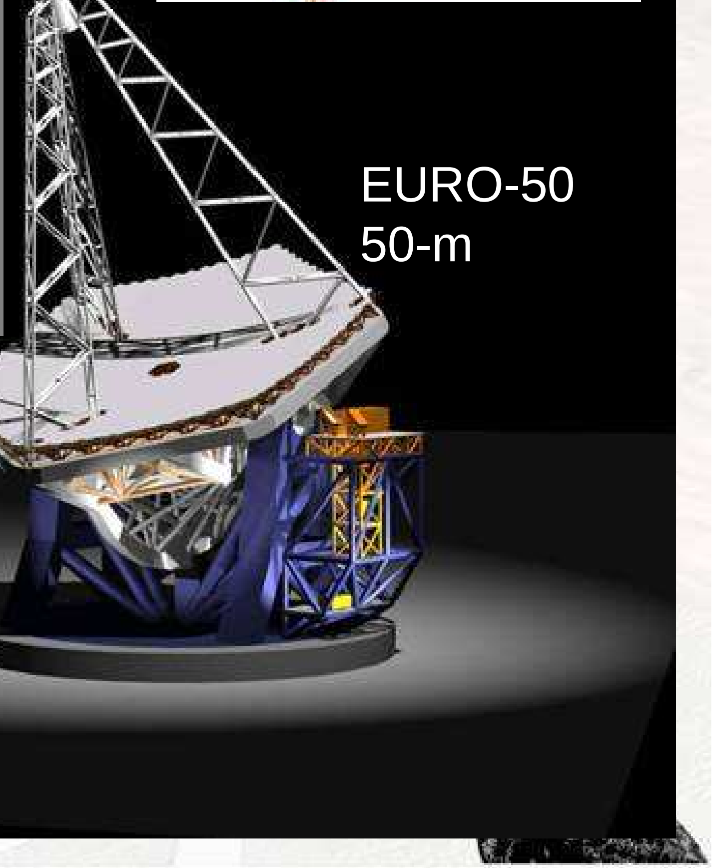


GSMT
30-m

HDRT
25-m

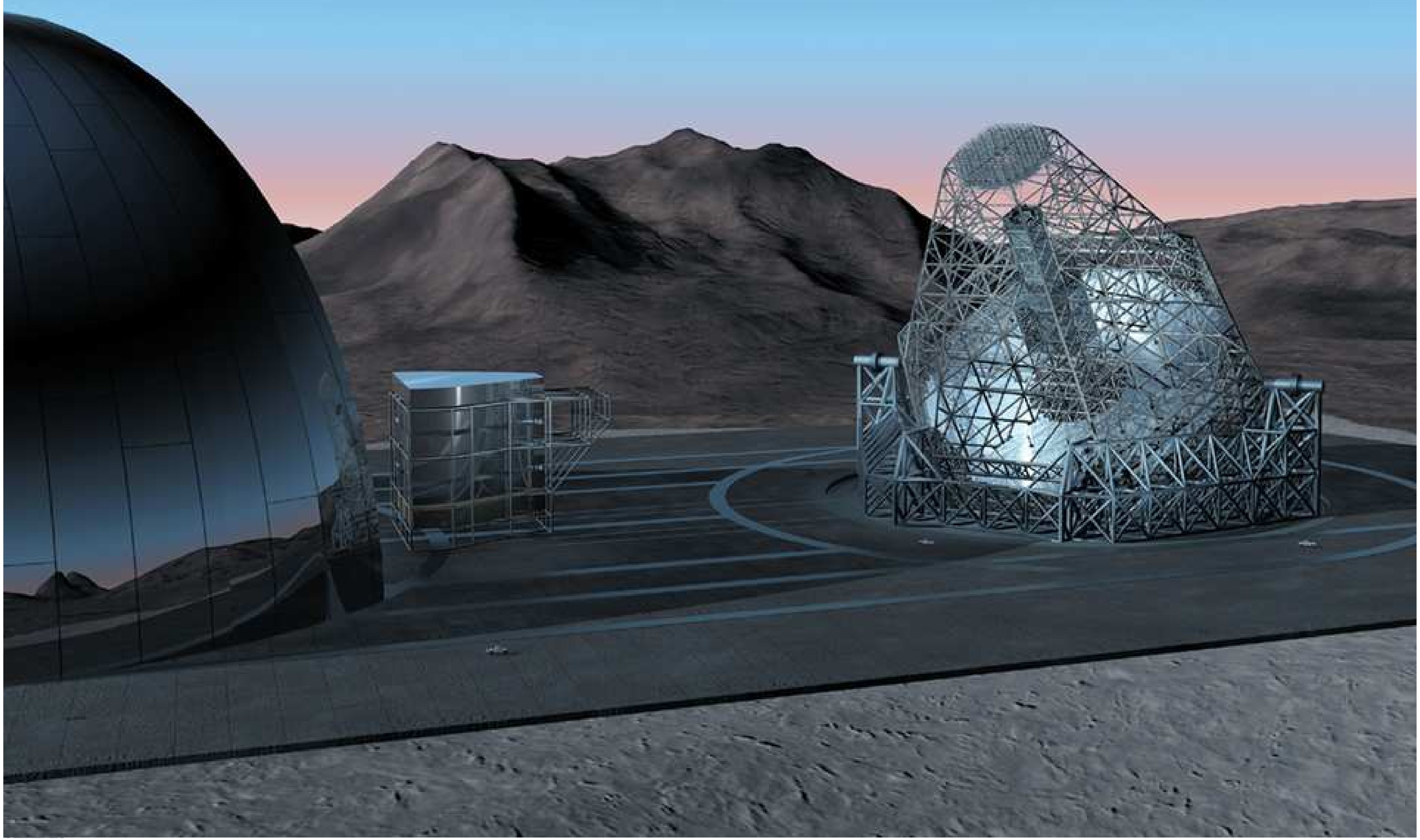


CELT (30-m)



EURO-50
50-m

OWL: superlative future



Requirements

Top level

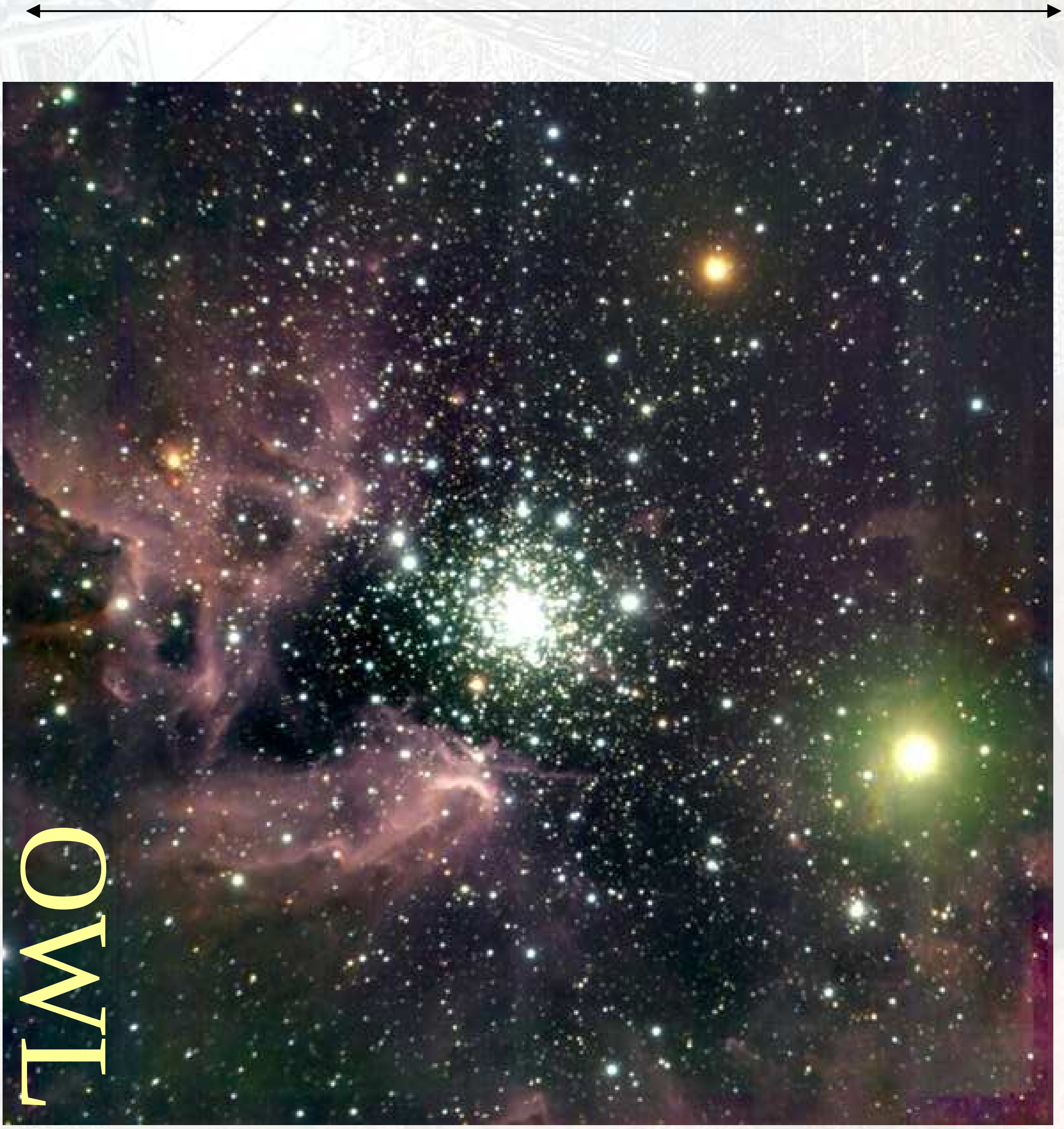
- Pupil size: 100-m diameter, collecting area > 6,000 m^2
- Multi-conjugate Adaptive Optics
- Diffraction-limited resolution over field of view:

  Visible > 30 arc seconds
  IR (2μm) > 2 arc minutes
- Strehl ratio > 20% in the visible, goal 30%.
- Wavelength range 0.32 - 2.5 (12) μm

Cost < 1,000 MEuros (capital investment)

Timescale Start of science ~2016

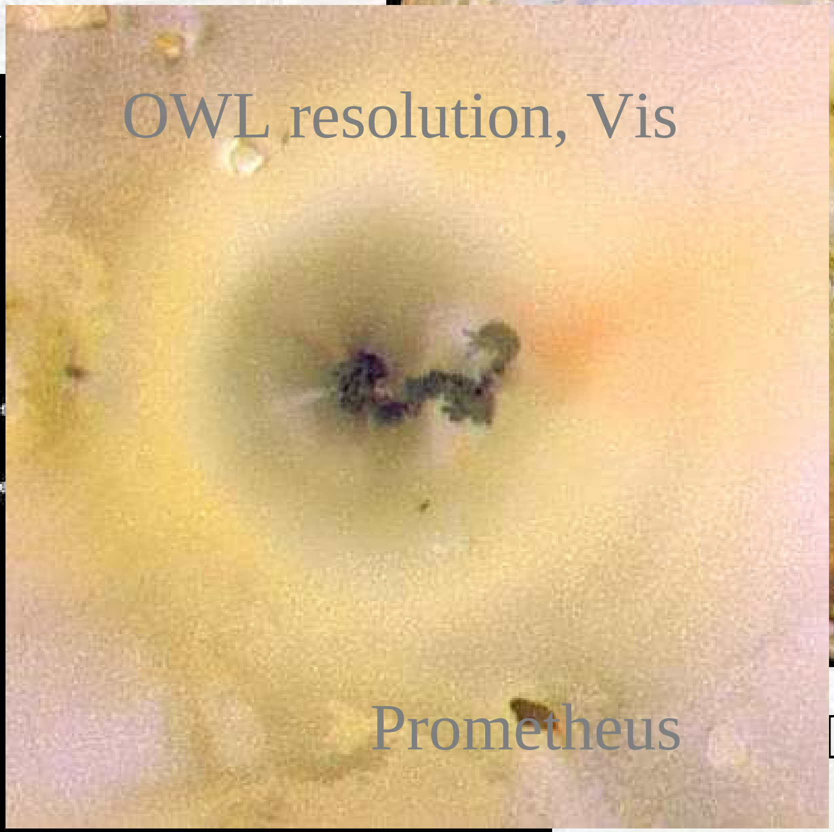
0.6 arcsec



Spatial resolution

4.8 μm ground

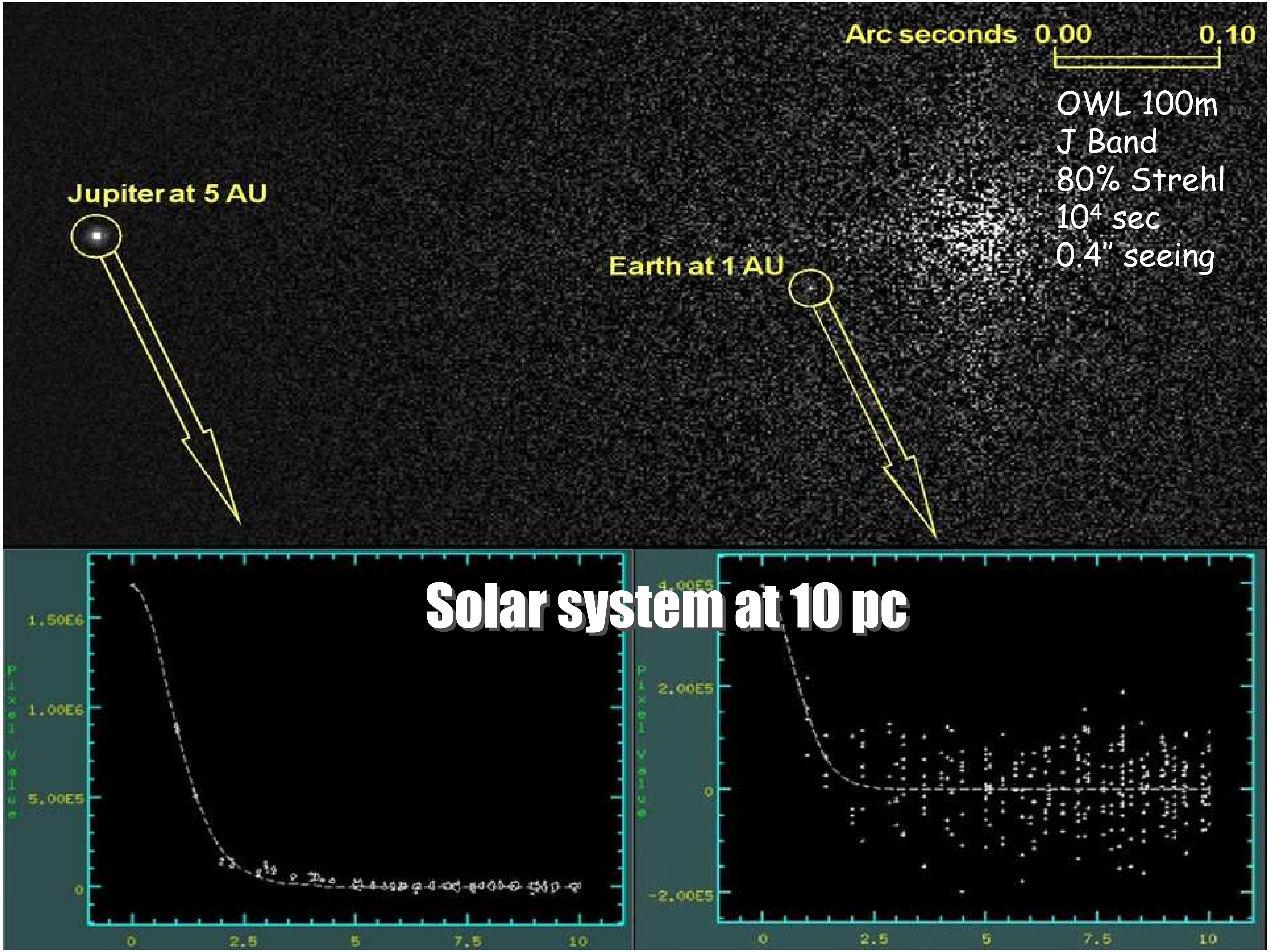
OWL resolution, Vis



Prometheus

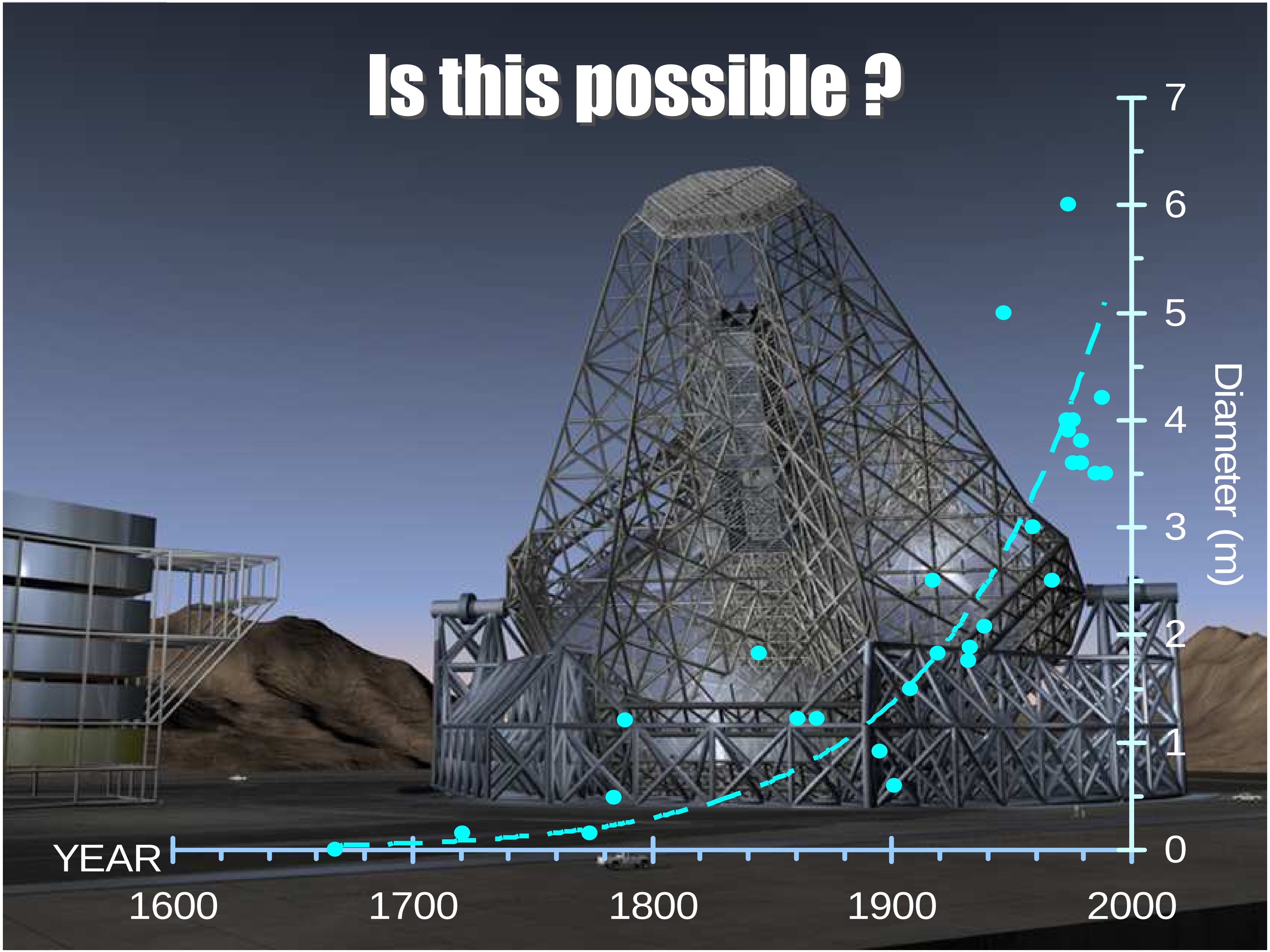
L resolution at 4.8 μm

Solar system at 10 pc



OWL 100m
J Band
80% Strehl
10^4 sec
0.4" seeing

Is this possible ?



Feasibility – progress of technology

Glass-making

- Slowly evolving technology
- Extrapolation from 5-m required active optics !
- ***Not easily scalable***

Segmentation

Optical figuring

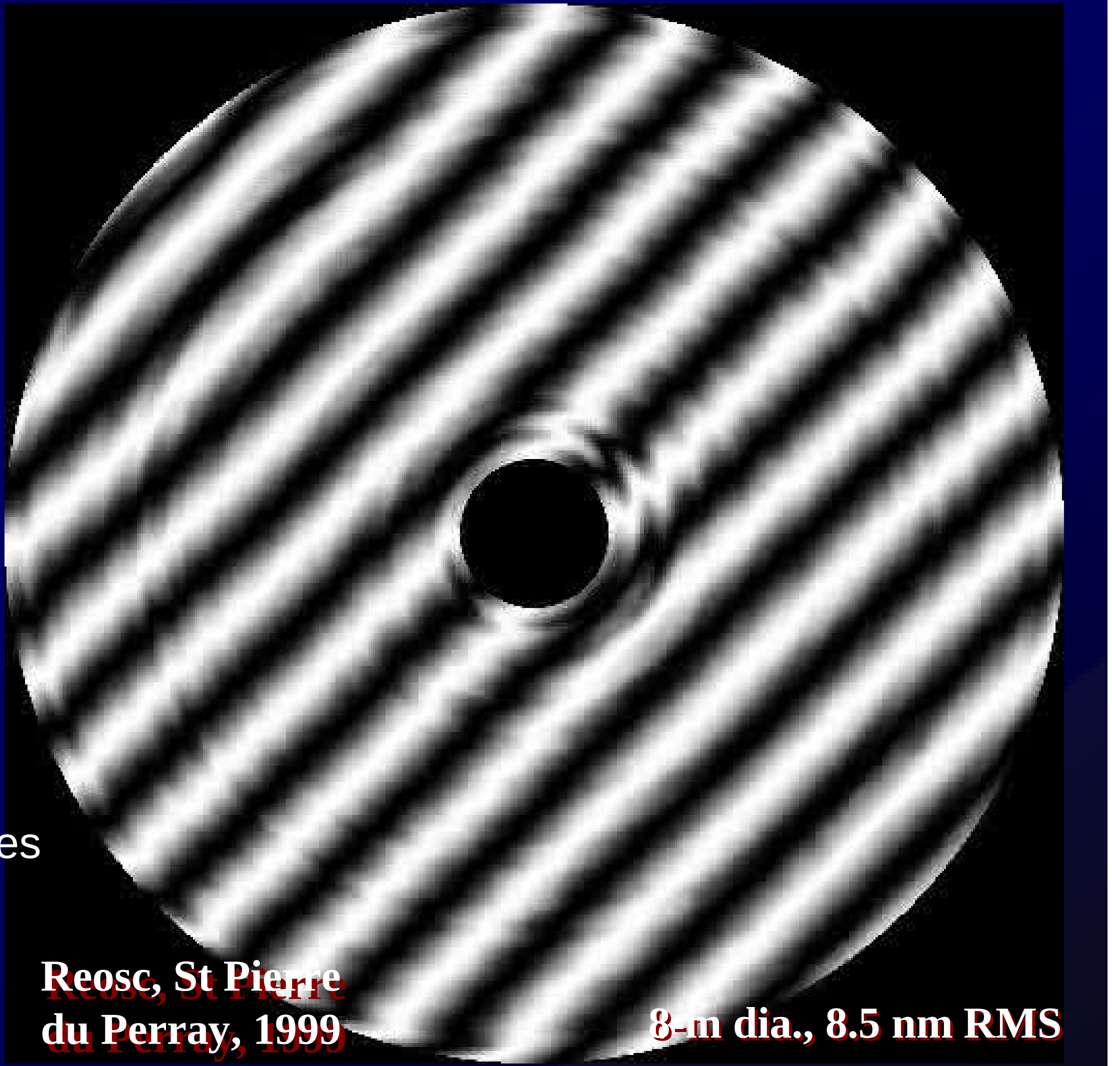
- Metrology-dependent
- Rapid evolution
- ***Scalable (somewhat)***

Segmentation

Wavefront control

- In-situ control of performance
- Dealing with inevitable error sources
- Tolerances relaxation
- ***Scalable***

Active optics

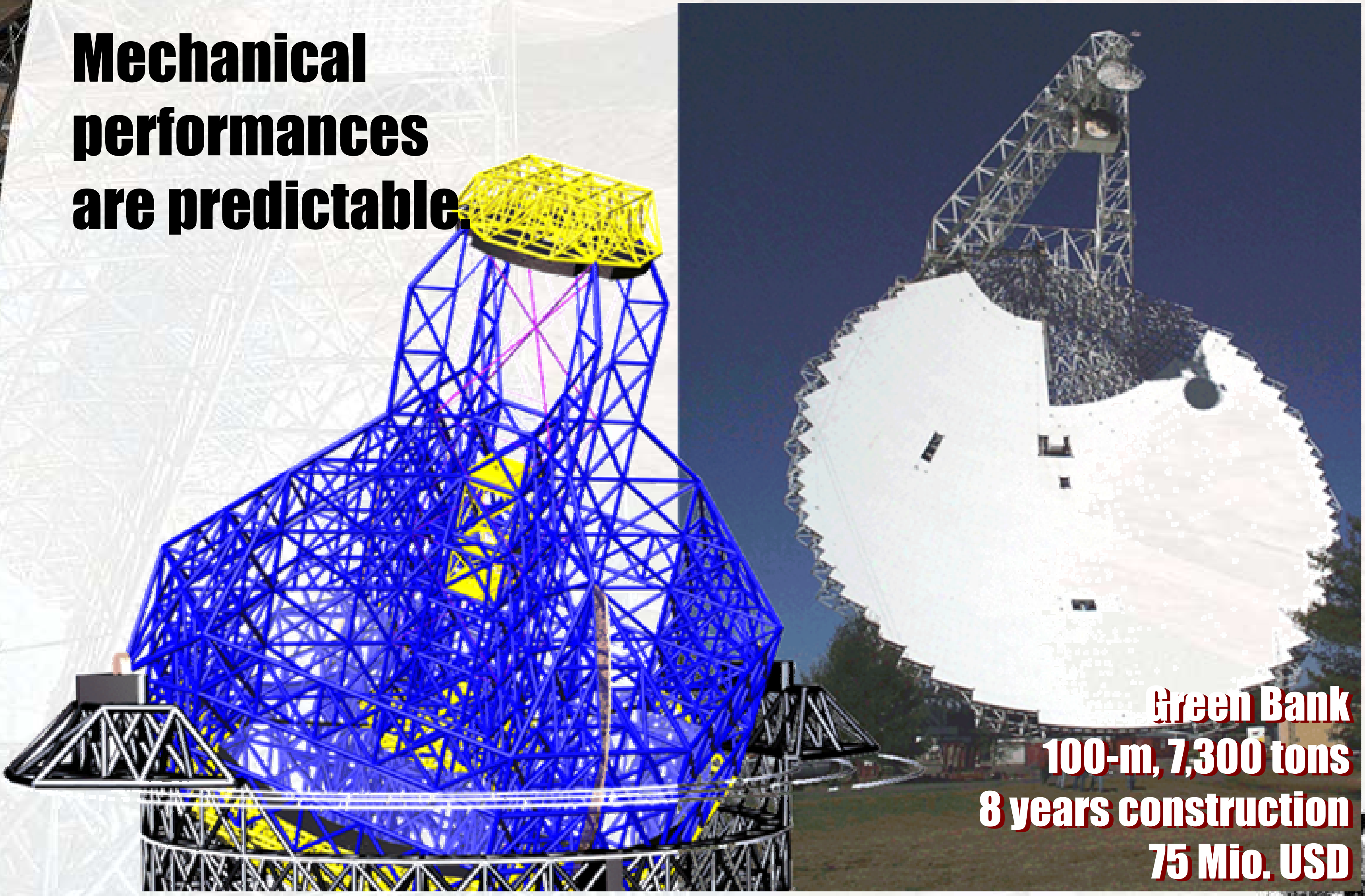


Reosc, St Pierre du Perray, 1999

8-m dia., 8.5 nm RMS

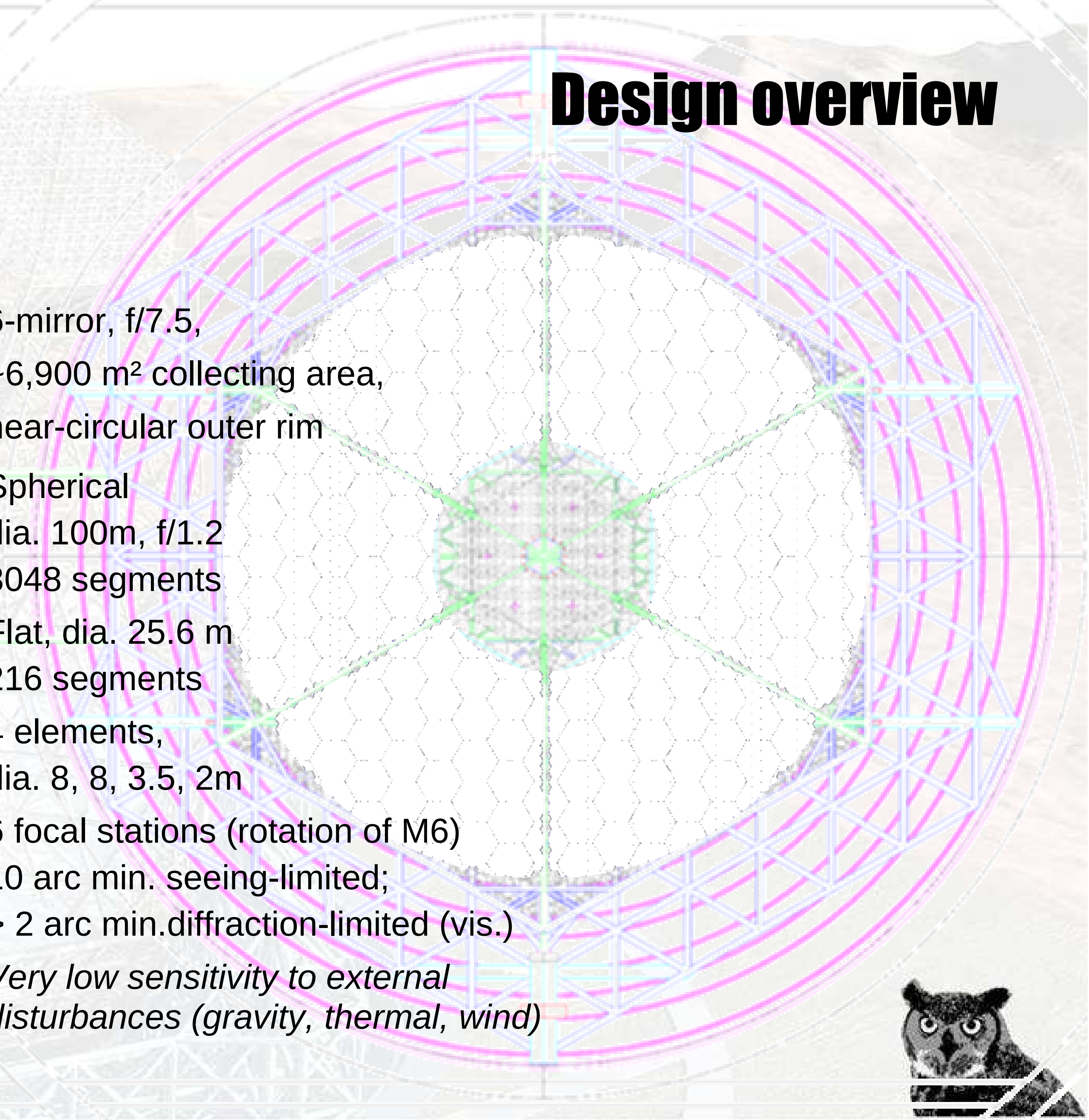
Where the limit ?

Mechanical performances are predictable.



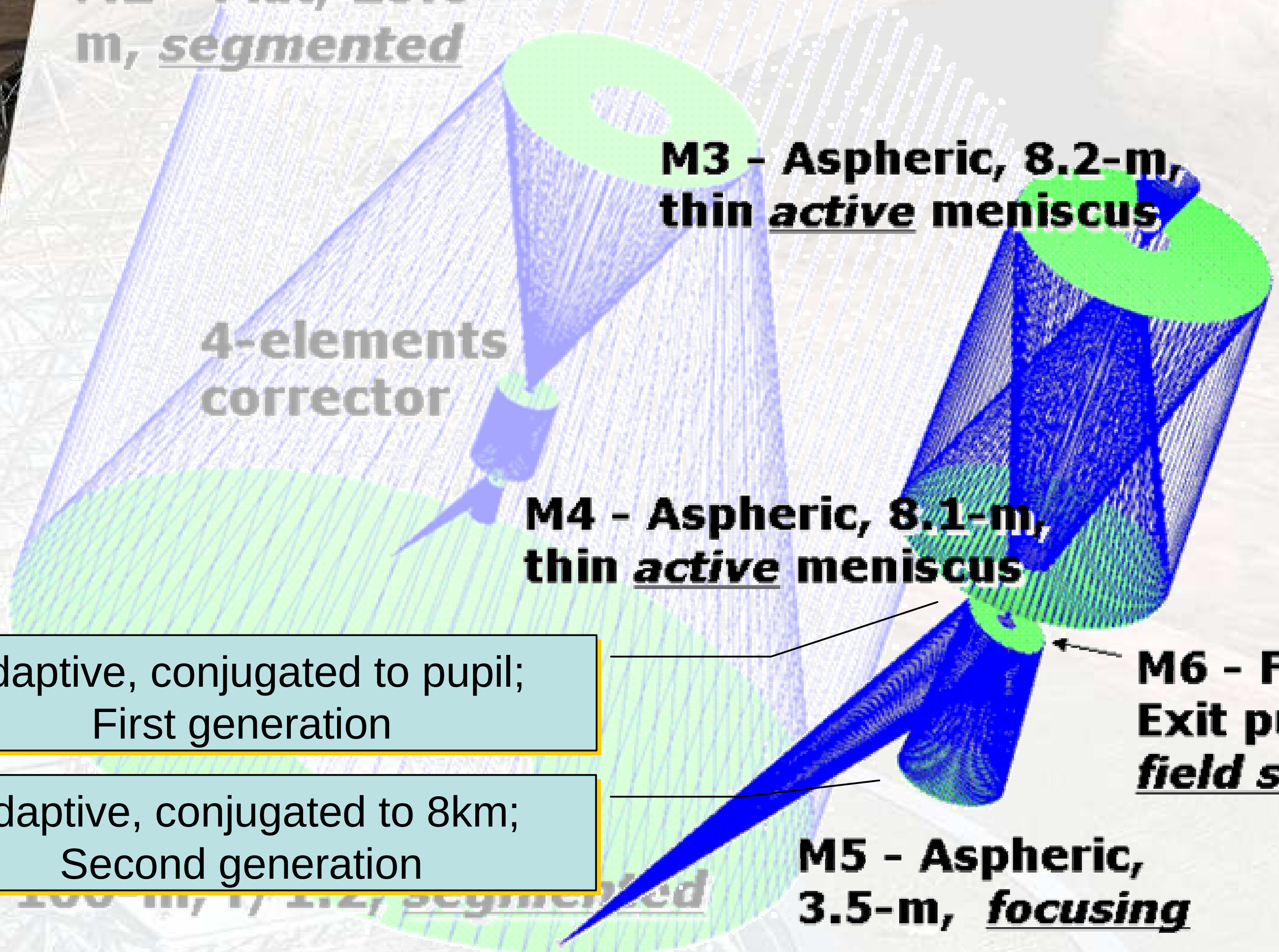
Green Bank
100-m, 7,300 tons
8 years construction
75 Mio. USD

Design overview



Optics	6-mirror, f/7.5, ~6,900 m² collecting area, near-circular outer rim
M1	Spherical dia. 100m, f/1.2 3048 segments
M2	Flat, dia. 25.6 m 216 segments
Corrector	4 elements, dia. 8, 8, 3.5, 2m
FOV	6 focal stations (rotation of M6) 10 arc min. seeing-limited; > 2 arc min.diffraction-limited (vis.)
Stability	*Very low sensitivity to external disturbances (gravity, thermal, wind)*

Optical design



M2 - Flat, 25.6-m, *segmented*

M3 - Aspheric, 8.2-m, thin *active* meniscus

4-elements corrector

M4 - Aspheric, 8.1-m, thin *active* meniscus

Adaptive, conjugated to pupil;
First generation

Adaptive, conjugated to 8km;
Second generation

M6 - Flat, 2.2-m,
Exit pupil,
field stabilization

M5 - Aspheric,
3.5-m, *focusing*

100-m, f/1.2, *segmented*

10 arc min f/6
Field of view

Why a spherical primary / flat secondary ?

System ——— Performance ——— Risk & cost

- Larger corrected field of view than equivalent Ritchey-Chretien
- Low sensitivity to M2 decenters
- Corrector ⇨ excellent baffling options
- Secondary mirror an issue with aspherical primary
  - Small M2 (< 3-m) ⇨ very high sensitivity to disturbances
  - Large M2 (> 3-m)

    ⇨ severe fabrication issue if convex
    ⇨ added tube length if concave (Gregorian)
- All wavefront control functions with 6 surfaces
- Multi-conjugate AO (2 mirrors 2- and 4-m, conjugated to 0, 8 km)
  - Moderately large FOV (0.5 – 2 arc min) an essential mode
  - Needs re-imaging; OWL provides dual conjugate with 6 surfaces only !
- Maintainability: 3,000 segments, all identical & interchangeable.

Why a spherical primary / flat secondary ?

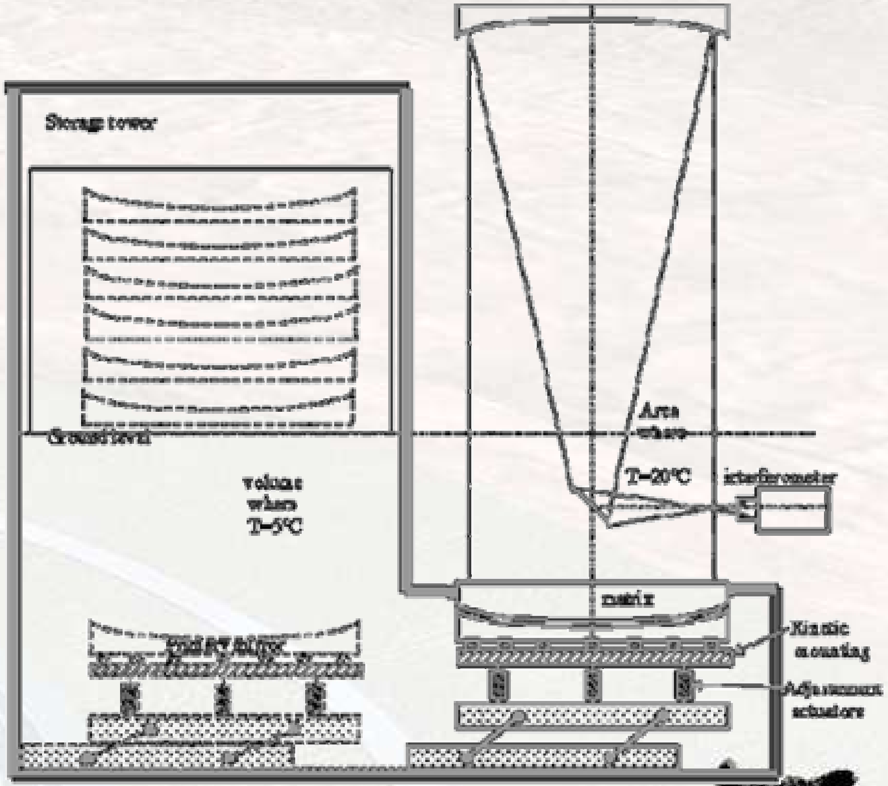
System —— **Performance** —— Risk & cost

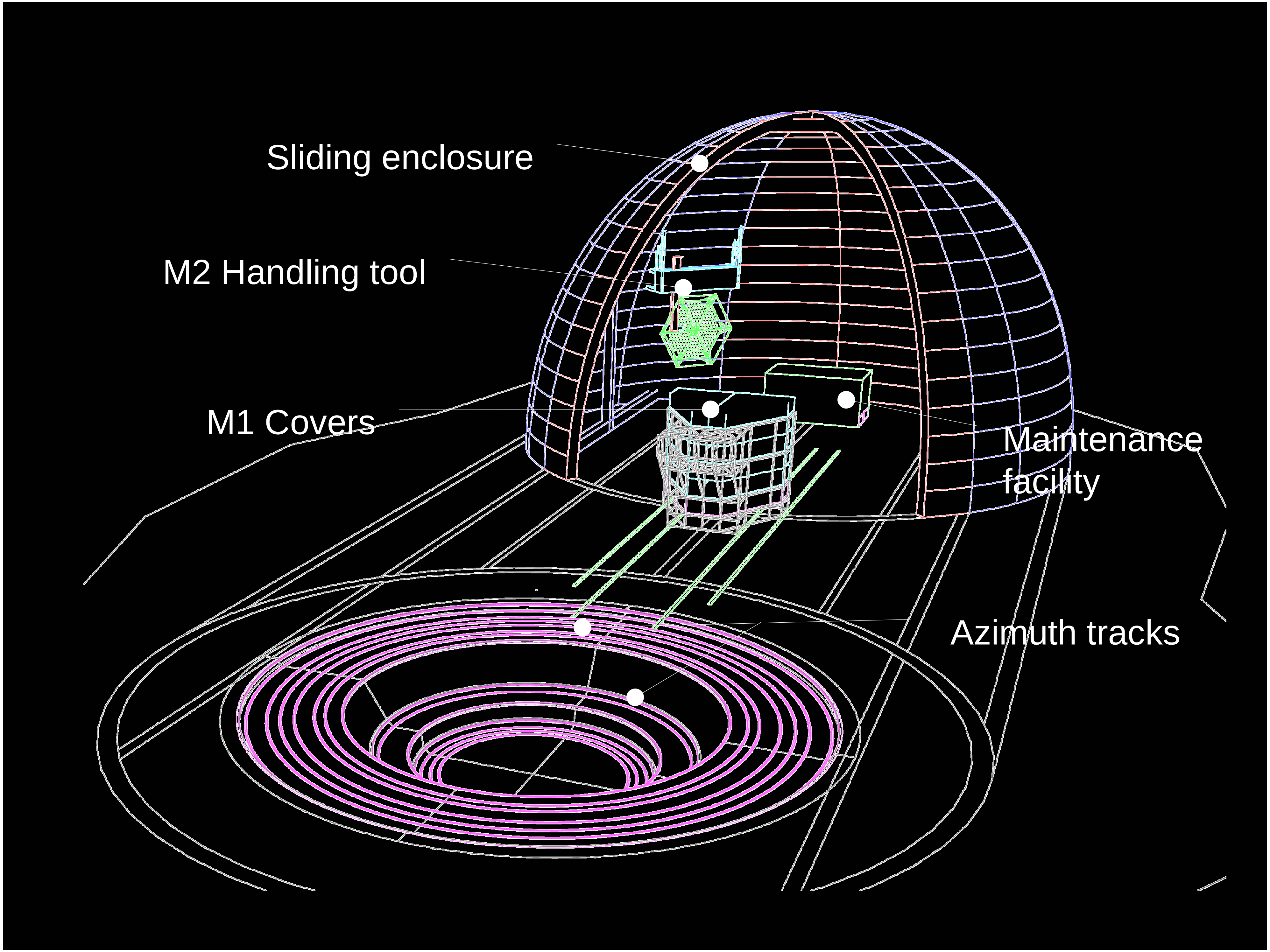
- Use of planetary polishers or large stiff figuring tools
  - Lower segment edge misfigure
  - Stable reference, repeatability of radius of curvature
- No warping harness
  - Structured blanks possible (SiC a serious option)
  - Less stringent requirements on blanks internal stresses
- Segment size up to ~2.3-m possible
  - Limited by cost-effective transport in standard container
  - No asphherization ⇨ weak size-dependence
- Performance losses
  - Lower throughput than a Ritchey-Chretien (option: enhanced coatings ?)
  - Higher emissivity (option: single surface corrector for very small field of view ?)

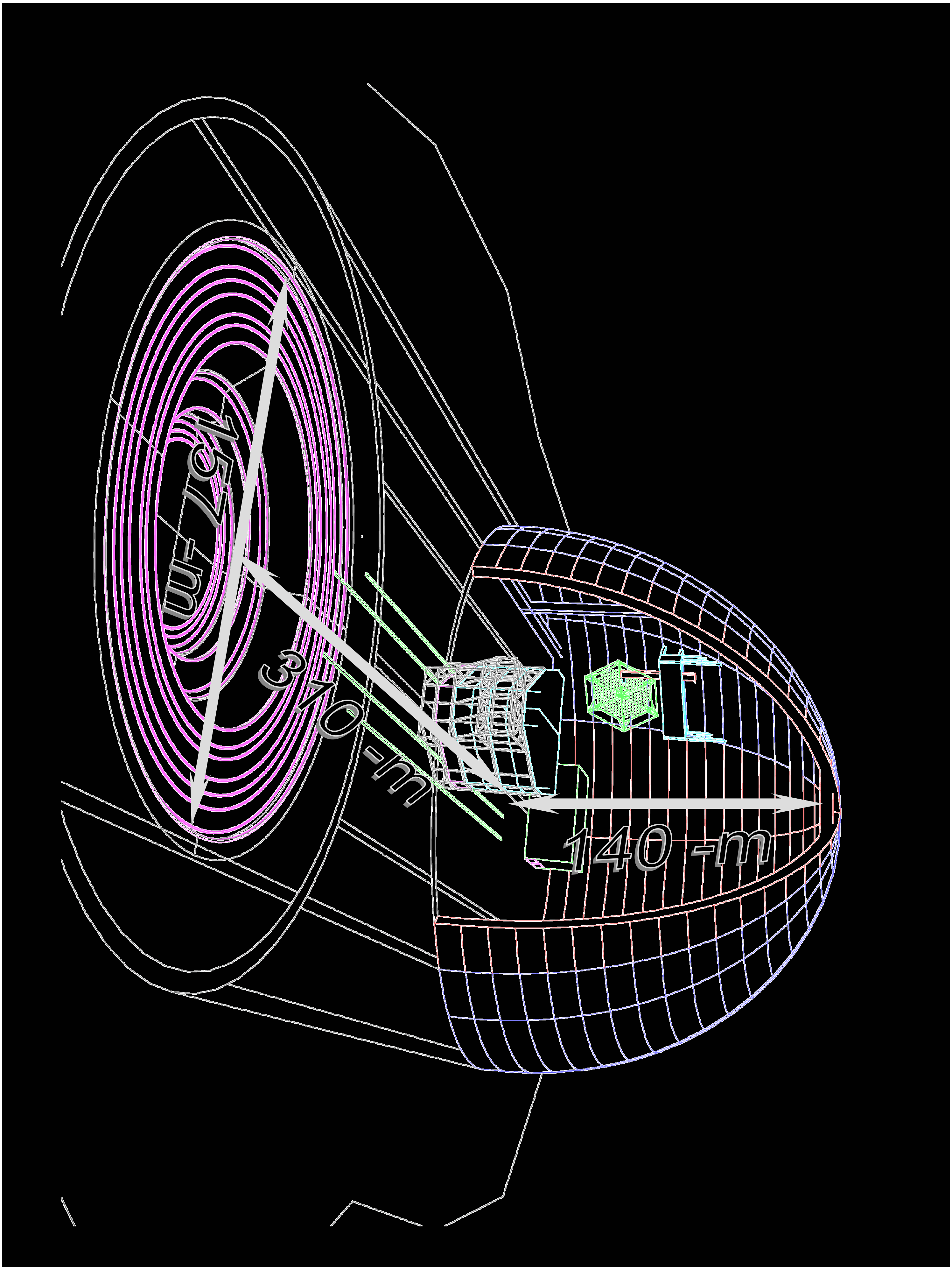
Why a spherical primary / flat secondary ?

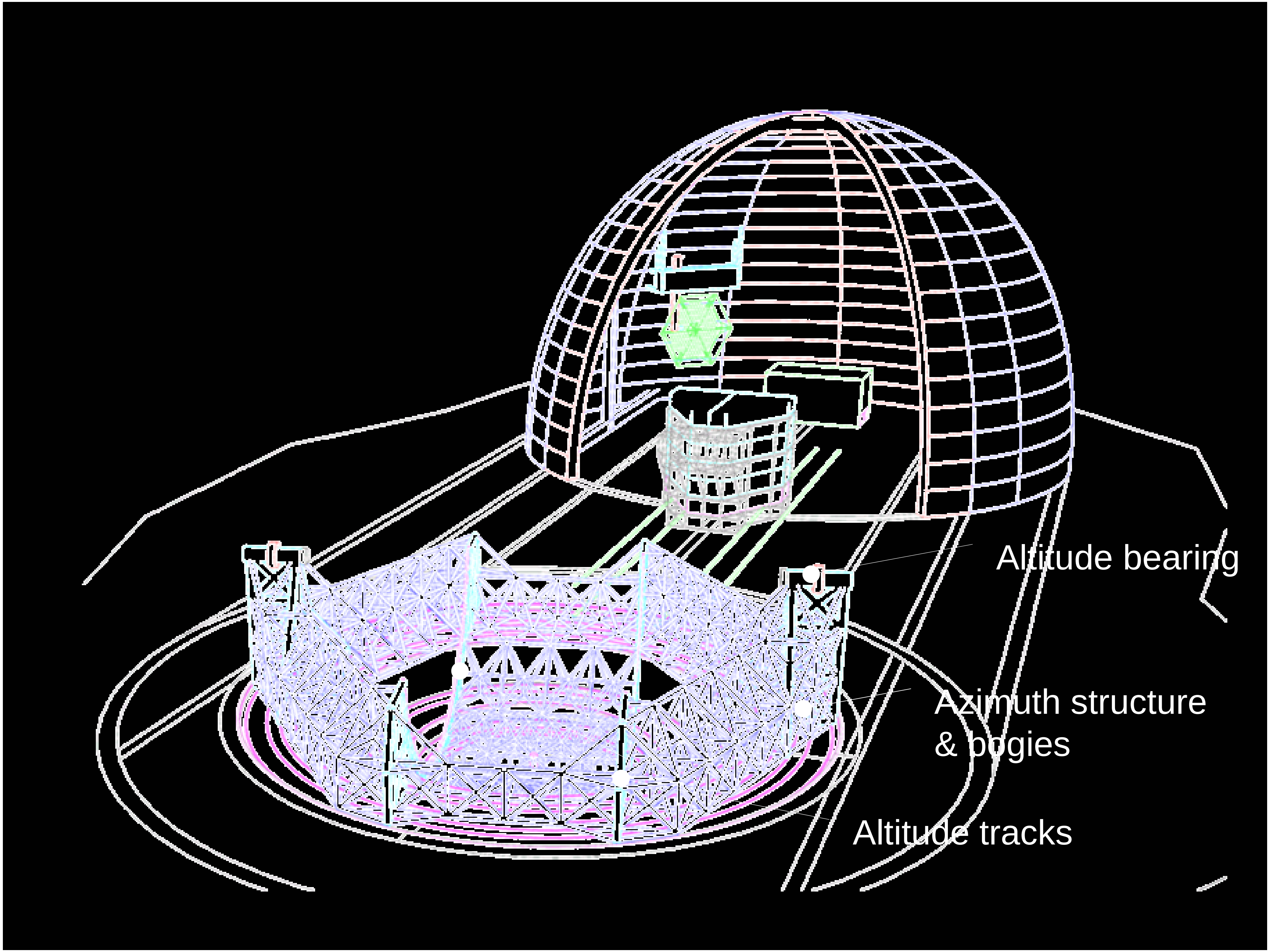
System — Performance — **Risk & cost**

- Spherical polishing
  - Simple and predictable processes, stable and predictable yield
  - Stable reference (rigid tools)
  - Fast process, high efficiency; OWL polishing tool area = 36 × largest GTC tool area !
  - Simple test set-up
    <u>Unique matrix</u>
    ⇨ no segments matching risk
- TBC: No edge cutting, polished hexagonal




Sliding enclosure
M2 Handling tool
M1 Covers
Maintenance facility
Azimuth tracks

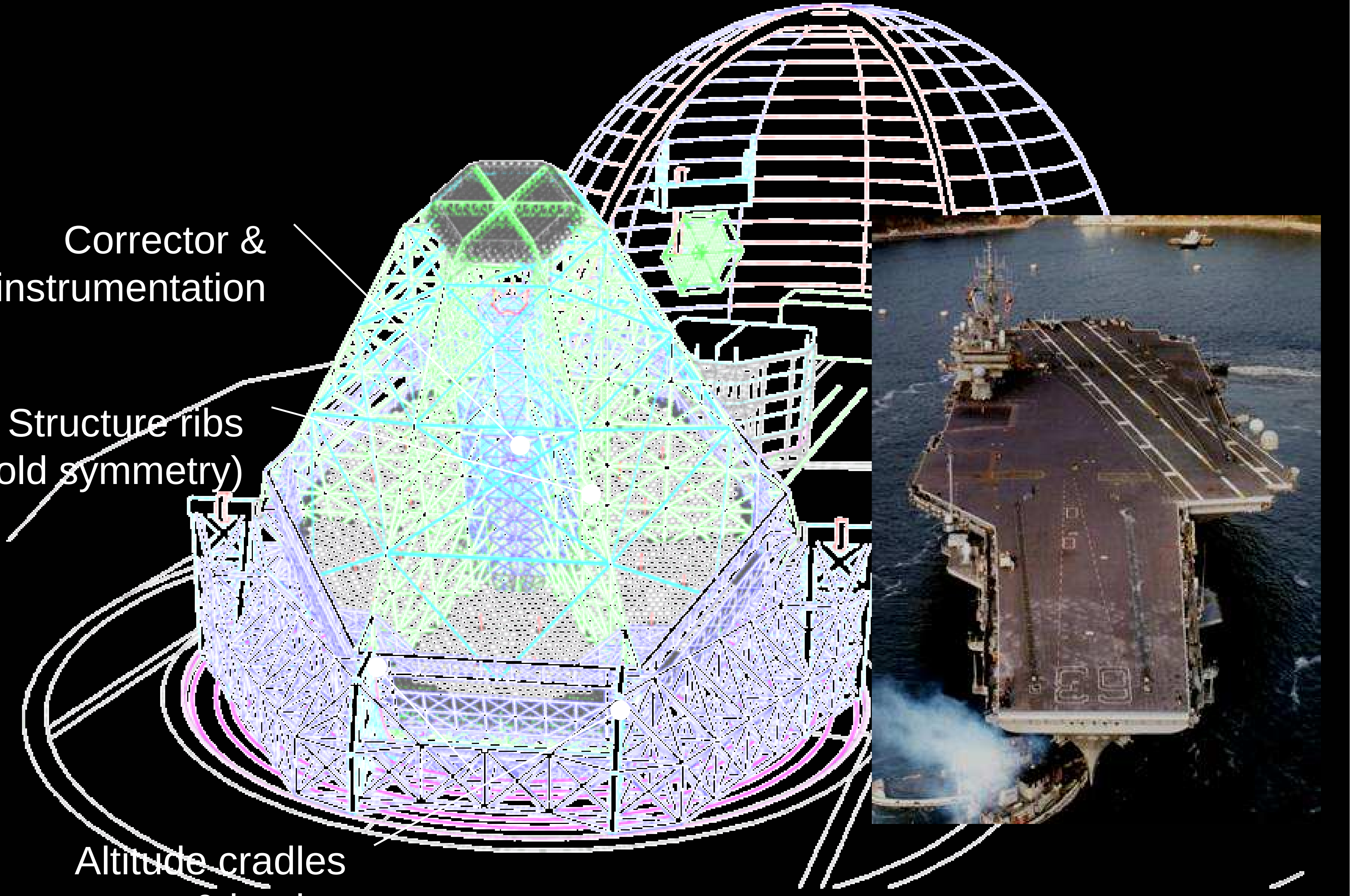

157 -m
310 -m
140 -m



Altitude bearing

Azimuth structure & bogies

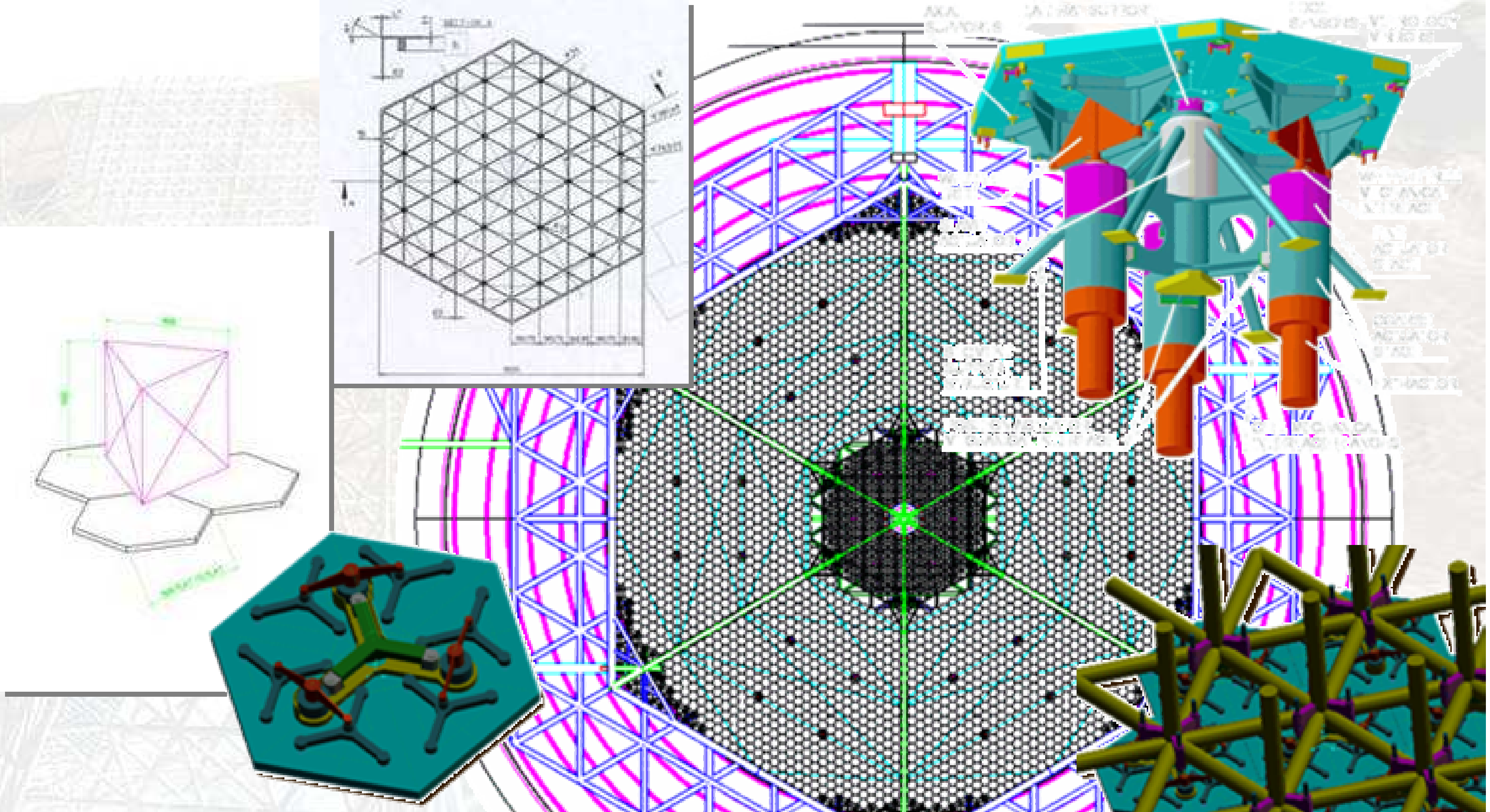
Altitude tracks

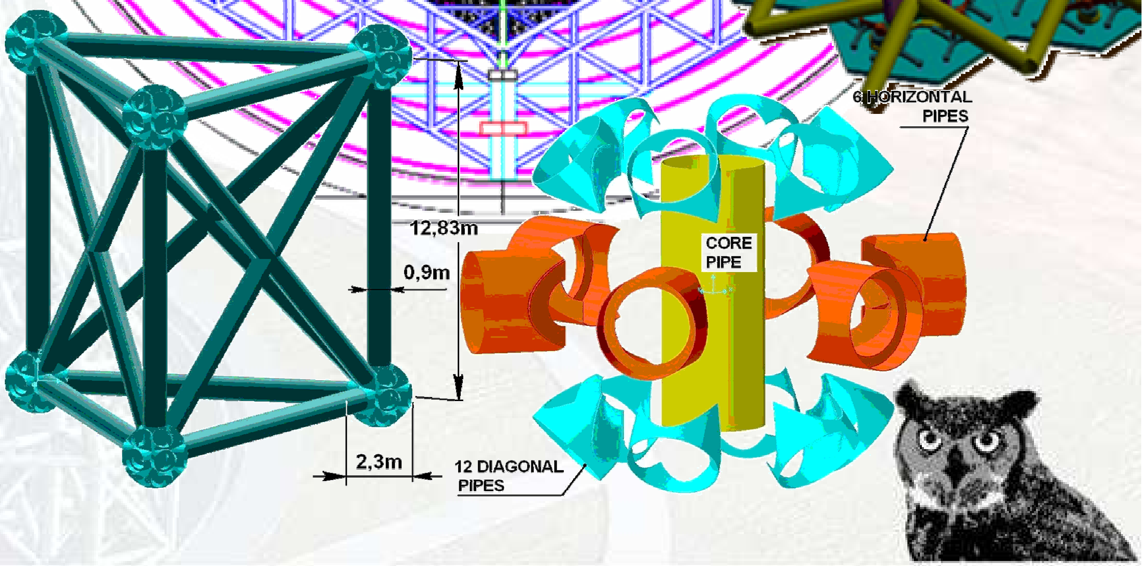


Corrector & instrumentation

Structure ribs (6-fold symmetry)

Altitude cradles & bogies





All dimensions as multiple of segment size

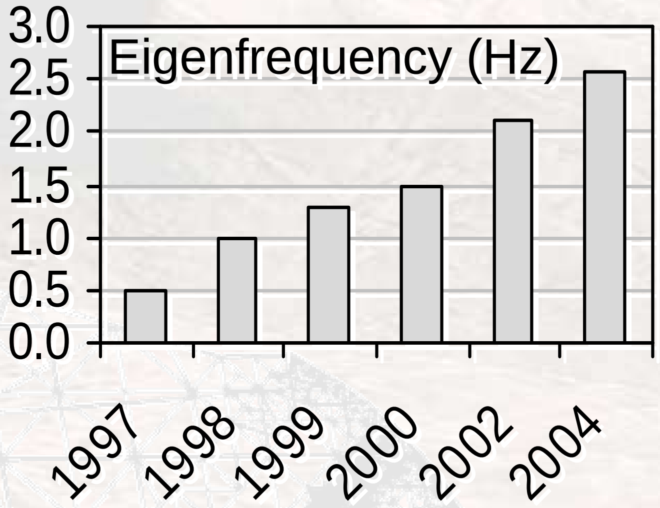
- Standardization
- Ease of integration
- Ease of maintenance
- Optimal loads transfers

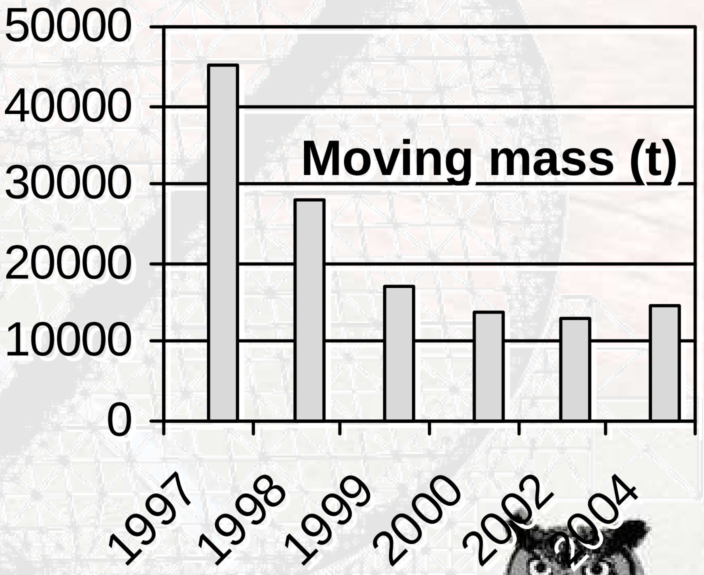
Optomechanics

Fractal design - Low-cost, lightweight steel structure

- **14,800 tons** moving mass
  (*60 times "lighter" than VLT*)
  Mass reduced to ~8,500 tons with SiC
  Ample safety margins (stresses, buckling)
- **2.6 Hz** locked rotor eigenfrequency
- Low thermal inertia
  (developed surface, natural internal air circulation inside structural elements)
- Differential M1-M2 decenters under gravity

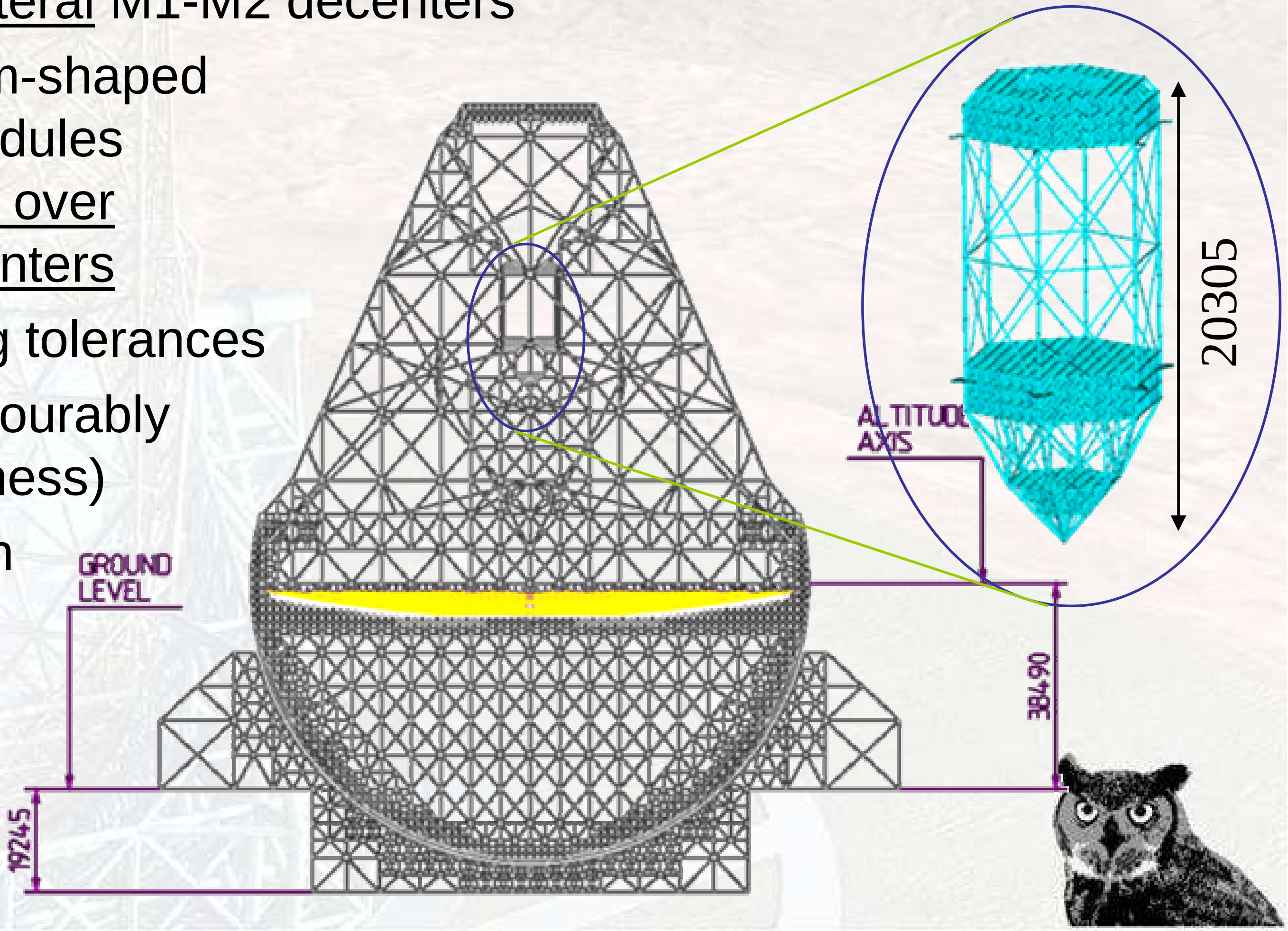
Piston	**3.4 mm**	**(rigid body motion)**
Lateral	**17.6 mm**	
Tilt	**3.4 arc secs**	





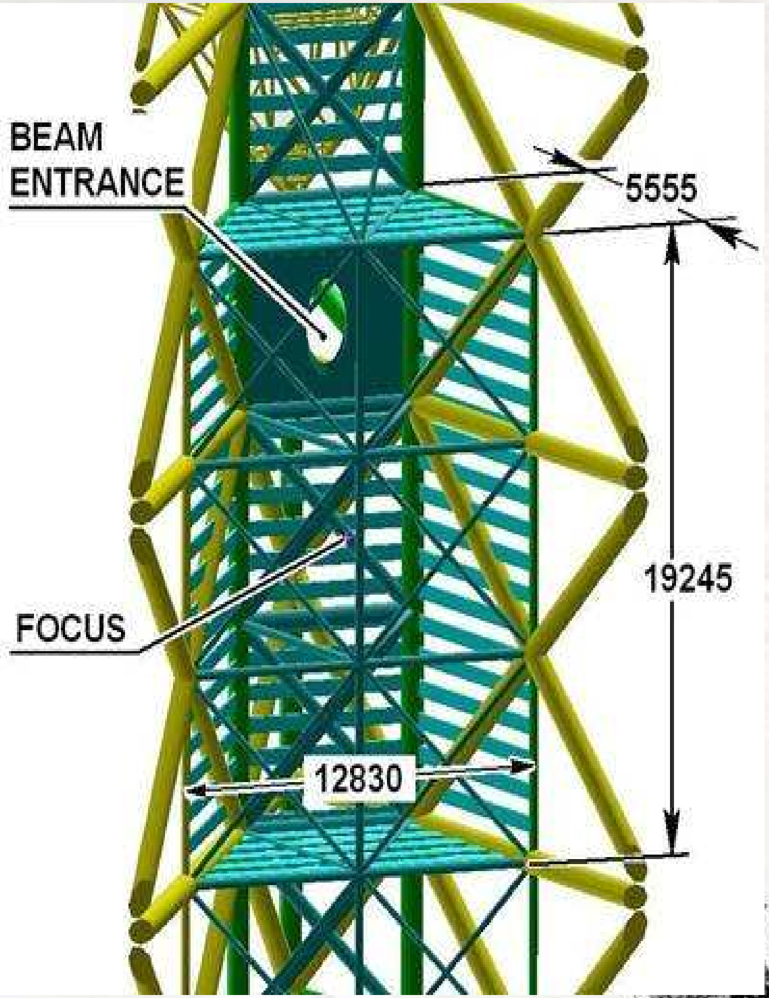
Reducing sensitivity by design

- Innocuous lateral M1-M2 decenters
- Parallelogram-shaped structural modules favour lateral over angular decenters
- Lose centring tolerances
- Corrector favourably located (stiffness)
- Ample design space



Instrument racks

- 6 focal stations; switch by rotating M6 about telescope axis.
- Max. instrument mass 15 tons each.
- Local insulation & air conditioning
- Issue: needs rigid connection with corrector (TBC).



Controlled optical system

<u>Pre-setting</u> ⇨ *bring optical system into linear regime*
Metrology: internal, tolerances ~ 1-2 mm, ~5 arc secs
Correction: re-position Corrector, M3 / M4 / M5

<u>Phasing</u> ⇨ *keep M1 and M2 phased within tolerances*
Metrology: Edge sensors, Phasing WFS
Correction: Segments actuators

<u>Field Stabilization</u> ⇨ *cancel “fast” image motion*
Metrology: Guide probe
Correction: M6 tip-tilt (flat, exit pupil, 2.35-m)

<u>Active optics</u> ⇨ *finish off alignment / collimation*
⇨ *relax tolerances, control performance & prescription*
Metrology: Wavefront sensor(s)
Correction: Rotation & piston M5; M3 & M4 active deformations

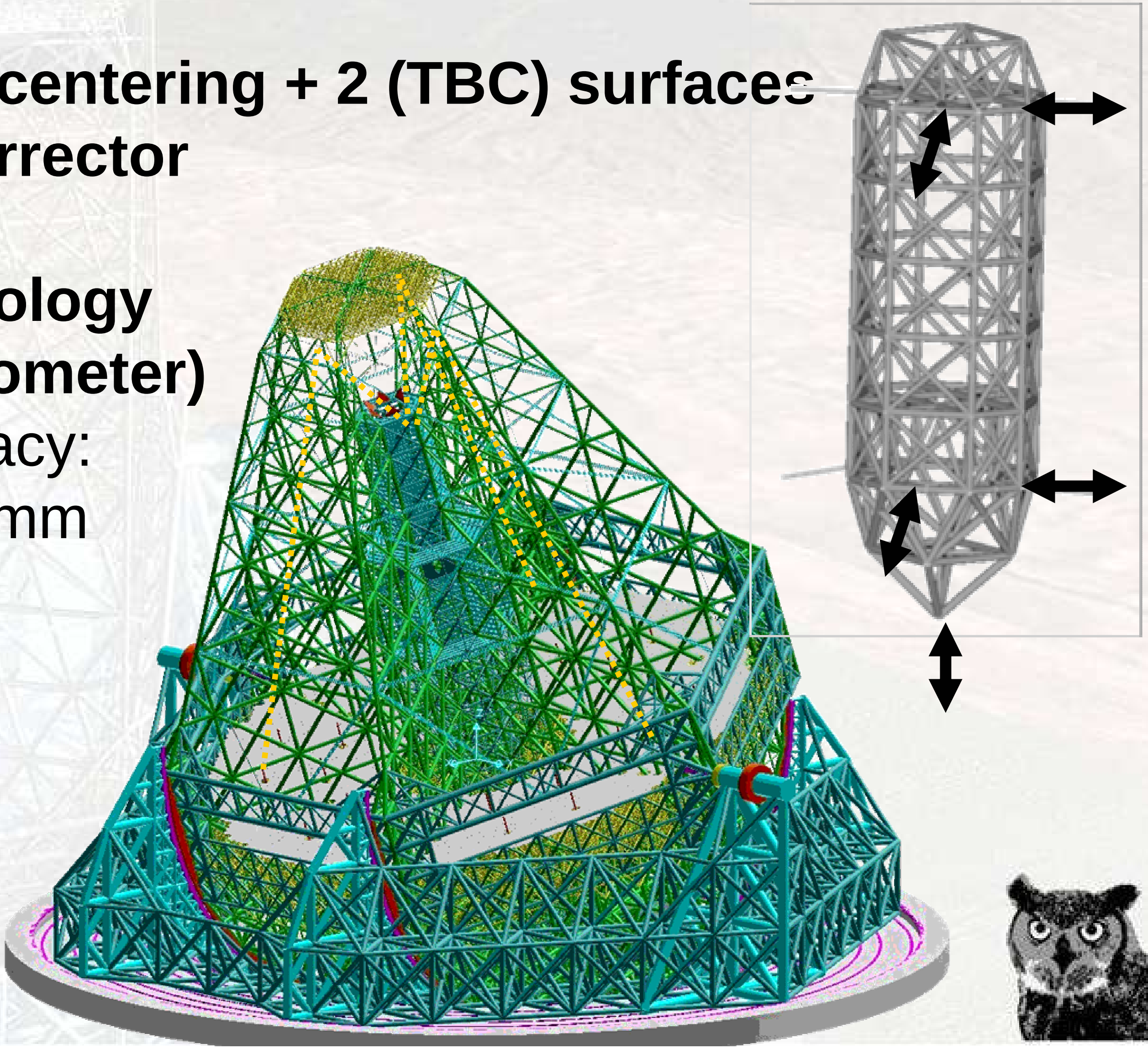
<u>Adaptive optics</u> ⇨ atmospheric turbulence, residuals
Metrology: Wavefront sensor(s)
Correction: M5, M6, …

Controlled opto-mechanical system
I – Pre-setting

Corrector re-centering + 2 (TBC) surfaces within the corrector

Internal metrology (fiber extensometer)
Typical accuracy:
Better than 1 mm
@ 100-m

Bandwidth
<< 1 Hz



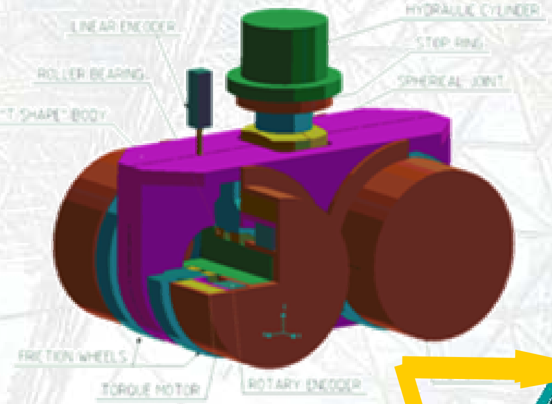
Controlled opto-mechanical system
II - Kinematics

Friction drives

Azimuth: 246 units

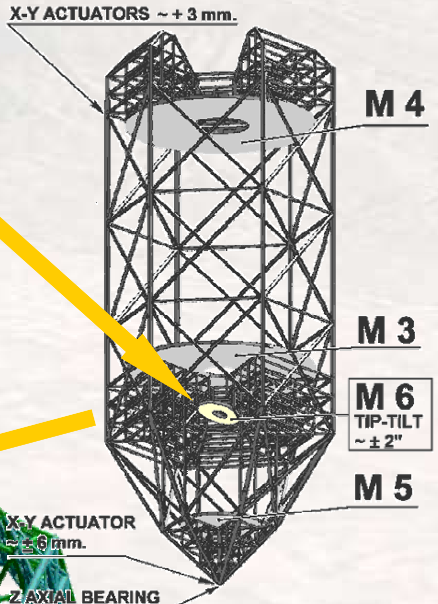
Elevation: 154 units

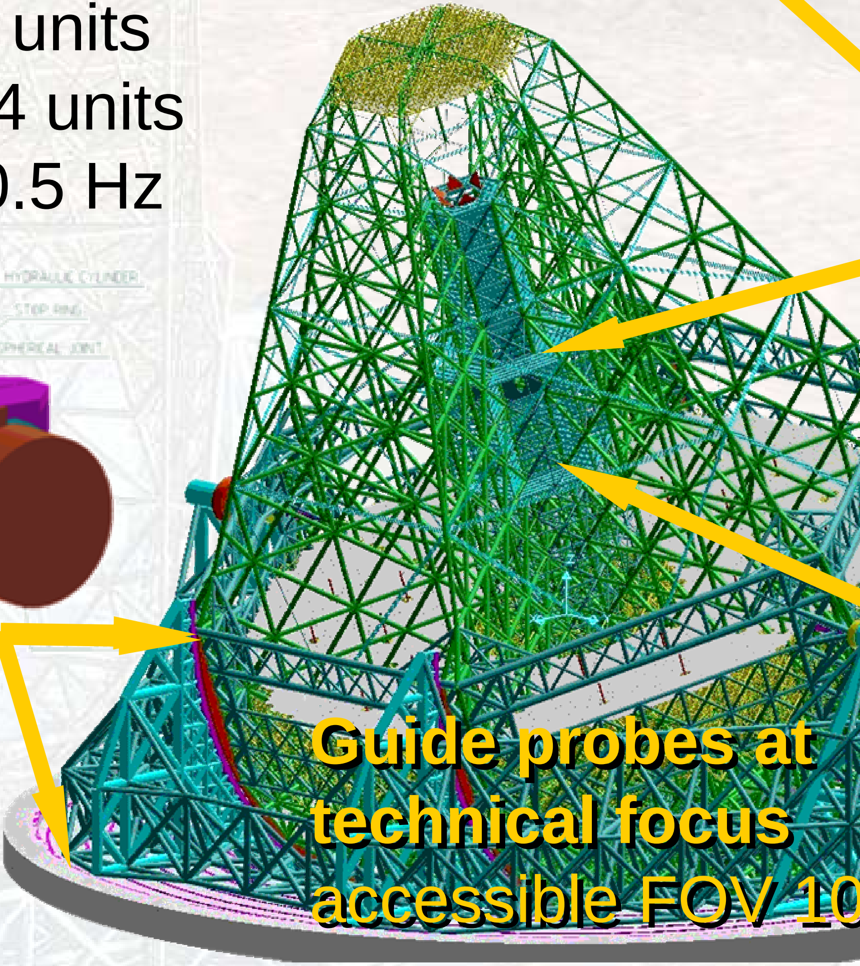
Bandwidth ~0.5 Hz



Fast steering mirror

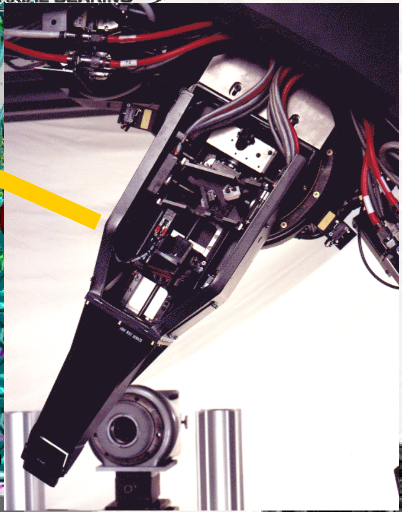
M6, dia. 2.35m





Guide probes at technical focus

accessible FOV 10’



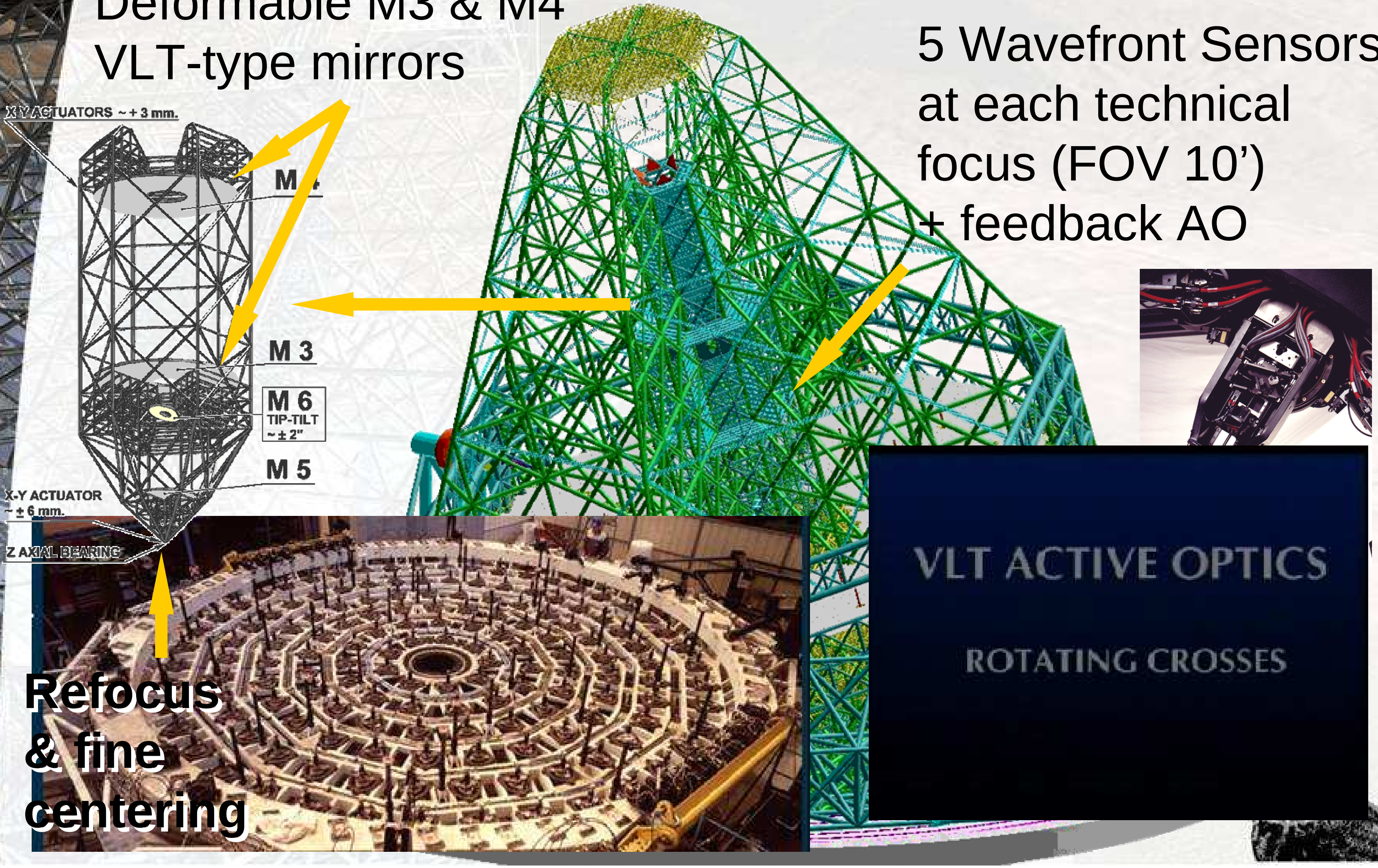
Controlled opto-mechanical system
III – Active optics

Dual conjugate active optics

Deformable M3 & M4

VLT-type mirrors

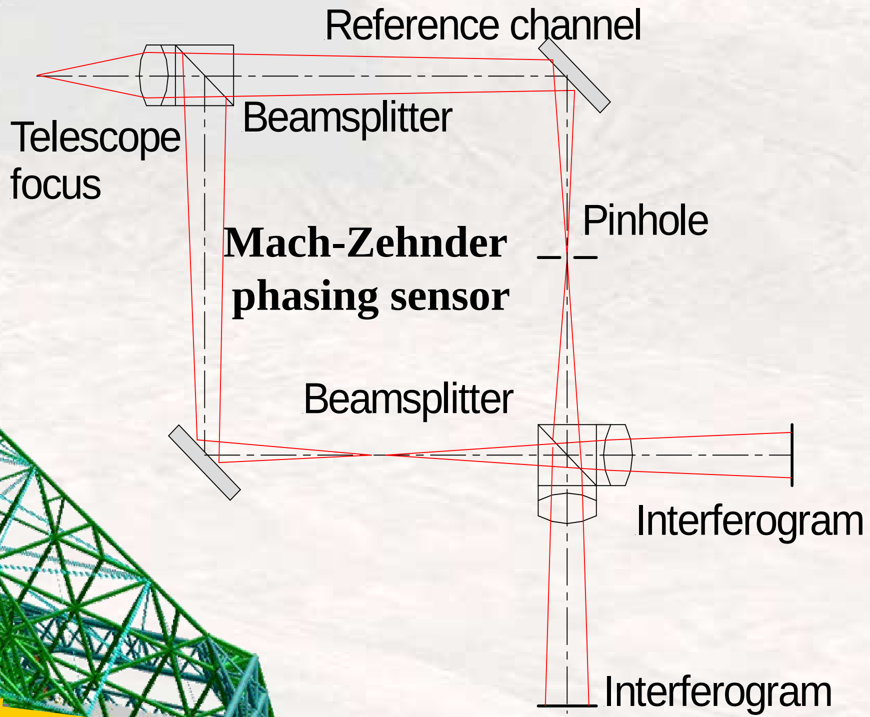
5 Wavefront Sensors at each technical focus (FOV 10’) + feedback AO

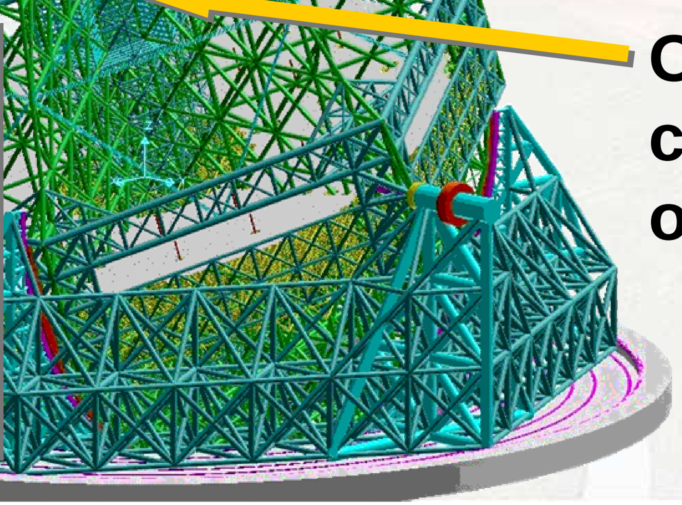


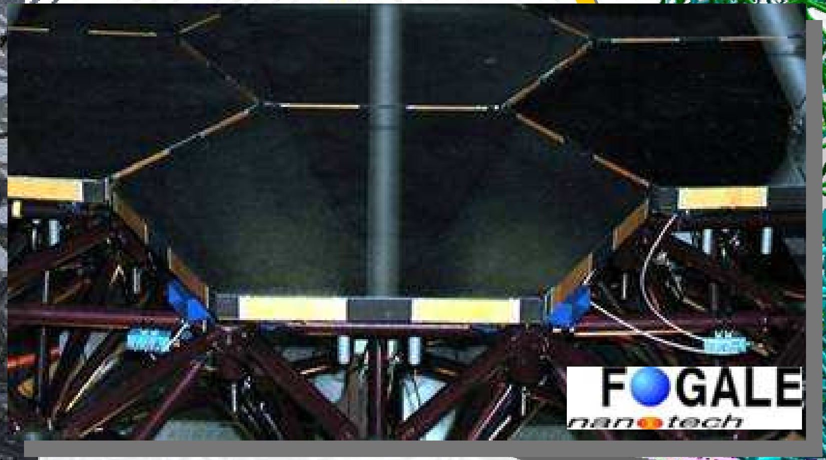
Refocus & fine centering

Controlled opto-mechanical system
IV – Phasing

Two segmented mirrors
Bandwidth ~5 Hz TBC
Edge sensors (capacitive, Inductive or optical)

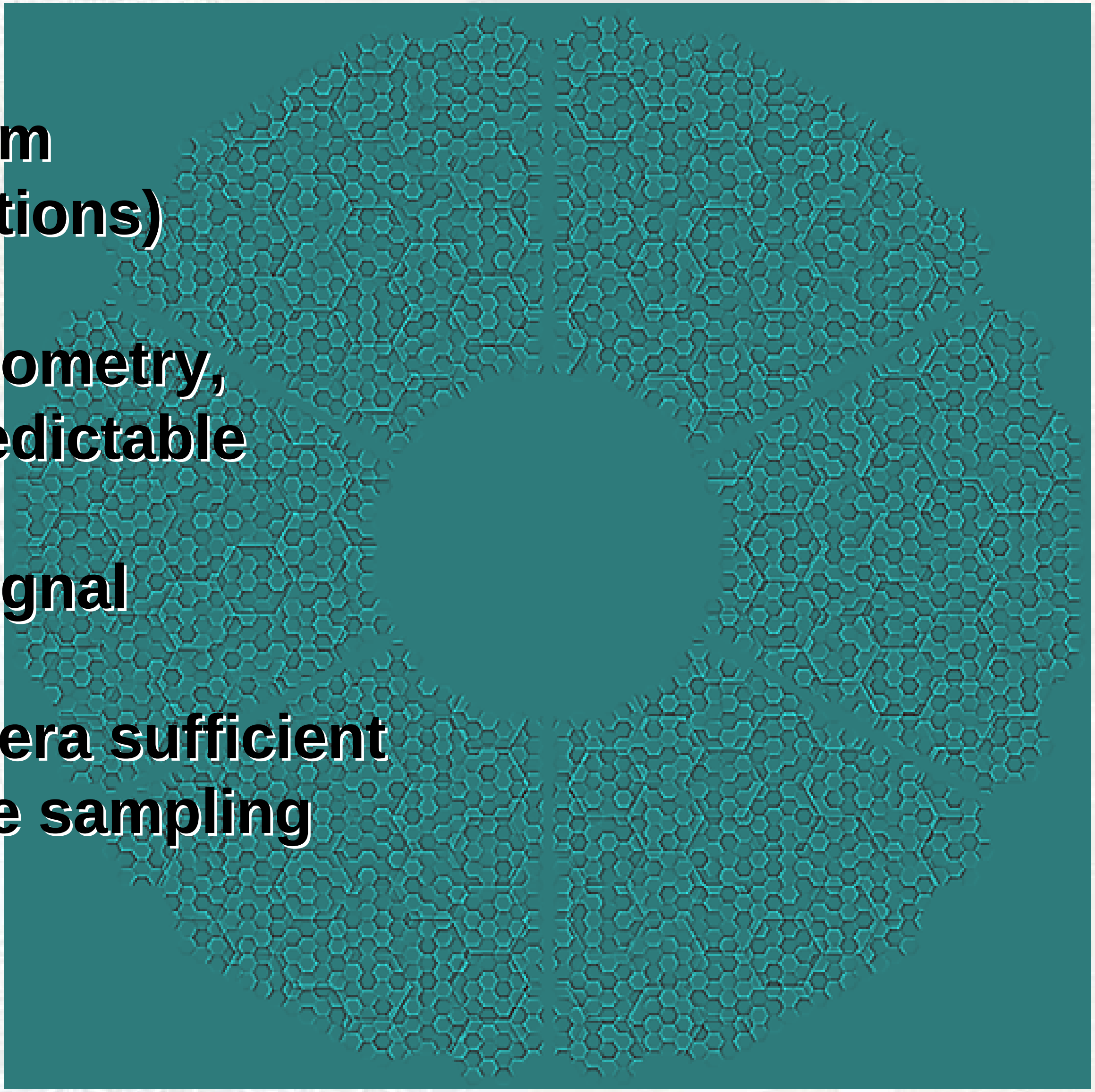






On-sky calibration off-axis

Mach-Zehnder calibration sensor



Interferogram (ideal conditions)

Complex geometry, But fully predictable

Localized signal

2k x 2k camera sufficient for adequate sampling

Piston, Tip, and Tilt: Examples

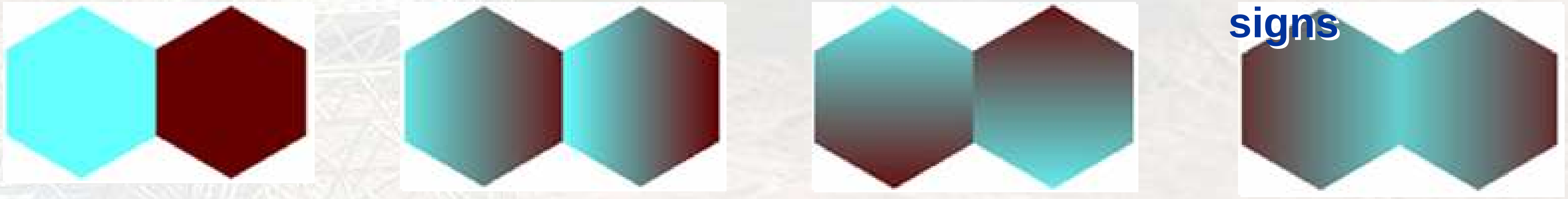
Piston only

X – tilts same signs

Y – tilts opposite signs

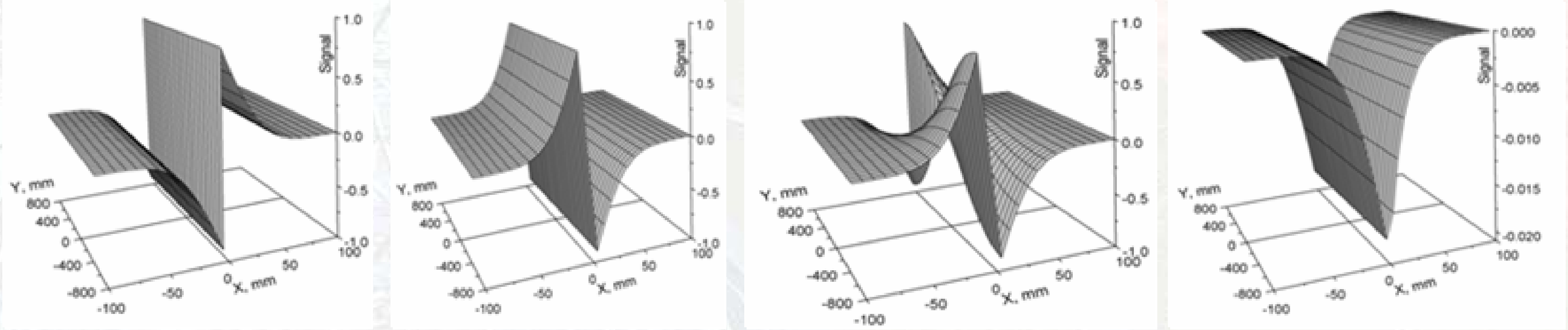
X – tilts opposite signs

Phase



Signal

Features



Antisymmetry axis Y

Antisymmetry axis Y

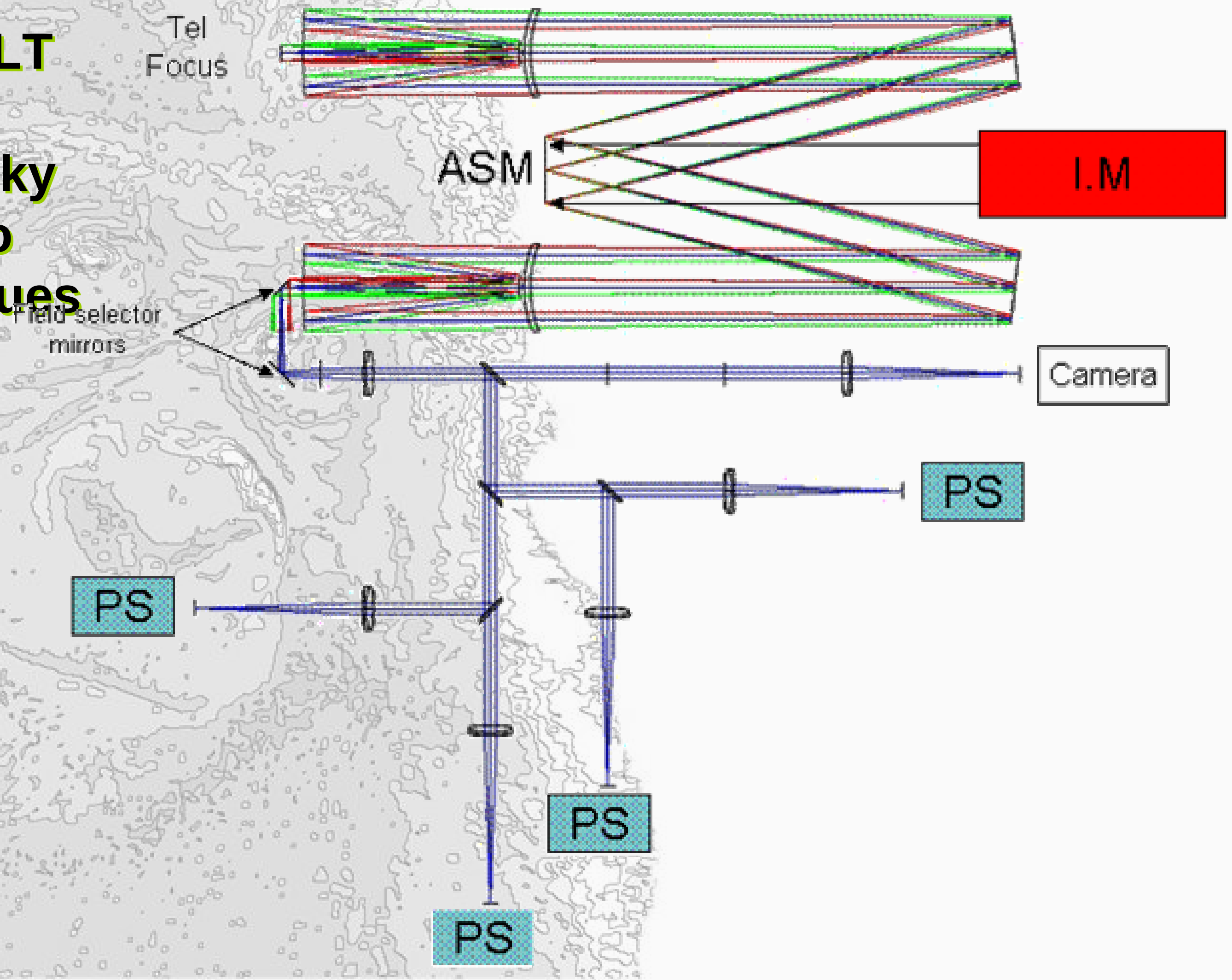
Antisymmetry axis X

Symmetry axis Y

From concept to sky testing: APE

Active Phasing Experiment

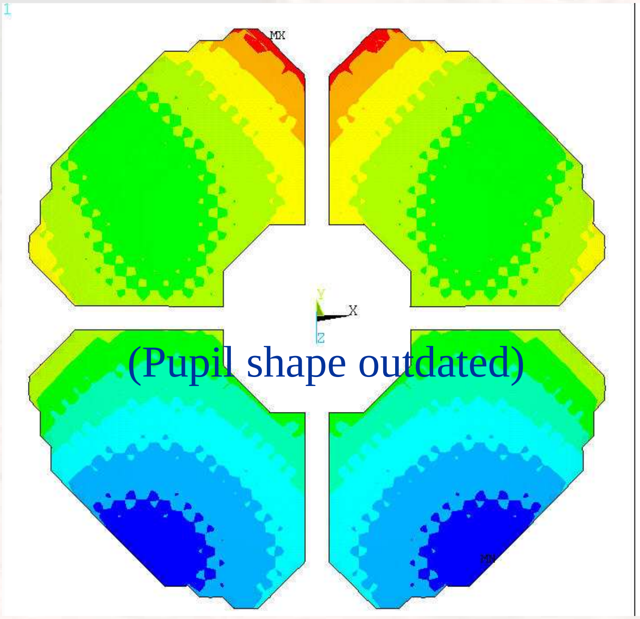
- Segmenting the VLT
- Laboratory & on-sky evaluation of up to 3 phasing techniques
- Integration of phasing into global wavefront control
- On-sky by 2007



Telescope performance (wind)

Tracking : low concern

- M2 flat ! Design insensitive to M2 lateral decenters
- Structural design privileges M2 lateral decenter over M2 tilt
- Corrector at very stiff location



(Pupil shape outdated)

DYNAMIC ANALYSIS

Worst caseS combined (orientation), 10 m/s, conservative drag coefficients

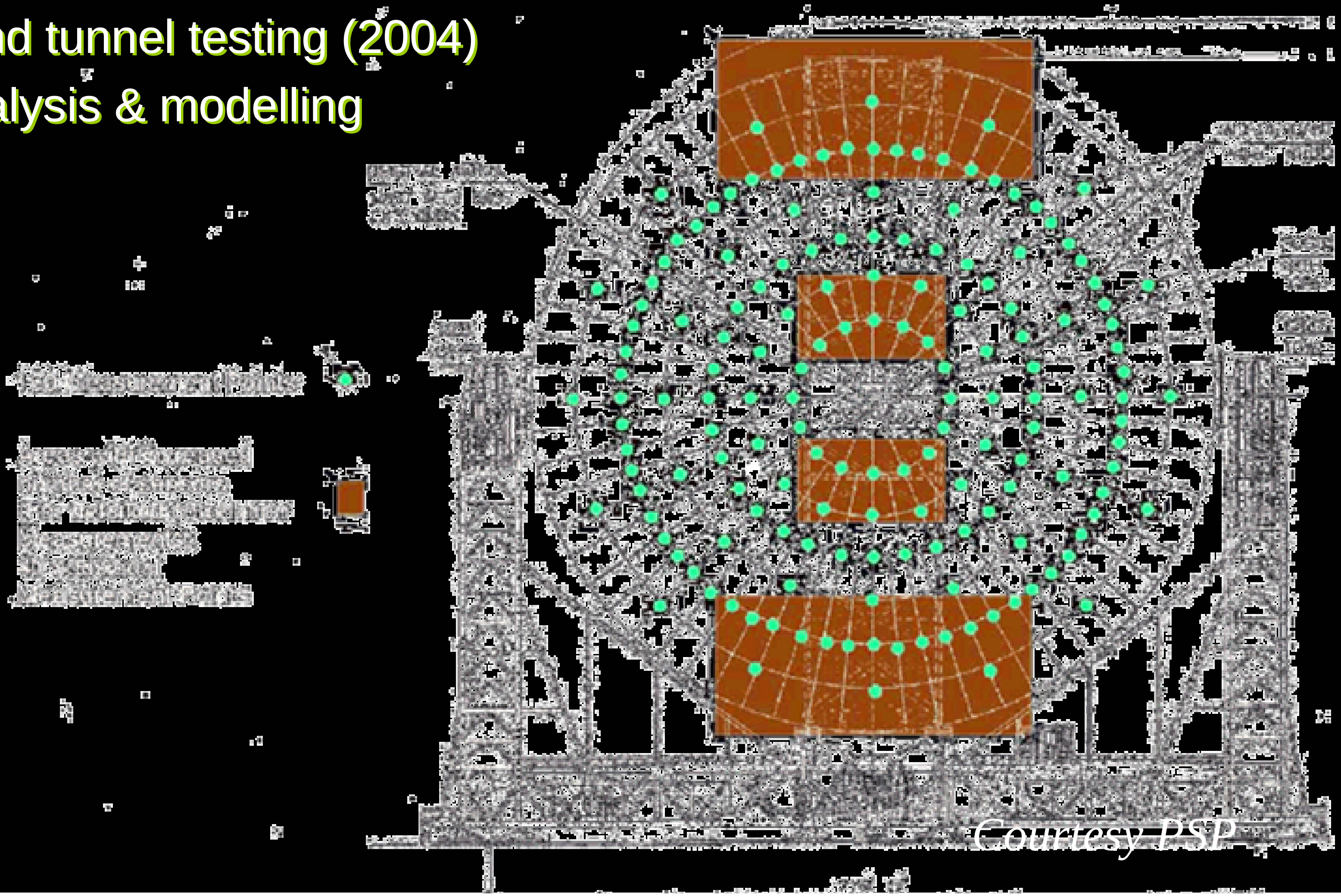
Maximum mean displacements out of worst load cases

Mirror	Piston (uz)	Tilt (rotx)	Decenter (uy)
	[mm]	[arcsec]	[mm]
M1	-0.216	0.420	-0.129
M2	-0.336	1.680	-1.132

Wind

MODELLING & TESTING

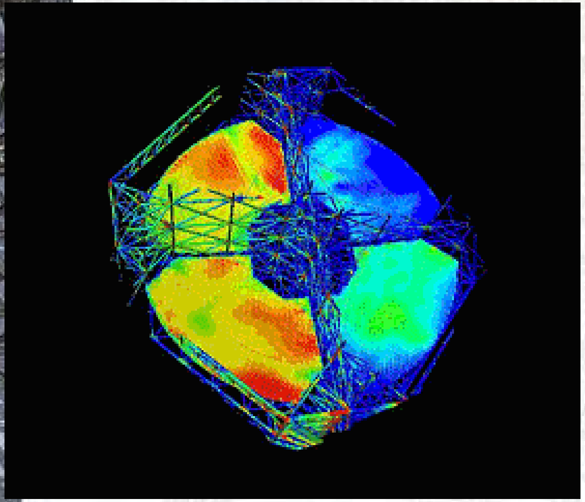
- Limited confidence in CFD (Results suspiciously good !)
- Wind measurements at Jodrell Bank (2004)
- Wind tunnel testing (2004)
- Analysis & modelling



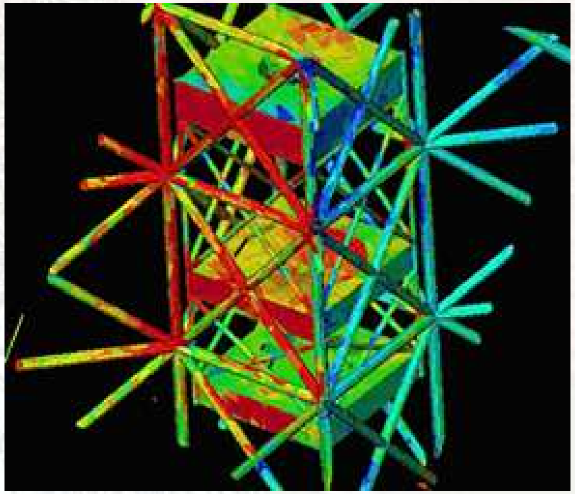
Courtesy PSP

Wind (pressure distributions)

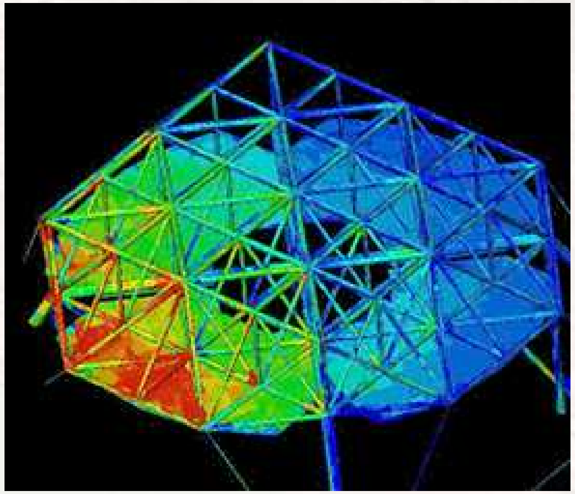
ACCELERATED - ACTUAL ELAPSED TIME 150 SECONDS



M1



Corrector

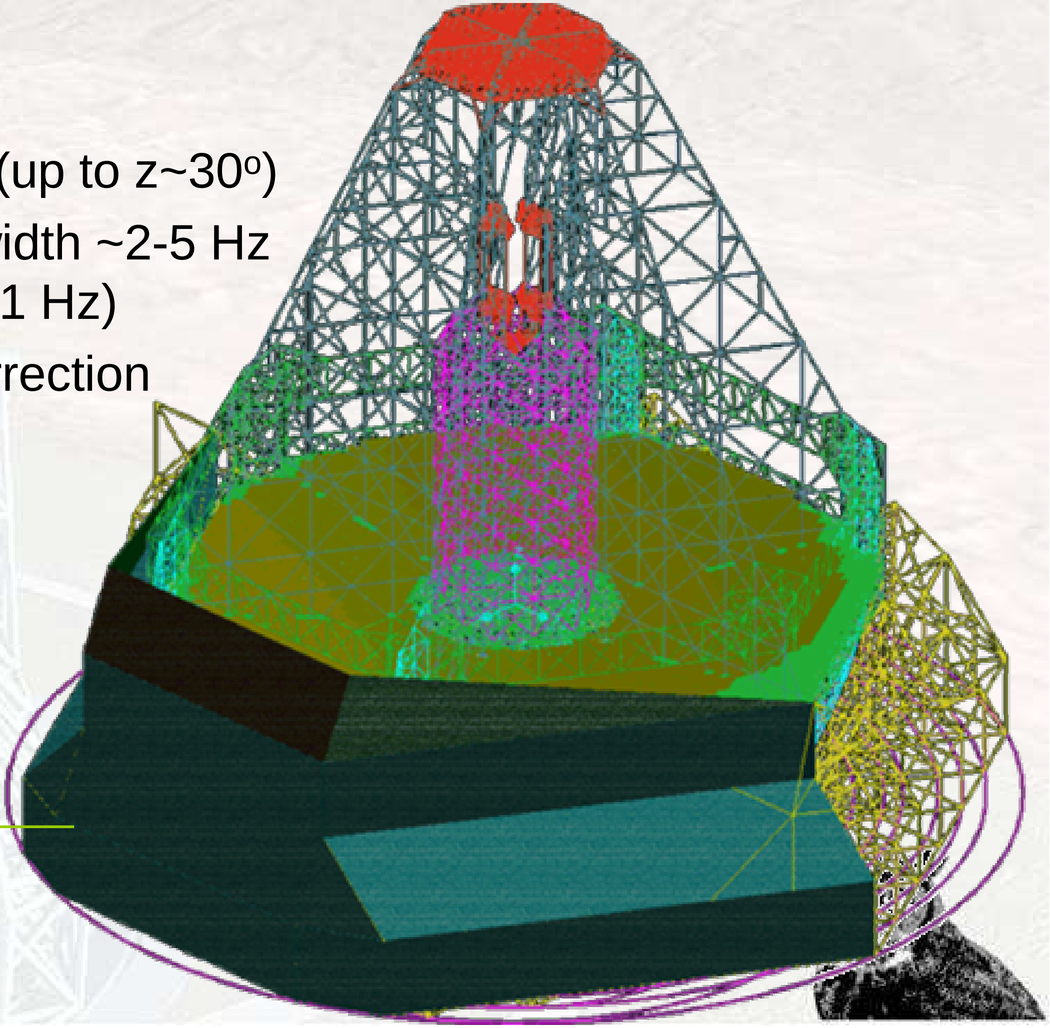


M2

Wind – design options

1. Higher local stiffness (substructure supporting segments)
   ⇨ increases resistance to high spatial frequencies
2. Use of SiC segments
   ⇨ higher M1 & M2 bandwidth
3. Embedded variable wind screens (up to z~30º)
4. Increase M4 (active mirror) bandwidth ~2-5 Hz
   (VLT M1 support dimensioned for 1 Hz)
5. Increase range of M6 adaptive correction
6. Operational constraints
7. Site selection

… required
for AO anyway



Variable wind screen embedded in the azimuth structure (notional design);
M2 wind screen not shown

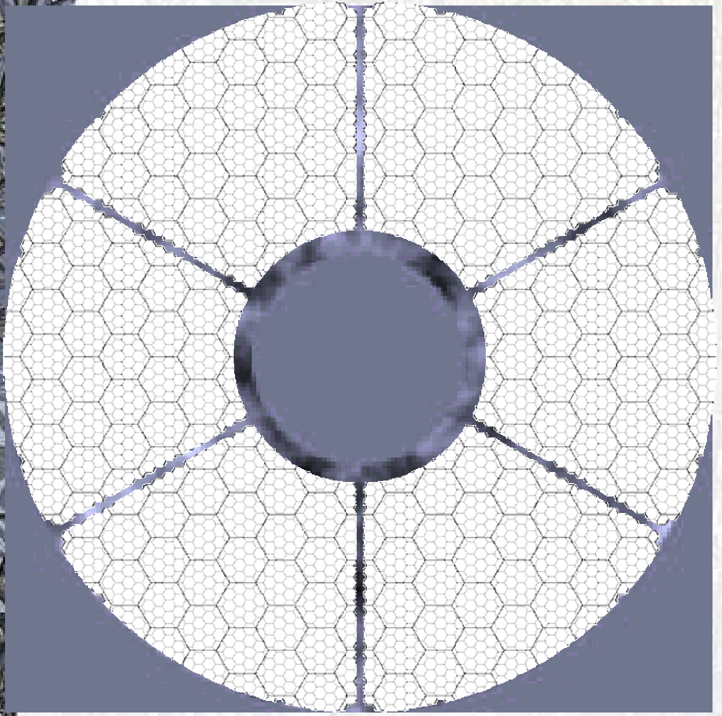
Adaptive Optics

	Today	2008	2015	2019
IR Deformable Mirrors	LBT (JWST)	Prototype	OWL 1st Gen.	2nd Gen.
Diameter	**1-m (2-m)**	**0.3-m**	**2-m**	**4-m**
Actuator spacing	**30 mm**	**15 mm**	**10-15 mm**	**10 mm**
XAO corrector				Moems/Pzt
Detector	256x256 ?		512x512	1kx1k
AO real time control			*Almost OK*	
Reference stars	NGS (LGS)		NGS	NGS / LGS

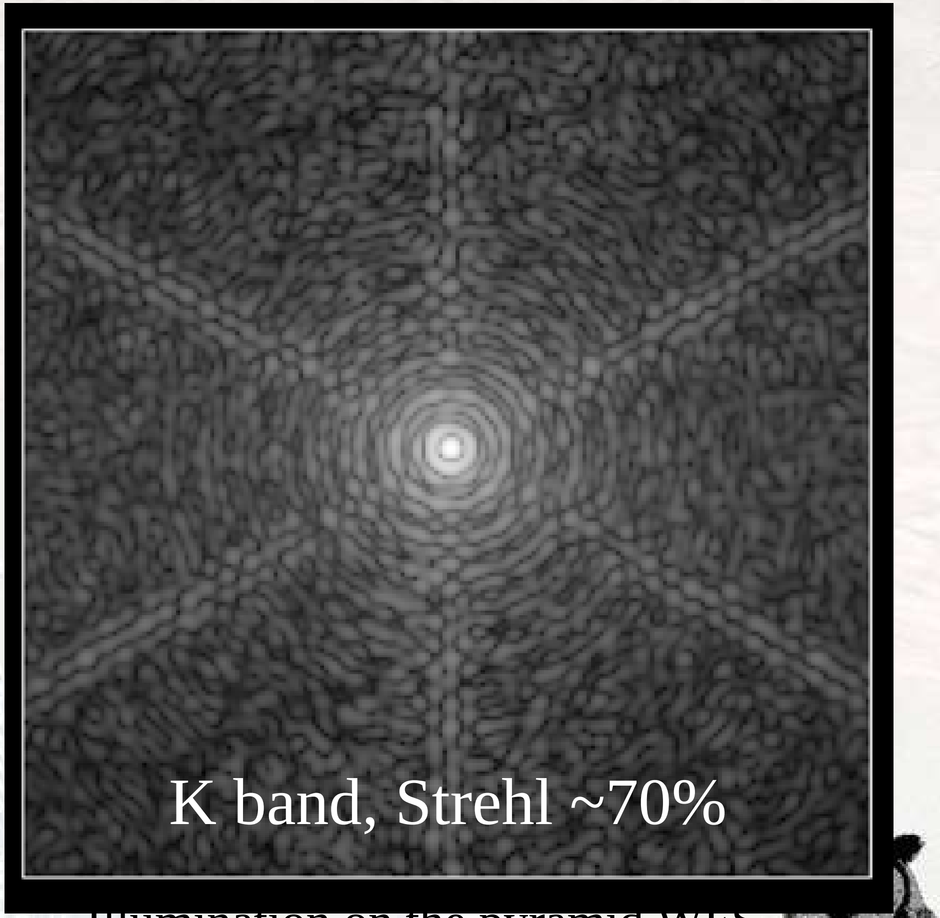
- High sky coverage in the near-IR (better filling of metapupil)
- LGS needed ~2018; lower number of LGS,
- Cone effect requires novel approaches e.g. PIGS (Ragazzoni et al)

AO Simulations on OWL.

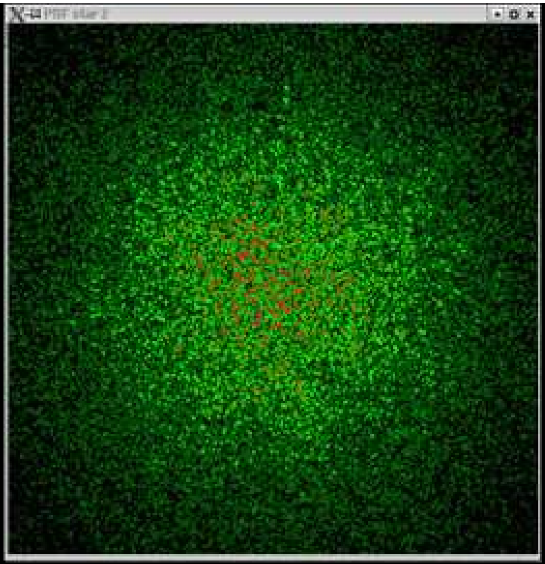
125 sub-apertures across pupil, 11198 actuators on M6
Bright NGS on-axis, 1 kHz frame-rate, ~1 sec of real-life PSF
4 ms coherence time, 0.5’’ seeing (at 0.5 μm)
OWL pupil + cophasing M1 & M2: 35 nm WFE RMS each

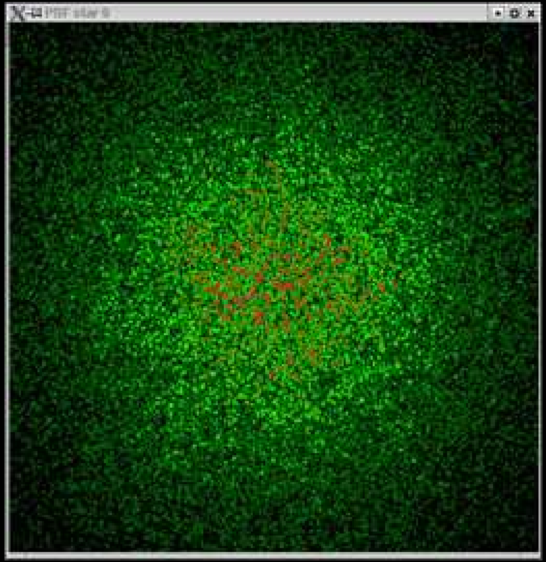


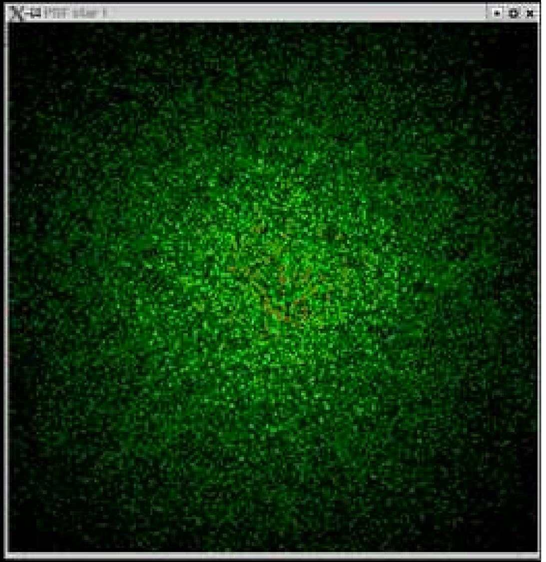
Atmosheric Wavefront

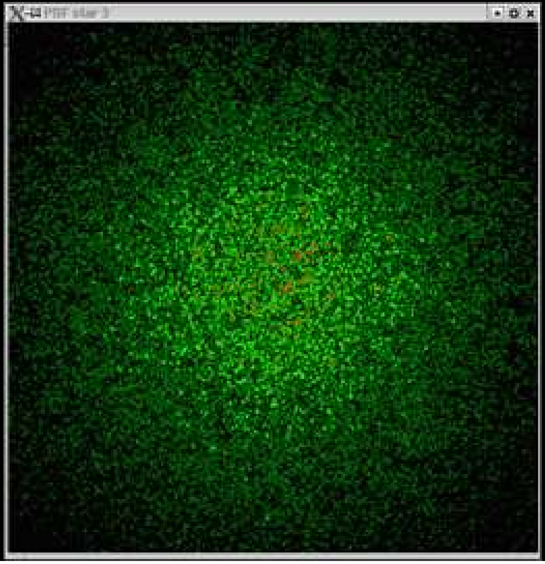


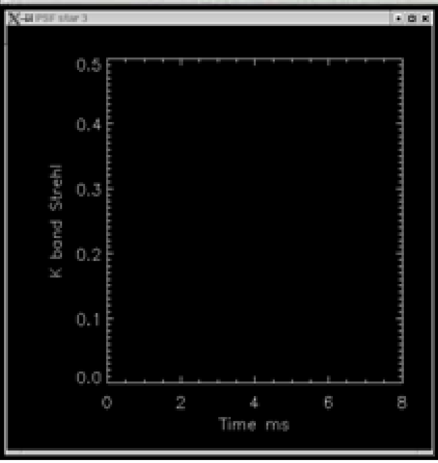
Illumination on the pyramid WFS

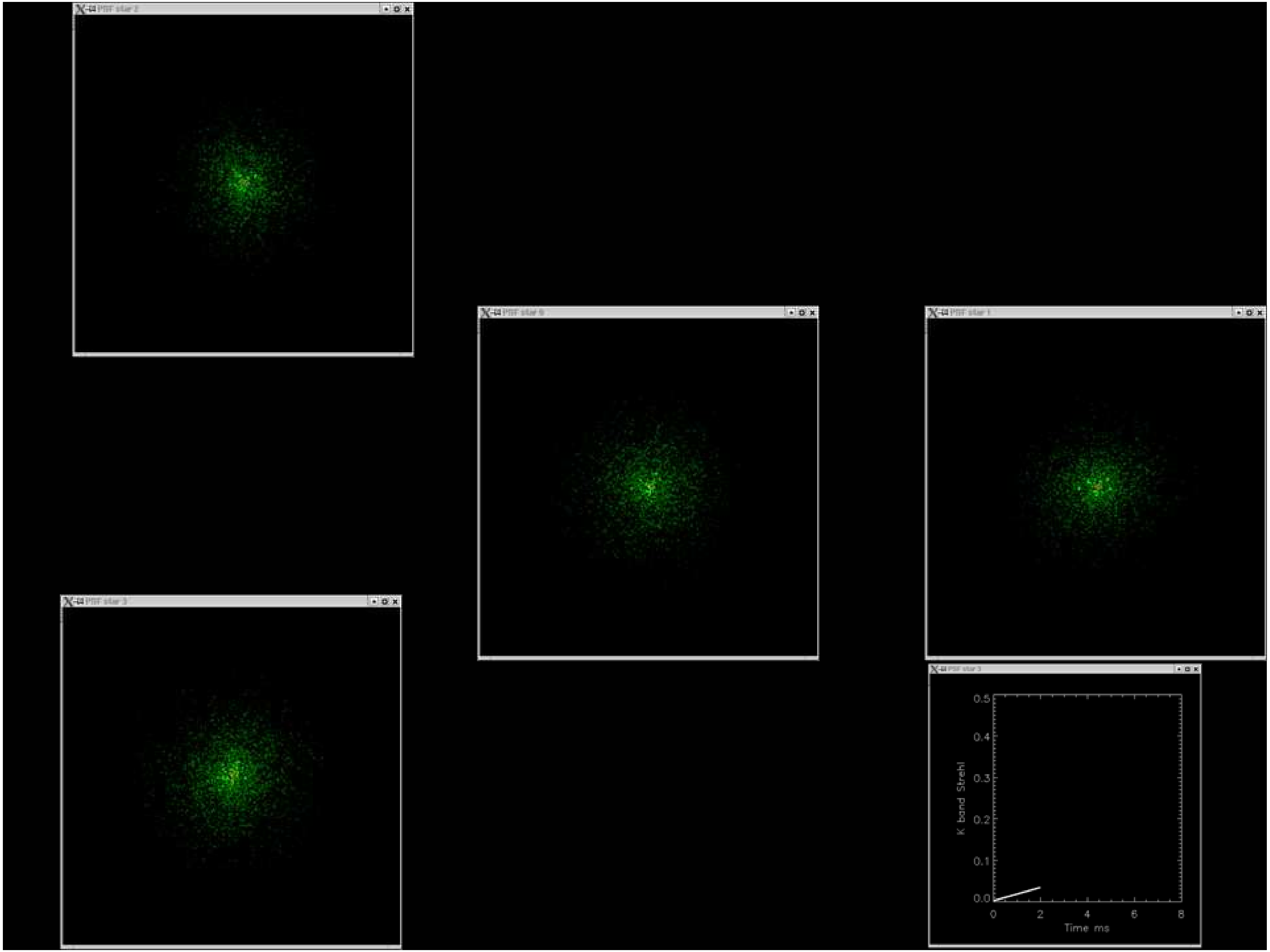

PSF star 2

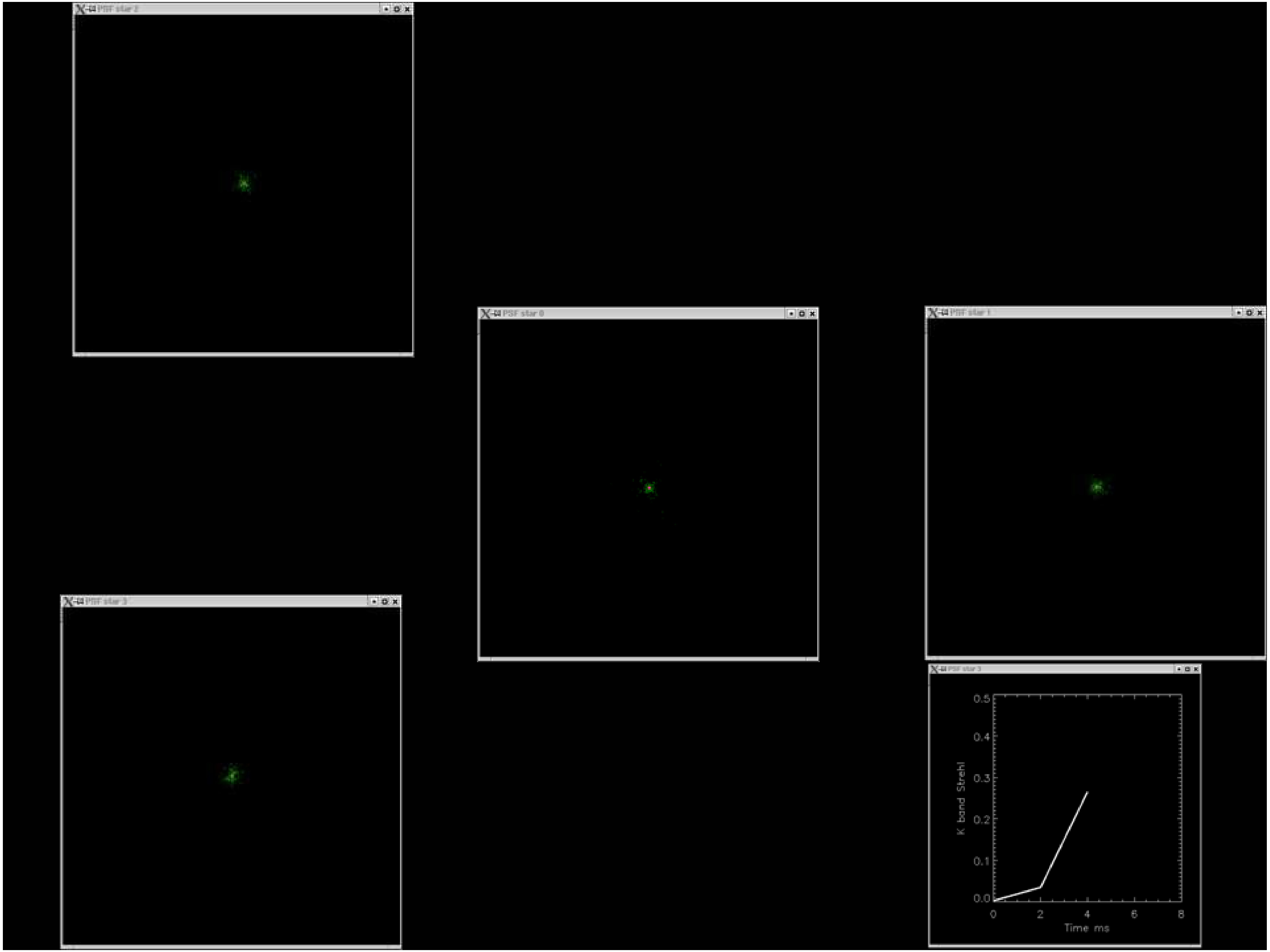

PSF star 0

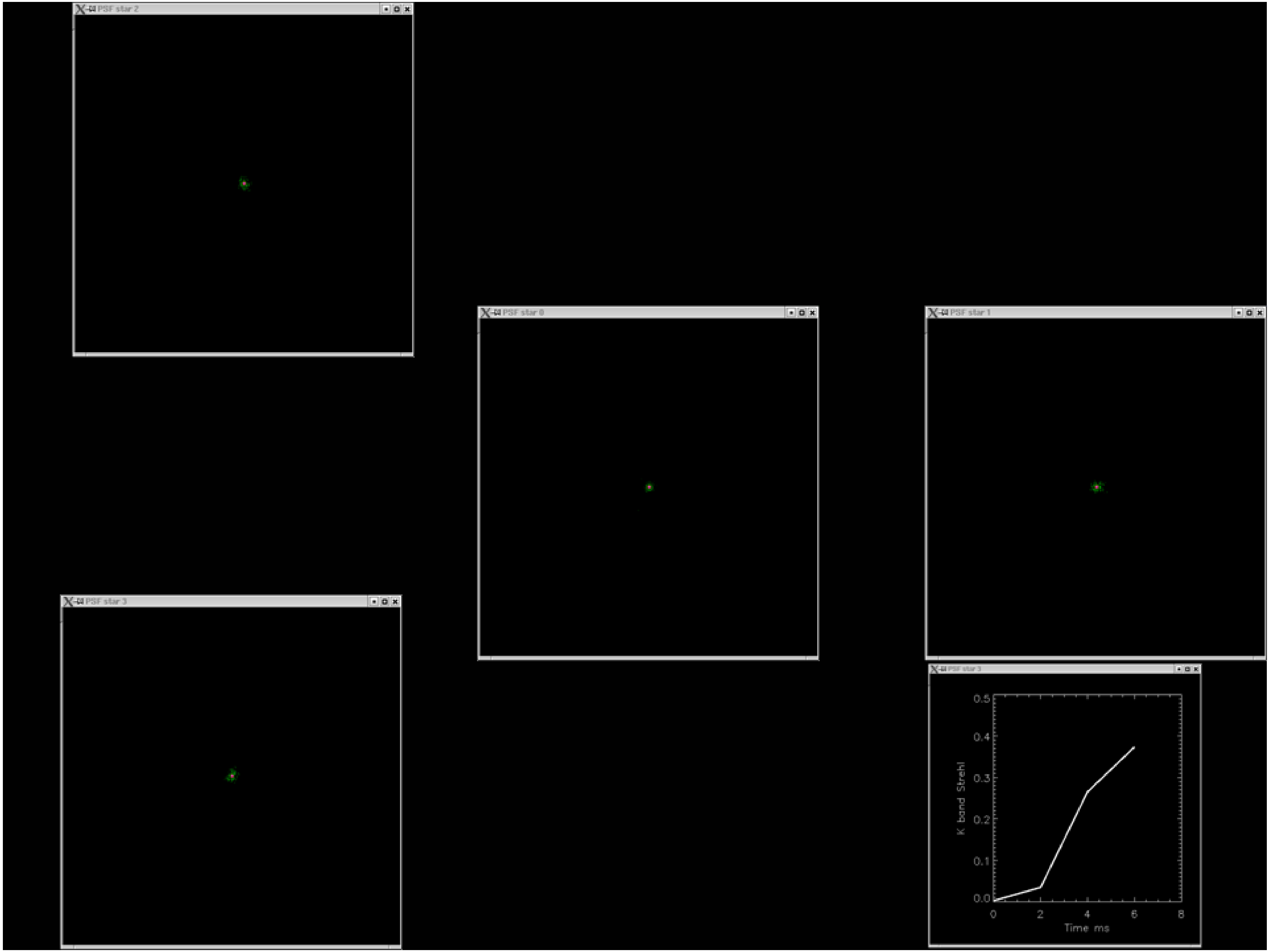

PSF star 1


PSF star 3

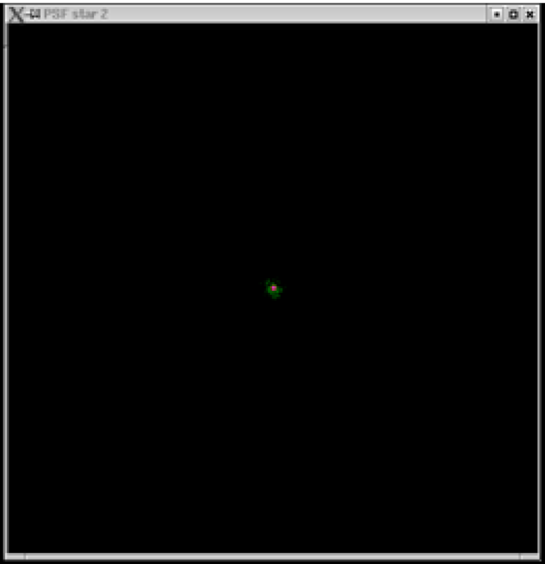

PSF star 3
0.5
0.4
0.3
0.2
0.1
0.0
K band Strehl
0
2
4
6
8
Time ms

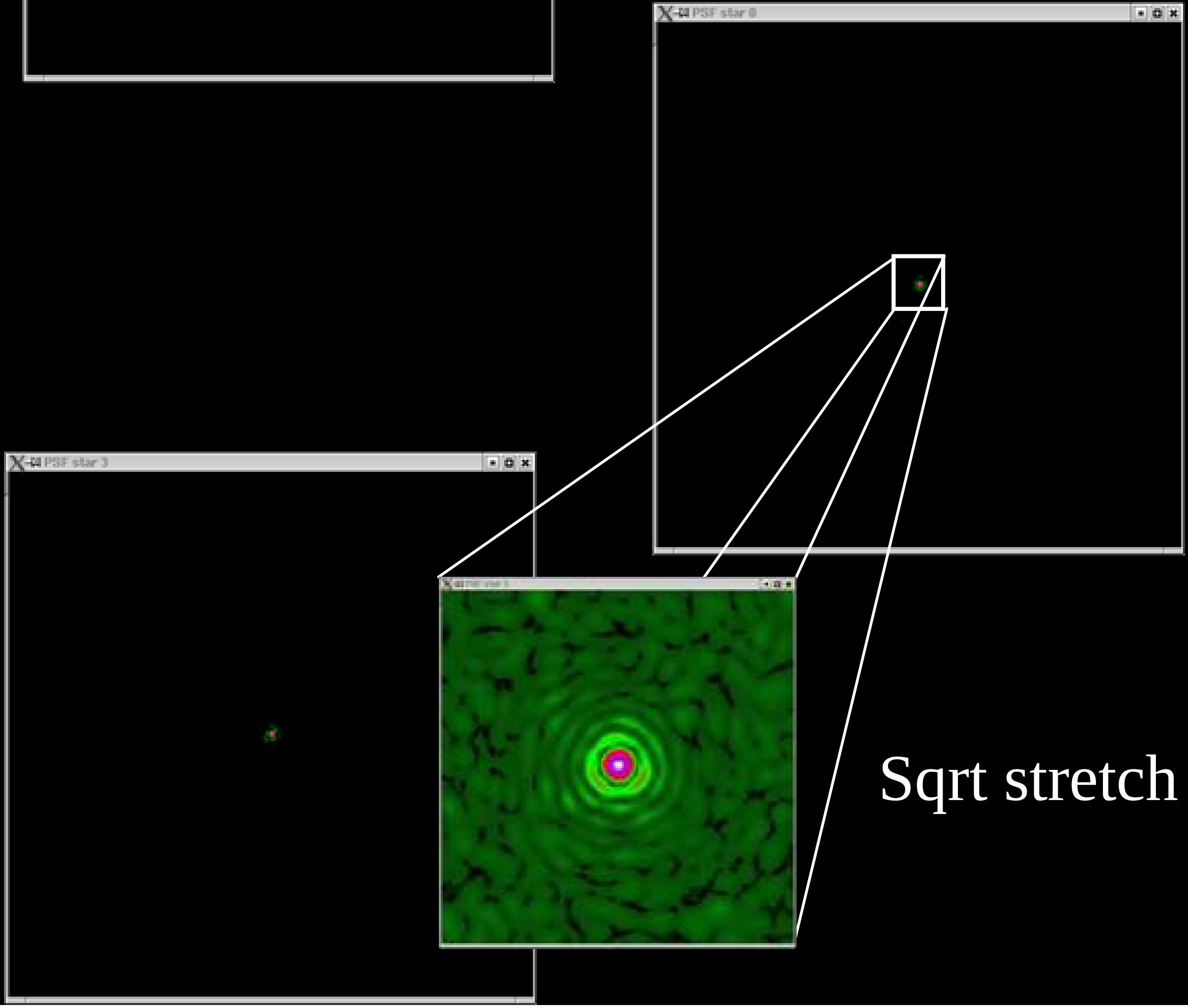

PSF star 2
PSF star 6
PSF star 1
PSF star 3
PSF star 3
K band Strehl
0.0
0.1
0.2
0.3
0.4
0.5
0
2
4
6
8
Time ms


PSF star 2
PSF star 0
PSF star 1
PSF star 3
PSF star 3
K band Strehl
0.0
0.1
0.2
0.3
0.4
0.5
0
2
4
6
8
Time ms

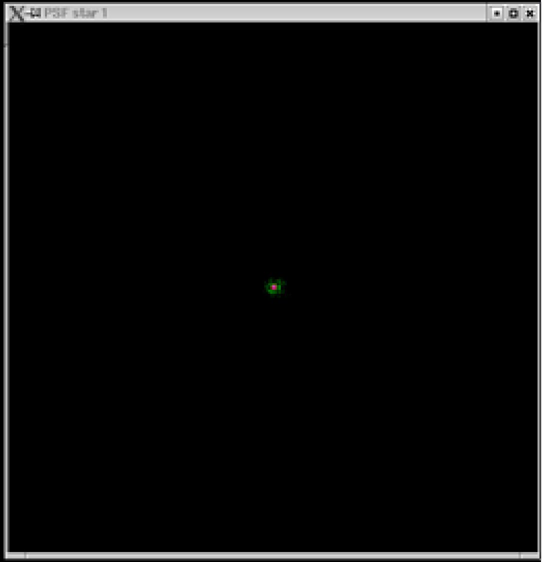

PSF star 2
PSF star 0
PSF star 1
PSF star 3
PSF star 3
K band Strehl
0.0
0.1
0.2
0.3
0.4
0.5
0
2
4
6
8
Time ms

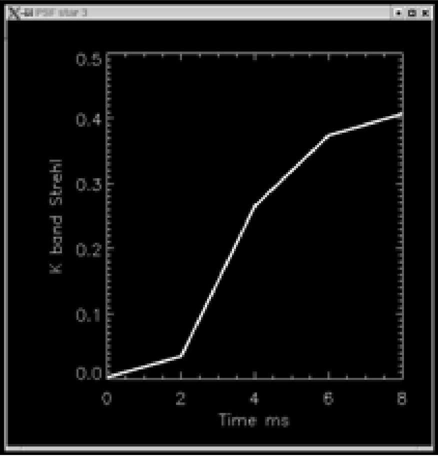
2 arc minutes field, λ=2.5 μm
2 adaptive mirrors, 8000 actuators each
3 guide stars

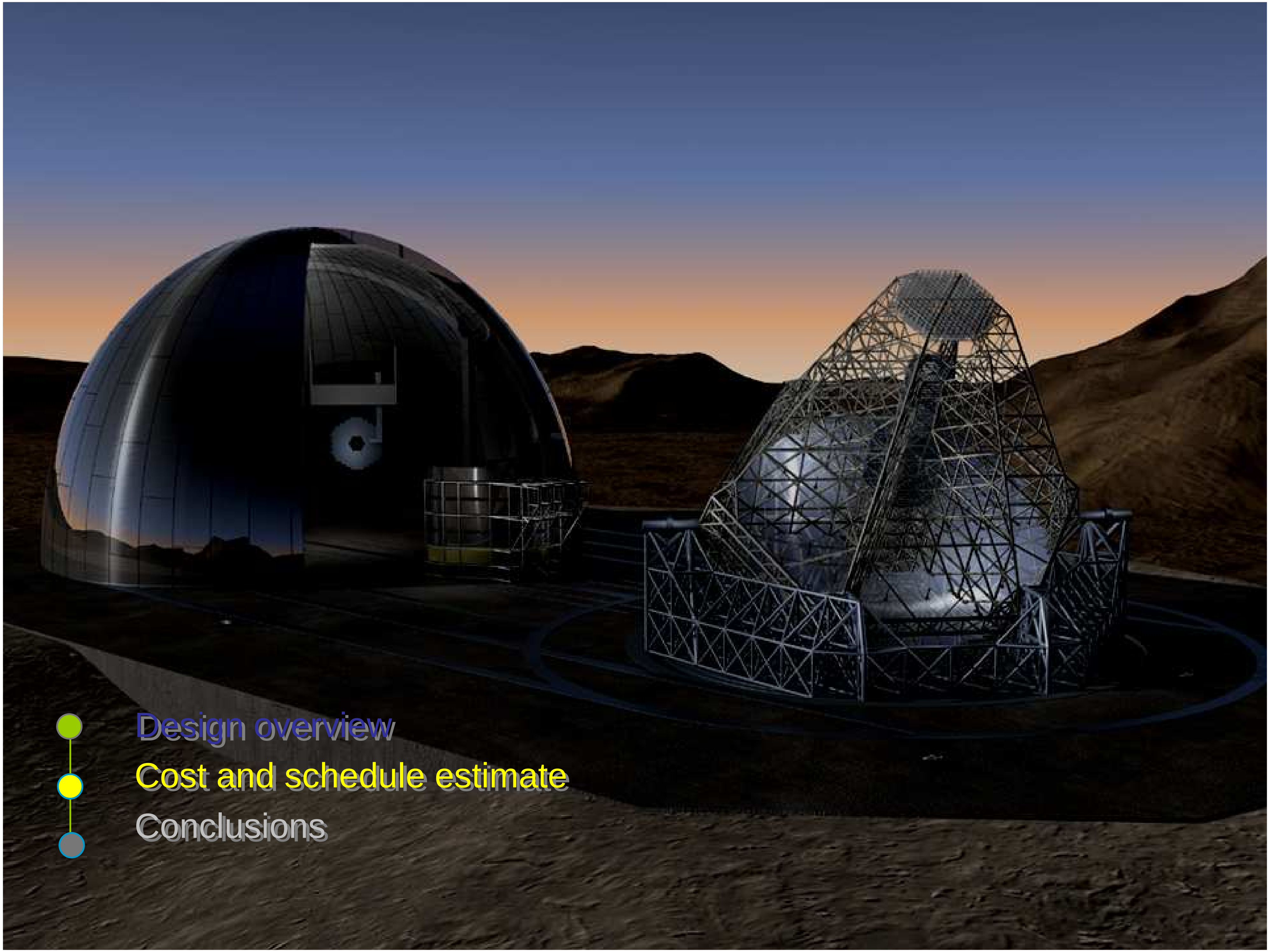




Sqrt stretch







- Design overview
- Cost and schedule estimate
- Conclusions

Cost estimate (capital investment)

SUMMARY	MEuros	
OPTICS	**406**	
Primary & secondary mirror units		355.2
M3 unit		14.4
M4 unit		21.4
M5 temporary unit		5.3
M6 temporary unit		10.1
ADAPTIVE OPTICS	**110**	
M5/M6 design & prototypes		10
M6 AO unit		25
M5 AO unit		35
XAO units		20
LGS		20
MECHANICS	**185**	
Azimuth		53.8
Elevation		34.9
Cable wraps		5.0
Azimuth bogies (incl. motors)		14.7
Altitude Bogies & bearings		5.7
Mirror shields		15.0
Adapters		6.0
Erection		50.0
CONTROL SYSTEMS (*)	**17**	
Telescope Control System		5.0
M1 Control System		8.0
M2 Control System		2.0
Active optics Control System		2.0
CIVIL WORKS	**170**	
Enclosure		40.4
Technical facilities		35.0
Site infrastructure		25.0
Concrete		70.0
INSTRUMENTATION	**50**	
INSTRUMENTATION		50
Total without contingency	**939**	*938.9*

(*) High level cs only; local cs included in subsystems

Assumes "friendly site"

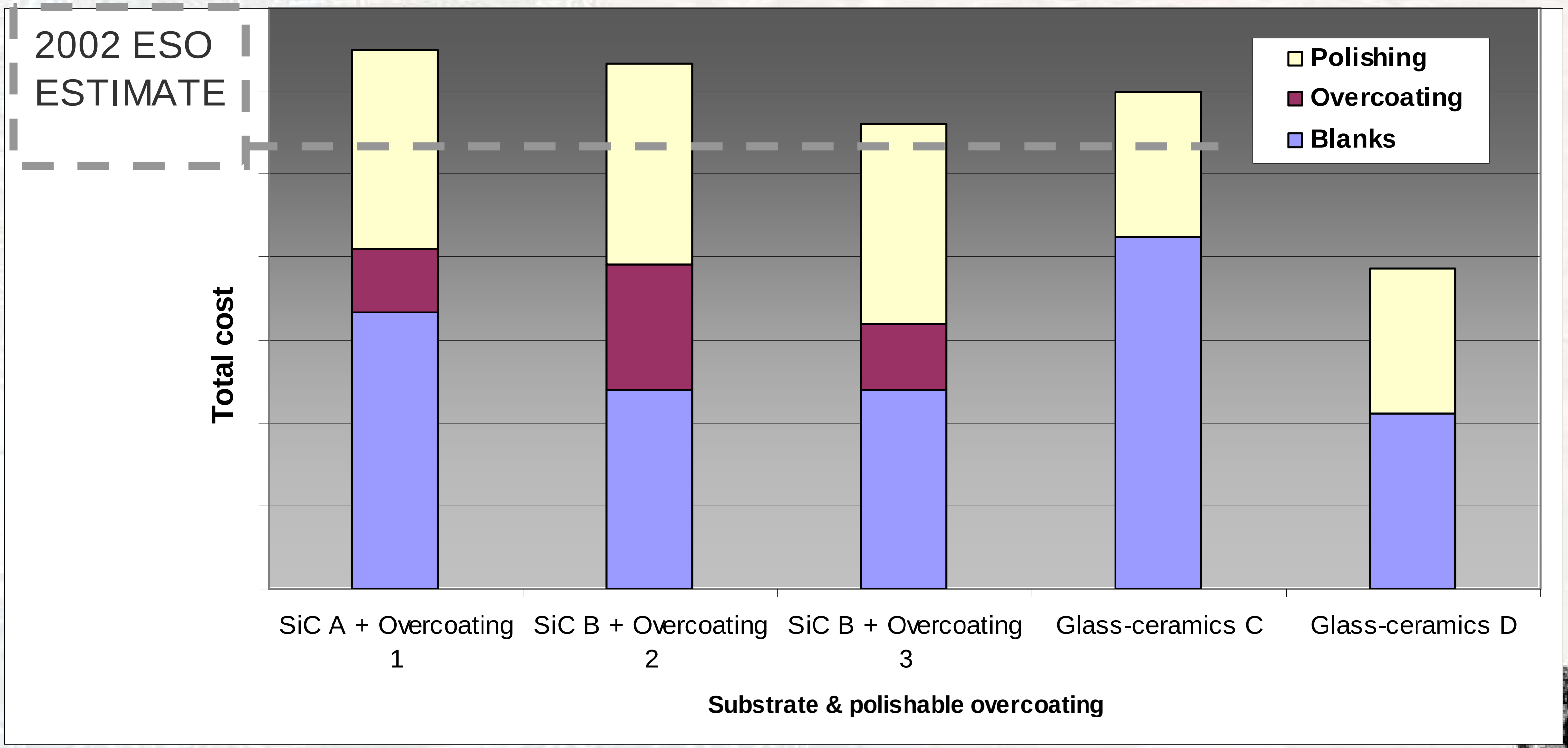
- ➢ Seismically quiet
- ➢ Moderate altitude
- ➢ Average wind speed
- ➢ Moderate investment in infrastructures

Cost estimates (industrial studies)

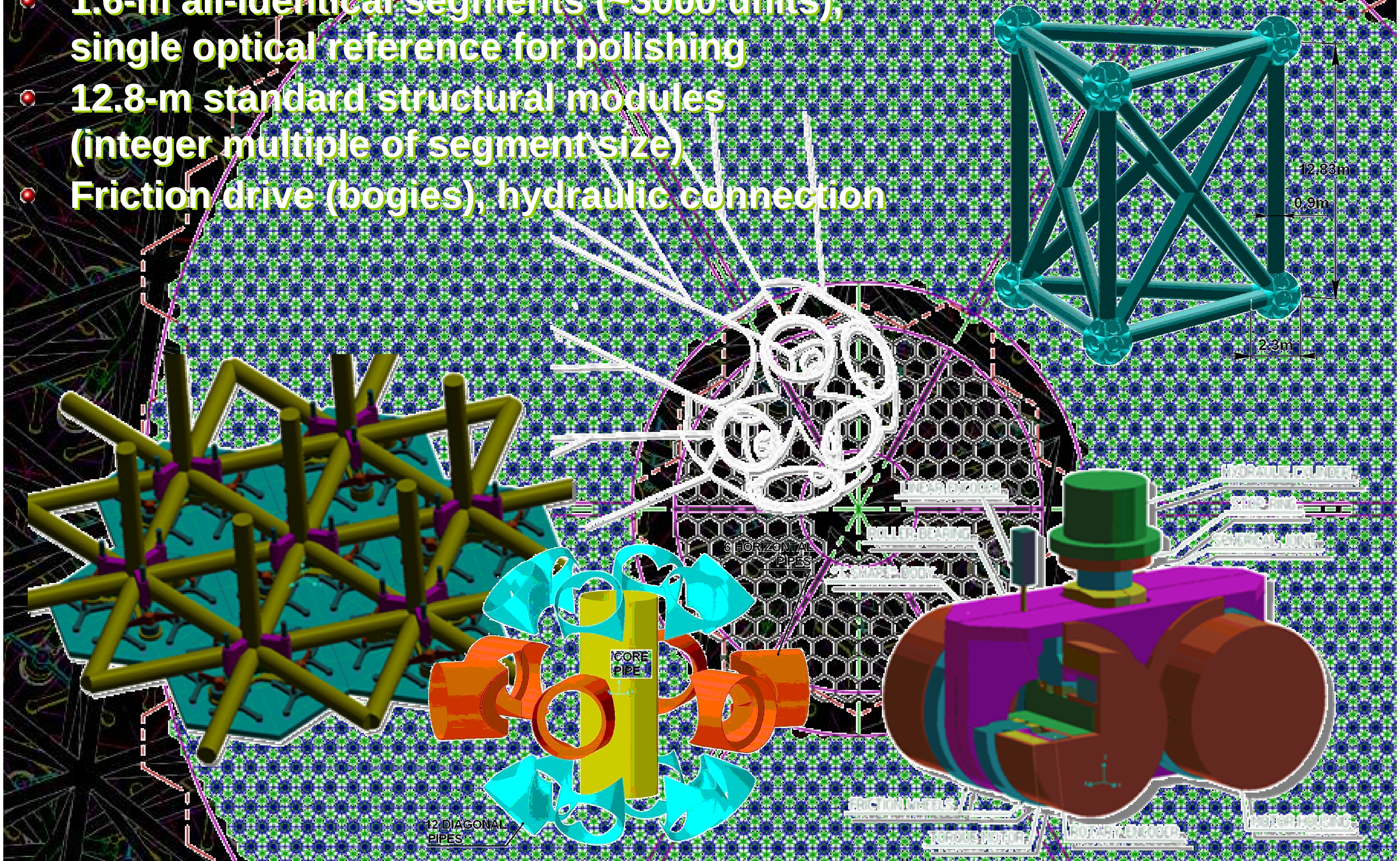
Primary & secondary mirror segments; 1.8-m; polished, prices ex works.

Blanks: SiC (2 suppliers A and B) with overocatings (3 suppliers 1, 2, 3)
Glass-Ceramics (2 suppliers C and D)

Polishing: 2 suppliers, only one shown (both agree within 10%)



- Optimized geometry (interface optics-mechanics)
- All parts fitting in 40-ft containers
- 1.6-m all-identical segments (~3000 units), single optical reference for polishing
- 12.8-m standard structural modules (integer multiple of segment size)
- Friction drive (bogies), hydraulic connection

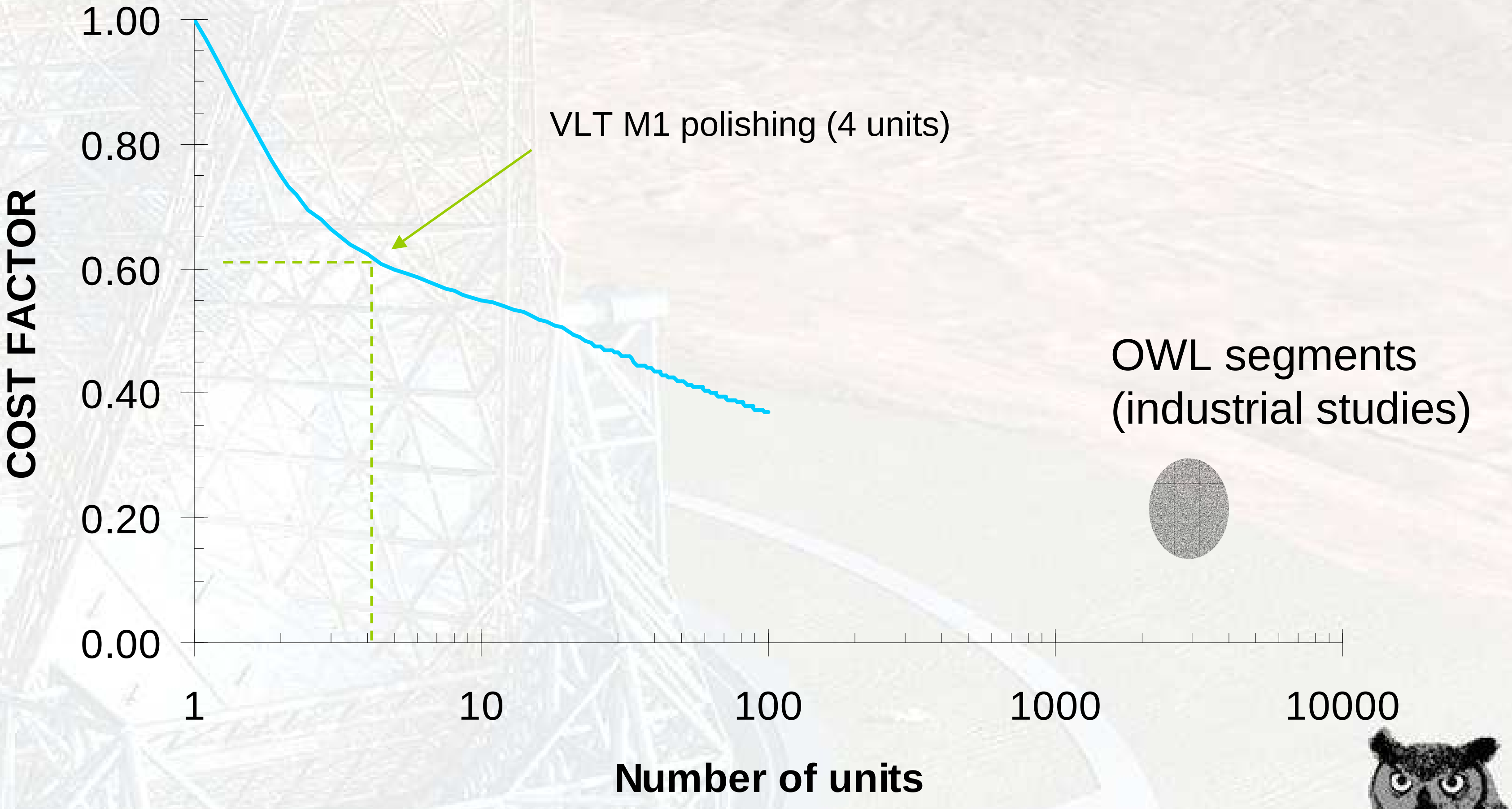


Cost vs quantity

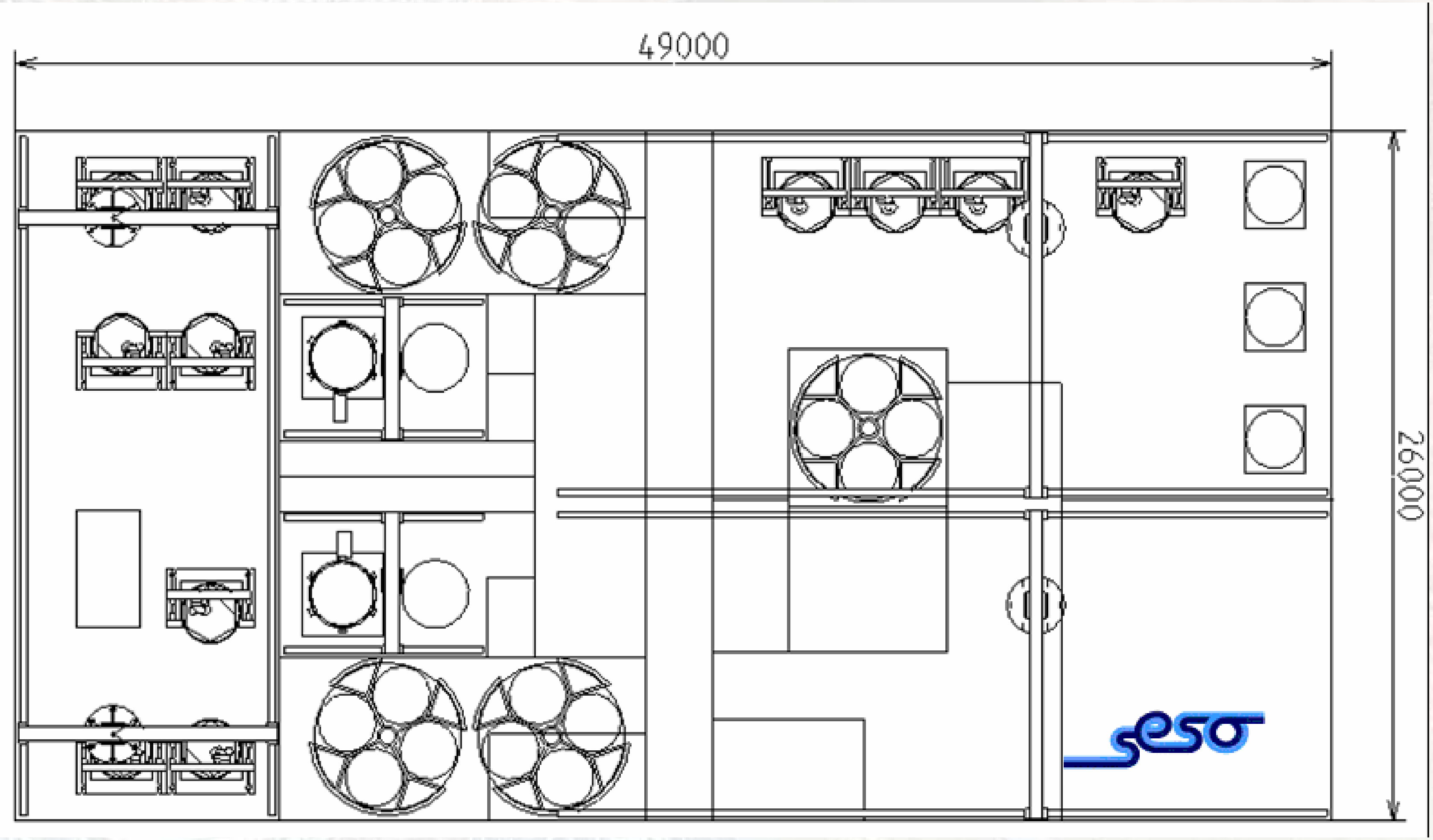
Industrial data

Applies to conceptually simple items

(e.g. segments, structural nodes)



Polishing: factory implementation



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

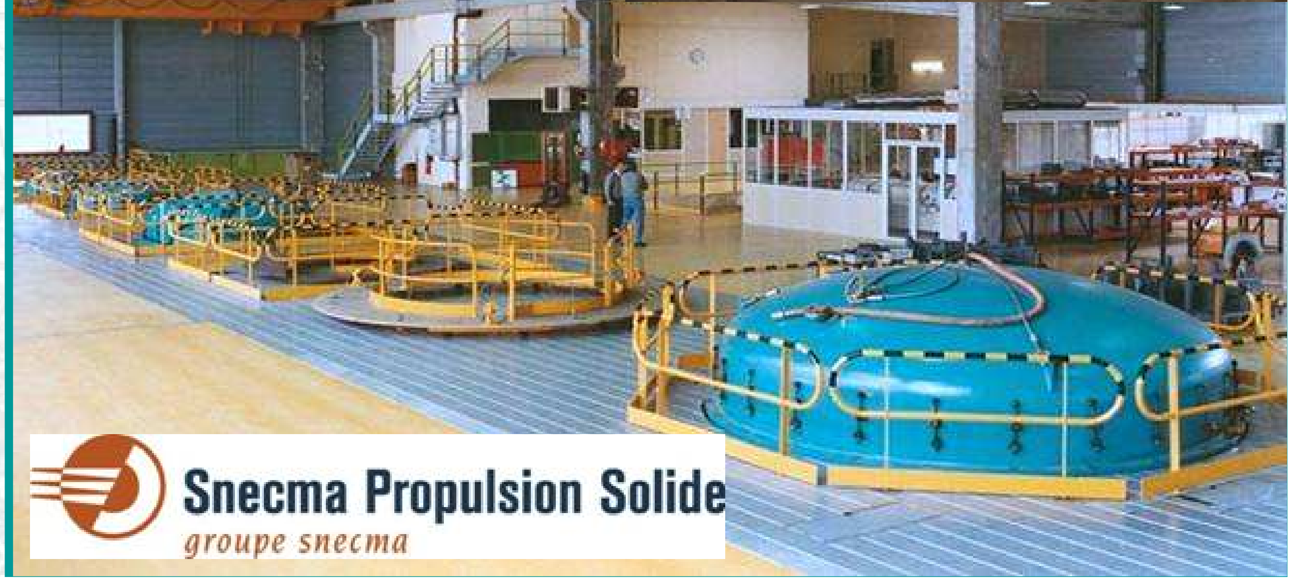
Meanwhile ...

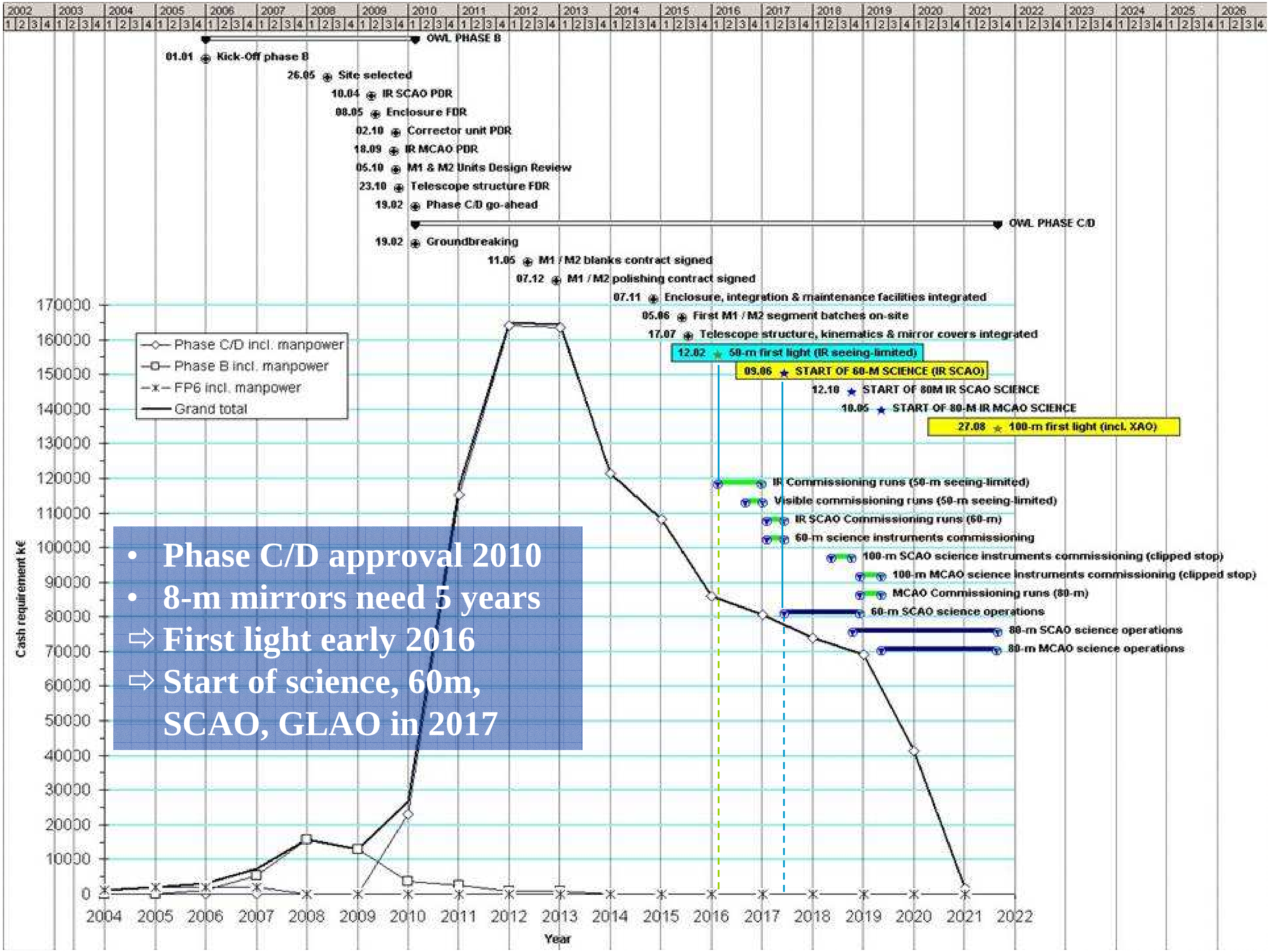

SCHOTT
glass made of ideas


CoorsTek and Boostec –
Partnering F
BOOSTEC


SCHOTT
glass made of ideas


ECM
Helios


Snecma Propulsion Solide
groupe snecma



- Phase C/D approval 2010
- 8-m mirrors need 5 years

⇨ First light early 2016

⇨ Start of science, 60m, SCAO, GLAO in 2017

OWL in brief

A concept already at an advanced stage of design

- Design supported by analysis & competitive industrial studies
- Cost estimate > 50% completed, supported by competitive studies
- Cost-effective design principles & solutions allow major jump in capability

Substantial science at early stage

- Schedule constrained by funding, not by technology
- Progressive implementation of capabilities
- 60-m with IR AO in 2017, 100-m with MCAO in 2019

European-wide technology & concepts development

- Industrial & academic synergy
- ELTs “building blocks”, design-independent

Concerns	***…and solutions***
➢ Adaptive optics	Gradual implementation, max. time for R&D
➢ Wind	SiC segments, embedded wind screens, etc.
➢ Pavlov	Think seeing = 0.001 arc seconds, v=37-38
➢ Money	Open to suggestions.

Almost there ?

- Design solutions compatible with state-of-the-art technology and with industrial production
- Metrology & control systems allowing real-time optimization of performances
- Rapidly evolving adaptive optics concepts and technologies
- A quantum leap in scientific potential
- I wish I were a student today …