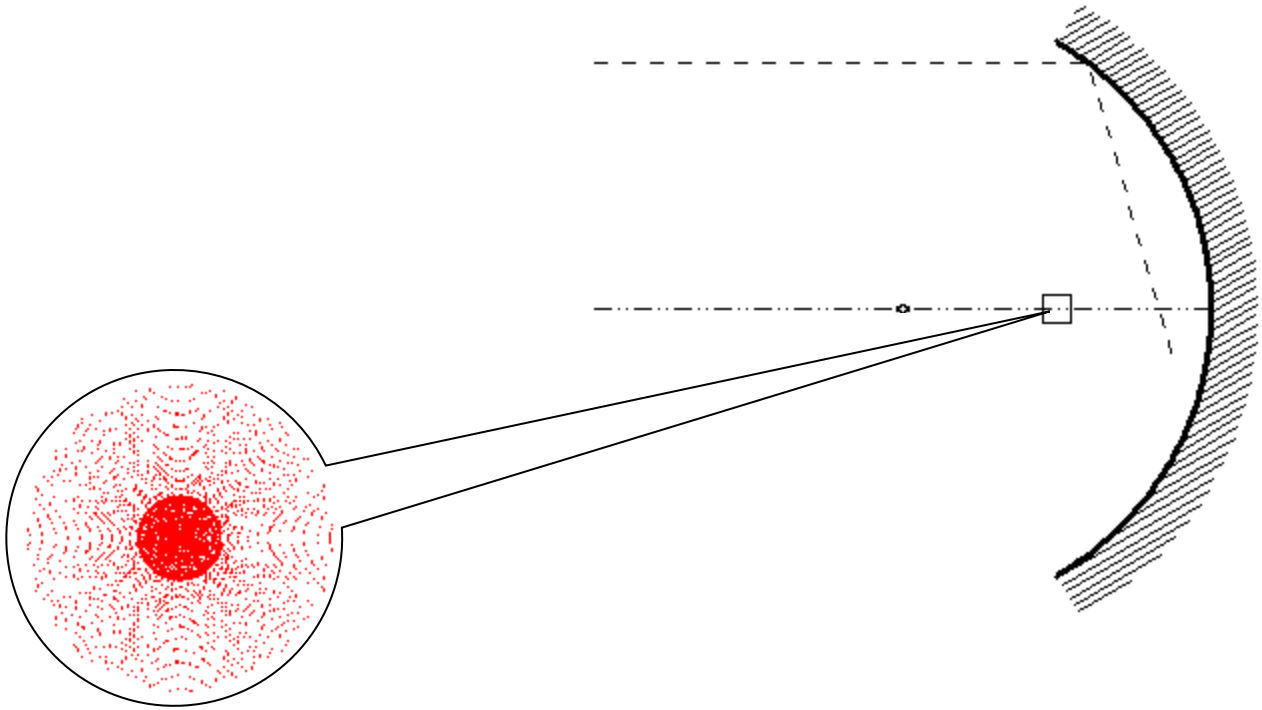
Observational Astronomy

Telescopes, Active and Adaptive Optics

Kitchin pp.109-130; Chromey 169-190

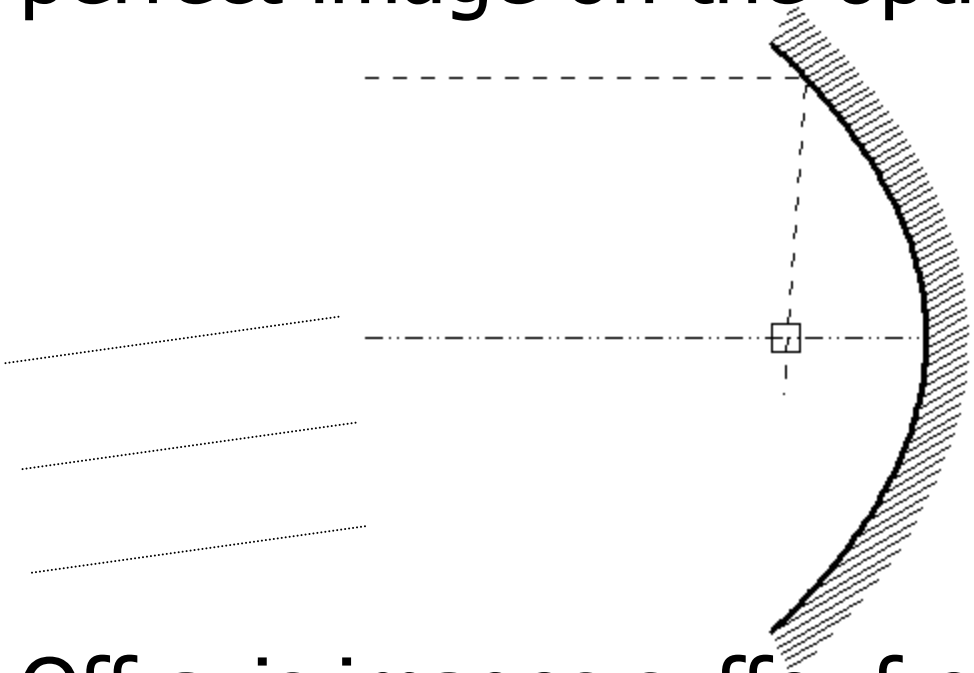
Optical Schemes

Spherical mirrors cannot focus light properly due to spherical aberrations:



Optical Schemes

… but a single parabola can produce perfect image on the optical axis:



Off-axis images suffer from coma.

Ritchey-Chrétien telescope

Parabolic primary and hyperbolic secondary solve main aberration problems (spherical and coma) in a rather large field of view (tens of arcminutes). These advantages require to use Cassegrain or Nasmyth focus.

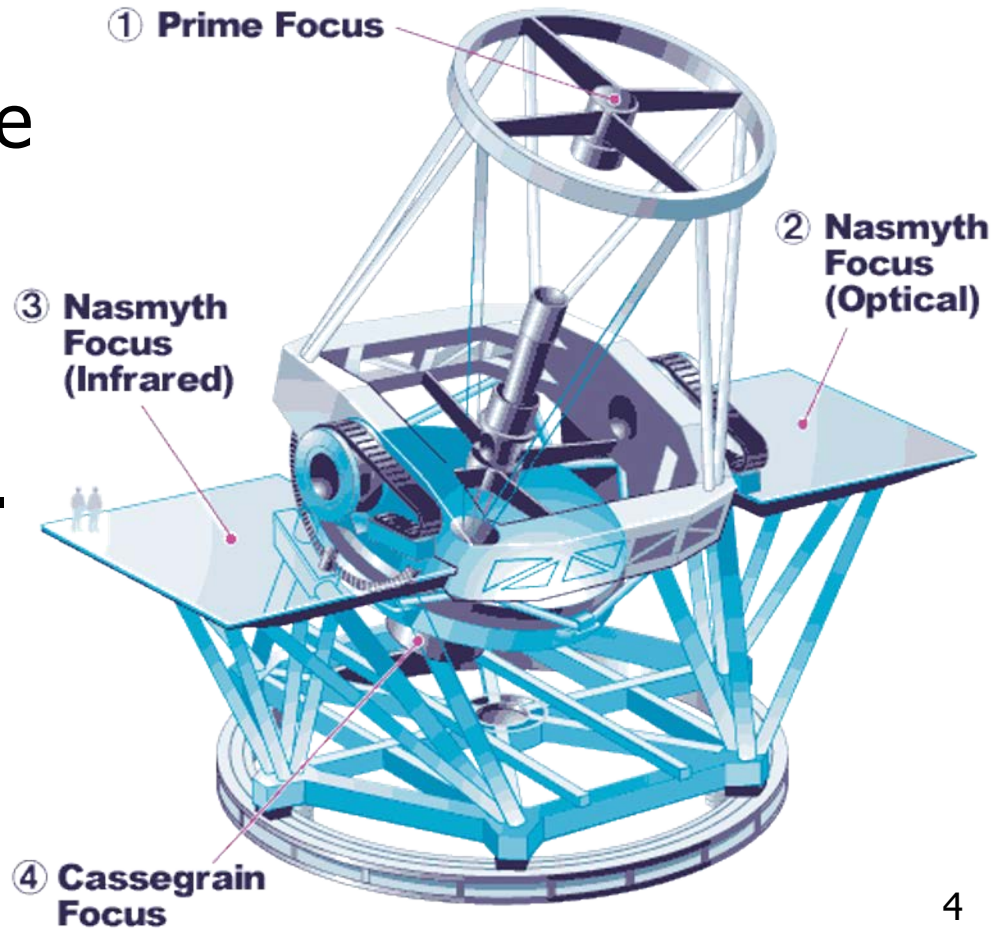
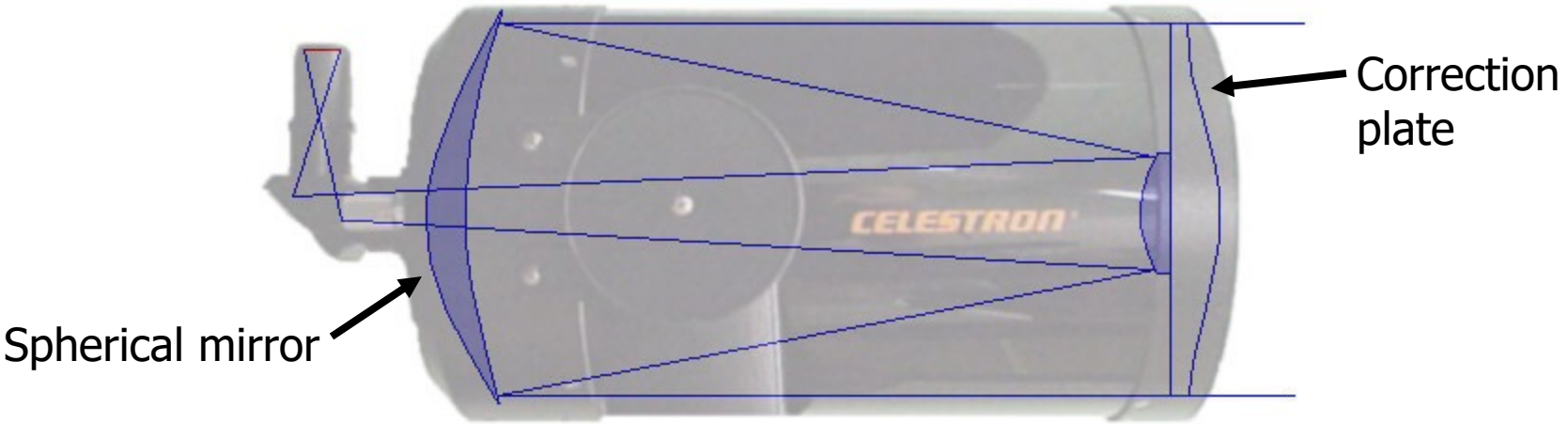


Illustration by Takaetsu Endo, taken from Nikkei Science 1996

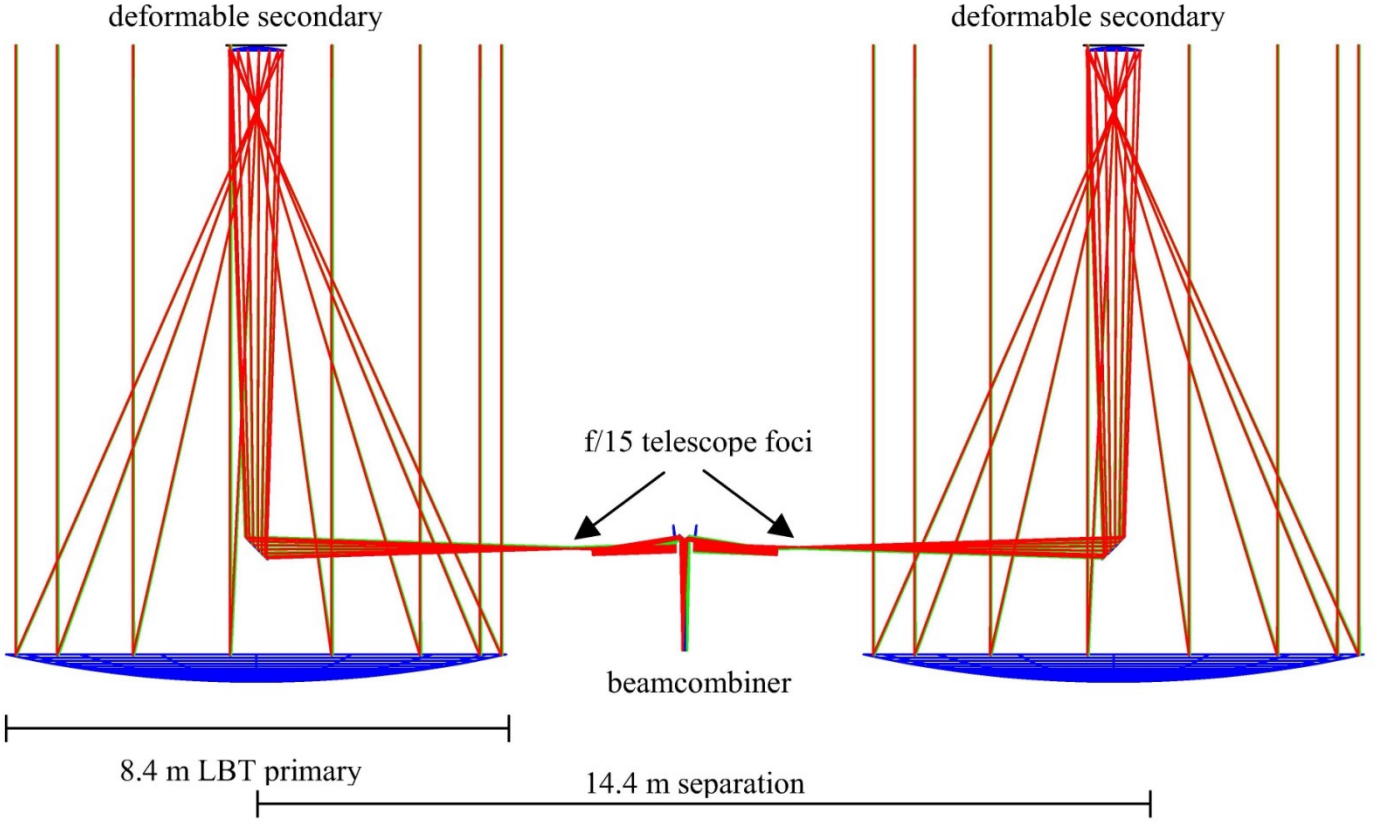
Schmidt-Cassegrain

- RC provides very good image quality in a relatively modest FoV ($1^o \times 1^o$)
- For larger FoV a refractive corrector is needed.
- These are known as Schmidt-Cassegrain or Schmidt camera:



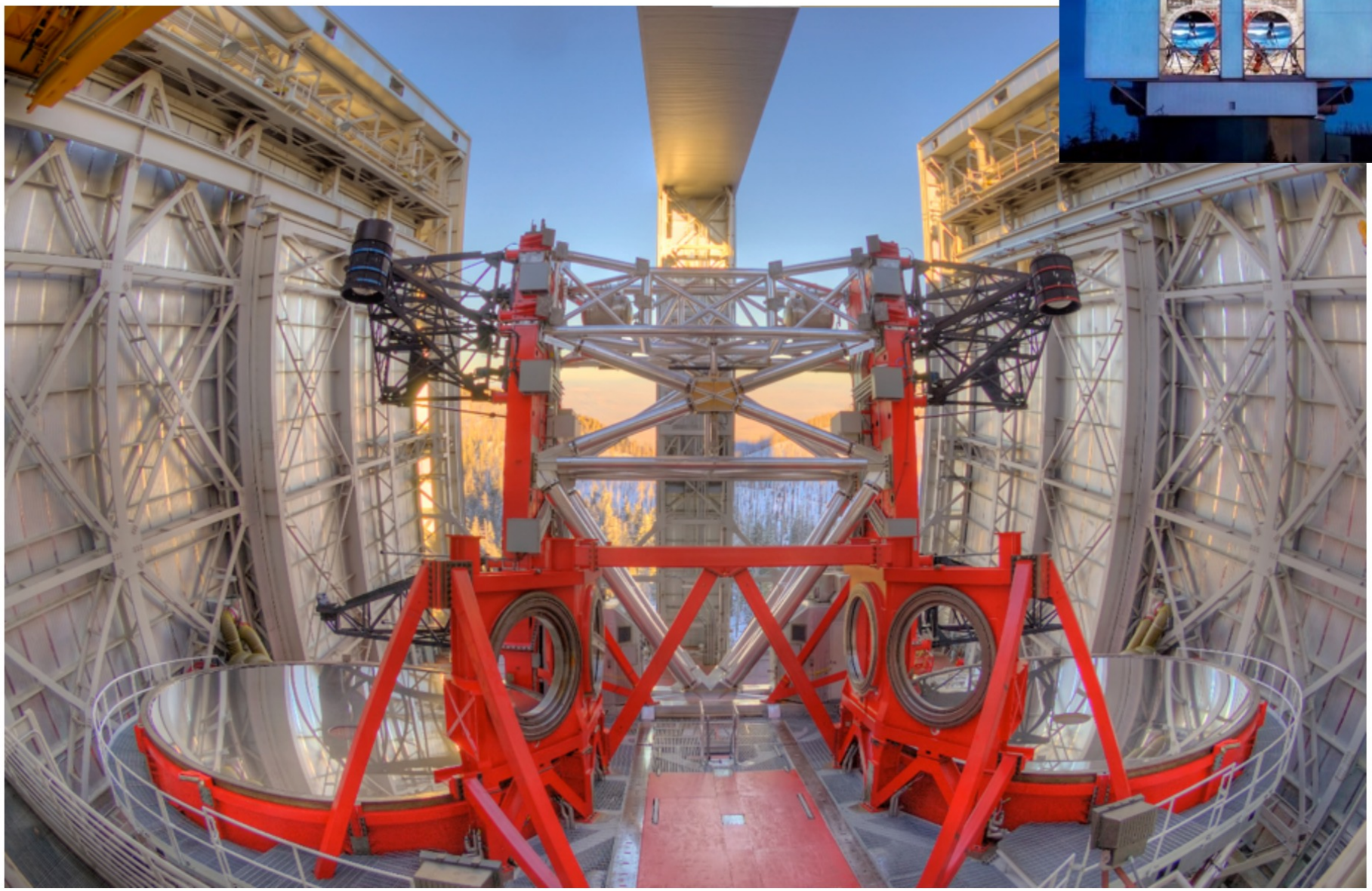
Alternative to RC: Gregorian system

Concave secondary <u>after</u> the primary focus:



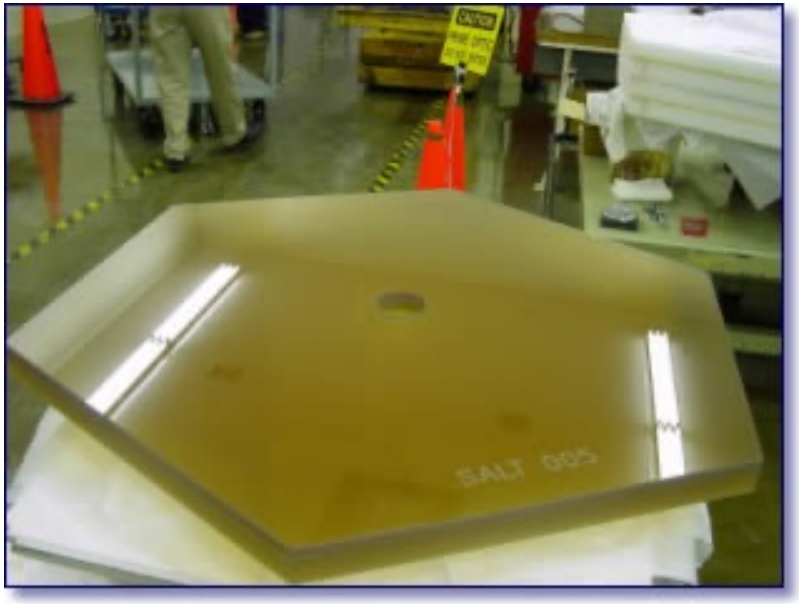
Courtesy of AIP Potsdam

Here is a cool picture of the LBT



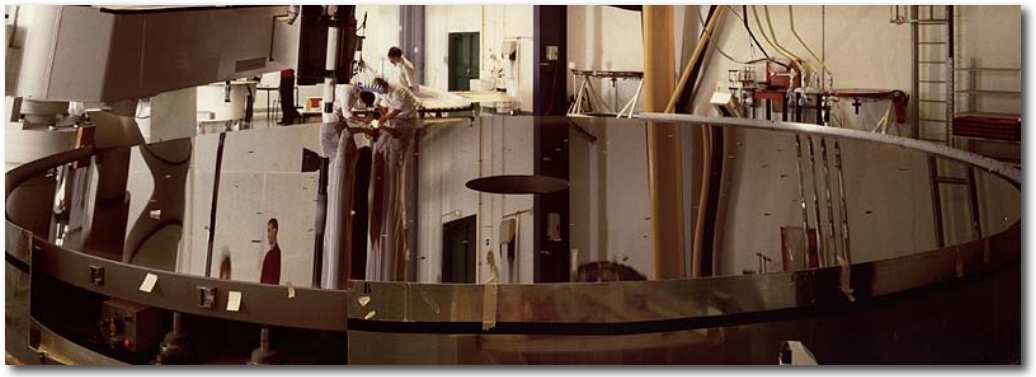
Materials for mirrors

Low thermal expansion: zerodur & sitall



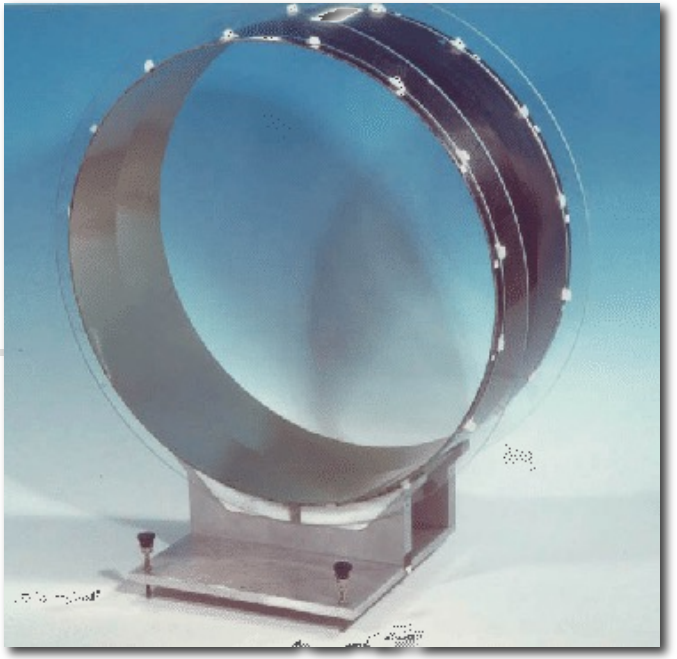
Astro-sitall blank at LZOS
(VST, VISTA, SALT, LAMOST, OWL?)

mean linear coefficient of thermal expansion within temperature range
-60^{o} to $+60^{o}$ C is $<10^{-8}$ cm $^{o}C^{-1}$



Zerodur VLT primary at REOSC

More materials



SiC 60 cm X-ray mirror
Weight: 6.2 kg

Silicon Carbide

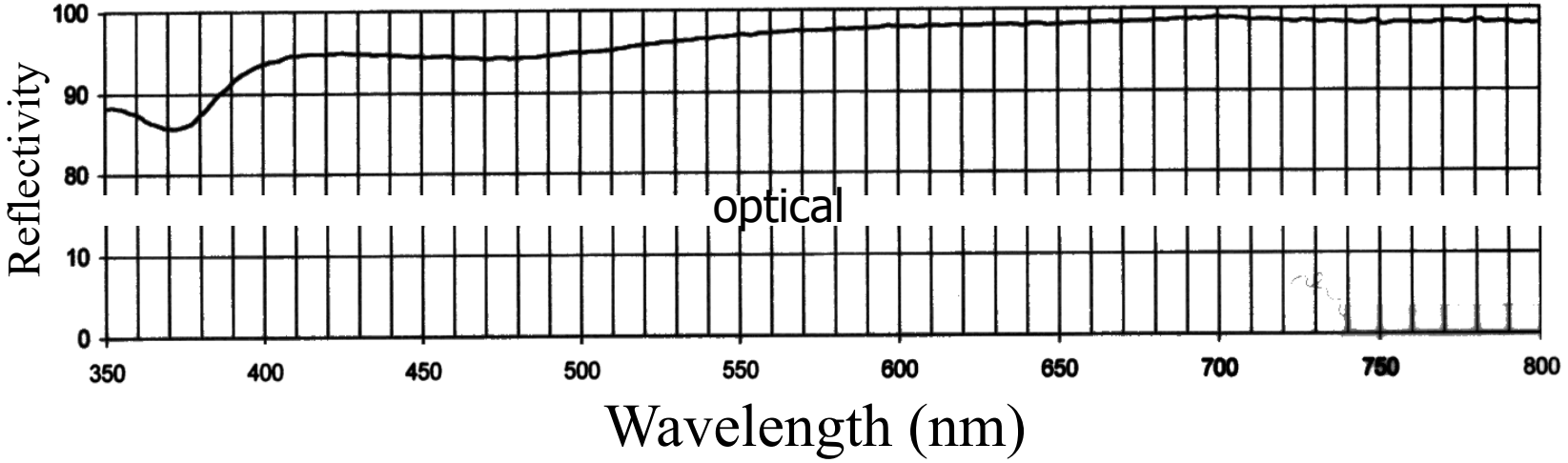
- Low thermal expansion (not as good as glass)
- Very light
- Very hard, keeps the shape well
- Hard to make in large pieces
- Fragile, difficult to process

Coatings

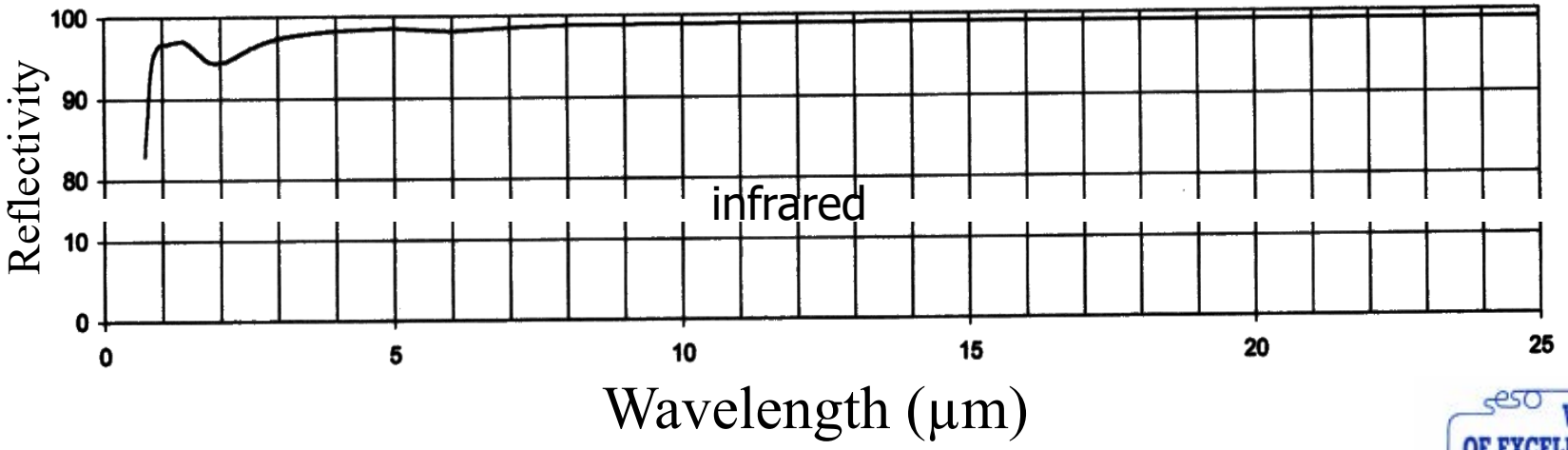
- Mirror must reflect light:
  - Aluminum (protected by SiO)
  - Silver-based coatings. Also needs protection.
- Lens coating must not reflect light: MgF_2

Examples of Mirror Coatings

Enhanced Silver coating results (from 350 nm to 800 nm)



Hard Gold coating results (from 0.7 µm to 25 µm)

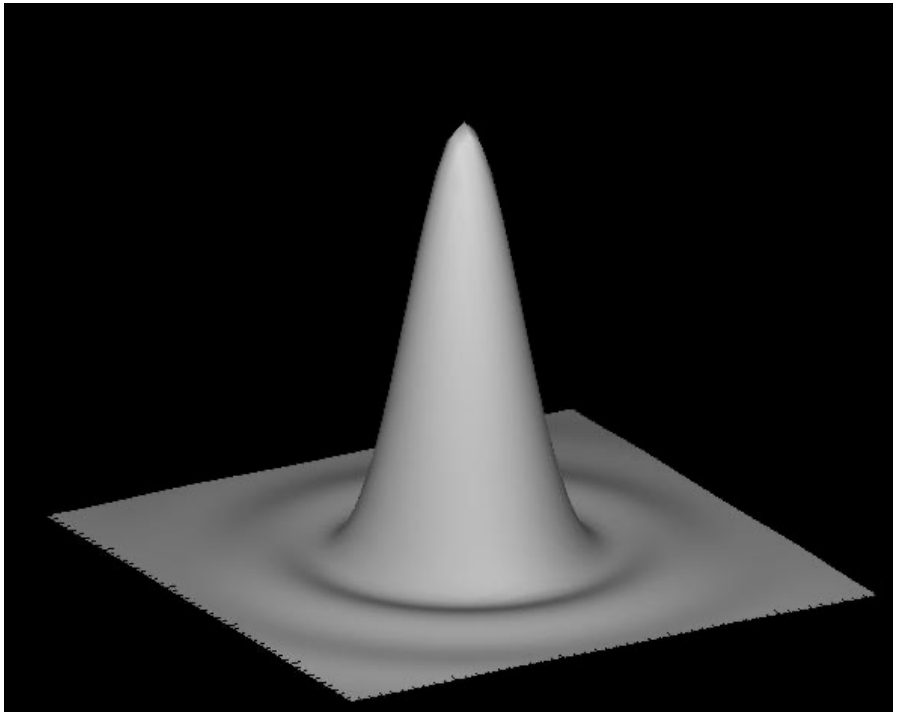


VISION OF EXCELLENCE

JWST mirror coating

Point Spread Function

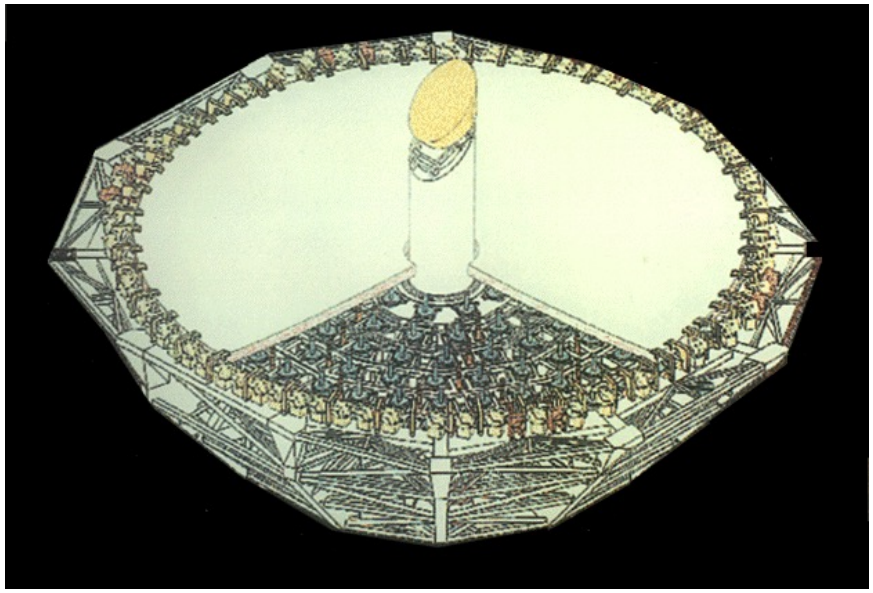
- PSF is the intensity distribution in the focal plane of a telescope produced by a point source.
- Ideal PSF for an axially symmetric system is know as Bessel function.

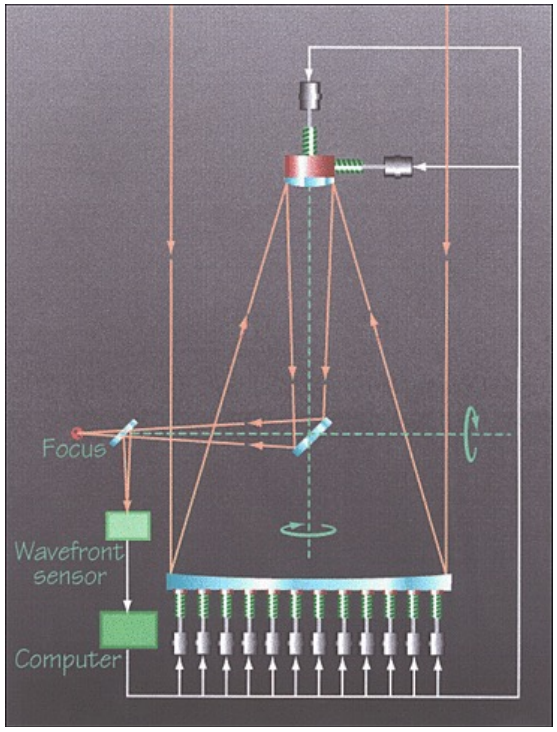


Active optics

Large thin mirrors are shaped by support system: VLT mirror is 8.2m in diameter

and only 18 cm thick!

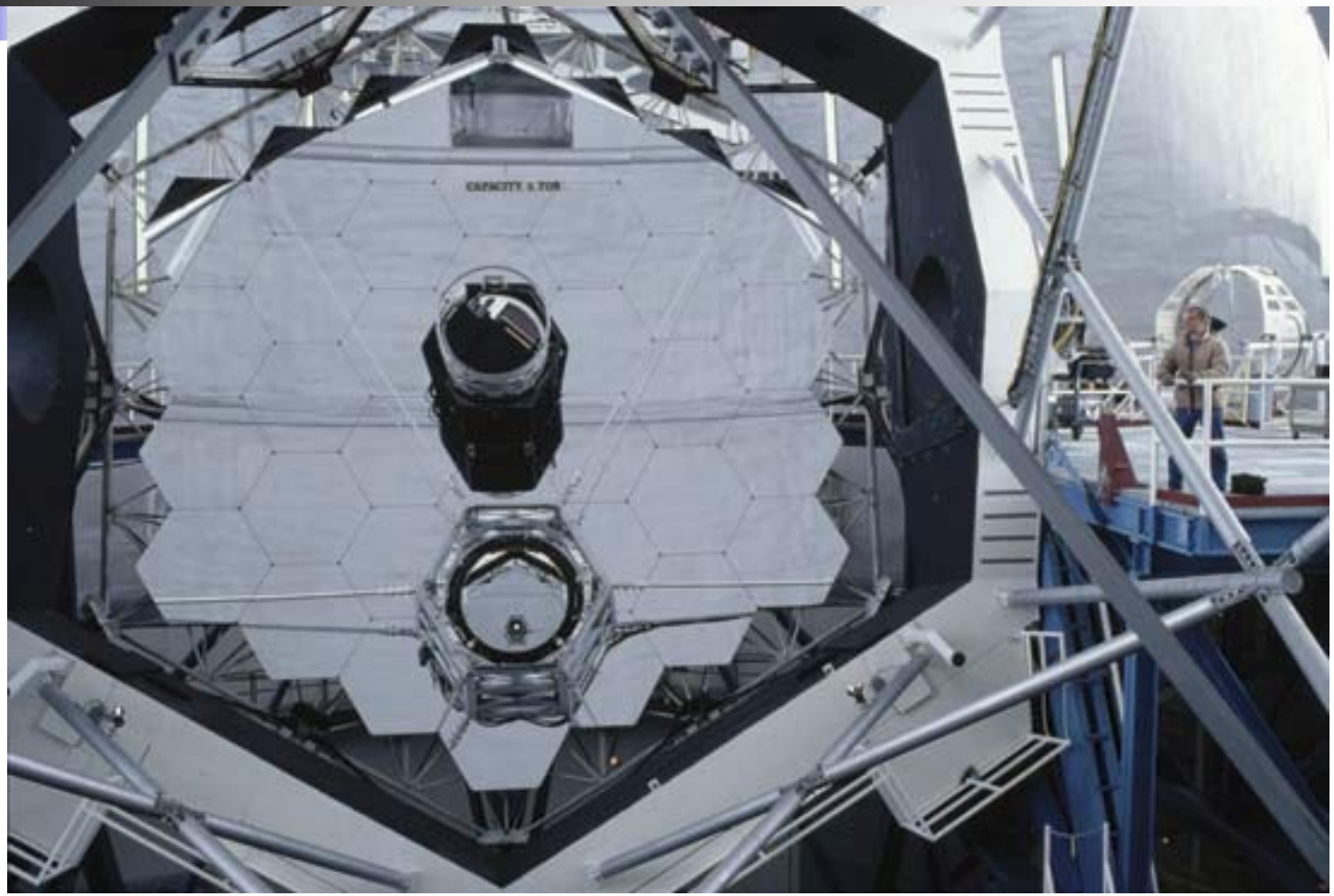




ACTIVE OPTICS

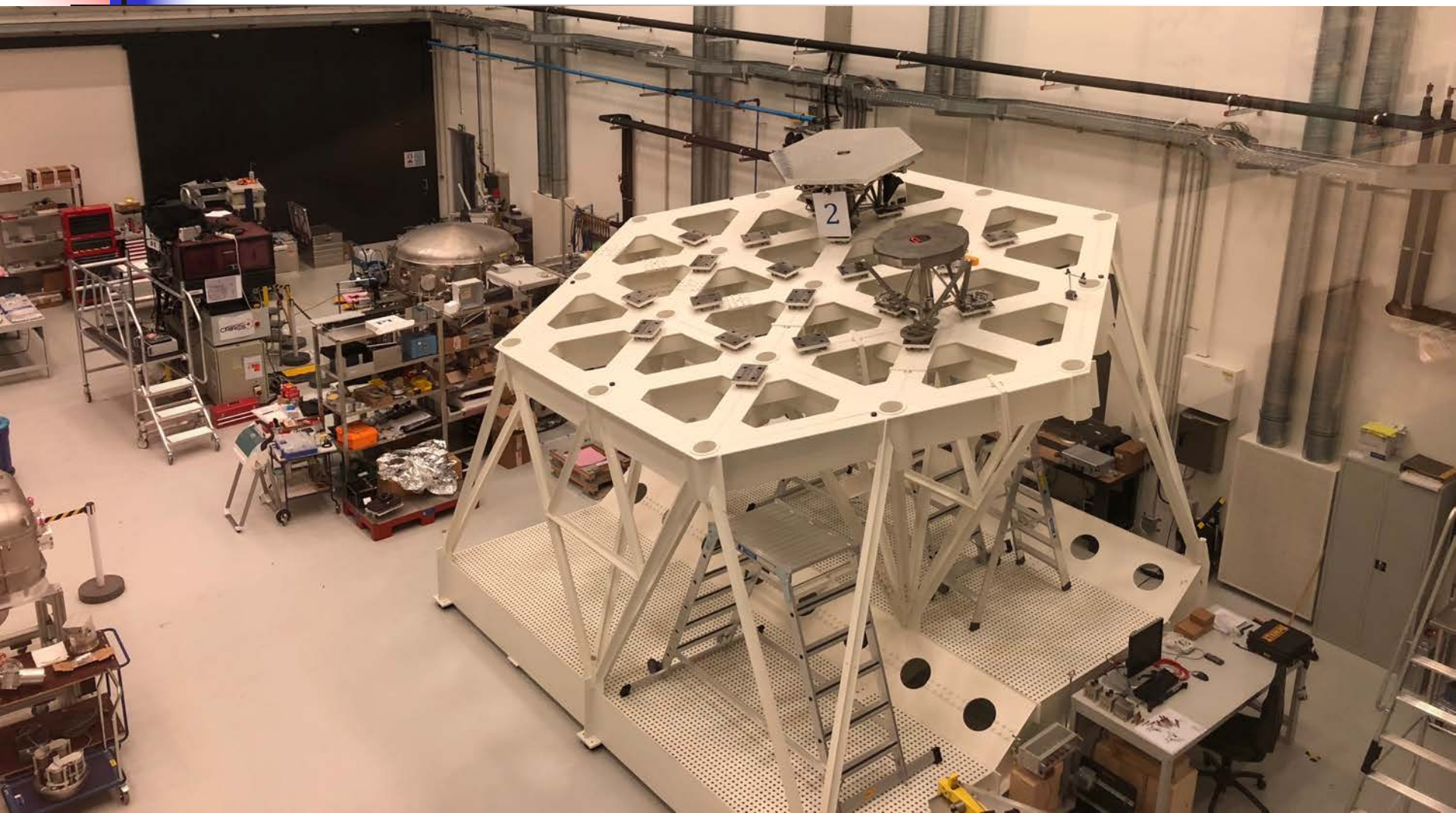
- Compensates for thermal and gravity distortions;
- Uses stored parameters;
- Corrects at low frequency: 30 s cycle;
- Uses hundreds of actuators.

Segmented mirror (Keck, 10m)



Courtesy of Keck Observatory

ELT (39m): 798 segments!

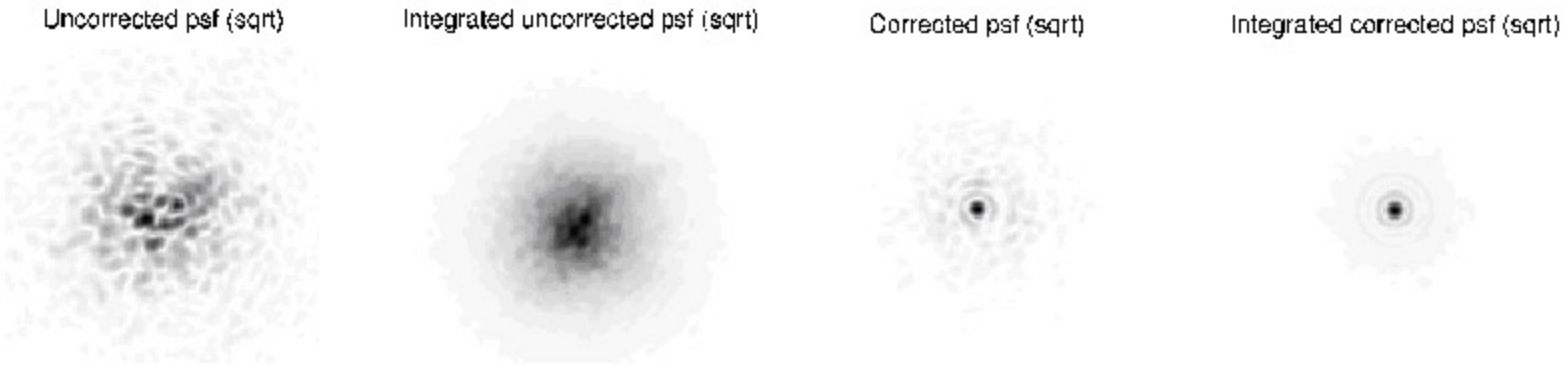


Active optics

- For solid mirror the shaping is achieved by pushing/pulling and several hundred places.
- For segmented mirrors, segment orientation is adjusted based on preset parameters and edge sensors.
- Parameters are obtained by looking at point sources at different altitudes and at different temperatures.

Adaptive optics

Seeing corrections (PSF):



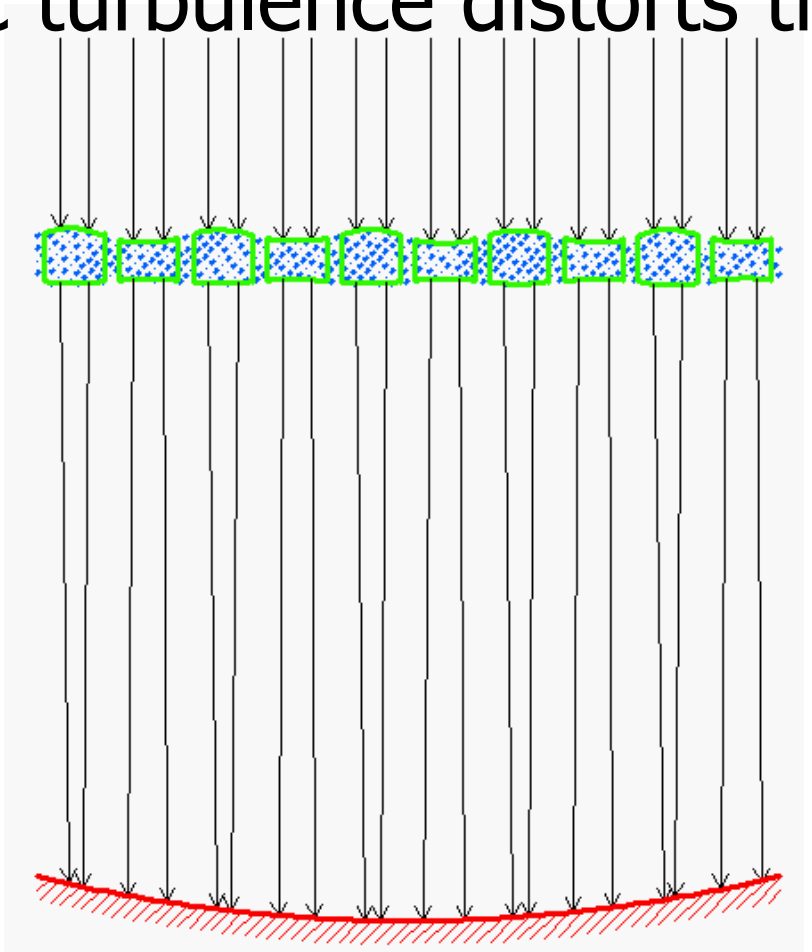
The *Strehl* ratio is the ratio of peak intensities in the observed and ideal point spread functions (Born and Wolf 1999).

Why do we need adaptive optics?

Atmospheric turbulence distorts the wave front.

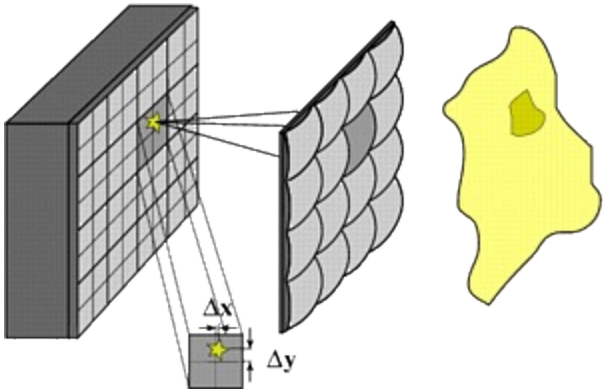
Three ways of looking at the focal plane image:

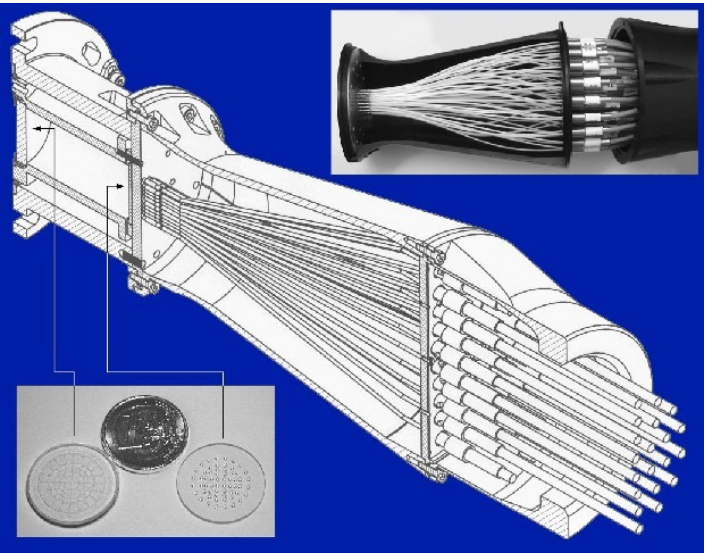
1. Non-collimated beams (speckles)
2. Curved wavefront (phase shifts)
3. Changing intensity distribution

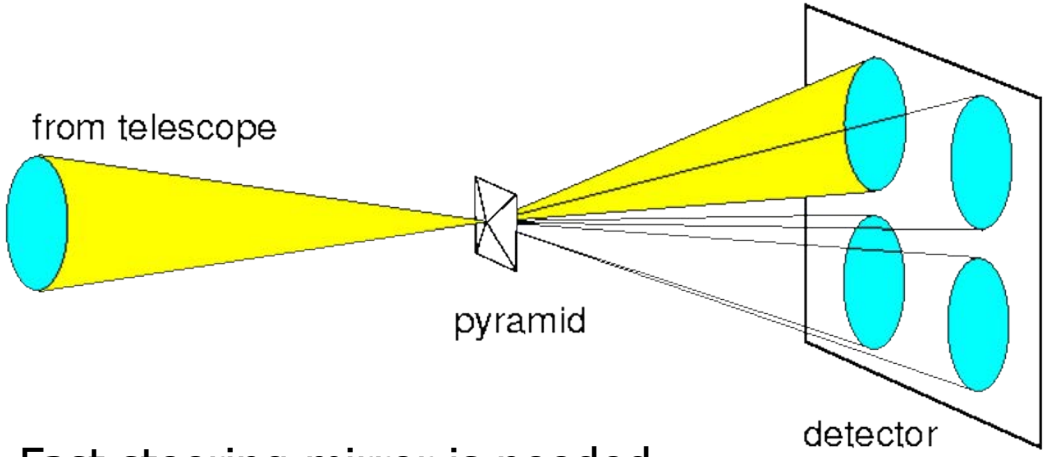


Wavefront sensor

- Shack-Hartmann
- Curvature sensor
- Pyramid WFS





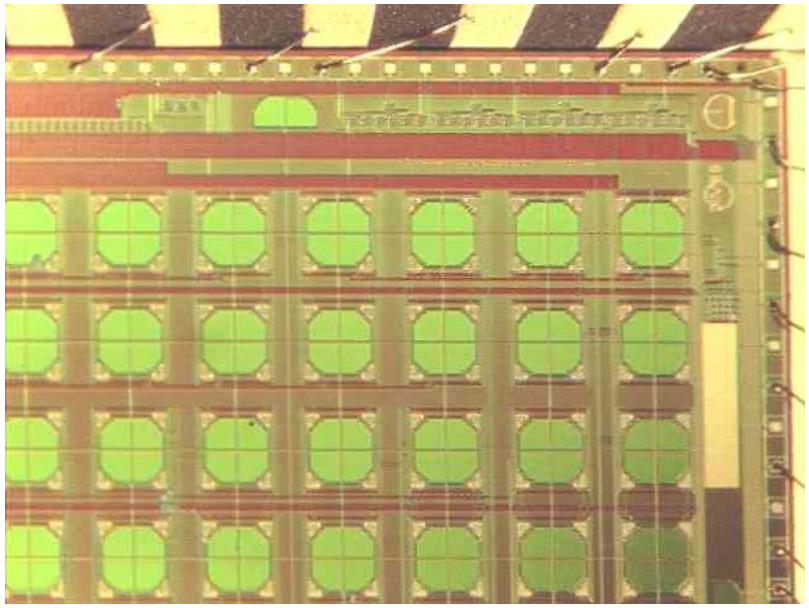


Fast steering mirror is needed to get all pixels in focus

Sensor implementation

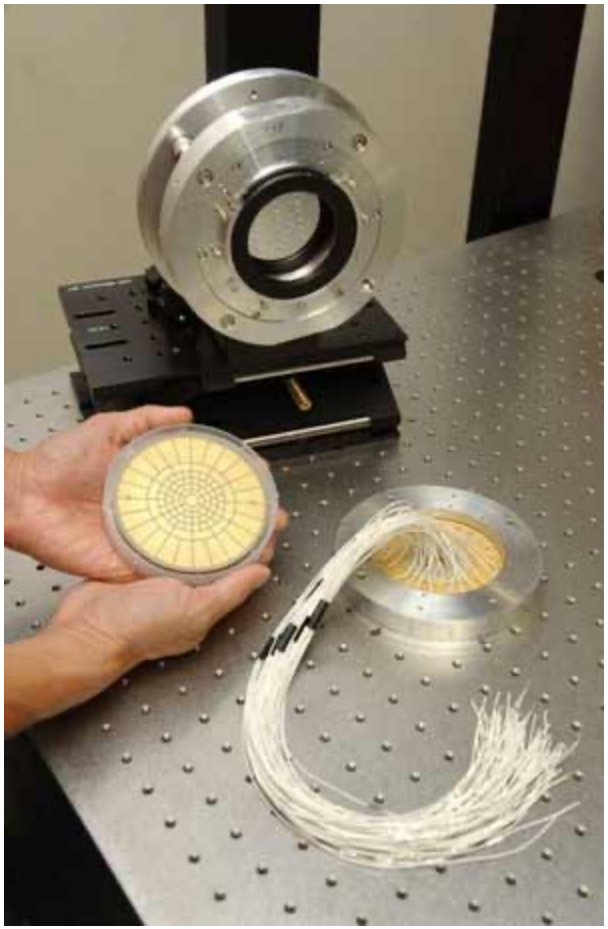
Wavefronts must measured many at 100 kHz rate!

Sensor chip on a printed-circuit board.

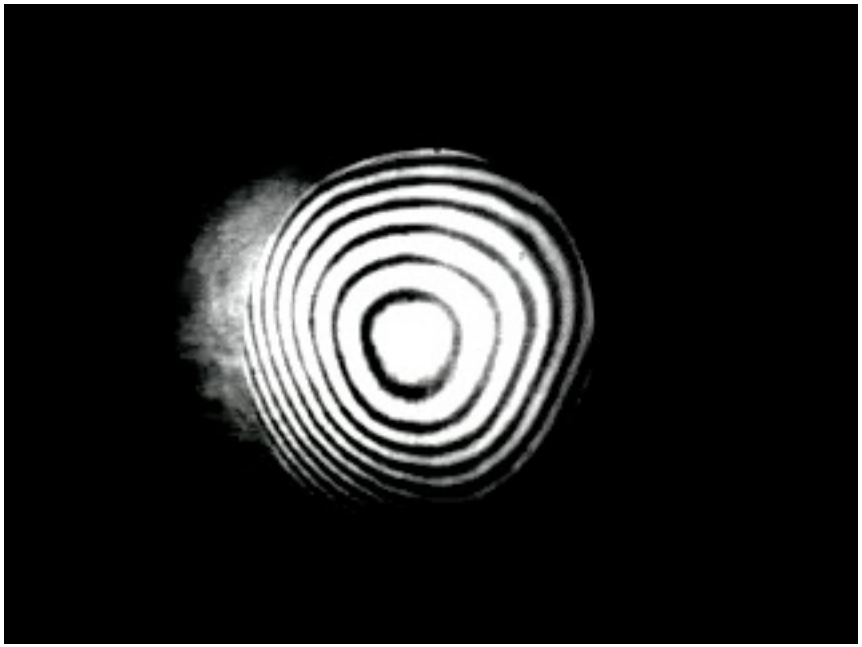


A corner of the 1cmX1cm wavefront-sensor chip implemented in standard CMOS. The green elements are the position-sensitive detectors.

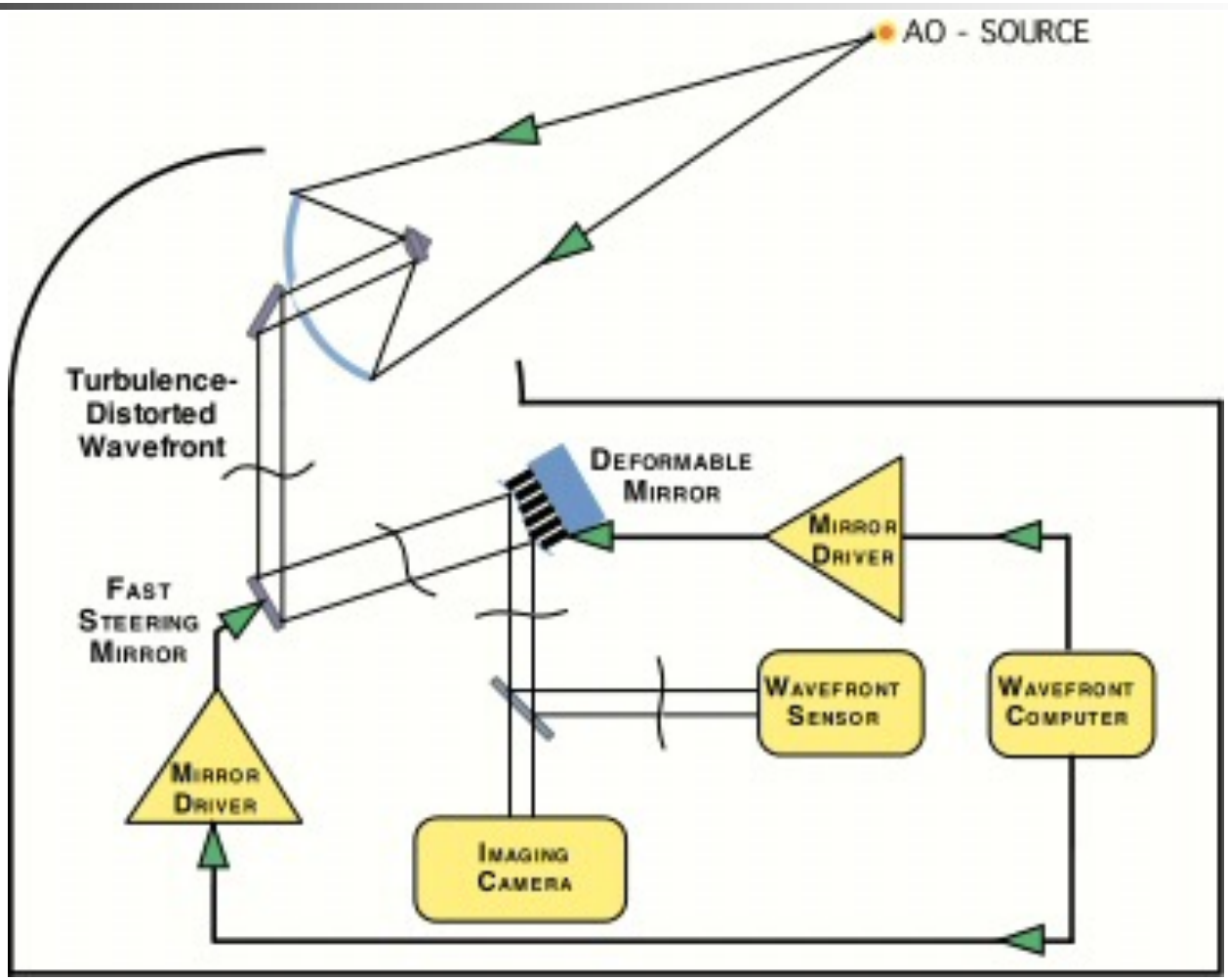
Deformable mirror



Various shapes of a deformable mirror with 37 actuators

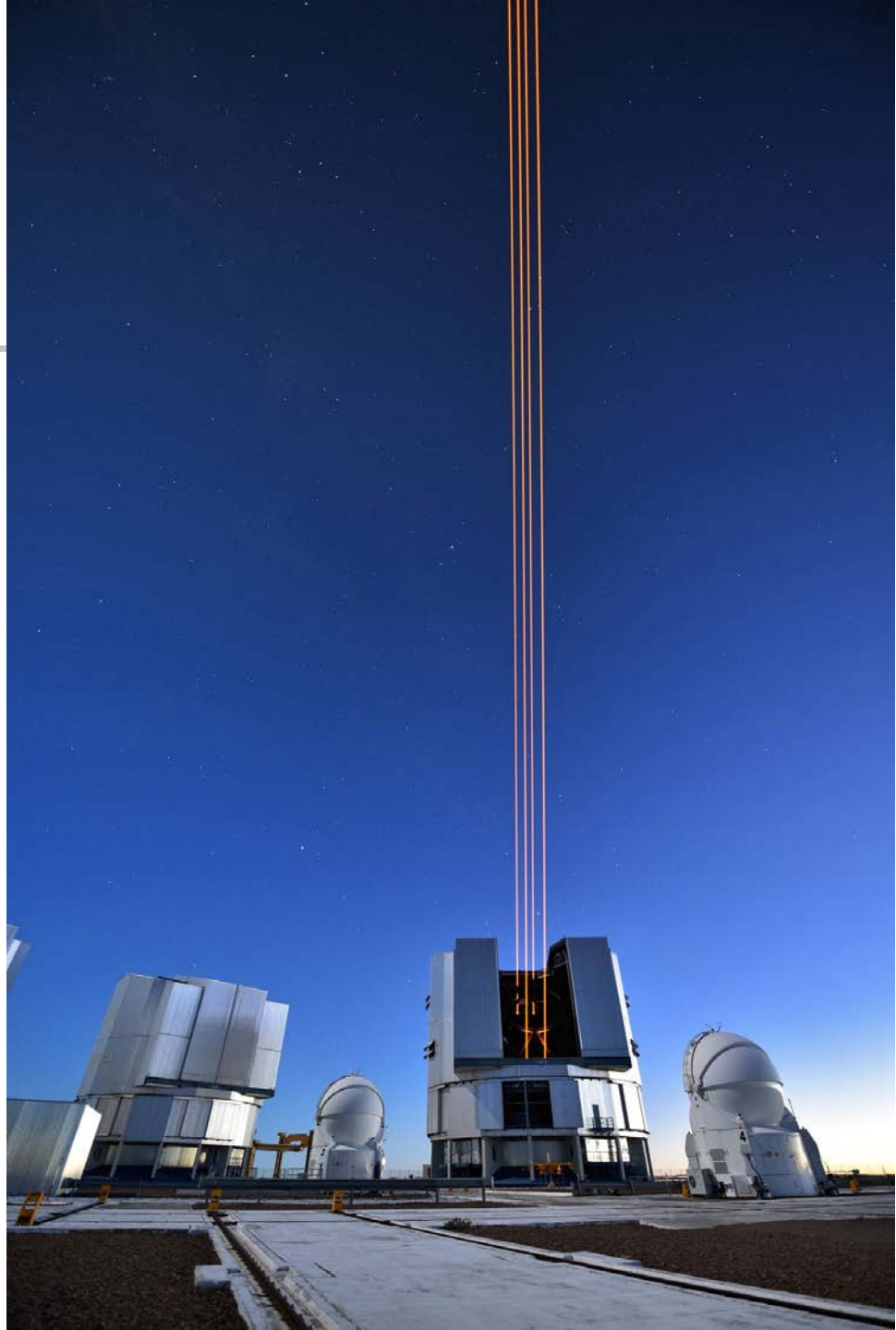


Closing the loop

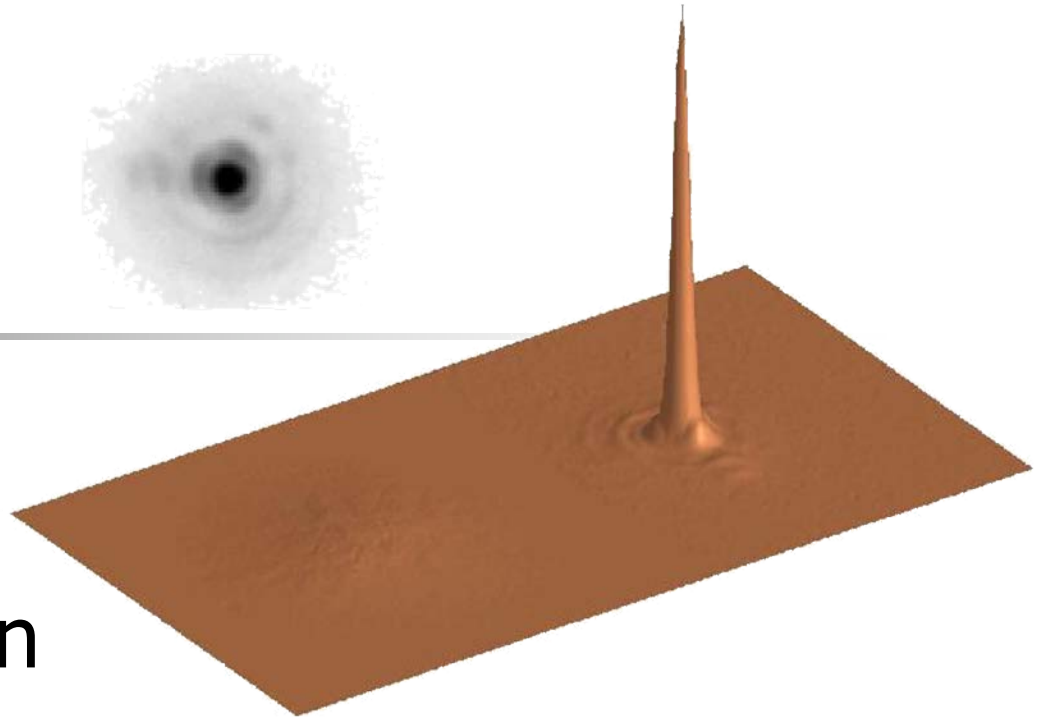


Laser Guide Star

The Laser Guide Star Facility at one of the 8m ESO telescopes on Paranal

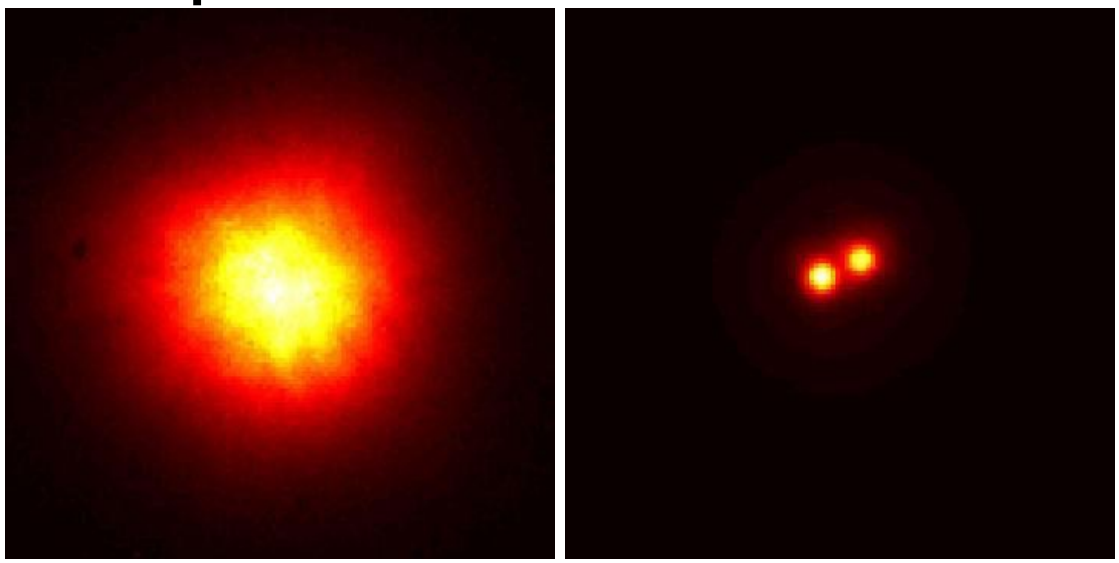


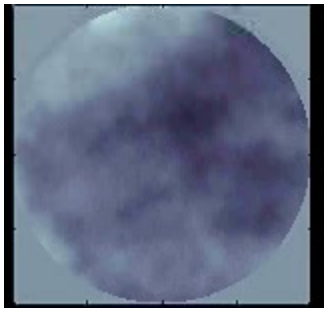
AO result



VLT NACO:

PSF and resolution improvements





Home work

- Find a telescope with Silicon Carbide mirror. Explain the reason to use this material?
- When using adaptive optics, what are the pluses and minuses of using natural and laser guide star?

Next time…

Direct Imaging and Photometry

Presentations:
Specialized telescopes