Adaptive Optics

(and its implementation on the WHT)

- Overall principle
- Subsystems (DM, WFS, etc.)
- Laser Guide Star

Objective: to understand what are the key components of the system

Image quality

Telescope diffraction limit

Angular resolution ~λ/D
for 2.5m telescope in V band this is 0.045 arcsec !

Intrinsic optical performance

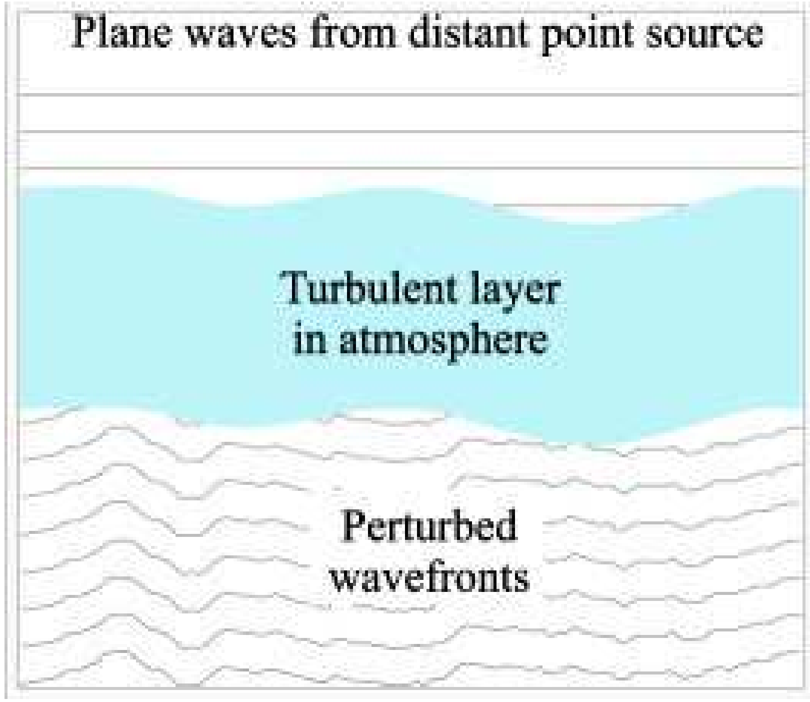
for classical telescope of order few times 0.1 arcsec

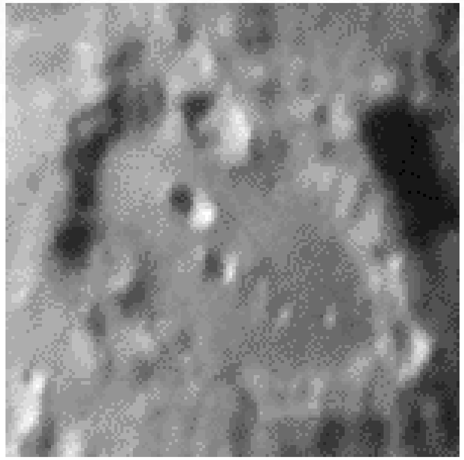
Atmosphere

typically 1 arcsecond

Conclusion: for any large telescope the atmosphere is the limiting factor in setting the spatial resolution

Atmospheric turbulence and seeing

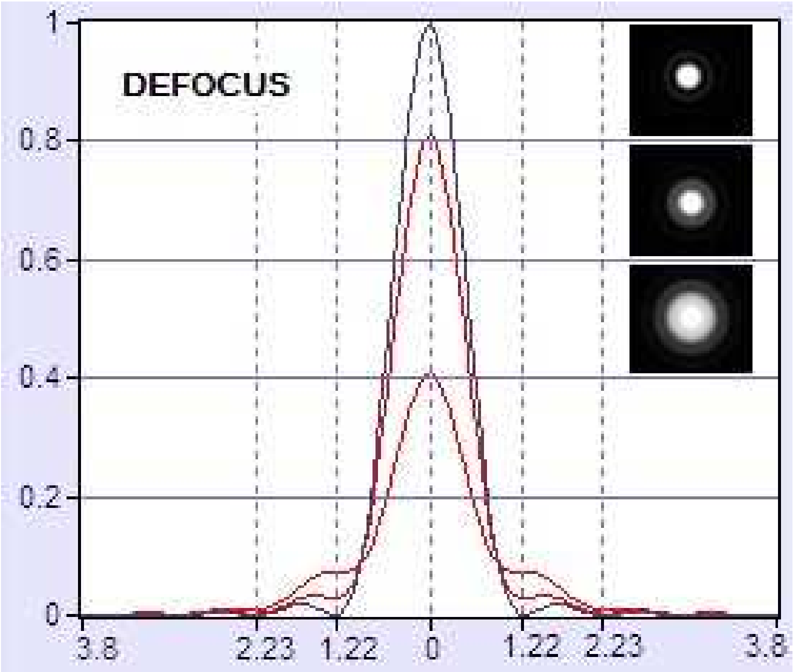




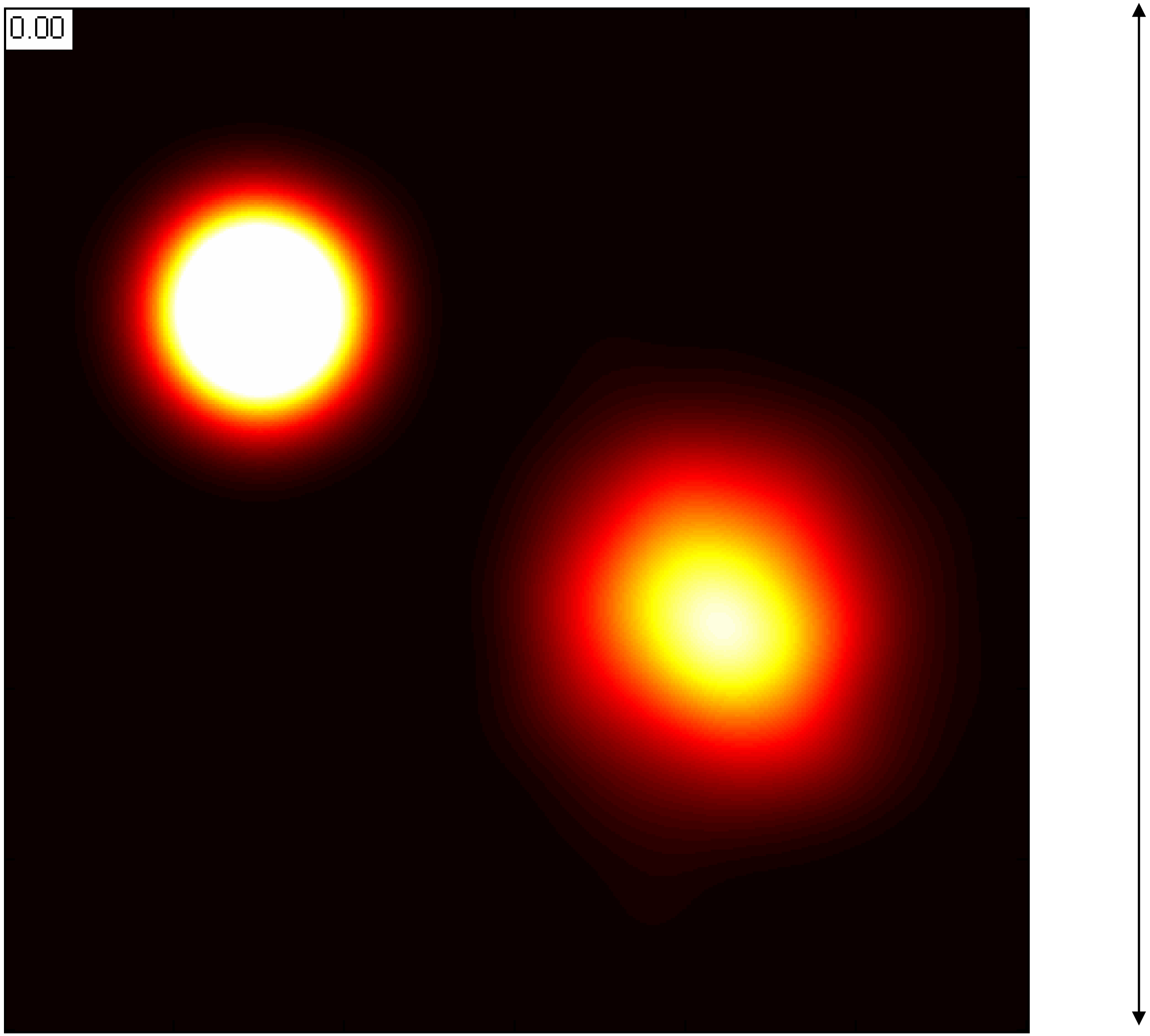
A few key concepts #1:

FWHM: width of the image at half height

Strehl ratio: ratio of peak intensity of aberrated image compared to perfect image



Euro50 Adaptive Optics Simulation

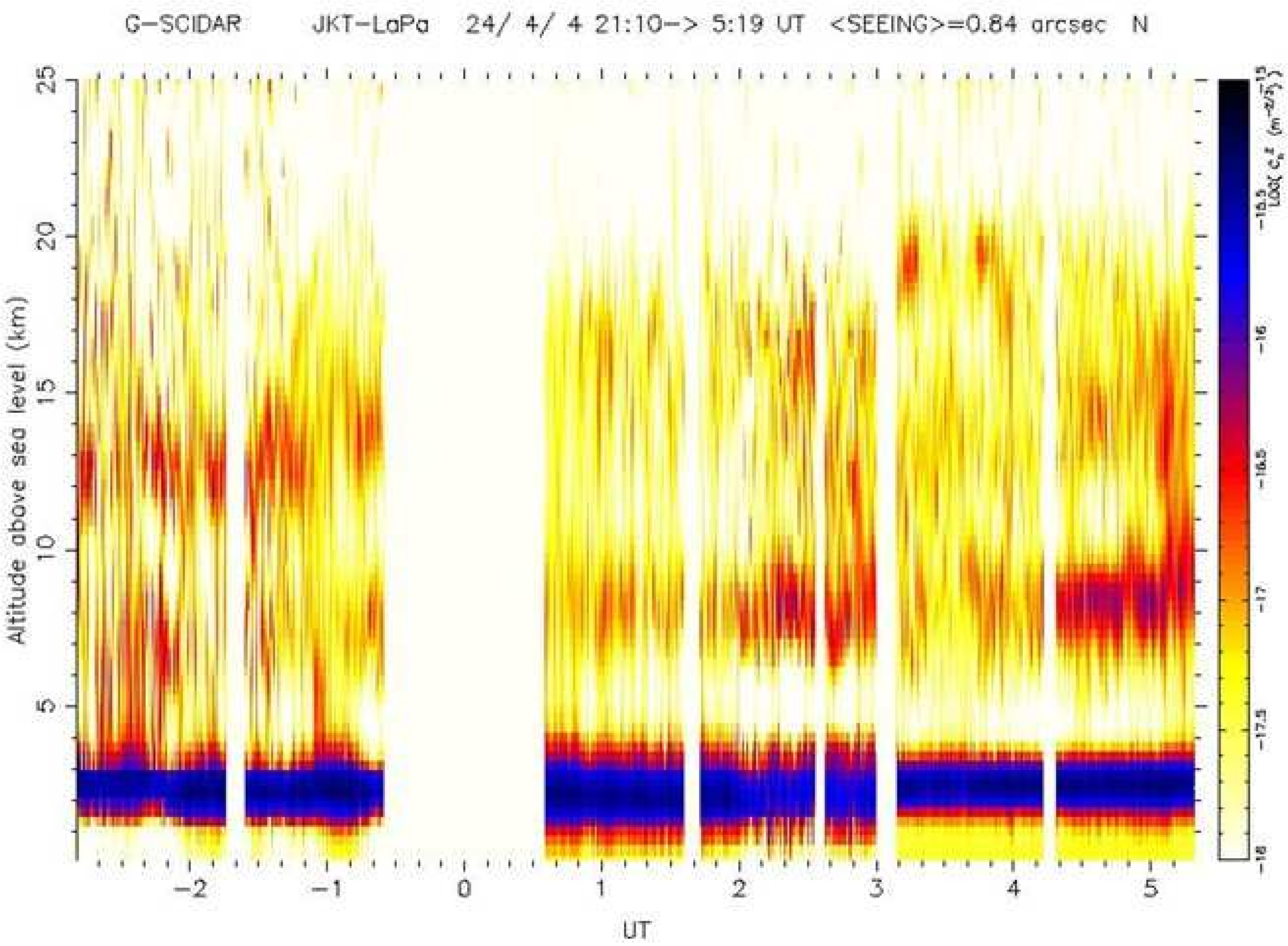


K-band

A few key concepts #2:

C_n^2 … osphere … g.

r_0 … scale … d the



A few key concepts #3:

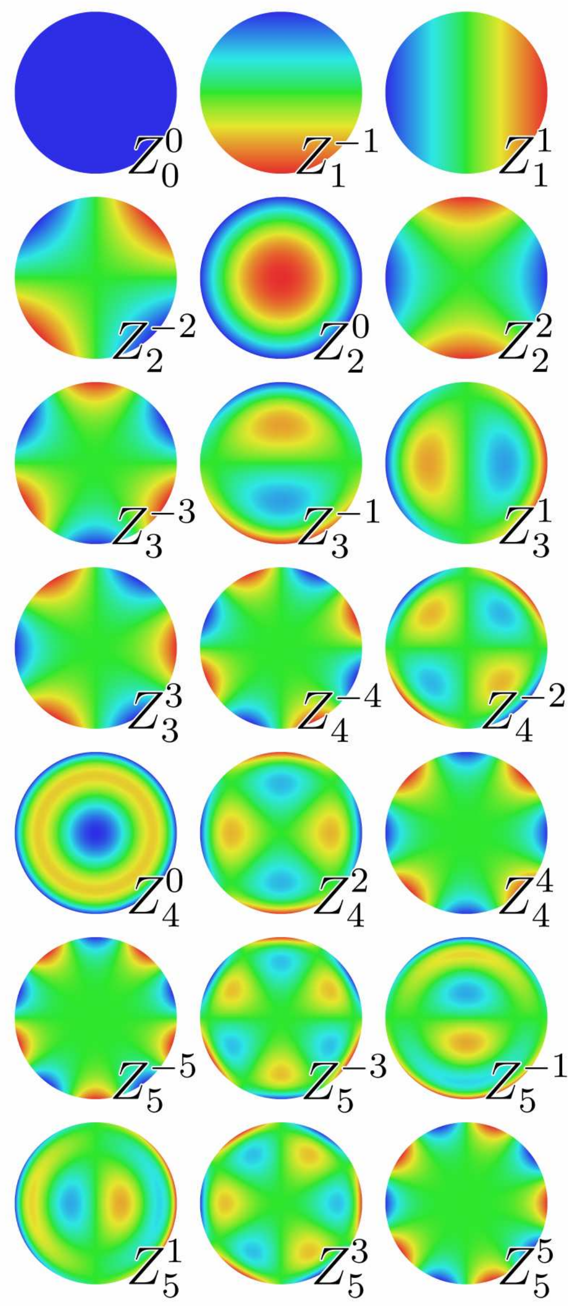
Wavelength dependence of seeing:

Everything related to seeing improves towards longer wavelengths

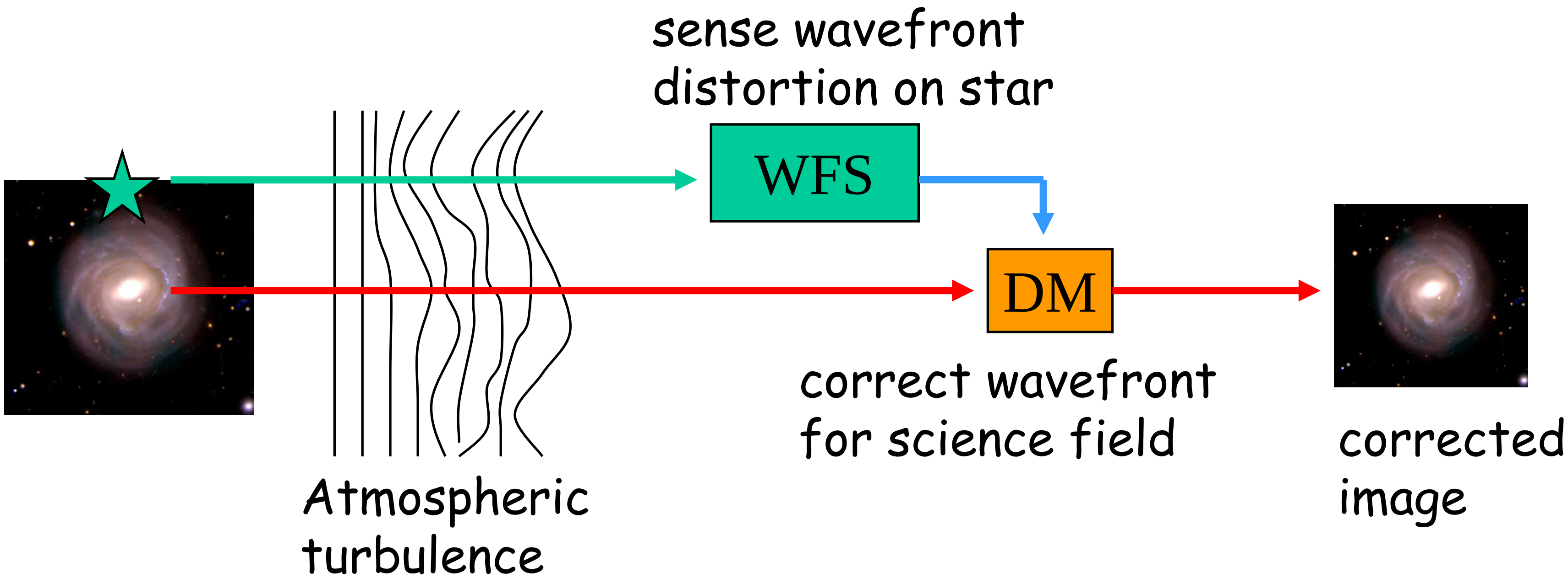
'Seeing' FWHM ~ λ/r_0 ~ $\lambda^{-1/5}$

Zernike polynomials:

a mathematical description used to describe wavefront distortions



Adaptive Optics seeks to correct for the atmospheric turbulence in order to recover the theoretical diffraction-limited image quality of the telescope.



The Adaptive Optics cycle

Measure the wavefront distortion

Calculate optimal position of adaptive mirror

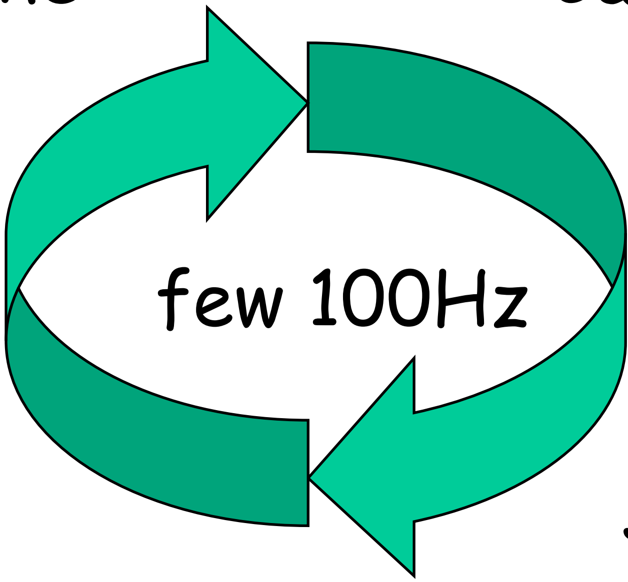


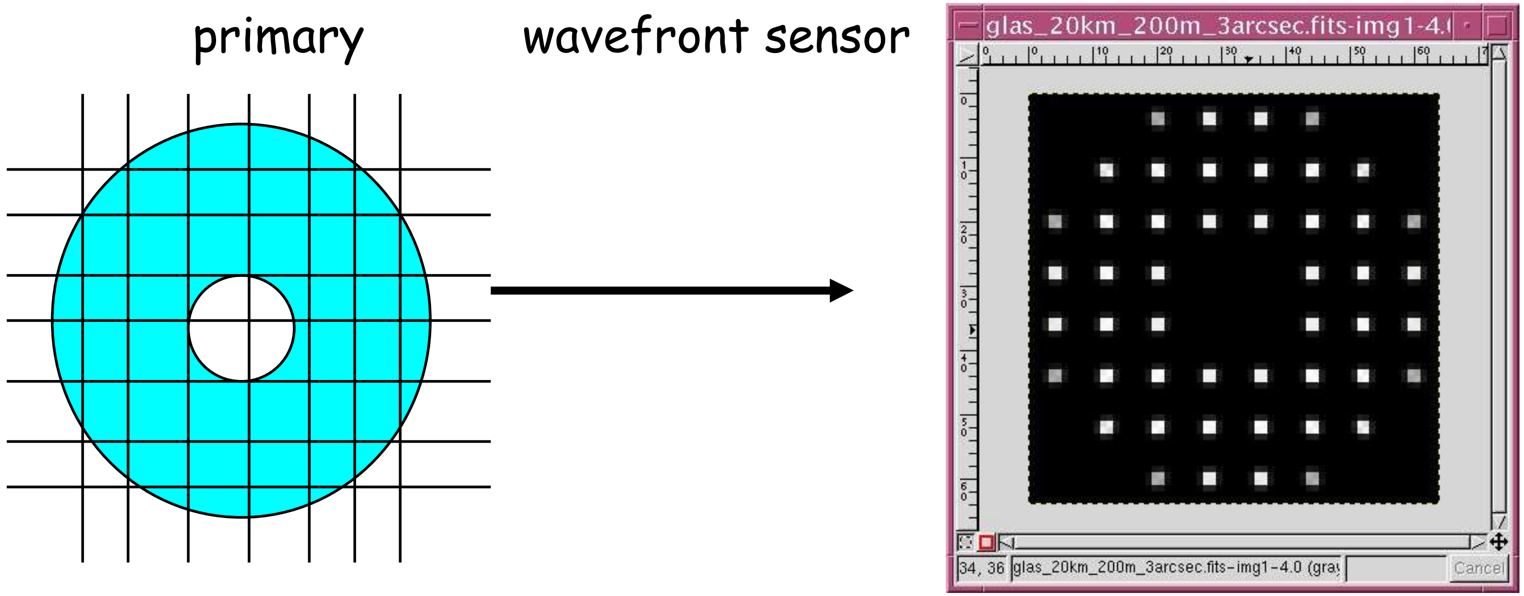
Image improves

Set adaptive mirror

Wavefront Sensor

WHT primary

Shack-Hartman wavefront sensor

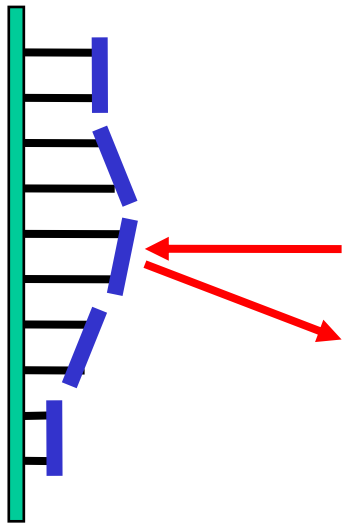


Divide up the primary mirror ('telescope pupil')
Image star for each segment
Spot centroid positions are a measure for the local wavefront tilt.
The centroids are used to correct the DM.

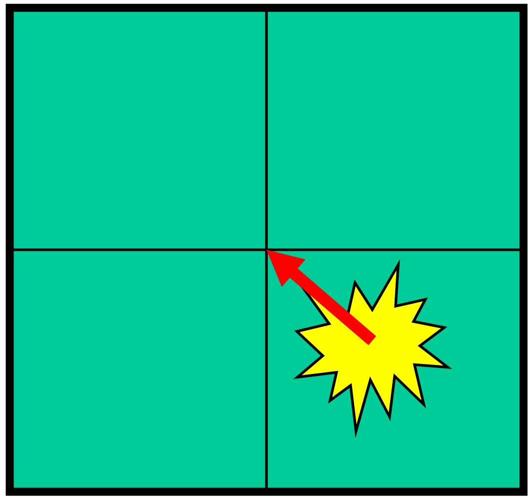
Wavefront distortion

A local wavefront tilt causes a star image to slightly shift to away from the centre.

By tilting an element on the deformable mirror the wavefront is flattened again.

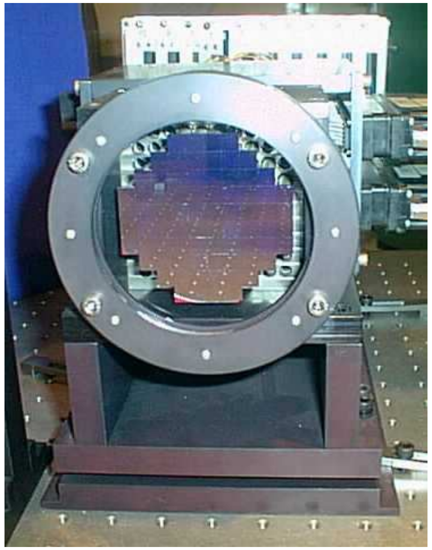


Deformable mirror

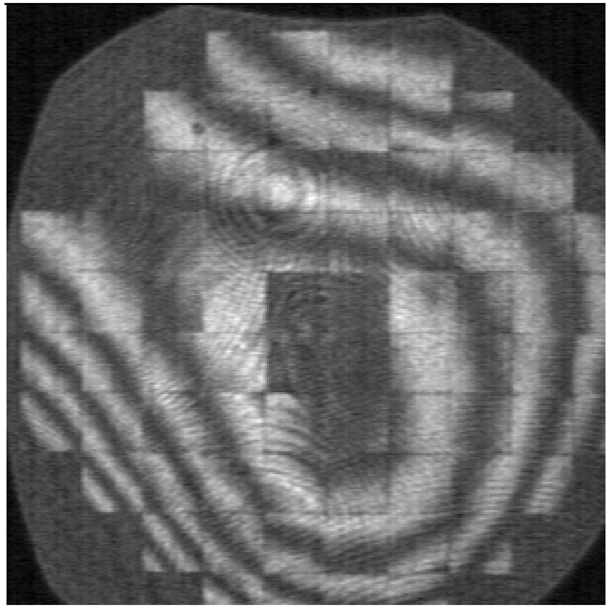


Wavefront sensor element

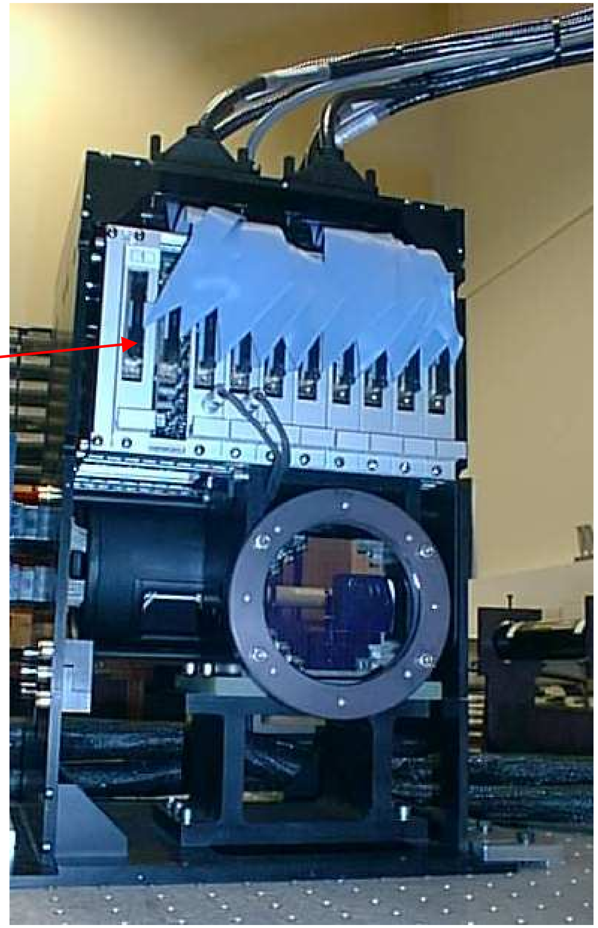
Deformable Mirror



76 element segmented mirror.
Each mirror element is mounted on three piezo elements with strain gauge

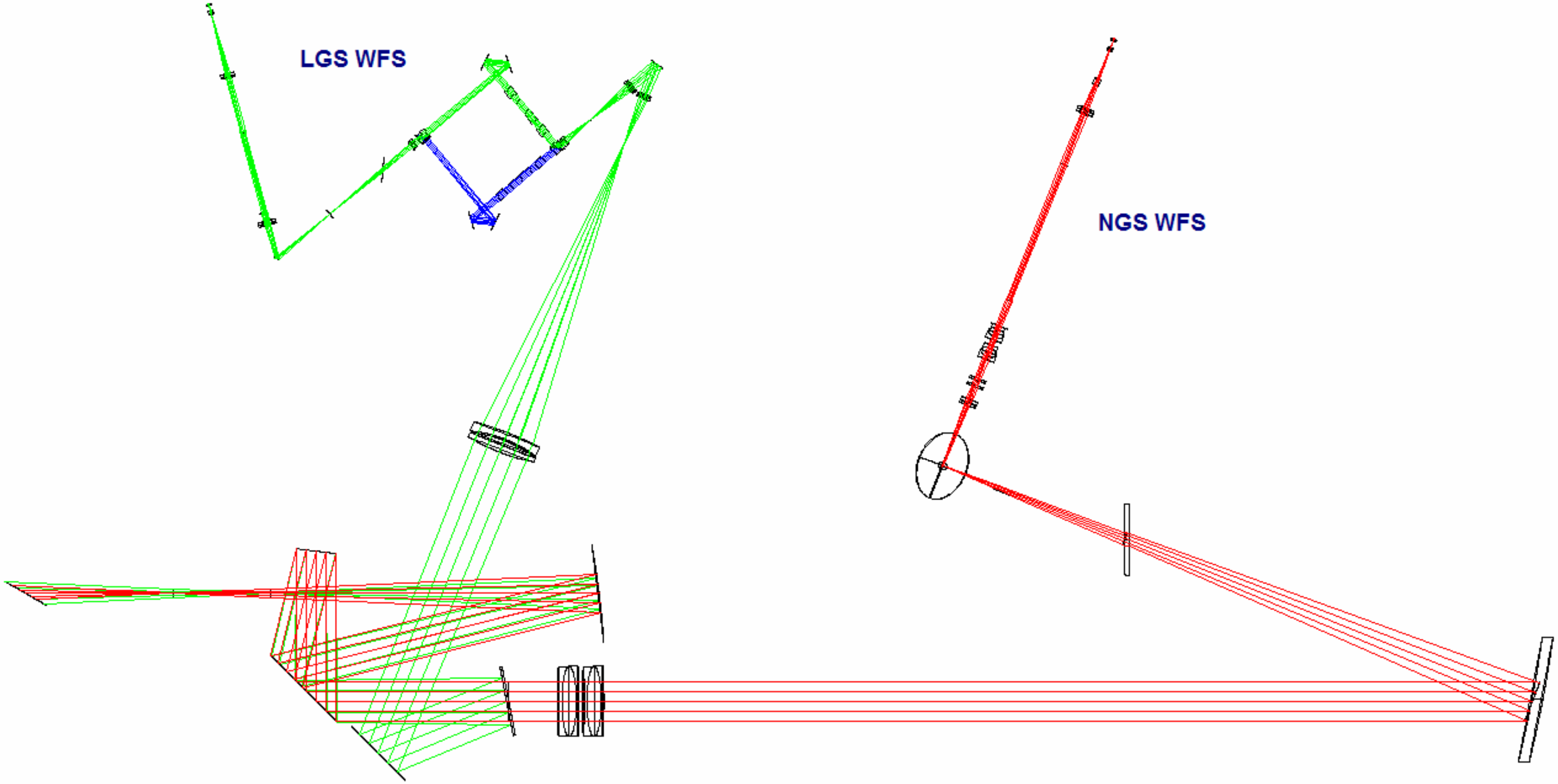


Interferometric view



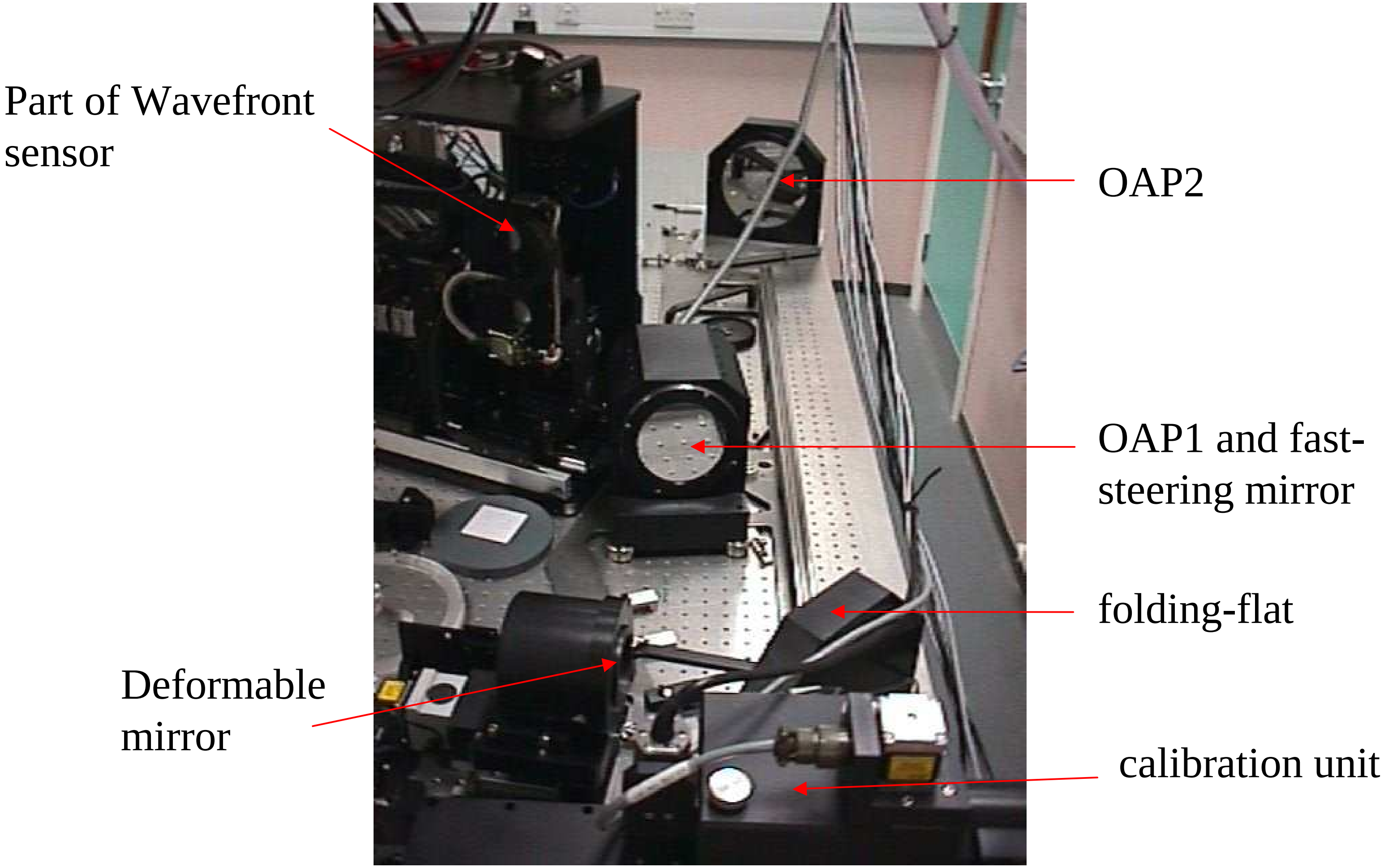
The DM in its mount
With Strain Gauge
Pre-amps

NAOMI



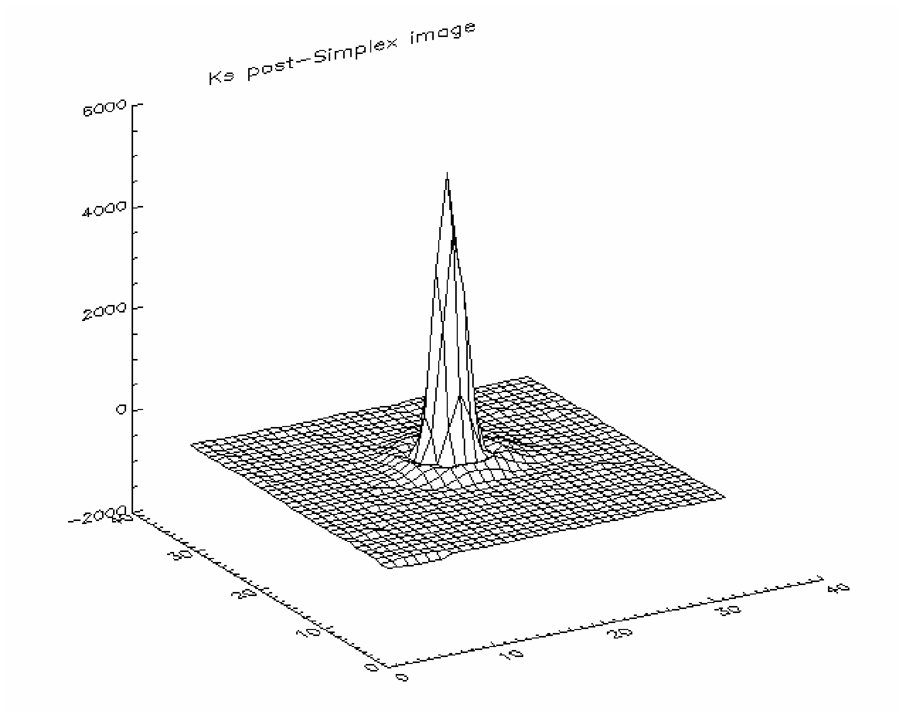
NAOMI AO SYSTEMS

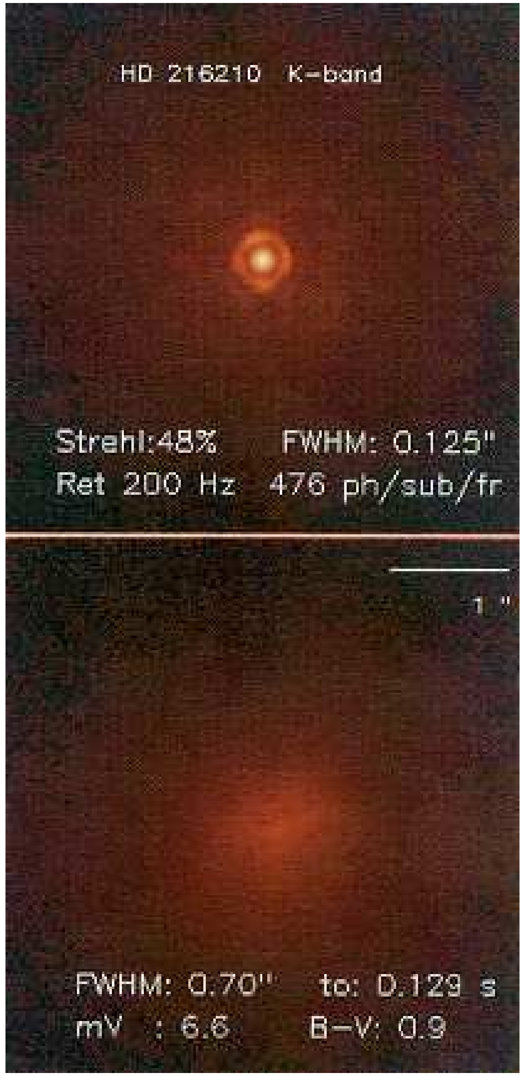
NAOMI



An image showing NAOMI during laboratory integration.

When AO works...





Limitations

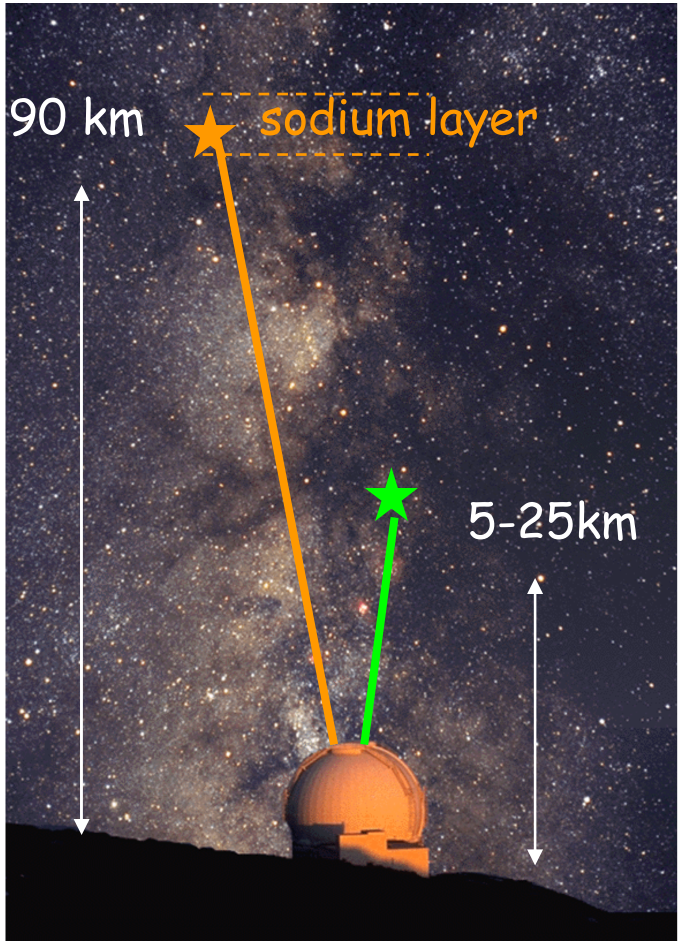
Performance degrades at shorter wavelengths as r_0 and t_0 both reduce with wavelength. The result is that at shorter wavelength wavefront sensing and correction must happen on a *finer scale* as well as at *higher frequency*

High Strehl ratios are readily obtained in K-band but are still impossible in the optical.

Limitations

Needs bright star very close to target, resulting in sky coverage of ~1%

Improve this using laser guide star – Sodium or Rayleigh laser



Entry Course on A

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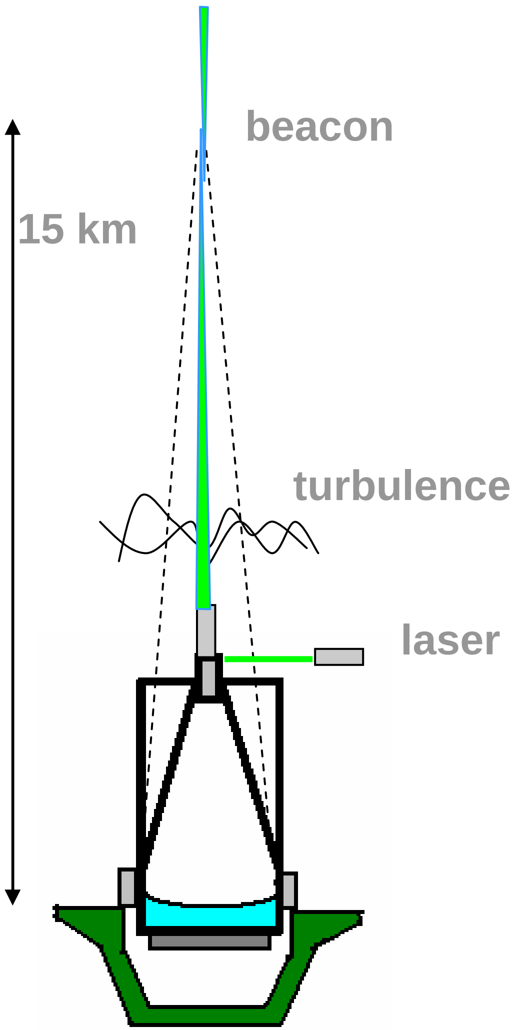
GLAS laser schematic

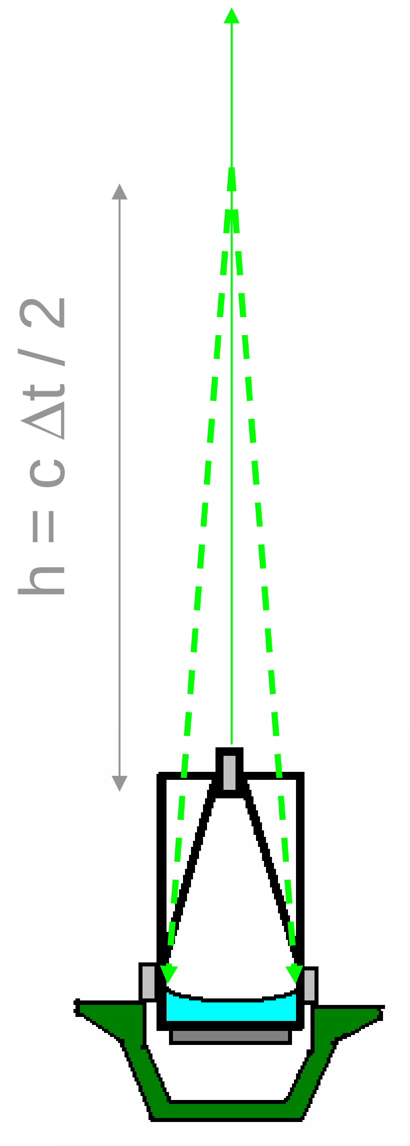
Laser focussed at of 15km

First expand beam, then project using small telescope

Back scattered light is used for wavefront sensing



GLAS principles

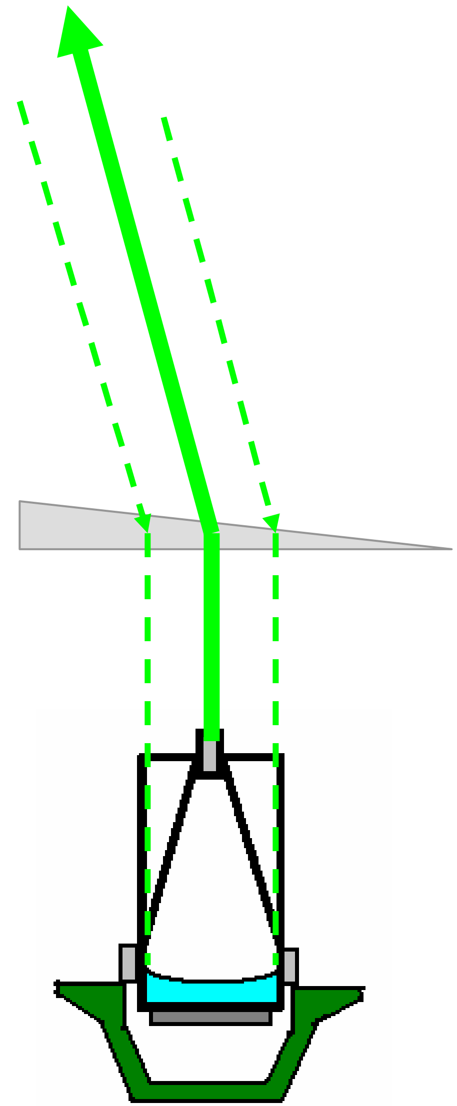


Project laser beam on small spot at ~15km

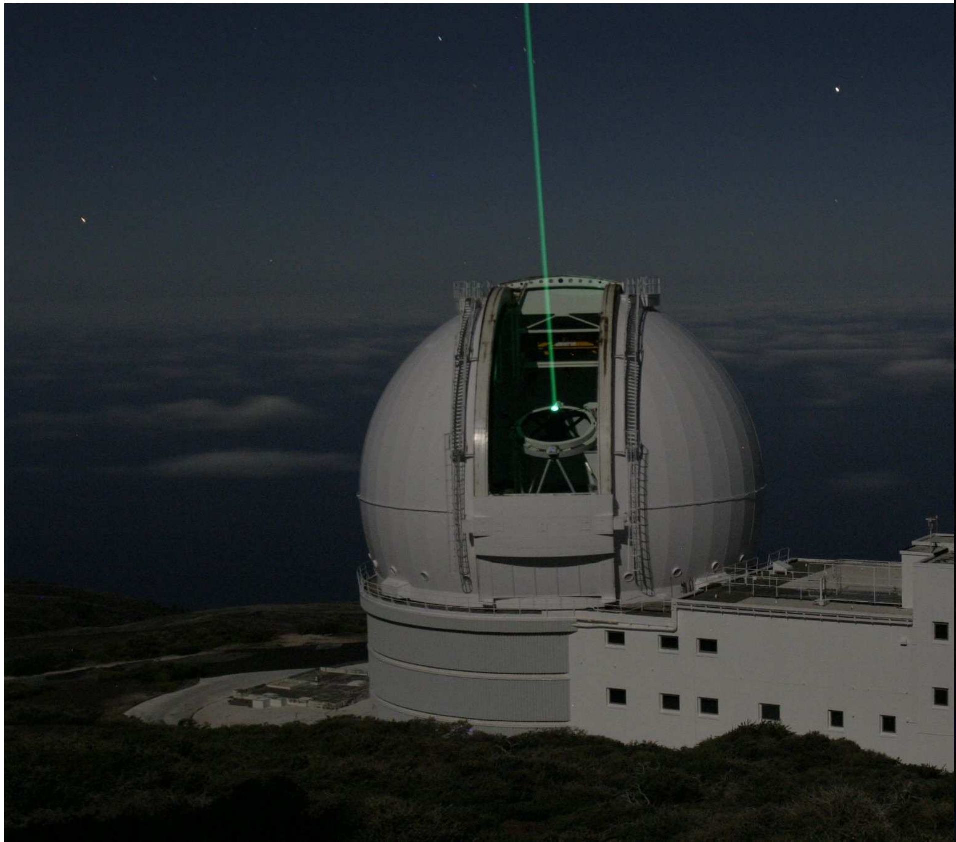
Pulsed laser linked to fast shutter to select height and duration of scatter region

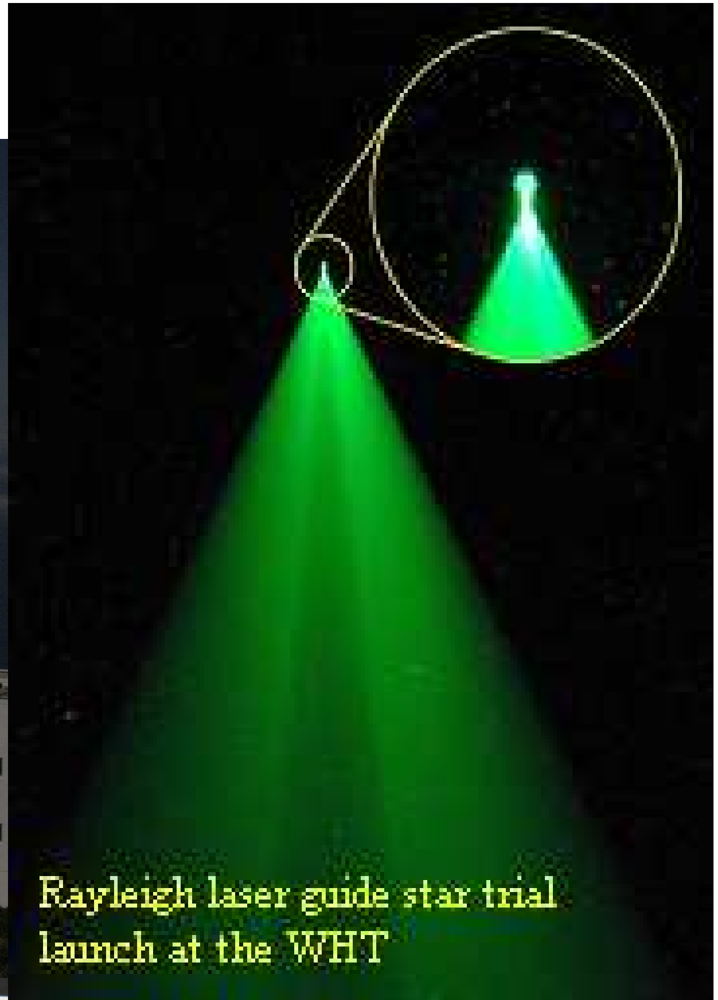
Still needs natural star

Two wavefront sensors, for star and laser



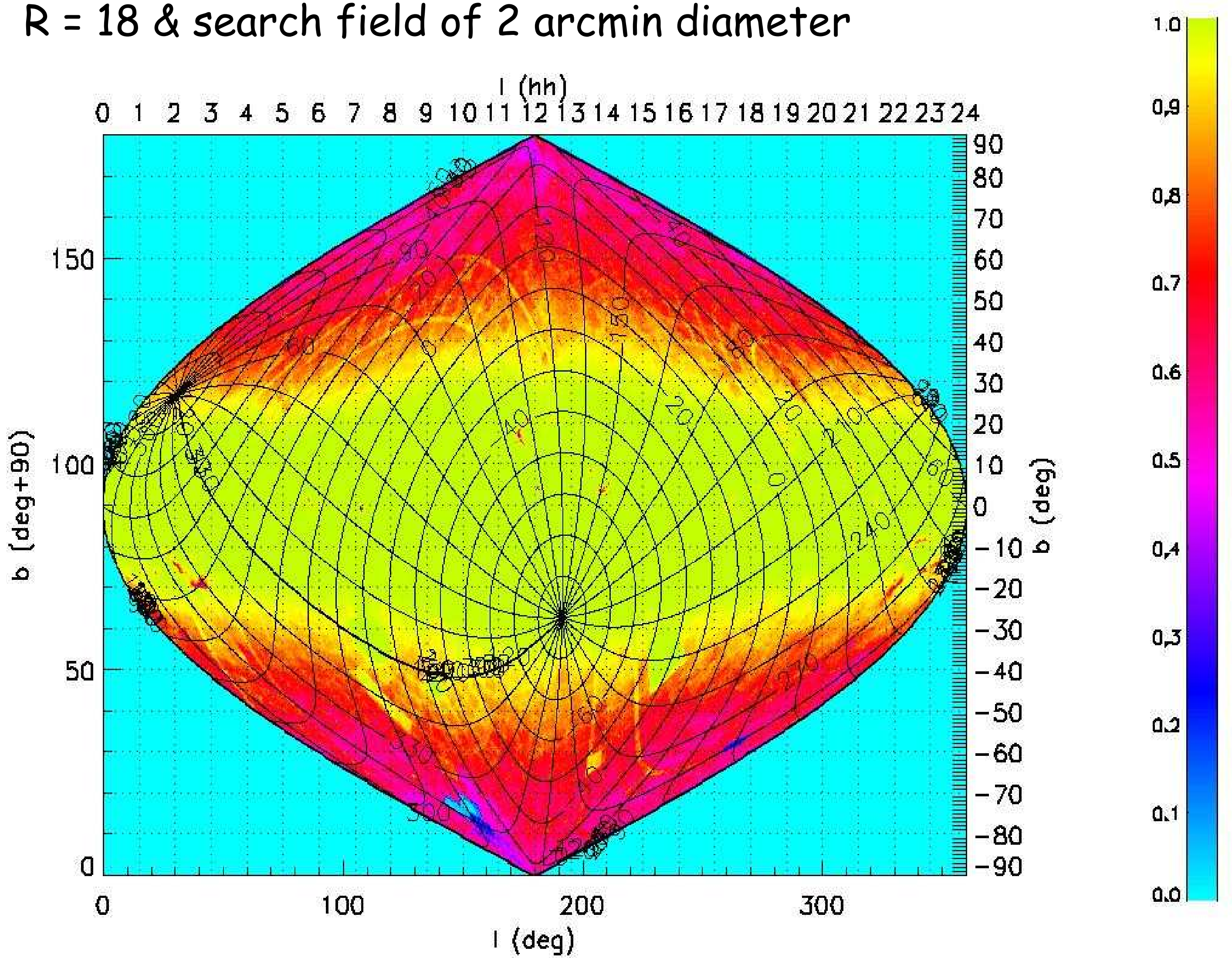
The laser at work…





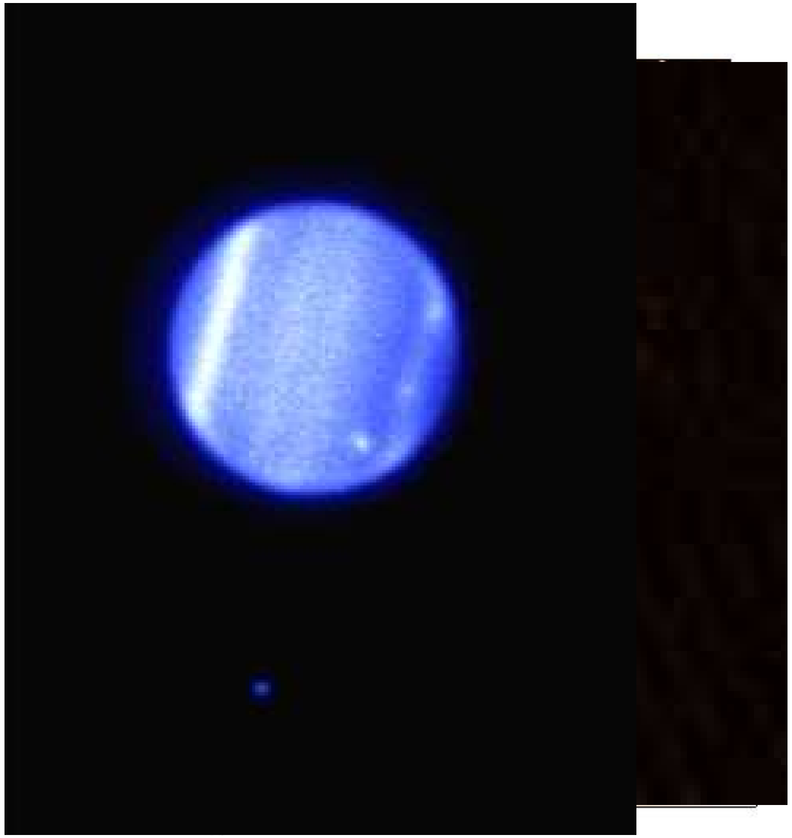
Sky coverage

R = 18 & search field of 2 arcmin diameter

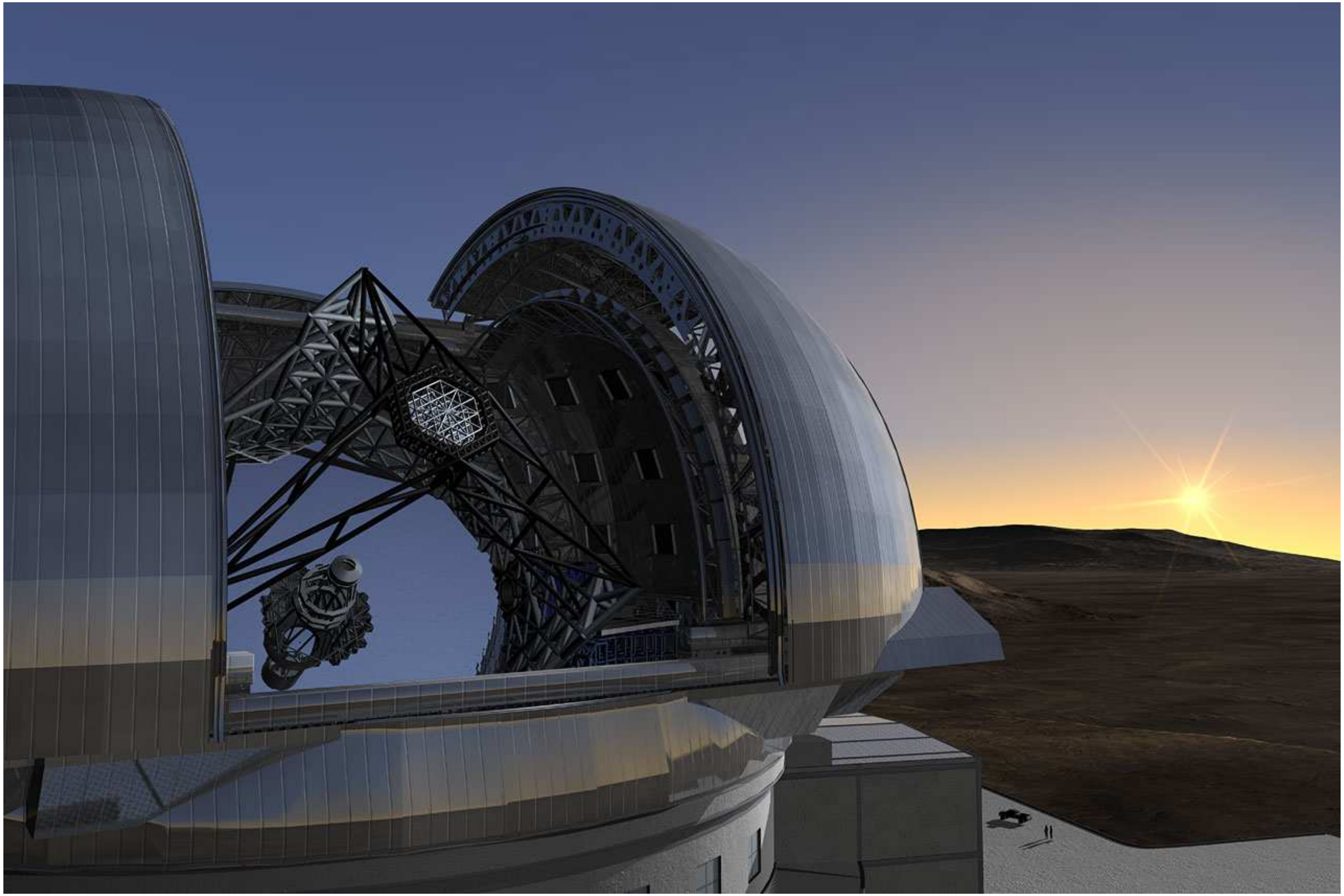


Remko Stuik
Leiden

When Laser AO works...



The 42-m E-ELT



1 arcsecond

E-ELT
(diffraction limit a few milliarcsec in the near-IR)

Entry Course on Adaptive Optics