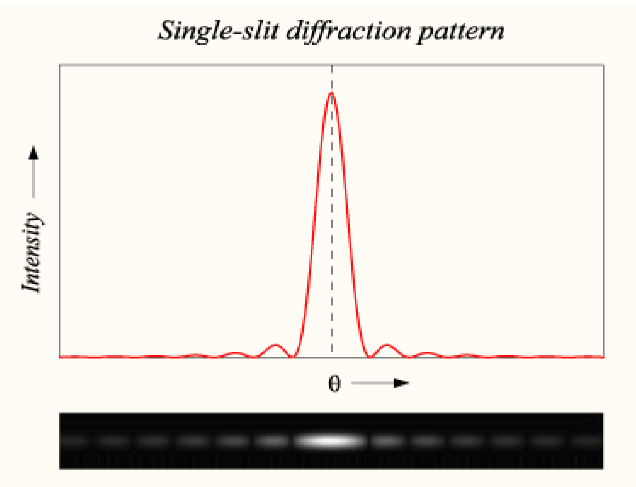
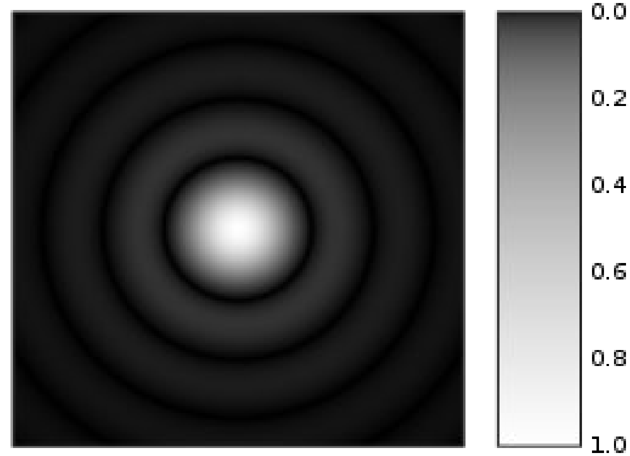
Diffraction Limit

What is the *best* angular resolution a telescope would achieve in idealised conditions?

Circular aperture: $\theta_{min} \approx 1.22\ \lambda/d$





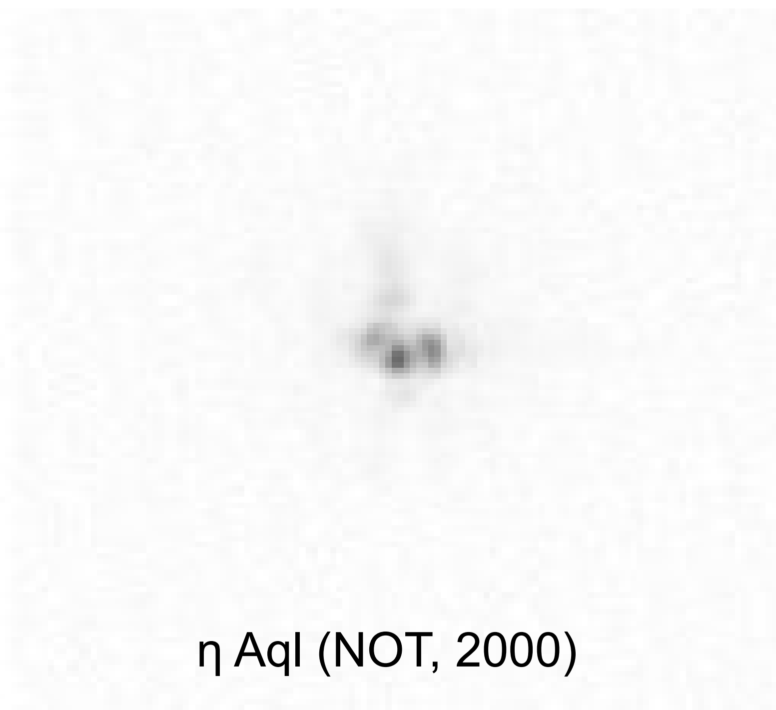
Airy disc

For the HST: d=2.4m and λ=500nm

$\rightarrow \theta_{min} = (1.22 \times 500 \mathrm{x} 10^{-7}) / (2.4 \mathrm{x} 100)$

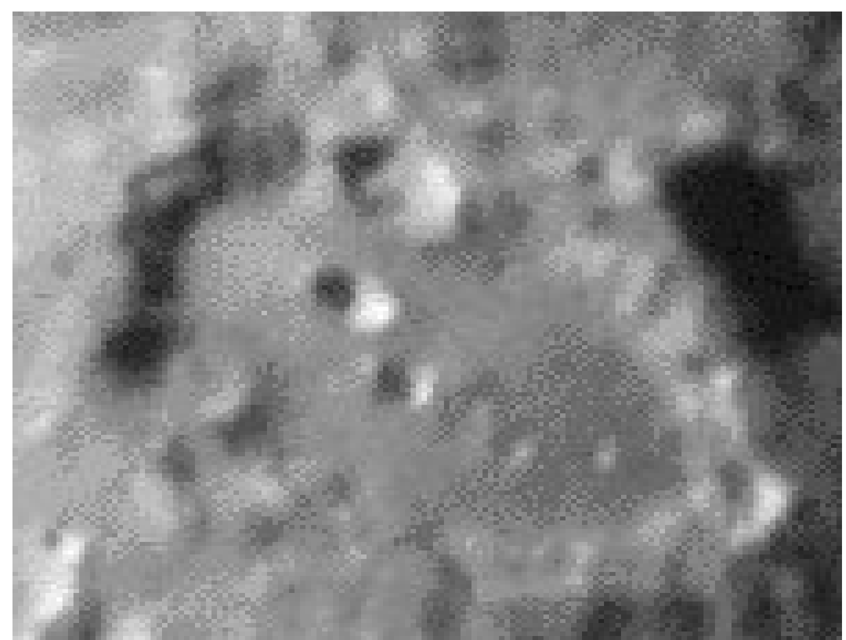
$\rightarrow \theta_{min} \approx 2.5 \mathrm{x} 10^{-7}$ rad $\approx 0.05''$

Atmospheric turbulence and specles



η Aql (NOT, 2000)

Slow motion images showing the effects of atmospheric turbulence



Atmospheric turbulence and specles

Resulting images are the *superposition* of many ***Airy discs*** at different locations, called ***speckles***. Each Airy disc is defined by the *diffraction limit* of the telescope

Diffraction limit ~λ/d = 500nm/2.4m = 0.05''

Atmospheric turbulent cells d_0~ 0.1m moving at 5 m/s

Movement through d_0 ~ 20ms

Offset angle due to d_0 ~ 1'' (~0.4'' for good sites)

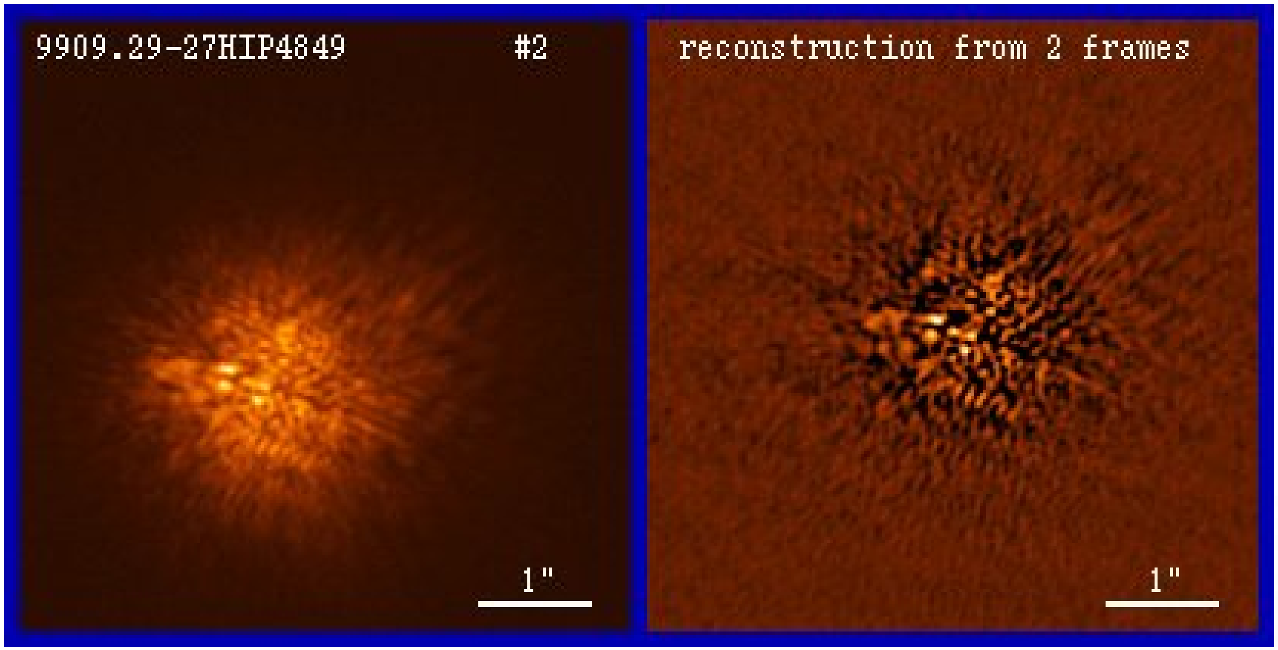
Multiple wavefronts due to telescope size:

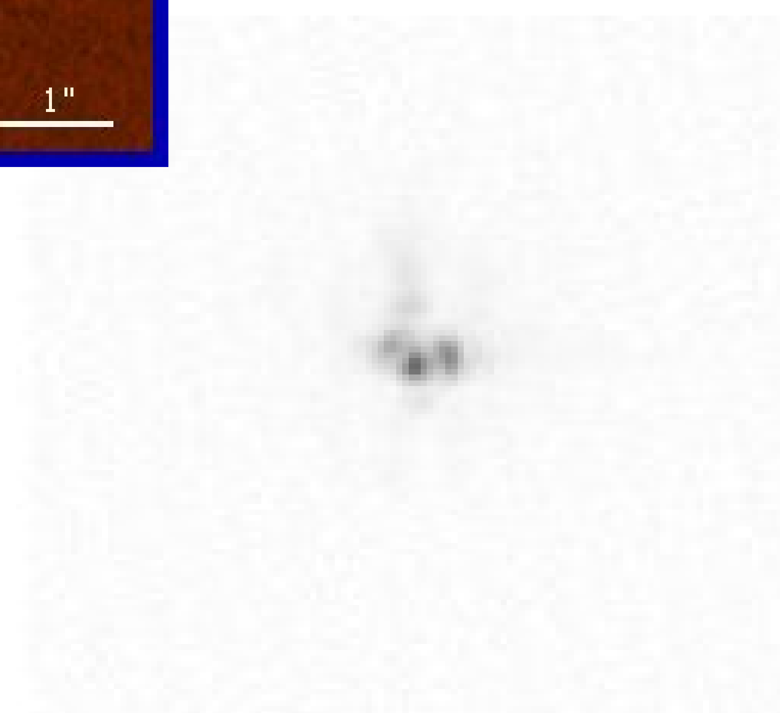
~ $d/d_0 \approx$ 2.4m/0.1m ≈ 24 speckles (1D) ≈ 450 speckles (2D)

Speckle interferometry

- Recall that turbulent cells move through d_0 in about 20ms
- If our exposures are much shorter (<10ms), then each image will be a snapshot of the atmospheric seeing at exactly that moment
- Each exposure will be close to the diffraction limited, but displaced slightly from the original position
- We can then use image processing techniques to find the location of sources in each image (*e.g.*, using the brightest speckle) and stack these images after having shifted these positions to a common frame (***image stacking***)
- ***Speckle interferometry*** involves combining the different images in the Fourier domain

Speckle interferometry



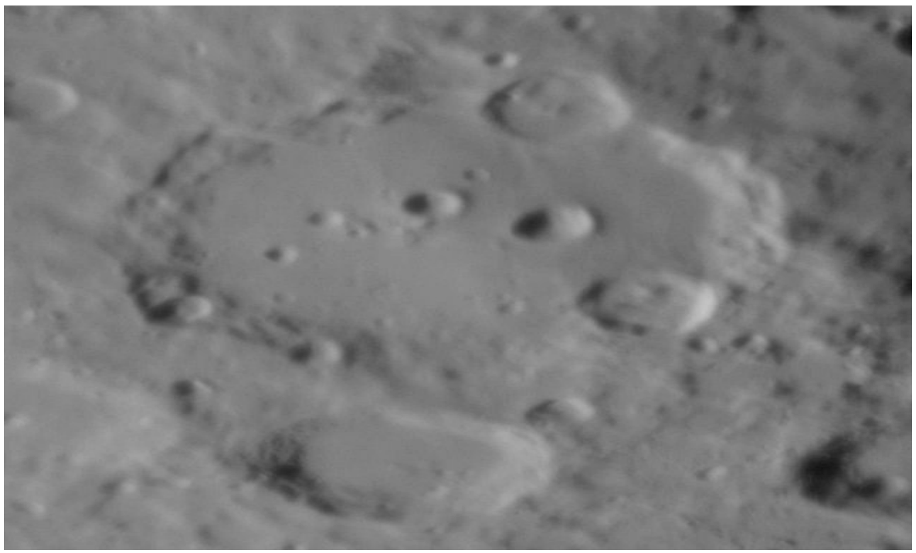


Lucky Imaging

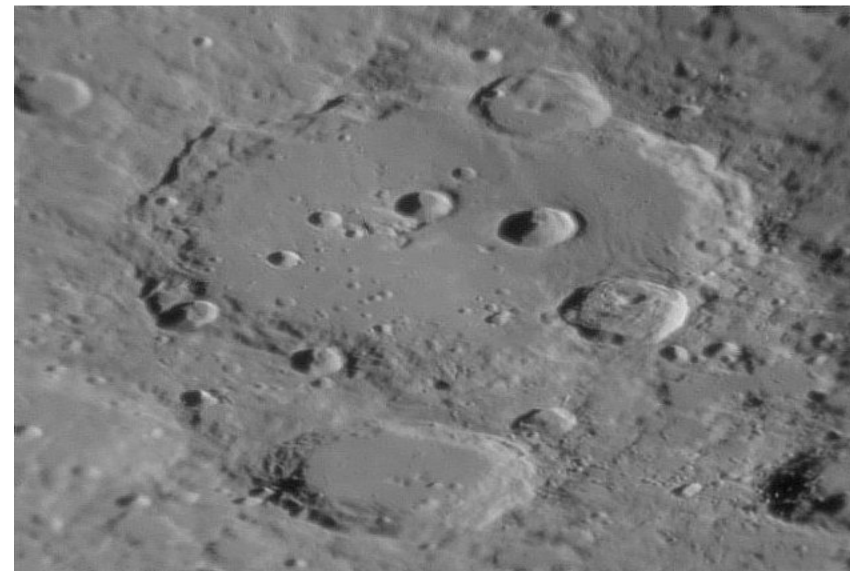
An image of Saturn taken with a large telescope during times of good seeing.

An amateur average lucky image of Saturn taken with a modest telescope and a webcam!

Lucky Imaging



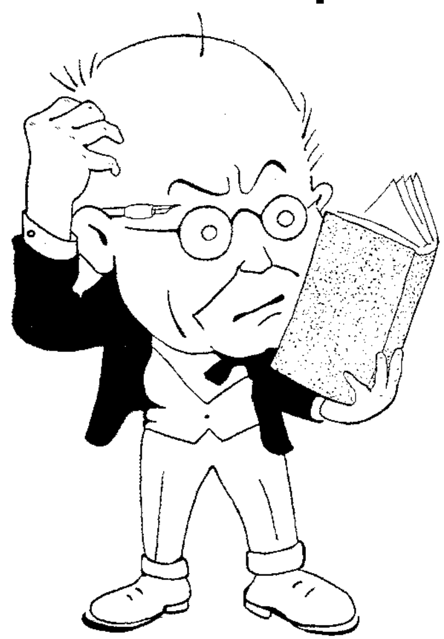
A series of consecutive images of the Moon.



The amateur average lucky image of the Moon using the Registax Version 4 software package

Adaptive optics

What if the observed source is too faint to be seen with short exposures?



We have to find a method to apply atmospheric corrections *before* acquiring the image, not after!

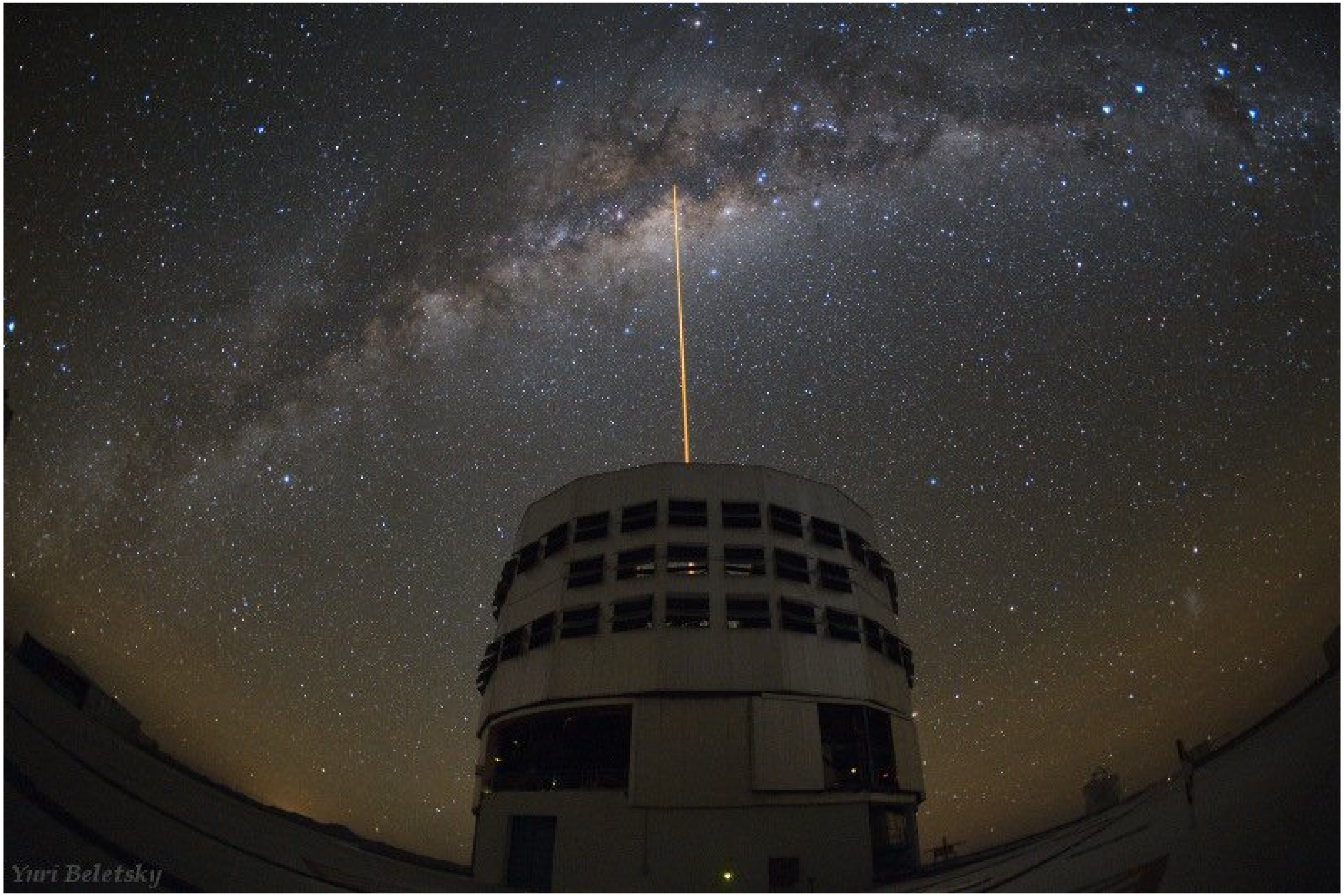
Adaptive optics
Deformable mirrors

- If the wavefront in a given region is delayed, the mirror surface in that region has to be delayed, thus the mirror surface in that region is brought *forward!*
- This is *not* done on the primary mirror (too large!) but usually on the secondary or tertiary
- For a 0.1m deformable mirror there may be several hundred tiny pistons (actuators) adjusting the height of the reflecting surface

Adaptive optics: Sensing the wavefront

- To deform the mirror correctly we need to know *in advance* the instantaneous (~1ms) wavefront shape of the incoming light.
- To do this we need a bright reference star in the observed field.
- This rarely happens, as most interesting astrophysical sources are *faint*!
- Thus, we make a *fake* star with a laser!

Adaptive optics:
Sensing the wavefront



Adaptive optics: Sensing the wavefront

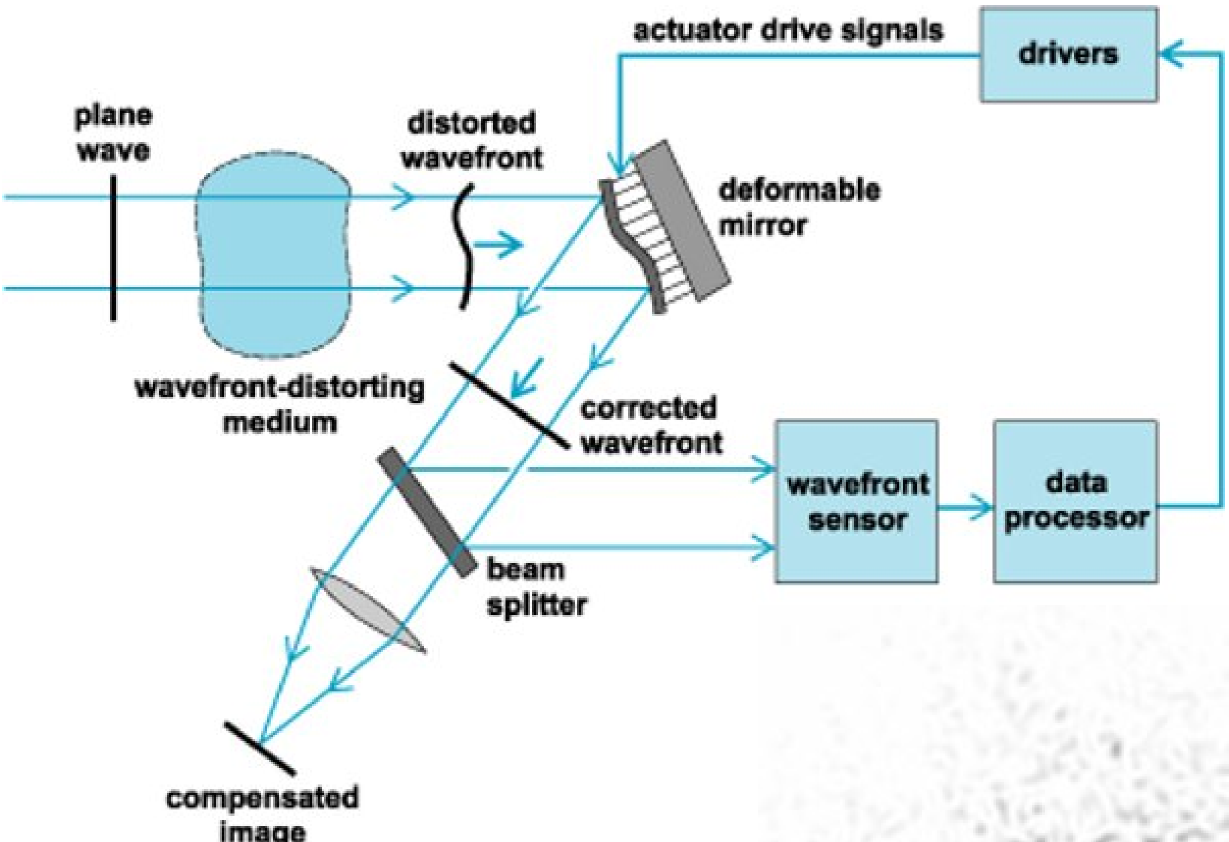
- A laser illuminating a thin layer of atmosphere, usually of sodium at 90km altitude, appears as a *fake* star.
- The returning light from this fake star is used to deform the mirror and correct for atmospheric turbulence

Is this the whole story? What other problems would cause this method not to perform perfectly?

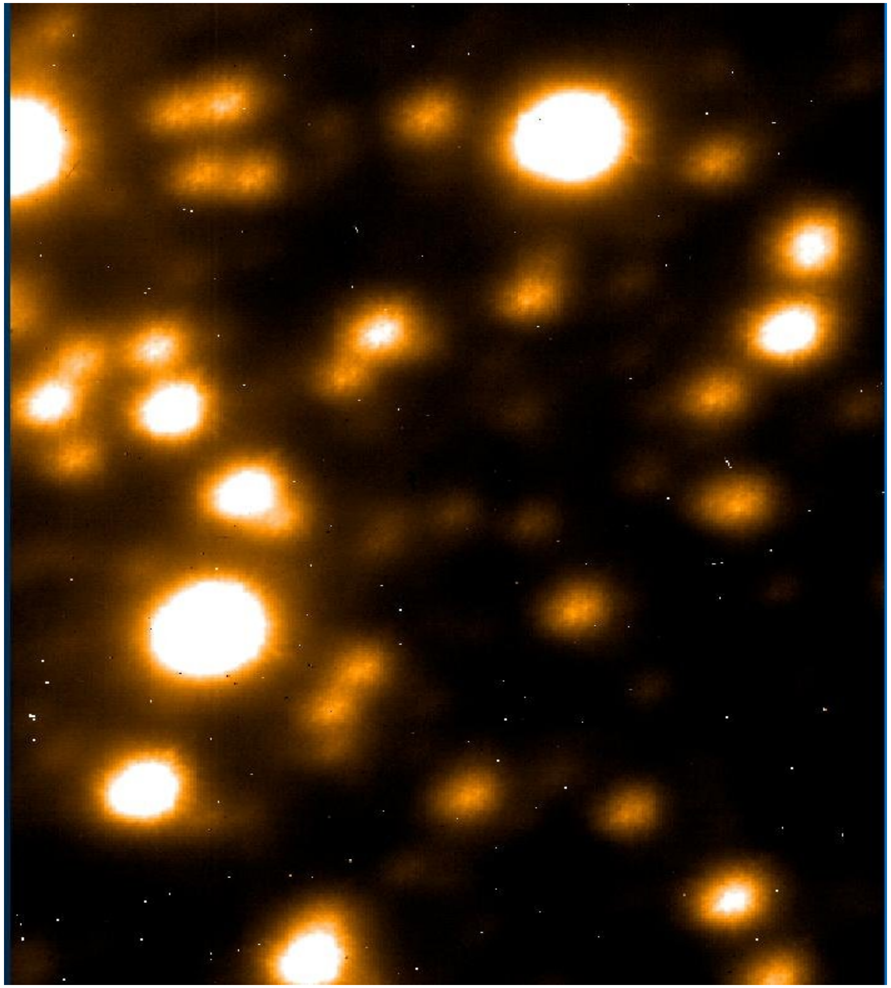
Adaptive optics: Closed loop

- The laser light has to travel *upwards* before it is reflected downwards, and this has to be also compensated for
- We can use a faint star in the field to do this, since the initial laser correction will be enough to start picking these out from the background noise
- This whole process is then repeated continuously in a *closed loop* (see page 127)

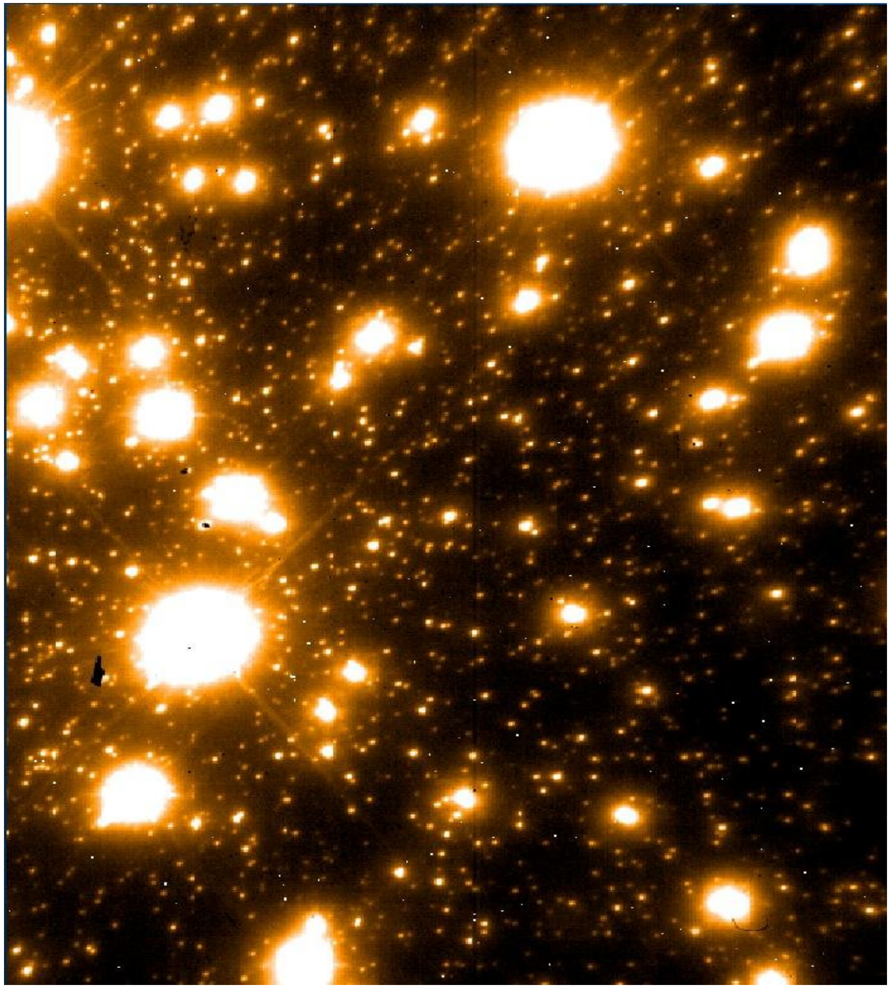
Adaptive optics: Closed loop



Adaptive optics: Closed loop



Before AO



After AO