Adaptive Optics

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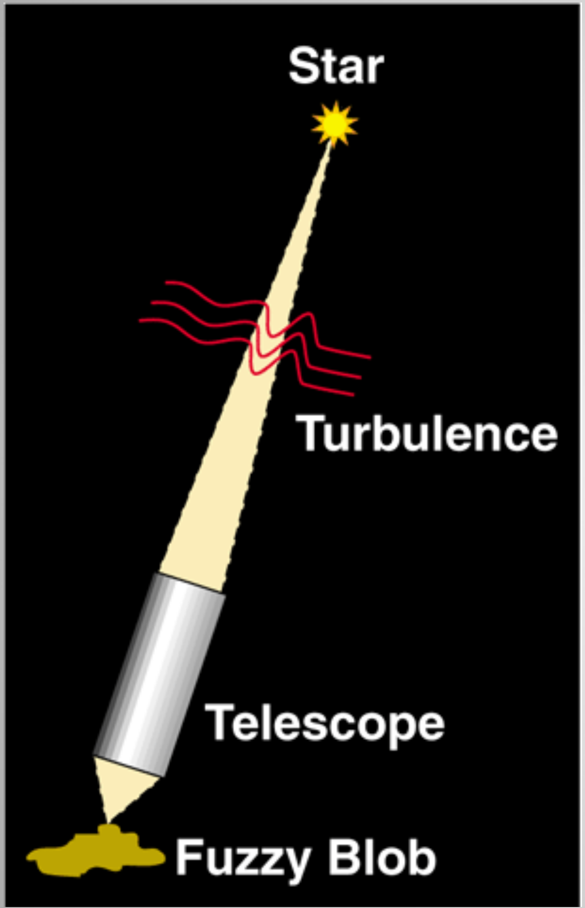
Large portion is adopted from Claire Max’s lecture in UCSC

03/30/2011

Why is adaptive optics needed?

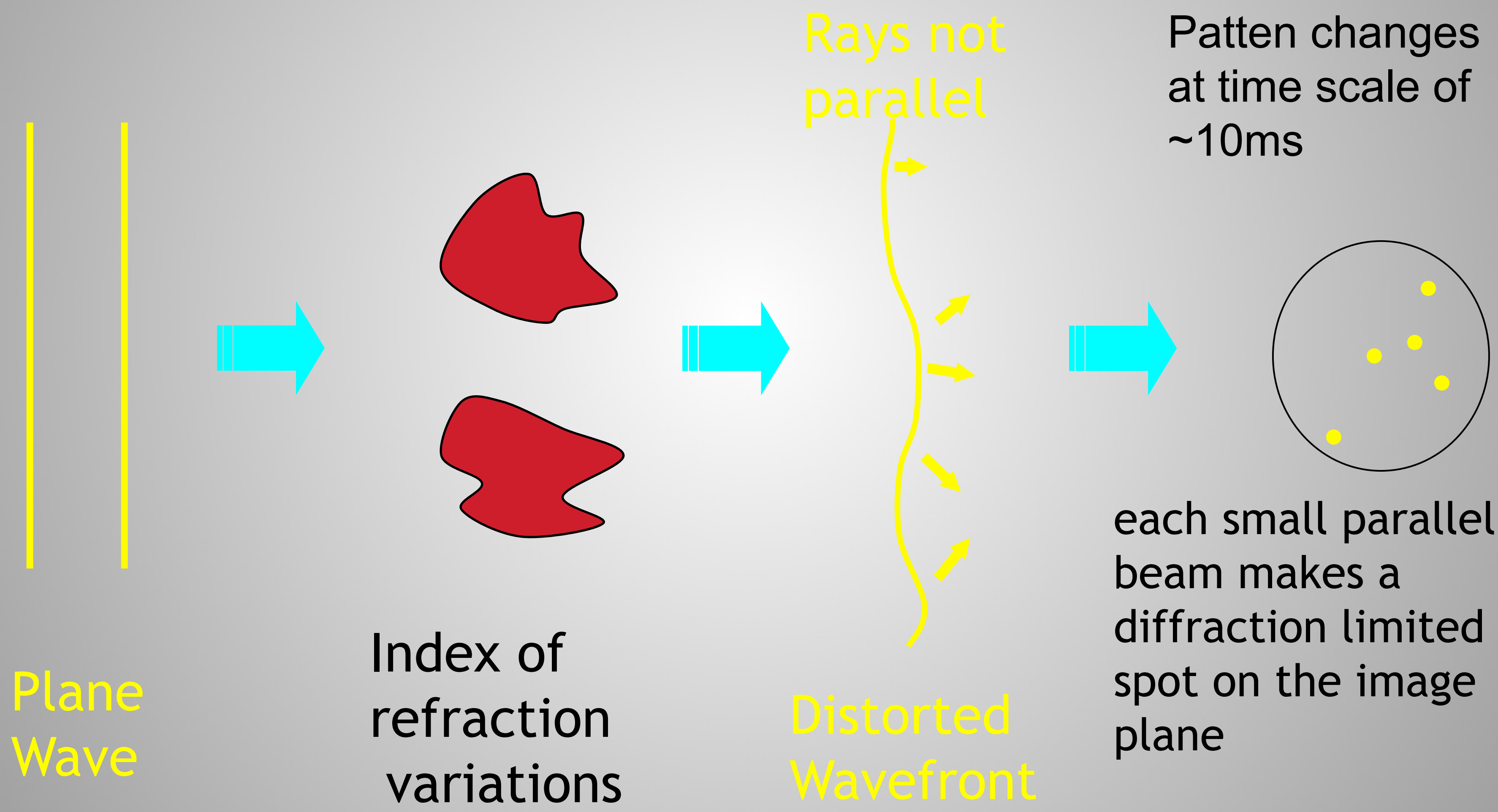


Turbulence in earth's atmosphere makes stars twinkle

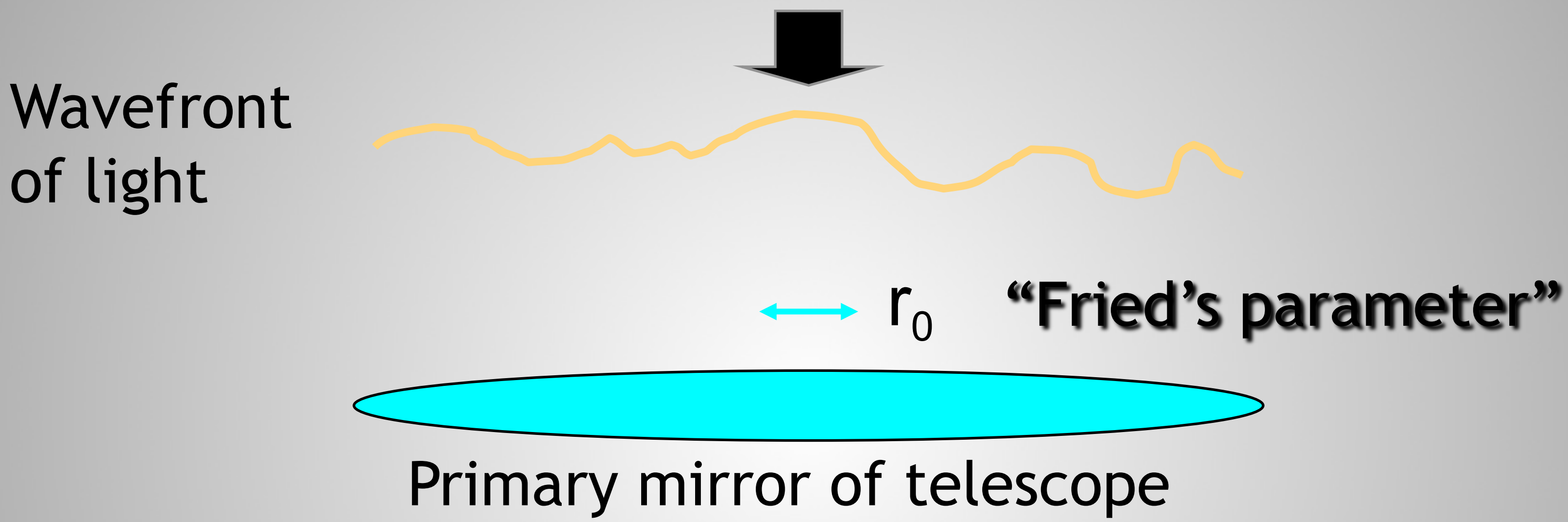
More importantly, turbulence spreads out light; makes it a blob rather than a point

Even the largest ground-based astronomical telescopes have no better resolution than an 8" telescope

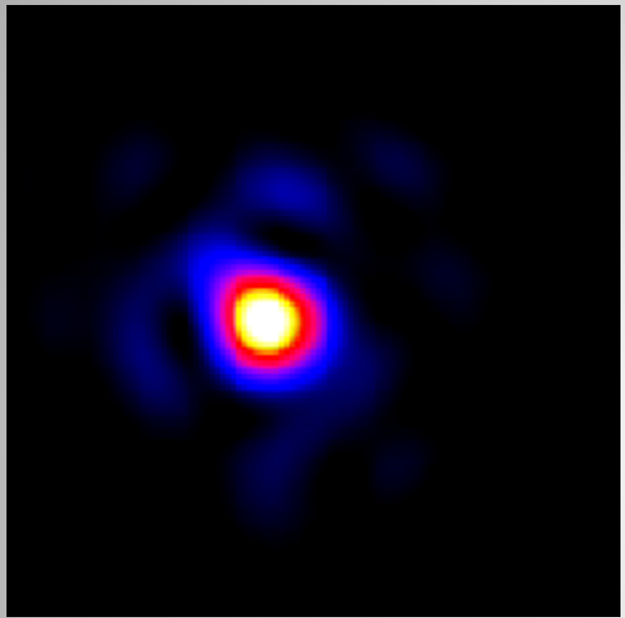
Atmospheric perturbations cause distorted wavefronts



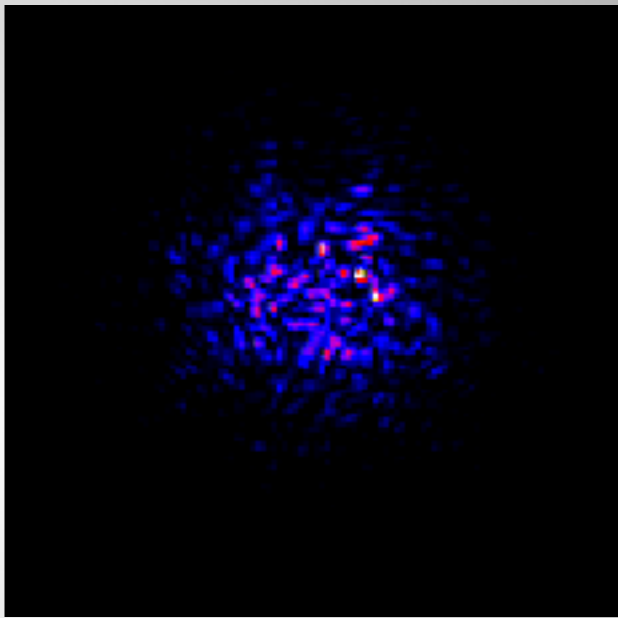
Characterize turbulence strength by quantity r_0



- "Coherence Length" r_0 : Diameter of the circular pupil for which the diffraction limited image and the seeing limited image have the same angular resolution. (r_0 ~ 15 - 30 cm at good observing sites
- Pupil larger than r_0, images are seeing dominated.



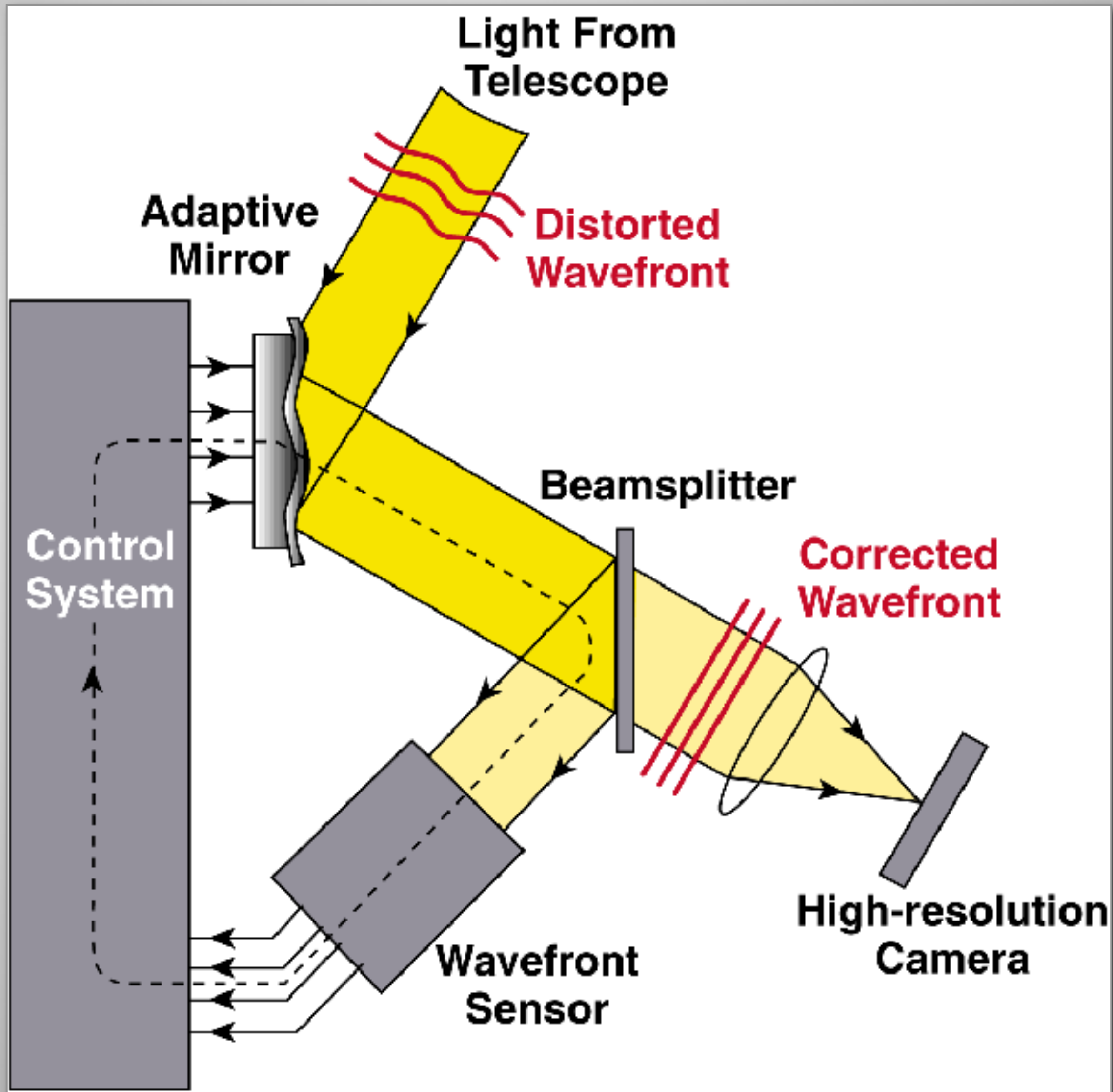
Real time sequence from a small telescope with aperture the size of r_0



A much larger telescope, aperture contains many r_0

Schematic of adaptive optics system

Feedback loop: next cycle corrects the (small) errors of the last cycle

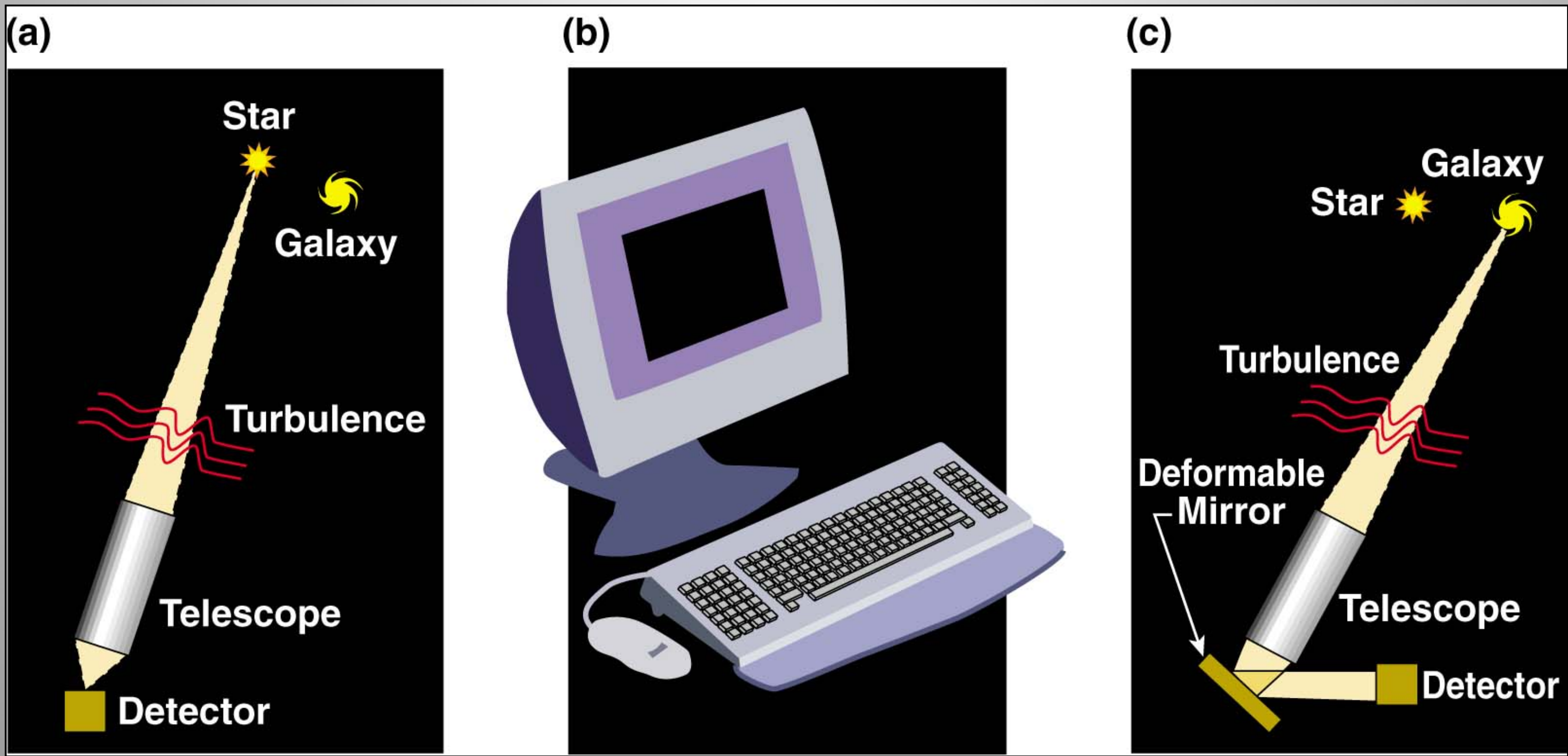


How does adaptive optics help? (cartoon approximation)

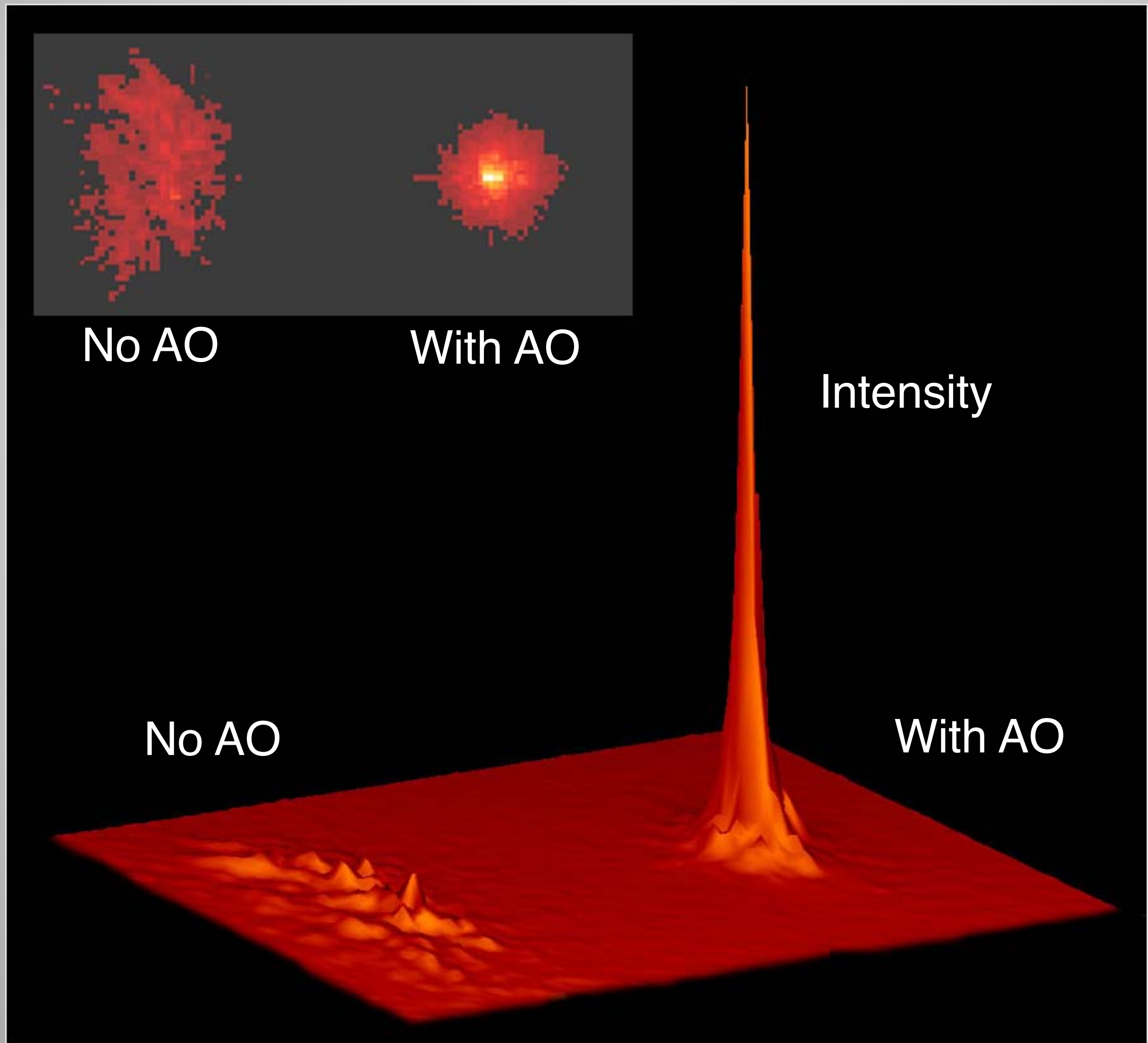
Measure details of blurring from "guide star" near the object you want to observe

Calculate (on a computer) the shape to apply to deformable mirror to correct blurring

Light from both guide star and astronomical object is reflected from deformable mirror; distortions are removed

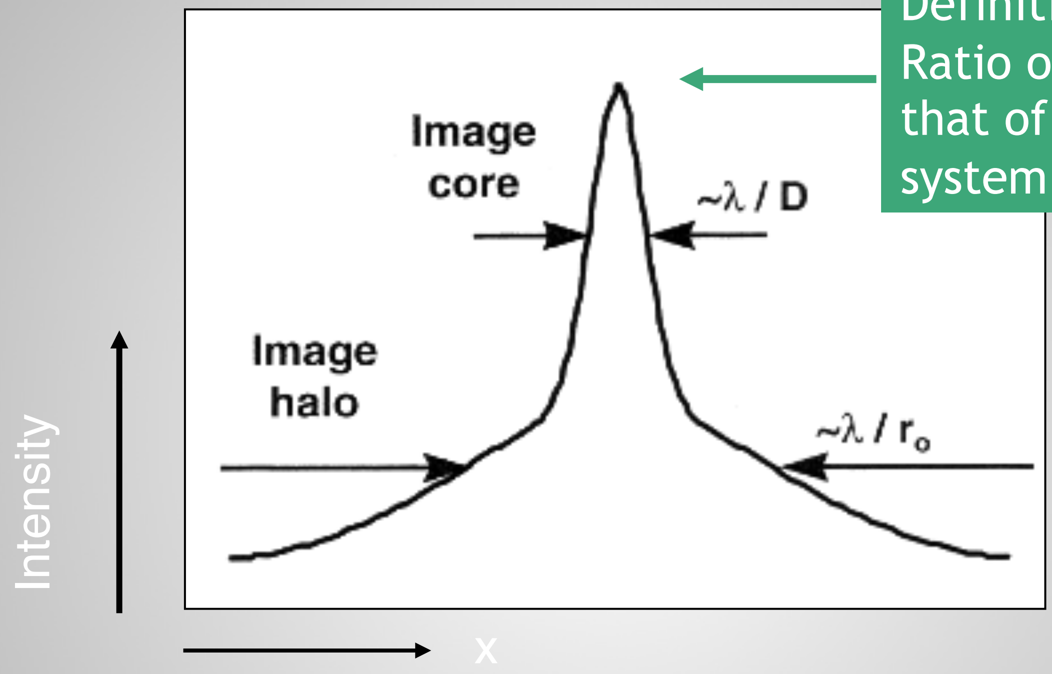


Adaptive optics increases peak intensity of a point source



Lick Observatory

AO produces point spread functions with a "core" and "halo"



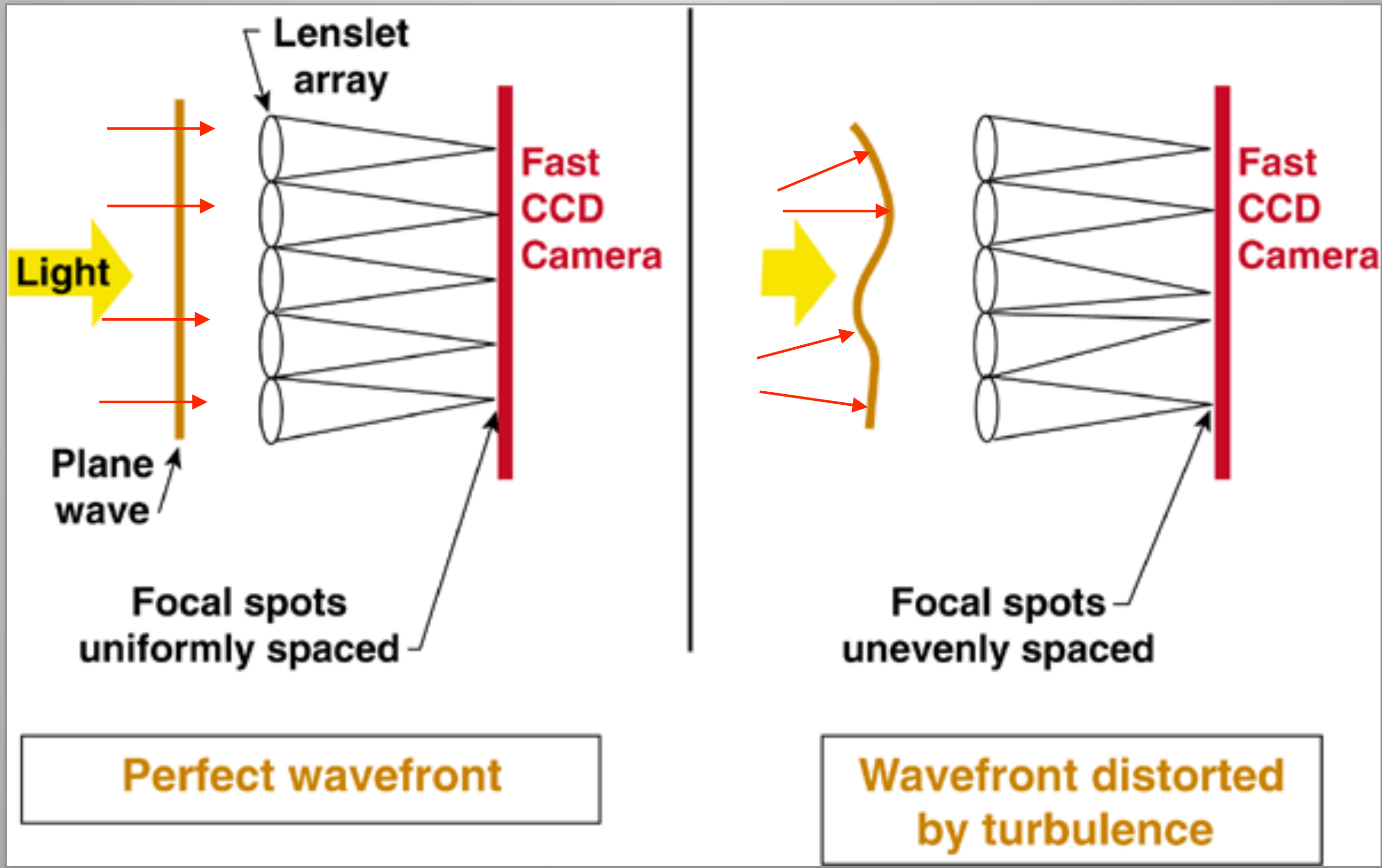
Definition of "Strehl": Ratio of peak intensity to that of "perfect" optical system

When AO system performs well, more energy in core

When AO system is stressed (poor seeing), halo contains larger fraction of energy (diameter ~ r_0)

Ratio between core and halo varies during night

How to measure turbulent distortions (one method among many)

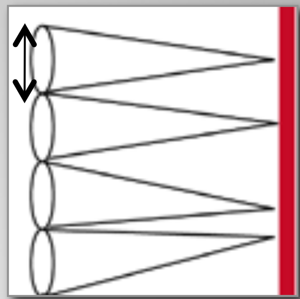


Shack-Hartmann wavefront sensor

Shack-Hartmann wavefront sensor measures local "tilt" of wavefront

Divide pupil into subapertures of size ~ r_0

Number of subapertures $(D / r_0)^2$

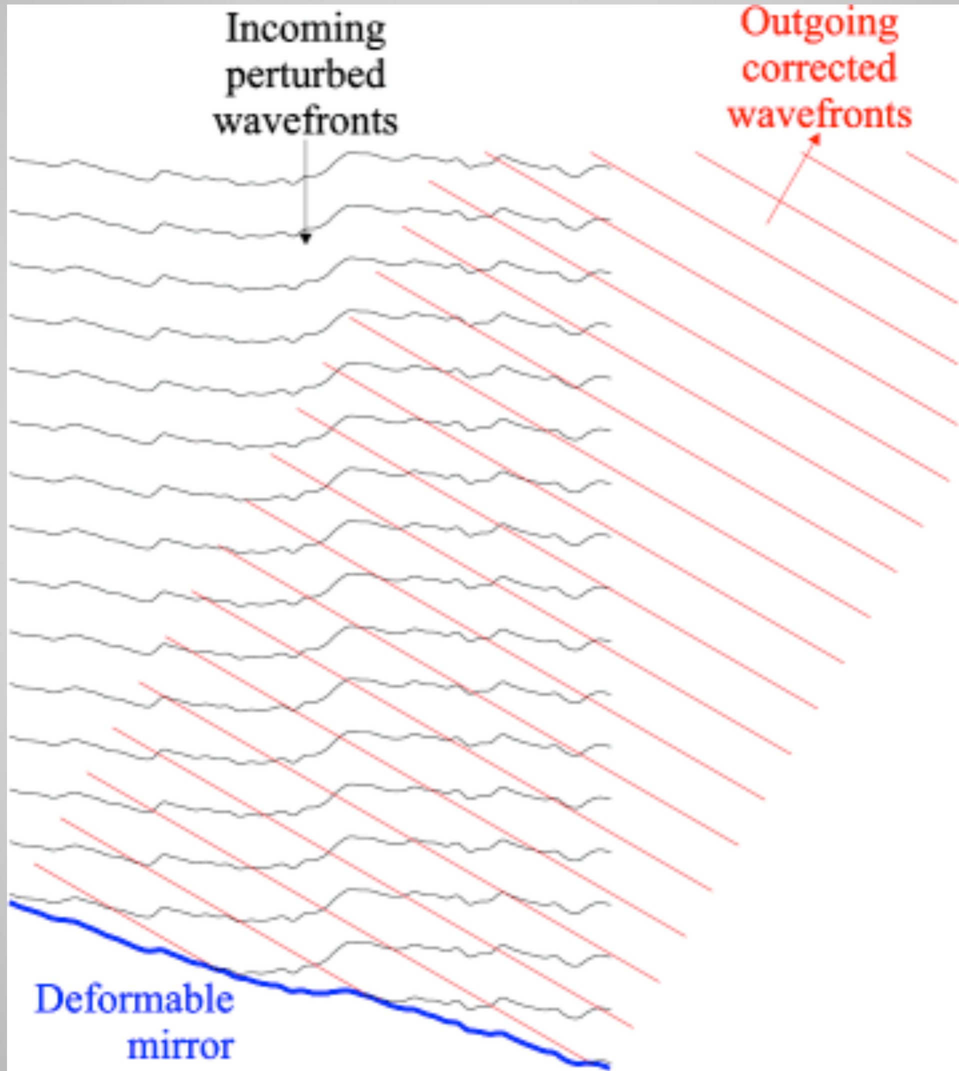


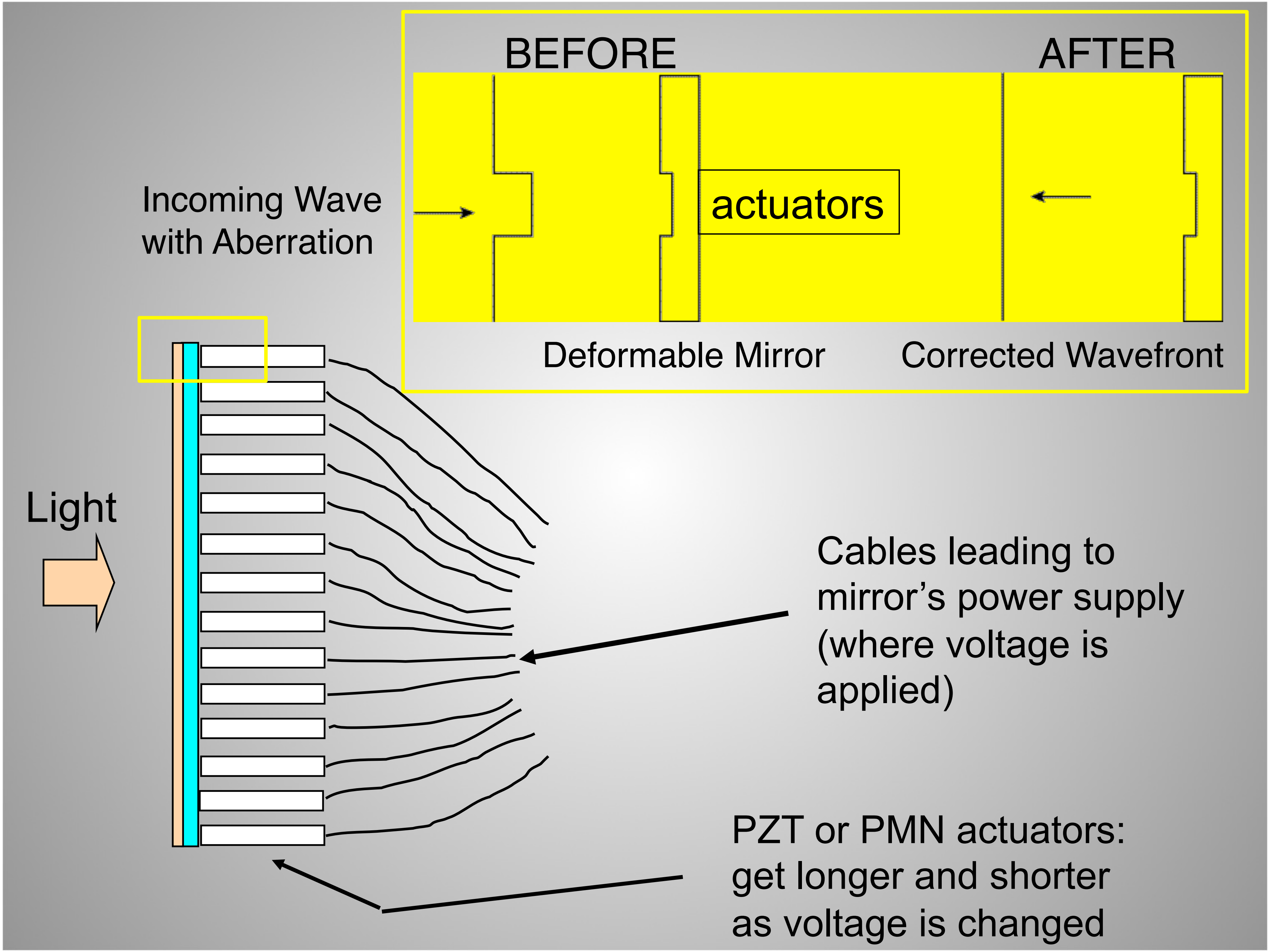
Lenslet in each subaperture focuses incoming light to a spot on the wavefront sensor's CCD detector

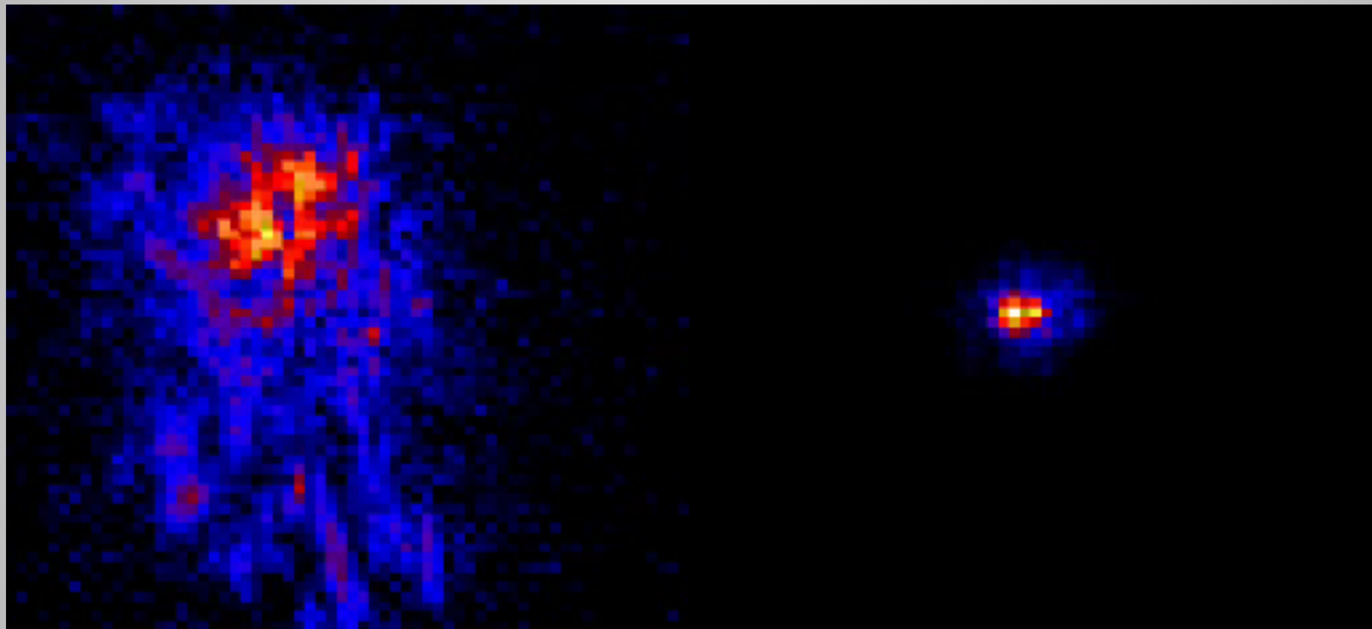
Deviation of spot position from a perfectly square grid measures shape of incoming wavefront

Wavefront reconstructor computer uses positions of spots to calculate voltages to send to deformable mirror

Deformable Mirror for real wavefronts

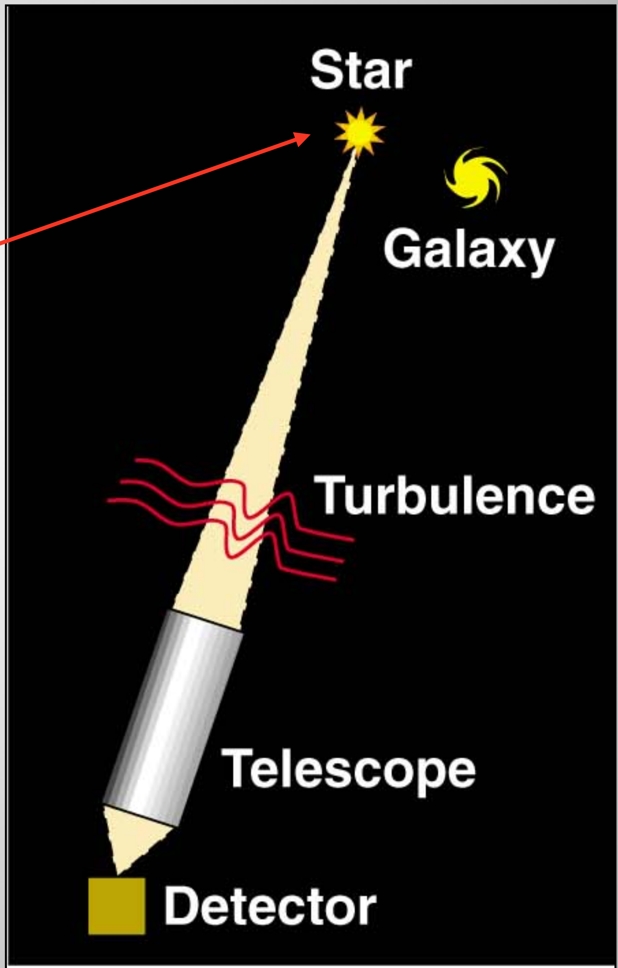



BEFORE
AFTER
Incoming Wave
with Aberration
actuators
Deformable Mirror
Corrected Wavefront
Light
Cables leading to
mirror's power supply
(where voltage is
applied)
PZT or PMN actuators:
get longer and shorter
as voltage is changed



If there's no close-by "real" star, create one with a laser (Laser guide star)

Use a laser beam to create artificial "star" at altitude of 100 km in atmosphere



Laser guide stars are operating at Lick, Keck, Gemini North, VLT, Subaru Obsy's

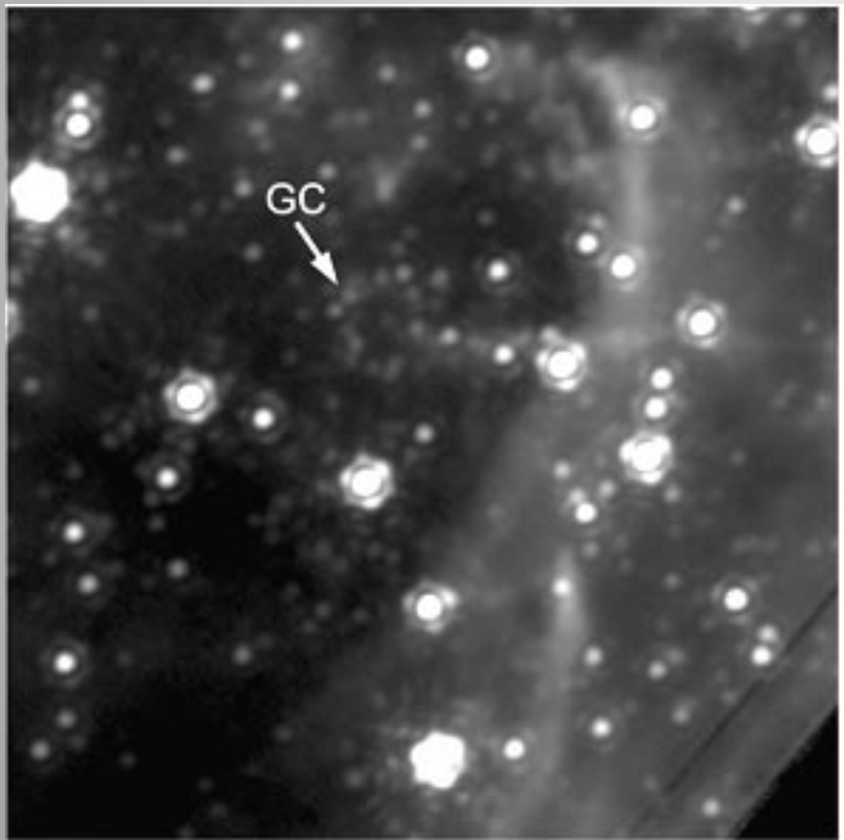
Lick Observatory

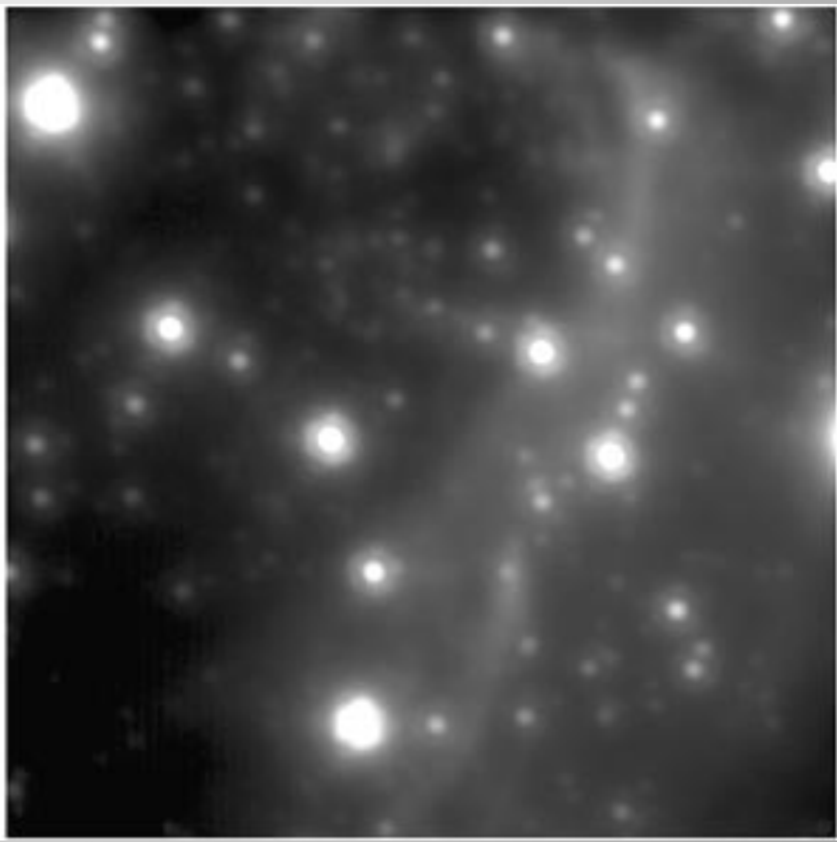
Keck Observatory

Galactic Center with Keck laser guide star

Keck laser guide star AO

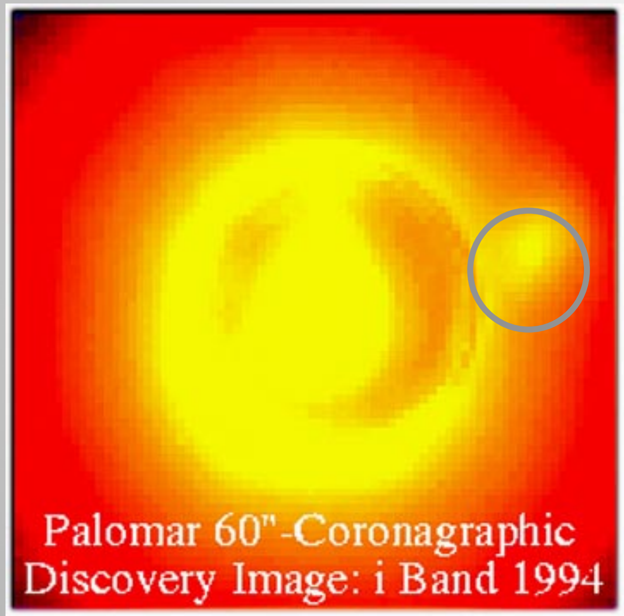
Best natural guide star AO



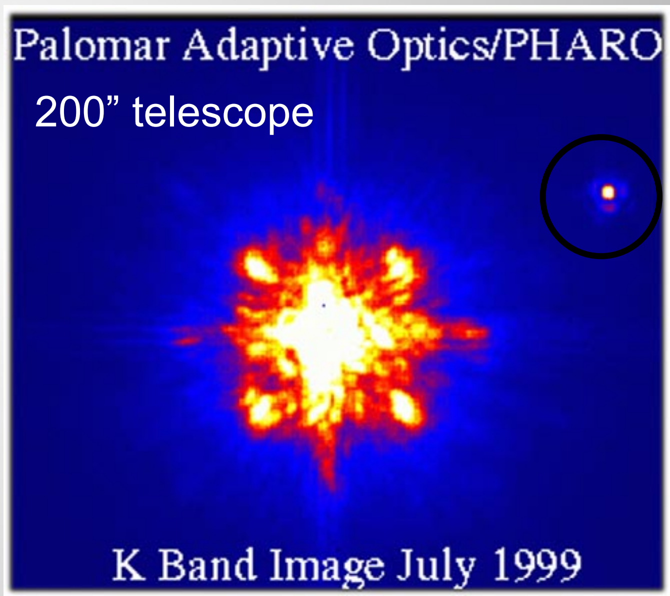


Adaptive optics makes it possible to find faint companions around bright stars

Two images from Palomar of a brown dwarf companion to GL 105



No AO

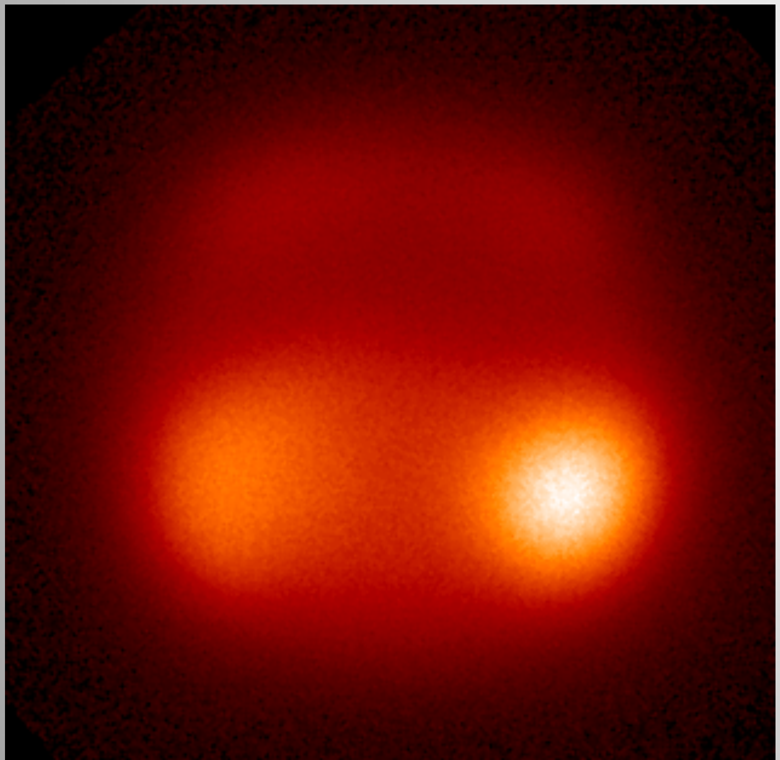


With AO

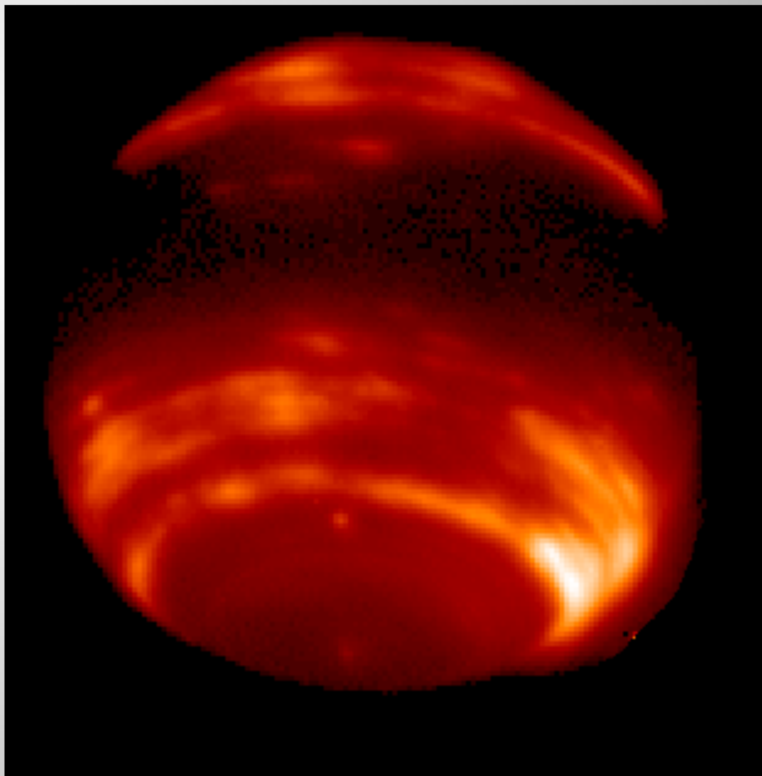
Credit: David Golimowski

Neptune in infra-red light (1.65 microns)

Without adaptive optics



With Keck adaptive optics



Frontiers in AO technology

- New kinds of deformable mirrors with > 5000 degrees of freedom
- Wavefront sensors that can <u>deal</u> with this many degrees of freedom
- Innovative control algorithms
- “Tomographic wavefront reconstuction” using multiple laser guide stars
- New approaches to doing visible-light AO

Thank you !