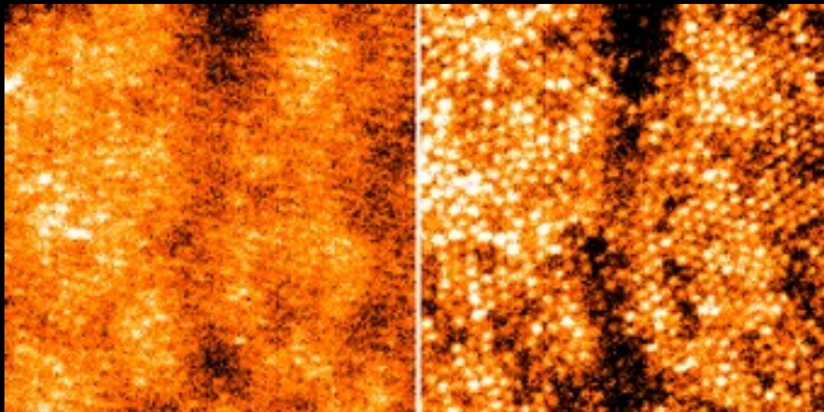
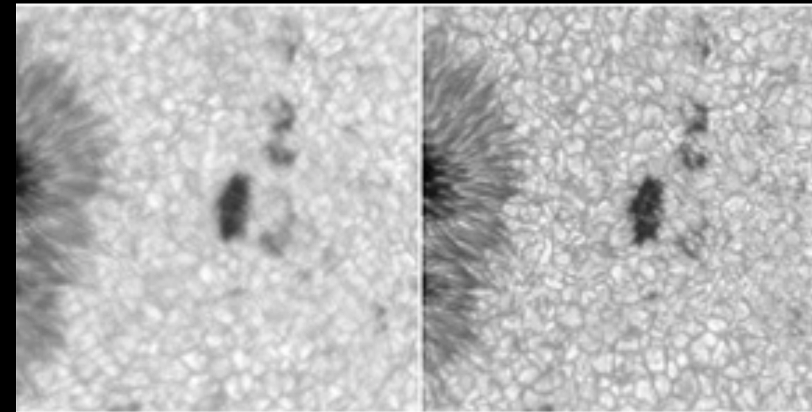
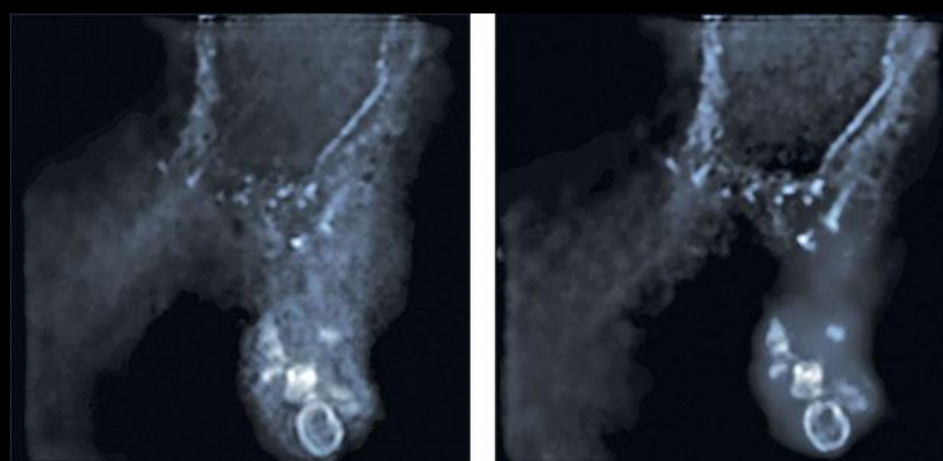



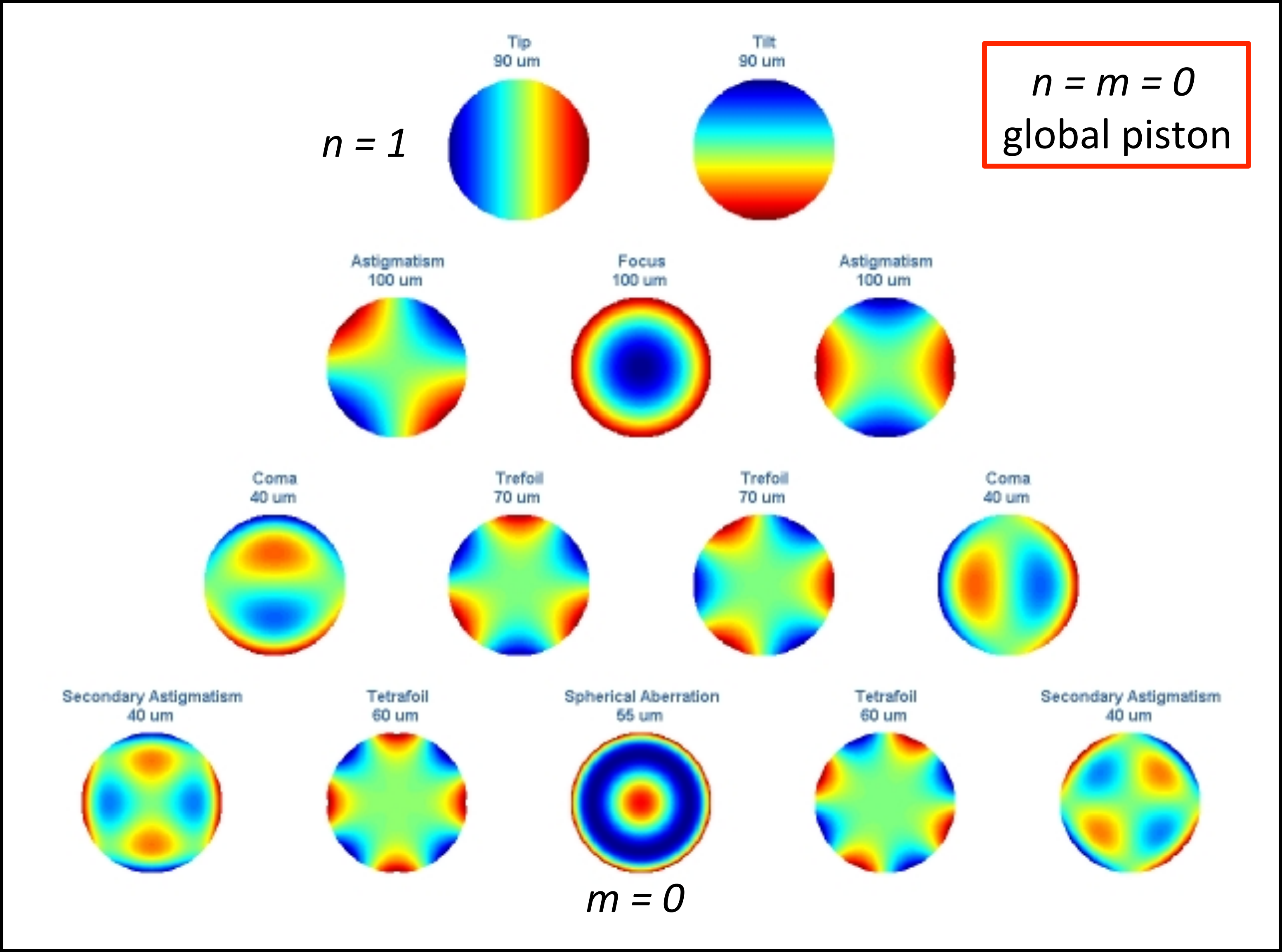
Adaptive Optics

Special Topic in Astrophysics

ASTRON 250 - Fall 2013

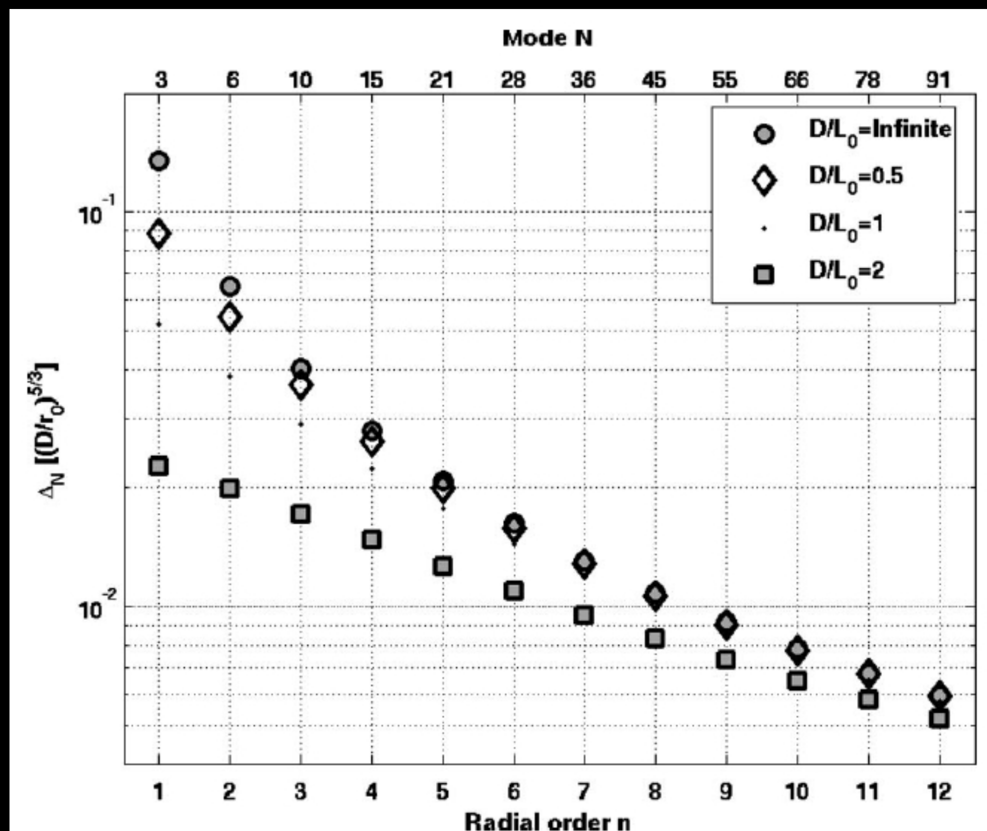

Atmospheric turbulence and Zernike's



Atmospheric turbulence and Zernike's

- Kolmogorov: $E(k) \sim k^{-5/3}$
  - Most of the energy is in the large spatial scale

r.m.s. of residual phase
after correcting N modes



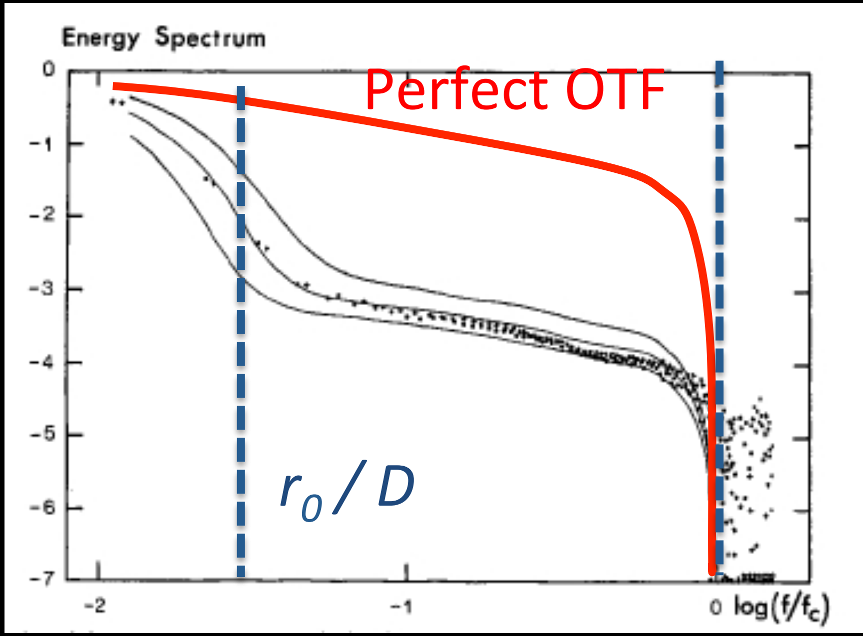
Conan (2008)
See also Noll (1976)

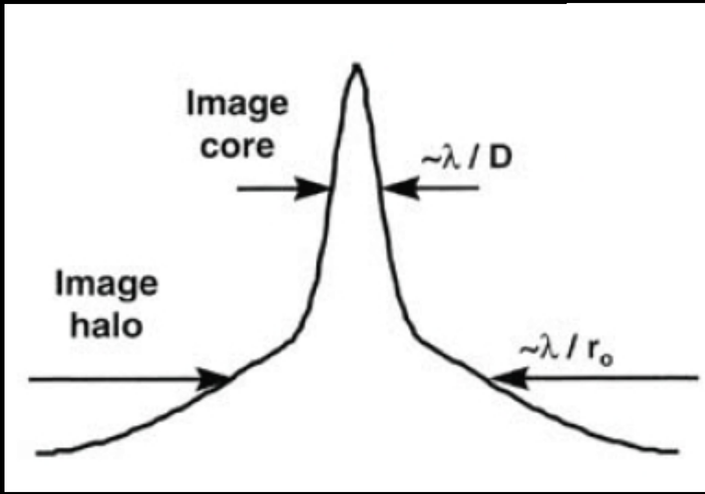
Short and long exposure image

- Short exposure ("frozen turbulence") contains information out to the highest frequency
  - It is "diffraction-limited"
  - Independent parts of wavefront form images in different locations: speckle pattern
- Long exposures is sum of random short exposures, with constant phase scrambling
  - All high-frequency info is lost, image is completely "turbulence-limited"

OTF under atmospheric turbulence

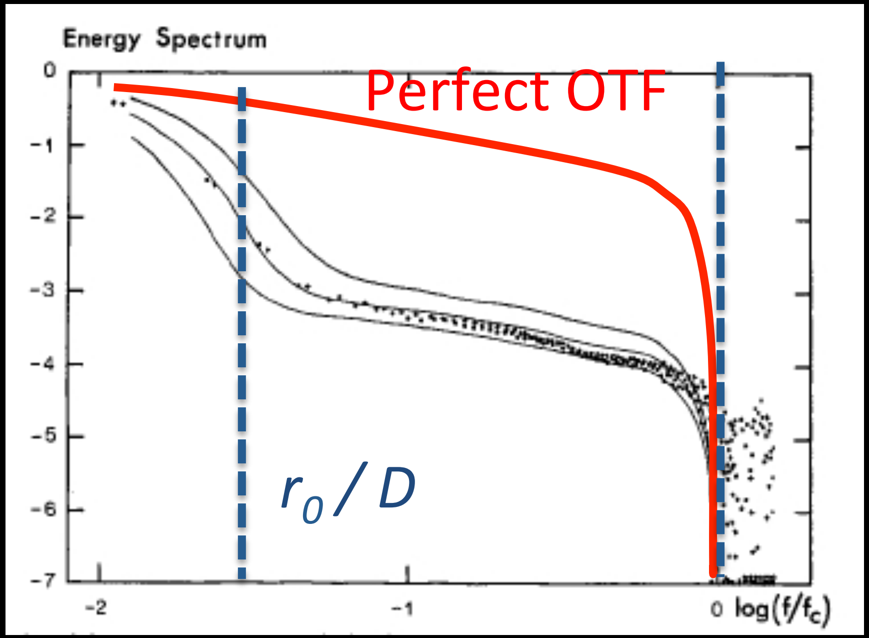
- Can be described as 2 independent components
  - Same applies to the resulting PSF
  - High-frequency component cancels for long t_{int}, unless AO correction is applied

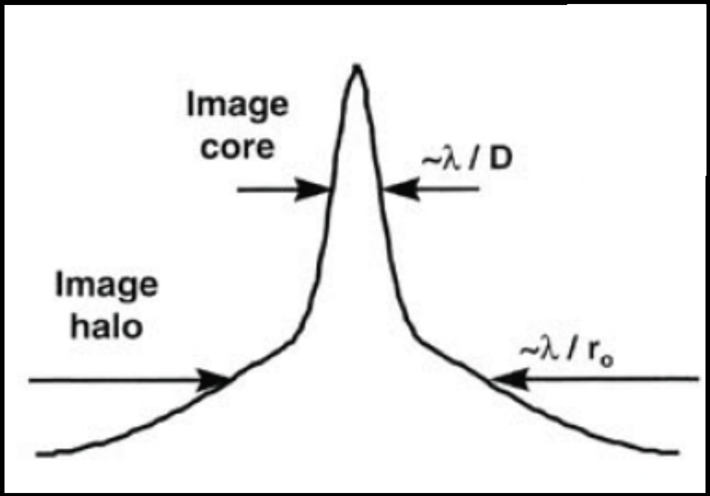




OTF under atmospheric turbulence

- In first approximation, AO-corrected OTF_{atm} is a constant at high frequencies:
  - *$A(f) \approx exp(-\sigma_\varphi^2)$,* with σ_φ^2 the leftover phase residuals

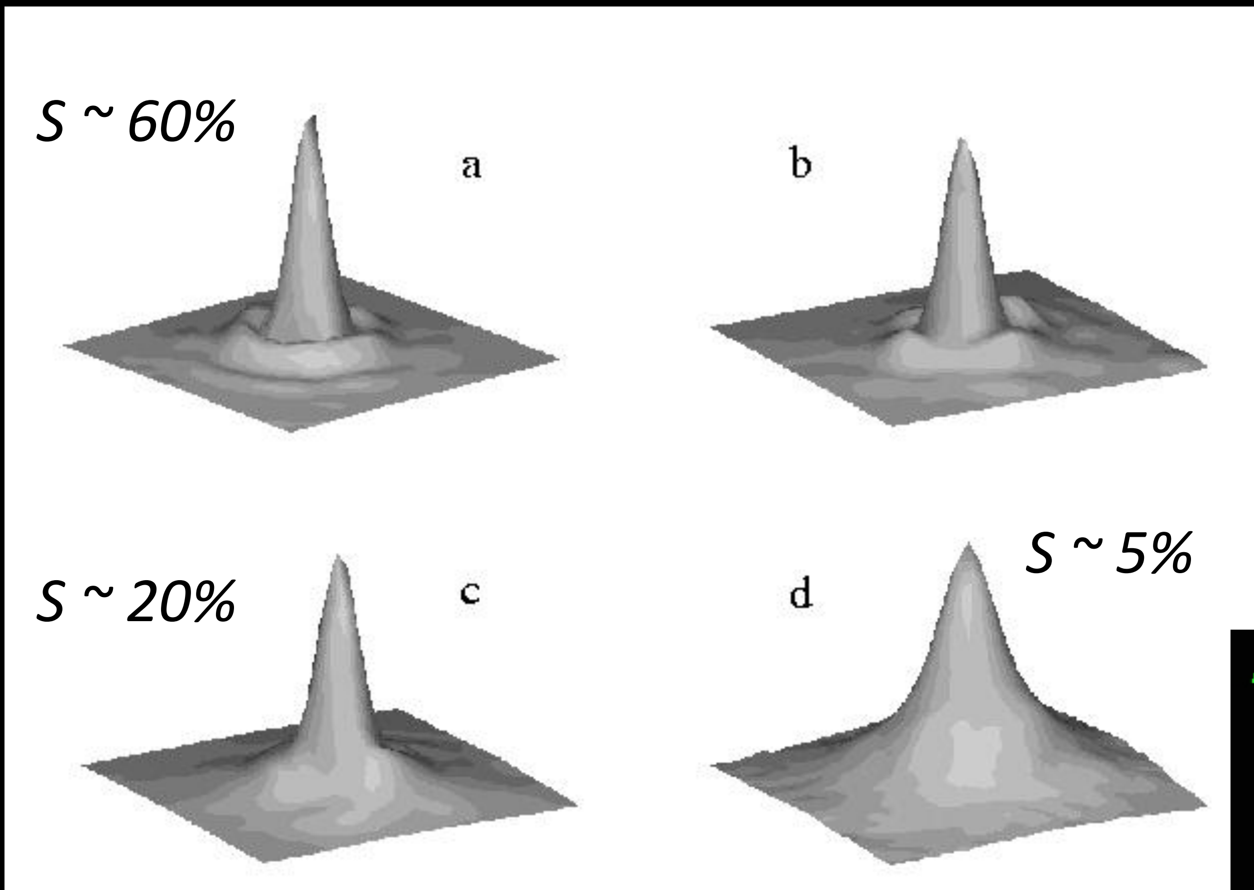




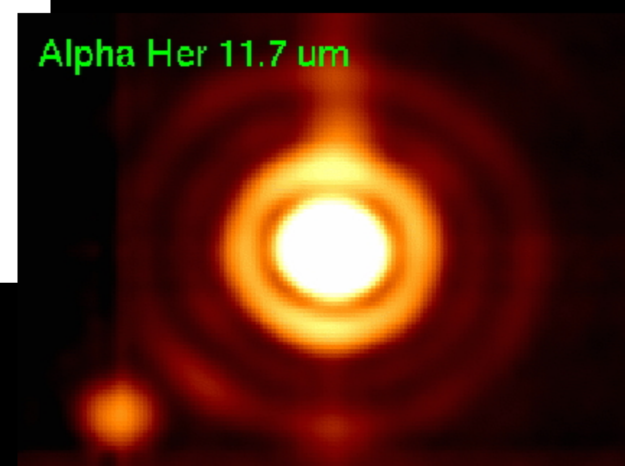
Strehl ratio

- A common metric of image quality for diffraction-limited imaging devices
  - In an image: ratio of peak intensity to that of diffraction-limited image
  - From the OTF: ratio of integral of the OTF with and without aberration
  - Equivalent for diffraction-limited images ($S > 0.1$) as peak and total intensities are proportional
    - In this case $SR \approx exp(-\sigma_{\varphi}^{2})$

Strehl ratio



S ~ 98% !

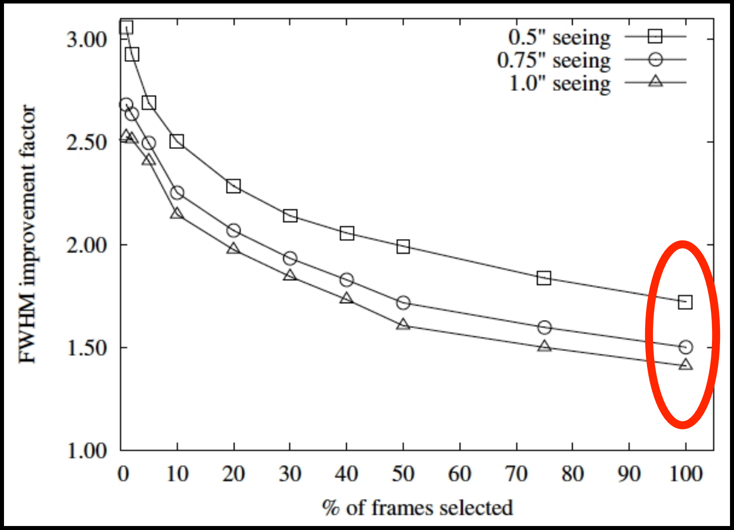


Close et al. (2003)

Non-AO methods to beat turbulence

- Law et al. (2006): Lucky Imaging
  - Combine shift-and-add with frame selection for large series of short exposures
- Proba of diffraction-limited image is low

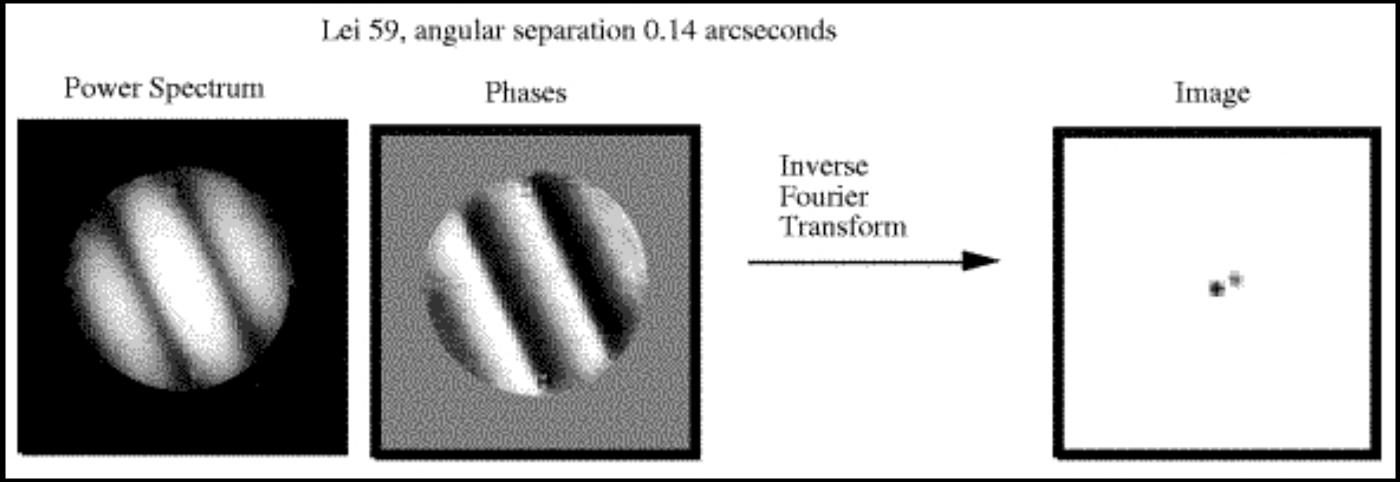
  $\approx 5.6\, exp[-0.1557\, (D/r_0)^2]$ (Fried 1978)



Even without frame selection, recentering is a significant improvement!

Non-AO methods to beat turbulence

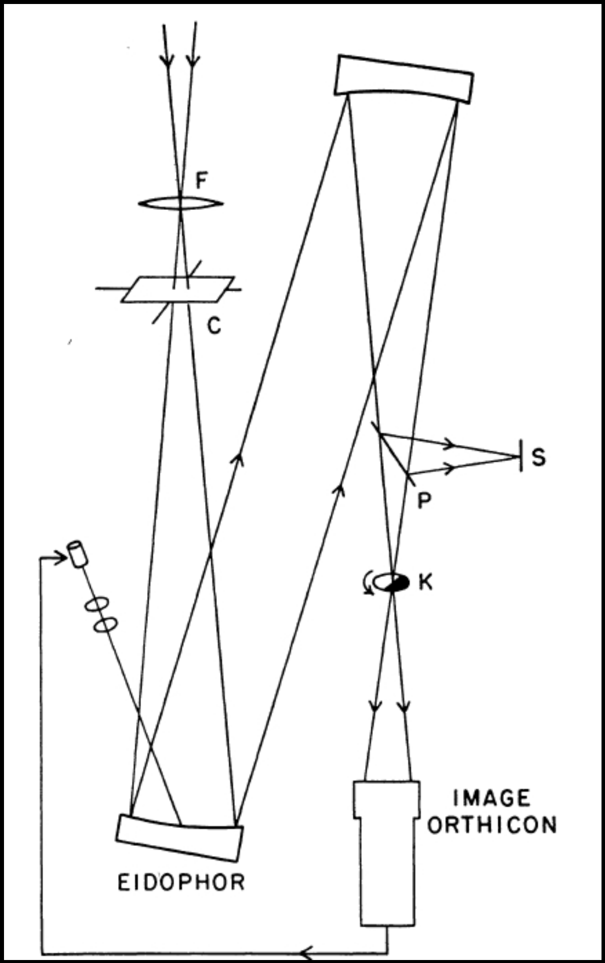
- Labeyrie (1970): speckle interferometry
  - Fourier analysis of the speckle patterns, which are intrinsically diffraction-limited
  - Only difference between speckles is their phase, which are randomly fluctuating around the mean and average out in the Fourier domain



Patience et al. (1998)

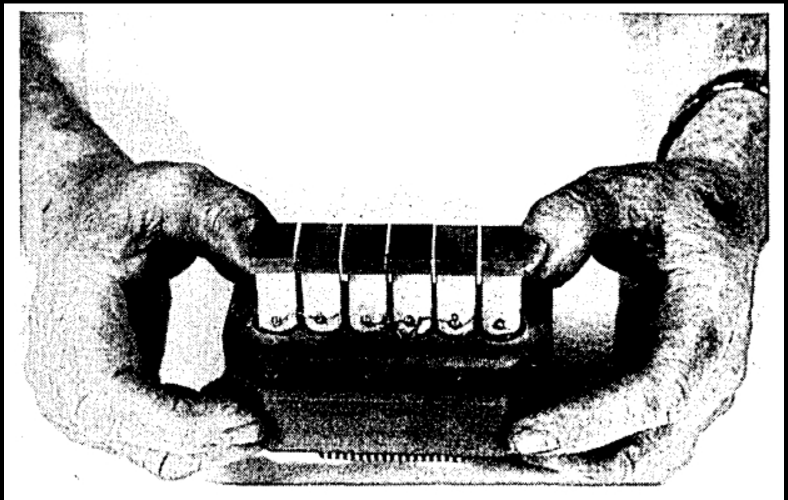
Babcock's original idea

- All the basic elements of AO:
  - A "deformable mirror"
  - A real-time wavefront sensor
  - A continuous control loop
- Based on sensing the slope of the wavefront
- No computer! Simple R-C circuit



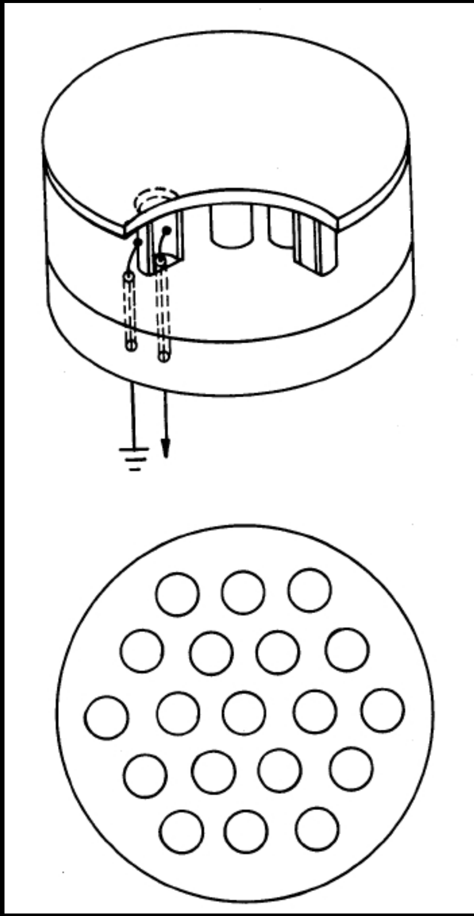
The first astronomical AO systems

- Buffington et al. (1977)
- McCall et al. (1977)
- Successful despite hard conditions

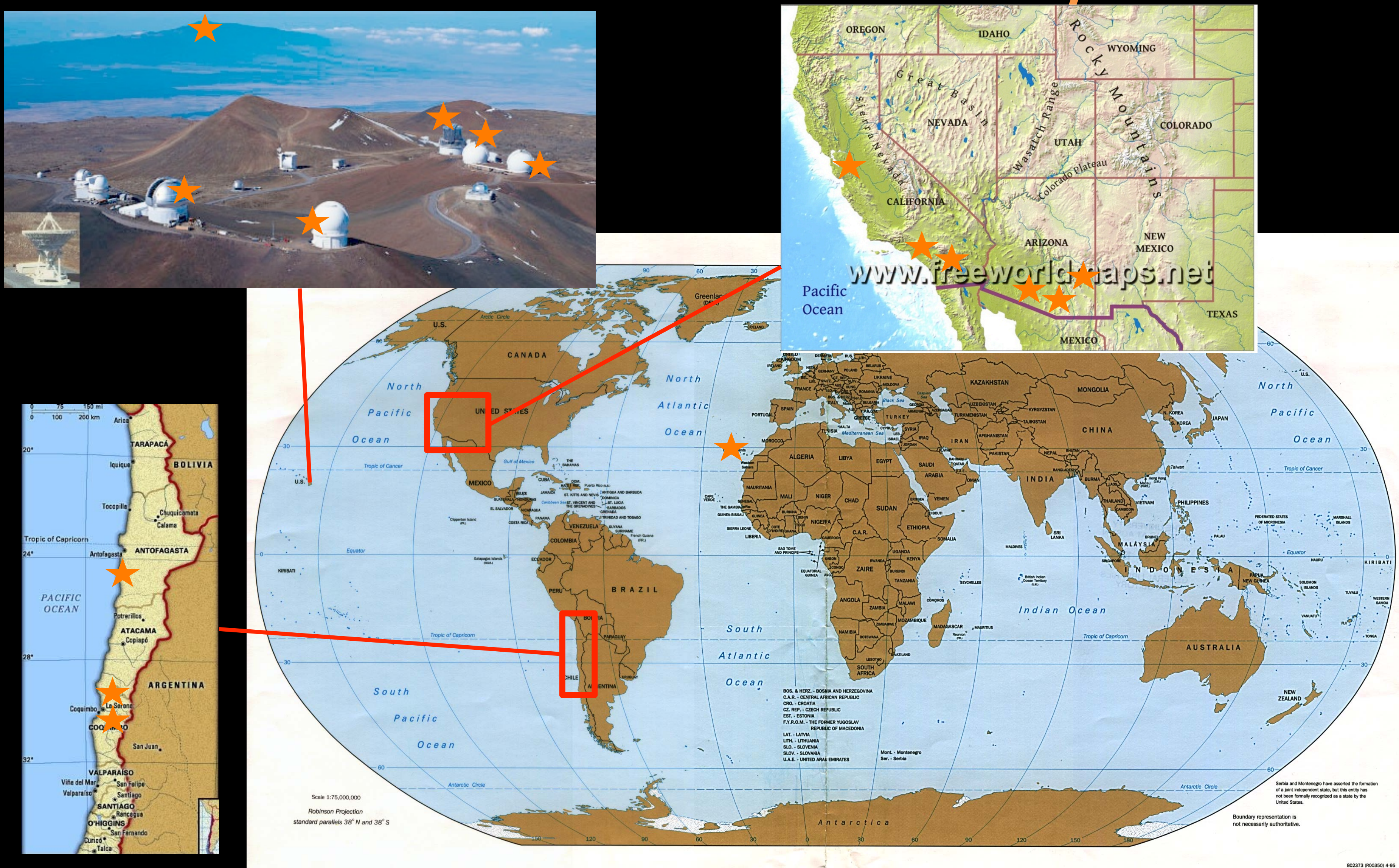


Segmented, linear

Circular membrane



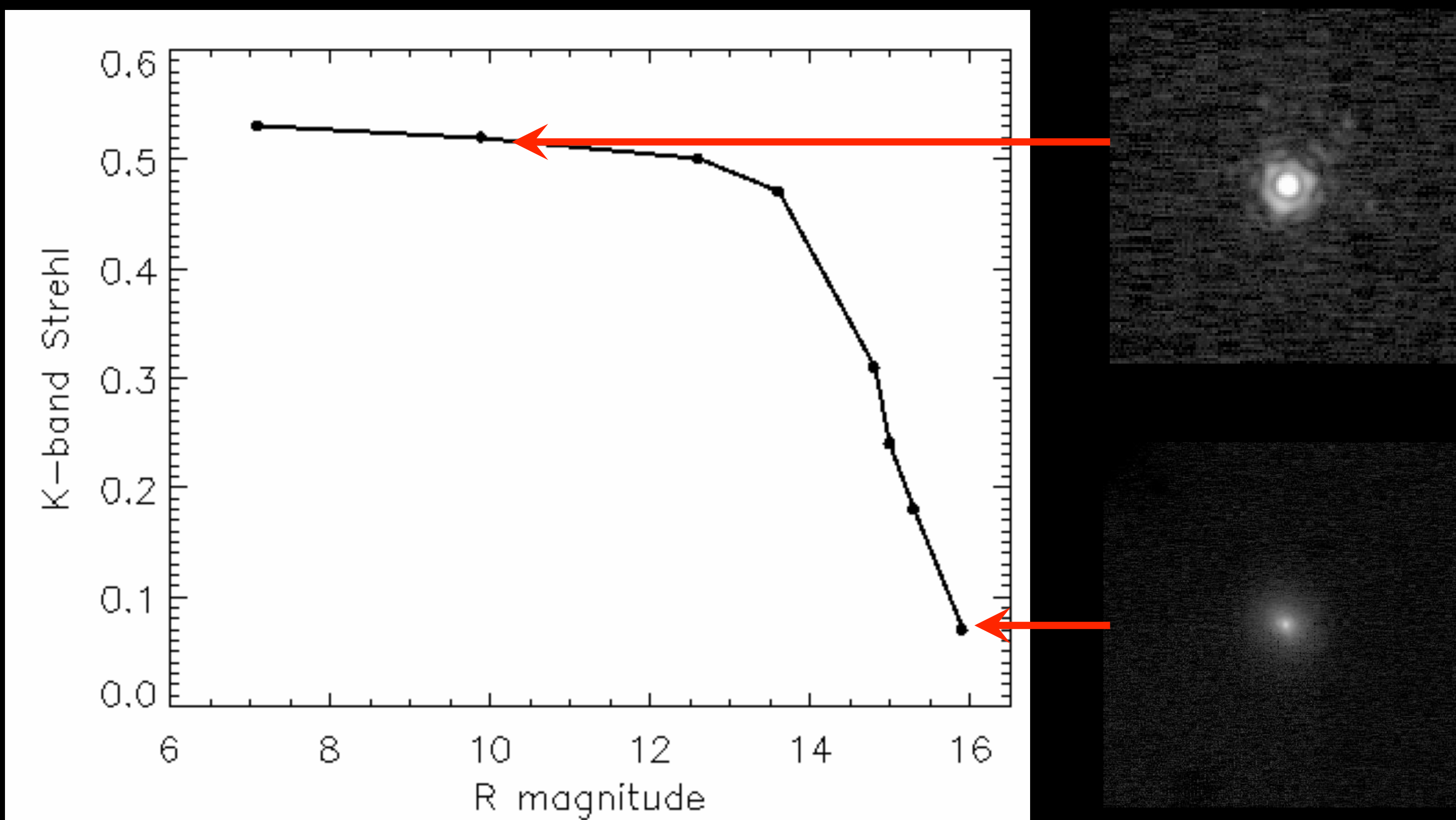
Current astronomical AO systems



(Keck)

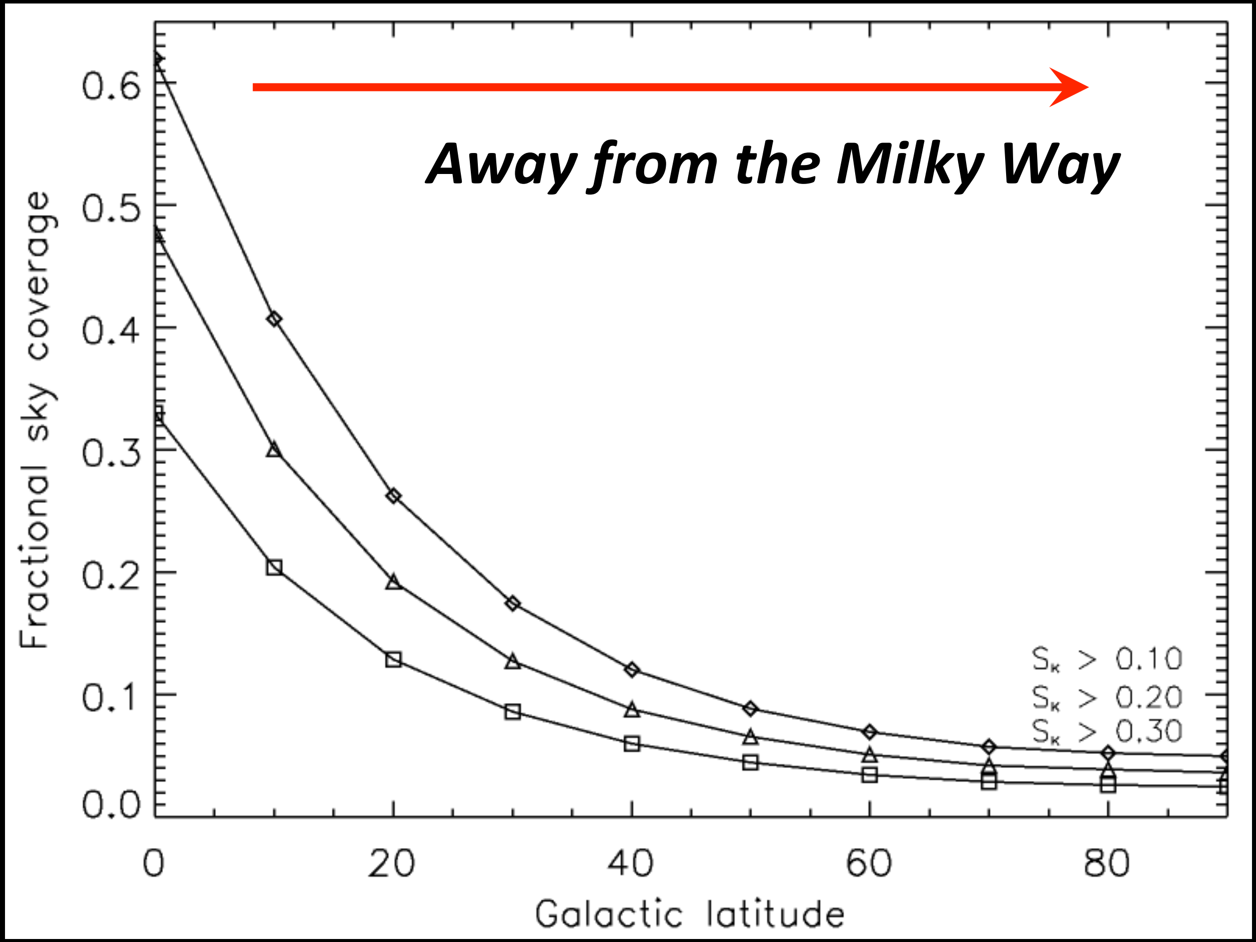
Performance of "typical" AO systems

- AO correction depends on star brightness



(Keck)
Performance of "typical" AO systems

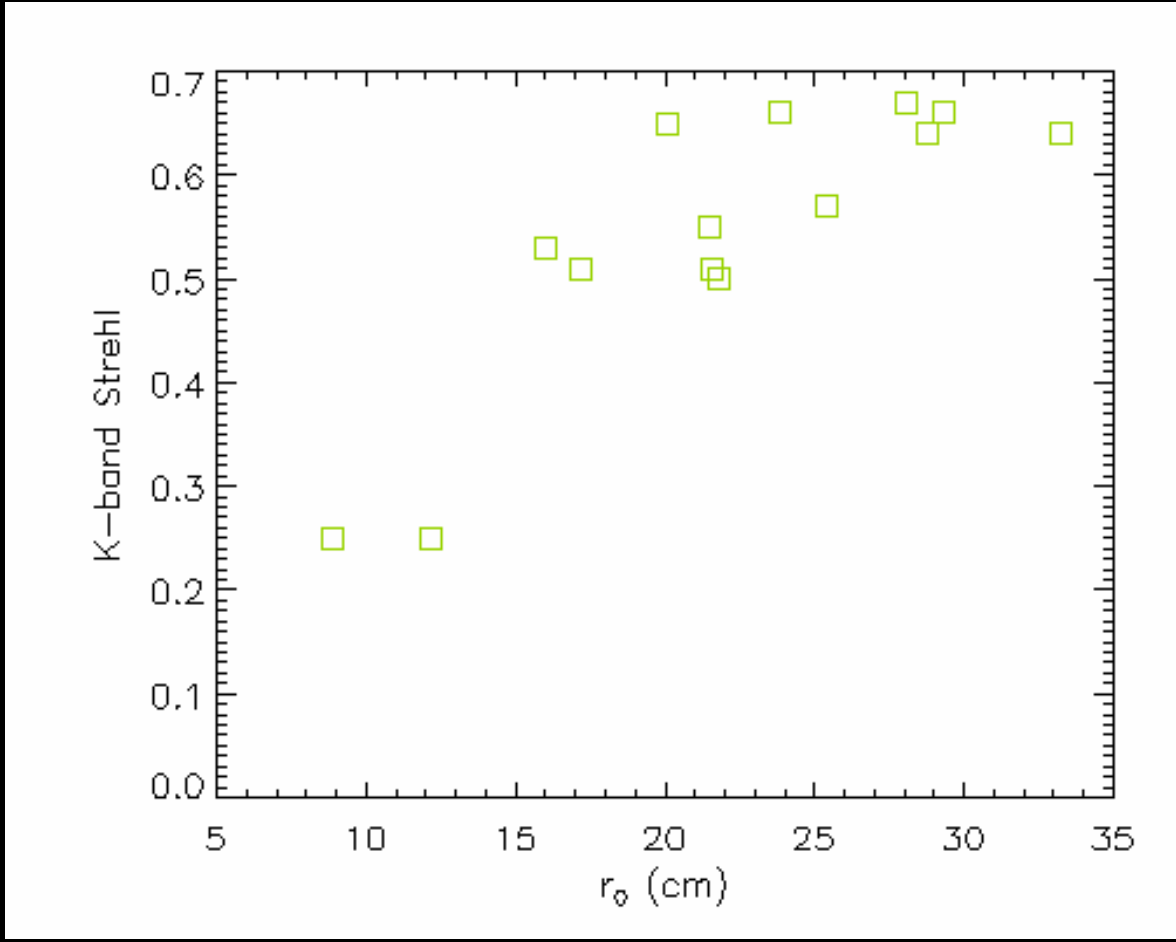
- Only a fraction of the sky is "AO-accessible"



(Keck)

Performance of "typical" AO systems

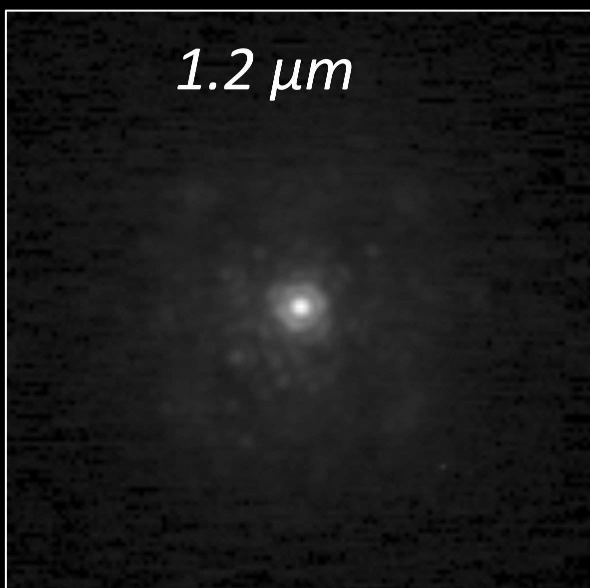
- Quality of correction depends on turbulence properties



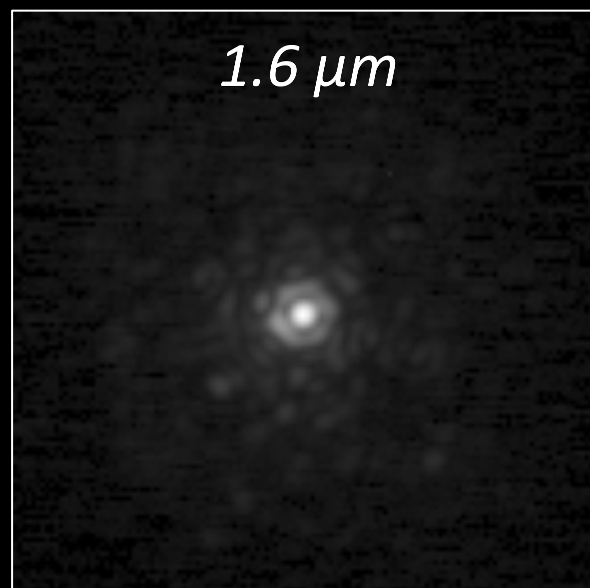
(Keck)

Performance of “typical” AO systems

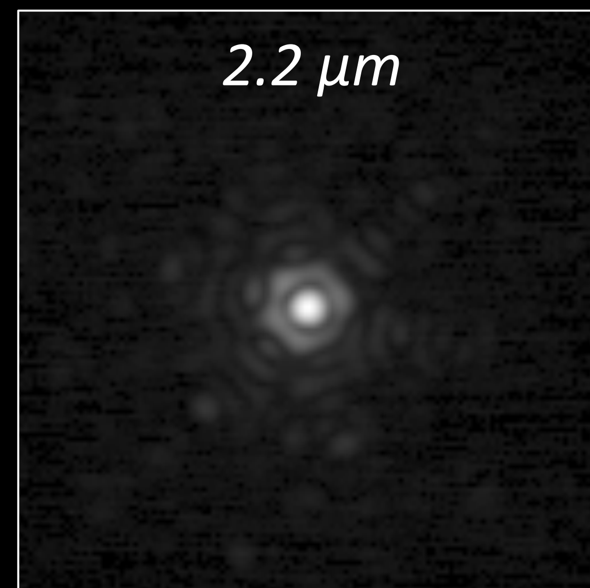
- Quality of correction depends on wavelength
  - Best compromise depends on science…



SR = 22%
FWHM = 0.030’’



SR = 41%
FWHM = 0.039’’



SR = 62%
FWHM = 0.047’’

Next week’s readings

- Speckle properties
  - Hinkley et al. (2007)
- Anisoplanatism
  - Tyson’s book (§3.2.6)
  - Wilson & Jenkins (1996, §1-4)
- PSF prediction
  - Véran et al. (1997, §1-3)
- Deconvolution
  - Ten Brumelaar et al. (1996)
  - Christou (1999)