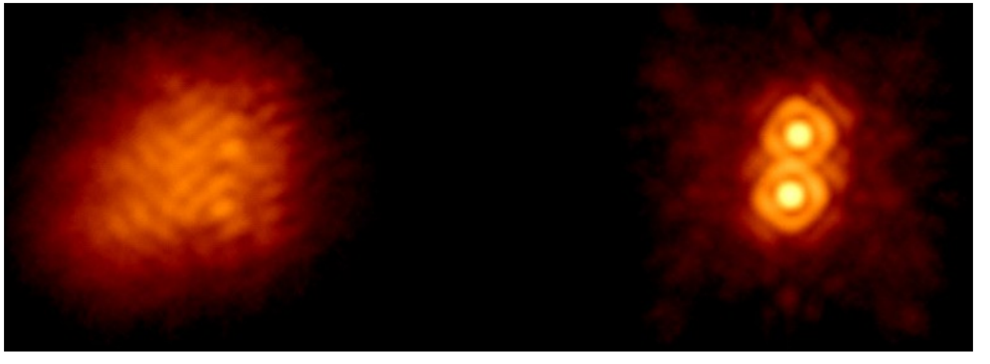
Adaptive Optics



Without adaptive optics
(Palomar 200 inch telescope)

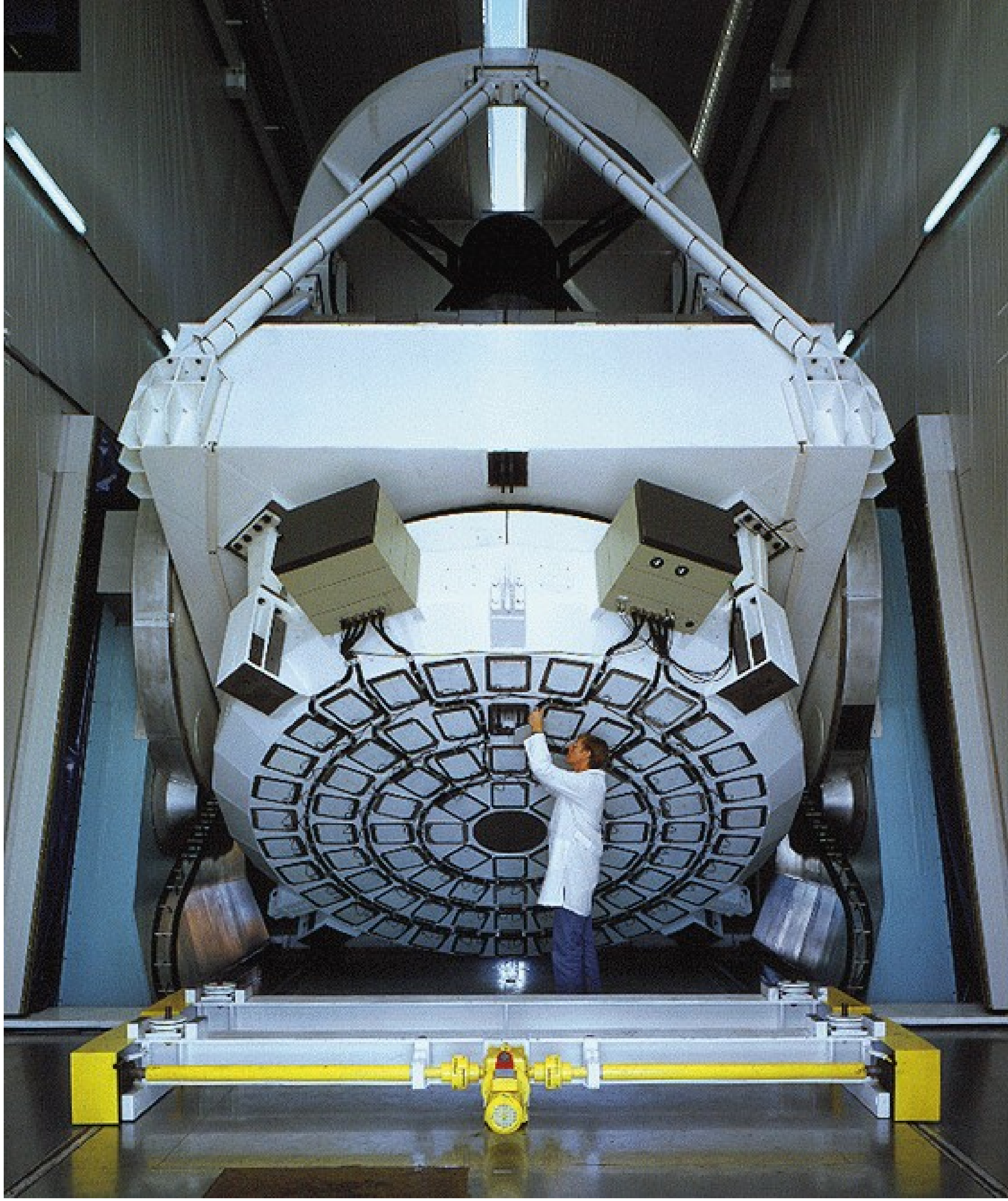
The binary star IW Tau is revealed through adaptive optics. The stars have a 0.3 arc second separation. The images were taken by Chas Beichman and Angelle Tanner of JPL.

Active Optics

- Is meant to correct actively the shape of the mirror, to prevent deformation (thermal, mechanical, wind).

Adaptive Optics

- Corrects the distortions in the image (seeing) introduced by turbulence



Active Optics Support of the NTT main mirror. Credits: @ESO. First light of the NTT: 1989

Angular resolution: Rayleigh criterium

$$\alpha\ [\mathrm{rad}] = \mathbf{1{,}22}\ \boldsymbol{\lambda} / \boldsymbol{d}$$

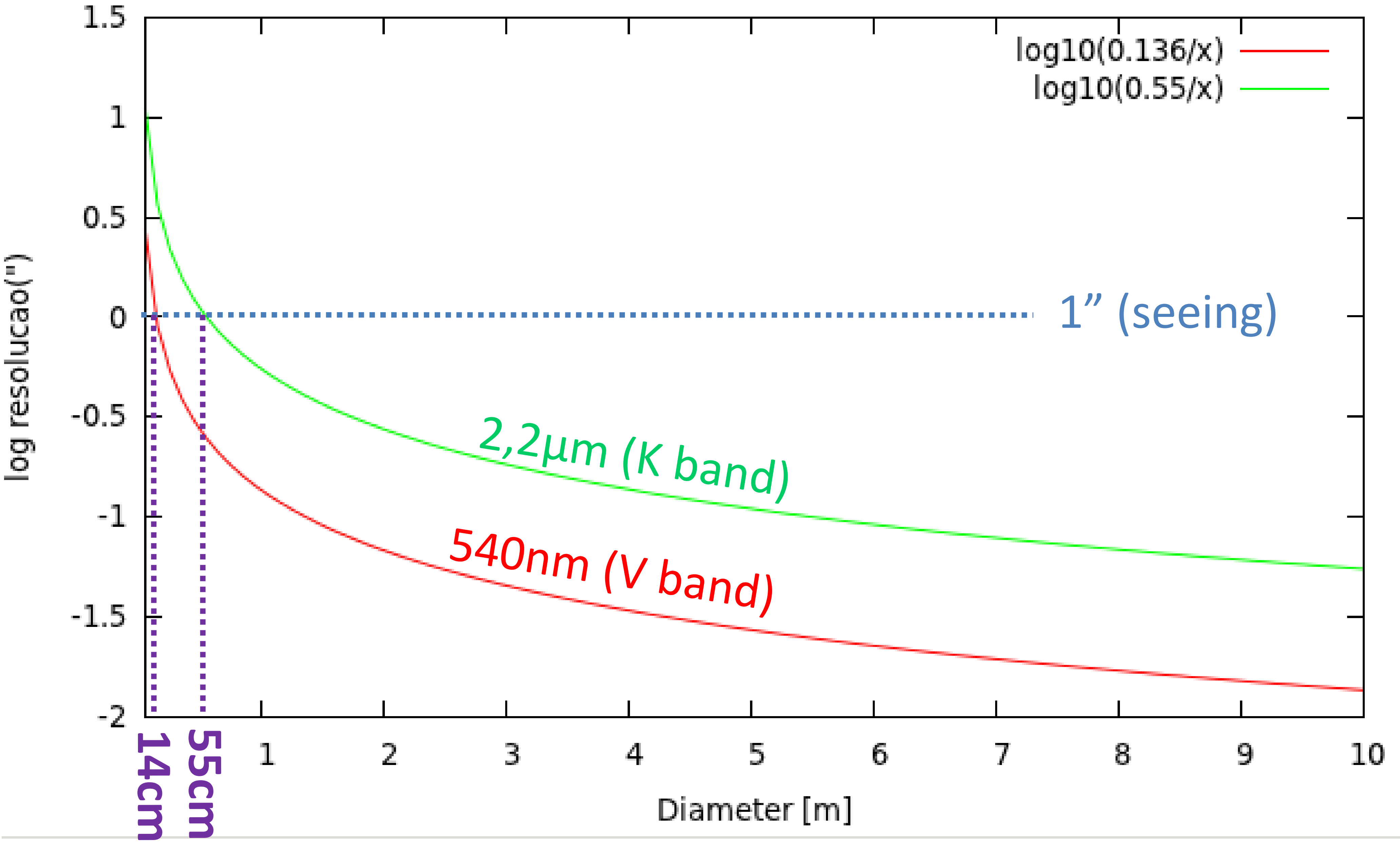
For V = 540nm:

$\alpha[''] = 0{,}136\ / d[\mathrm{m}]$

For K = 2,2μm:

$\alpha[''] = 0{,}55\ / d[\mathrm{m}]$

A telescope with ***d* = 14 cm** reaches an **angular resolution of 1”** in the optical, about the same as that imposed by ***seeing*** **(~ 1”)**




```
gnuplot> set xr [0.05:10]; plot log10(0.136/x), log10(0.55/x); set xlabel 'Diameter [m]'; set ylabel 'log resolucao(")'
```

The seeing depends on both airmass and λ

$$S = S_0 \text{ airmass}^{3/5}$$

$$S = S_0\, \lambda^{-1/5}$$

Where S_0 is the seeing at the zenith and usually reported at 0.5μm

Effects of atmospheric turbulence

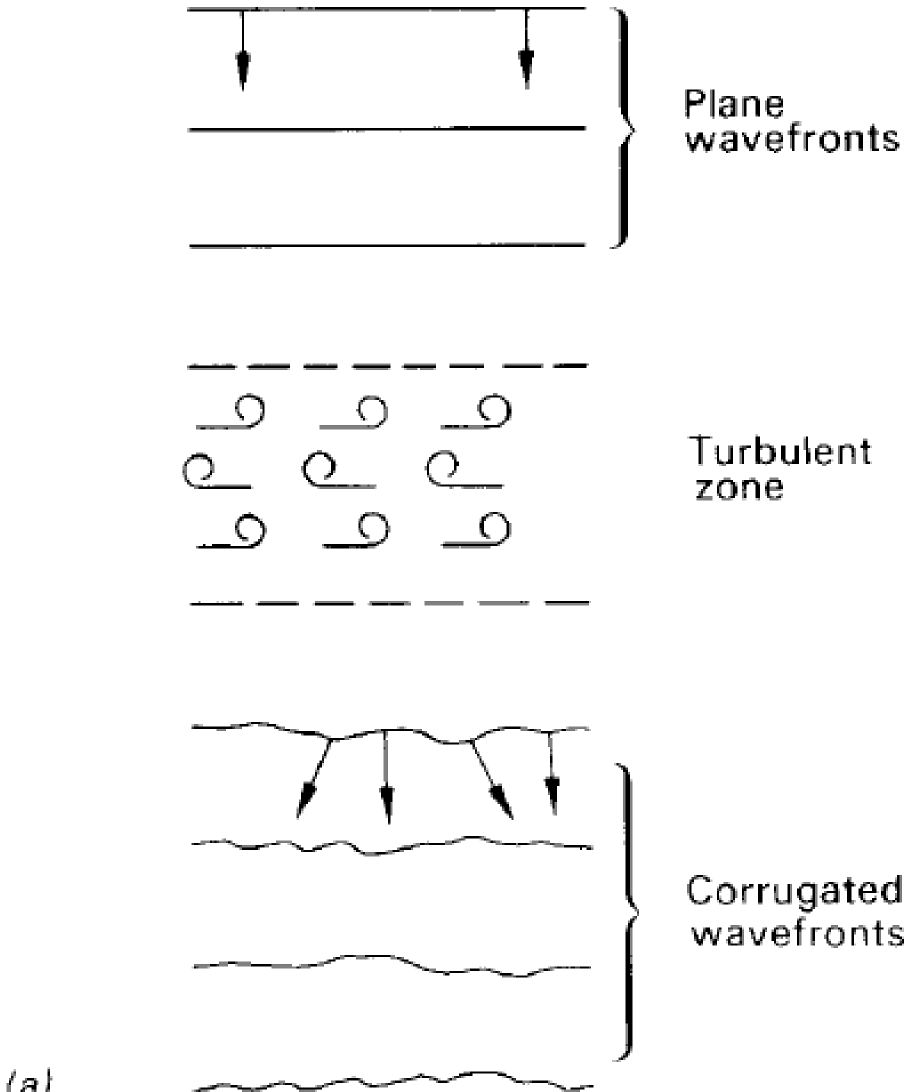
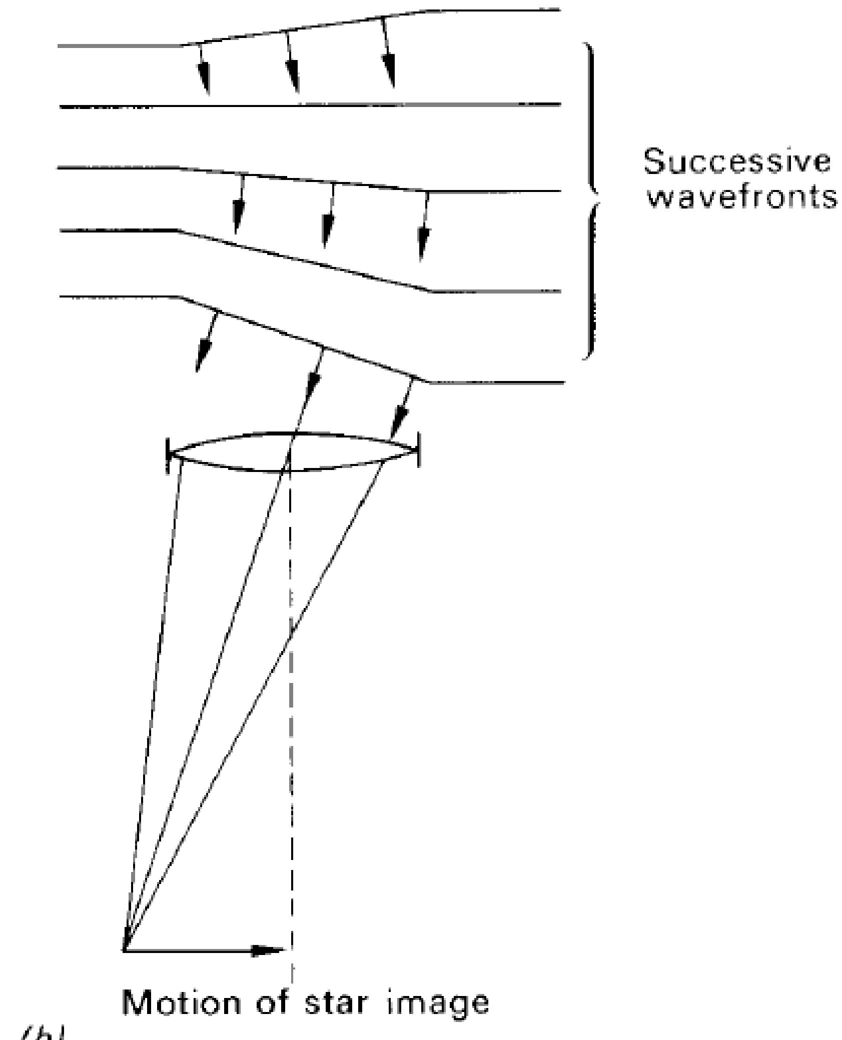
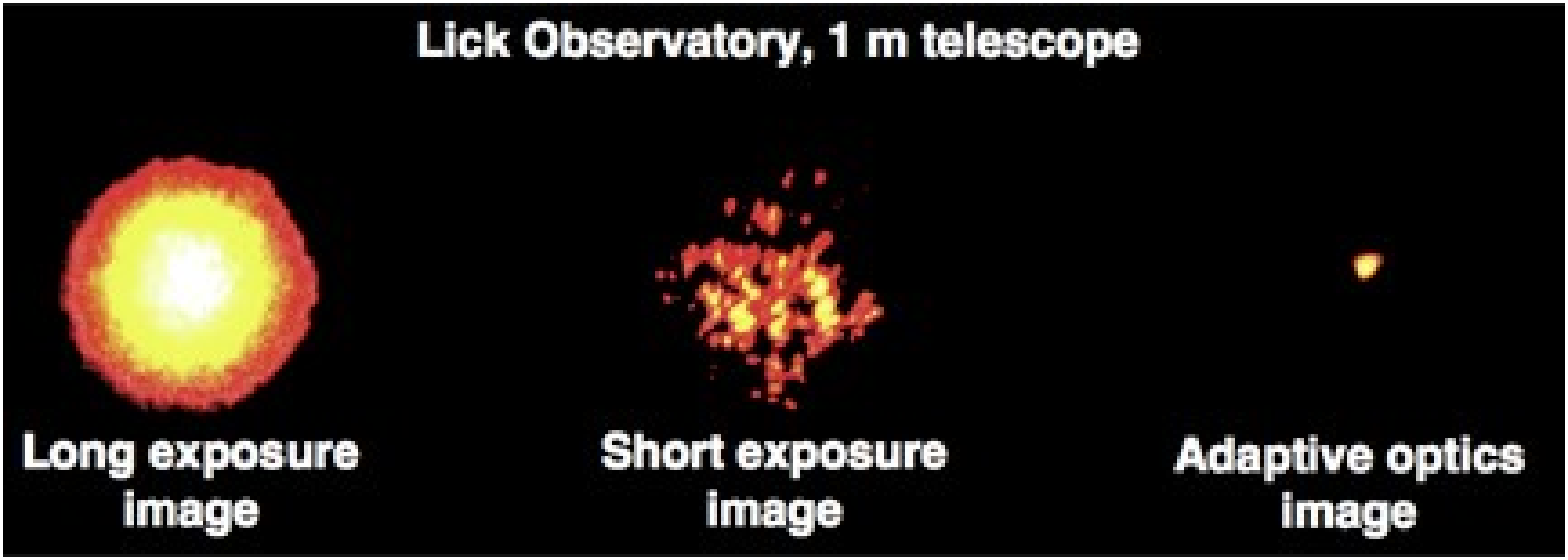


Figure 19.7. (*a*) The effect of atmospheric turbulence.



(*b*) The dancing effect of a star image when viewed with a small telescope.

Bright Star (Arcturus)



http://www.ucolick.org/~max/max-web/History_AO_Max.htm

Timescale for turbulence?

Coherence length is ~ 10cm at 0,5μm

Turbulent layer wind speed is ~ 10 m/s

→ ~ 0,01 s (= 10ms).

Timescale for turbulence in the optical ~ 1 - 10ms

Seeing vs. Diffraction (angular resolution) limit

Airy disc, I_A. The ratio, $S = I_S/I_A$, is referred to as the **Strehl index** and it is not uncommon for it to be no greater than a few per cent.

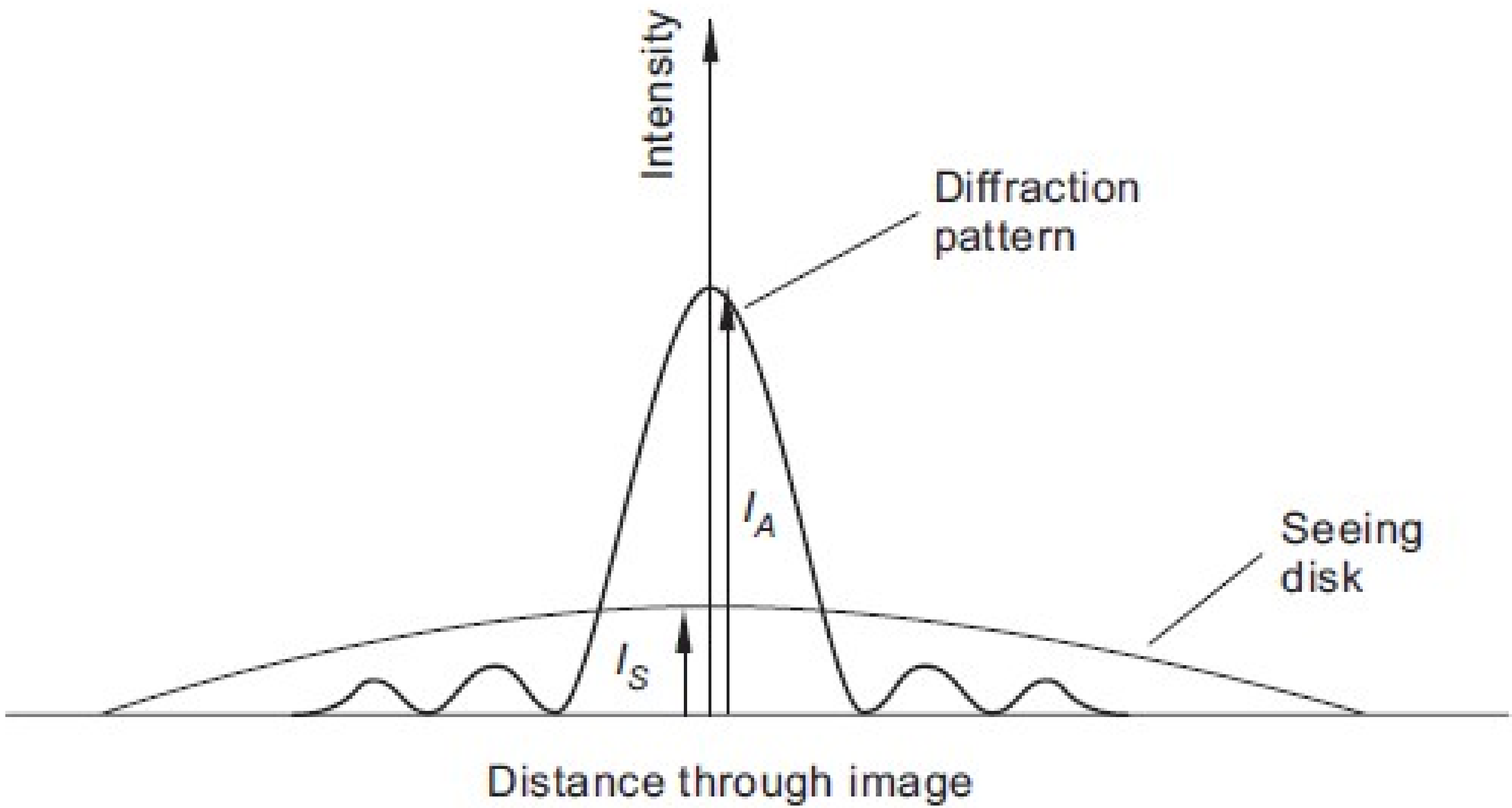
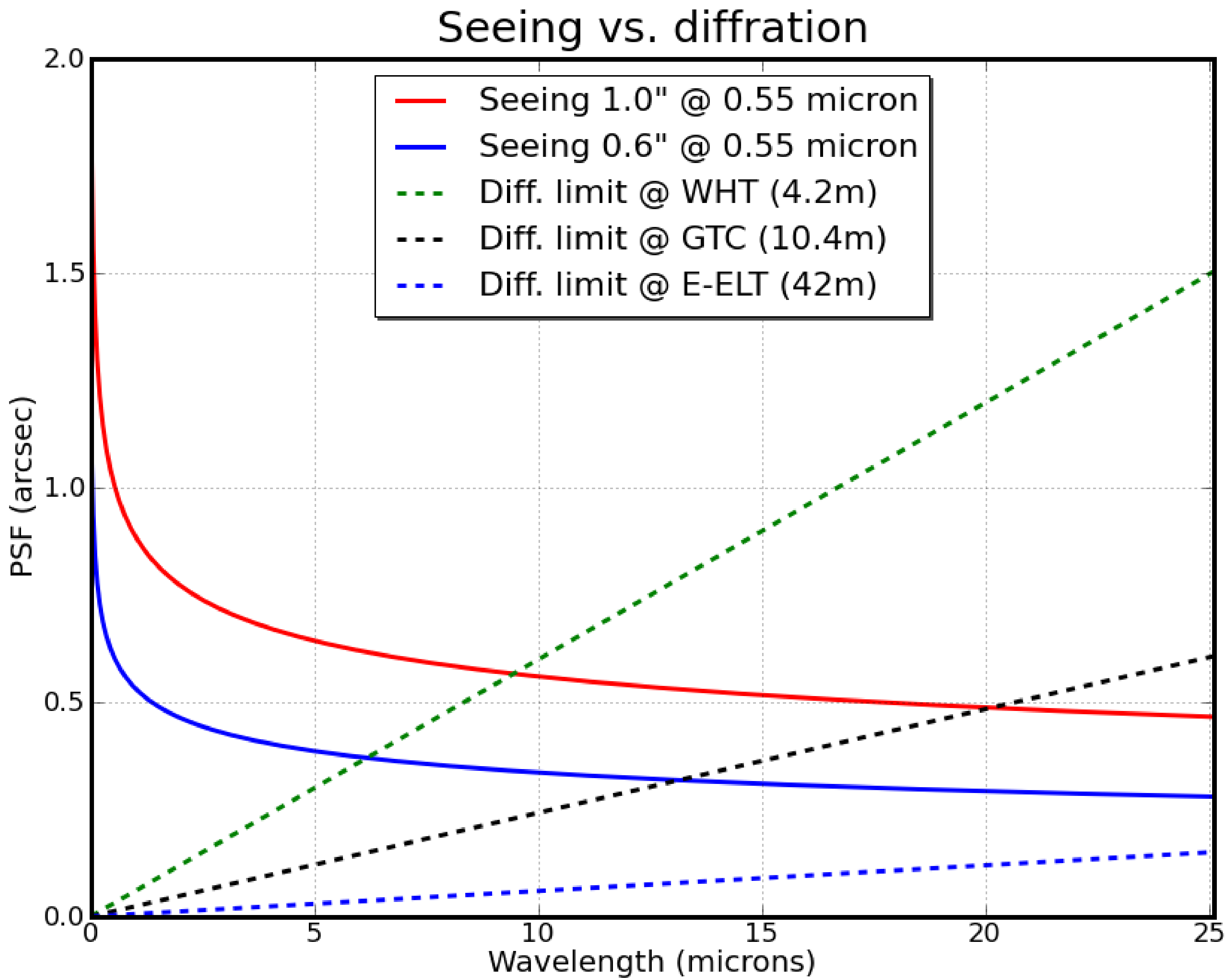


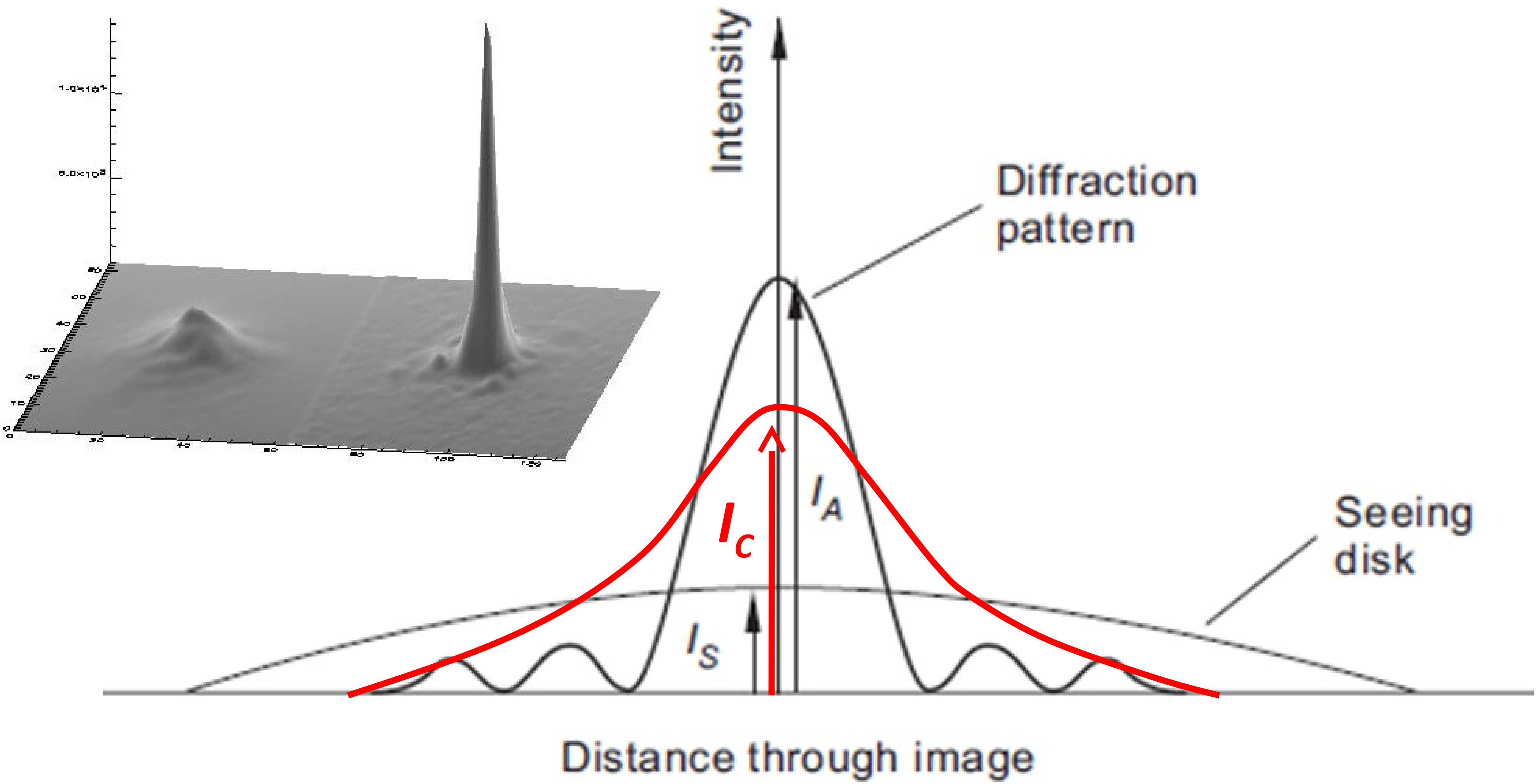
Figure 19.8. The seeing disc of a star is superposed in the theoretical diffraction pattern in the image plane. The ratio of the peak intensities, I_S/I_A is referred to as the Strehl index.



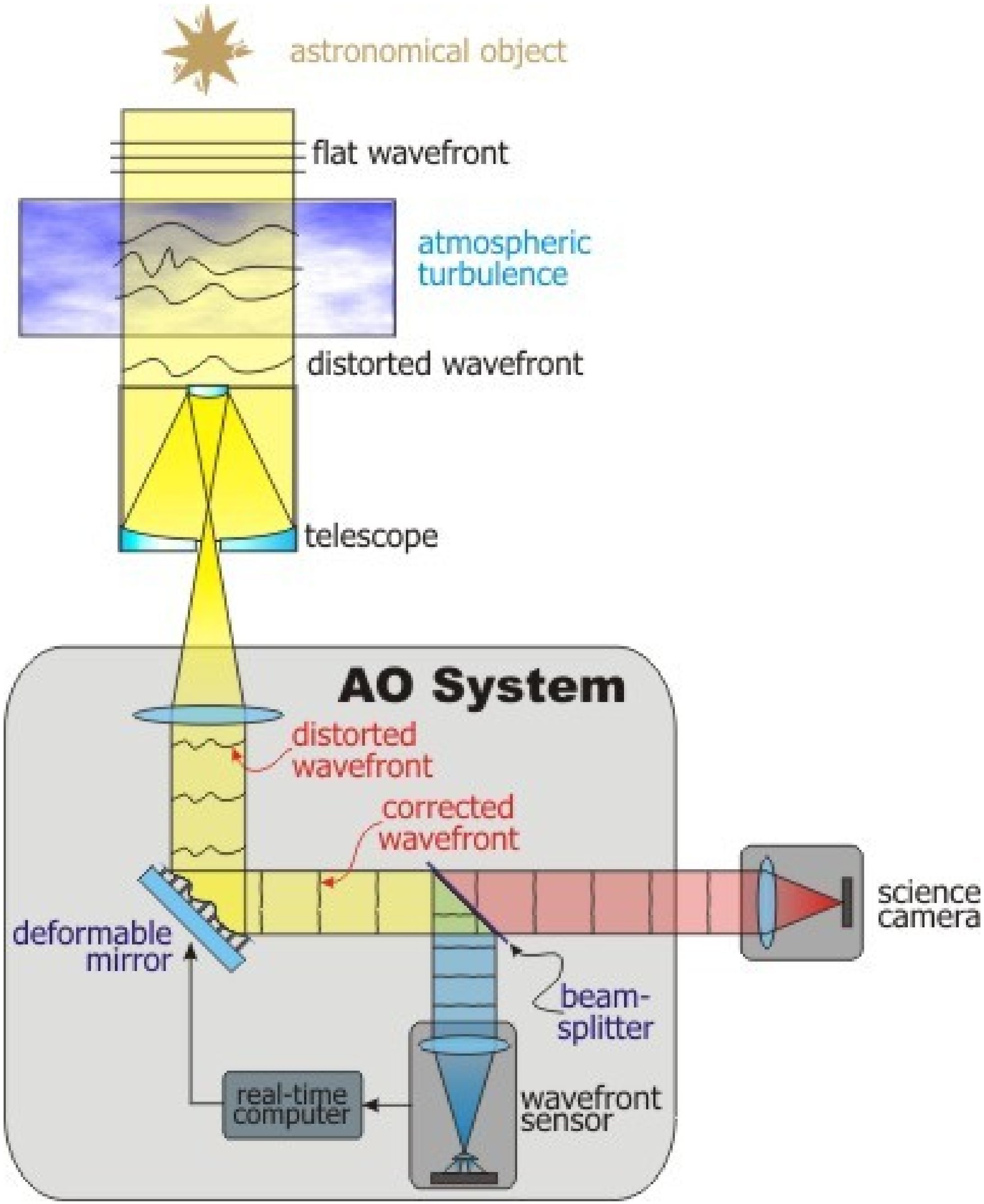
http://www.gtc.iac.es/en/pages/instrumentation/canaricam/mir.php

Quality of the correction: Strehl ratio

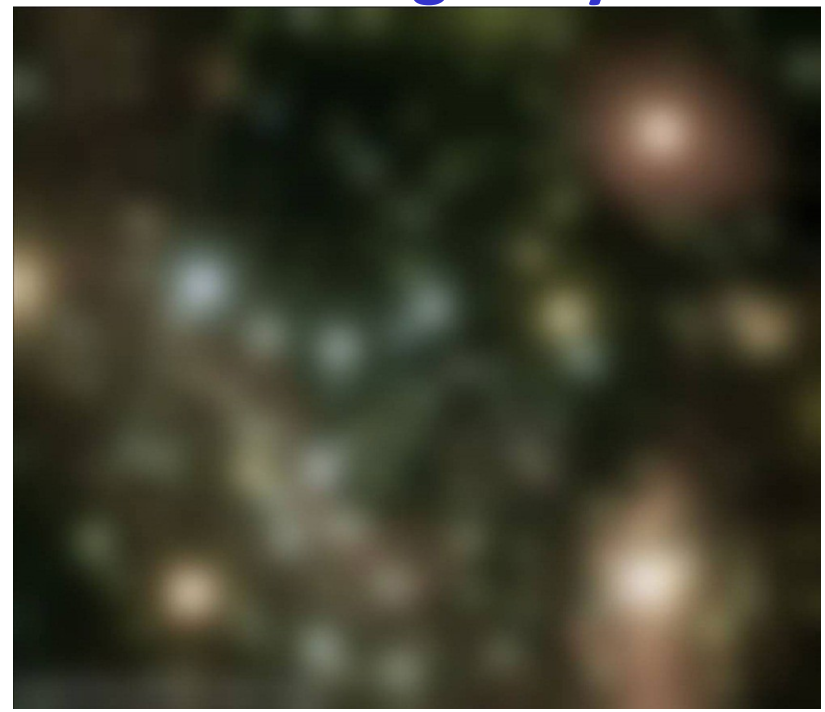
$$\text{Strehl ratio} = I_{corrected} / I_{difraction}$$



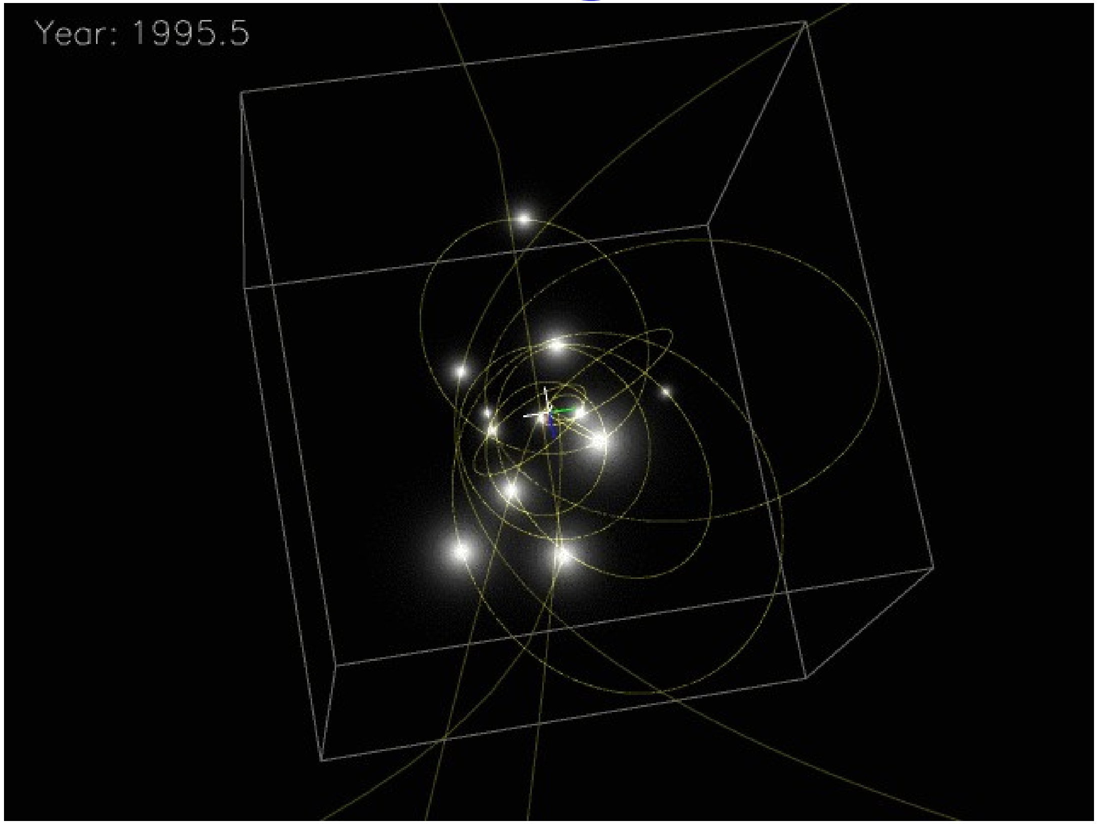
Adaptive optics



Center of our galaxy



Stars orbiting the Galactic center



http://astro.uchicago.edu/cosmus/projects/UCLA_GCG/

Andrea Ghez
Orbits around the Galactic center imply **black hole of 4 million solar masses**

Professor Ghez has actively disseminated her work to a wide variety of audiences through more than 100 refereed papers and 200 invited talks, as well features in textbooks, documentaries, and science exhibits. She has received numerous honors and awards including the Crafoord Prize, a MacArthur Fellowship, election to the National Academy of Sciences and the American Academy of Arts & Sciences, the Aaronson Award from the University of Arizona, the Sackler Prize from Tel Aviv University, the American Physical Society's Maria Goeppert-Mayer Award, the American Astronomical Society's Newton Lacy Pierce Prize, a Sloan Fellowship, a Packard Fellowship, and several teaching awards. Her most recent service work includes membership on the National Research Council's Board on Physics & Astronomy, the Thirty-Meter-Telescope's Science Advisory Committee, the Keck Observatory Science Steering Committee, and the Research Strategies Working Group of the UC Commission on the Future.

TED TALK: http://www.ted.com/talks/andrea_ghez_the_hunt_for_a_supermassive_black_hole.html

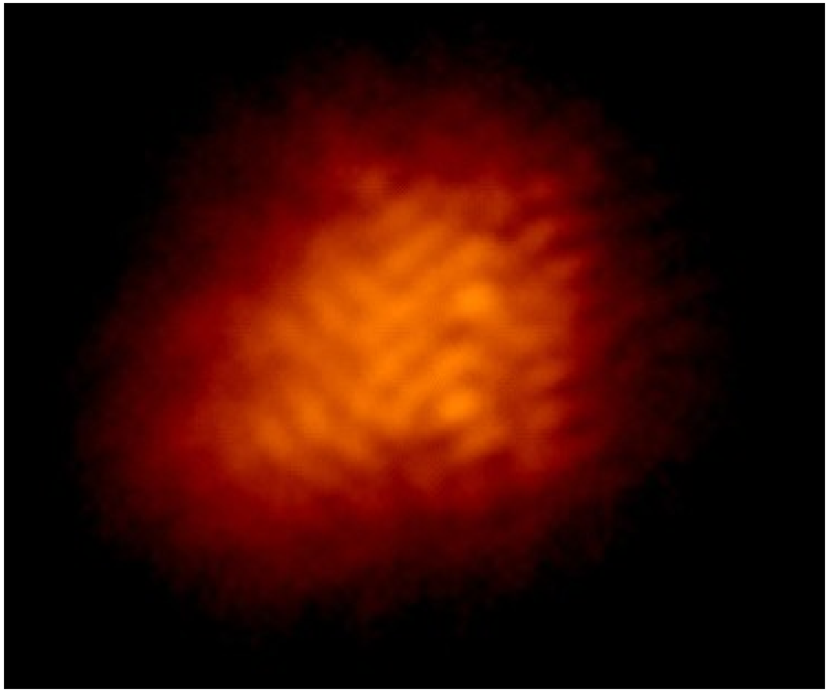
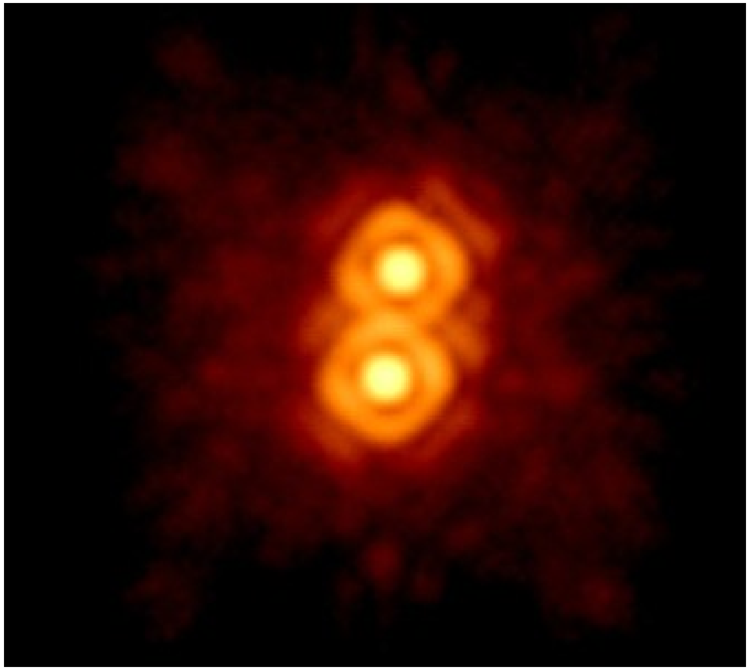


Image of a binary system (without correction)

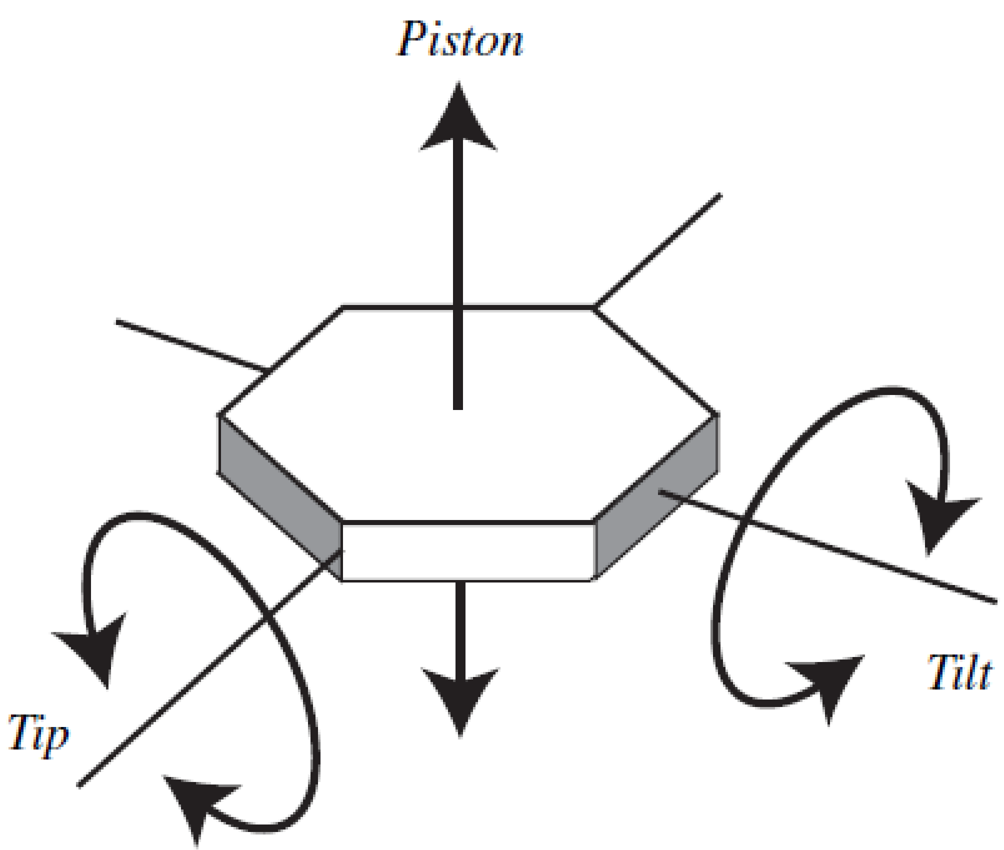


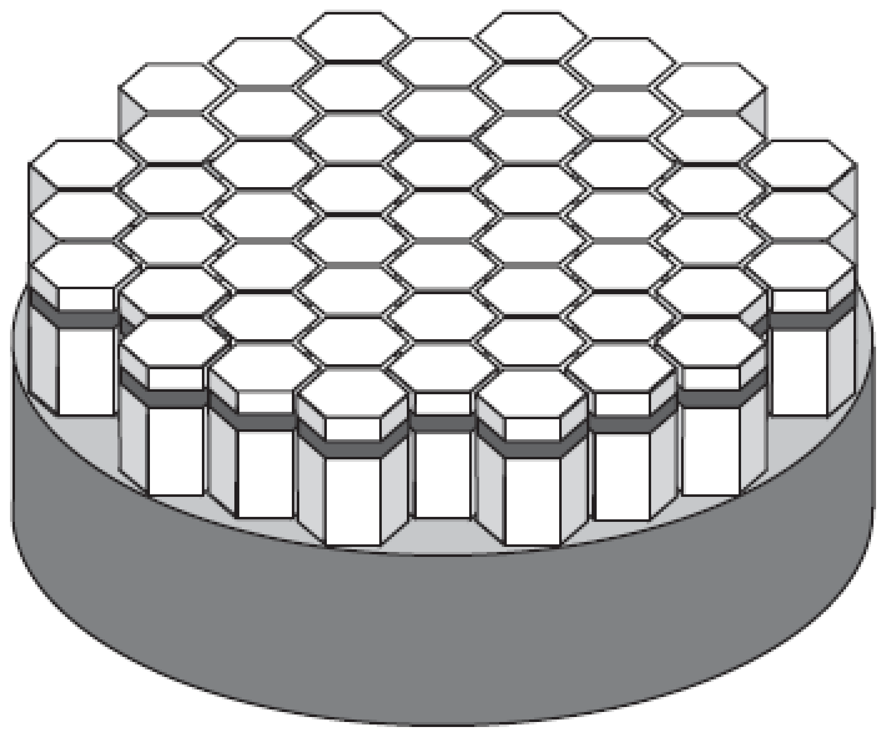
With adaptive optics

The binary star IW Tau is revealed through adaptive optics. The stars have a 0.3 arc second separation. The images were taken by Chas Beichman and Angelle Tanner of JPL. *Observations at Palomar P200*

Segmented mirror for Adaptive Optics

Fig. 6.16 A segmented, adjustable mirror for adaptive optics. Individual hexagonal segments (left) are adjustable in piston, tip, and tilt.





Shack-Hartmann sensor for AO

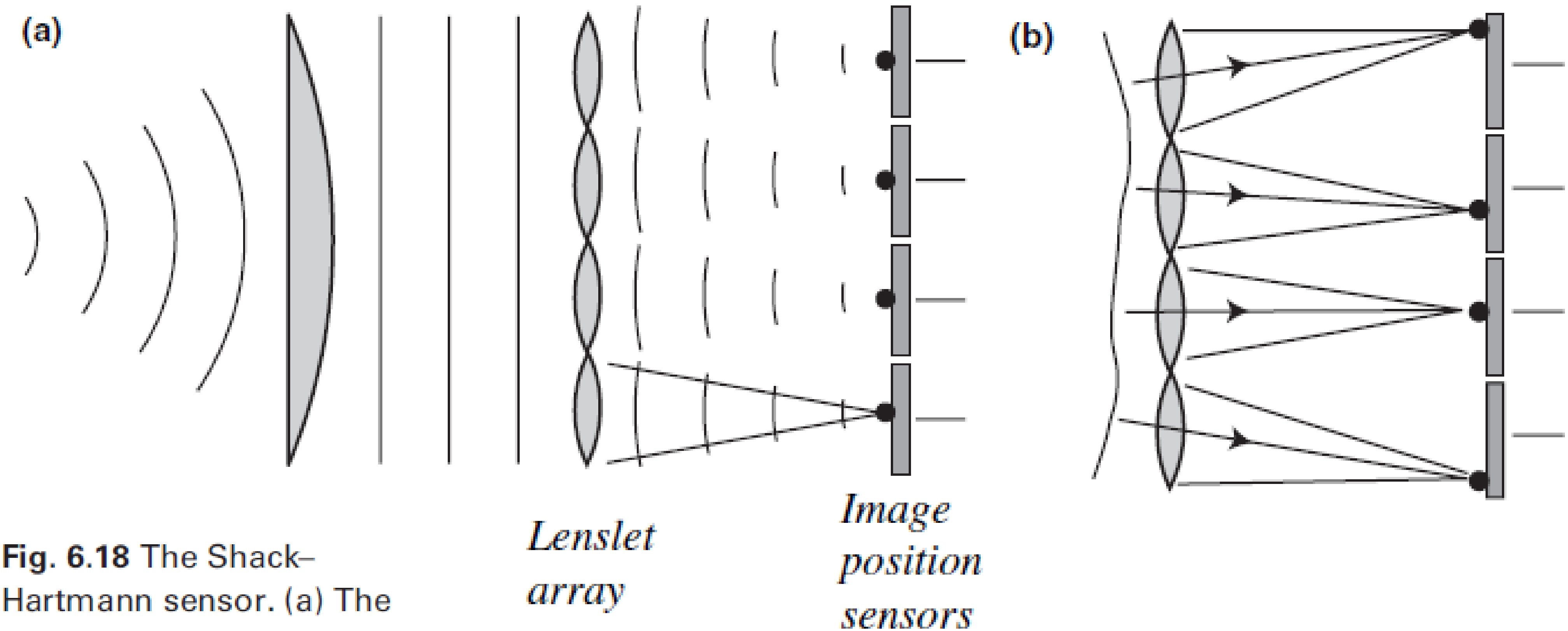


Fig. 6.18 The Shack–Hartmann sensor. (a) The beam from a perfect point source – all images on the sensors are in the null position. (b) A distorted wavefront and the resulting image displacements from tilted segments.

WFS stars must be nearby

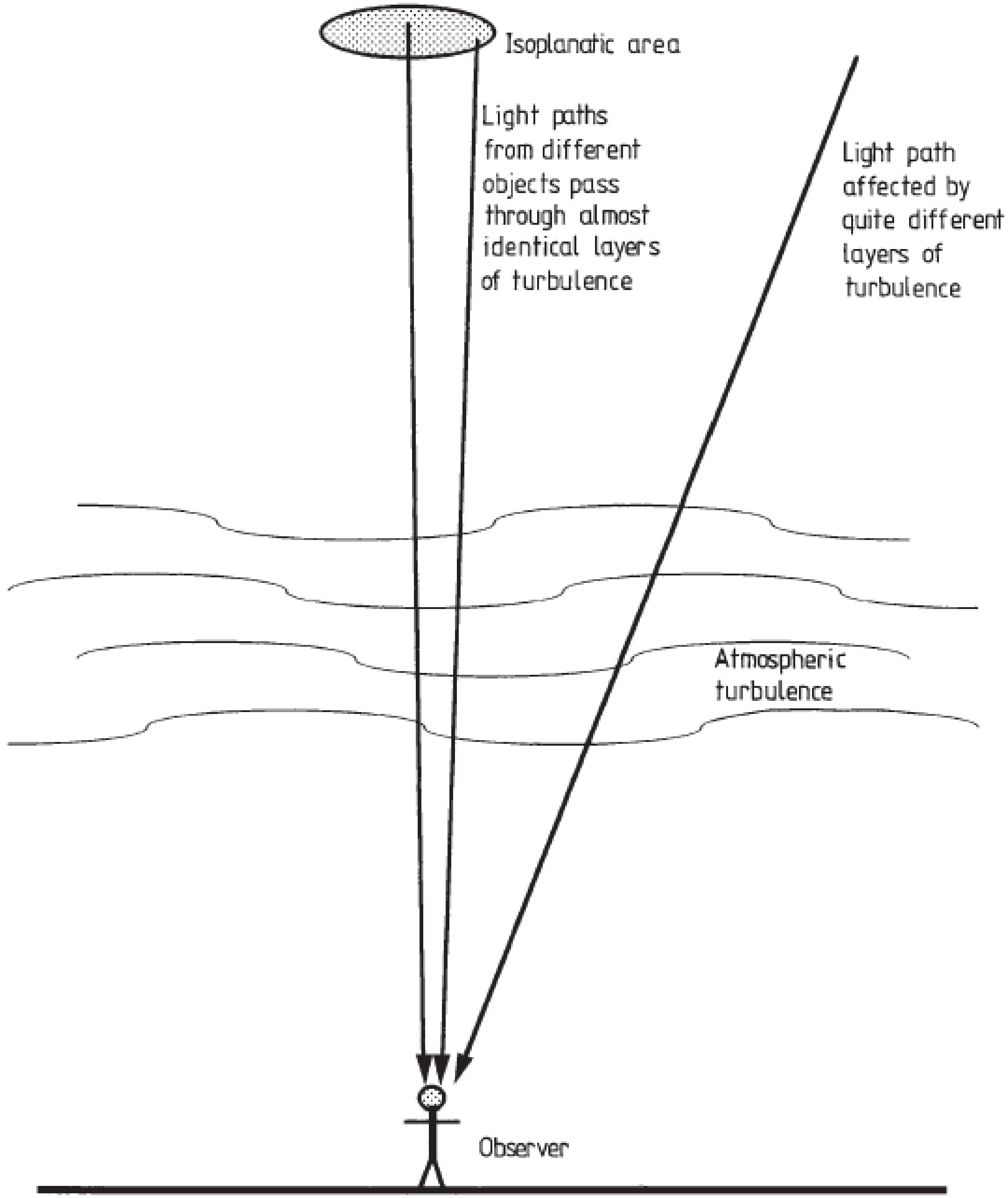


Figure 1.1.53. The isoplanatic area.

WFS stars must be bright

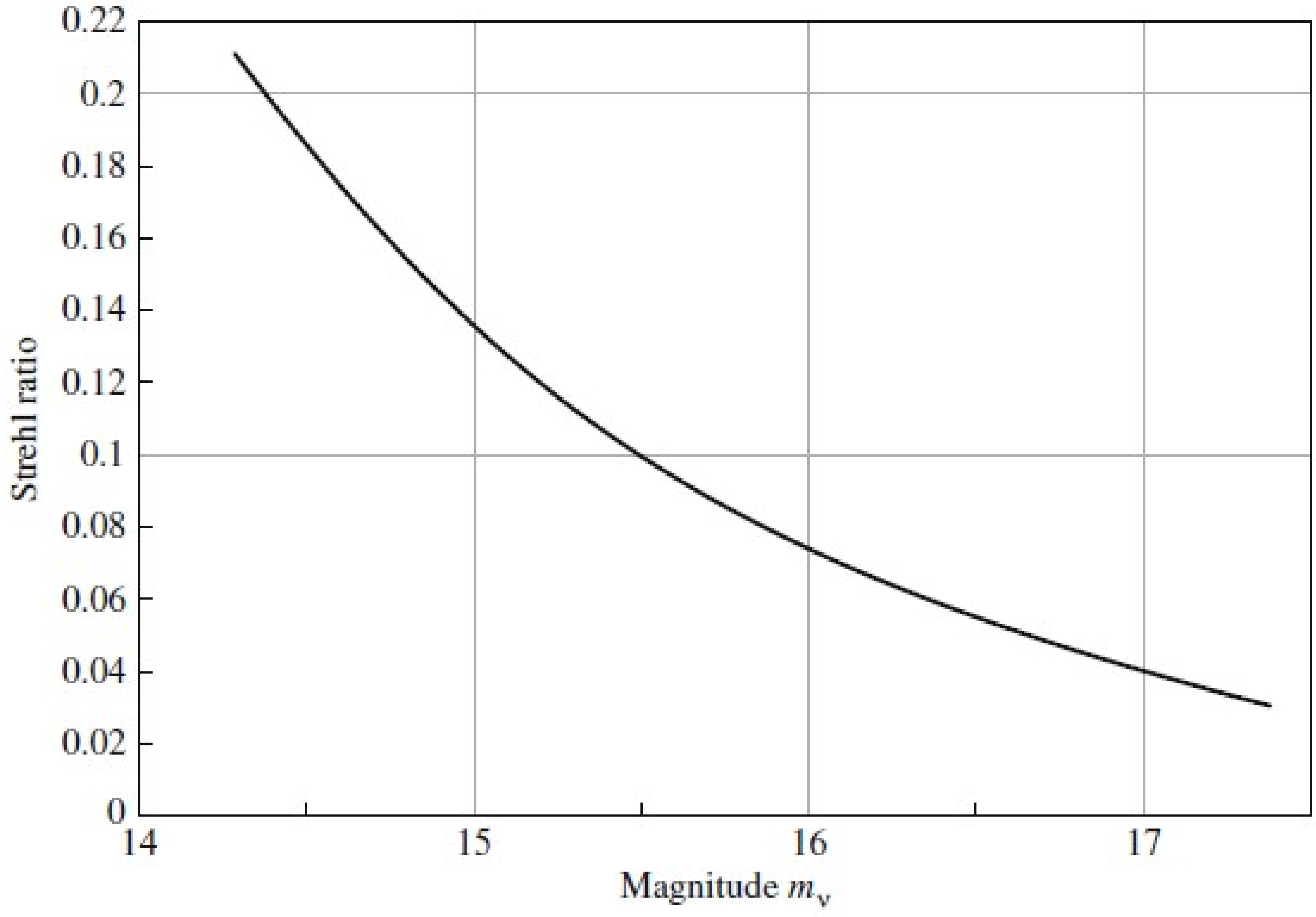
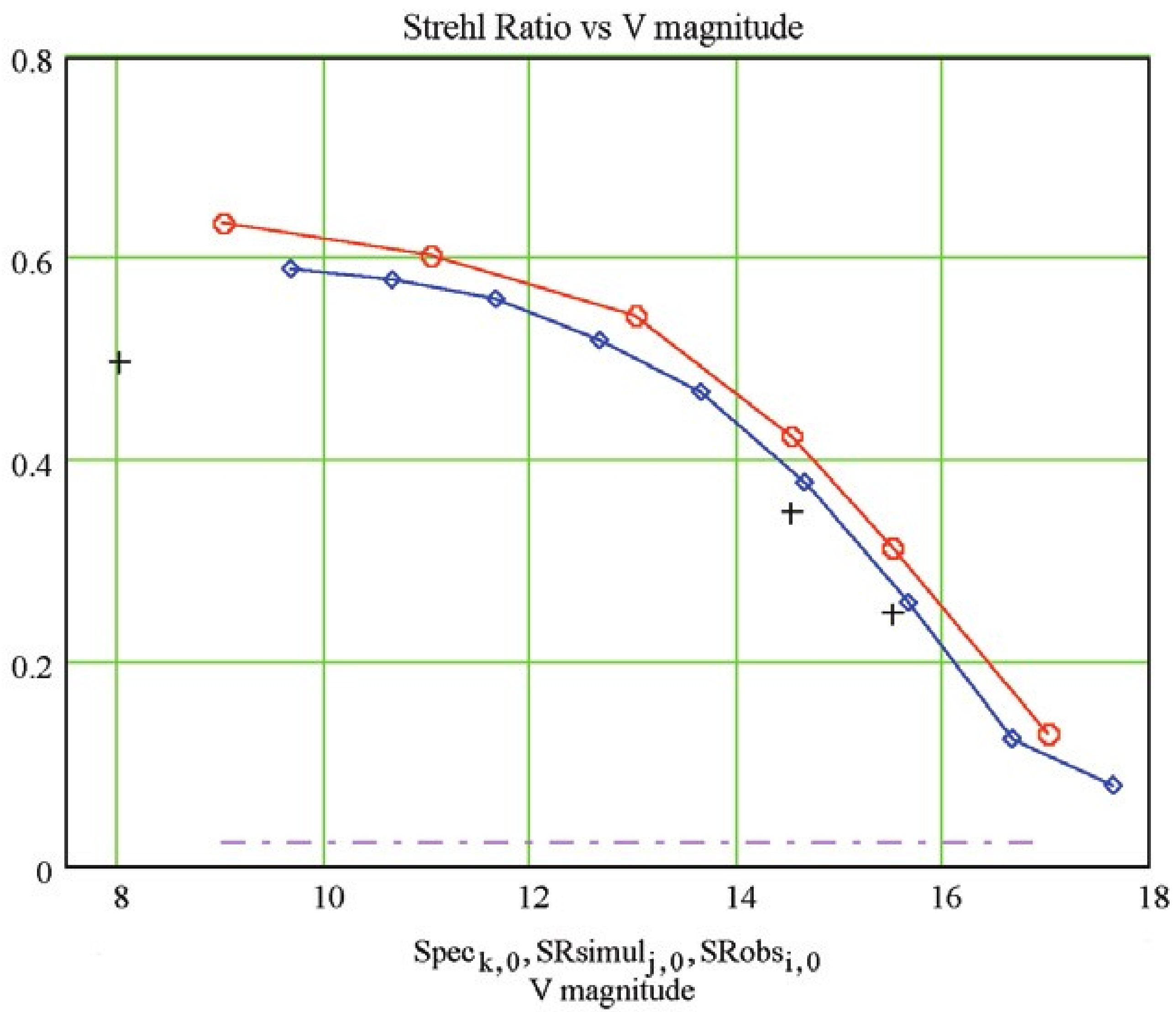
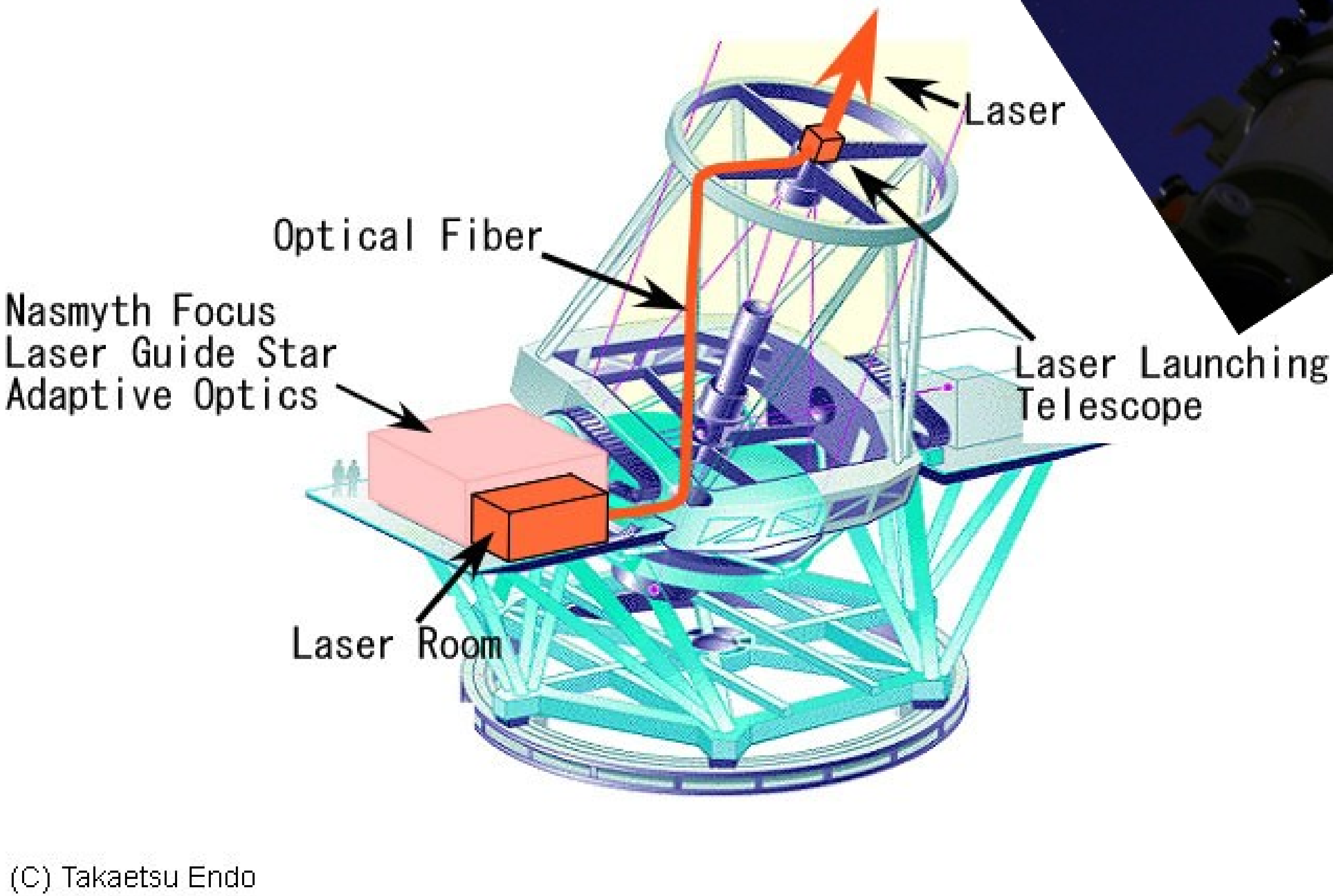


Fig. 6.20 Sensitivity of adaptive optics. *Ordinate*: Strehl ratio $\mathscr{S}$ for an image corrected at $\lambda = 2.2\ \mu m$ (spectral band K), in average turbulence conditions. *Abscissa*: Magnitude m_V of the source used by the wavefront analyser (hence analysis wavelength $\lambda_0 = 0.55\ \mu m$). We assume here that the sensor is equipped with a detector with high quantum efficiency (CCD, $\eta = 0.6$) and a very low readout noise ($2e^-$ rms). From Gendron E., doctoral thesis, 1995



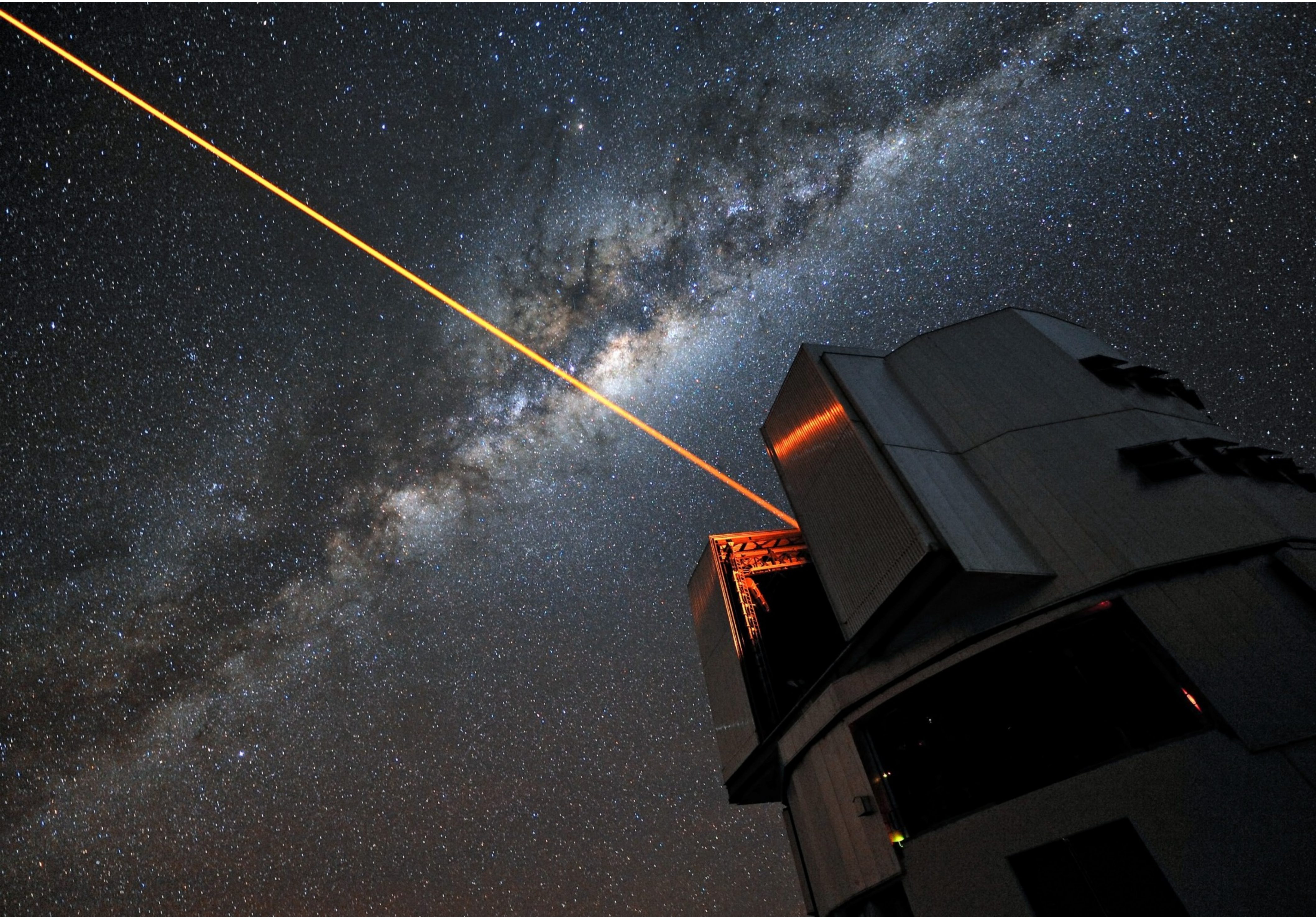
MACAO-VLTI first light: Adaptive optics at the service of interferometry

No stars in your field?
Create your own star!



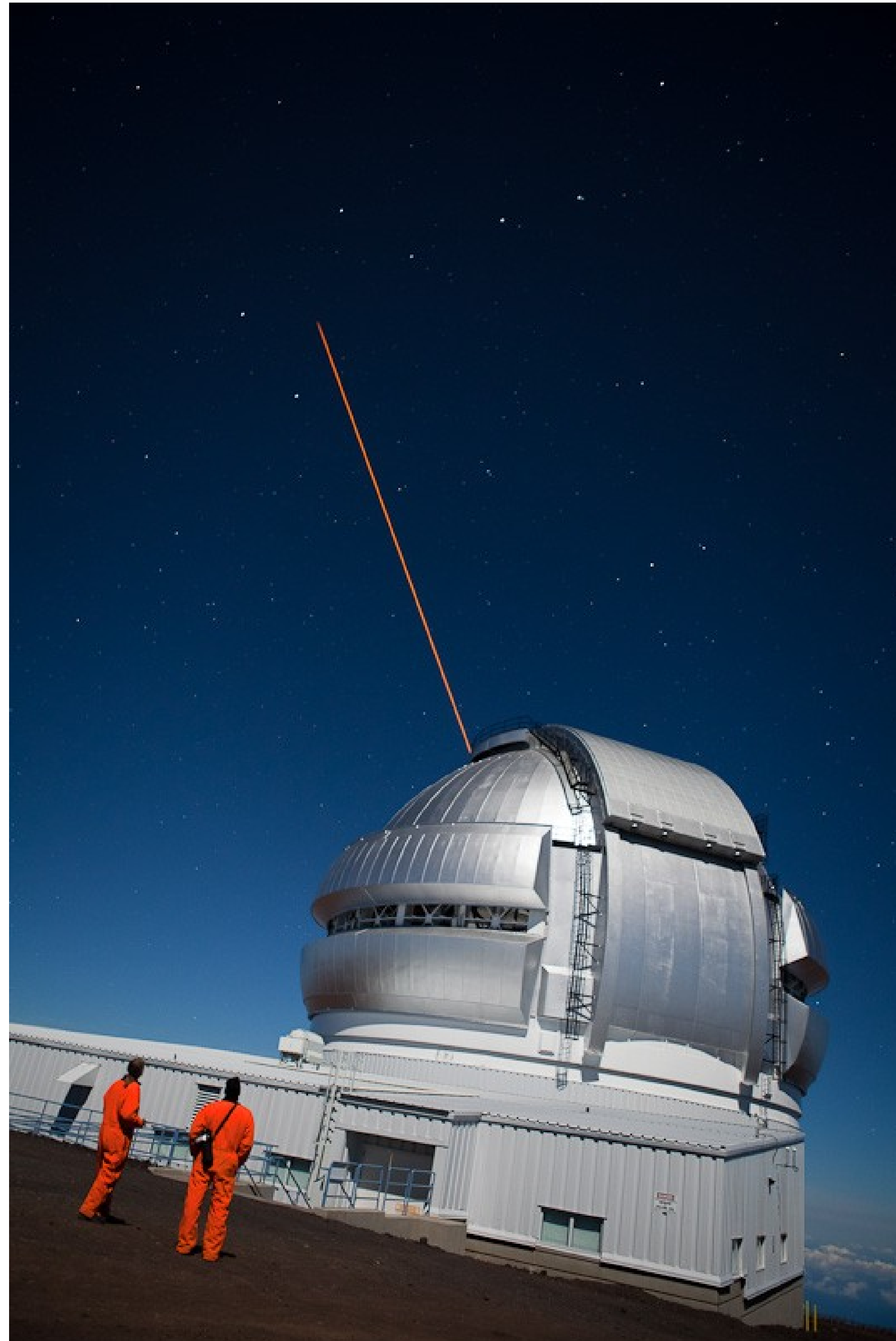
http://subarutelescope.org/Pressrelease/2005/07/06/

VLT laser



Spotters at Gemini observatory

In the past spotters were used to check for aircrafts. They have been replaced by automated systems



Two aircraft spotters make sure no aircrafts pass close to the laser beam.

http://www.paulanthonywilson.com/blog/why-do-some-telescopes-use-laser-beams/

Problem with laser stars : cone effect

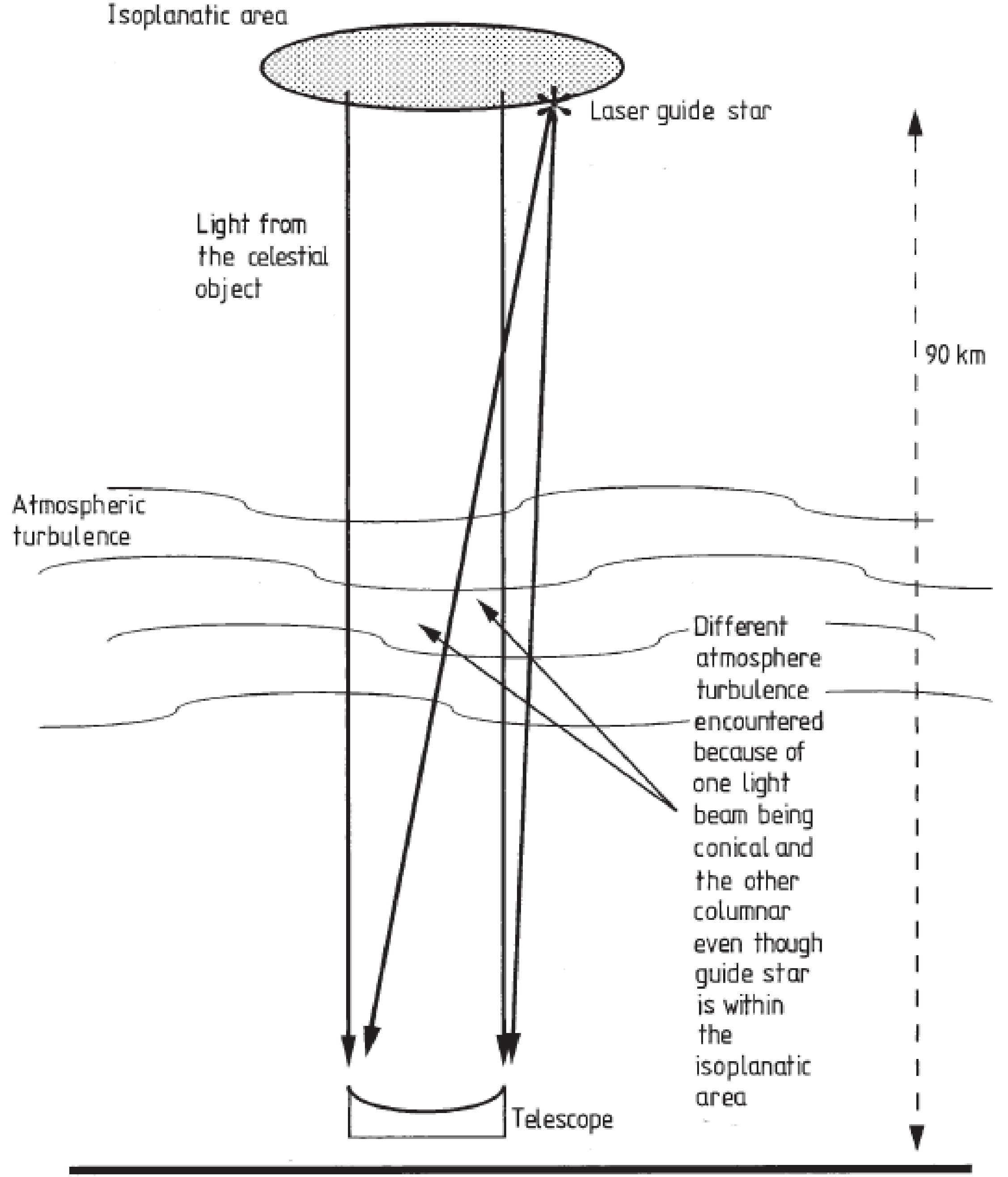


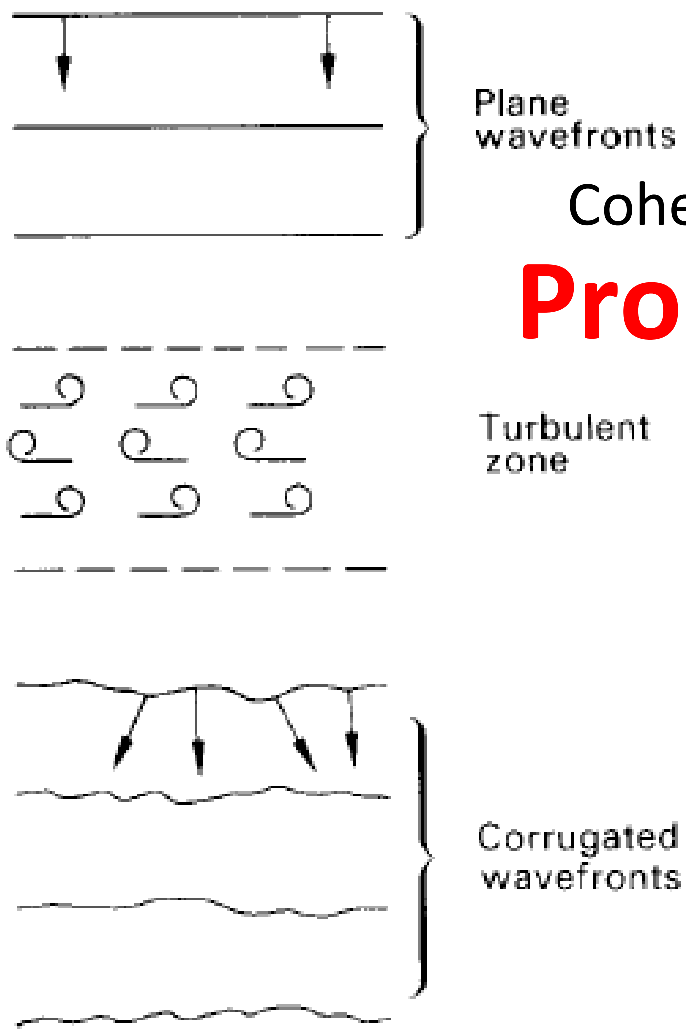
Figure 1.1.54. Light paths from a celestial object and a laser guide star to the telescope.

Real-time atmospheric compensation

© Kitchin

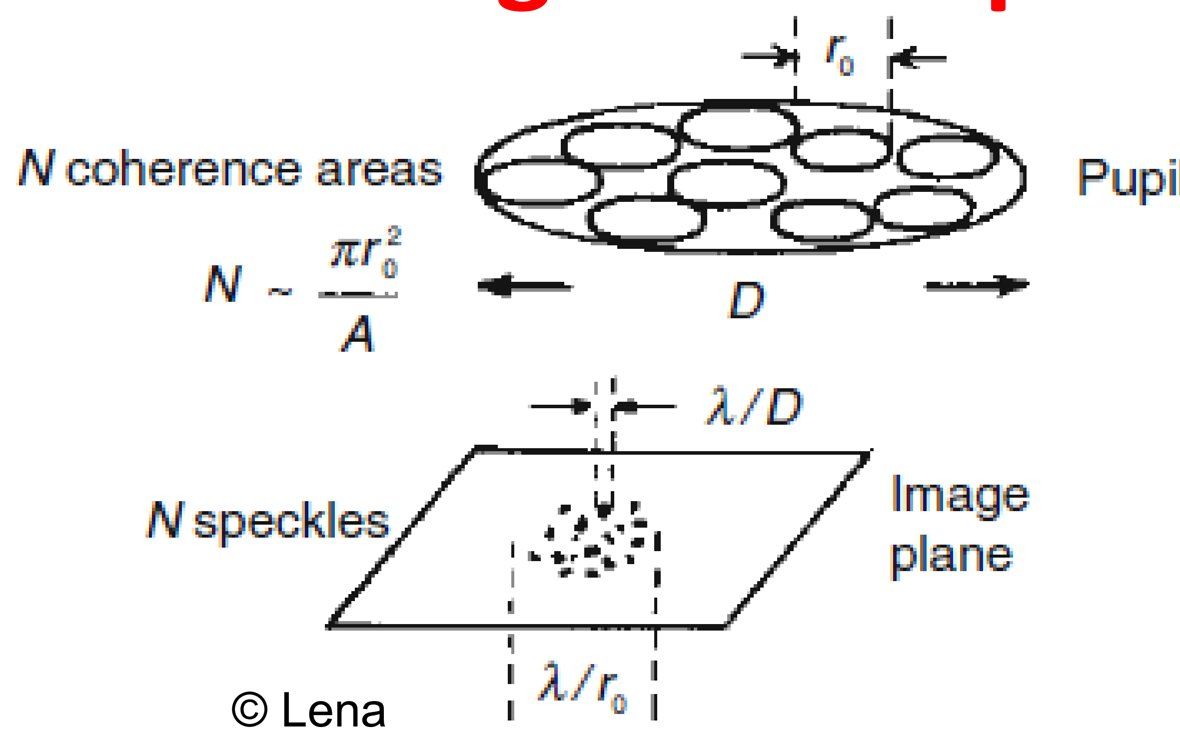
The resolution of ground-based telescopes of more than a fraction of a metre in diameter is limited by the turbulence in the atmosphere. The maximum diameter of a telescope before it becomes seriously affected by atmospheric turbulence is given by Fried's coherence length, r_0,

$$r_0 \approx 0.114\left(\frac{\lambda \cos z}{550}\right)^{0.6} \text{ m} \qquad (1.1.73)$$

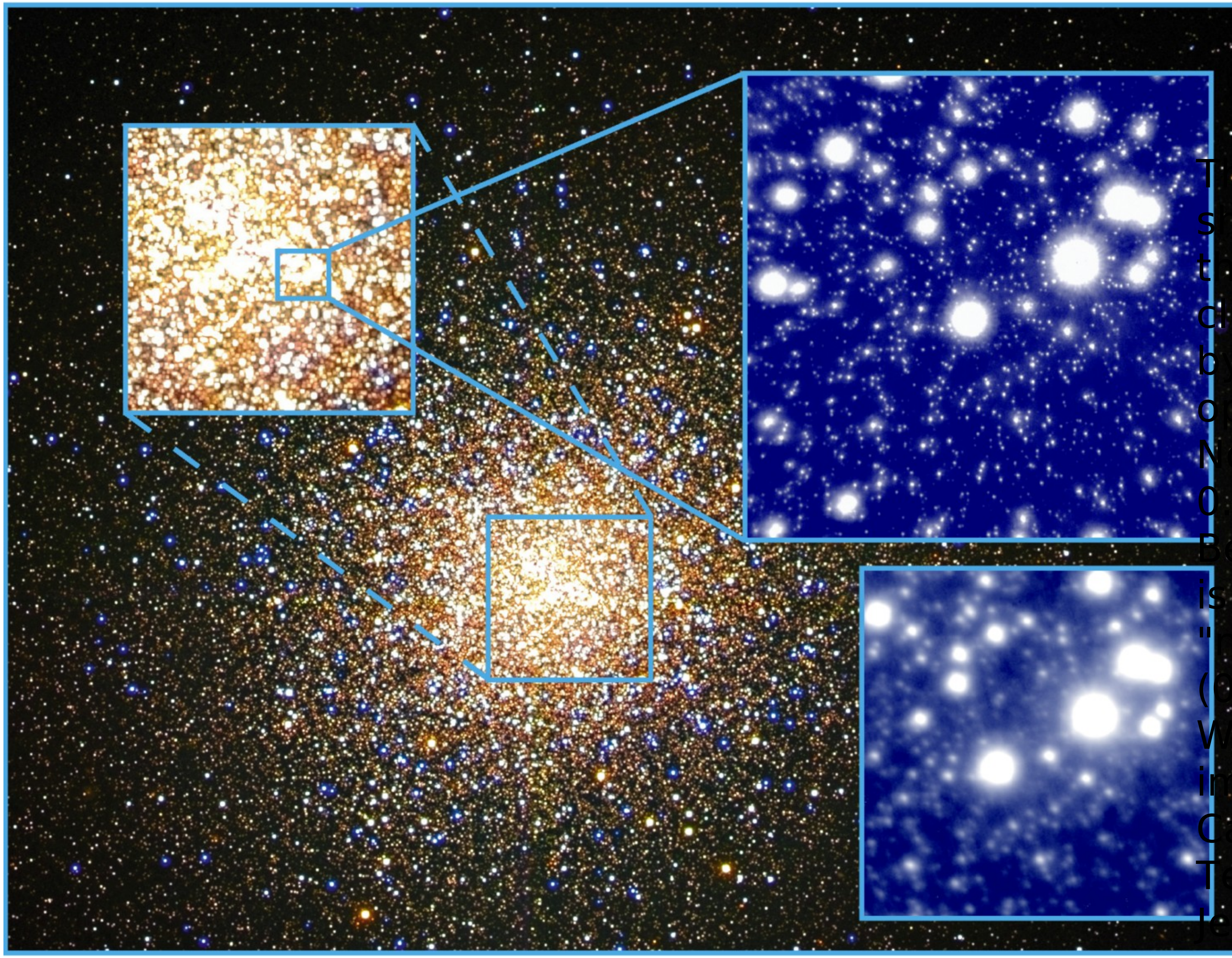


Coherence length is 10cm at 0,5μm, at 20 μm is ~ 8,4m

Problem with large telescopes



© Lena



This composite image shows a small section of the core of the globular cluster M-13 as imaged by the Altair adaptive optics system on Gemini North (upper blue inset; 0.060 arcsecond resolution). Beneath the Altair image is an uncorrected "natural seeing" image (0.26 arcsecond resolution). Wide-field background image courtesy of the Canada-France-Hawai`i Telescope/Coelum/ Jean-Charles Cuillandre.

www.gemini.edu