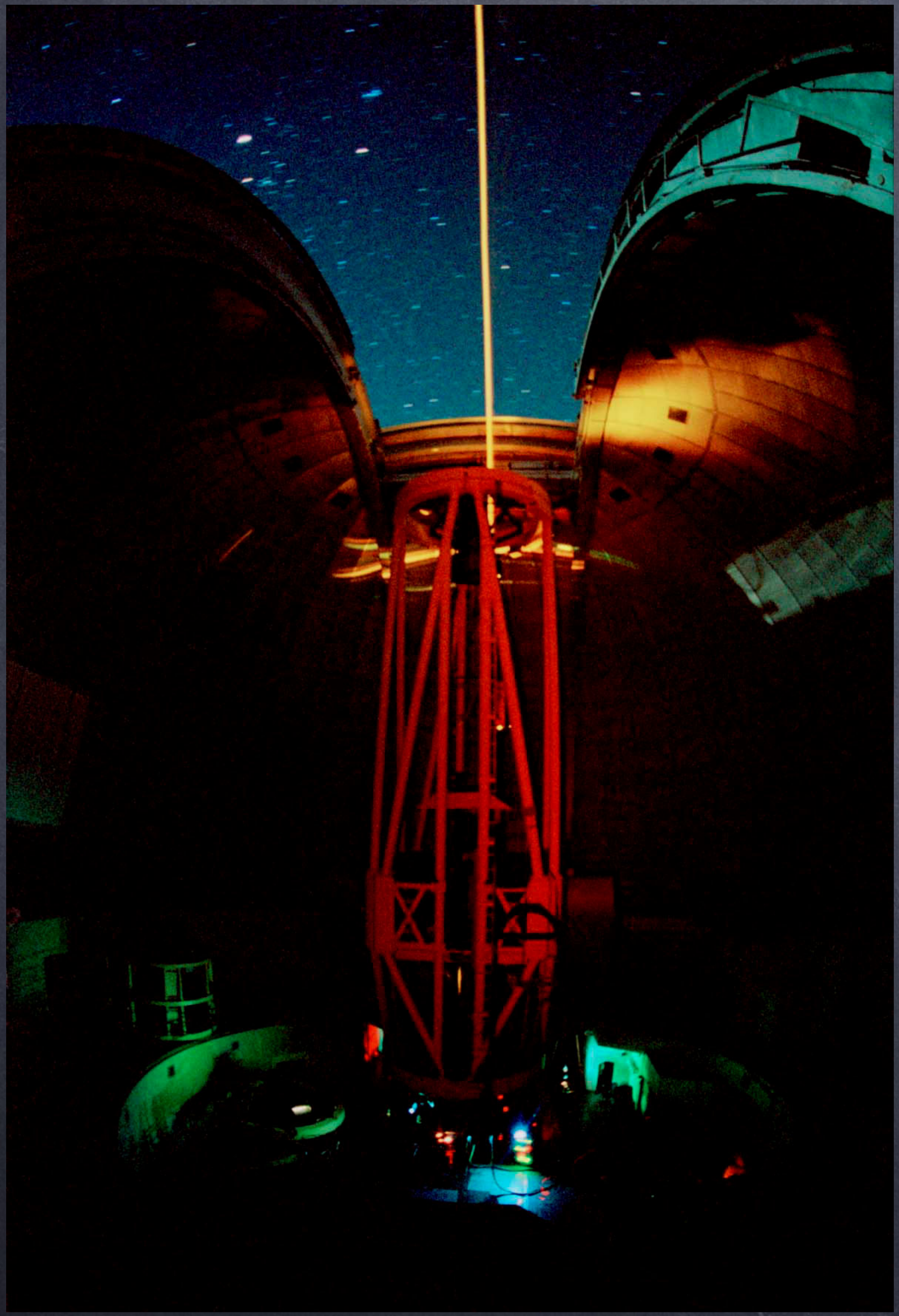
Laser Guide Star AO - 1

[Happer 1982, Foy & Labeyrie 1985]



(Keck Observatory)

+ https://www.youtube.com/watch?v=3BpT_tXYy_I

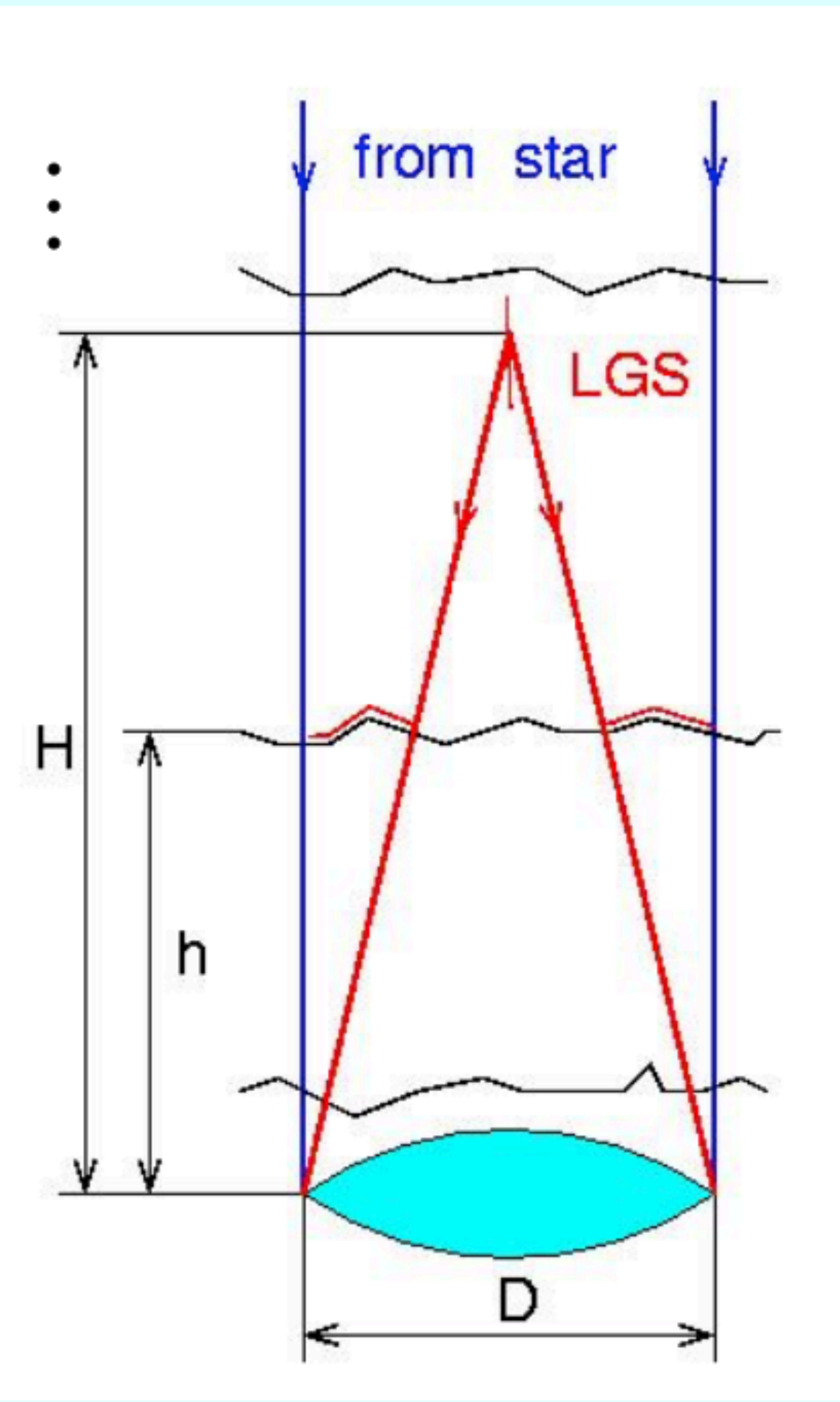
Laser Guide Star AO - 2

Specific LGS errors:

1- Cone effect (focus aniso.)
2- Tip-tilt indetermination
3- Perspective elongation

In addition (Na LGS case):
- Rayleigh backscattering until ~35km,
- variation of the Na layer column density (seasonally: a factor ~5! but also short time) and of the centroid height.

Science w/LGS: solar system bodies, YSO (circumstellar material), brown dwarves, Galactic novae, starbust galaxies, AGN, radio galaxies, gravitational lenses, clusters of galaxies, etc.



Laser Guide Star AO - 3

1- Cone effect

- LGS formed at finite altitude (H_{LGS}), with H_{LGS}=90-100km for a Sodium (Na) LGS, and H_{LGS}=10-20km for a Rayleigh LGS.
- If $h_{layer}>H_{LGS}$, the turbulent layer is not sensed.
- Even when $h_{layer}<H_{LGS}$, the outer portions of the turbulent layer are not sensed (with if $h_{layer}\neq 0$).
- The turbulent layer at altitude h_{layer} is also sampled differently by the LGS and the observed object at infinity (if $h_{layer}\neq 0$)
  => the laser beam diameter is reduced by a factor (1-h/H)
  => there is a differential « stretching » between the laser wavefront and the object wavefront, and:

$$\sigma^2_{\text{cone}} = \left(\frac{D}{d_0}\right)^{\frac{5}{3}}, \text{ with } d_0 \sim 2.91\ \theta_0\ H_{\text{LGS}}$$

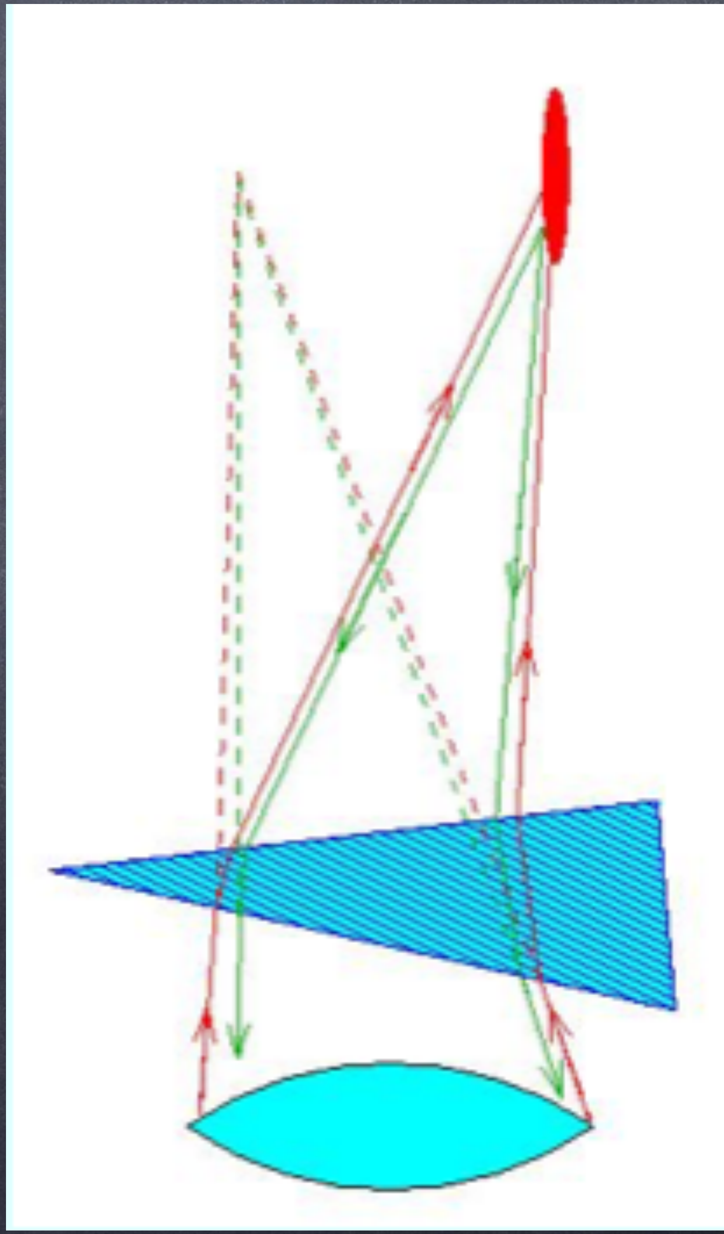
For example: θ_0~2.5", H=90km => d_0~3.2m.

- Multiple beacons => focal anisoplanatism decreases !
  [see Nature cover 01/2000, Ragazzoni]

Laser Guide Star AO - 4

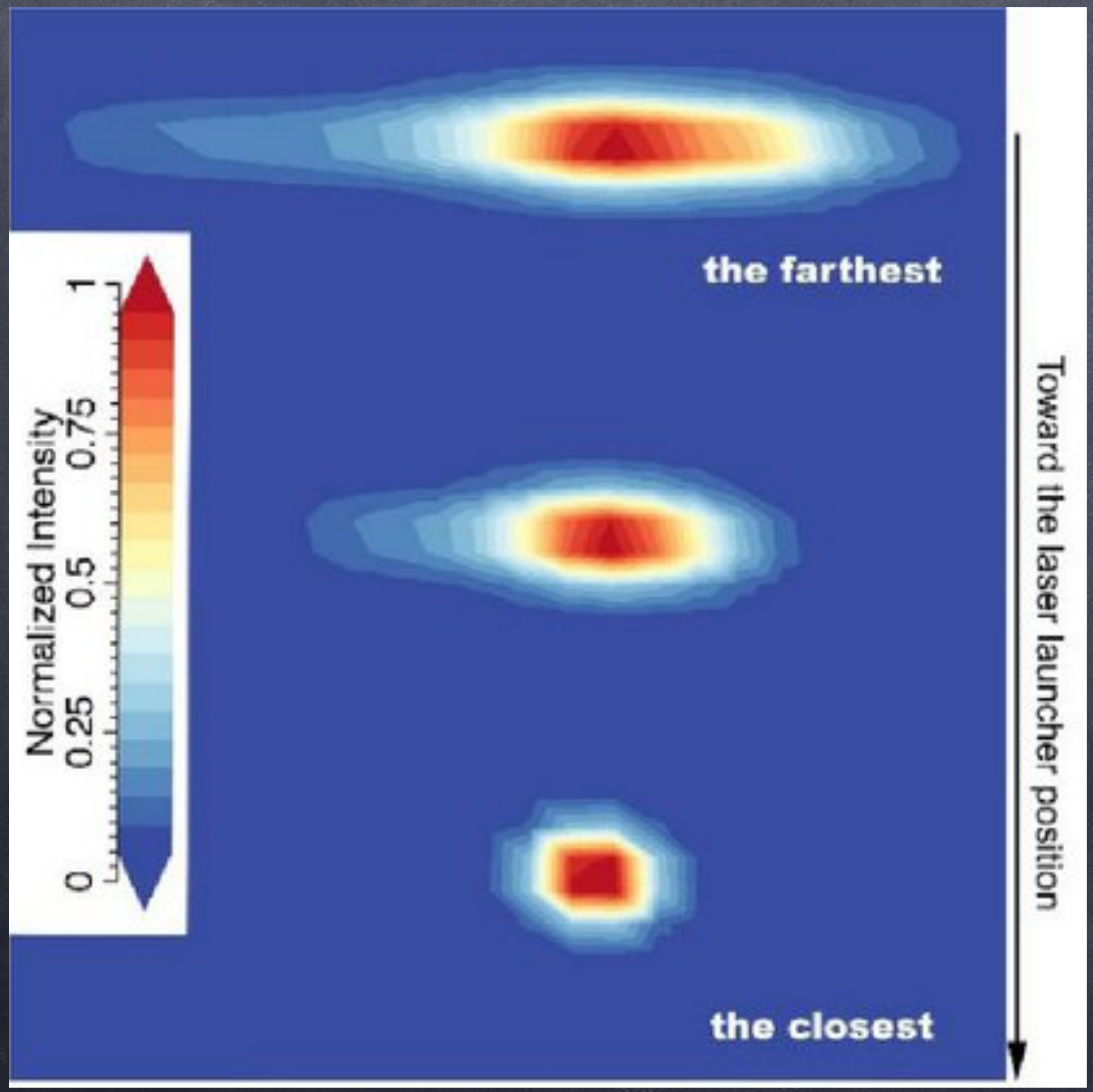
2- Tip-tilt indetermination => tip-tilt anisoplanatism error (= anisokinetism error)

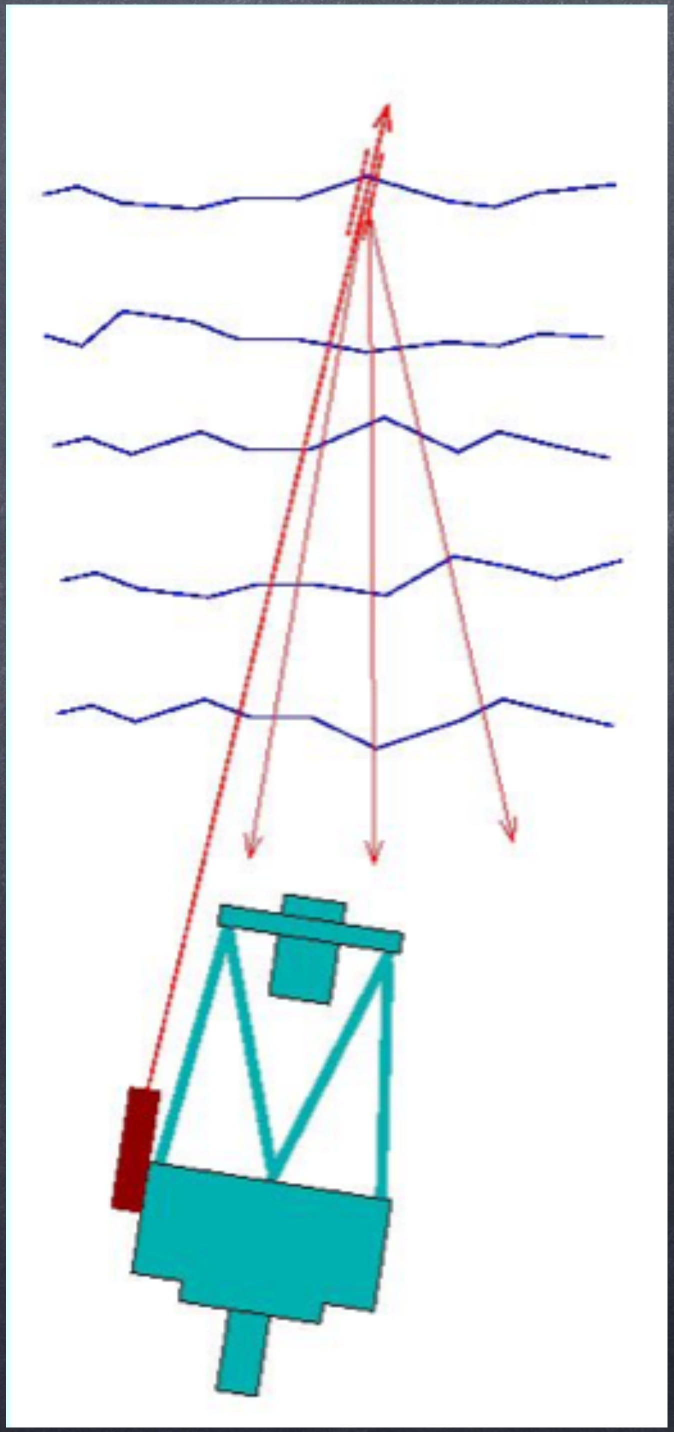
$$\sigma^2_{\mathrm{TT\ aniso.}} \sim 0.1 \left(\frac{\theta}{\theta_0}\right)^2 \left(\frac{D}{r_0}\right)^{-\frac{1}{3}}$$



Laser Guide Star AO - 5

3- Perspective elongation => SH spots elongation
(Na: 10–15km@90–100km, 589nm,
Rayleigh: ~2km@10–20km, 355nm)





Quality of correction ? - 1

$$S = \frac{I_{\text{post AO}}[0,0]}{I_{\text{perfect}}[0,0]}$$

where *I[0,0]* is the intensity of the PSF at the optical center of the field (K. Strehl, Zeit. Instrumenkde 22, 213 (1902)).

$$S \simeq \exp\{-\sigma^2_{\text{post AO}}\}$$

in the framework of the Maréchal's approximation, where the variance (in radians^2) is supposed to be small enough...

-> see also page 4 of Carbillet et al., MNRAS (2017)

Quality of correction ? - 1+

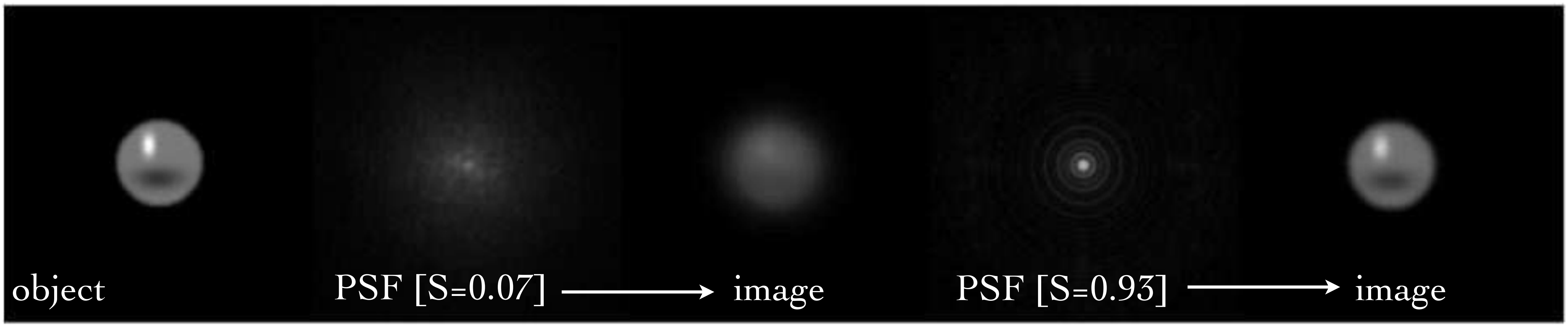
Approximation which neglects tip-tilt: ratio of the maxima

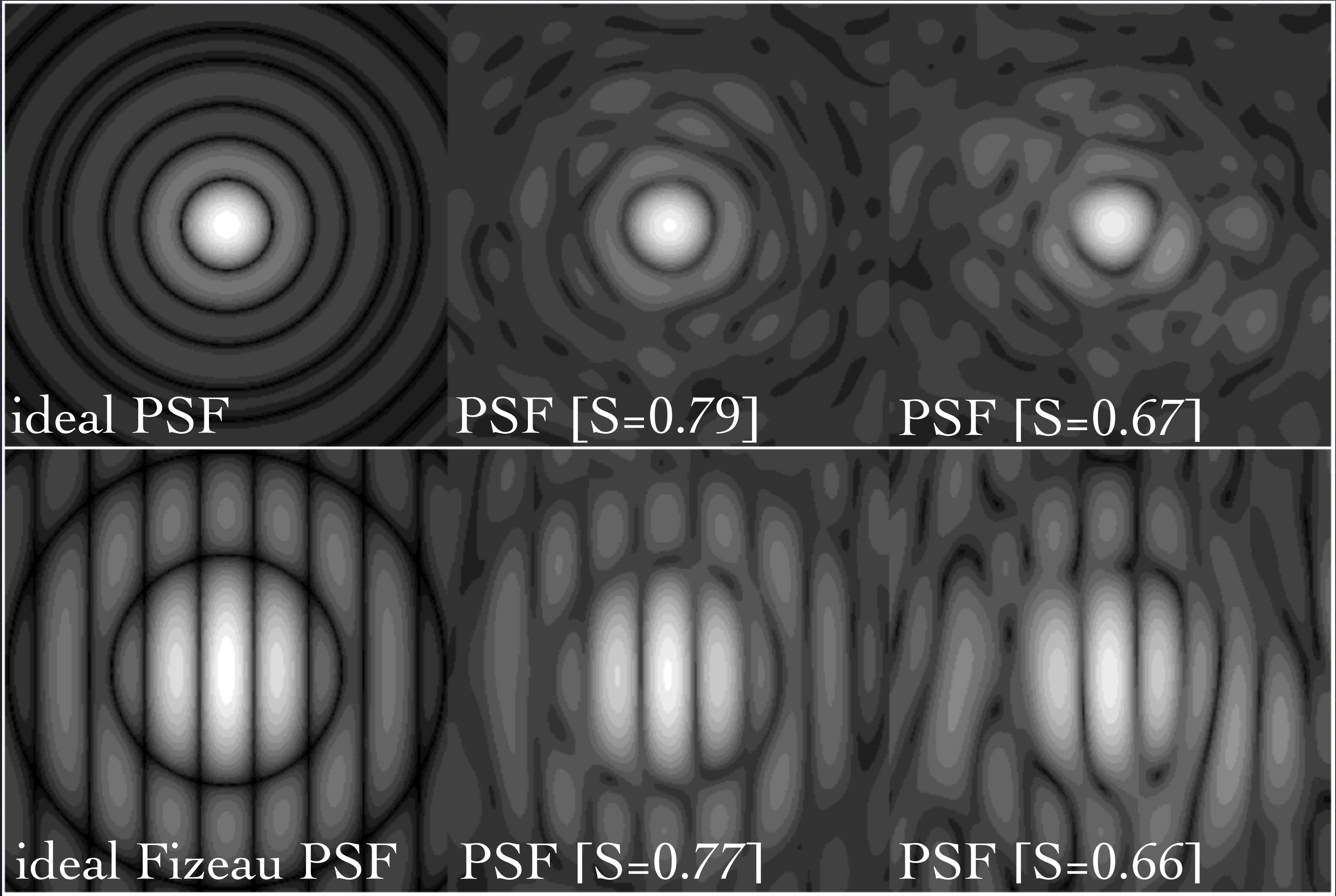
Ratio of the values at the centre of the image ≈ ratio of the OTF (see for example the paper by Roberts et al.)

Eq.10 of Tokovinin, PASP (2002):

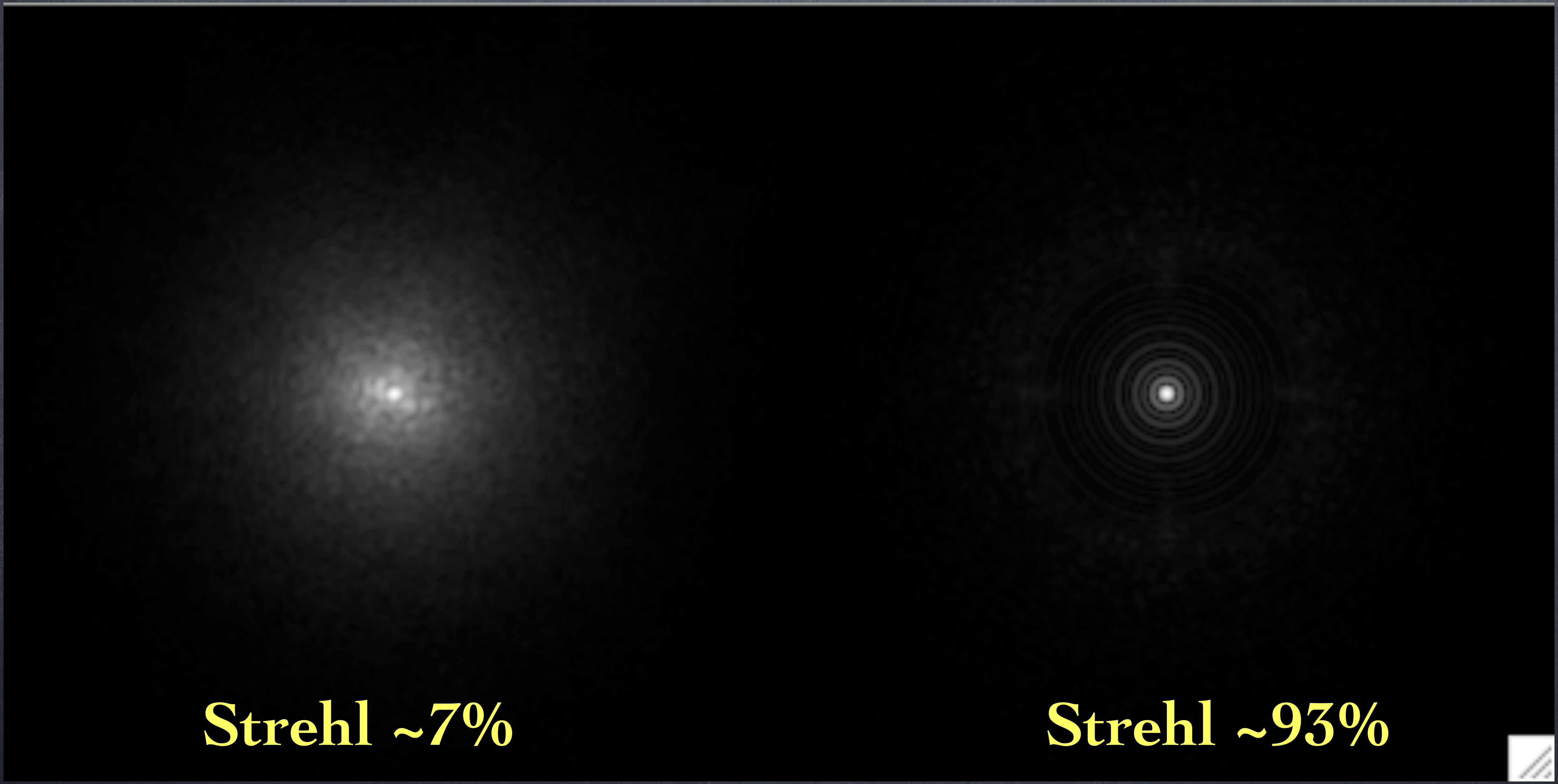
$$S = \frac{I_{max}}{I_{tot}} \frac{4}{\pi} \left(\frac{\lambda_{CCD}}{D \Delta x} \right)^2$$

Quality of correction ? - 2





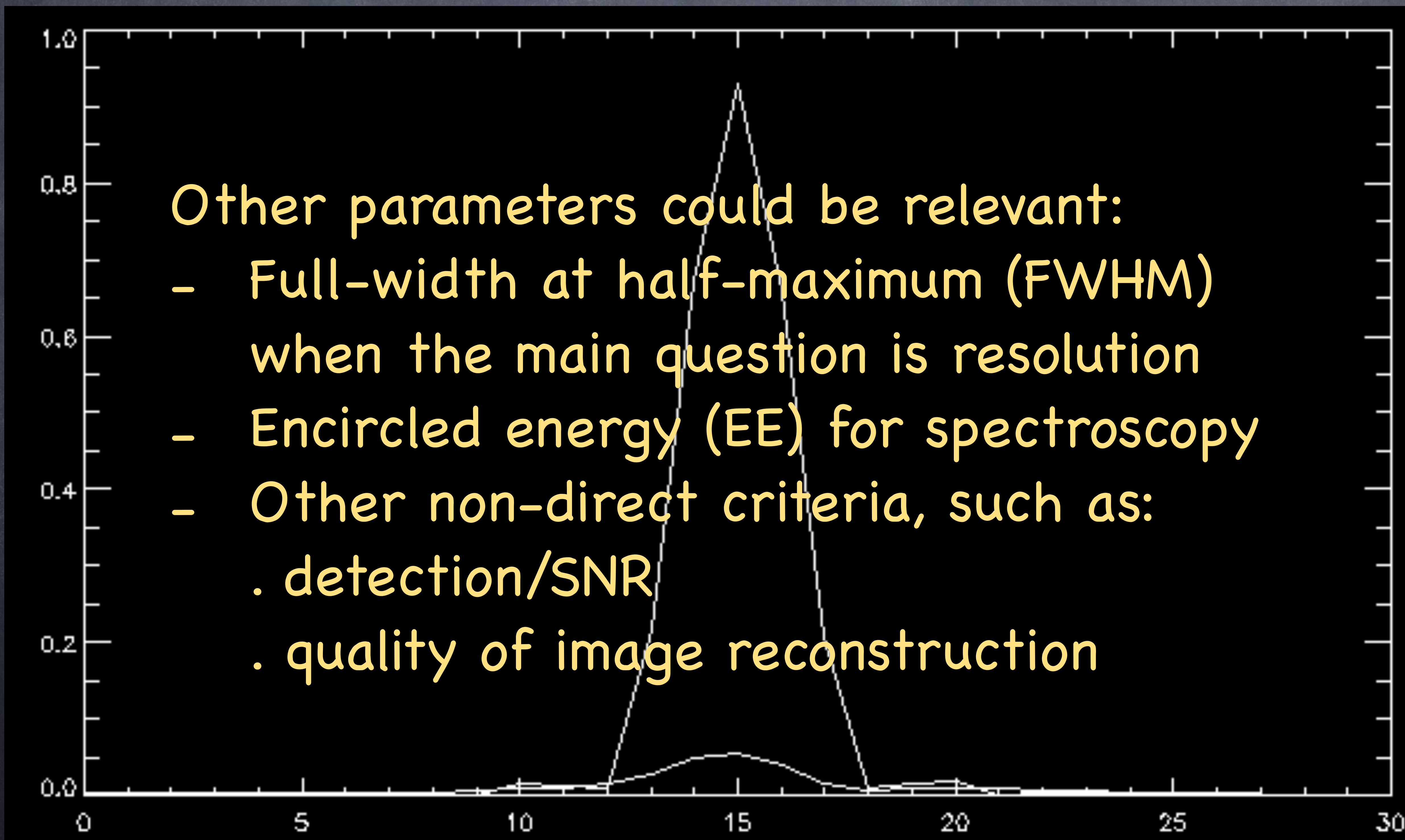
Quality of correction ? - 3



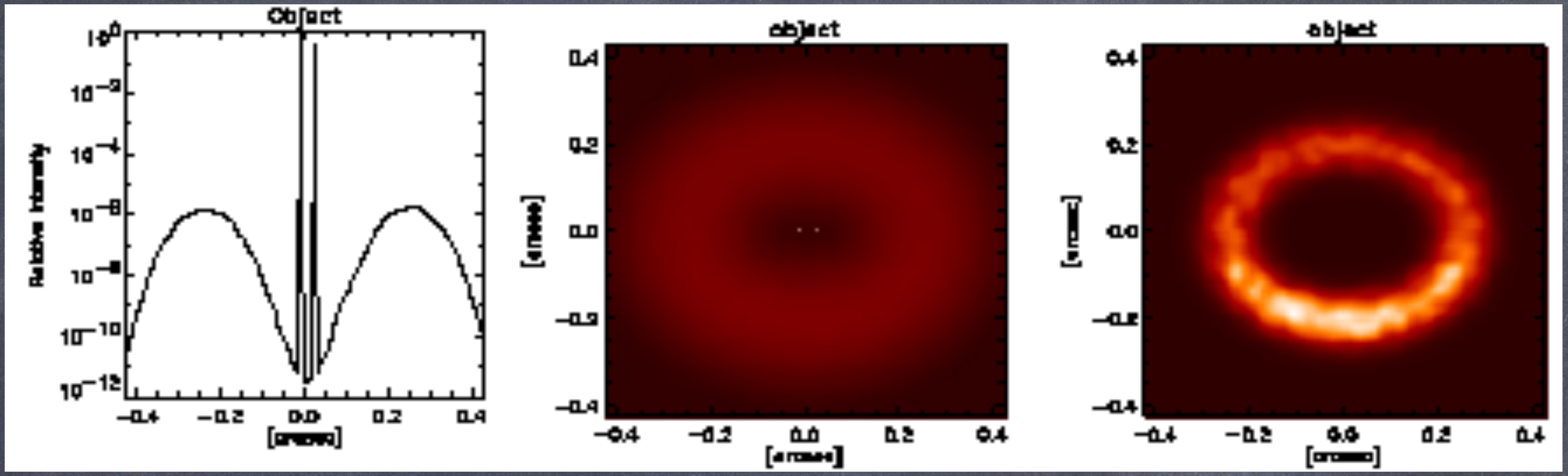
Quality of correction ? - 4

Other parameters could be relevant:

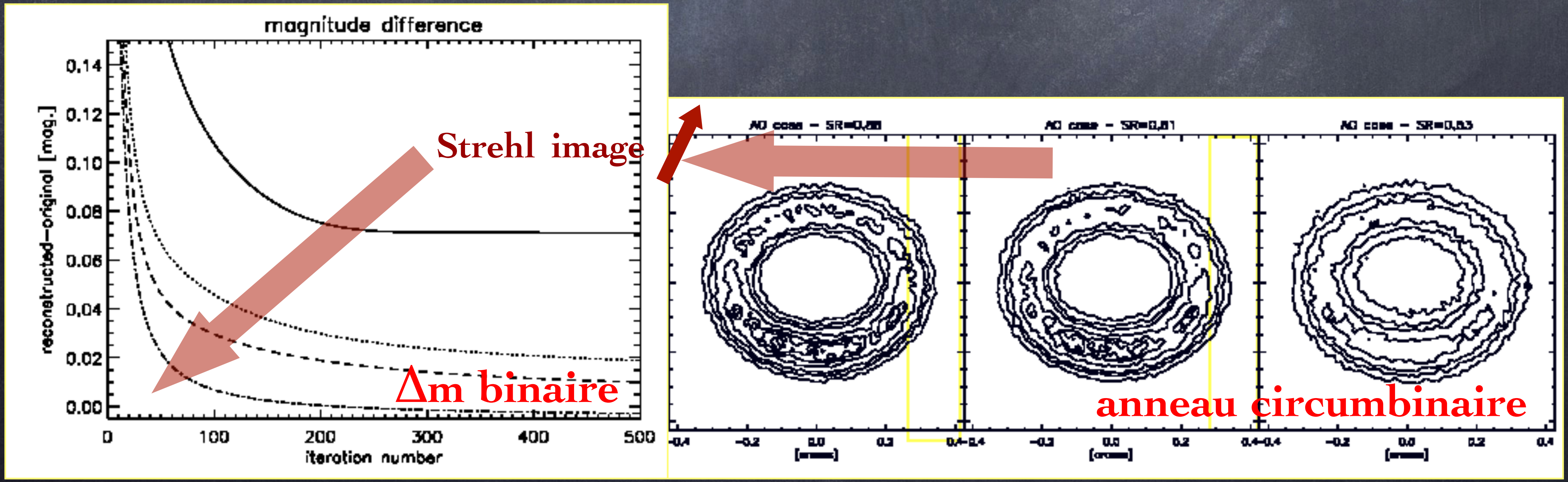
- Full-width at half-maximum (FWHM) when the main question is resolution
- Encircled energy (EE) for spectroscopy
- Other non-direct criteria, such as:
  . detection/SNR
  . quality of image reconstruction



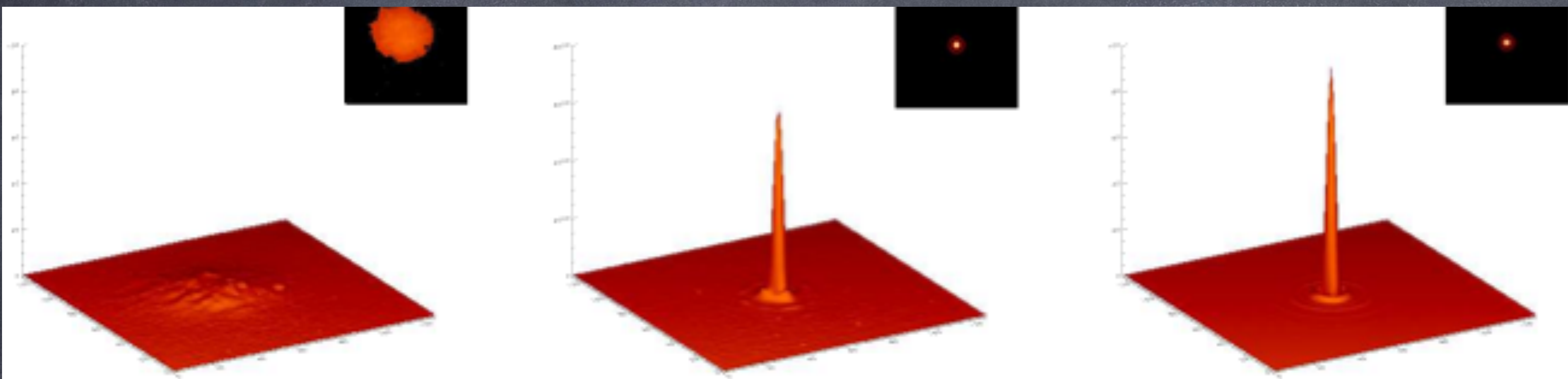
Quality of correction ? - 5



GGTau-type object: central binary + circumbinary ring



Post-AO PSF morphology - 1



no correction | corrected ($SR = 64\%$) | Airy pattern

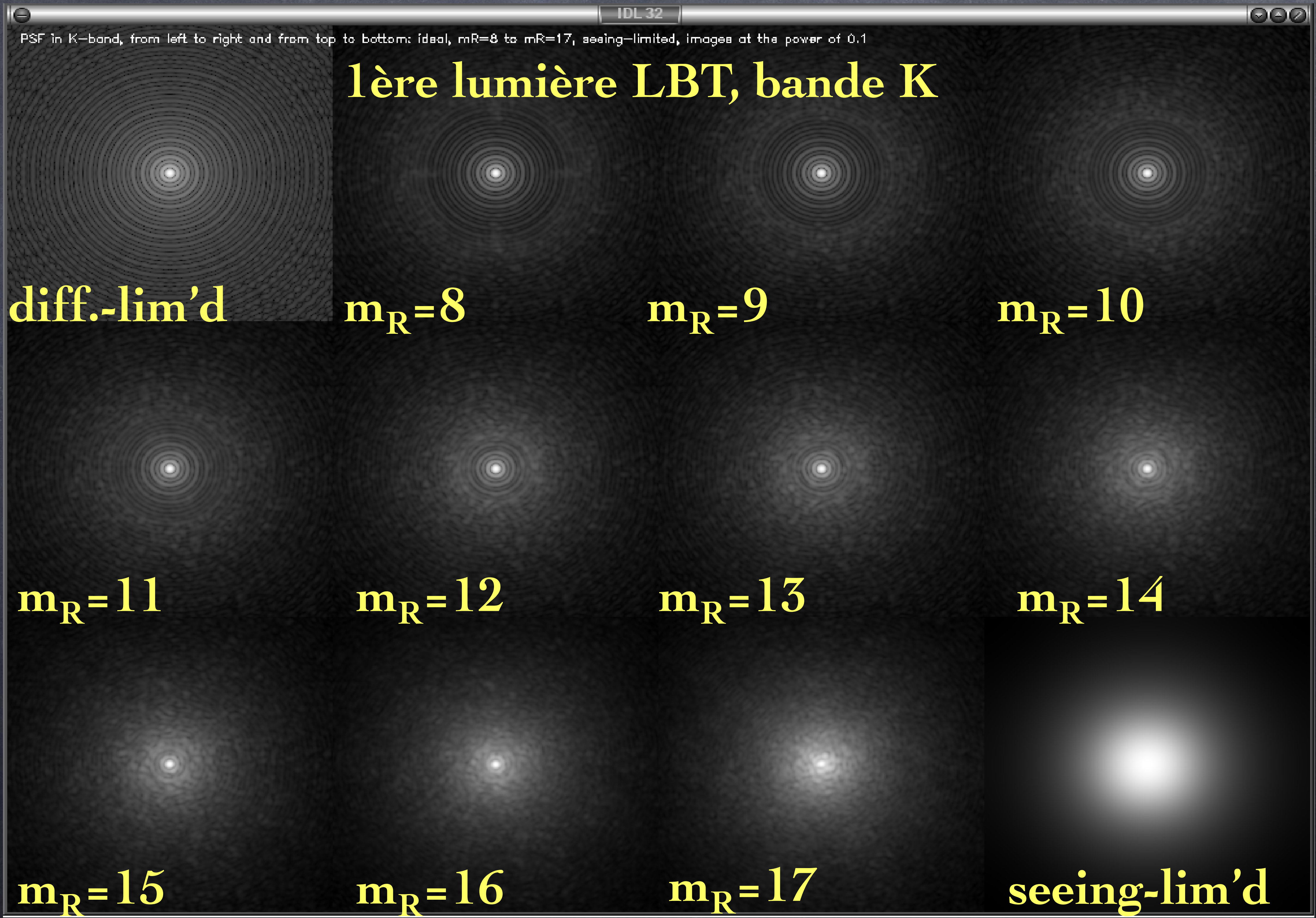
Imaging wavelength : $2.2\mu m$

Turbulence : $r_o = 1m$ à $2.2\mu m$, wind speed $= 10m/s$, telescope : $D = 8m$

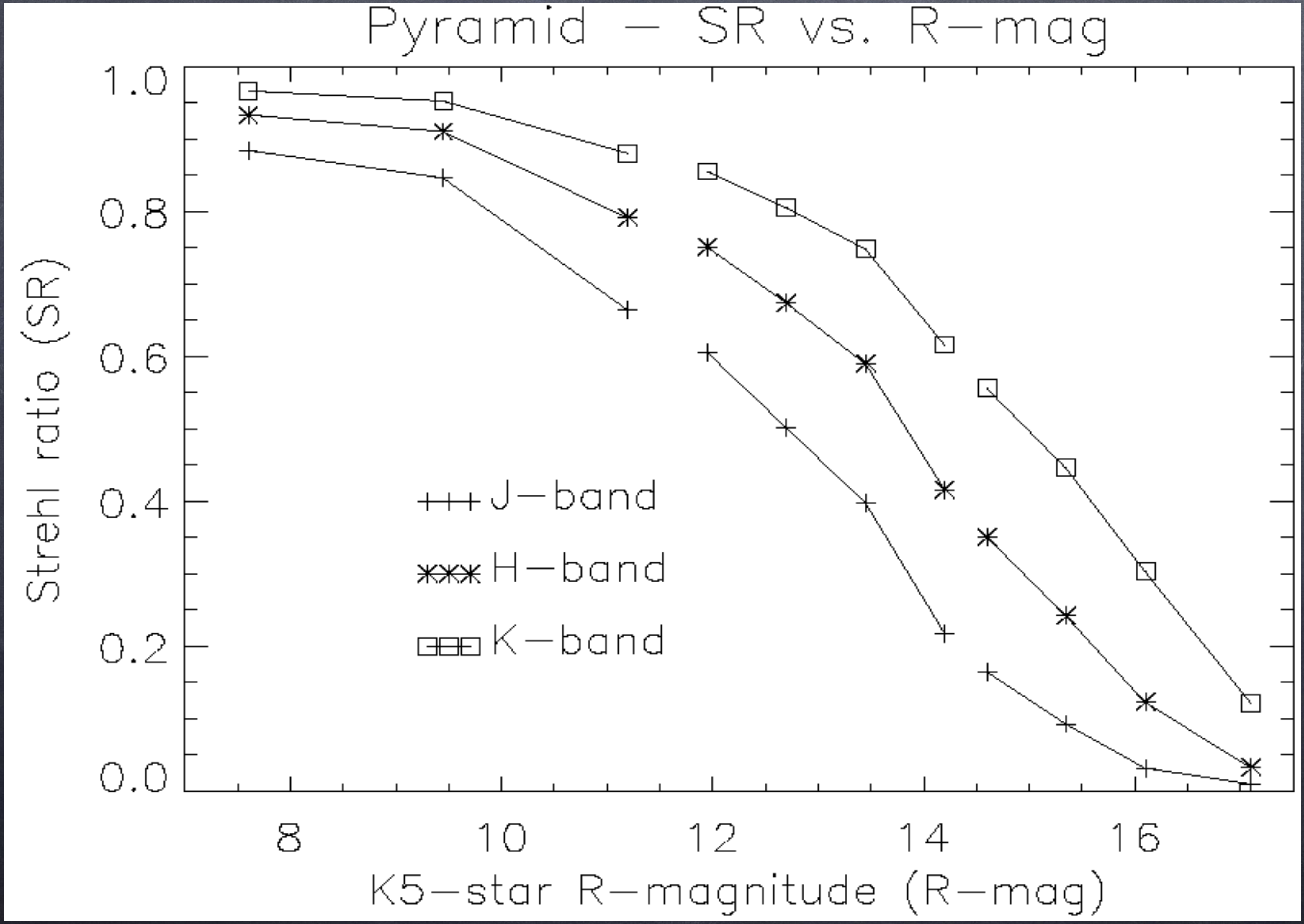
System (NAOS) : 144 sub-aperture, 185 actuators, $500Hz$ temporal sampling frequency

ONERA

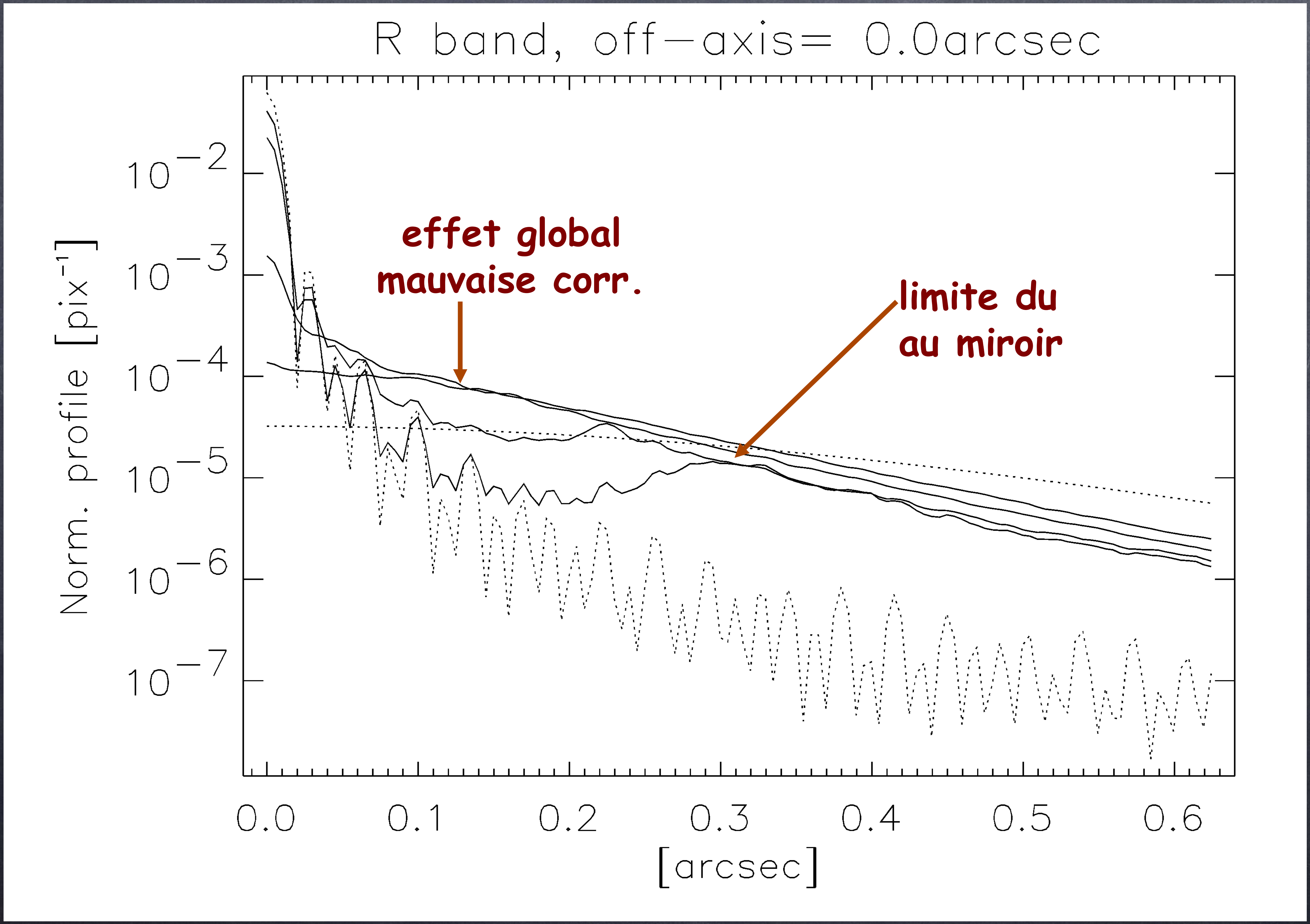
Post-AO PSF morphology - 2



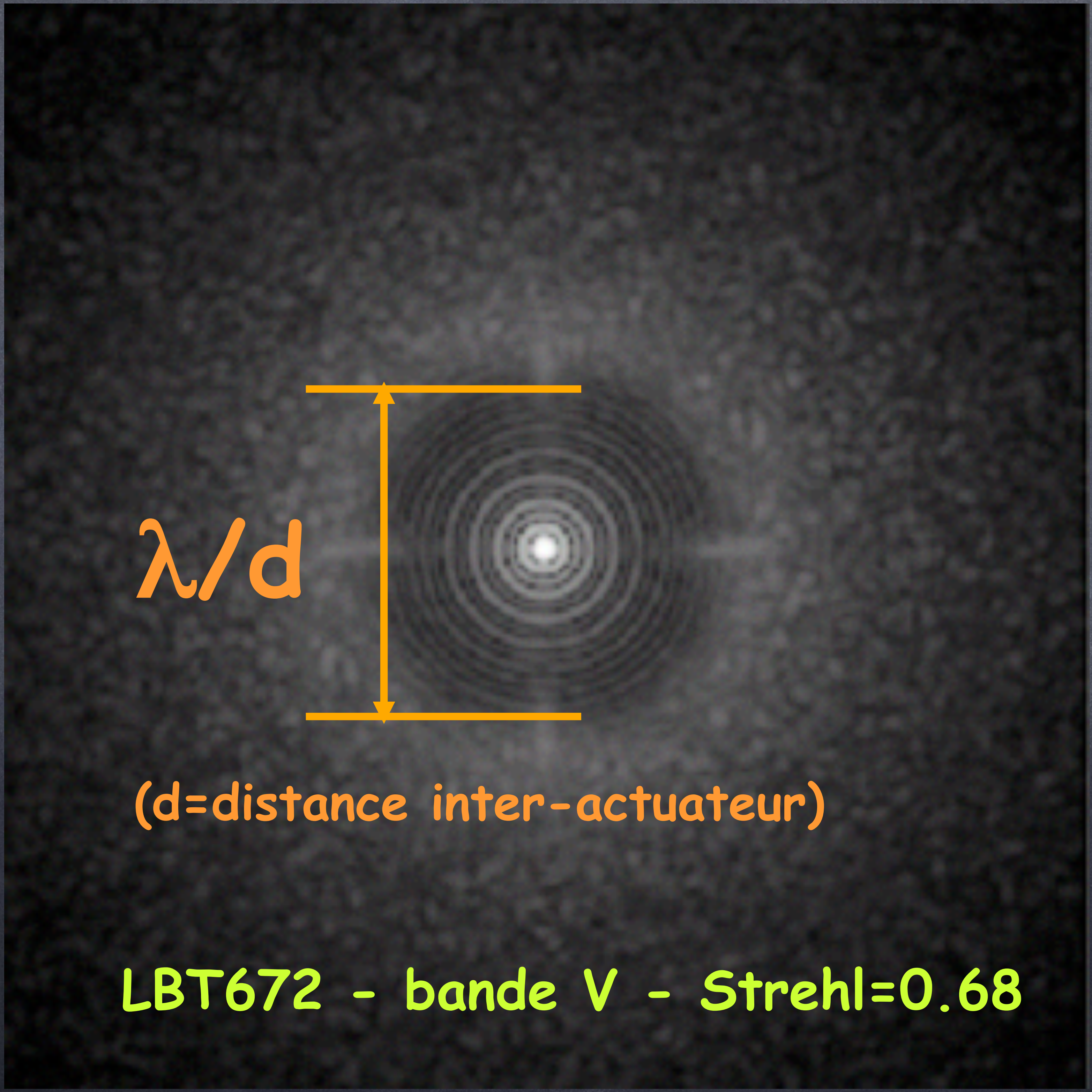
Post-AO PSF morphology - 3



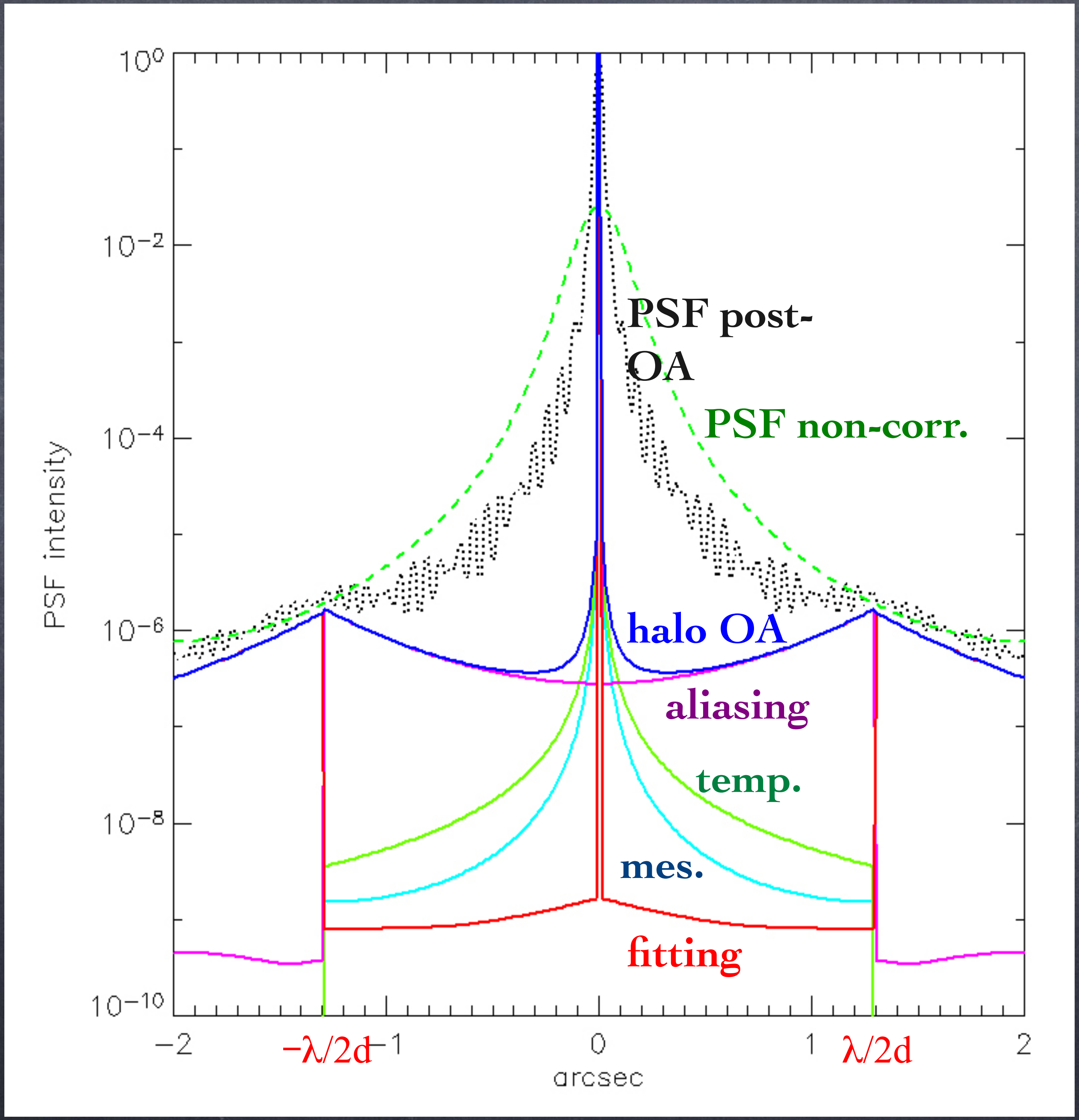
Post-AO PSF morphology - 4



Post-AO PSF morphology - 5

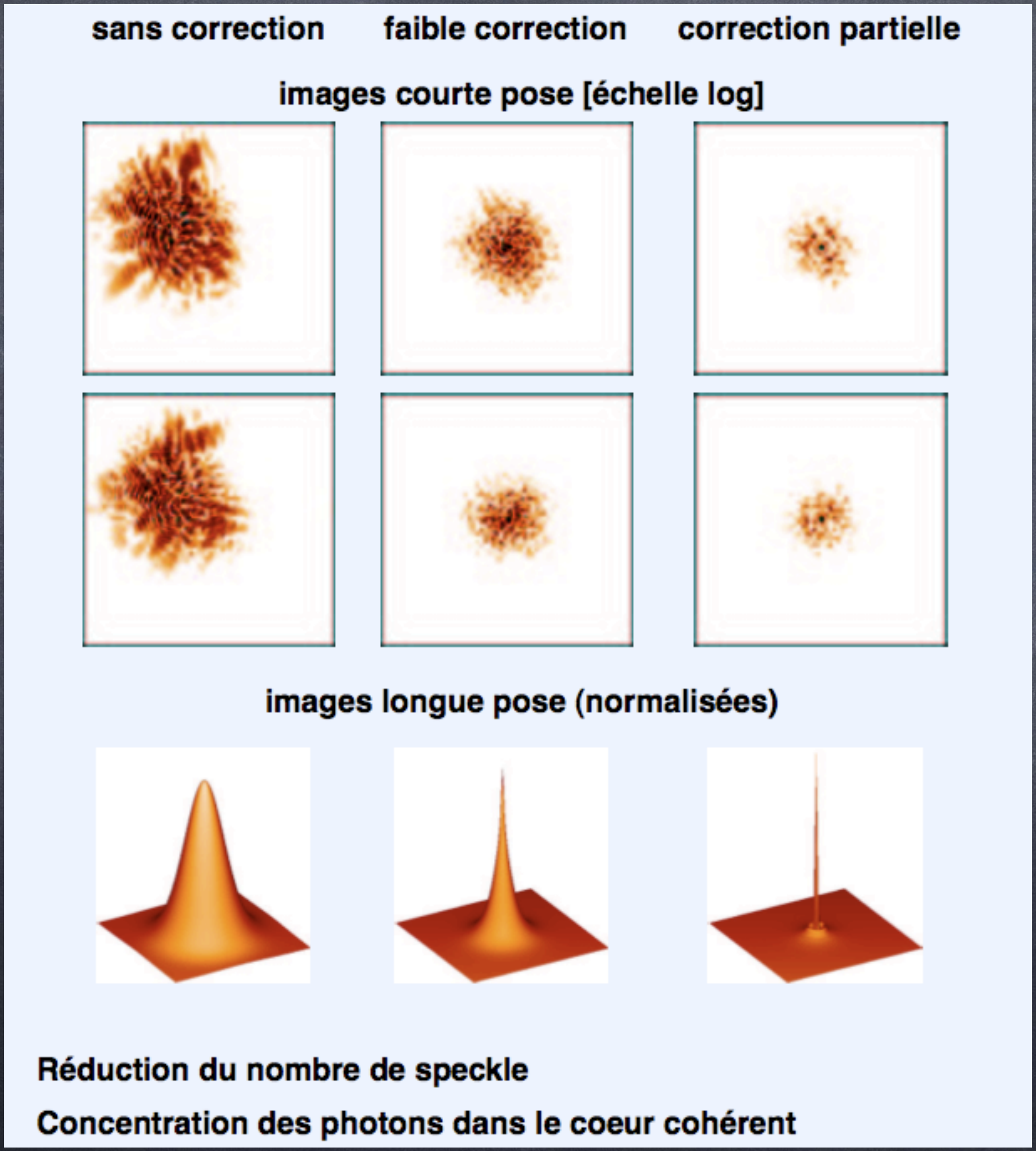


Post-AO PSF morphology - 6



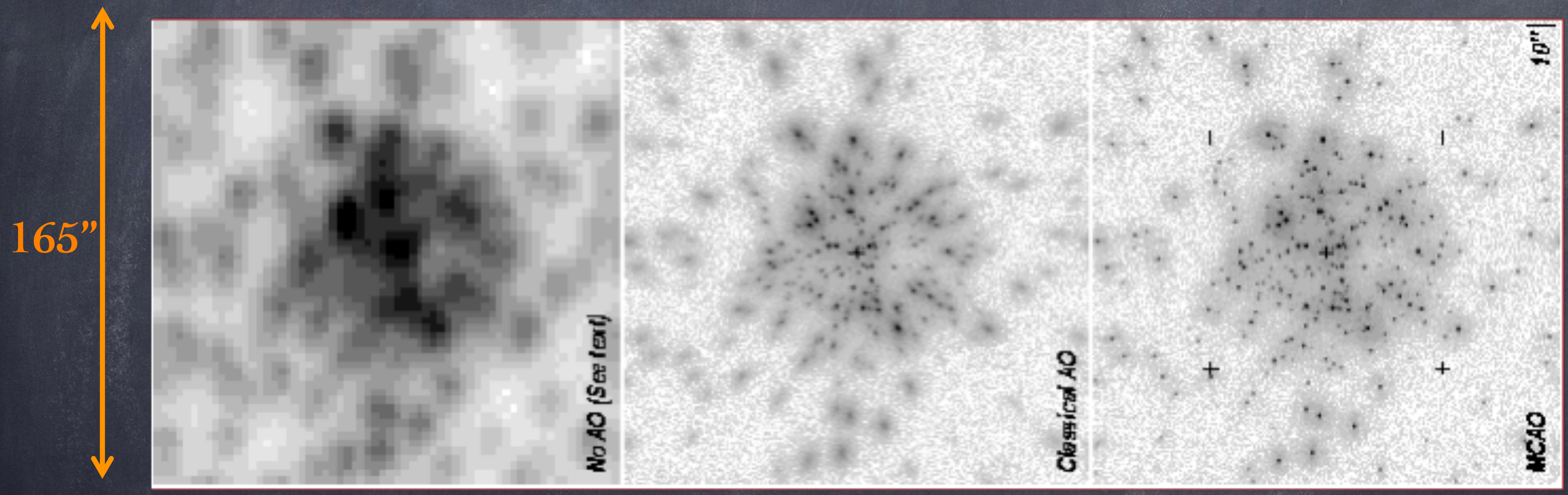
See also Jolissaint et al. (JOSAA, 2006) and Jolissaint (JEOS, 2010)

Post-AO PSF morphology - 7



Post-AO PSF morphology - 8

Wide-field AO case: anisoplanatism...

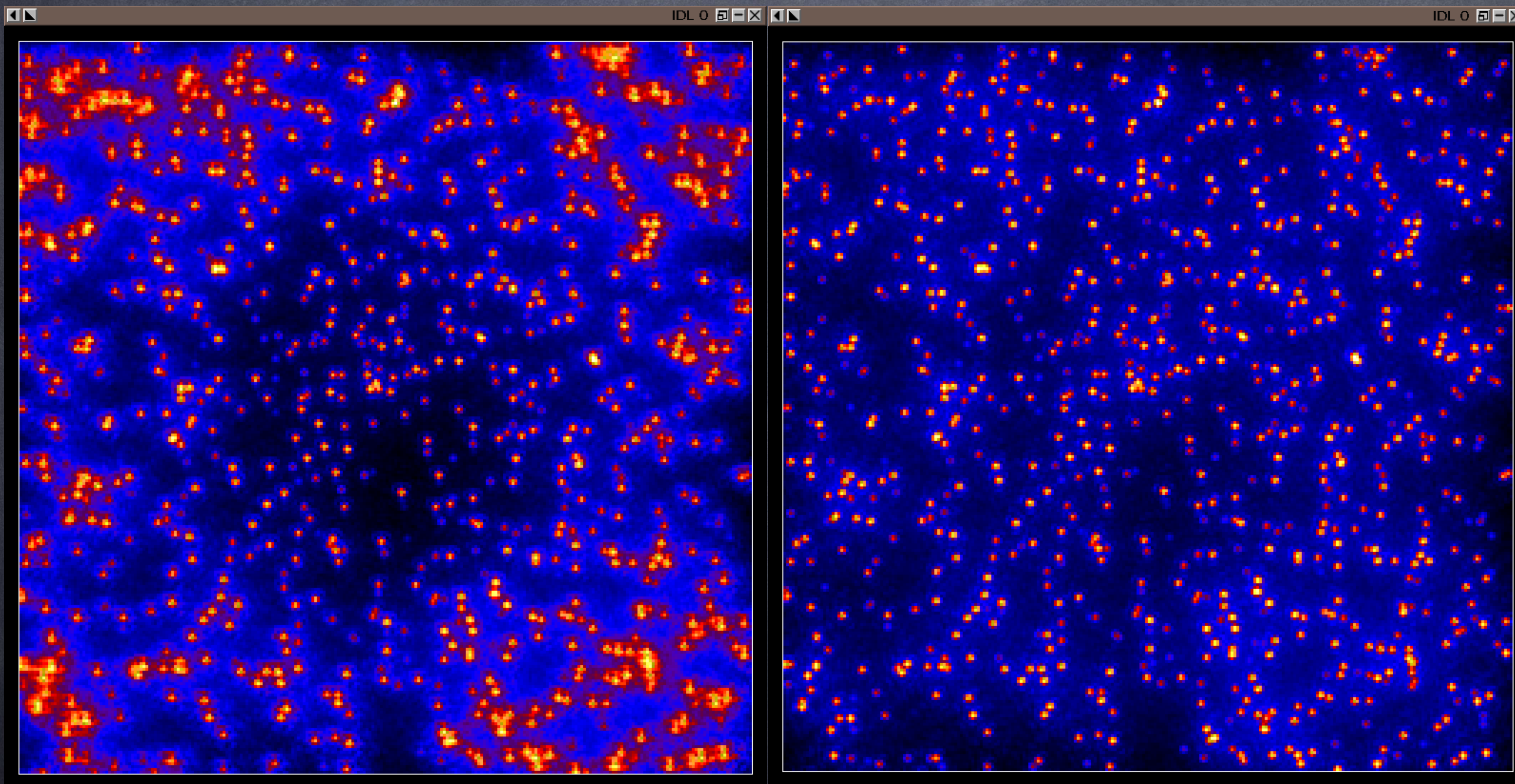


No AO

classical AO
(1 DM, 1 NGS)

MCAO
(2 DM, 5 NGS)

Post-AO PSF morphology - 9



(bande J, champ de 1', simu. B.Ellerbroek, Gemini Obs.)

Post-AO PSF morphology - 10