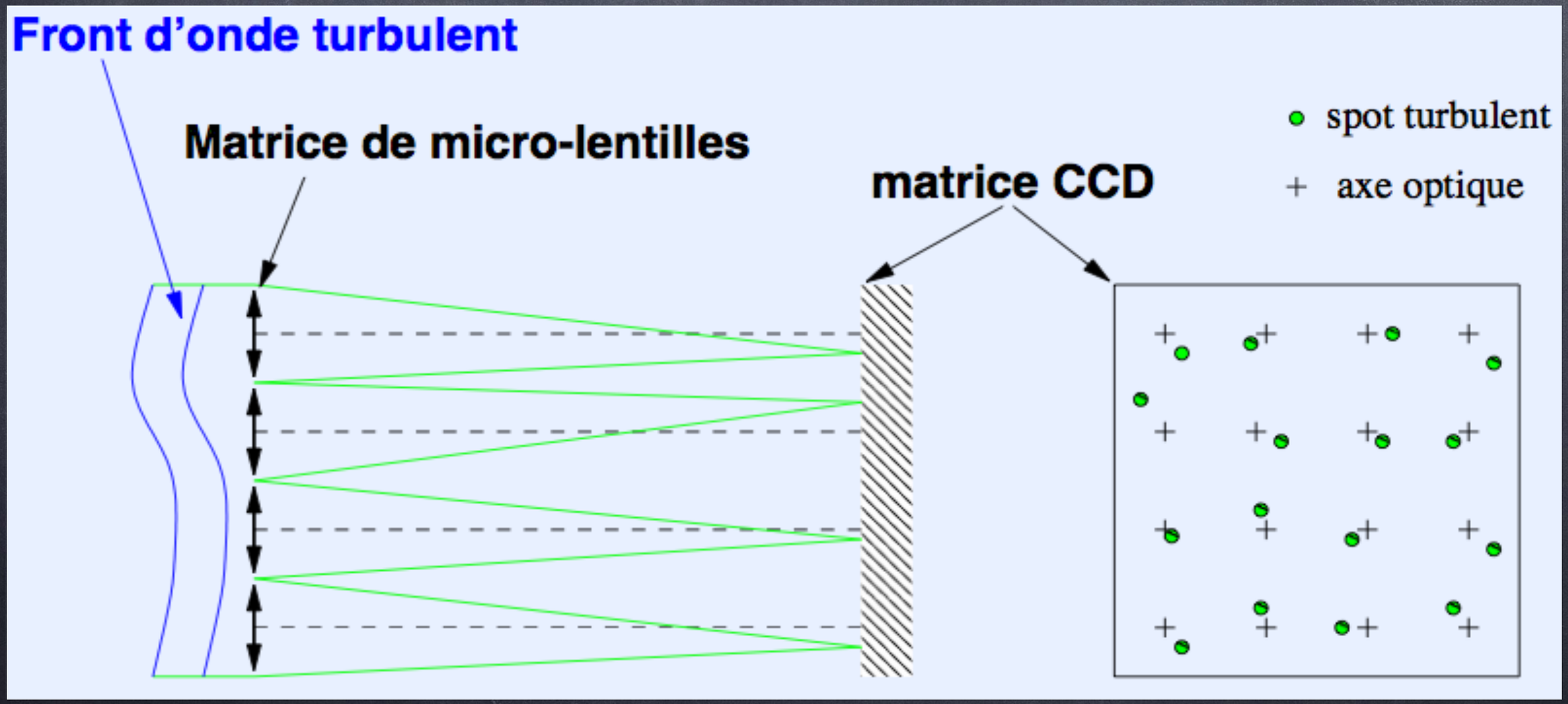
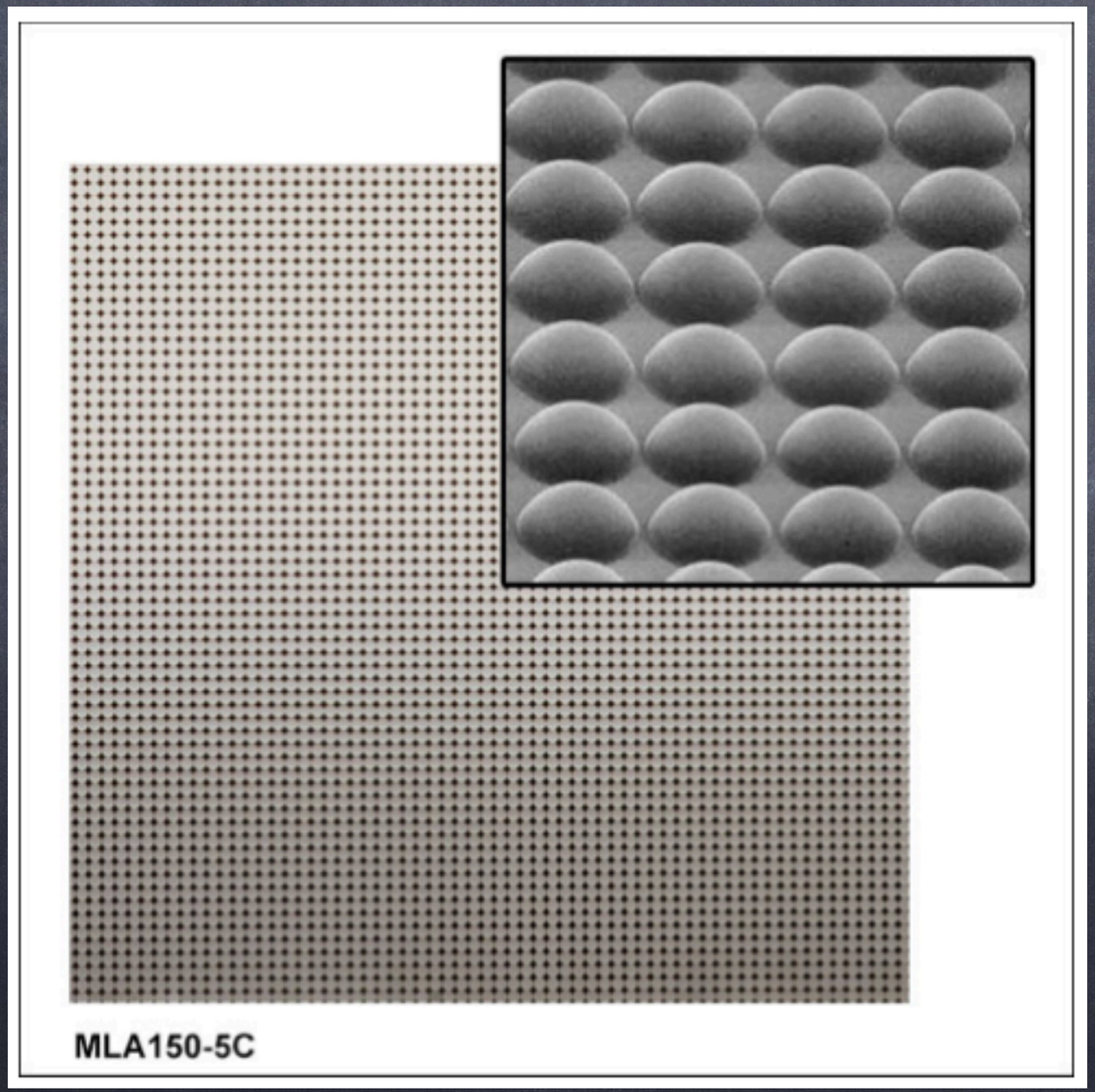
Wavefront sensors - 1

First example of wavefront sensor: Shack-Hartmann



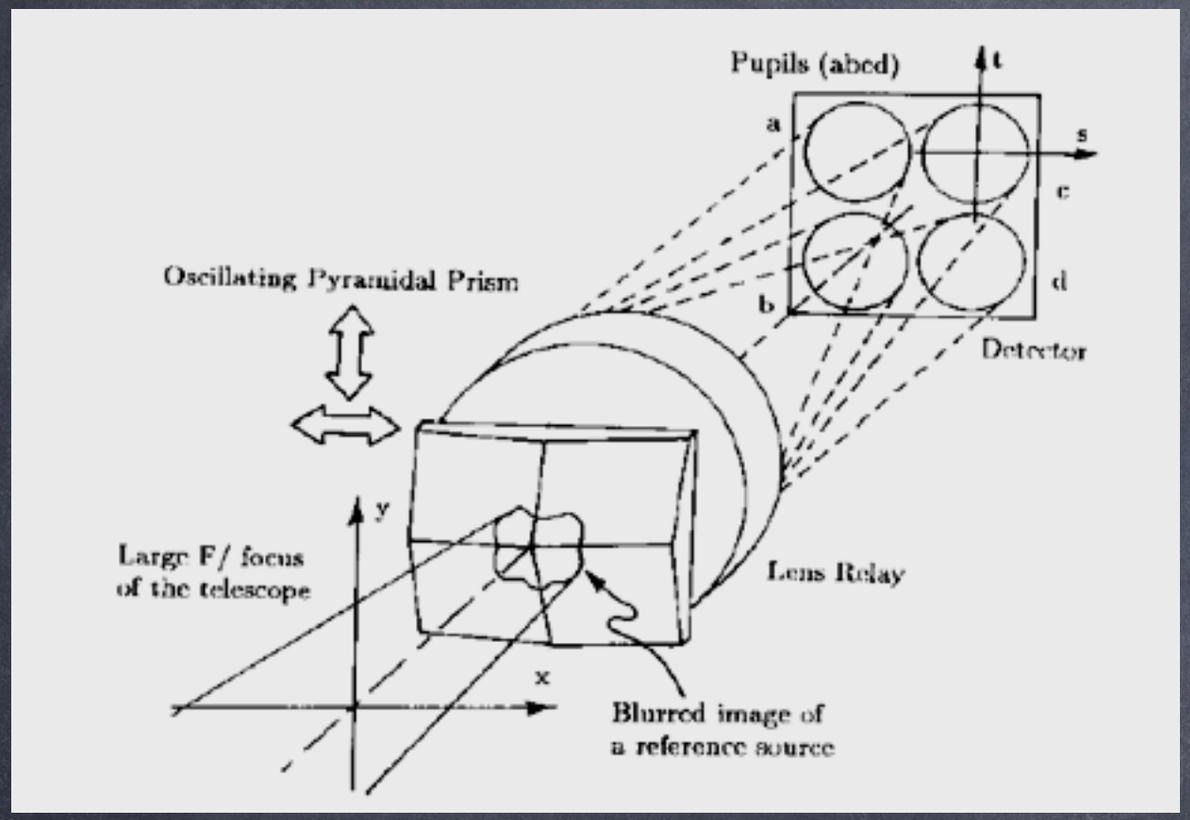
Wavefront sensors - 2

First example of wavefront sensor: Shack-Hartmann



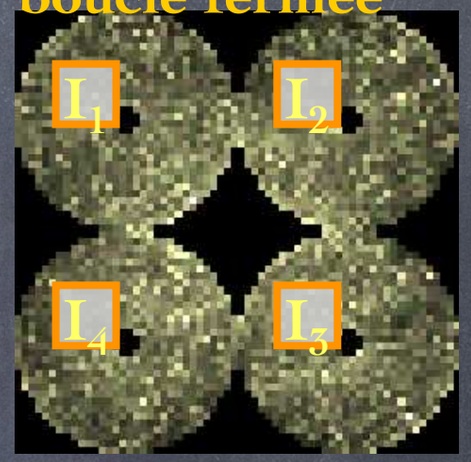
Wavefront sensors - 3

Another example: the Pyramid WFS



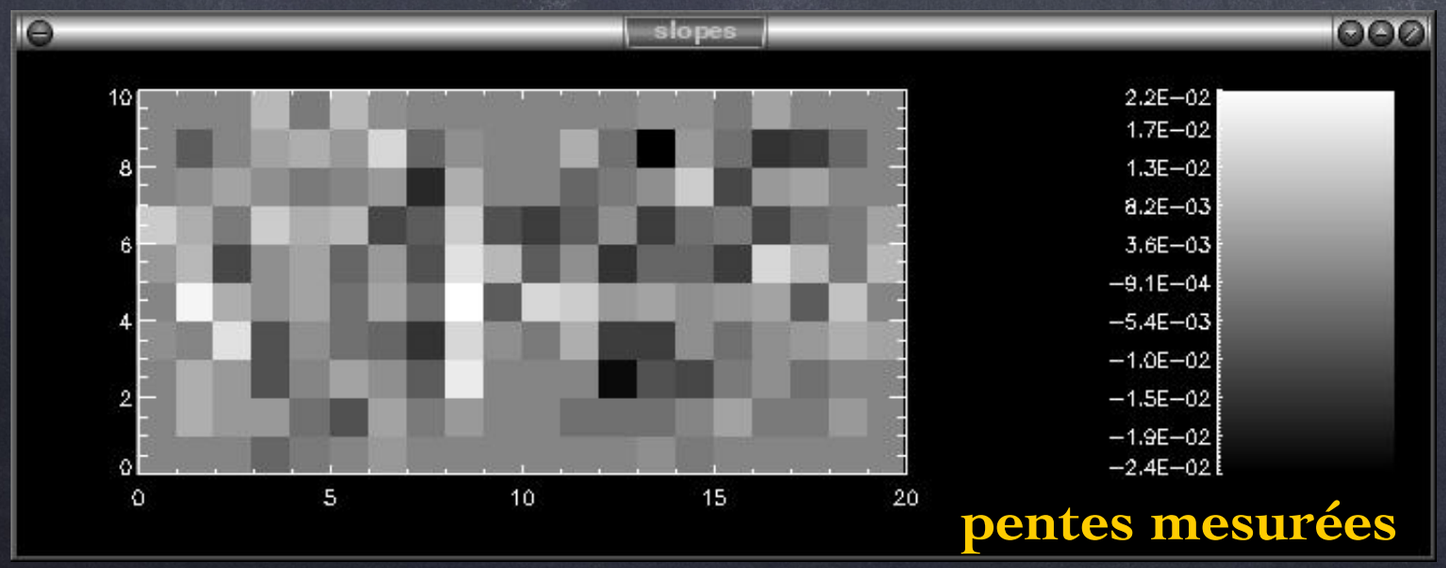
boucle ouverte

boucle fermée



$$S_x(x,y) = \frac{(I_1 + I_4) - (I_2 + I_3)}{\sum_i I_i}$$

$$S_y(x,y) = \frac{(I_1 + I_2) - (I_3 + I_4)}{\sum_i I_i}$$



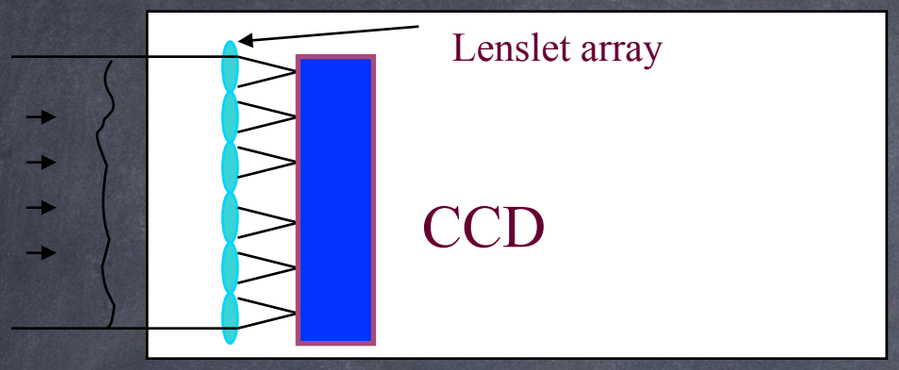
pentes mesurées

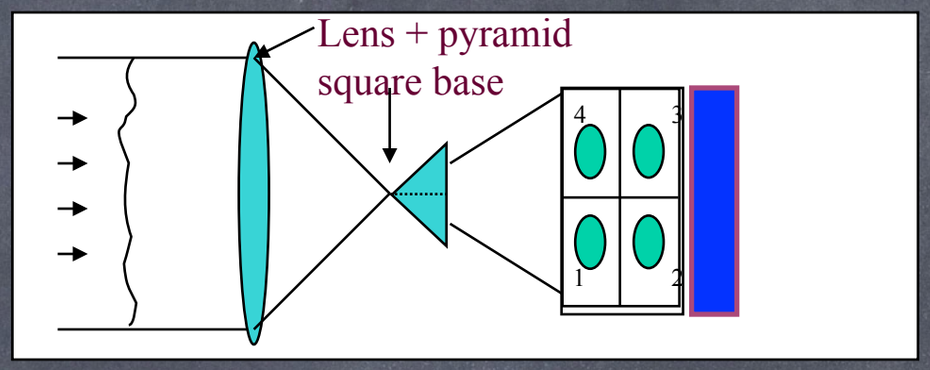
Wavefront sensors - 4

Another example: the Pyramid WFS

WH telescope's AO system

Wavefront sensors - 5





- SH: First on-sky AO results with COME-ON/VLT in 1989 [Rousset et al. 1990].
- Pyramid [Ragazzoni 1996], 2-*mag*. gain foreseen with respect to SH [Ragazzoni & Farinato 1999], confirmed by Monte-Carlo simulations [Esposito & Riccardi 2001].

Wavefront sensors - 6

Pyramid vs. Shack-Hartmann, 1st round

- Rousset et al., 1989-1990: 1st results of a SH WFS on sky on the VLT (COME-ON)
- Ragazzoni, 1995: proposal of a pyramid WFS
- Ragazzoni & Farinato, 1999: theoretical gain of 2 mag. (in limit mag.)
- Esposito & Riccardi, 2001: gain confirmed by numerical simulations (but: open-loop)
- Carbillet et al., 2003: gain in limit magnitude but alose in the bright-end (aliasing), from end-to-end simulations.

Wavefront sensors - 7

Pyramid vs. Shack-Hartmann, 2nd round

- Poyneer & Macintosh, 2004: spatial filtering of the SH WFS (lower aliasing error)
- Nicolle et al., 2004: optimized calculus of the SH signals (lower measure error)
- Fusco et al., 2005: spatial filtering+optimized calculus => SH at the level of the Pyramid (and less uncertainties on stability and robustness…)
- Vérinaud et al., 2005: Pyramid better close to optical axis, SH better far from it.

Wavefront sensors - 8

Pyramid vs. Shack-Hartmann, 2nd round

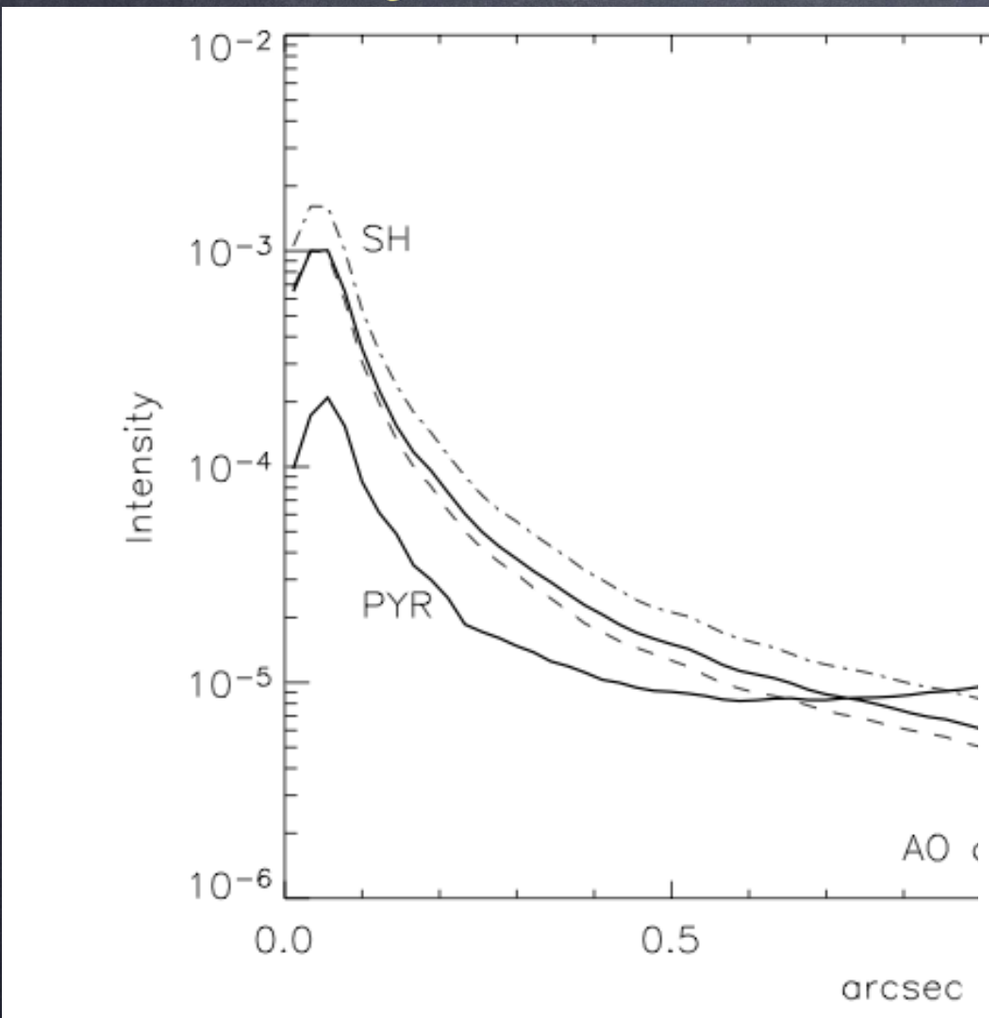


Figure 3. Circularly averaged residual halo (
20 photons per sub-aperture) for the SFSH
(SR = 0.946) and the PS (SR = 0.955) (soli
the WCOG, 20 photons per sub-aperture (dot
sub-aperture (dashed line).

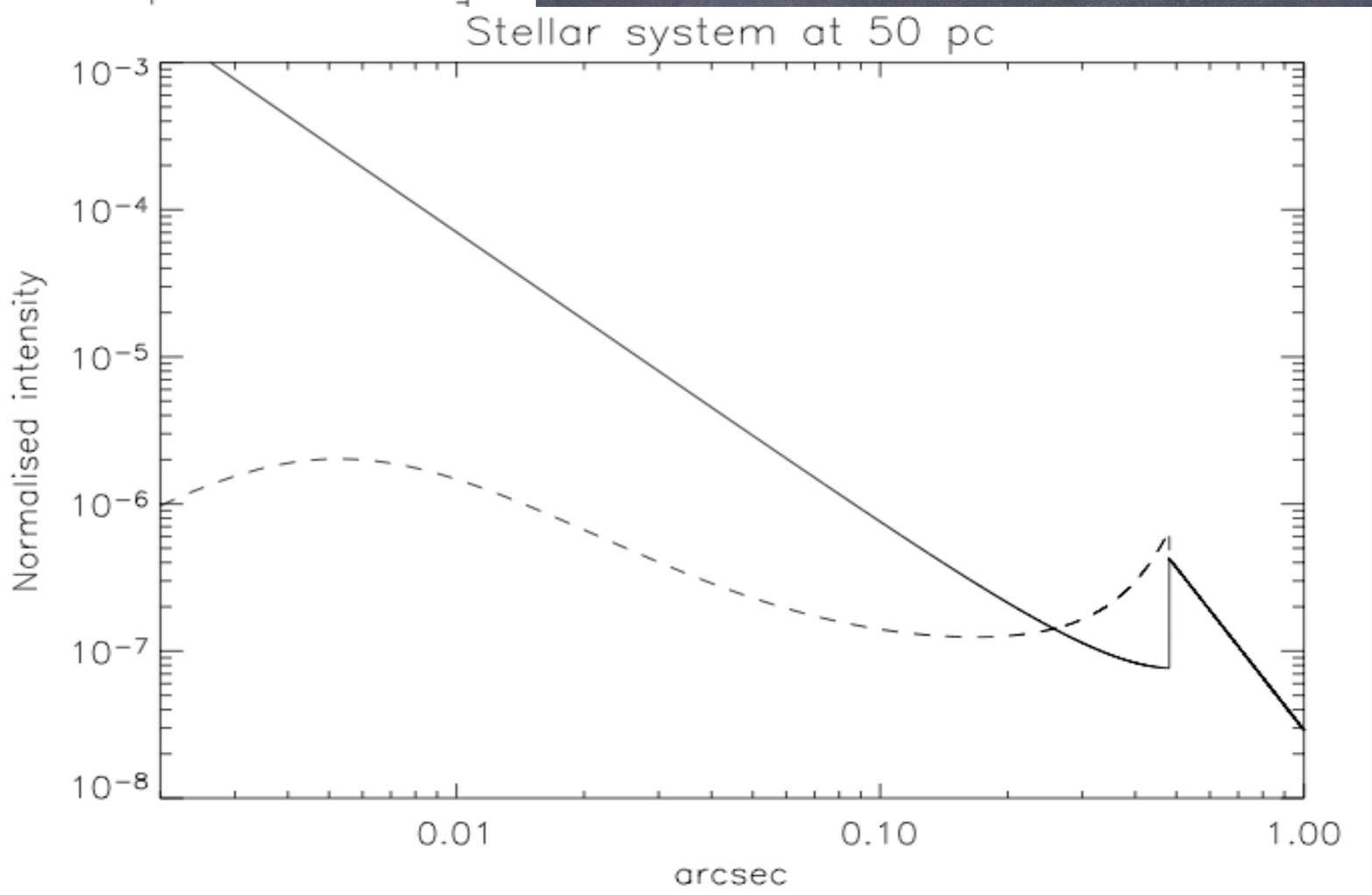


Figure 7. Residual halo in the *R* band for a SFSH-based system (solid line, SR = 0.79) and a PS-based system (dashed line, SR = 0.81) with a 15-cm actuator pitch on a 100-m telescope. The guide star *V* magnitude is 8.2, seeing = 0.7 arcsec, τ_0 = 3 ms, frame rate = 4 kHz.

Wavefront sensors - 9

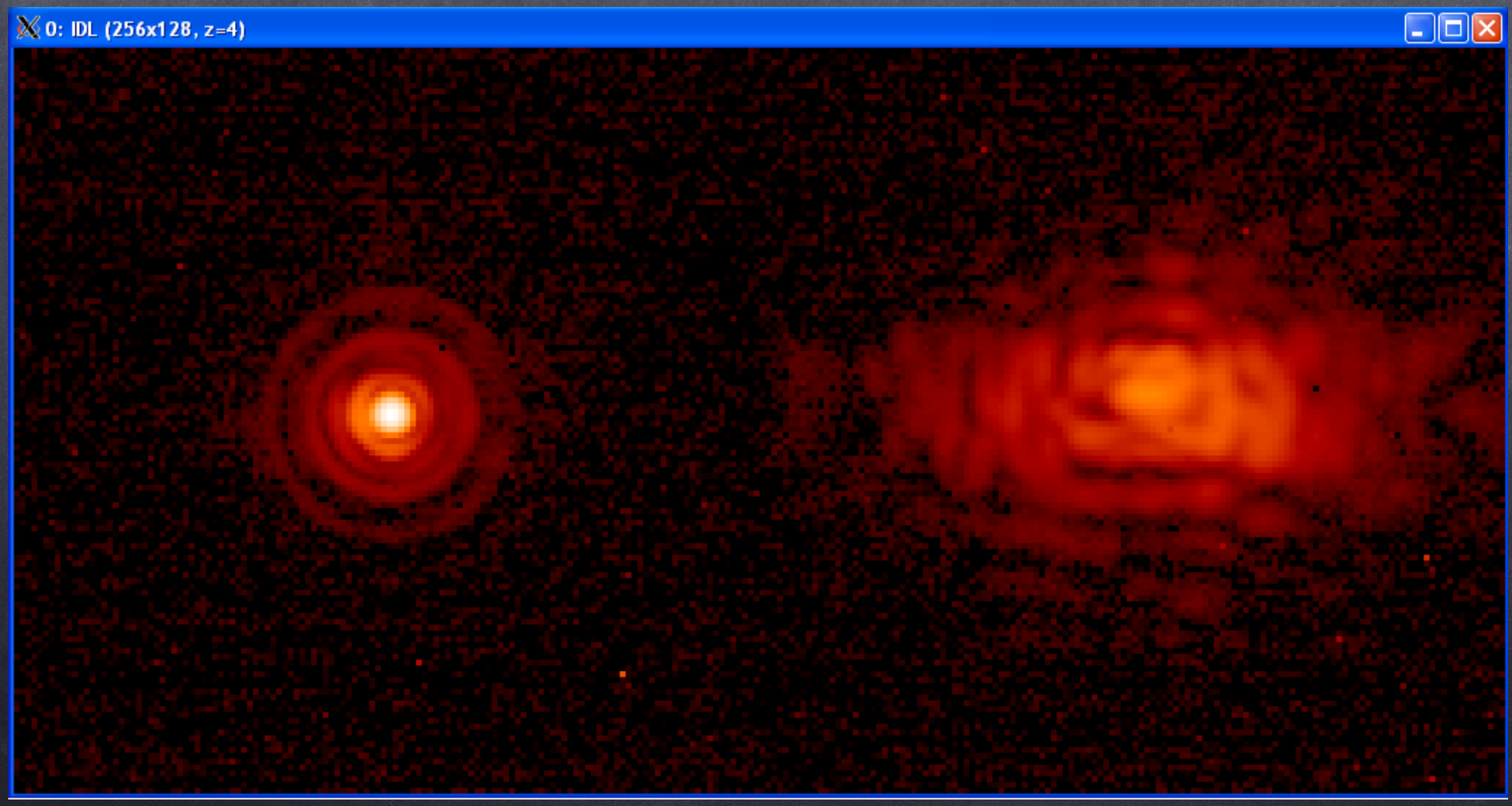
Pyramid vs. Shack-Hartmann, 3rd round

Press release (may/june 2010): LBT achieves breakthrough with adaptive optics ! (http://oldweb.lbto.org/AO/AOpressrelease.htm)

Wavefront sensors - 10

Pyramid vs. Shack-Hartmann, 4th round

(2014)

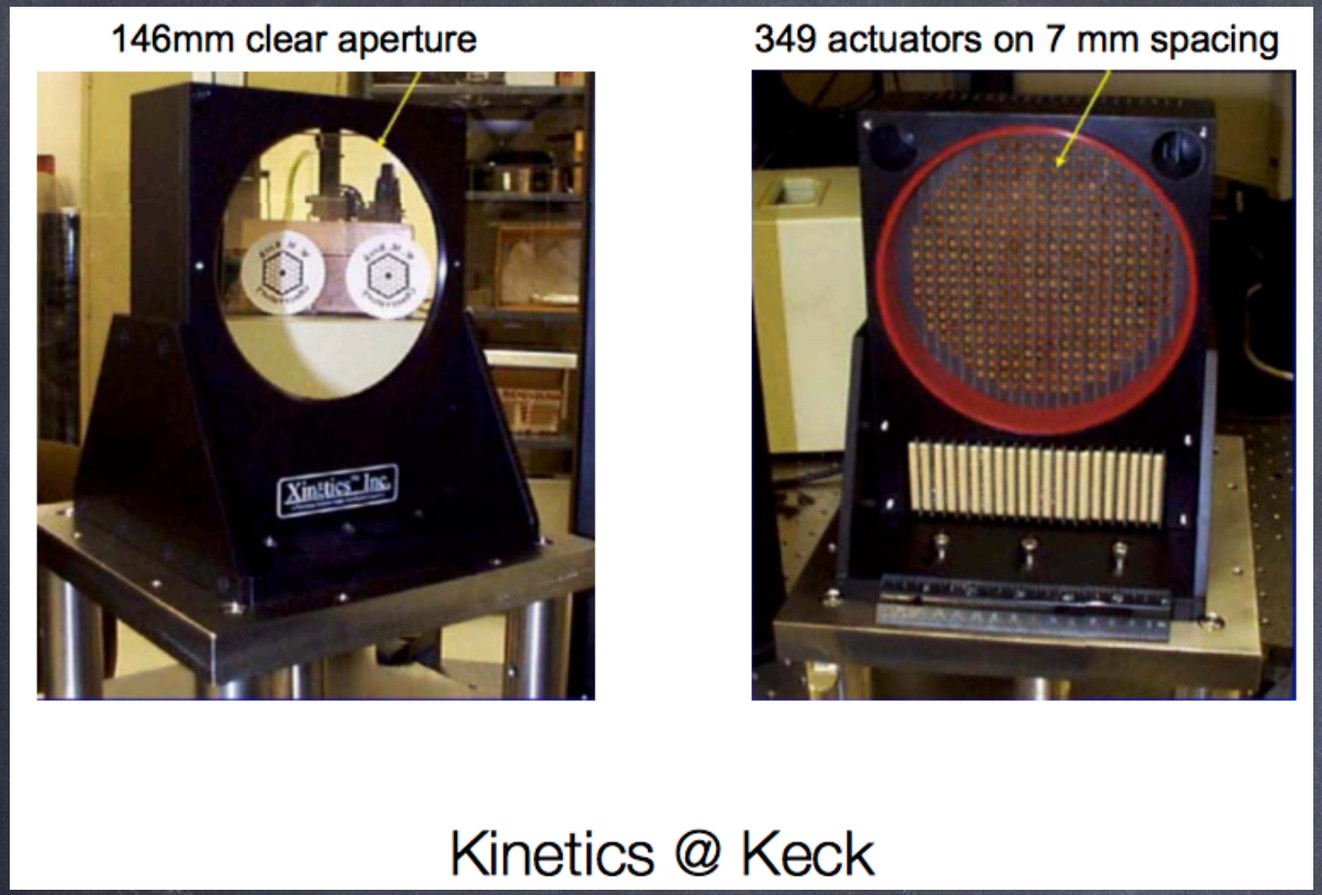


Deformable mirrors - 1

- Different technologies for DMs:
  - piezo-stacked arrays
  - piezo-electric bimorph mirrors
  - MEMS
  - voice-coil adaptive secondary mirrors (ASM)

- Different coefficients for the fitting error, different strokes, different possible bandwidths, different possible number of actuators, possible hysteresis, etc.

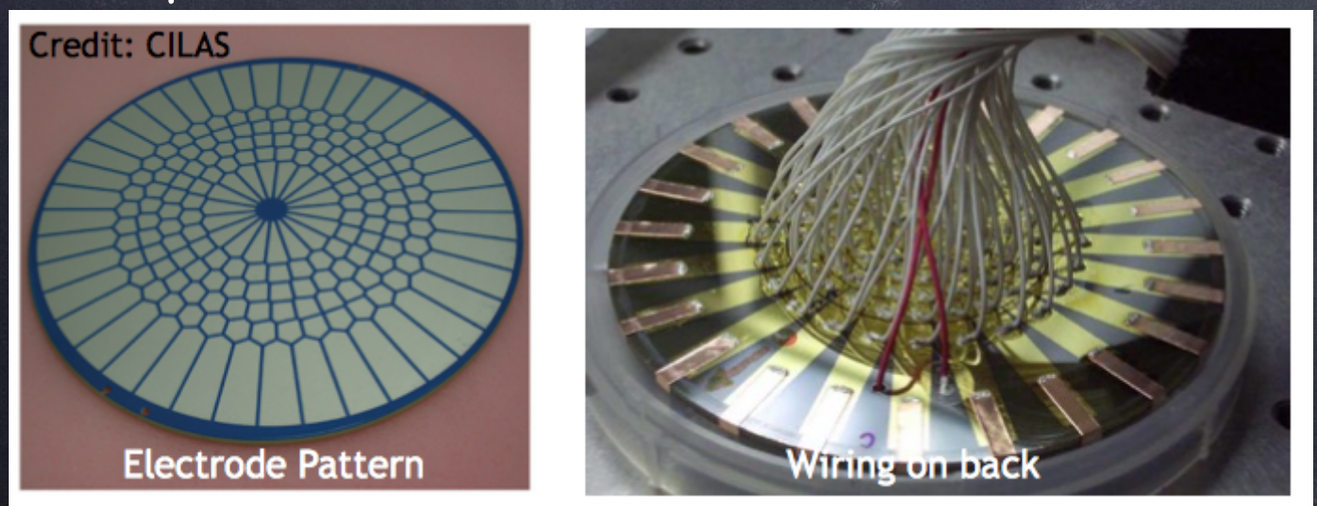
Deformable mirrors - 2

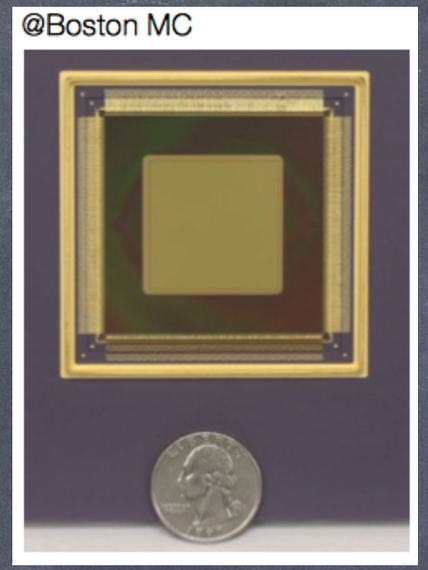


Kinetics @ Keck

Piezo-stacked array

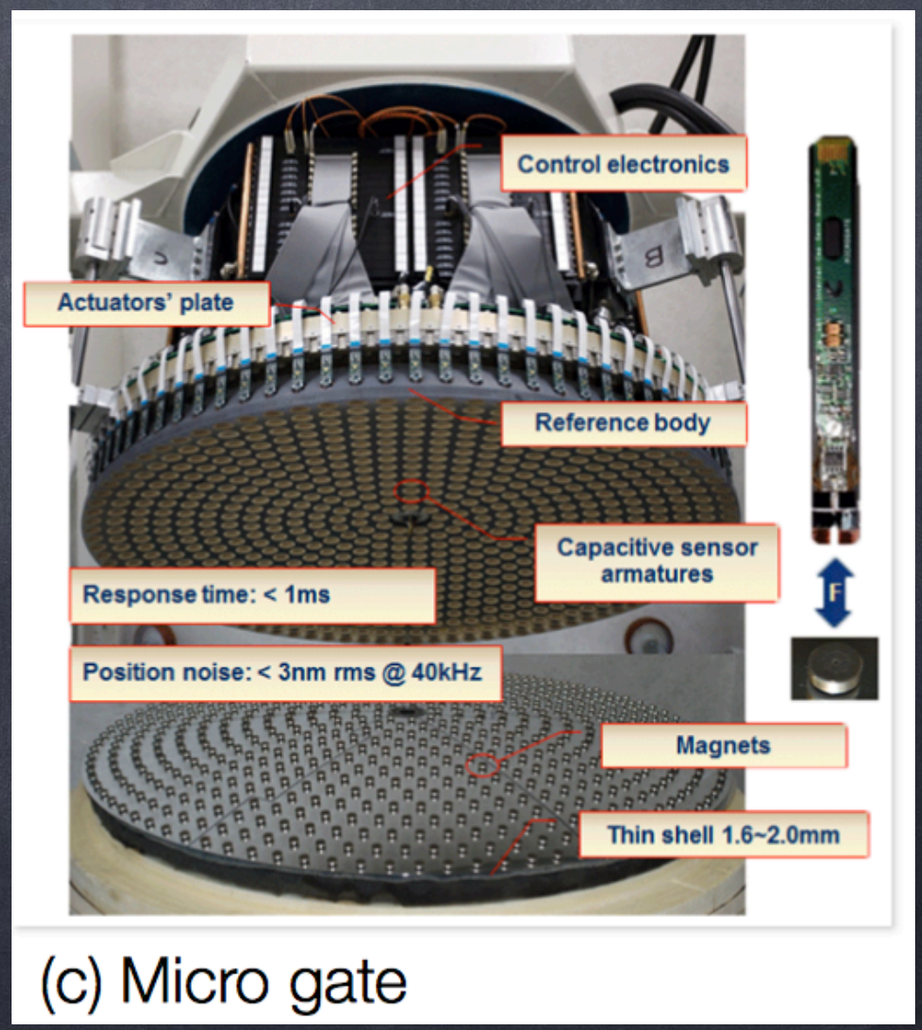
Bimorph





MEMS

Voice-coil
('adaptive secondary')



(c) Micro gate

Deformable mirrors - 3

- Different coefficients for the fitting error:

- Is the stroke enough ?
  If not: necessity to add a tip-tilt mirror…

Deformable mirrors - 4

- **How many actuators for a given Strehl ratio ? (considering a coeff. 0.3 for the fitting error)**

$$\sigma^2_{\text{fit.}} = 0.3 \left(\frac{d_{\text{act.}}}{r_0} \right)^{\frac{5}{3}}$$

$$S_{\max} = \exp\left(-\sigma^2_{\text{fit.}}\right)$$

- **if d = r_0 , then: S_{max}=exp(-0.3) ~ 0.74**
  if d = r_0/2, then: S_{max}=exp(-0.3/$2^{5/3}$) ~ 0.91

Deformable mirrors - 5

- **Influence functions => mirror modes**

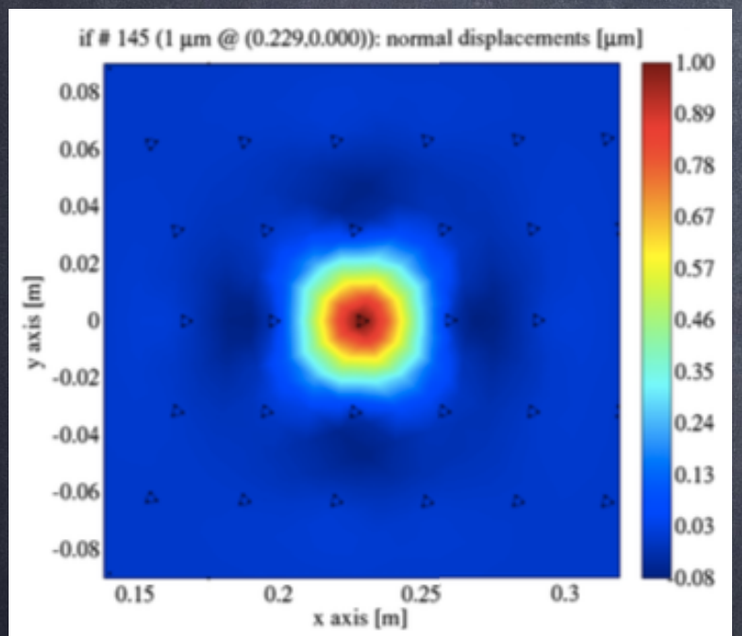
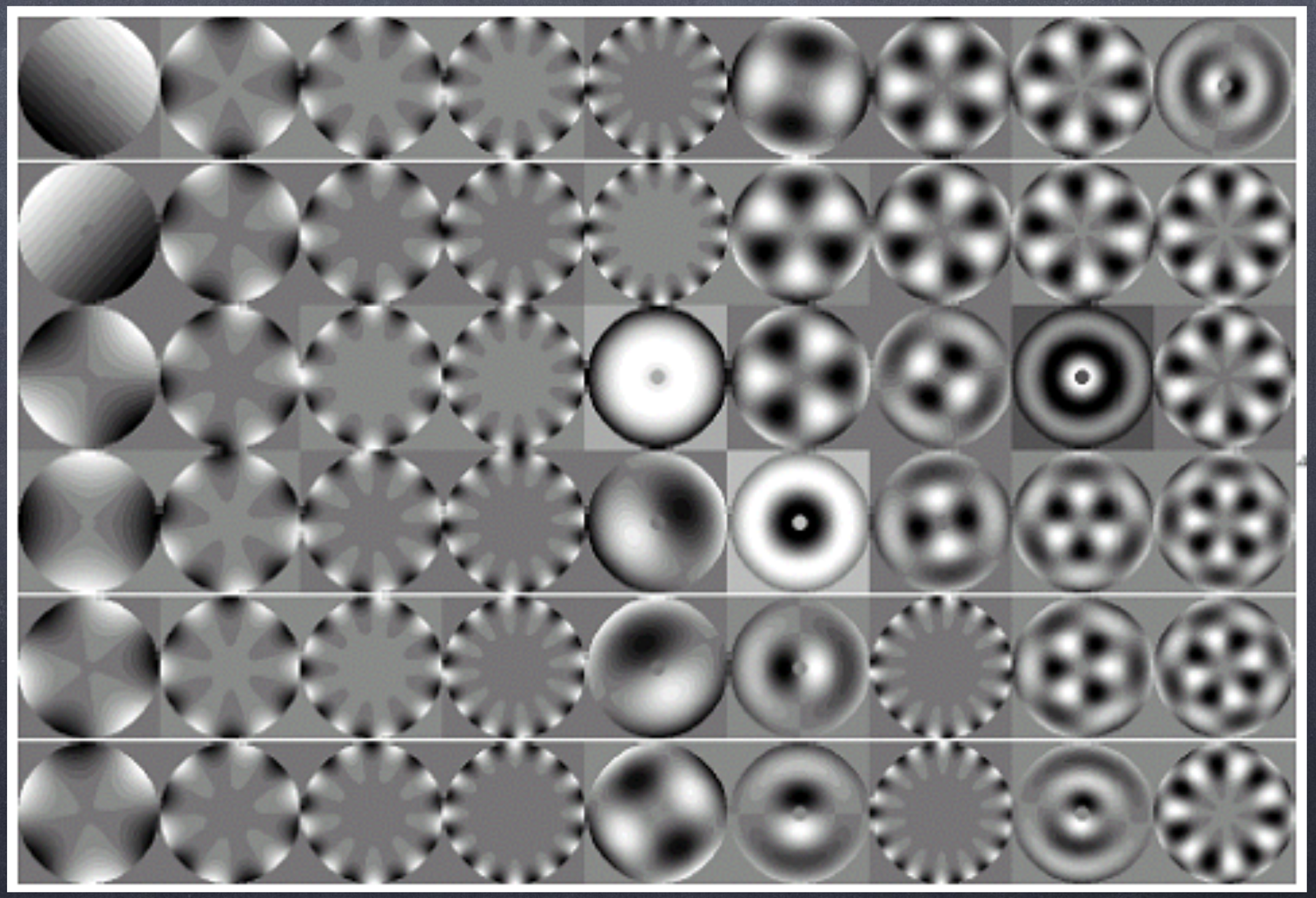


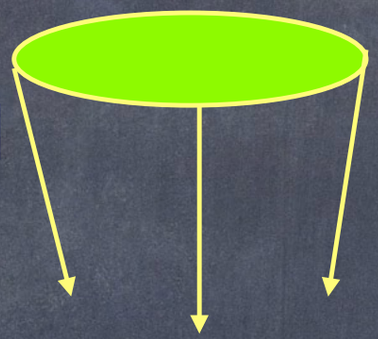
Figure 5: LBT DM: displacement normal to the surface when the actuator #145 is displaced by $w^* = 1\,\mu\text{m}$.



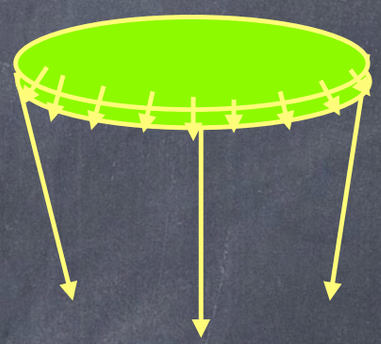
Deformable mirrors - 6

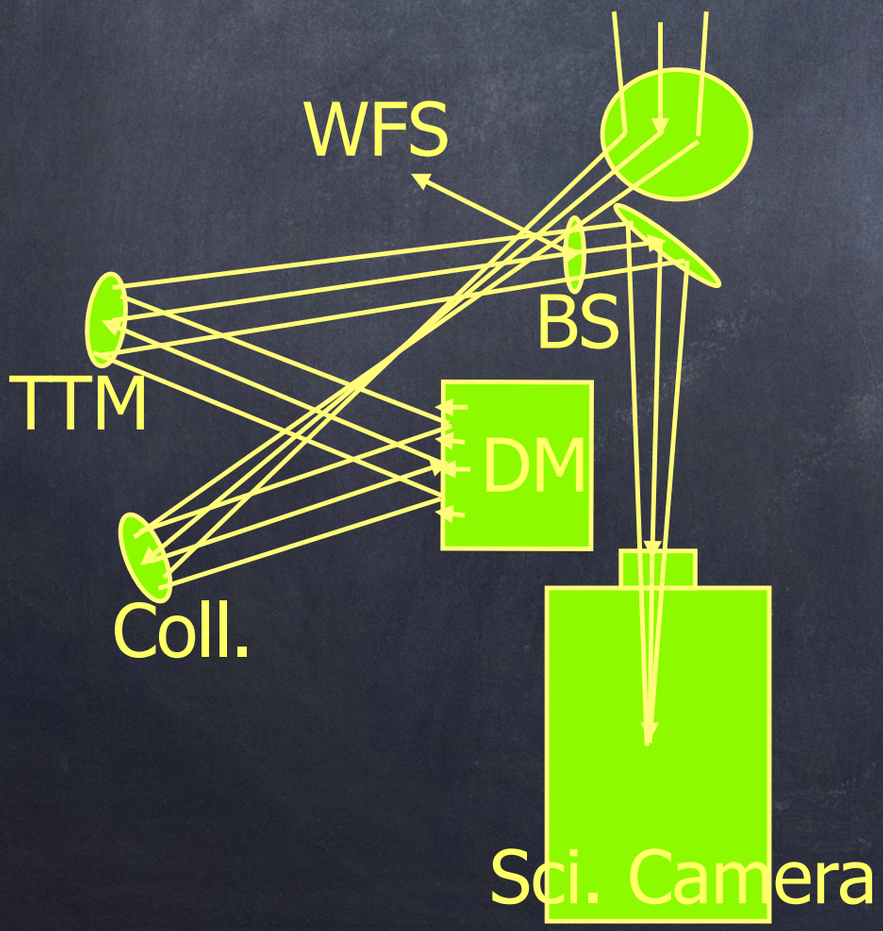
- **An interesting case: the ASM for LBT…**

Conventional Secondary



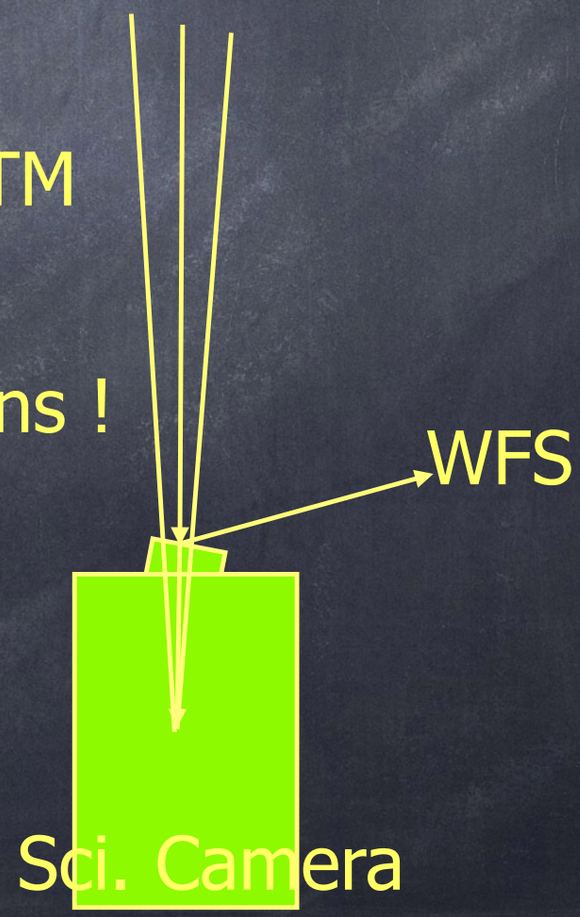
Adaptive Secondary





Mieux pour l'IR,
Pas besoin de TTM

Plus de photons !



Reconstruction & control of the commands - 1

Reconstruction	Contrôle
Inverse généralisée (SVD tronquée) → matrice d'interaction	Intégrateur (ou autre filtrage temp.) → déf. du filtre, déf. des gains/mode
MAP (Fusco 2001) → + coeff. bruit, var./covar. spat.	Idem
OMGI (Gendron & Léna 1994) → matrice d'int., coeff. bruit/mode, DS de la phase/mode (débruitée)	
OMGI alternatif (Dessenes 1998) → matrice d'int., DS de la phase/mode (bruitée)… + ajustement de la DS !	
Kalman (éq. MAP en boucle fermée - Le Roux et al. 2004) → matrice d'interaction, coeff. bruit, var./covar. spatio-temp.	

Pure integrator case:

$$s(t) = g\left(s(t-\Delta t) + \frac{\Delta t}{2}e(t-\Delta t) + \frac{\Delta t}{2}e(t)\right)$$

Reconstruction & control of the commands - 2

matrice d'interaction

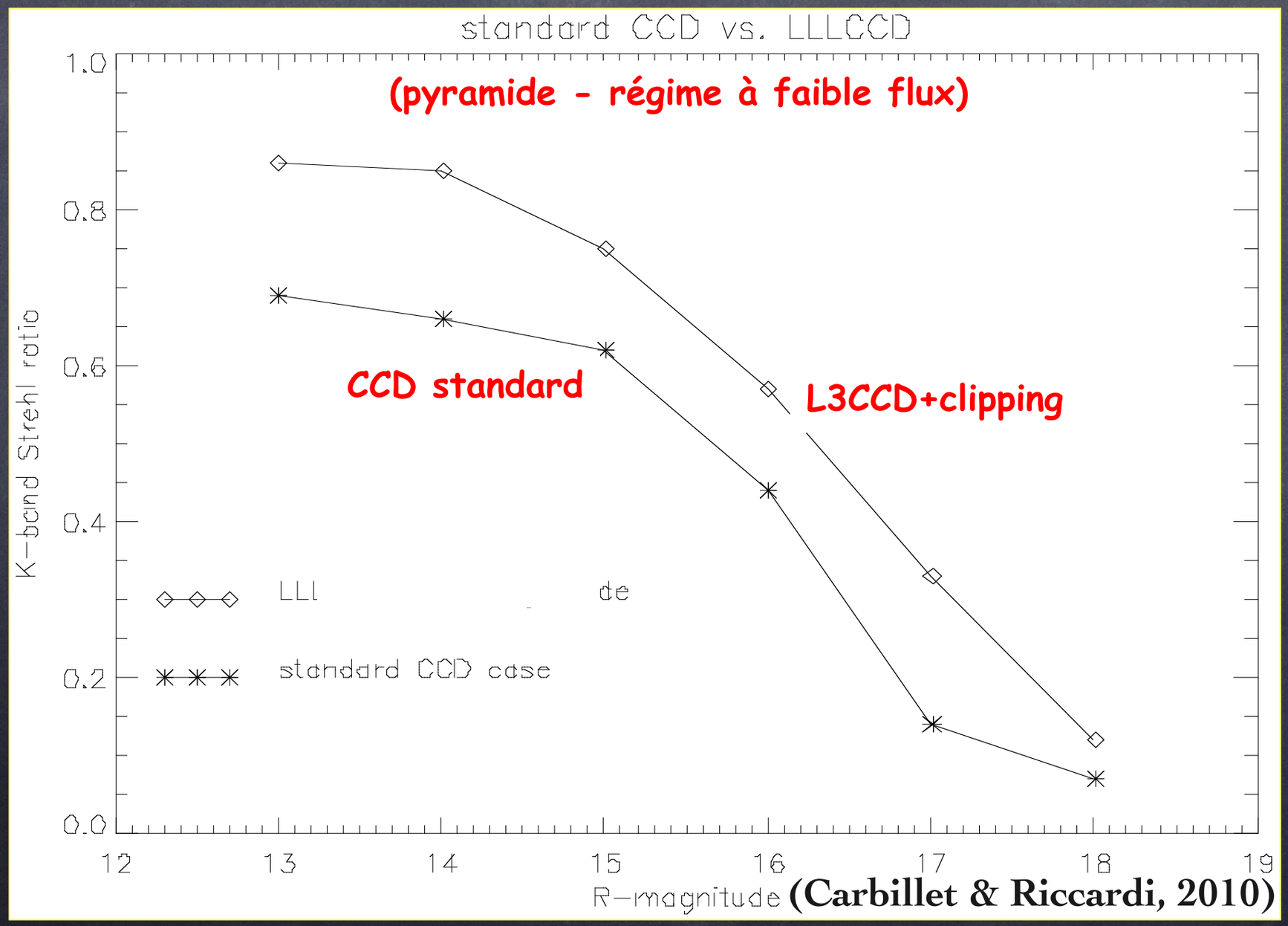
671 modes du miroir

1372 pentes (en x et en y)

The truncated SVD case

Are other improvements possible ? - Examples - 1

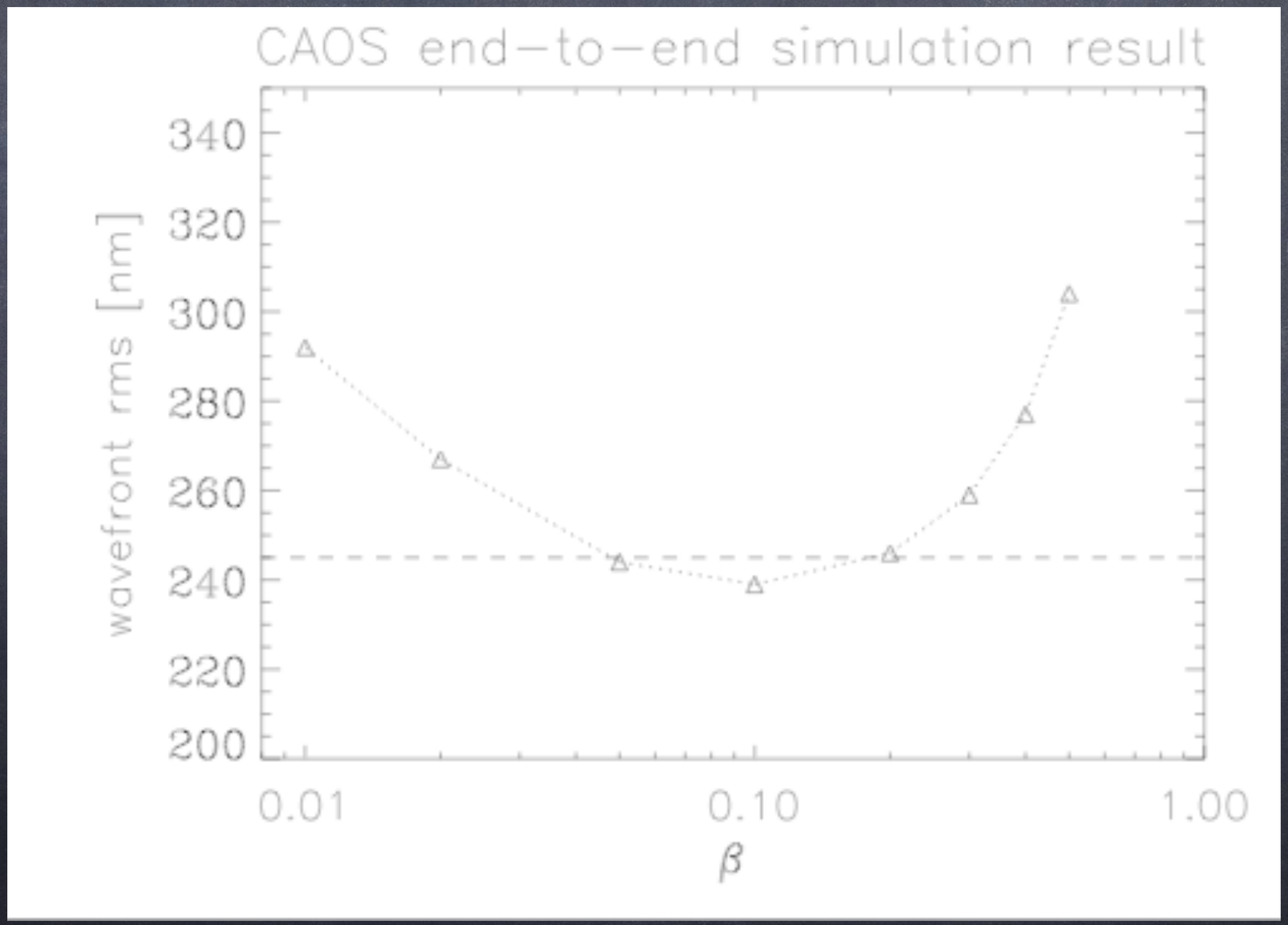
WFS: replace CCDs with EMCCDs ?...



(Carbillet & Riccardi, 2010)

Are other improvements possible ? - Examples - 2

WFS: add a TT sensor ?…



Are other improvements possible ? - Examples - 3

Image reconstruction : take into account the quality of correction within deconvolution process ?… (=> Strehl constraint)

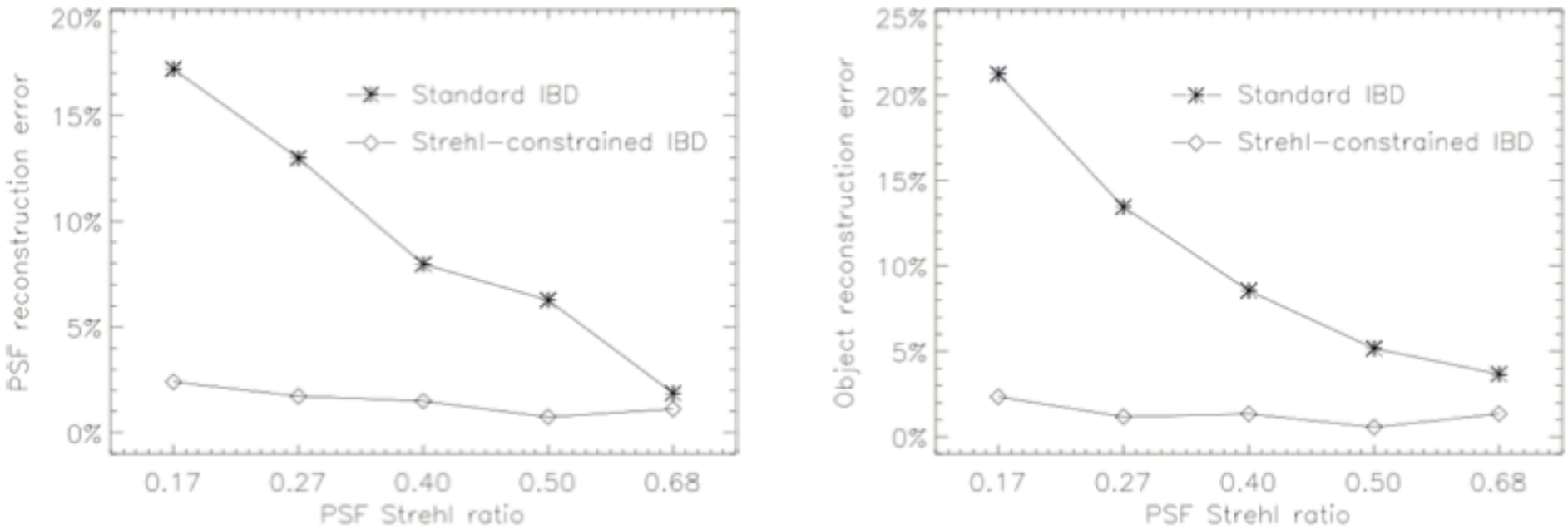
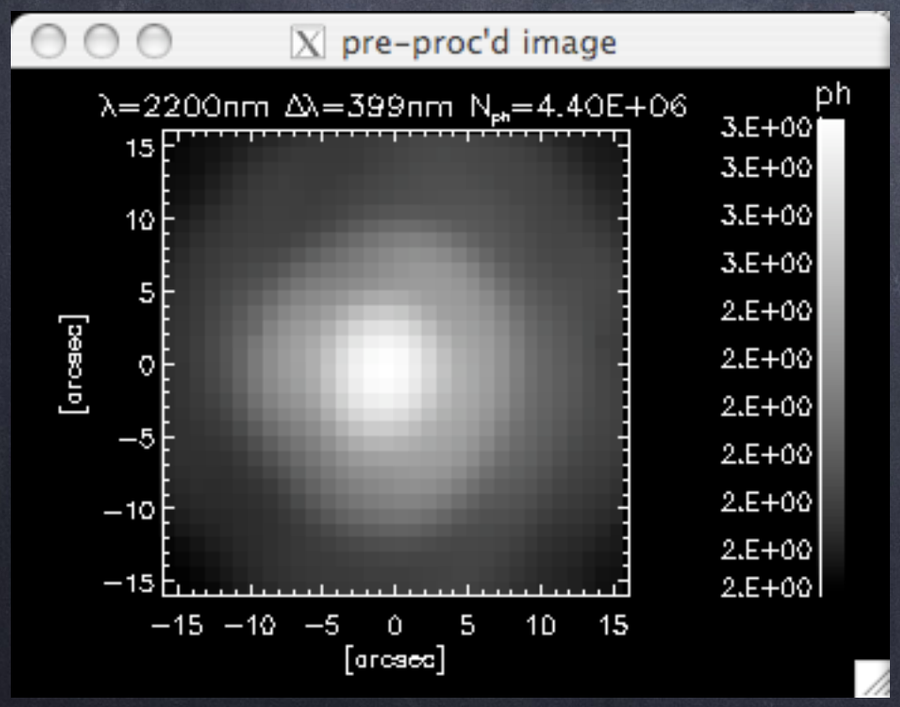
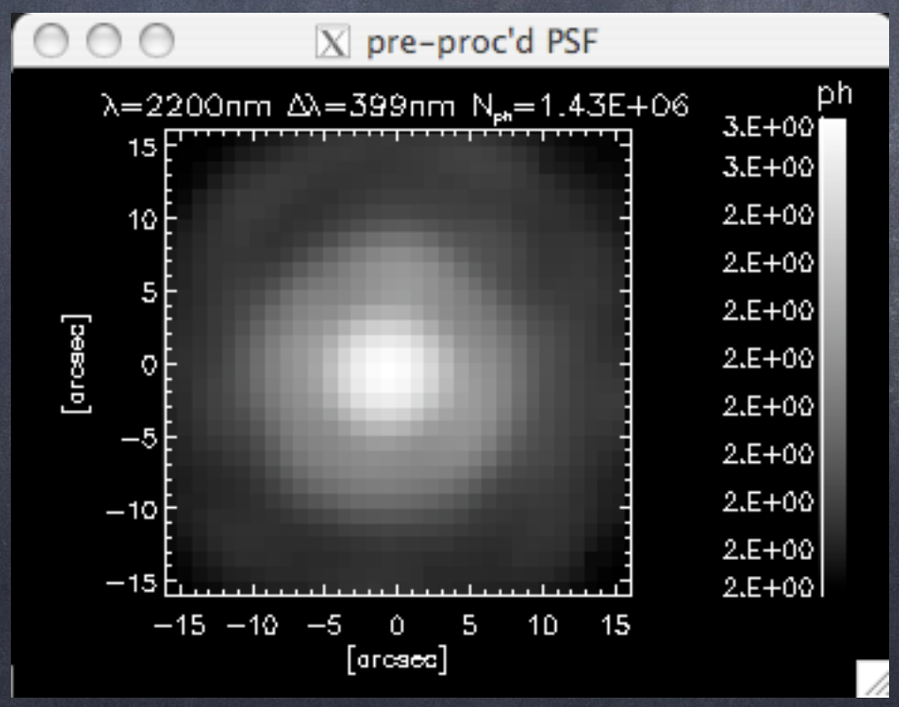


Fig. 2. *Left*: final error on the reconstruction of the PSF. *Right*: final error on the reconstruction of the object. Both plots are made as a function of the SR of the image data and comparing the simple IBD (rhombuses) to the Strehl-constrained IBD (asterisks). A gain of up to a factor ~10 is achieved for the poorer SR.

Are other improvements possible ? - Examples - 4

Image reconstruction : improve again resolution ?…
(=> Computational Super-Resolution)





(HD 87643 observed with NACO/VLT, super-resolution algorithm of Anconelli et al. (A&A 2005))