Optimization of coupling between Adaptive Optics and Single Mode Fibers

---

Non common path aberrations compensation through dithering

K. Saab[1], V. Michau[1], C. Petit[1] , N. Vedrenne[1], P. Bério[2], M. A. Martinod[2]

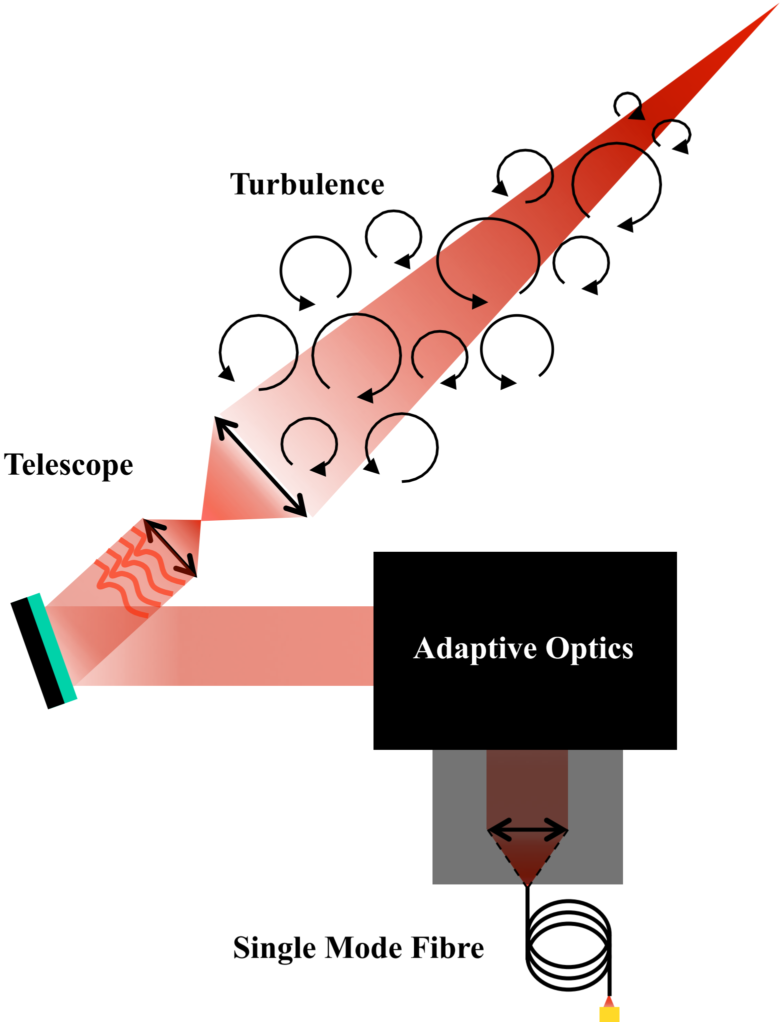
1. ONERA
2. Laboratoire Lagrange

retour sur innovation

Outline

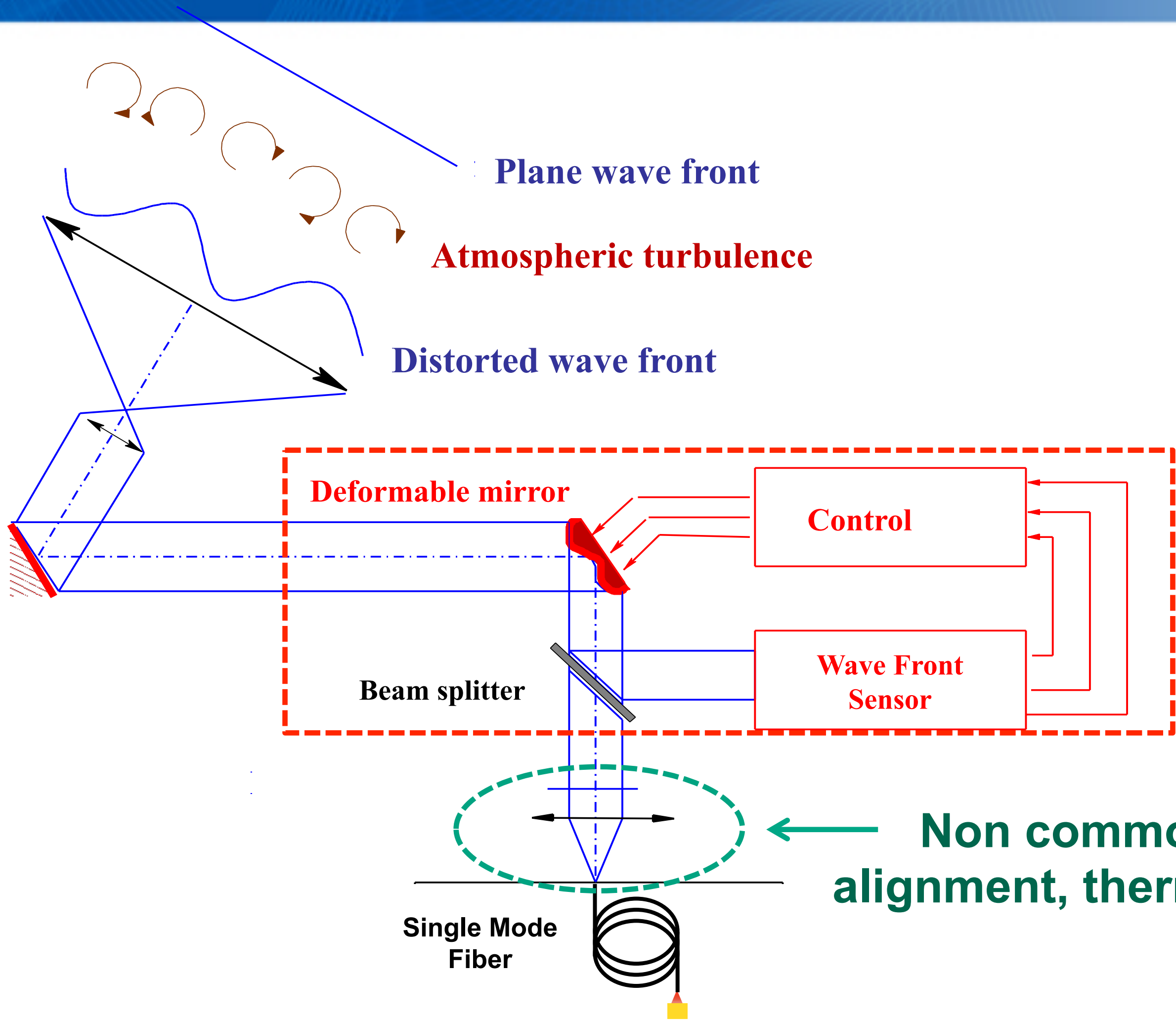
- Problem statement
- Concept
- Results
- Conclusions

Context



- Long baseline optical interferometry, Space-to-ground Optical Communications
- Injection of optical signal into SMF
- Use of AO for correction of atmospheric turbulence induced perturbations

Problem statement

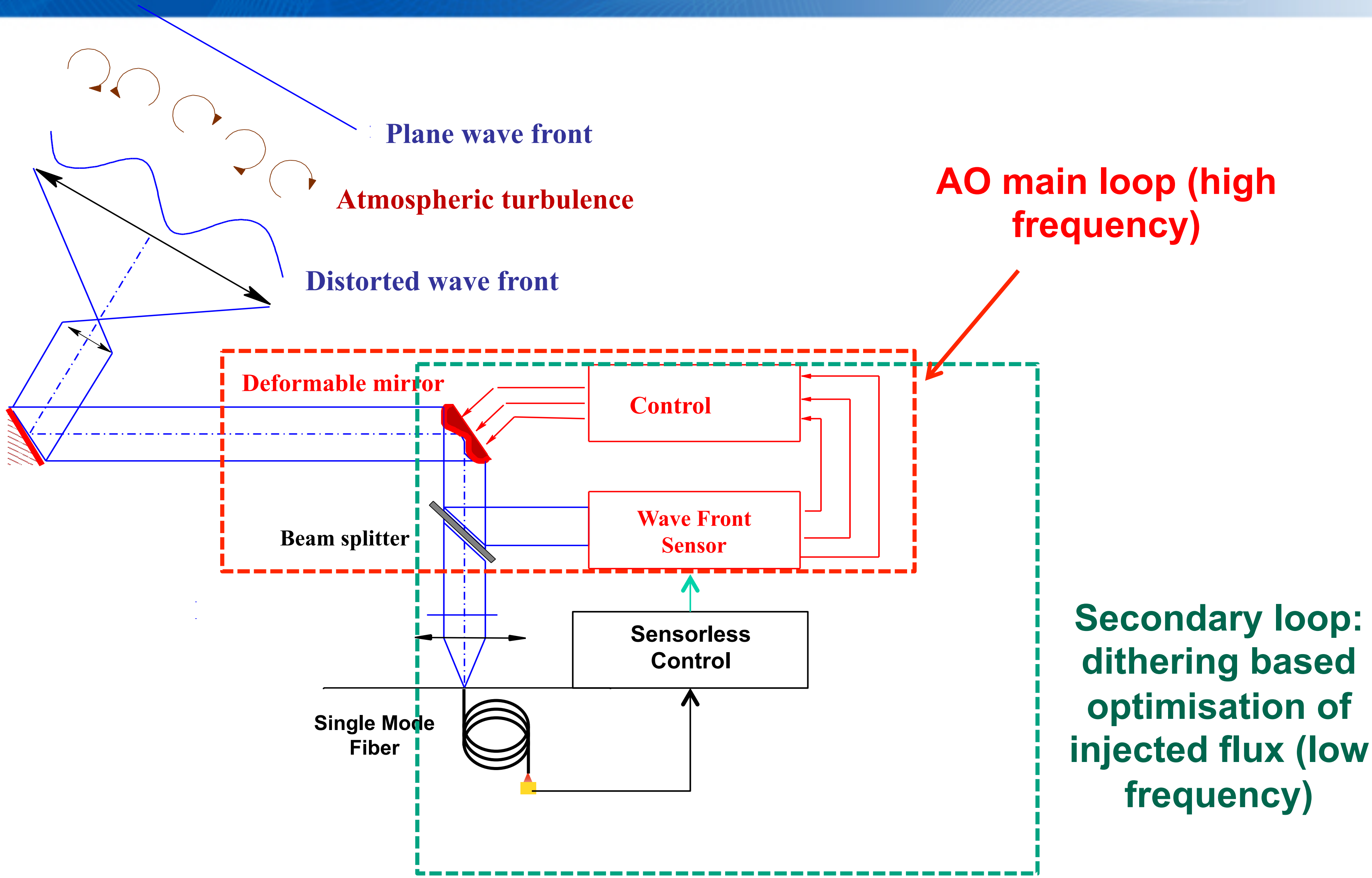


Adaptive Optics Loop: correction of wavefront seen by WFS

Non common path aberrations: alignment, thermo-mechanical effects .

Correction of wavefront injected into SMF ?

Problem statement



Concept of « sensorless » loop

- Single measurement (coupled flux), Multi dimension correction using AO deformable mirror => use of dithering

- Correction through AO: can only be introduced by modification of setpoint = reference slopes

- From control point of view: Cascade control

  Main AO loop (f_s>100 Hz)

  « sensorless » loop (f_s # 1 Hz)

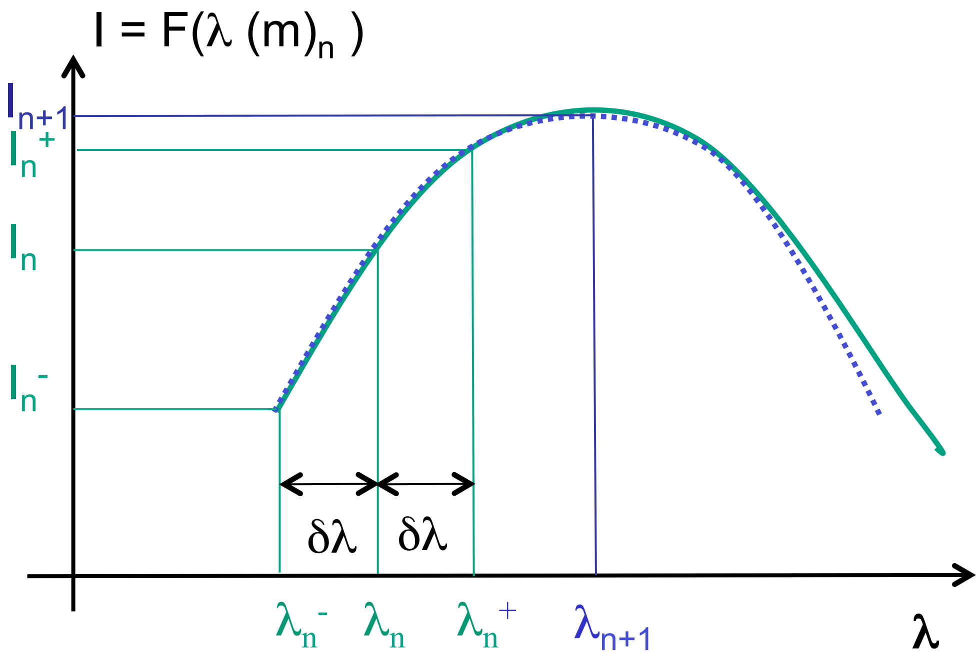
=> Modifications of DM shape introduced by the « sensorless » loop can be seen as quasi-static by the main AO loop (modification of setpoint of AO): temporal decoupling

- « sensorless » loop:
- Control in the AO loop eigen modes: (m) ;
- Application of sensorless loop control onto DM (v) by projection of modes (m) onto reference slopes (δp) of WFS: (δp)= A (m) then (v)= D (δp) (D= AO command Matrix);
- Iterative search of maximum along random directions of the eigen modes space $(m)_{n.}$

- Principle : dithering with parabolic fit. Can be related to Stochastic Parallel Gradient Descent (SPGD)

Optimization by dithering

Coupling efficiency I in one direction of modulation $(m)_n$



λ_n amplitude on mode $(m)_n$
I_n associated coupling efficiency

Choice of direction of modulation in eigen mode space $(m)_n$,

For that direction:

a. Modulation of amplitude +/- $\delta\lambda$ in mode space,

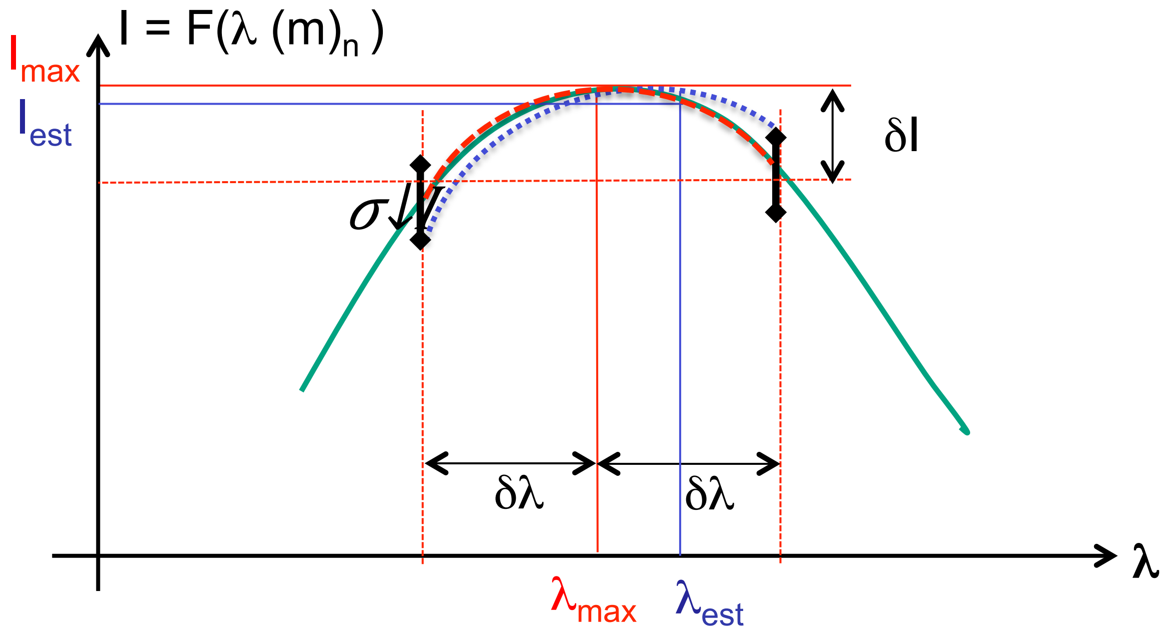
b. Detection of associated signals I_n^+, I_n^- ,

c. Determination of maximum by parabolic fit, λ_{n+1}

d. Conversion into slopes of associated mode vector and detection of output signal.

Impact of noise

Coupling efficiency I in one direction of modulation $(m)_n$



Modulation of amplitude
+/- $\delta\lambda$ in mode space
+/- δI in coupling efficiency

Internal source

$\sigma_I \rightarrow$ Detection noise

External source

$\sigma_I \rightarrow$ Turbulence

Attenuation : $<I_{max} - I_{est}>/I_{max} = 1/8$

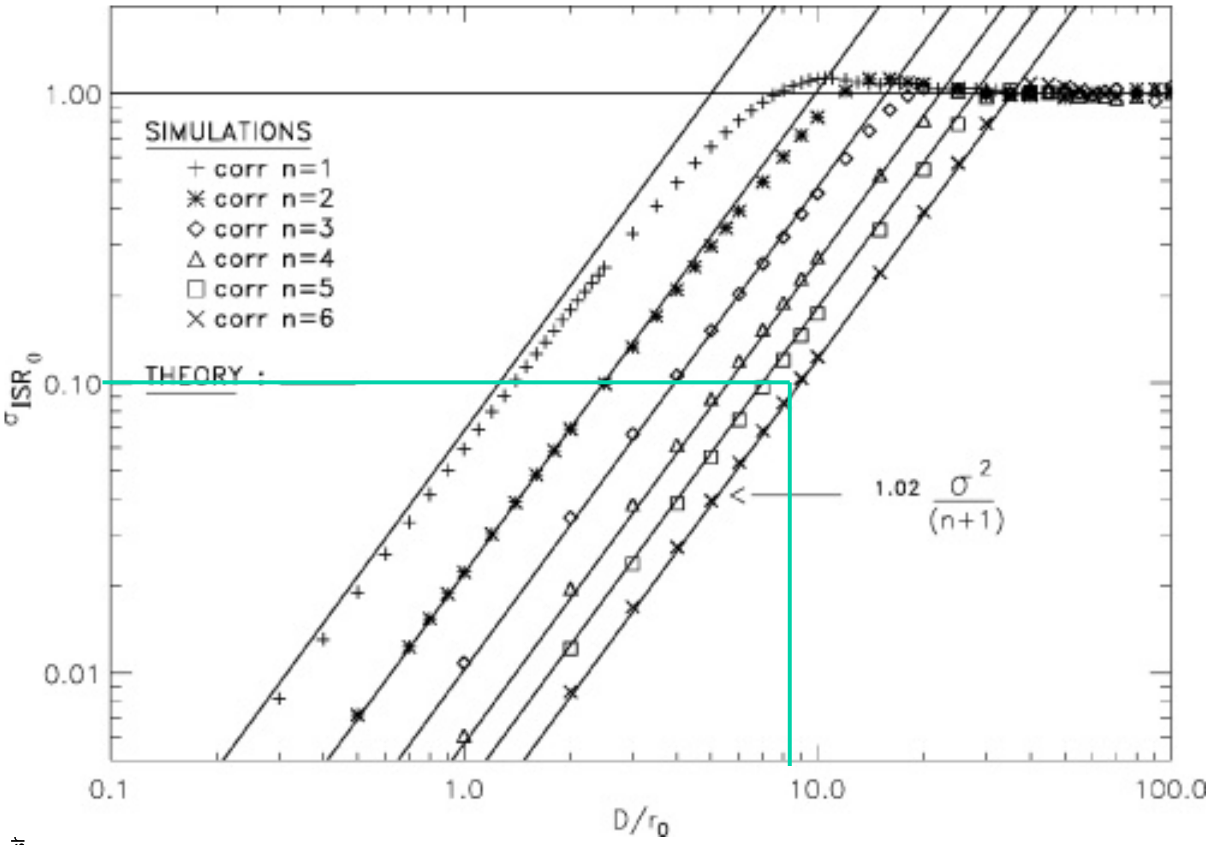
$$(\sigma_I/I_{max})^2\ I_{max}/dI$$

- Reduction of $\boldsymbol{\sigma_I}$: temporal averaging of coupled signal
- Increase of δI : increase of modulation amplitude $\delta\lambda$ in mode space

Optimization on sky with AO

fitting error limited AO case

SR rms



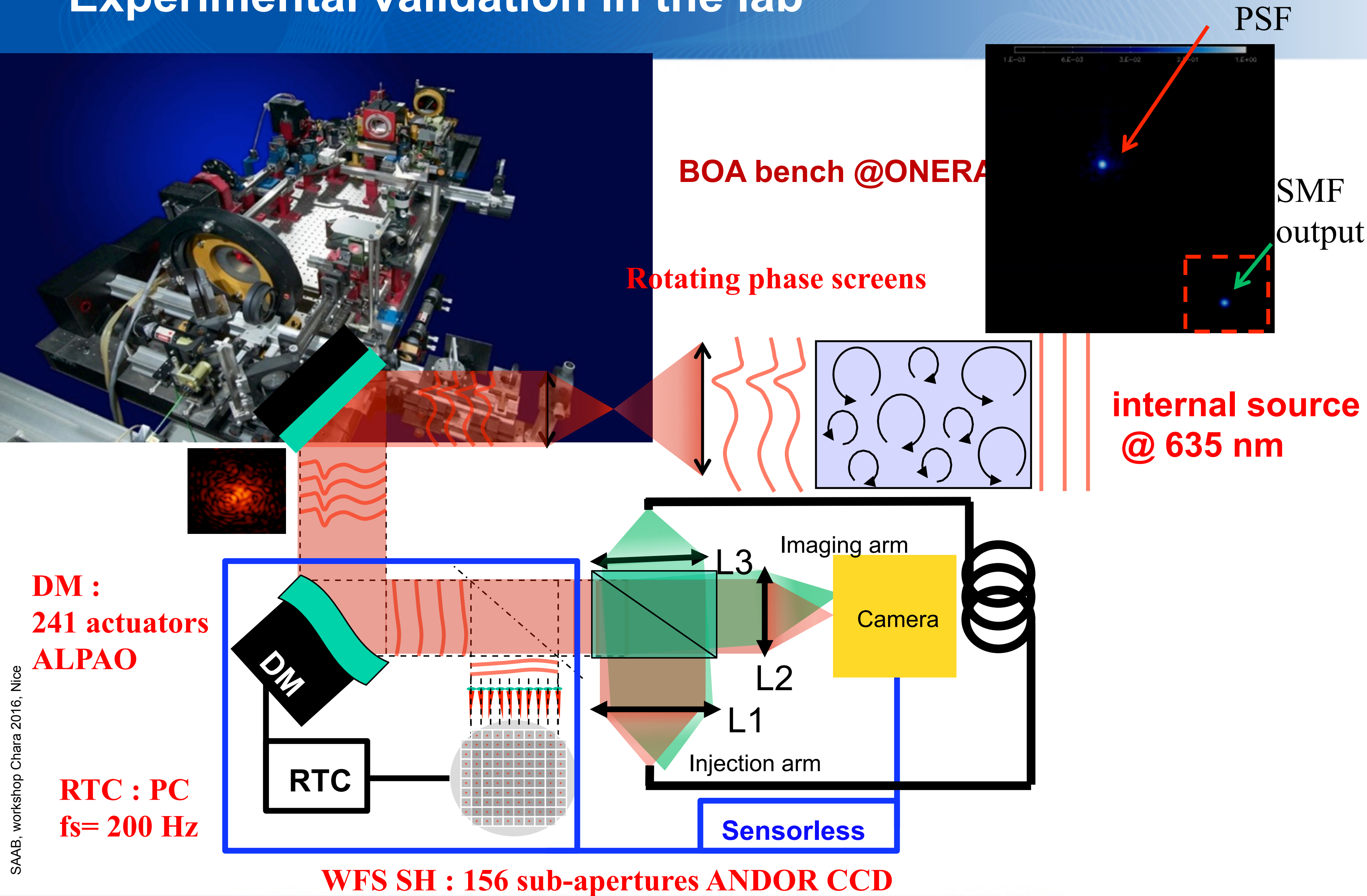
Thierry Fusco and Jean-Marc Conan, "On- and off-axis statistical behavior of adaptive-optics-corrected short-exposure Strehl ratio," J. Opt. Soc. Am. A ***21****, 1277-1289 (2004)*

- Assume modulation:

$I_{max}/dI = 0,1$

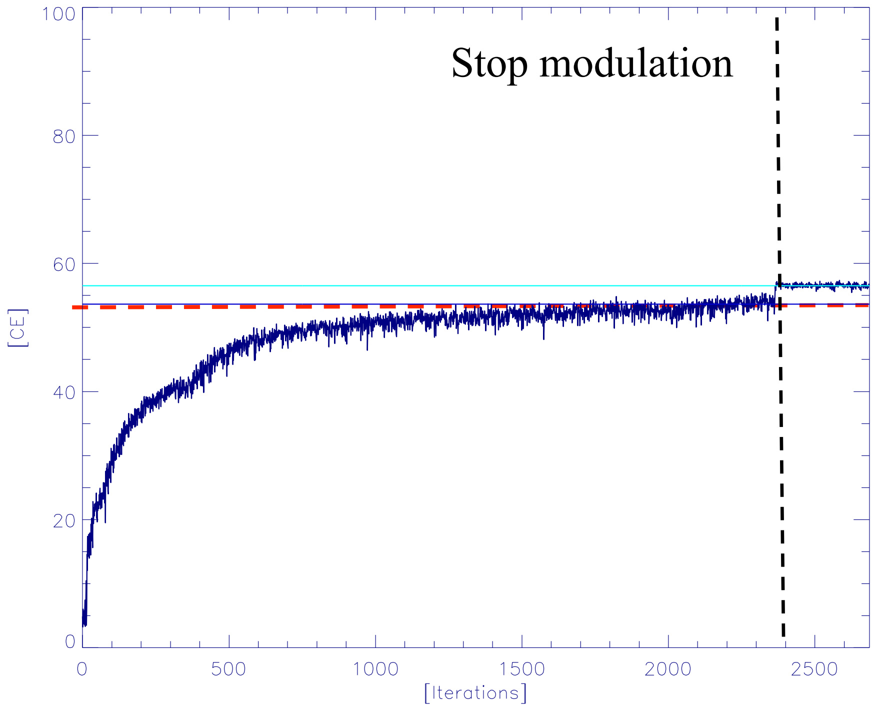
- Consider $I/I = 0,1$
- then $<I_{max} - I_{est}>/I_{max} = 0,01$

Experimental validation in the lab



Experimental validation in the lab: no turbulence case

Convergence of CE optimisation



56% CE

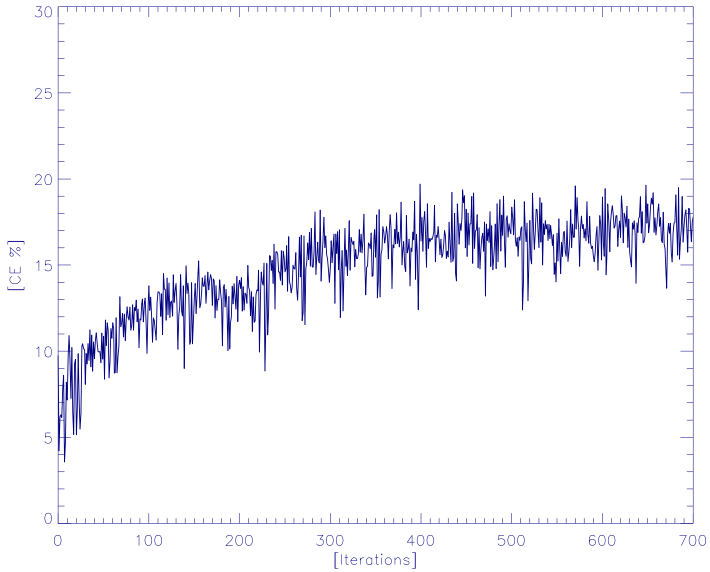
Itérations stands for each modulation

- Optimisation of static aberrations.
- Can be performed with input source (no use for intermediate reference source as in AO)
- Convergence speed not critical.

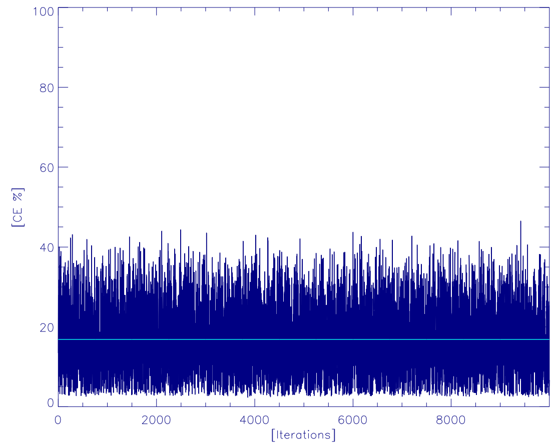
Experimental validation in the lab: turbulent case

- Turbulence ON

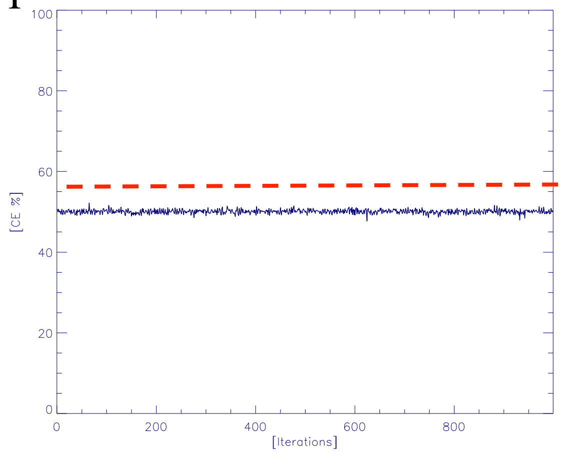
Convergence of CE optimisation



Stability after convergence



If phase screen removed ? Sensorless loop stopped



No turb: 56% CE

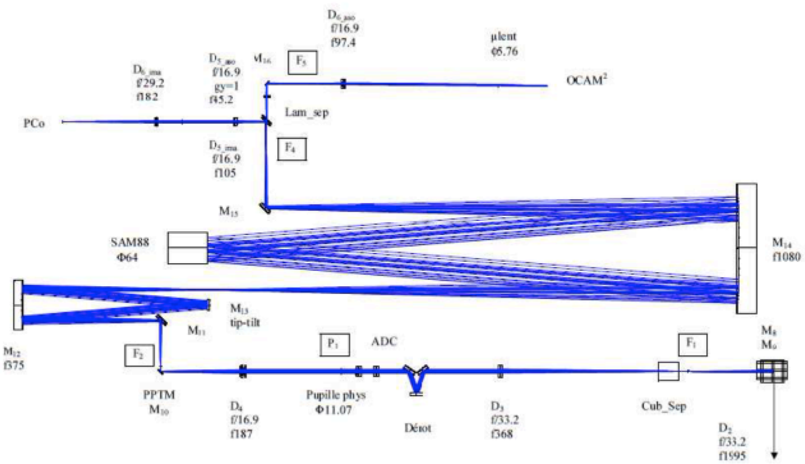
PS removed: 50% CE

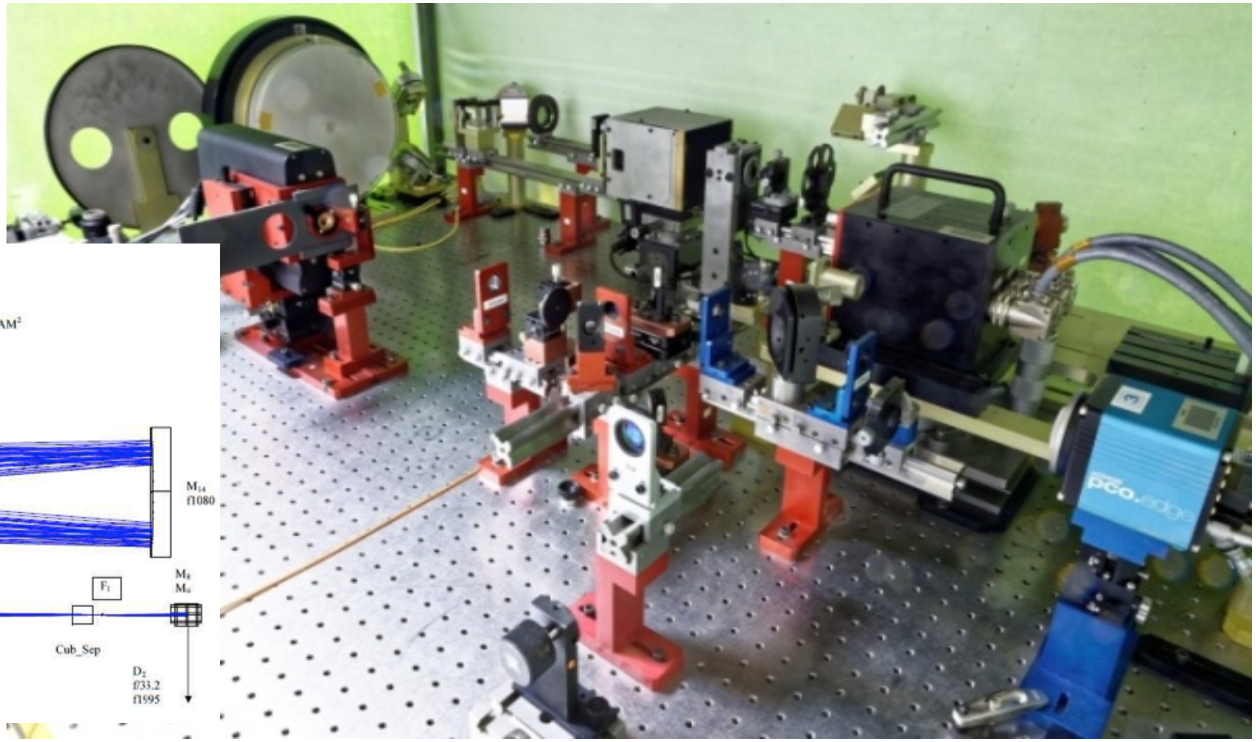
Residuals mainly driven by AO performance !

convergence speed and performance as fonction of number of actuators, amplitude of modulation, averaging to be analyzed

AO bench ODISSEE @ OCA

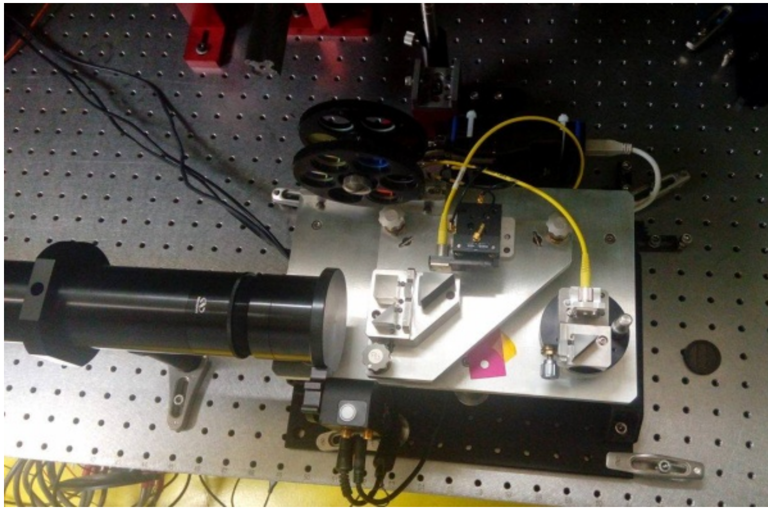
90 actuators
8x8 SH-WFS
Up to 1.5kHz



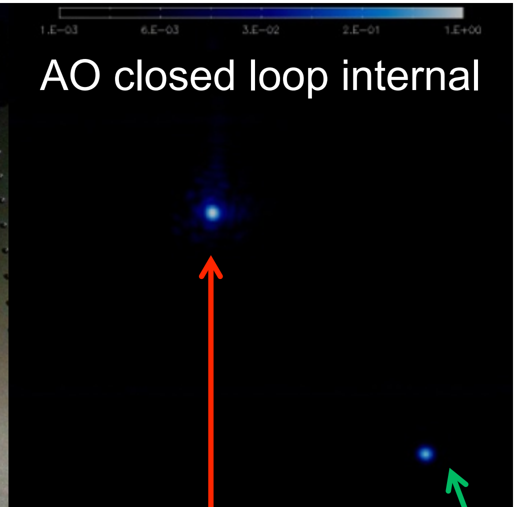


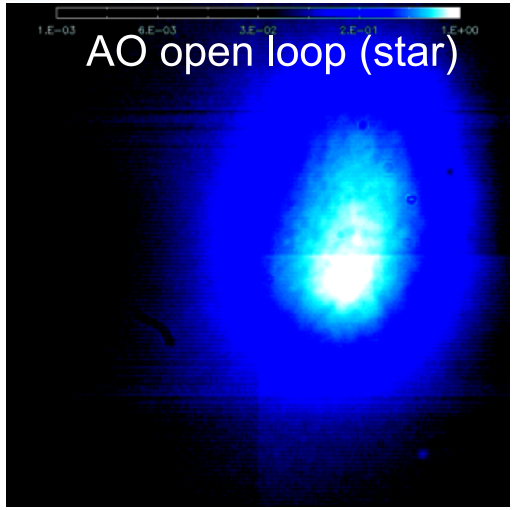
Validation of hybrid AO on ODISSEE (D = 1,5 m, 8x8 sous-pupilles, 1500 Hz)
CESAR mission: coupling of star light into SMF for long baseline interferometry (collaboration : ONERA/Lagrange).
SOTA/SOCRATES mission: coupling of telecom signal into SMF (collaboration : ONERA/CNES/NICT/OCA).

CESAR preliminary results (star @ 700 nm)



Cesar Module from Lagrange

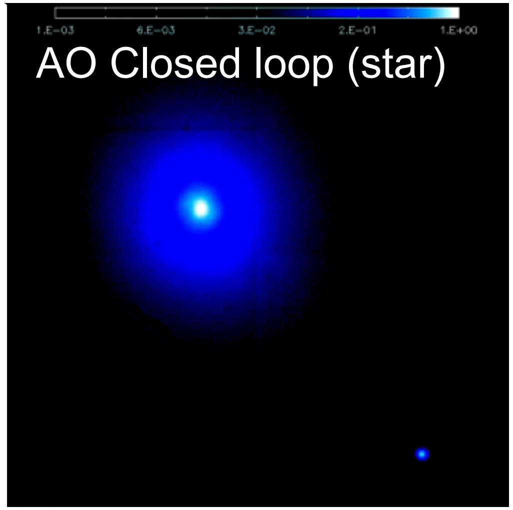




PSF from AO and **SMF output image** **opticaly combined onto the same detector**

Static (internal source) optimization of coupling

Coupling eff. measured ≈ 10 %
SR ≈ 11 %



Significant gain obtained through AO and sensorless loop.
Performance limited by AO system

ONERA

Conclusion

Sensorless loop concept:

- A simple approach which goal is to simplify complex systems: use of single or no calibration source (improve transmission), ensure stability of system (reduce need for thermo-mechanical stabilisation), on the whole reduce costs.
- First demonstration: numerical analysis comforted by in lab experiment and first tests on sky
- Still a lot of job to be done :
  - Analysis of convergence wrt time averaging/nbr of actuator/modulation amplitude
  - Possibility to enhance strategy (choice of dithering basis, hierarchical approach …)
  - Investigate fully automatic use of sensorless loop

Applications:

- Long base interferometry, optical communication, …