Two-wavelength focal-plane piston sensing: first experimental results with LIFT

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Context

- Design of Giant Magellan Telescope's Natural Guide star Wavefront Sensor

- GMT = segmented telescope

- Among the degrees of freedom, there is the **differential piston between segments**
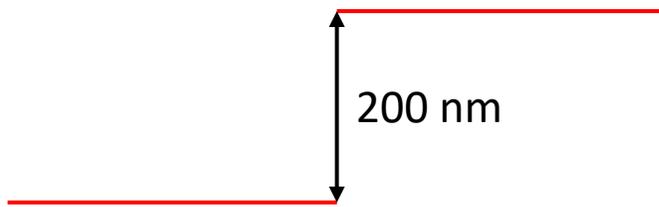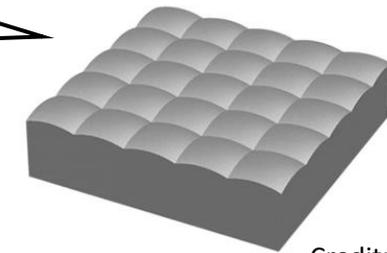
Wavefront sensor vs differential piston

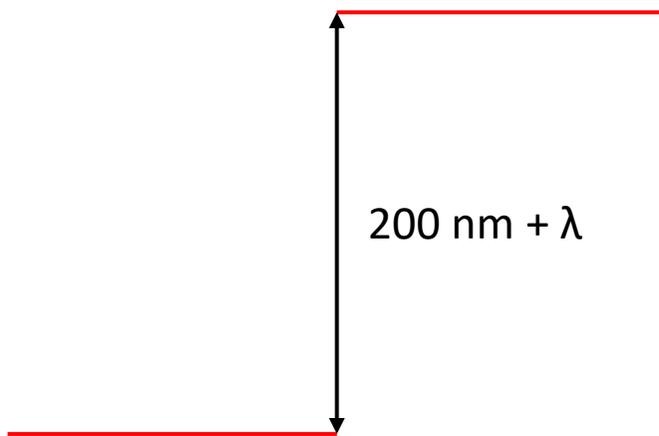Difference between these wavefront steps?

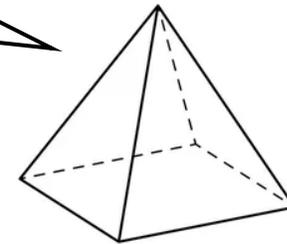Sensor @ λ

1)

200 nm
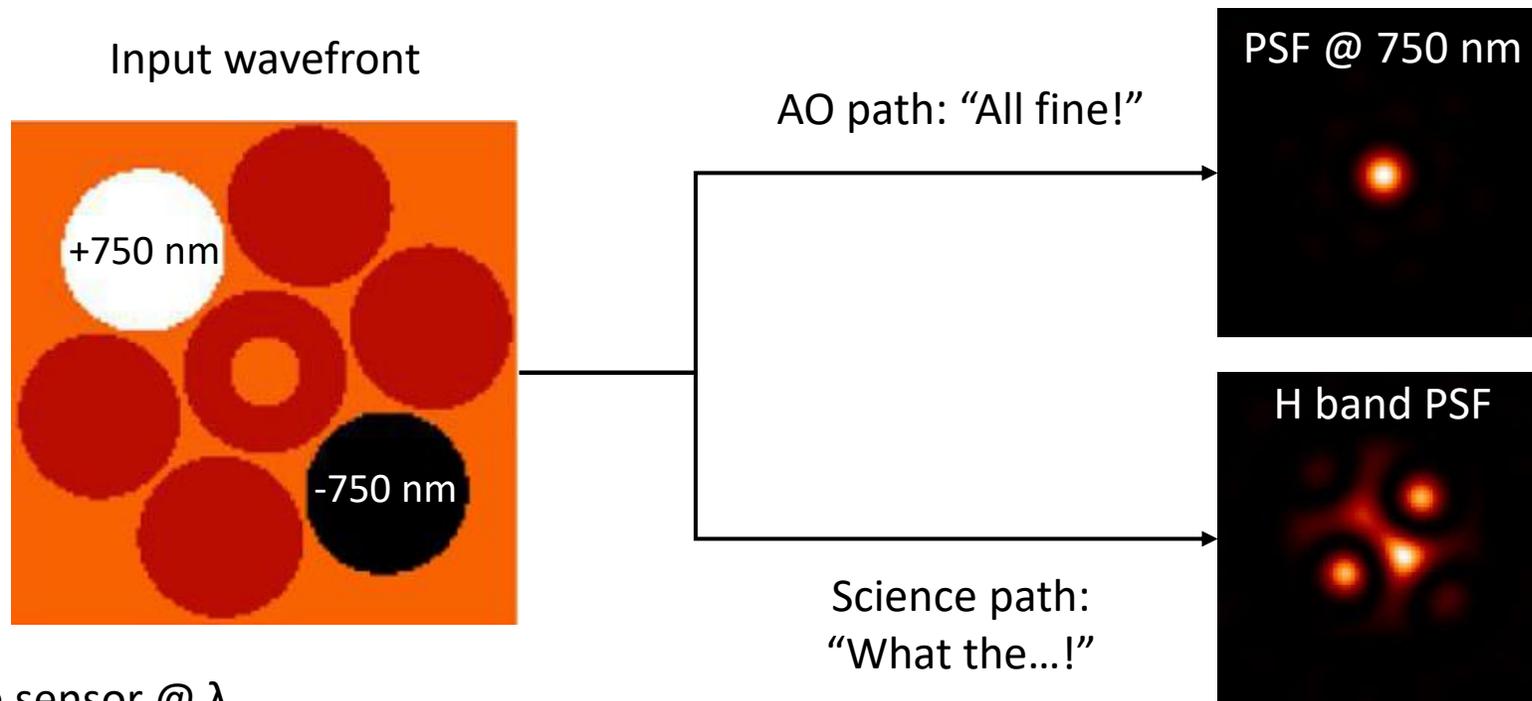
2)

200 nm + λ

Step? What step?

Credit: Thorlabs

What difference? Both are 200 nm!

AO vs Science path

GMT's Single-Conjugated Adaptive Optics done with **pyramid sensor @ λ_c = 750 nm**

Input wavefront

AO path: "All fine!"

PSF @ 750 nm

+750 nm

-750 nm

H band PSF

Science path:
"What the...!"

$\rightarrow$ Need for another sensor and/or wavelength to identify ejections

Single sensor @ λ
$\rightarrow$ segments converge at a multiple of λ

LIFT: principle

- LInearized Focal-plane Technique
- Phase diversity with single image
- Relies on diffractive image formation model
- Original goal: sense tip/tilt and focus on a faint NGS (with astigmatism phase offset)

- Model-based → can be extended to piston estimation
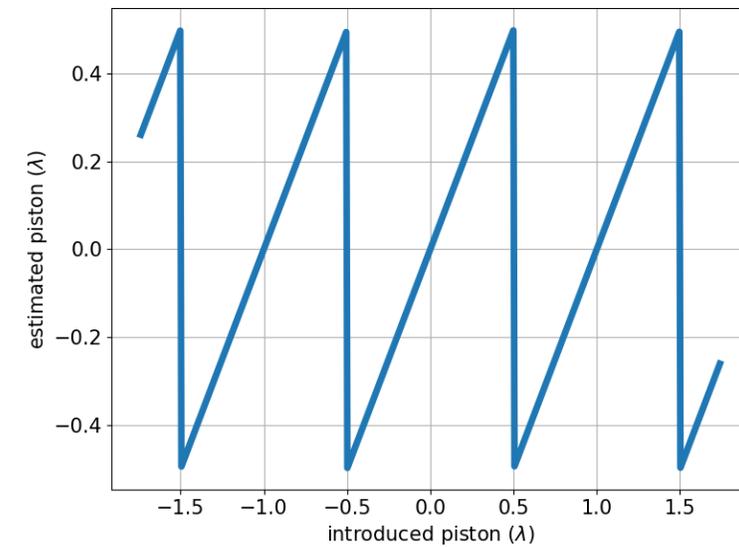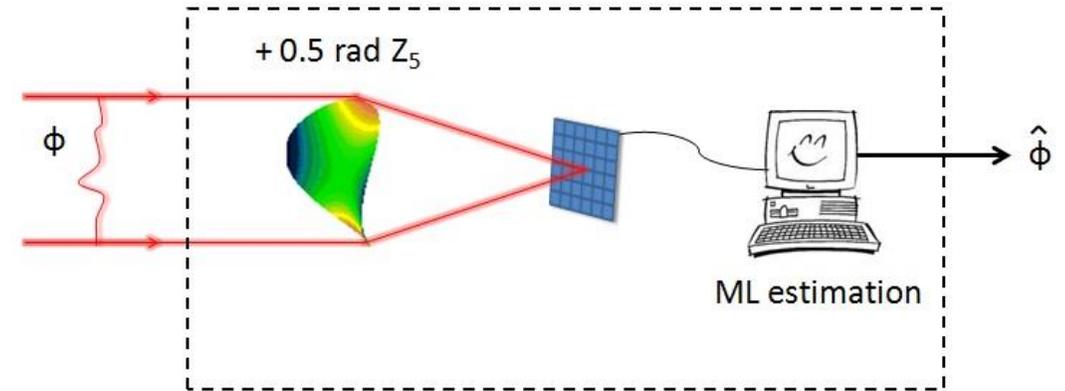
Double-wavelength LIFT: principle

- Need for a large capture range > λ → minimum 2 sensing wavelengths
- Astigmatism offset → focus offset (easier implementation)
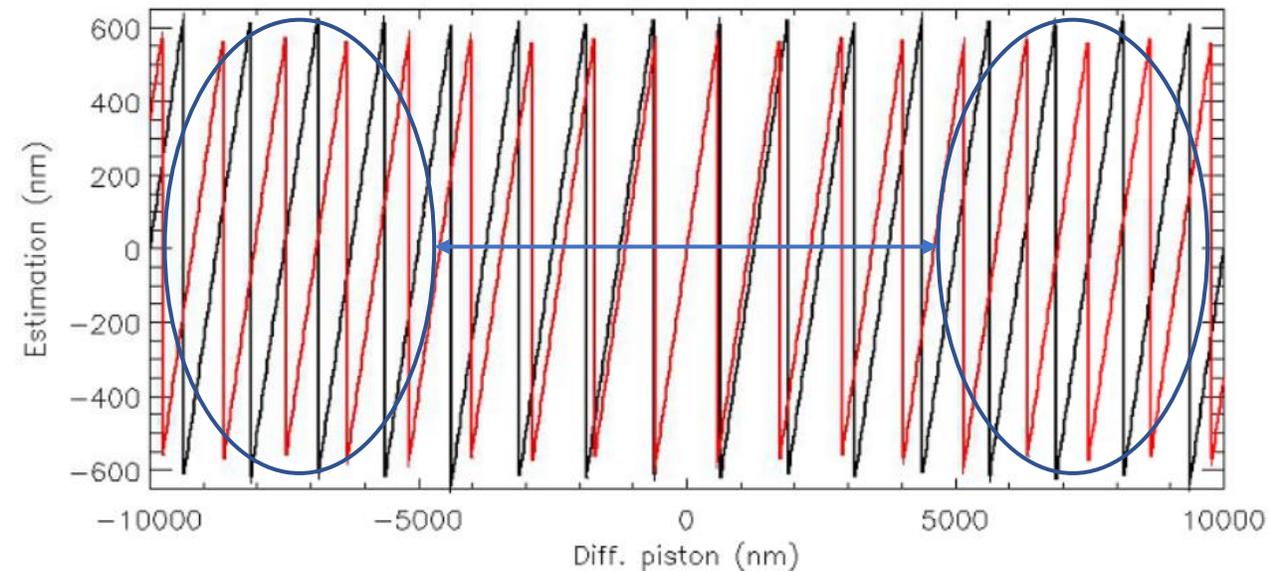- Simple algorithm to match estimation couple – piston amplitude

1150 nm

1250 nm
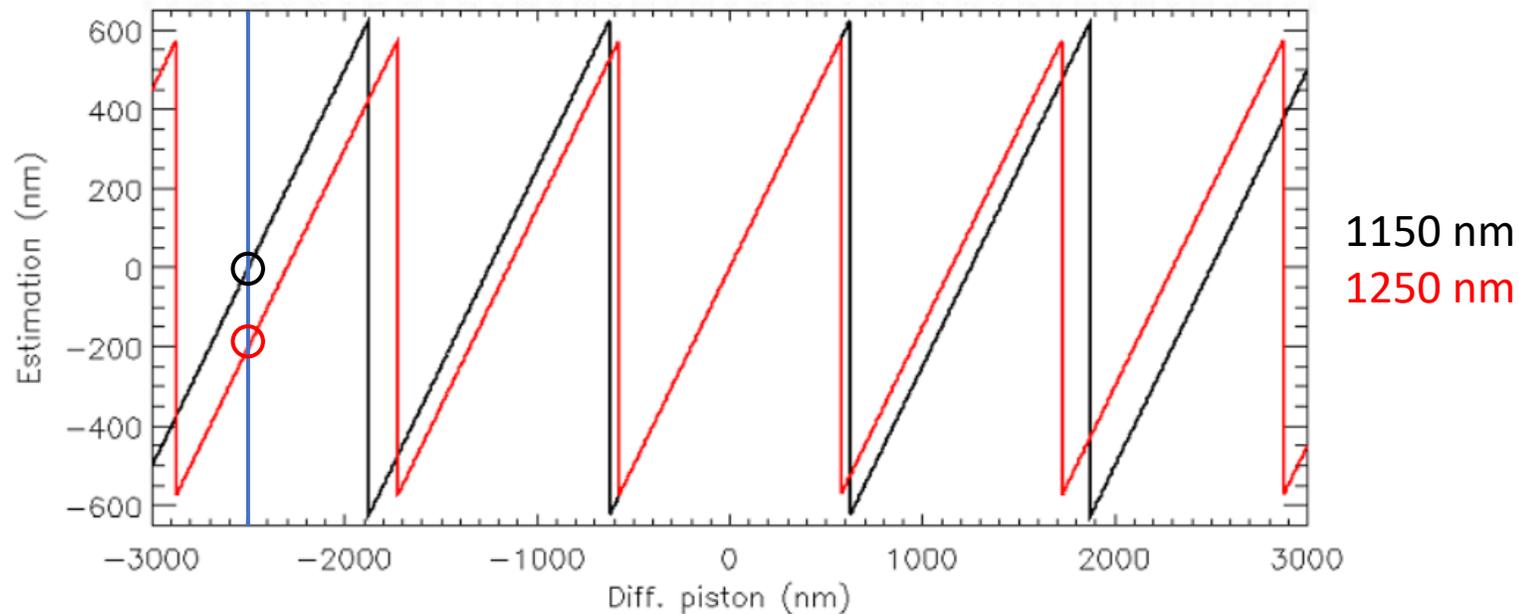
Double-wavelength LIFT: which wavelengths?

- Capture range → longer wavelengths, close to each other

- AO correction → longer wavelengths

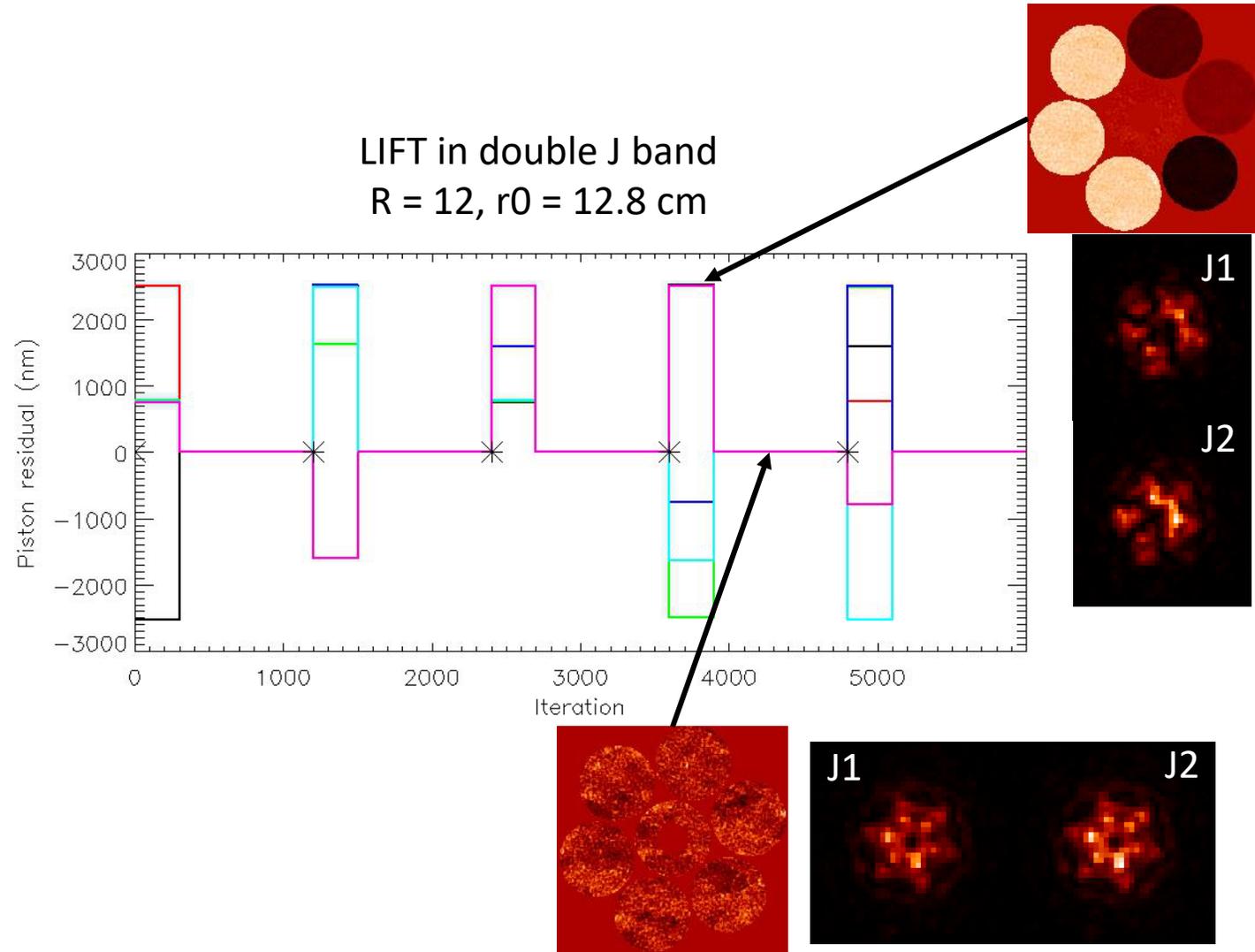- Good SNR → wavelengths as far as possible from a multiple of main AO's wavelength

Capture range limited by synthetic wavelength (beating frequency):

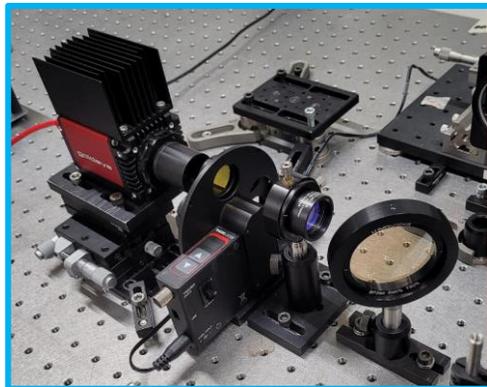$$\Lambda = \frac{\lambda_1 \lambda_2}{|\lambda_1 - \lambda_2|}$$

Example in simulations

- AO residual series for mag R = 12 and r0 = 12.8 cm

- Telescope regularly "scrambled" with differential pistons up to 2.5 um
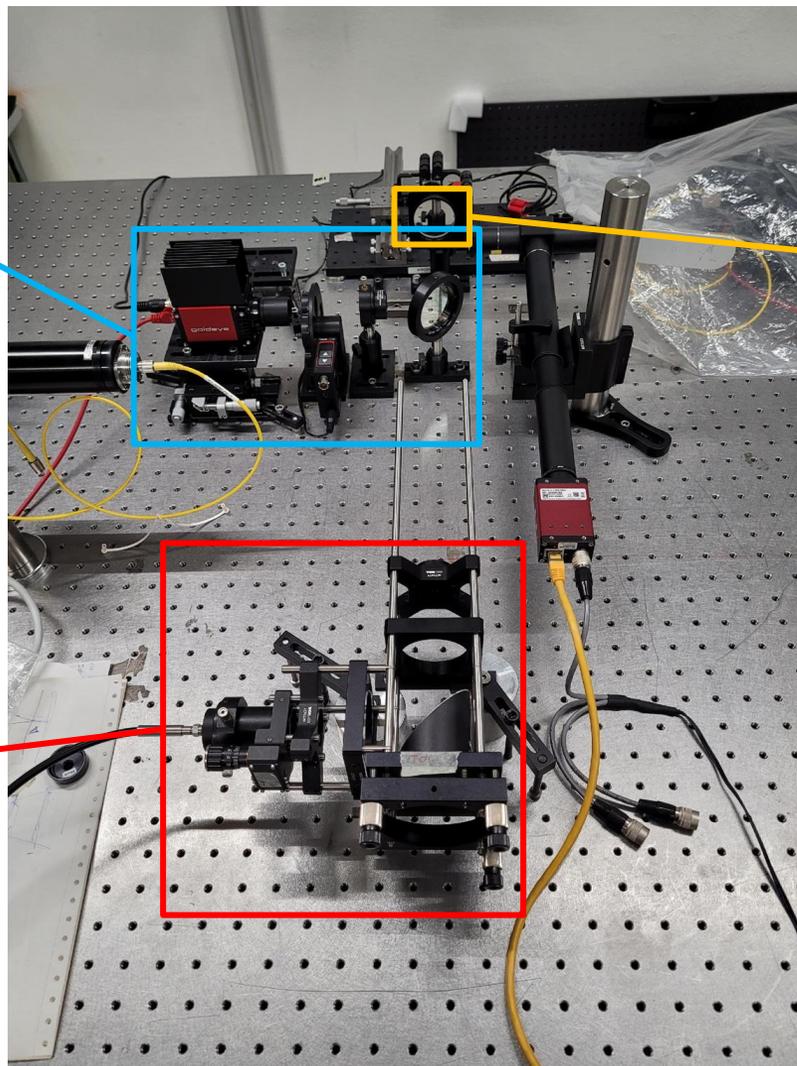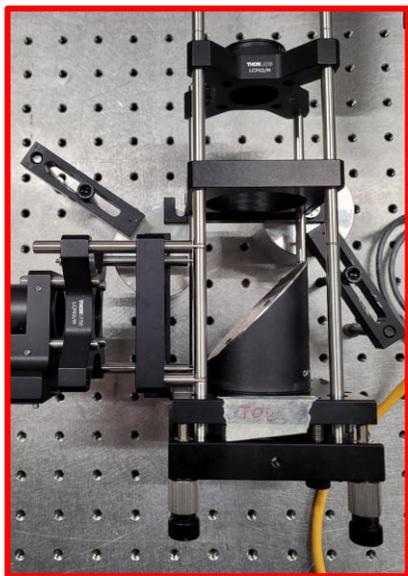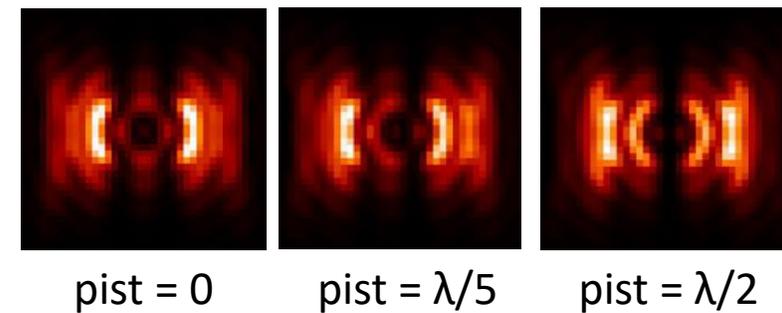

LIFT in double J band
R = 12, r0 = 12.8 cm

LIFT test bench

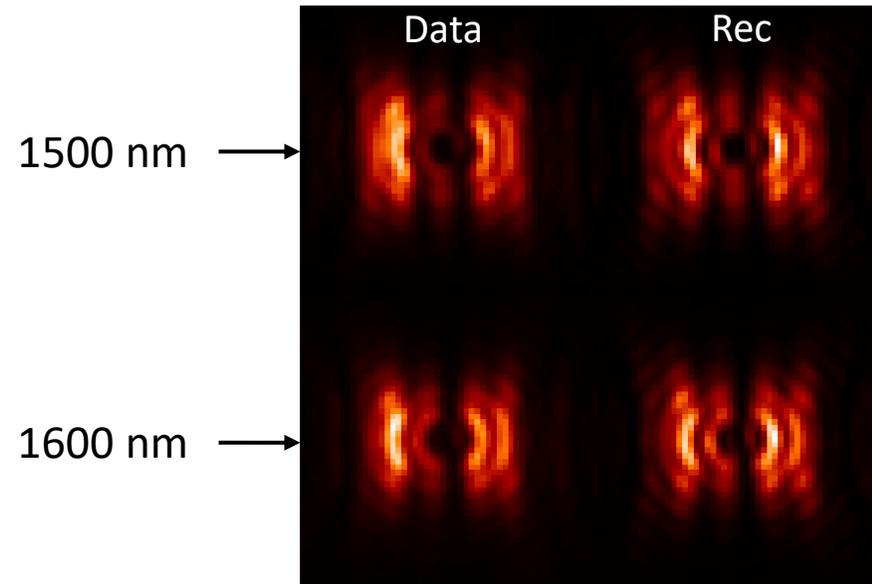LIFT camera with filter wheel
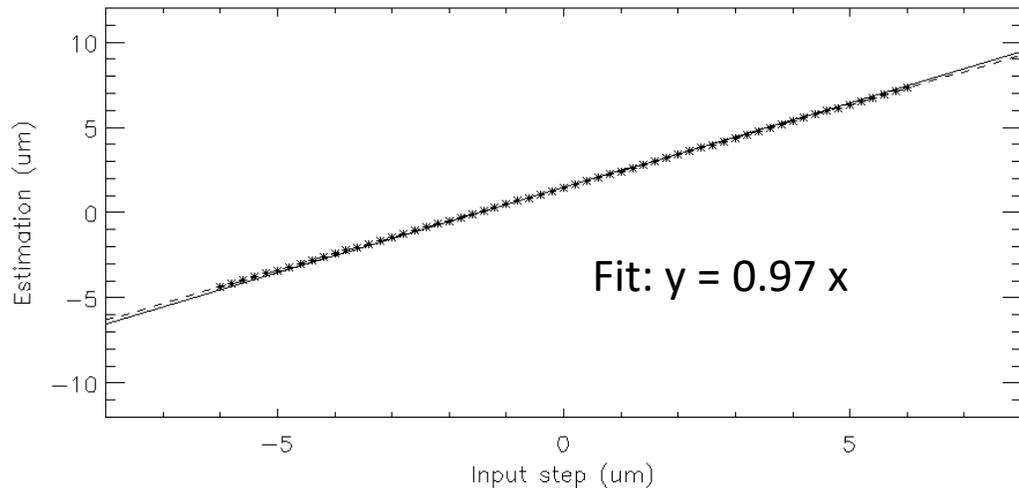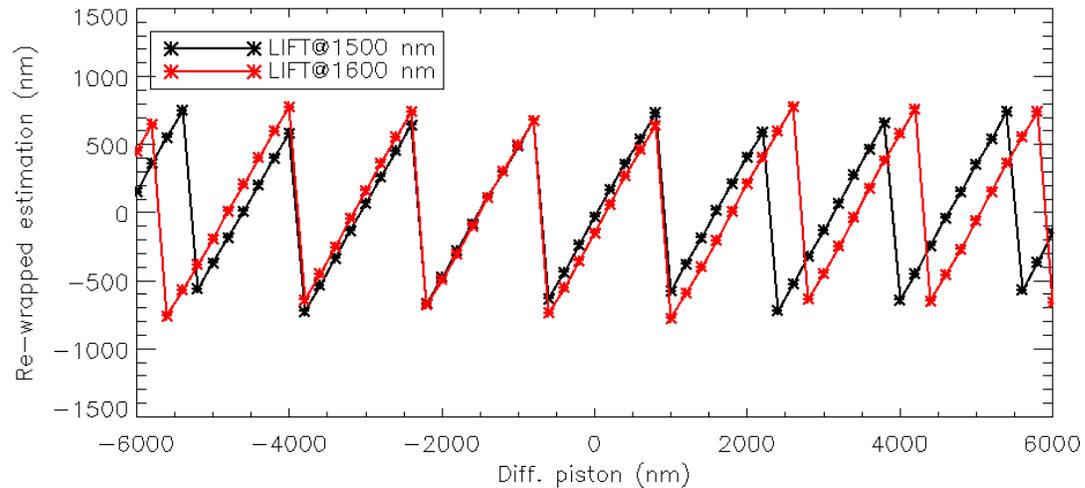
Fiber output + parabolic mirror for collimation

Diff. piston generator (flat mirror cut in half)
Encoder on Z translation

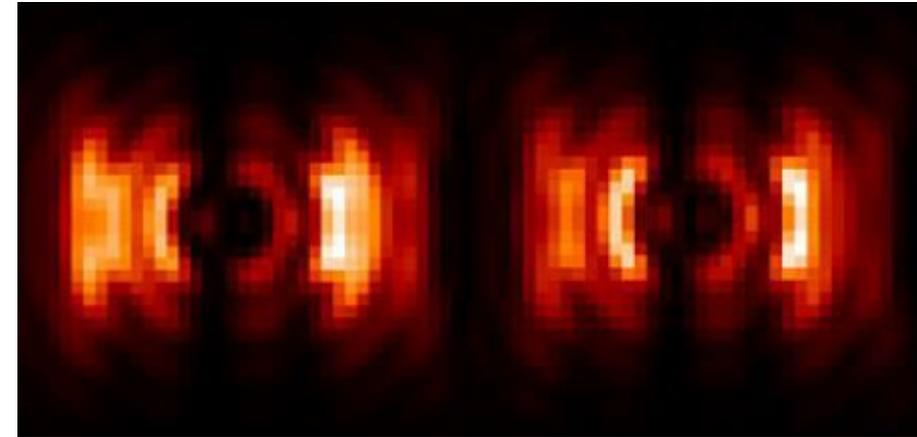pist = 0   pist = λ/5   pist = λ/2

Results

- Successful estimation in double H band (1500 + 1600 nm) on 12 um range
- RMS w.r.t. fit: 16 nm

Limits

- Diff. **tip**/tilt → bias on the estimation
  - Ok if bias << λ/2 on main channel
- Model-based → sensitive to model errors
  - Pupil apodization
  - Uncalibrated NCPAs
  - …

Tip 50" on one segment (no piston)   Diff. piston -360 nm

Conclusion & perspectives

- First experimental demonstration of differential piston sensing with LIFT!
- Next:
  - Setup improvement
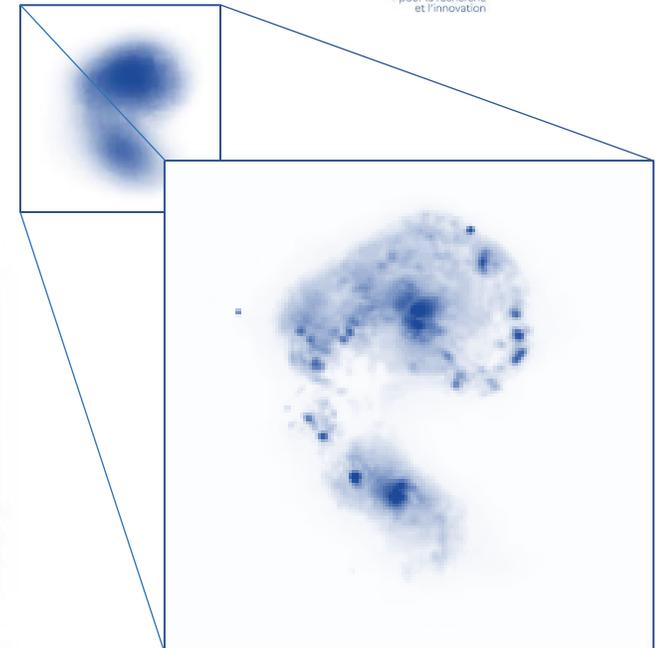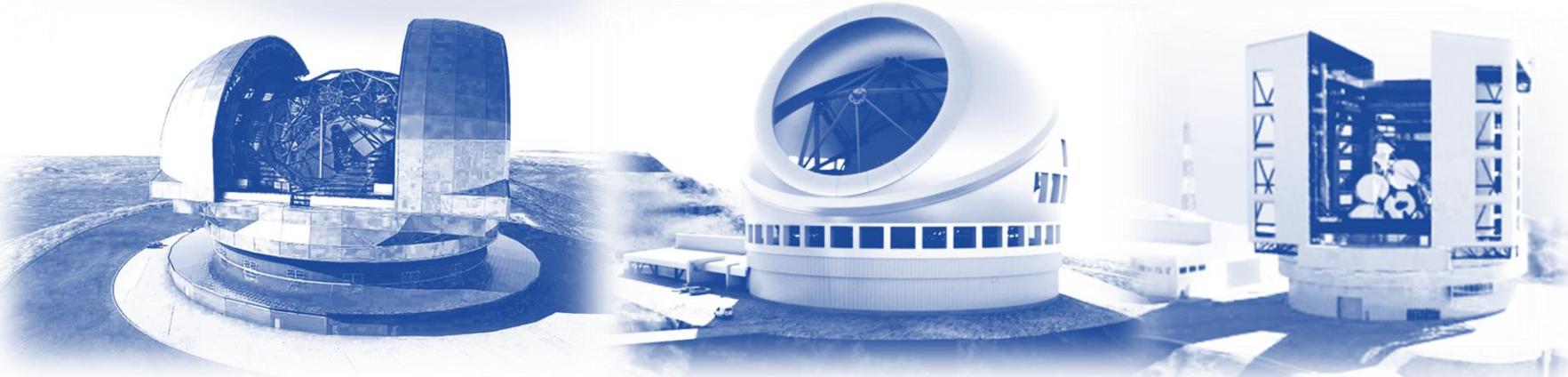 - Tests in presence of simulated residuals
  - On sky?

AO 4 ELT - 7th Edition

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Thank you for your attention!

Questions?