Experimental validation of online coronagraphic phase diversity & of the non-linear dark hole technique

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LAM LABORATOIRE D'ASTROPHYSIQUE DE MARSEILLE

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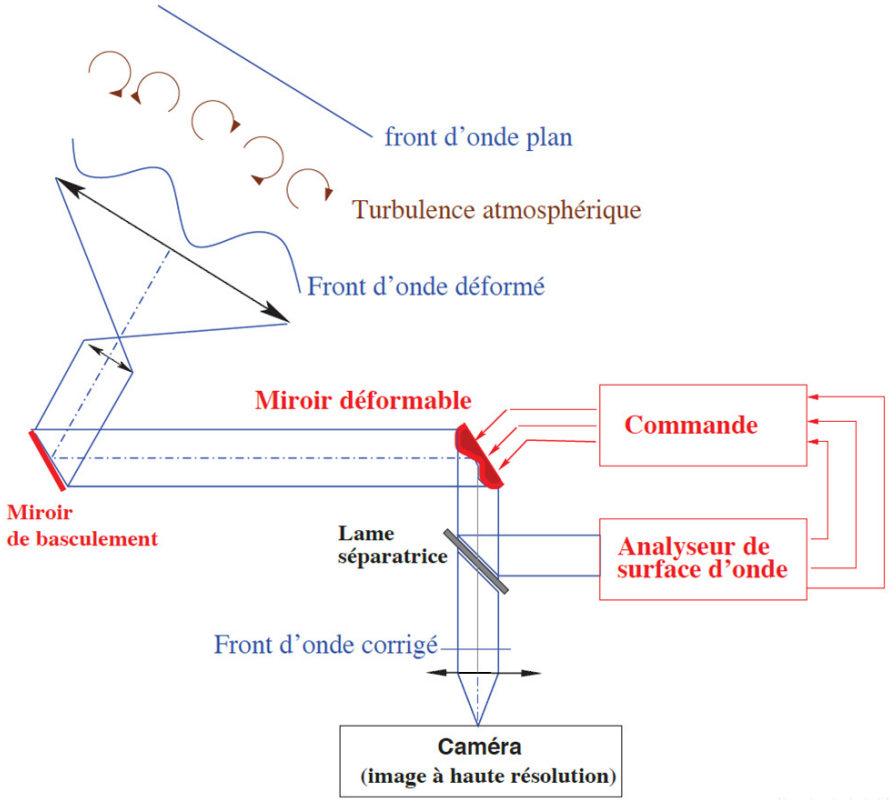
ITHD 2017

Need for focal-plane wave-front sensing



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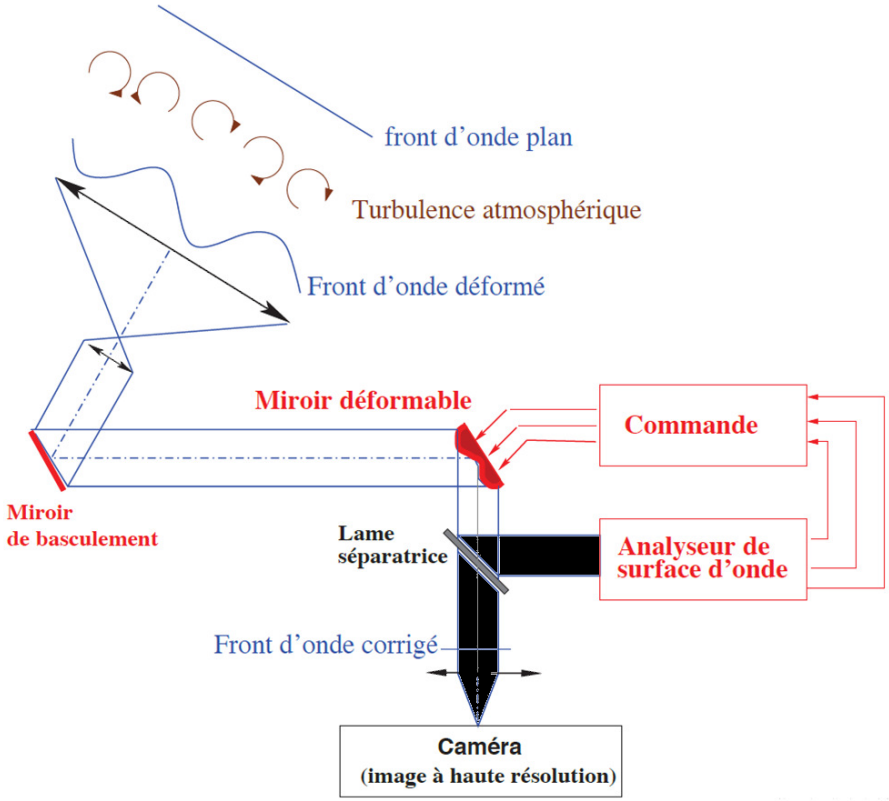
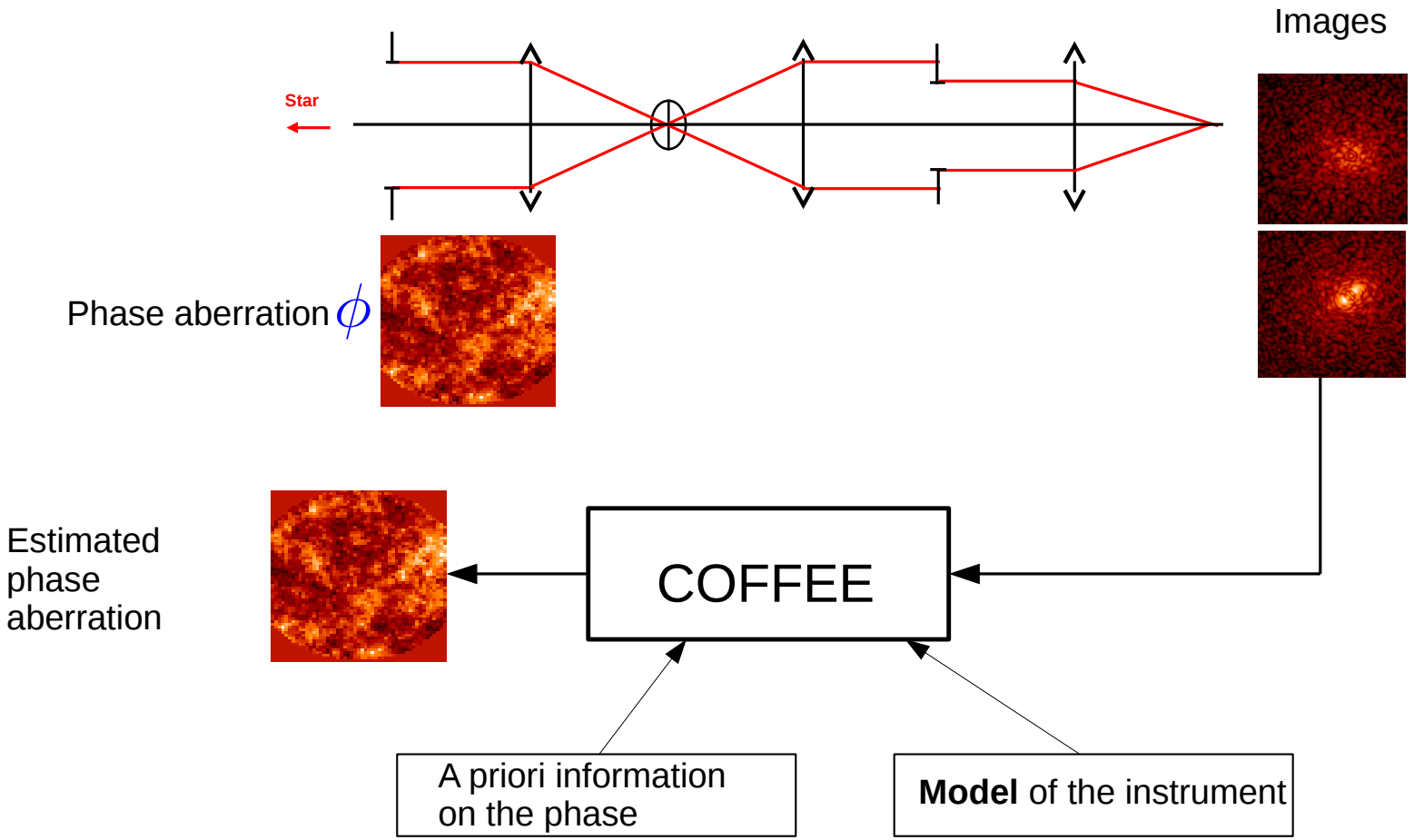


Non-common path aberrations $\Rightarrow$ need for wave-front sensing using the **scientific camera**

COFFEE (Paul, Mugnier, Sauvage...)

Principle of COFFEE: coronagraphic phase diversity



COFFEE: equation

Principle of COFFEE: maximum a posteriori estimation

Minimize

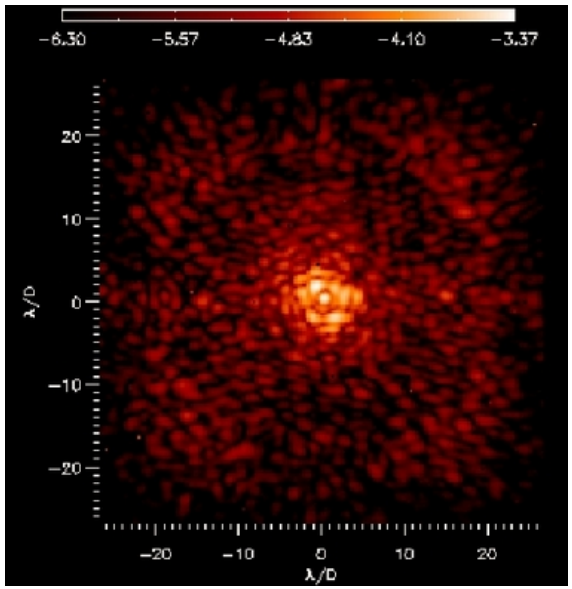
$$J(\phi) = \sum_{(x,y)} \left\| \frac{\text{images}(x,y) - \textbf{model}[\phi](x,y)}{\sigma(x,y)} \right\|^2 + \mathcal{R}(\phi), \quad (1)$$

- ϕ: phase aberrations that generates speckles
- "images": set of actual scientific images
- "model": set of outputs of our model of the instrument
- σ: standard deviation of the measurement noise
- $\mathcal{R}$: regularisation term (a priori information on ϕ)

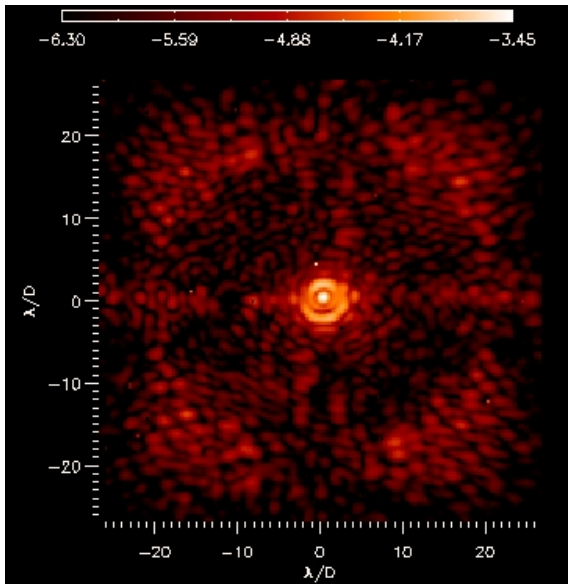
COFFEE on SPHERE during integration

Paul & al. 2014

Before COFFEE measurement and compensation



After COFFEE measurement and compensation



Need for an extended COFFEE

Limitations:

- Internal source calibration does not measure aberrations of the telescope
- Quasi-static aberrations evolve during the night (about 20 nm/hour on SPHERE)

$\Longrightarrow$ Need for aberrations calibration during the night

$\Longrightarrow$ Need for COFFEE on sky

$$J(\phi) = \sum_{(x,y)} \left\| \frac{\text{images}(x,y) - \textbf{model}[\phi](x,y)}{\sigma(x,y)} \right\|^2 + \mathcal{R}(\phi), \quad (2)$$

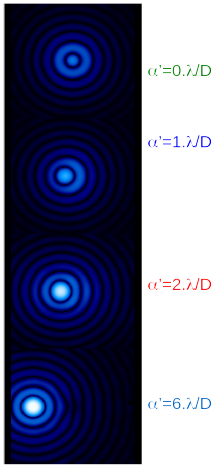
Problem: model of coronagraphic image formation with atmospheric turbulence?

Expression for long-exposure coronagraphic PSF

$$h_{lec}(\alpha; \phi, D_\phi) = \tag{3}$$

- h_{lec}: mean light intensity at any given point α of the detector
- ϕ: quasi-static aberrations
- D_ϕ: characterizes the statistic of atmospheric turbulence

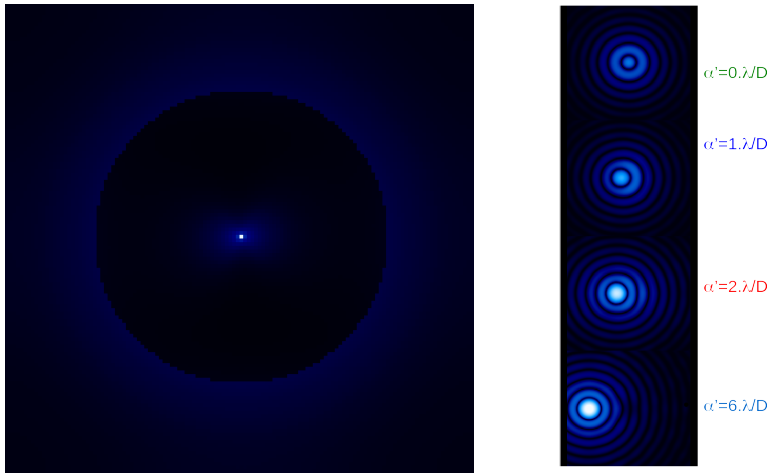
Expression for long-exposure coronagraphic PSF



$$h_{lec}(\alpha; \phi, D_\phi) = \int_{\alpha'} h_c(\alpha; \phi + \text{tilt}(\alpha')) \, \mathrm{d}\alpha' \qquad (3)$$

- h_{lec}: mean light intensity at any given point α of the detector
- ϕ: quasi-static aberrations
- D_ϕ: characterizes the statistic of atmospheric turbulence
- h_c: coronagraphic model without turbulence

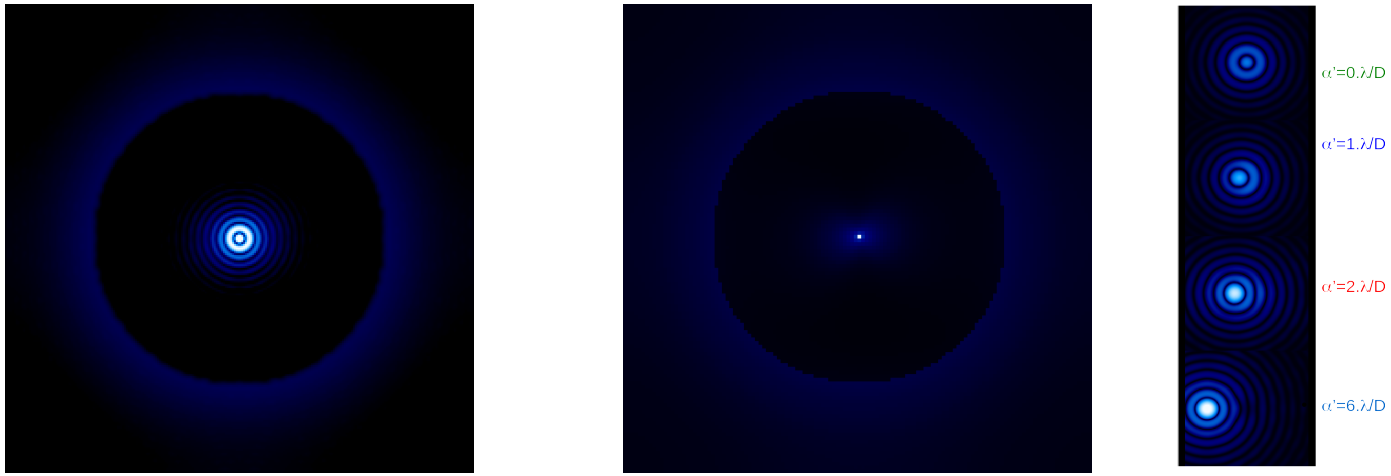
Expression for long-exposure coronagraphic PSF



$$h_{lec}(\alpha; \phi, D_\phi) = \int_{\alpha'} h_a(\alpha'; D_\phi) \times h_c(\alpha; \phi + \text{tilt}(\alpha'))\, \mathrm{d}\alpha' \qquad (3)$$

- h_{lec}: mean light intensity at any given point α of the detector
- ϕ: quasi-static aberrations
- D_ϕ: characterizes the statistic of atmospheric turbulence
- h_c: coronagraphic model without turbulence
- h_a: atmospheric PSF (energy spectrum density)

Expression for long-exposure coronagraphic PSF



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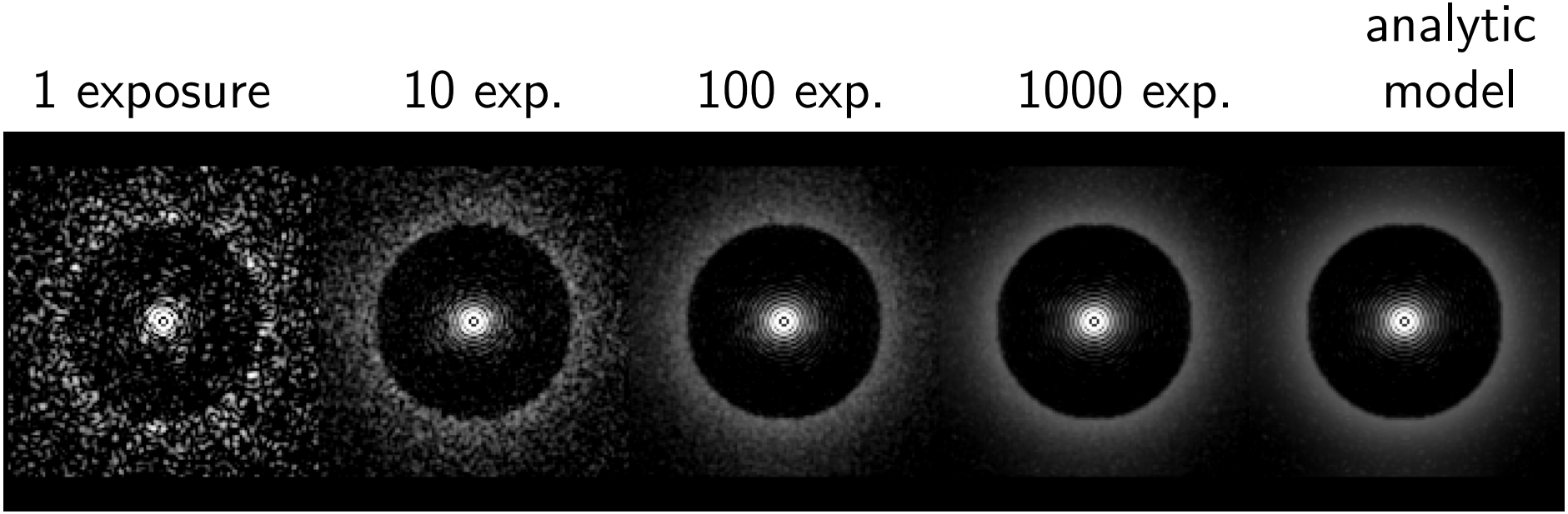
Validation + use cases

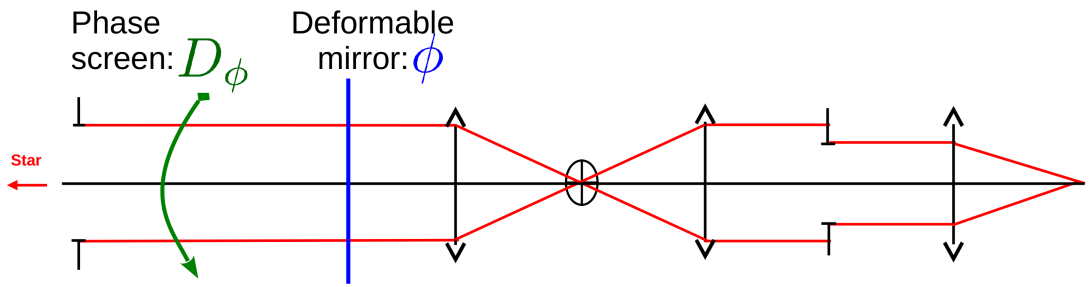


Useful for

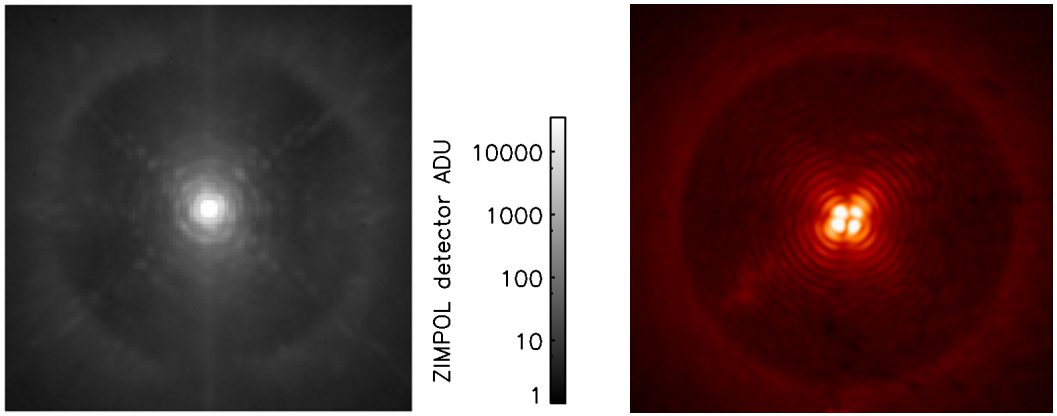
- Simulation;
- Image reconstruction (MEDUSAE);
- Online wave-front sensing (COFFEE).

Experimental validation of online COFFEE

MITHIC at laboratoire d'astrophysique de Marseille

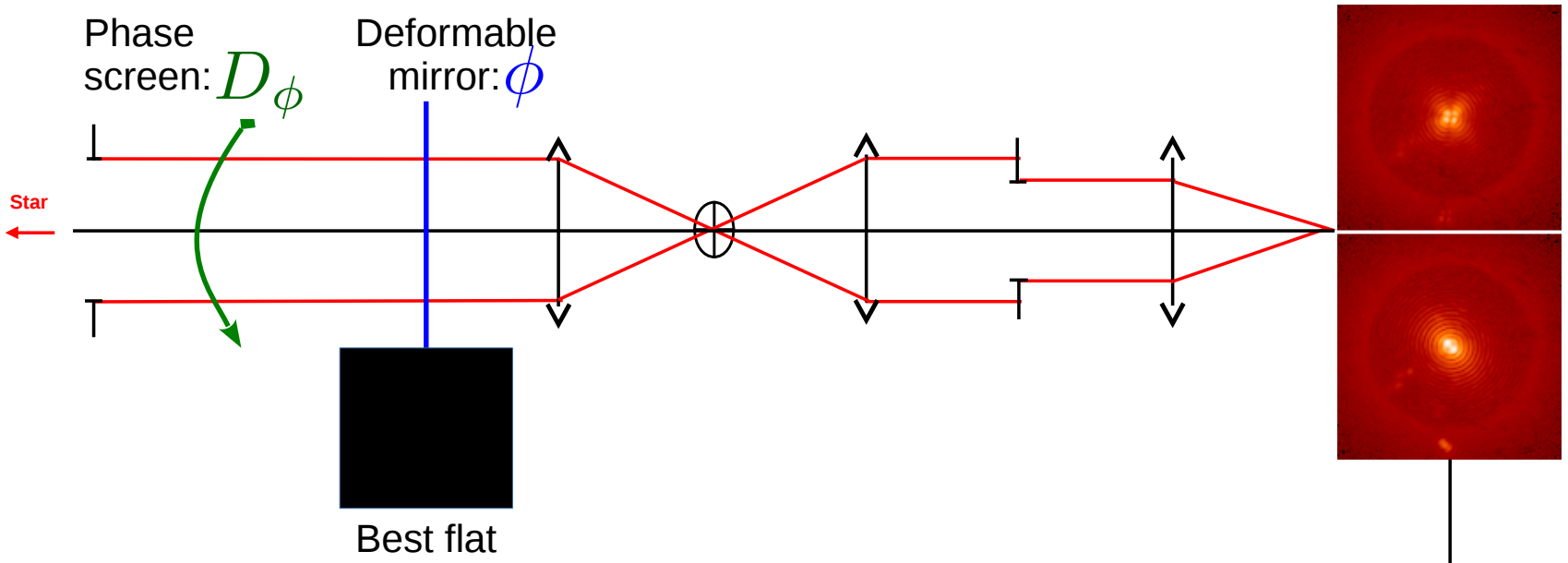


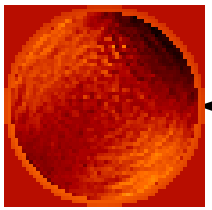
MITHIC+rotating residual phase screen: lab model of SPHERE on the Very Large Telescope:



Left: PSF of SPHERE on the VLT. Right: PSF on MITHIC

Data on the best flat





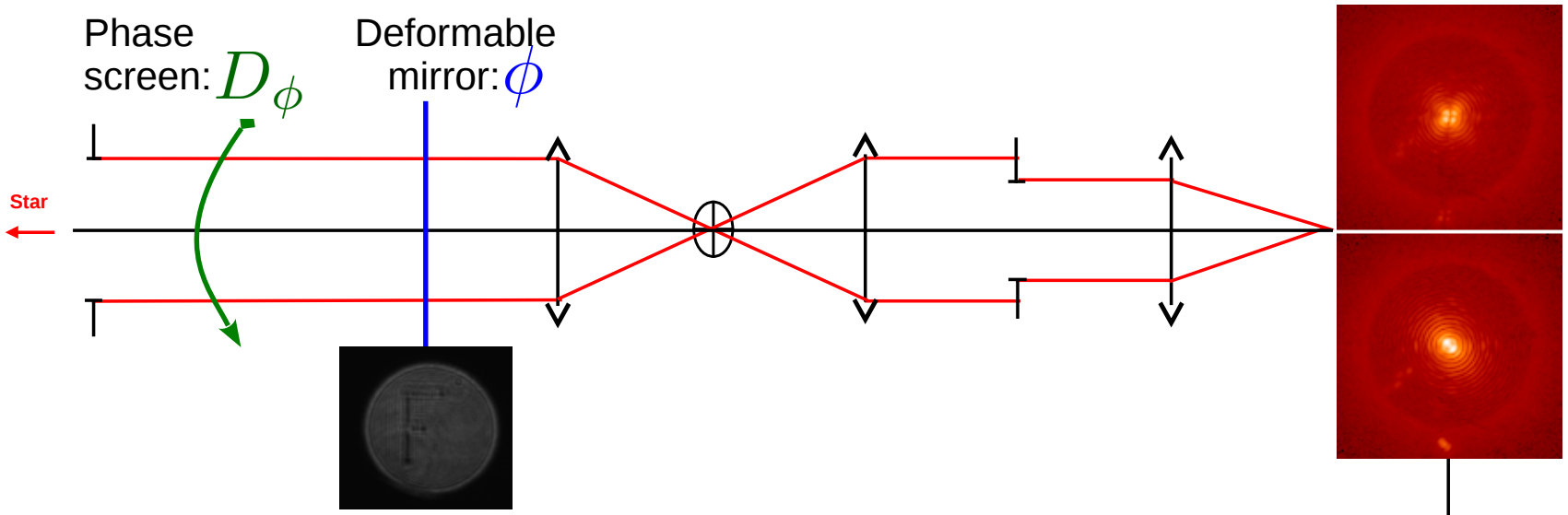
Estimated phase aberration of best flat

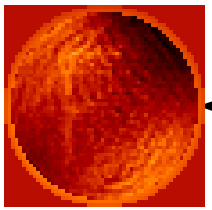
COFFEE

A priori information on the phase

Model of the instrument

Data on best flat + F (11 nm)





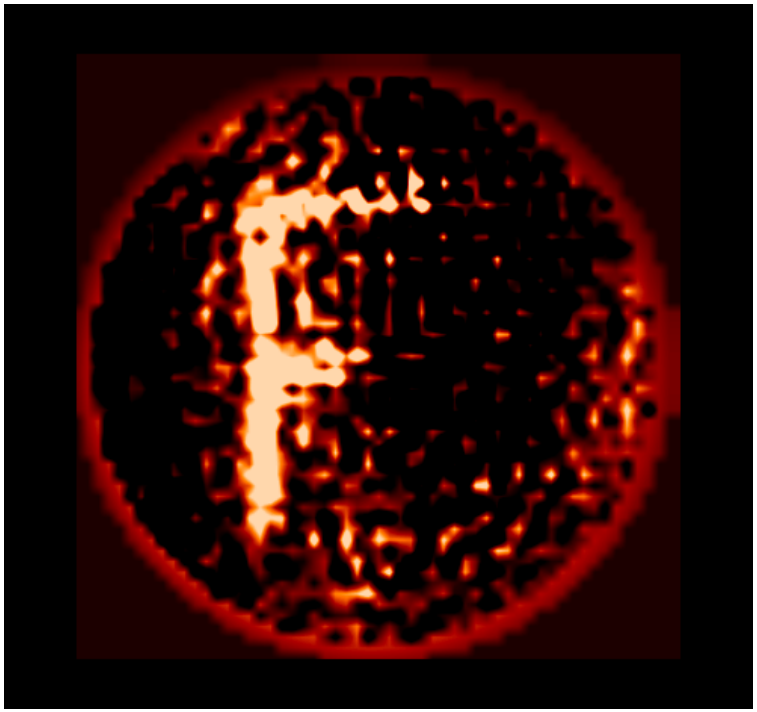
Estimated phase aberration of (best flat + F)

COFFEE

A priori information on the phase

Model of the instrument

A preliminary result



(estimated wave-front with best flat) - (estimated wavefront with F):
13.5 nm RMS

The non-linear dark hole

Principle of NLDH: energy minimization in the dark hole

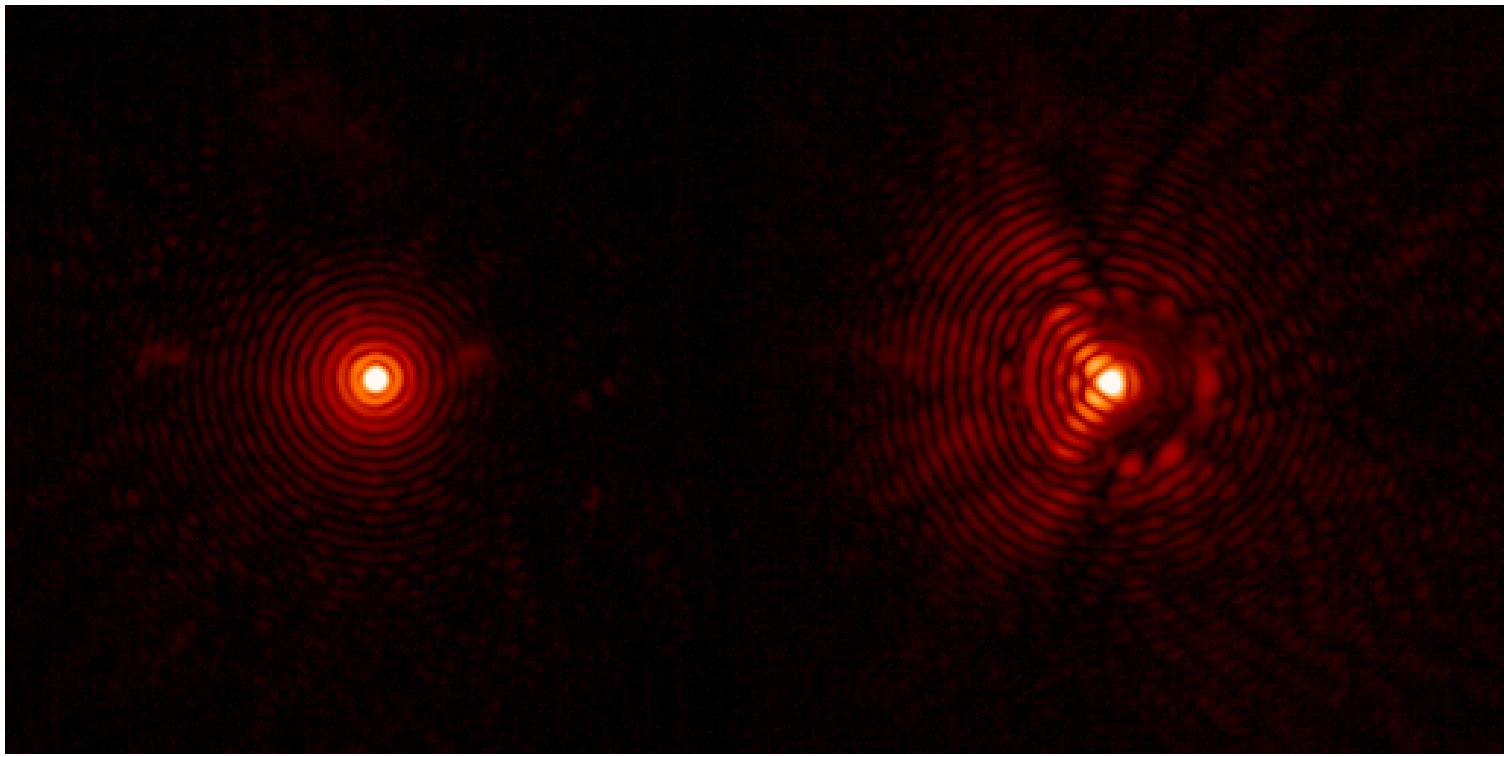
Minimize

$$J(\phi) = \sum_{(x,y)\in\mathcal{DH}} \|\text{model}[\phi](x,y)\|^2 \tag{4}$$

- ϕ: phase aberration
- "model": output of our imaging model of the instrument
- $\mathcal{DH}$: the dark hole in the focal plane

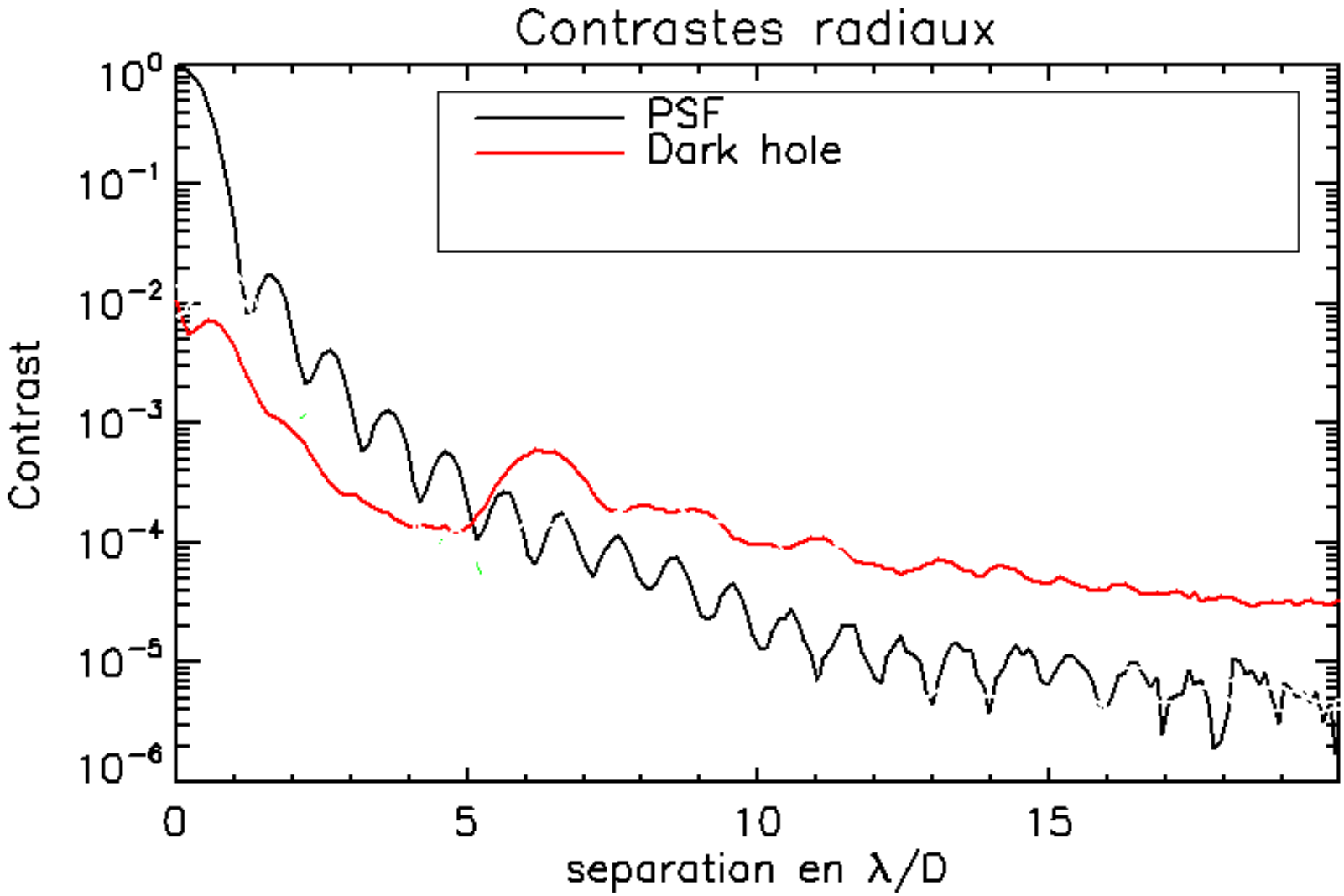
Experimental validation: psf

- Focal-plane phase measurement
- Calculation of actuators input for non-linear dark hole



Best flat Dark hole

Experimental validation: contrast



Conclusion & perspectives

- Analytic expression for long-exposure coronagraphic PSF
- Extension of COFFEE + first experimental validation
- First experimental validation of non-linear dark hole

- Soon: coronagraphic non-linear dark hole
- Soonish: COFFEE measurement and correction on sky