PHASE DIVERSITY AS A TOOL TO SENSE NON-COMMON PATH ABERRATIONS IN SHARK-NIR: STRATEGIES AND SIMULATED PERFORMANCES

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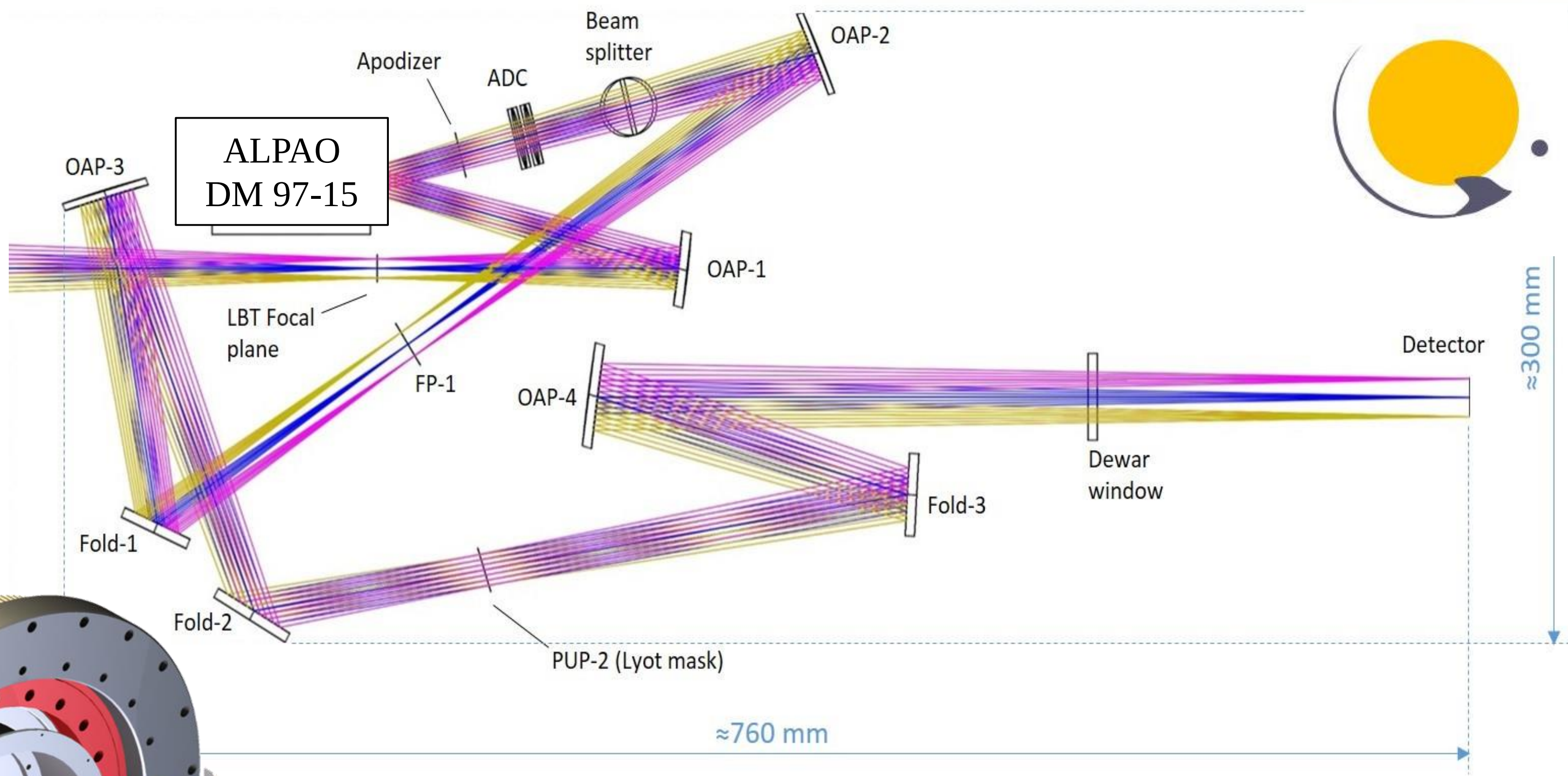
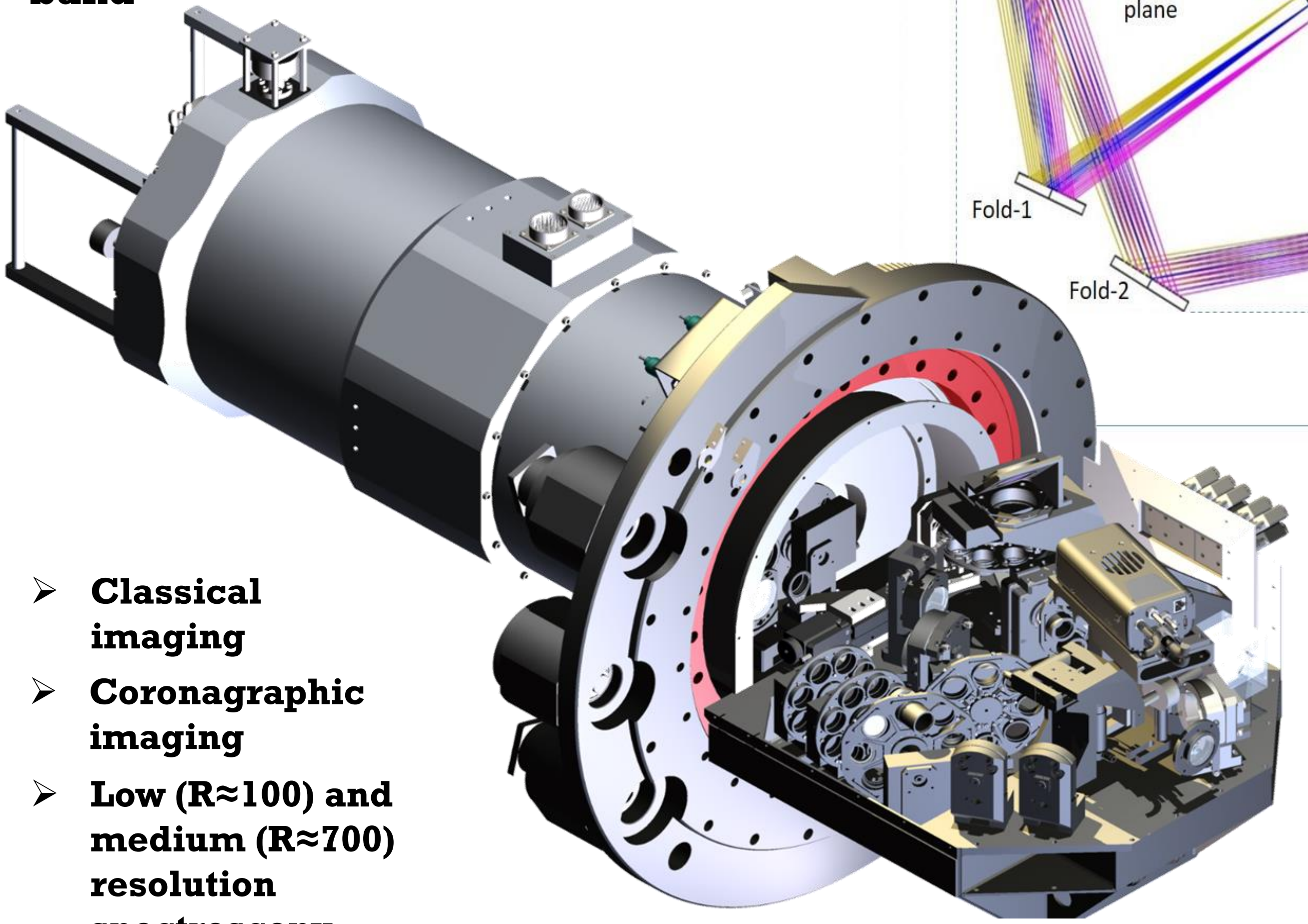
SHARK-NIR

System for **C**oronagraphy with **H**igh-order **A**daptive Optics from **R** to **K** band





- **Classical imaging**
- **Coronagraphic imaging**
- **Low (R≈100) and medium (R≈700) resolution spectroscopy**

Wavelength range	0.96 – 1.7 μm
Detector format [px]	2048 x 2048
FoV ["]	18 x 18
Pixel scale ["/px]	0.0145
Airy radius @ λ=0.95 μm [px]	2
Working F/#	31.4
# of mirrors	8 (3 flat, 1 DM and 4 off-axis parabolas)

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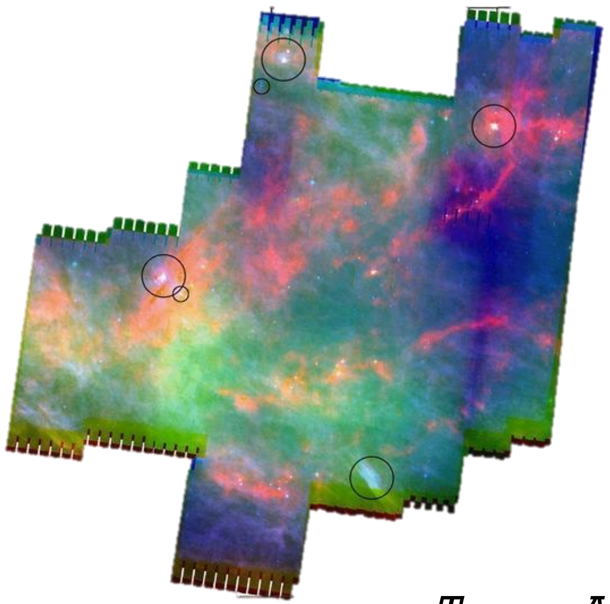
SCIENCE – EXOPLANETS WITH SHARK-NIR

What will SHARK-NIR hunt?

- Giant planets around low-mass stars in: SPECIAL
    - nearby Taurus-Auriga SFR (1-10 Myr)
    - young moving groups (10-100 Myr)

- Brown dwarfs in stellar associations/open clusters (e.g. Pleiades)



Taurus-Auriga star forming region (140 pc)

What can we do?

- Astrometry to determine dynamical masses (short period systems)

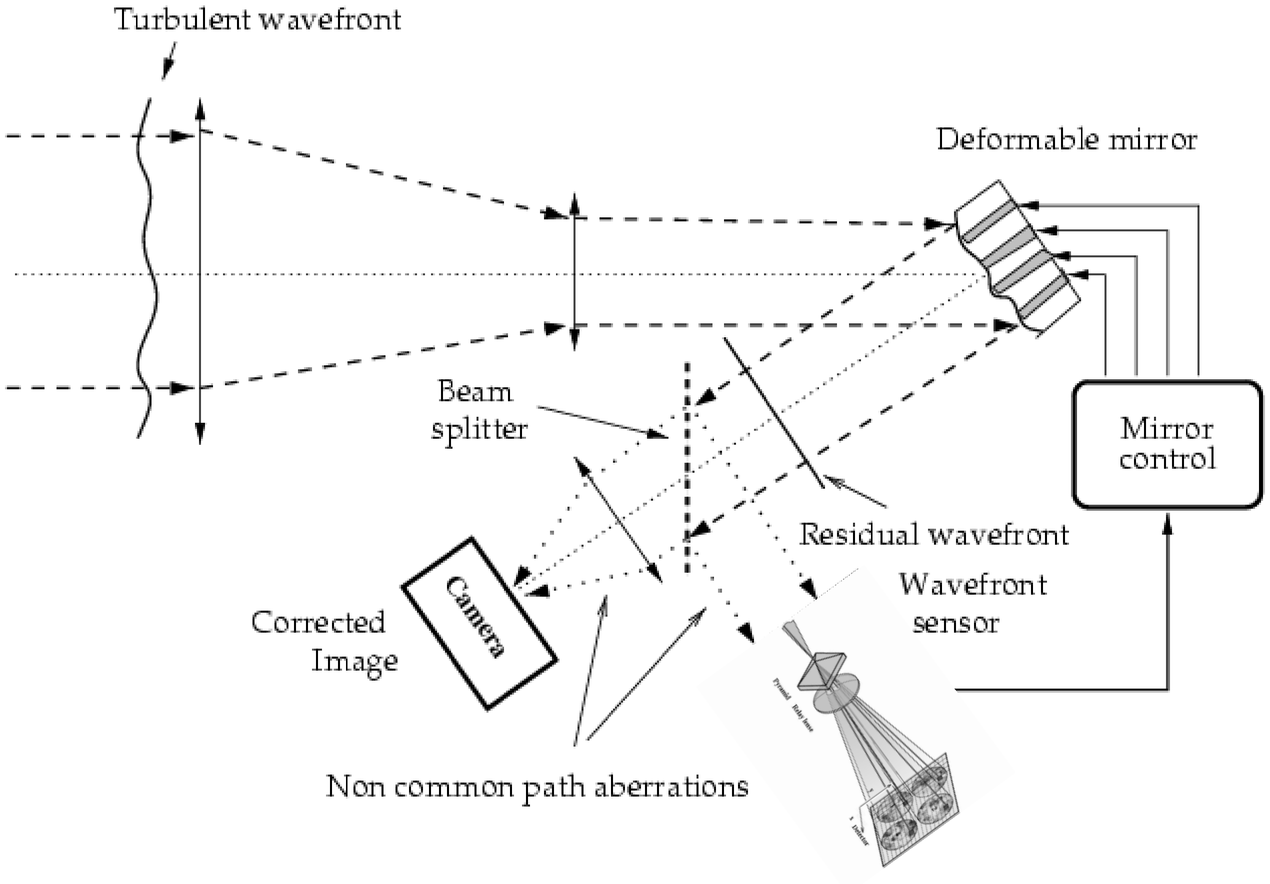
- Low and medium resolution long-slit spectroscopy to study the atmosphere

NON COMMON PATH ABERRATIONS

Differential aberrations between WFS and scientific camera

Stable over long periods… but if not that stable?

… need for a backup plan:
On-line Sensing and compensation



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NON COMMON PATH ABERRATIONS

Need for ***local*** and ***on-line*** sensing and correction

Which are the requirements then?

- Fast sensing
- Local, but with small opto-mechanical impact
- Sensitive to the whole non-common path upstream of the coronagraphs

PHASE DIVERSITY: THE PRINCIPLE

- What is Phase Diversity? A Focal Plane WFS technique

- How does this kind of sensor work? Recover phase information from intensity measurements (''*Phase retrieval*'' algorithm)

… Two major drawbacks using a single image:

I. Not unique solution
II. Only works with point-like sources

Gonsalves and Chidlaw (1982):

Use two images of the same (whatever) object with a known finite relative defocus

PHASE DIVERSITY: THE ALGORITHM

The algorithm has been developed at ONERA:

- Numerical minimization of the criterion:

$$J_{LS}(\phi) = \frac{1}{2}\sum_{v} \frac{\left(\left|\tilde{i}_f(v) - \tilde{h}_f(\phi,v)\tilde{o}(\phi,v)\right|^2\right)}{\sigma_f^{\ 2}} + \frac{\left(\left|\tilde{i}_d(v) - \tilde{h}_d(\phi,v)\tilde{o}(\phi,v)\right|^2\right)}{\sigma_d^{\ 2}}$$

- Joint estimation of object and phase by fast conjugate-gradient method

- Pixel-wise estimation

- Validated both in simulations and experimentally

J.-F. Sauvage, T. Fusco et al., "Calibration and precompensation of noncommon path aberrations for extreme adaptive optic", Journal of the Optical Society of America A, vol. 24, Issue 8, pp.2334-2346, 2007

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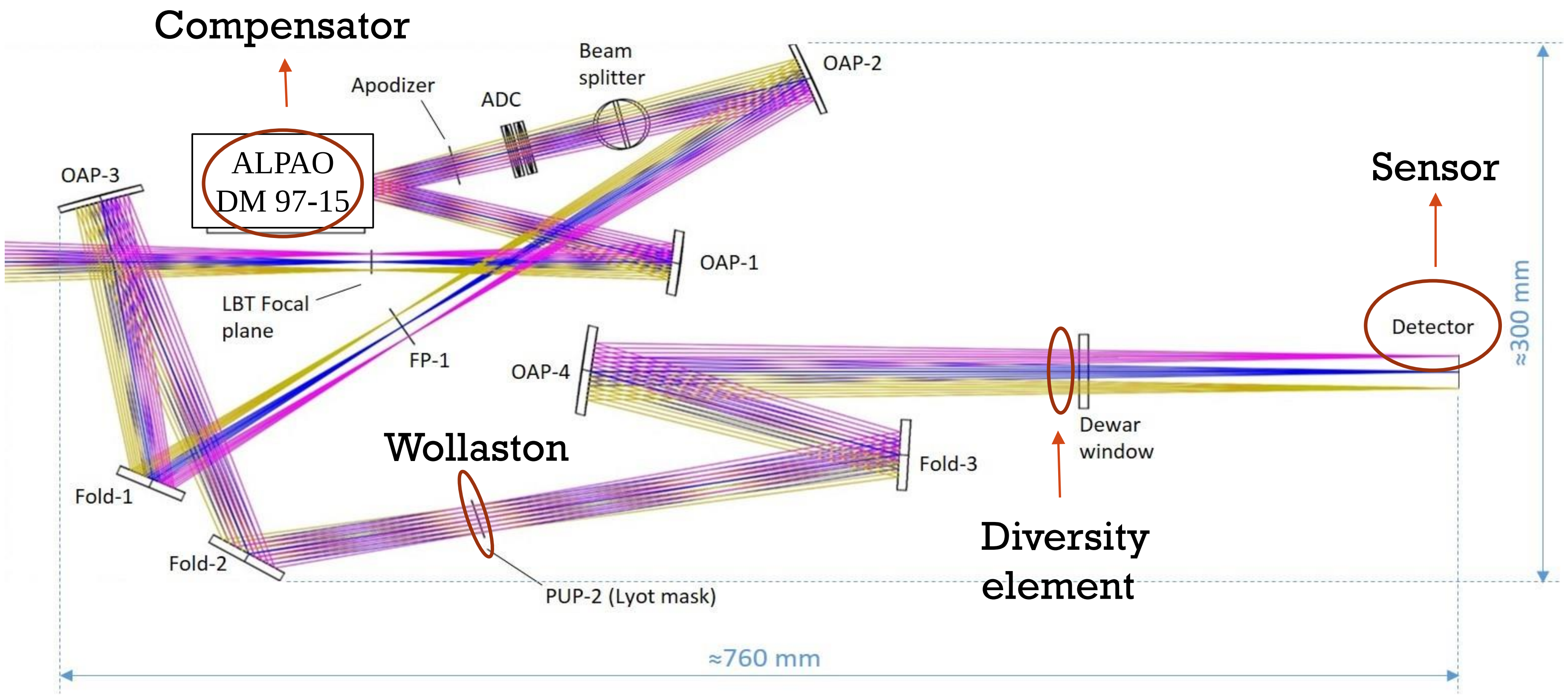
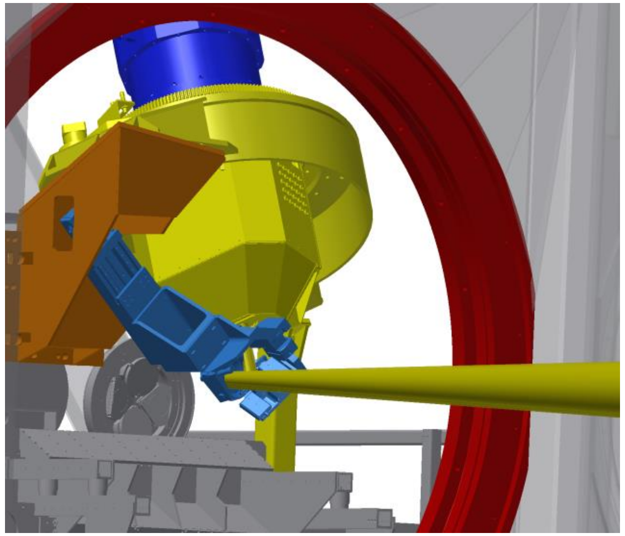
PHASE DIVERSITY IN SHARK-NIR

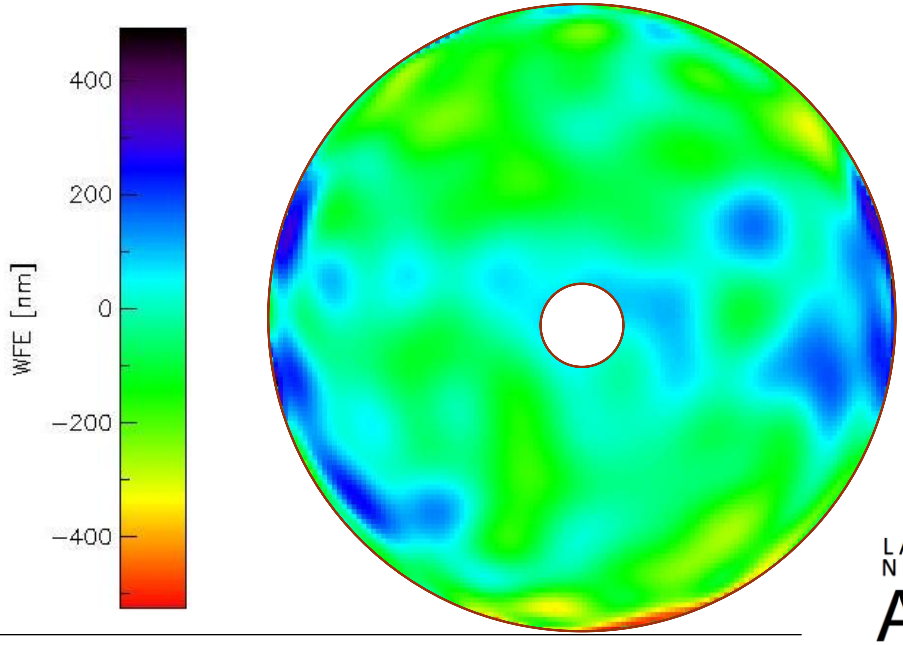
Simultaneous generation of focus/defocus images on the scientific camera with either natural or artificial light



NCPA IN SHARK-NIR

Contributor	rms WFE [nm]	Aberration type/spectrum
Dichroic nominal transmitted WFE	31	28nm chromatic dispersion + 13nm astigmatism.
Dichroic manufacturing transmitted WFE	28	The expected PSD is f^{-2} [cycles/pupil].
Dichroic manufacturing reflected WFE	23	The expected PSD is f^{-2} [cycles/pupil].
Manufacturing (dichroic excluded) tolerances	90	The expected PSD is f^{-2} [cycles/pupil].
Alignment tolerances	35	29nm astigmatism + 2nm coma + 3nm spherical ab.
TOTAL	110	





PD ON SKY: SIMULATIONS

POP (Physical Optics Propagation) code based on IDL library PROPER

R = 8 - 12

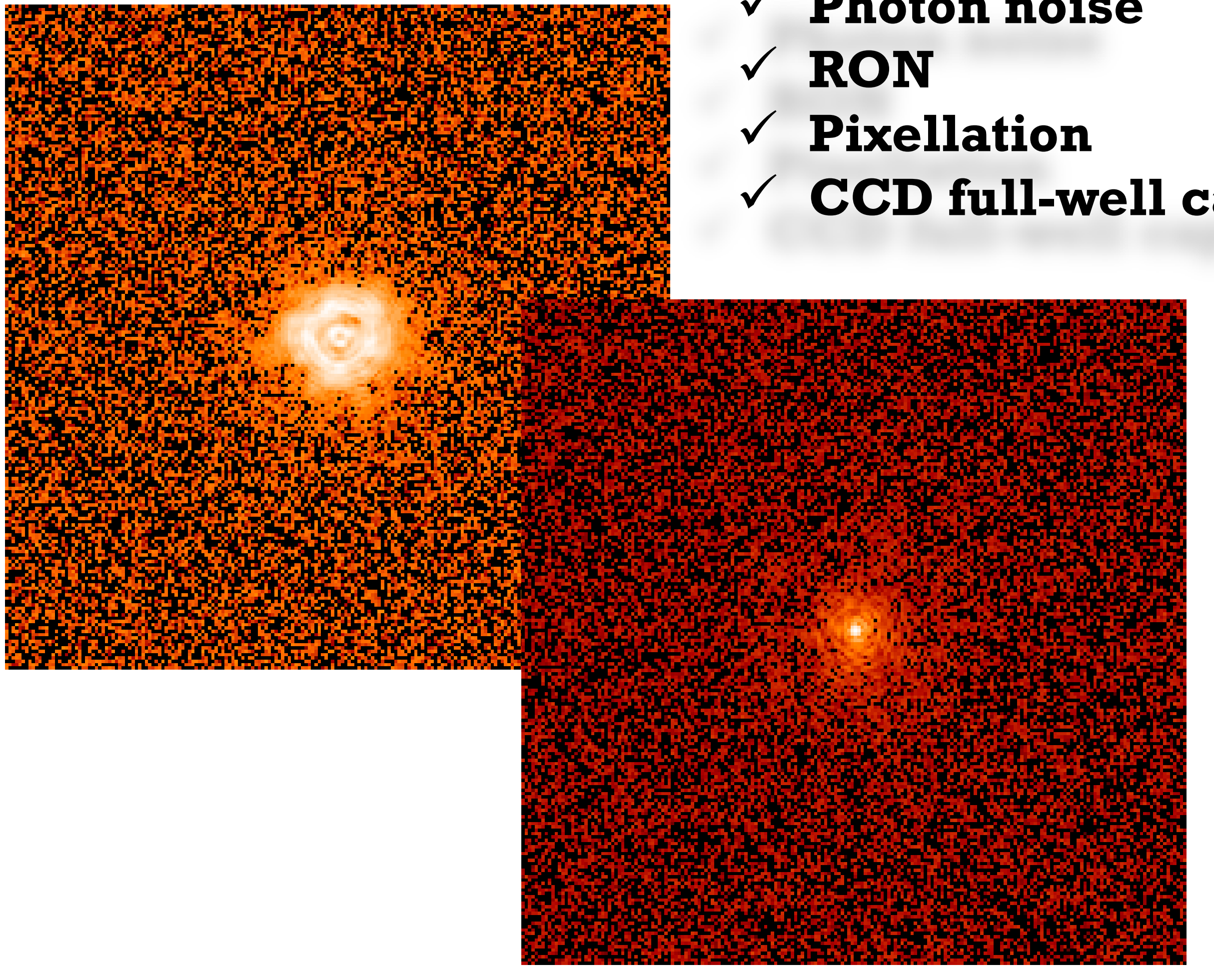
Seeing = 0.4” – 1.2”

DIT = 1-10 s

Residual jitter: 0-10 mas rms

Band: H (1.558 μm) - polychromatic

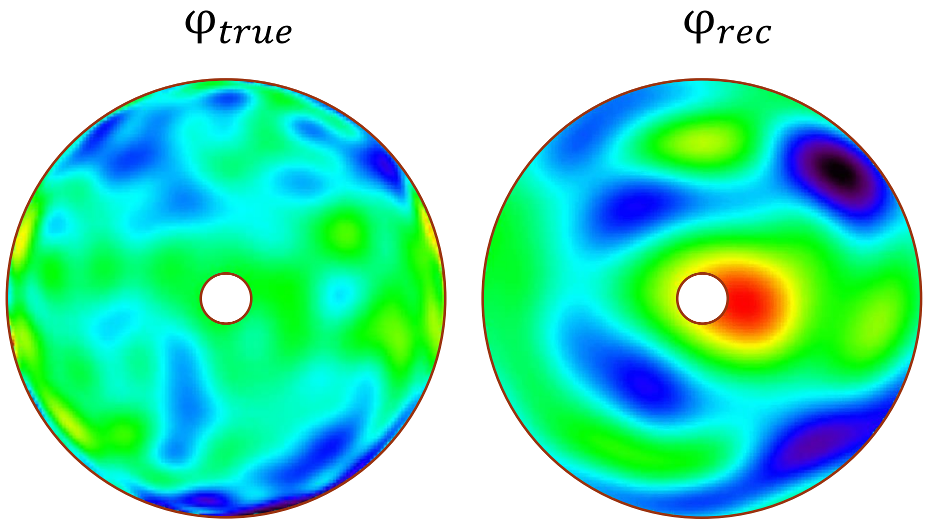
Defocus: 2λ ptv

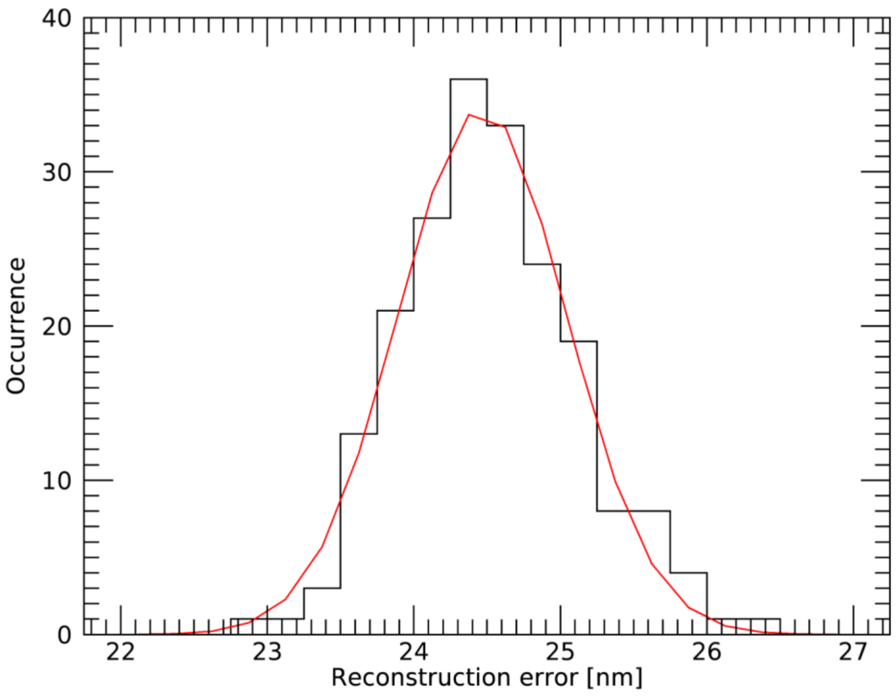


- ✓ **Photon noise**
- ✓ **RON**
- ✓ **Pixellation**
- ✓ **CCD full-well capacity**

RECONSTRUCTION ERROR

$$\text{Error} = rms(\varphi_{rec} - \varphi_{true})$$





~200 realizations of the focused/defocused images

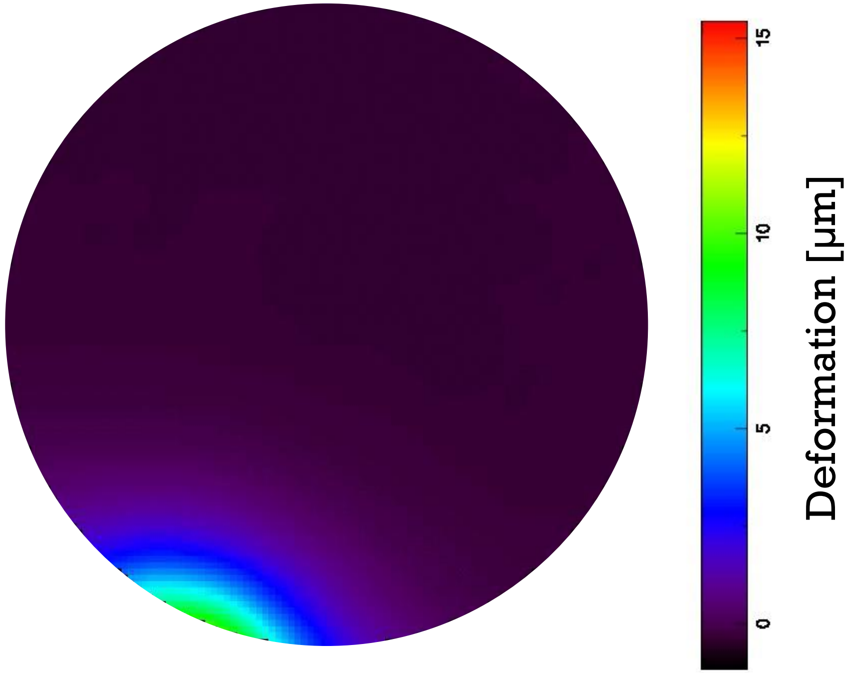
20s to convergence with high SNR

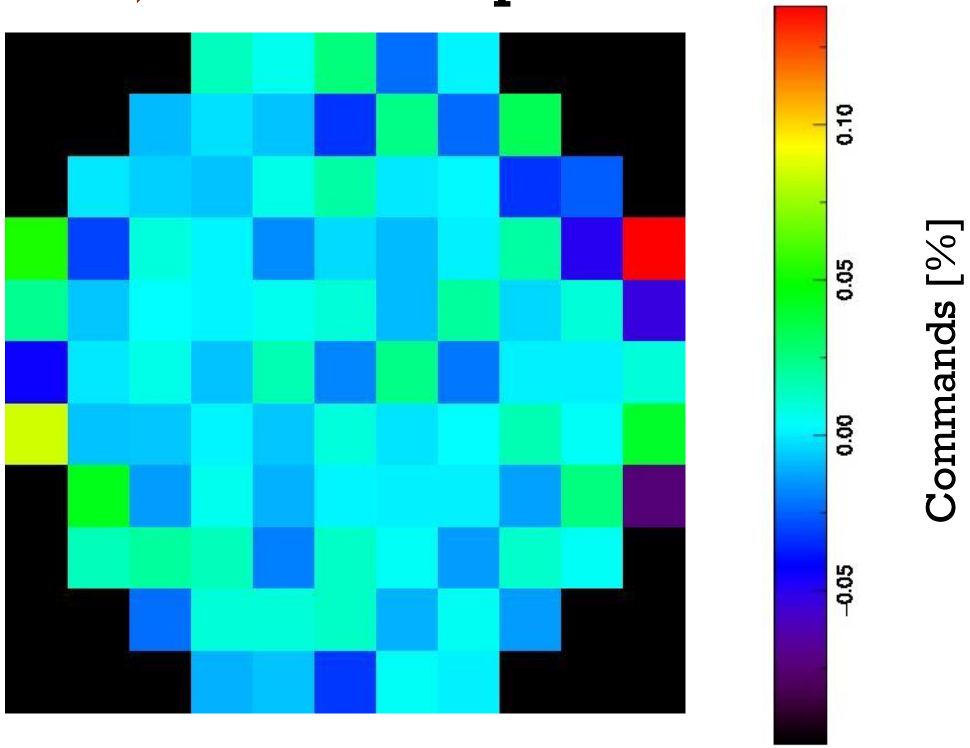
FITTING ERROR

Fit of the reconstructed map with **ALPAO DM97-15**

Real measured influence functions

Reconstructed wavefront ➡ DM commands ➡ Best DM shape





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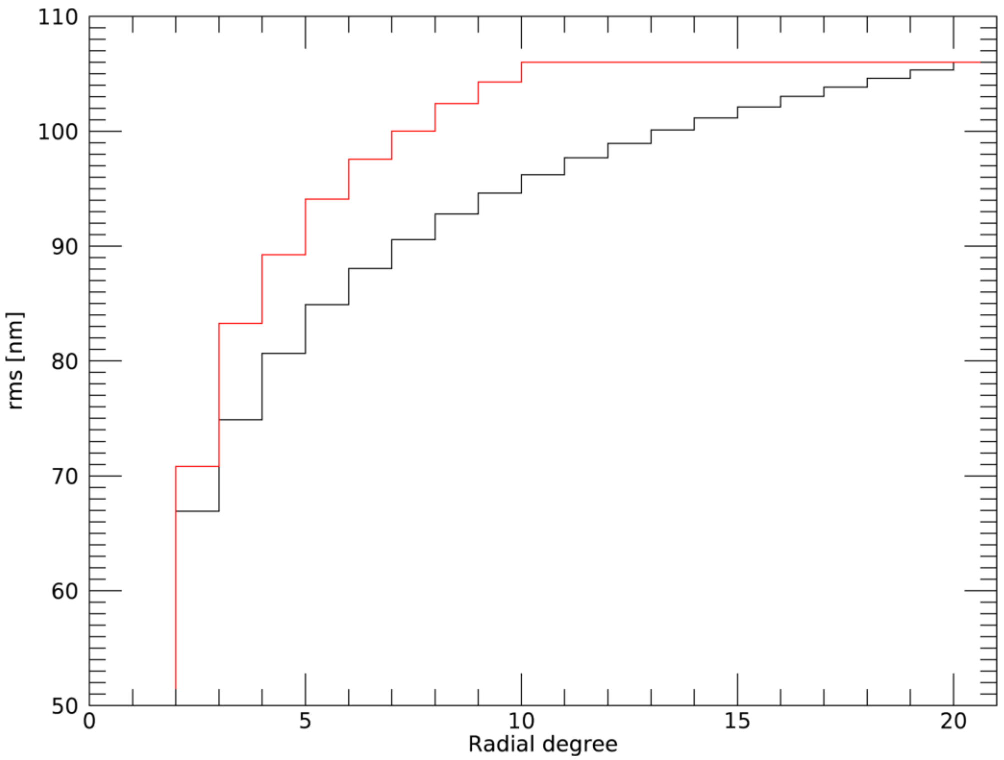
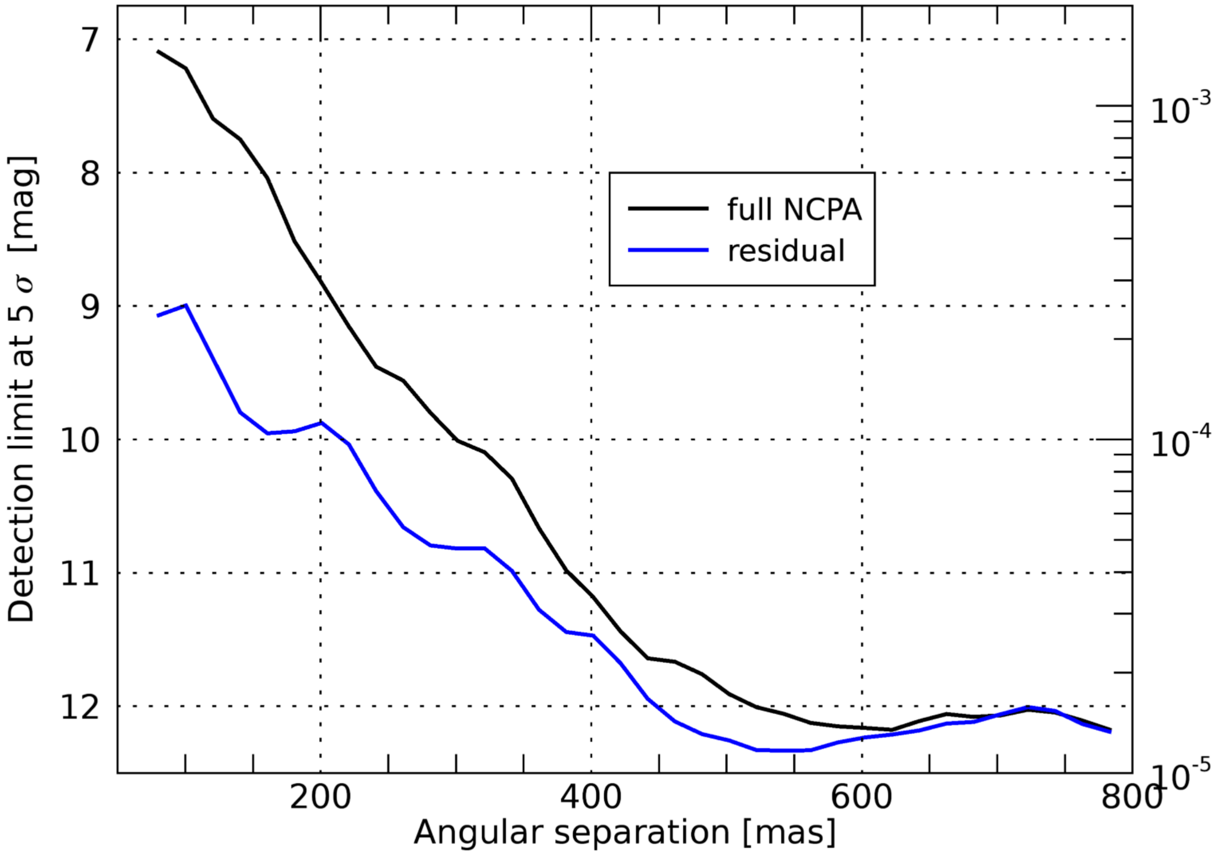
PD ON SKY: PERFORMANCE ESTIMATION

	Reconstruction Error [nm]	σ_{REC}	Residual after DM fitting [nm]	σ_{RES}
Low-orders	**15.7**	0.6	**20.4**	0.5
High-orders	**24.9**	0.6	**42.4**	0.3



Jitter: 3 mas rms
R = 10
Seeing = 0.6”
DIT = 1.0s

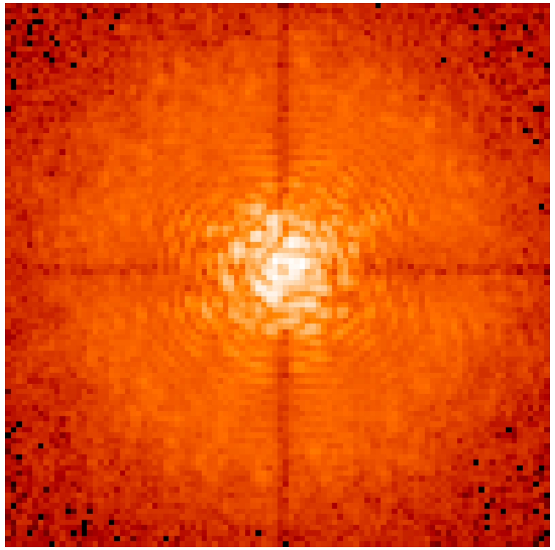
PD ON SKY: PERFORMANCE ESTIMATION



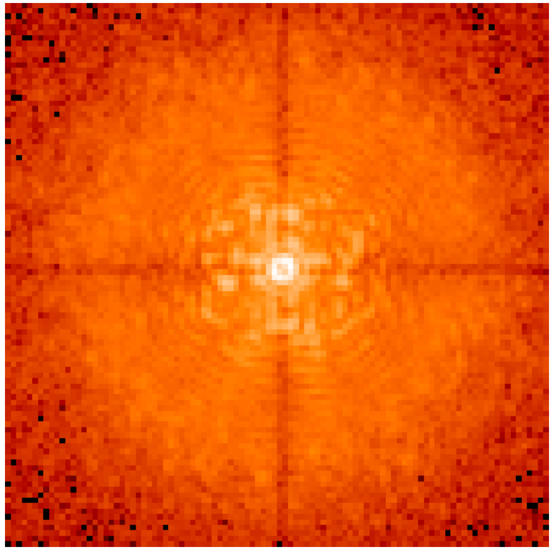
Detection limit post-ADI

FQPM coronagraph

Before



After



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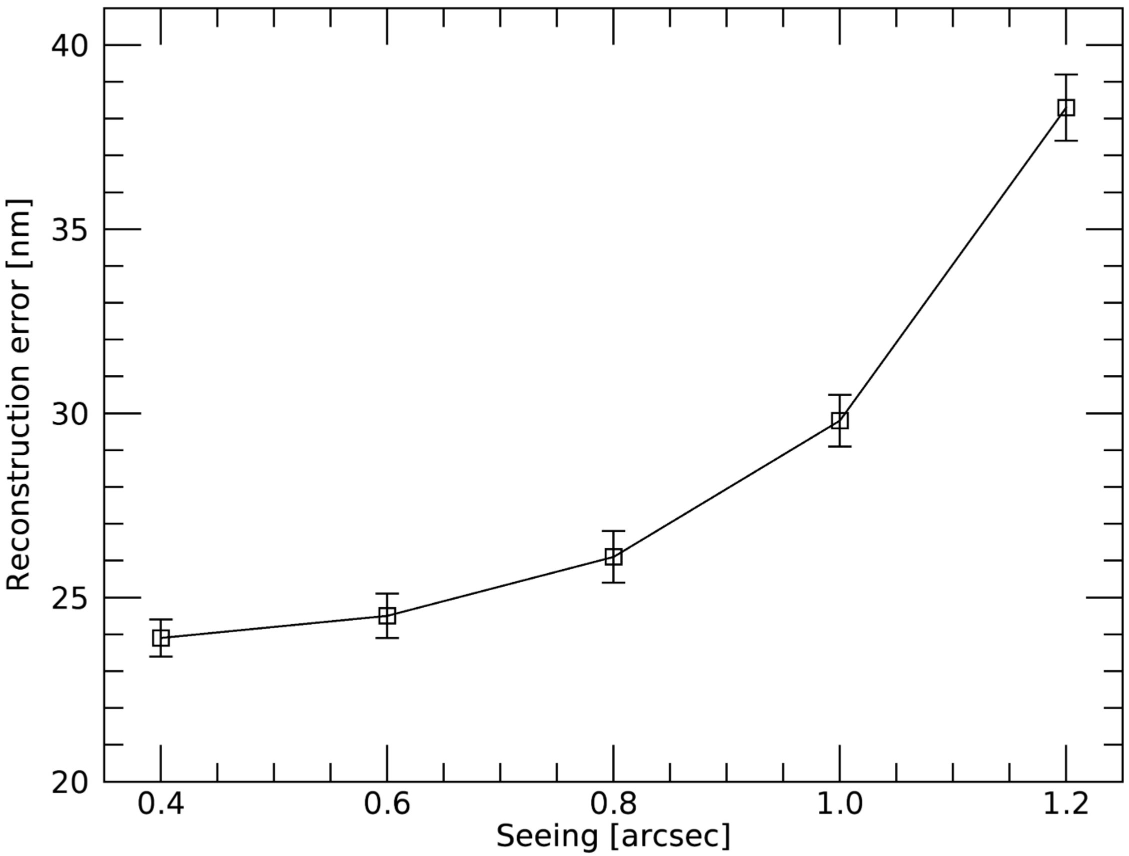
PD ON SKY: RECONSTRUCTION VS SEEING

Jitter: 10 mas rms
AO: FLAO
R = 8

Seeing ['']	SR	Error [nm]	σ [nm]
0.4	80%	23.9	0.5
0.6	76%	24.5	0.6
0.8	70%	26.1	0.7
1.0	61%	29.8	0.7
1.2	48%	38.3	0.9



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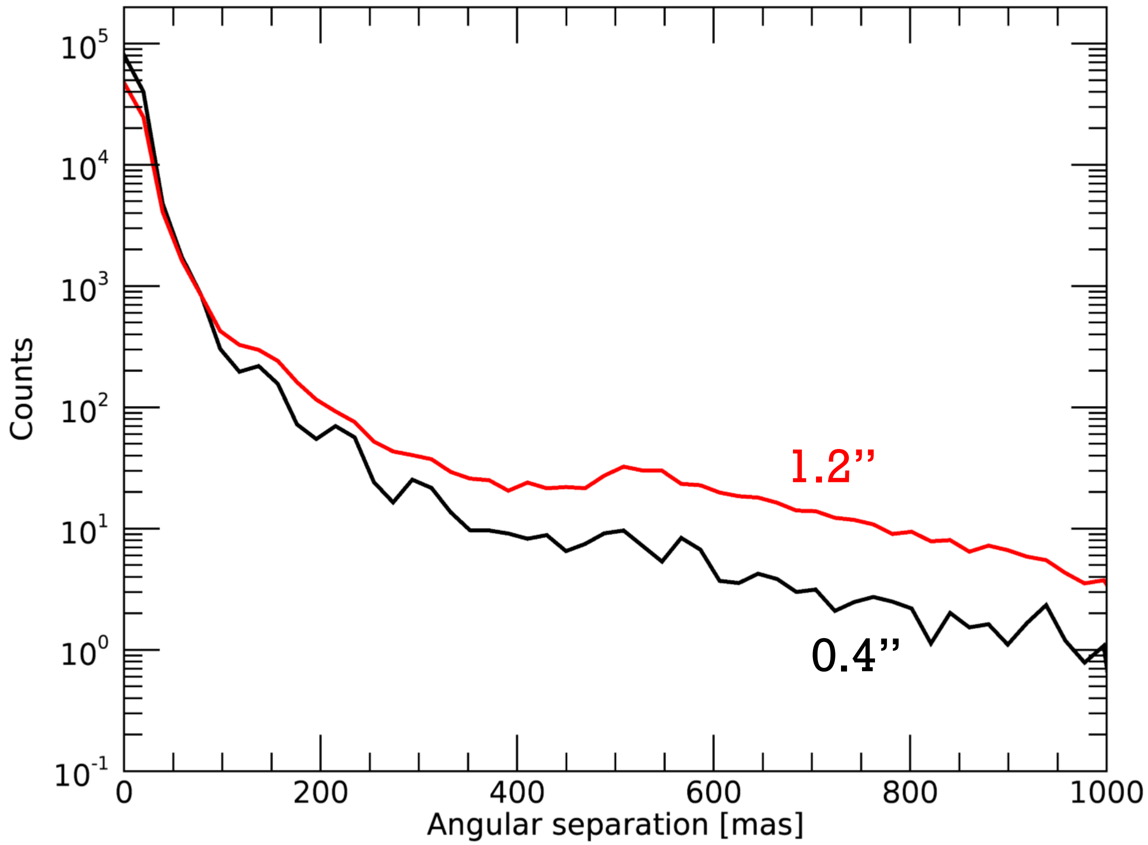
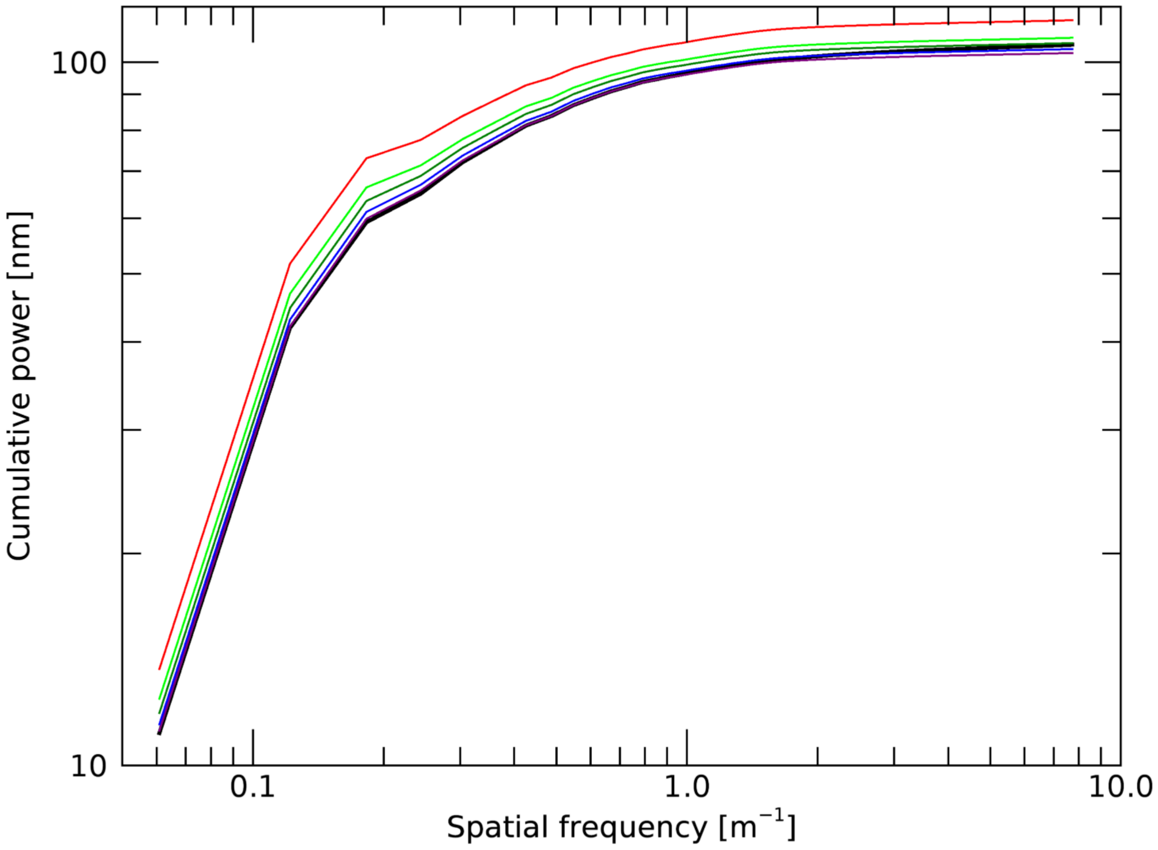
PD ON SKY: RECONSTRUCTION VS SEEING





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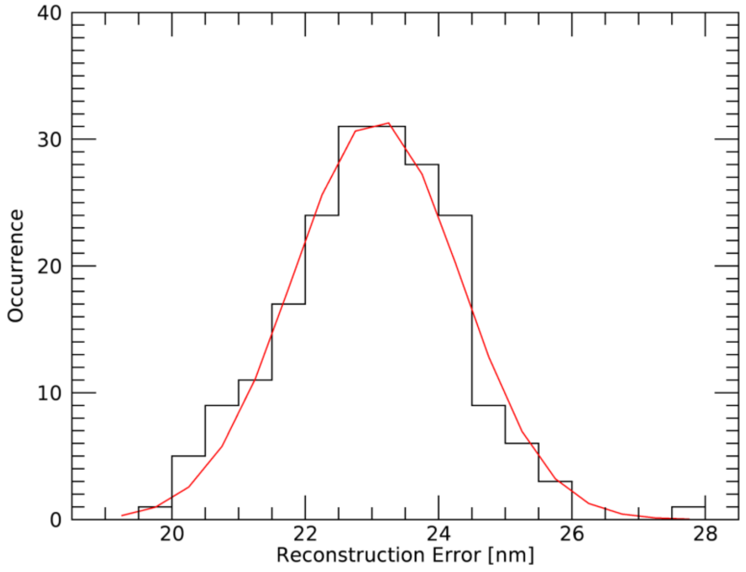
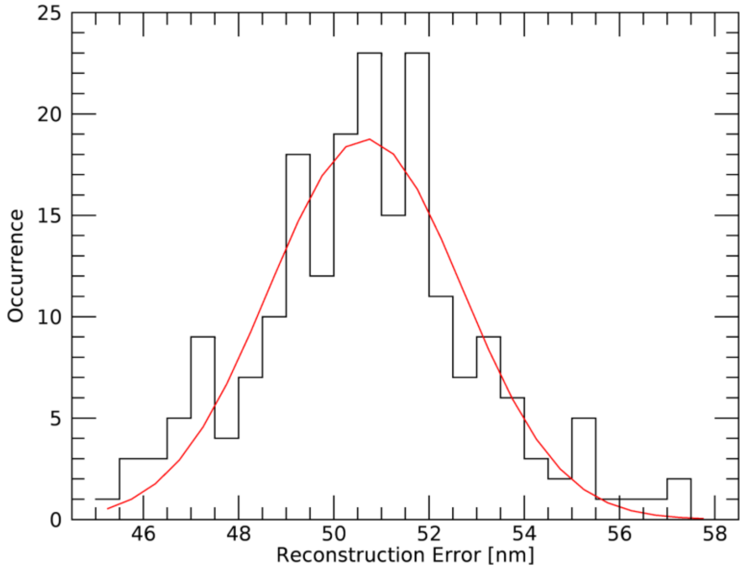
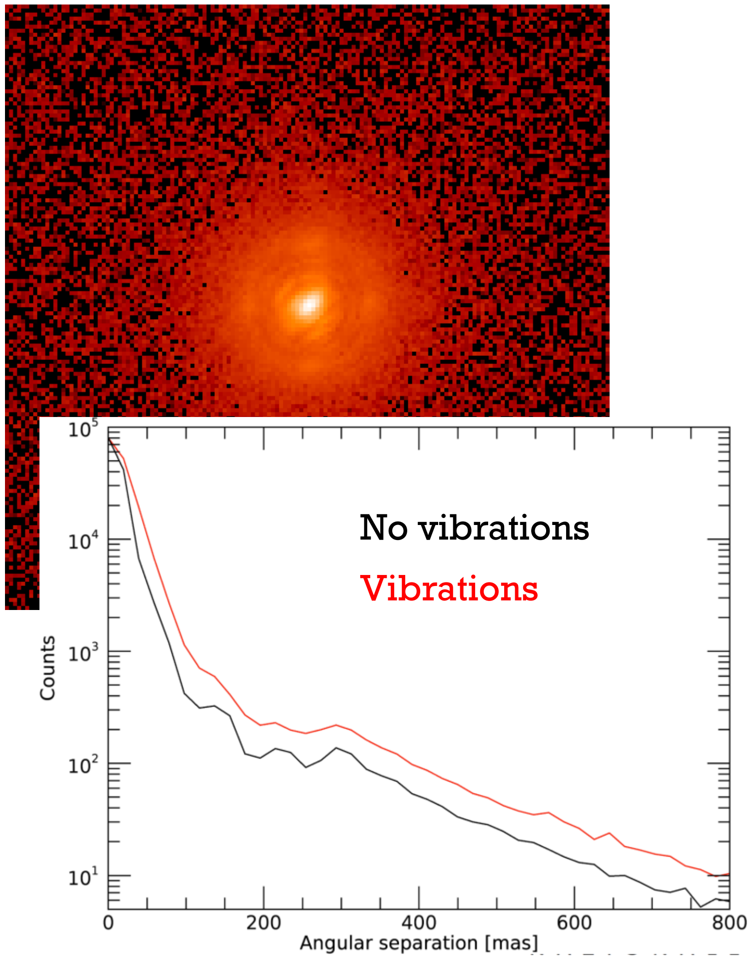
PD ON SKY: RECONSTRUCTION WITH VIBRATIONS

	SR	Error	σ_{REC}
NO VIB	57%	**23.1**	1.3
VIB	34%	**50.7**	2.0

Vibrations: ~70 mas (Open Loop)
R = 12
Seeing = 0.6”
DIT = 10 s







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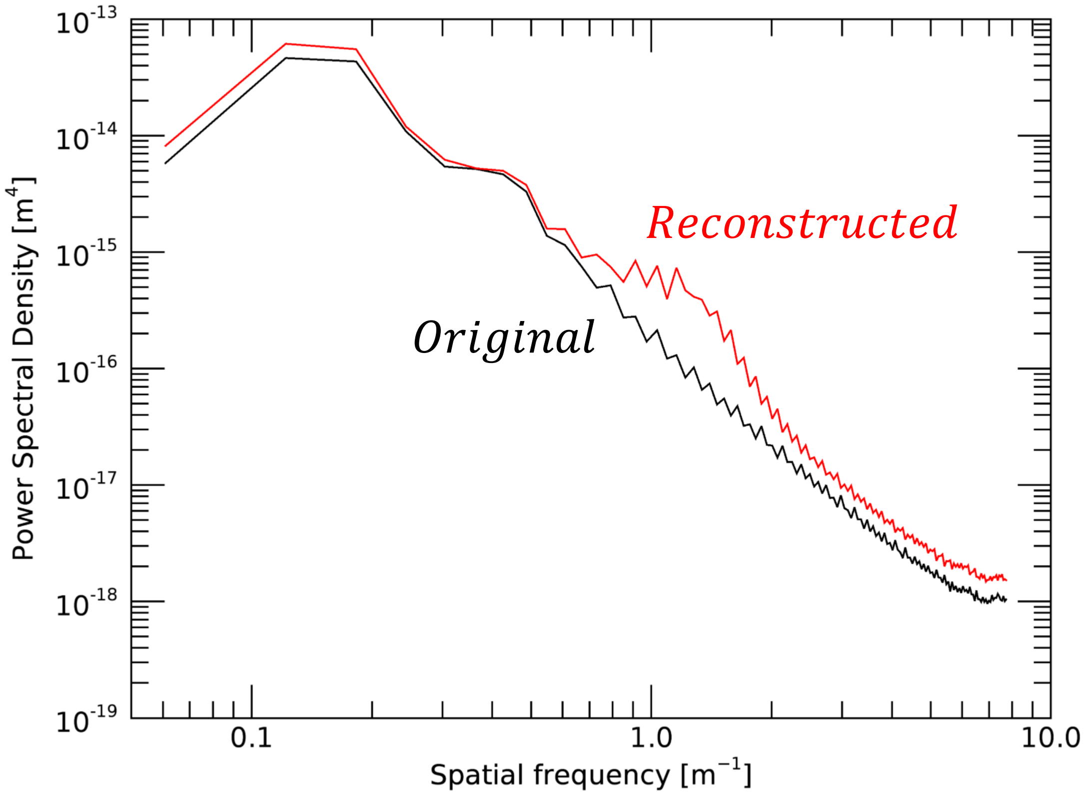
PD ON SKY: RECONSTRUCTION WITH VIBRATIONS

Power spectrum with vibrations:



- High extra-power at low orders
- Bump at 1.0 m-1… the control radius!

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FINAL REMARKS AND CONCLUSIONS

- Phase diversity could be a valuable option in SHARK-NIR for fast on-line sensing of non-common path aberrations

- Working with natural light, AO correction is mandatory in order to mitigate the noise introduced by atmospheric speckles: in closed-loop and high Strehl regime, residuals are expected to be as low as 20 nm using ALPAO DM 97-15

- Simulations show that seeing degradation and vibrations might limitate the recontruction capabilities of the algorithm.

THANK YOU!

PD WITH FIBERS

How to calibrate the defocus we are introducing?