VALIDATING THE PHASE DIVERSITY APPROACH FOR SENSING NCPA IN SHARK-NIR WITH E2E SIMULATIONS

Vassallo D. , Carolo E., Farinato J., Bergomi M., Greggio D., Magrin D., Marafatto L., Ragazzoni R., Viotto V., Agapito G., Esposito, S., Pinna E., Puglisi A.

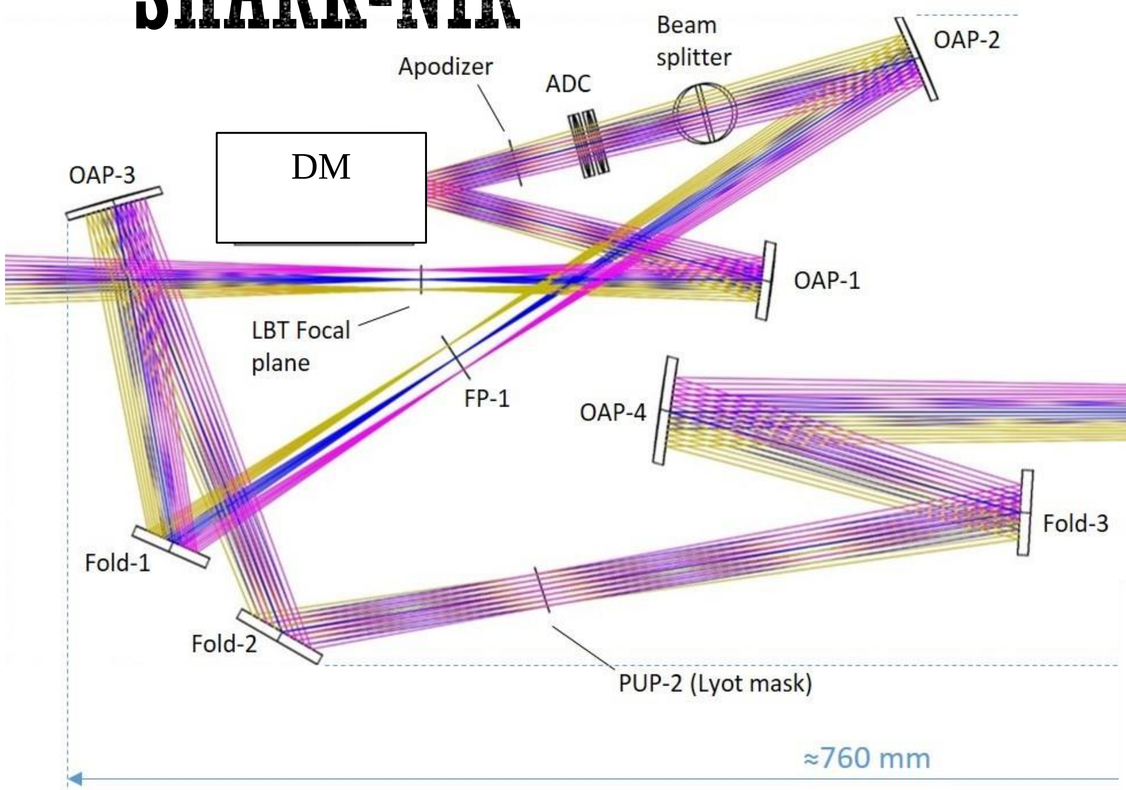
Wavefront sensing in the ELT era Padova, 3/10/2017

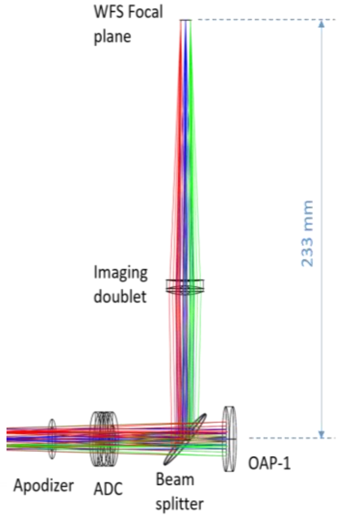
OUTLINE

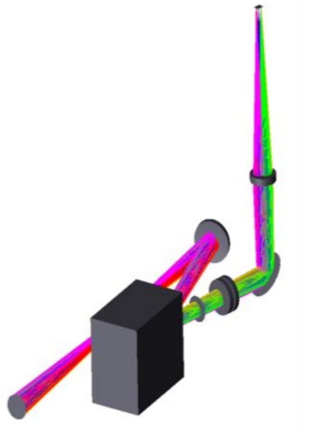
- SHARK-NIR: The II-generation high contrast imager for LBT
- Non Common Path Aberrations in SHARK-NIR
- The phase diversity approach: introduction
- Simulation results
- Final remarks and conclusions

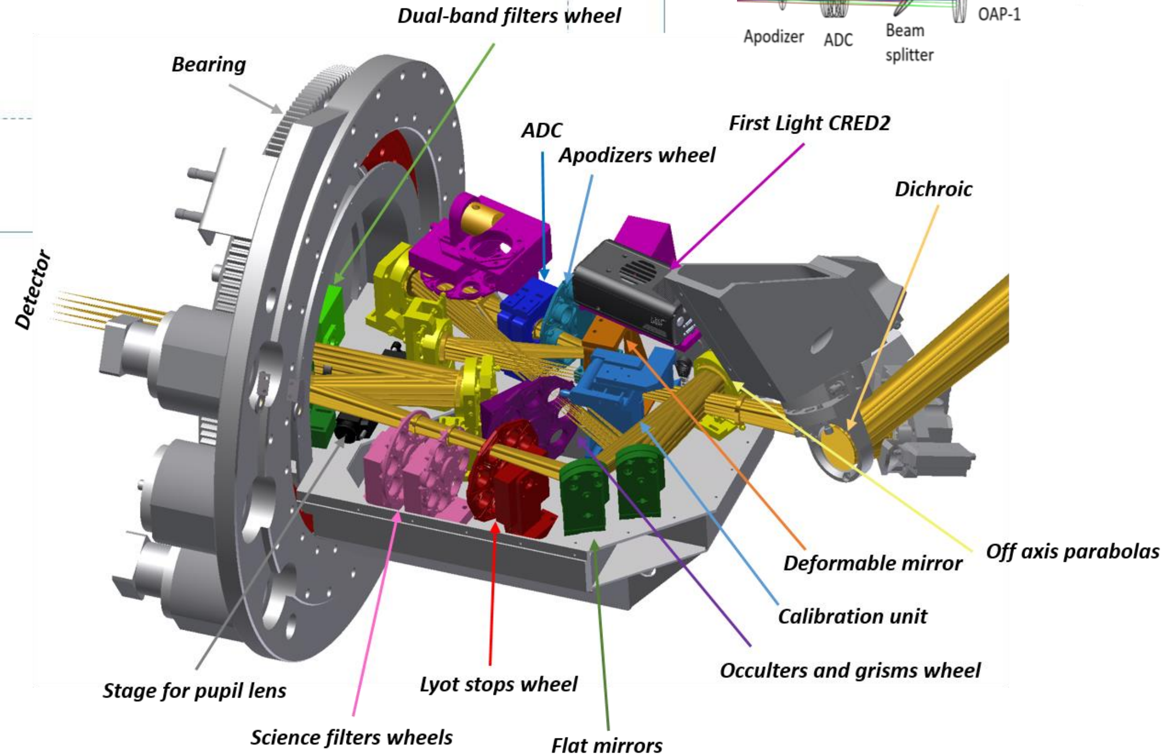
SHARK-NIR

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





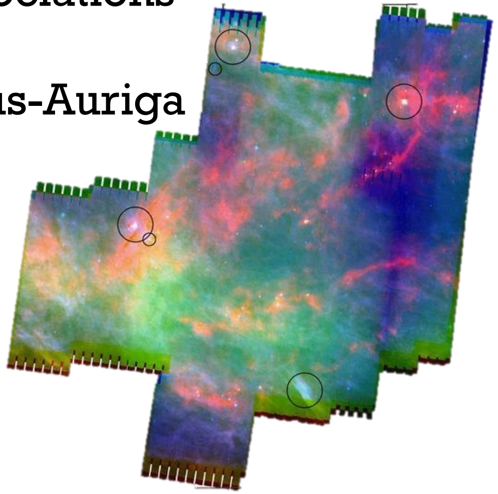


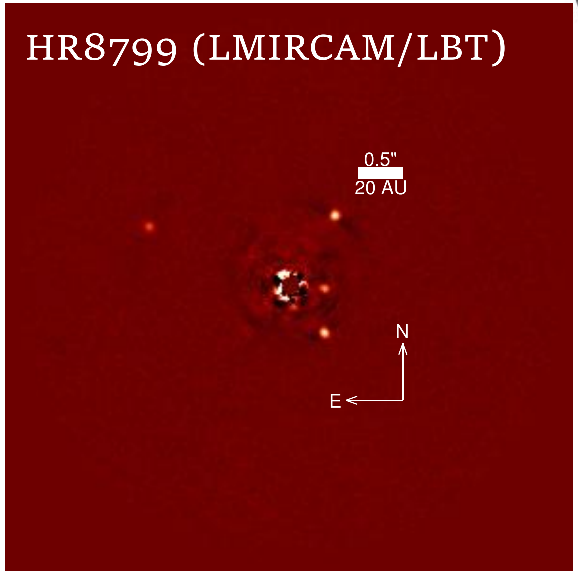


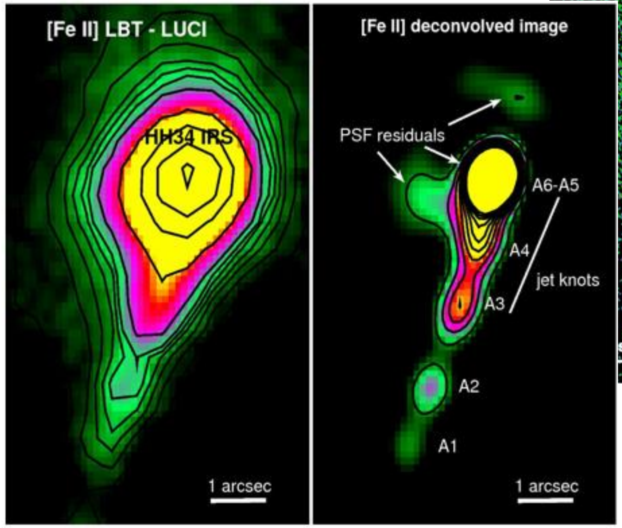
Wavelength range	0.96 – 1.7 μm
Detector format [px]	2048 x 2048
FoV ["]	18 x 18
Pixel scale ["/px]	0.0145
Airy radius @ λ=0.95 μm [px]	2
Working F/#	31.4
# of mirrors	8 (3 flat, 1 DM and 4 off-axis parabolas)

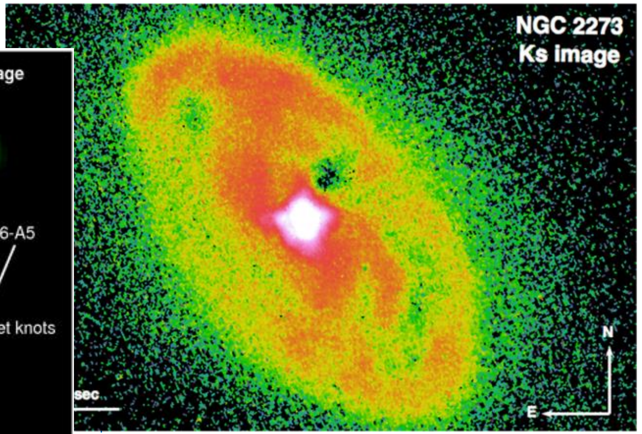
THE SCIENCE

- *Giant planets* around M dwarfs in nearby young associations
- Giant planets in nearby star-forming regions (Taurus-Auriga at 140 pc)
- Astrometry to determine dynamical mass of short period systems
- Spectroscopic characterization via low or medium resolution long slit spectroscopy





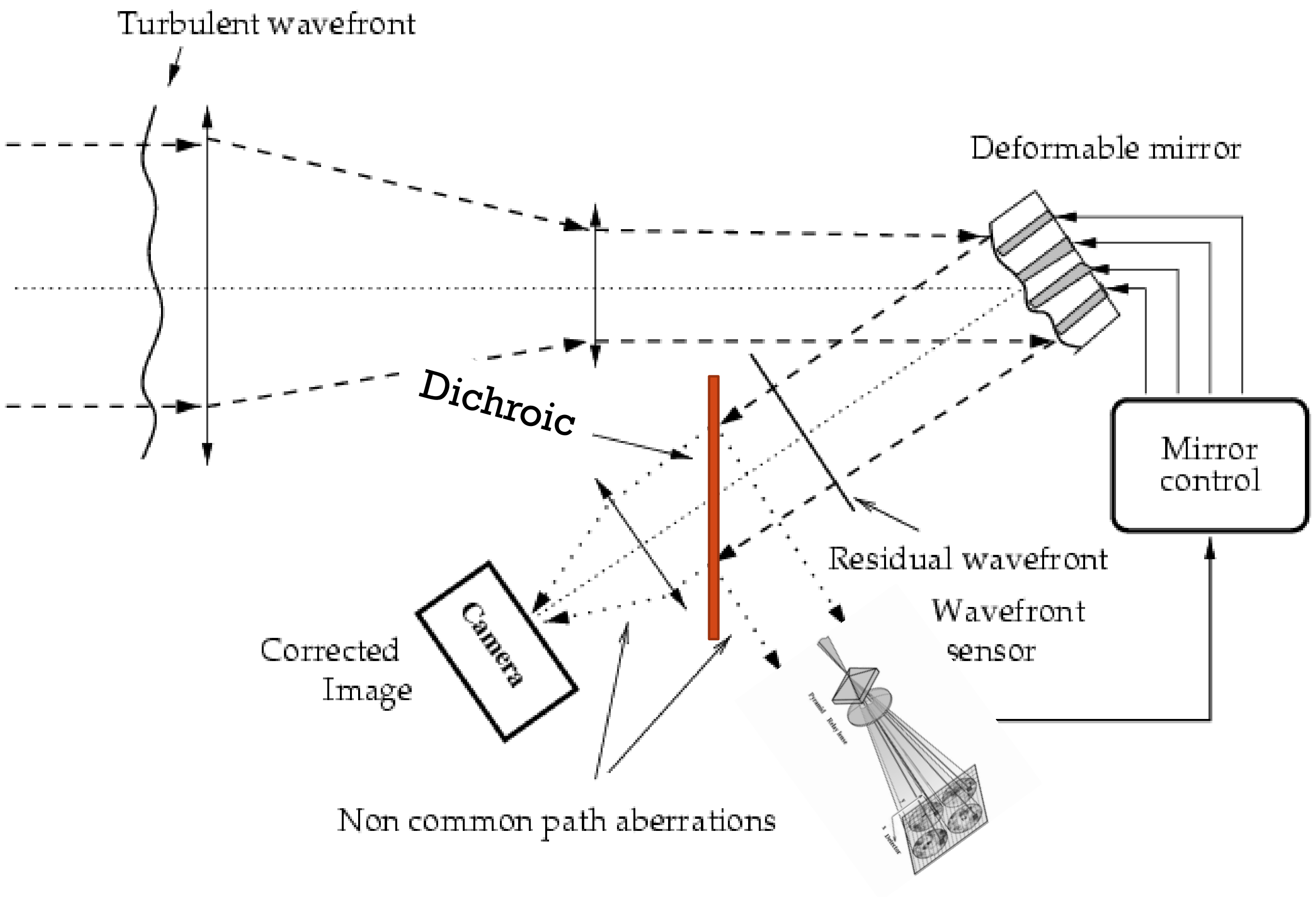




- *Protoplanetary disks*, disk/planets interaction
- Constrain brown dwarfs/giant planets formation mechanisms in local star associations (Pleiades)
- Coronagraphic imaging of *stellar jets* close to the launch zone
- Study the *AGN* feeding mechanisms

NON COMMON PATH ABERRATIONS

- Differential aberrations between WFS and scientific camera
- Speckles slowly varying in position and intensity as a consequence of instrument thermal and/or mechanical flectures
- Stable over long periods…



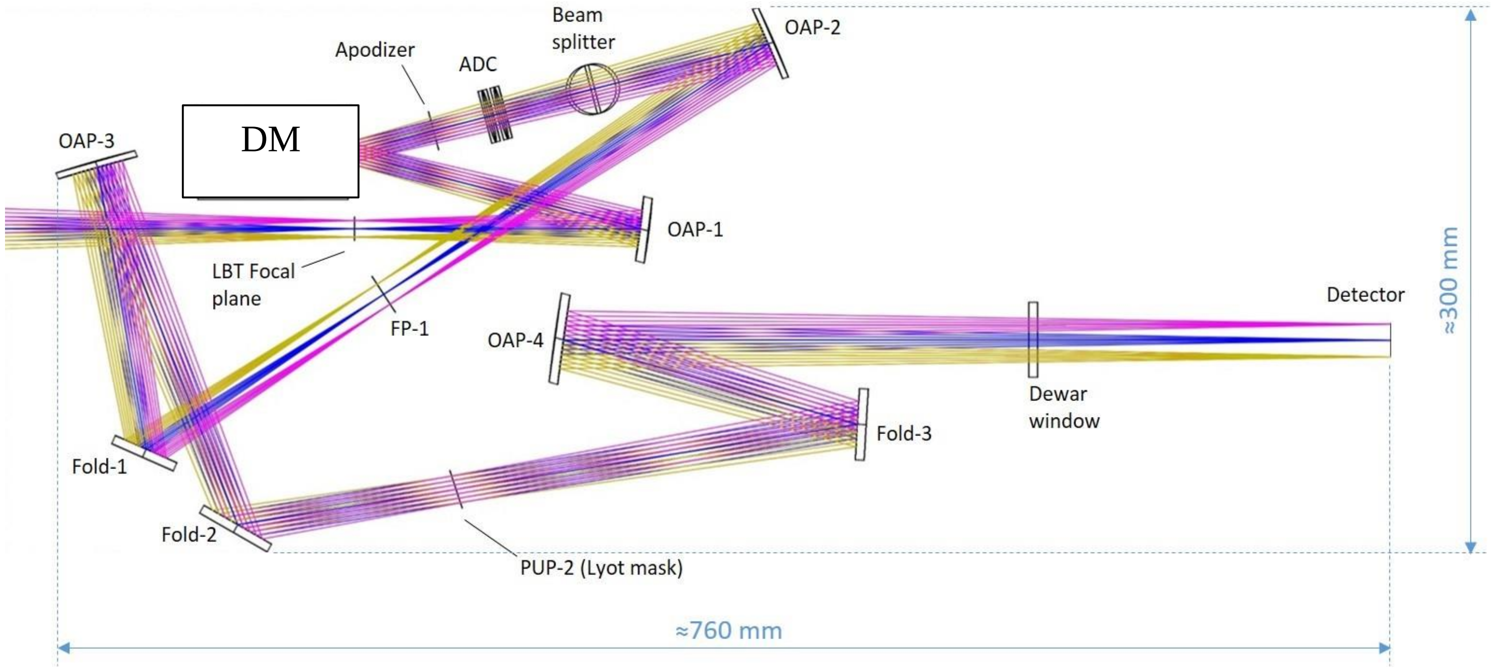
… but if not that stable?

NON COMMON PATH ABERRATIONS

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

Which are the requirements then?

- Fast sensing
- Small opto-mechanical impact
- Possibly without using the ASM



PHASE DIVERSITY

- ❑ What is Phase Diversity? A Focal Plane WFS technique

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

… Two major drawbacks using a single image:

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

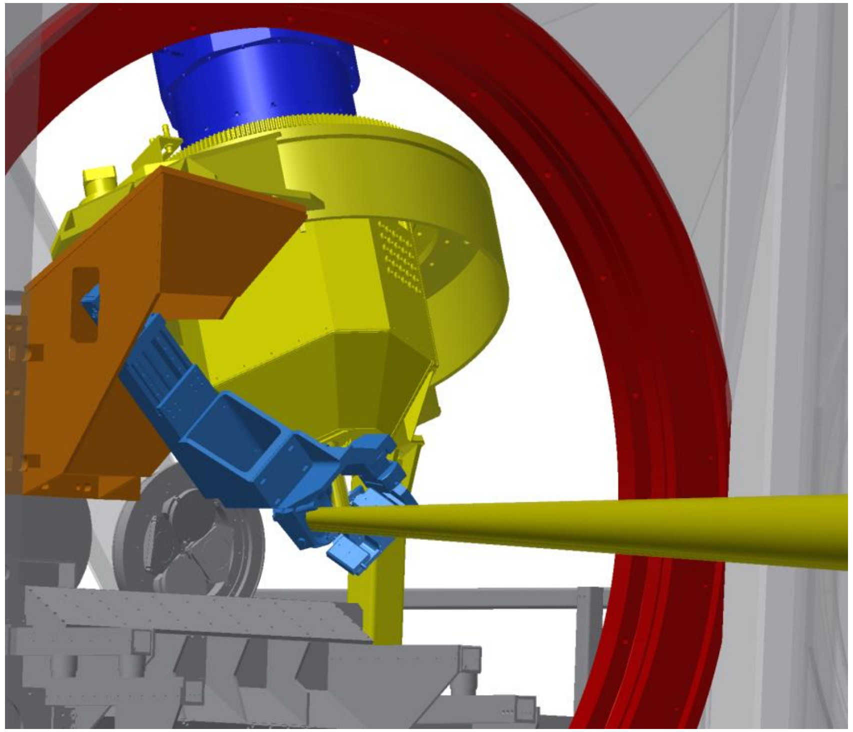
Solution:

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

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

Joint estimation of object and phase

NON COMMON PATH ABERRATIONS IN SHARK-NIR



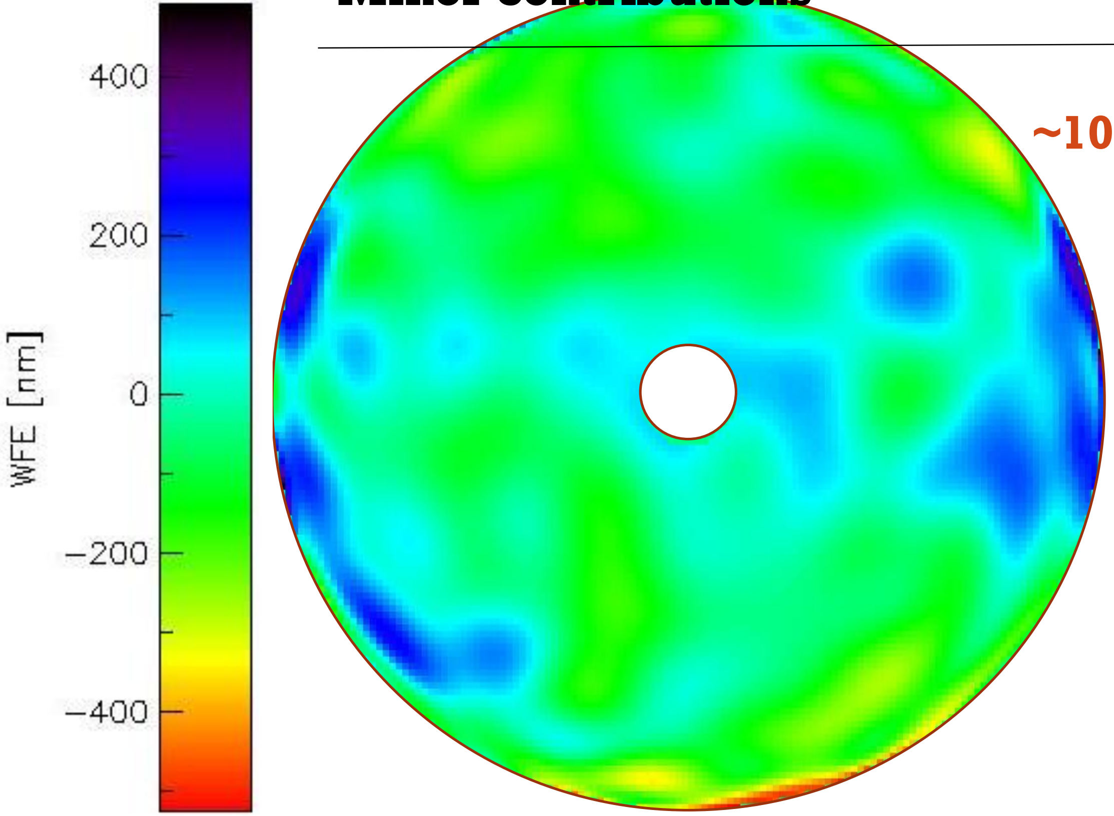
Dichroic (~45 nm) +

Optics Manufacturing (~90 nm) +

Alignment Tolerances (~30 nm) +

Minor contributions =

~100 nm



SIMULATIONS

End-to-end Fresnel simulator

- AO phase screens from PASSATA simulator (INAF-Arcetri)
- Telescope vibrations
- Temporal integration

R = 8

H = 6

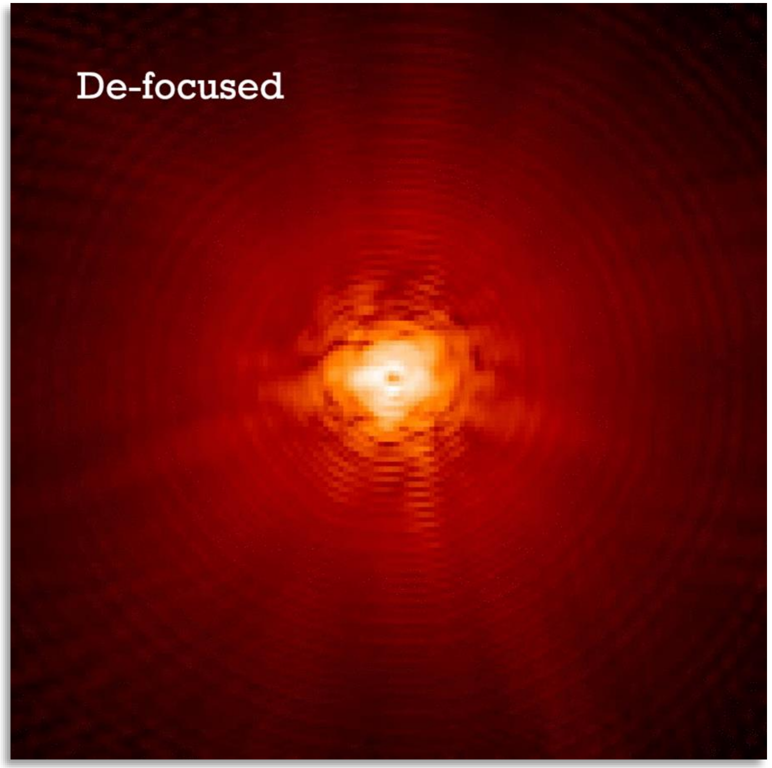
Seeing = 0.4”

DIT = 10 s

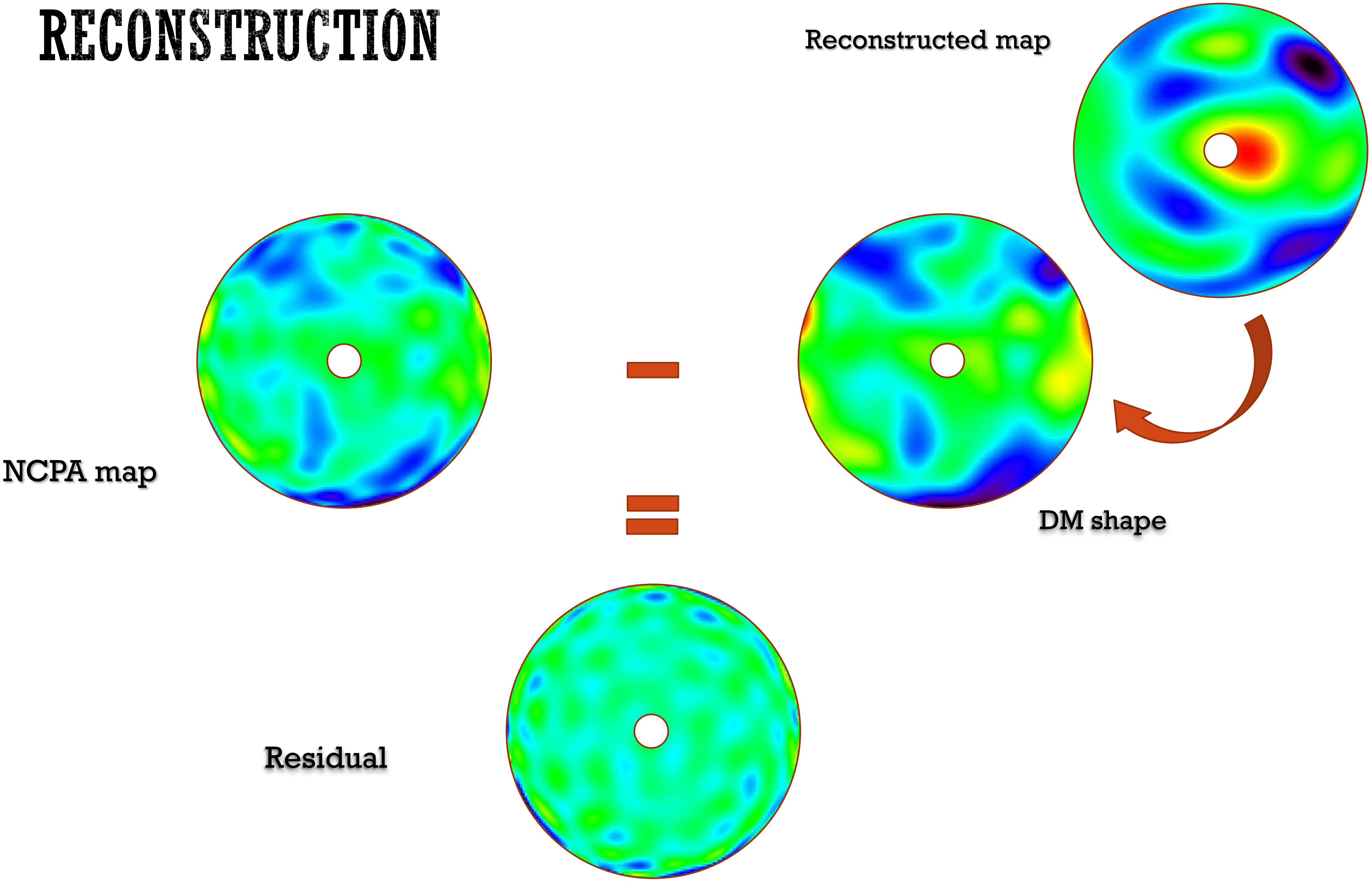
Residual jitter: 10 mas rms

Wavelength: 1.558 μm

RON: 15 phe-

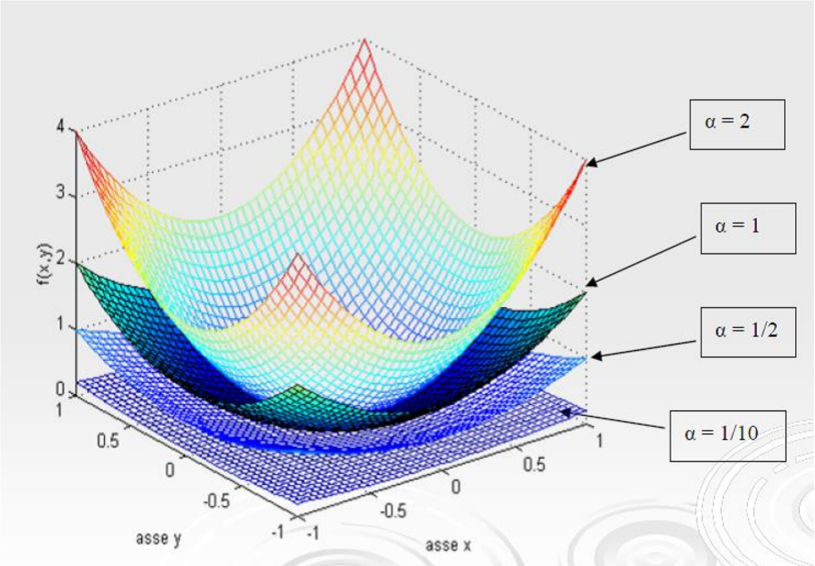


RECONSTRUCTION



SIMULATIONS

Optimal defocus



$$Z_4(\rho) = \alpha(x^2 + y^2)$$

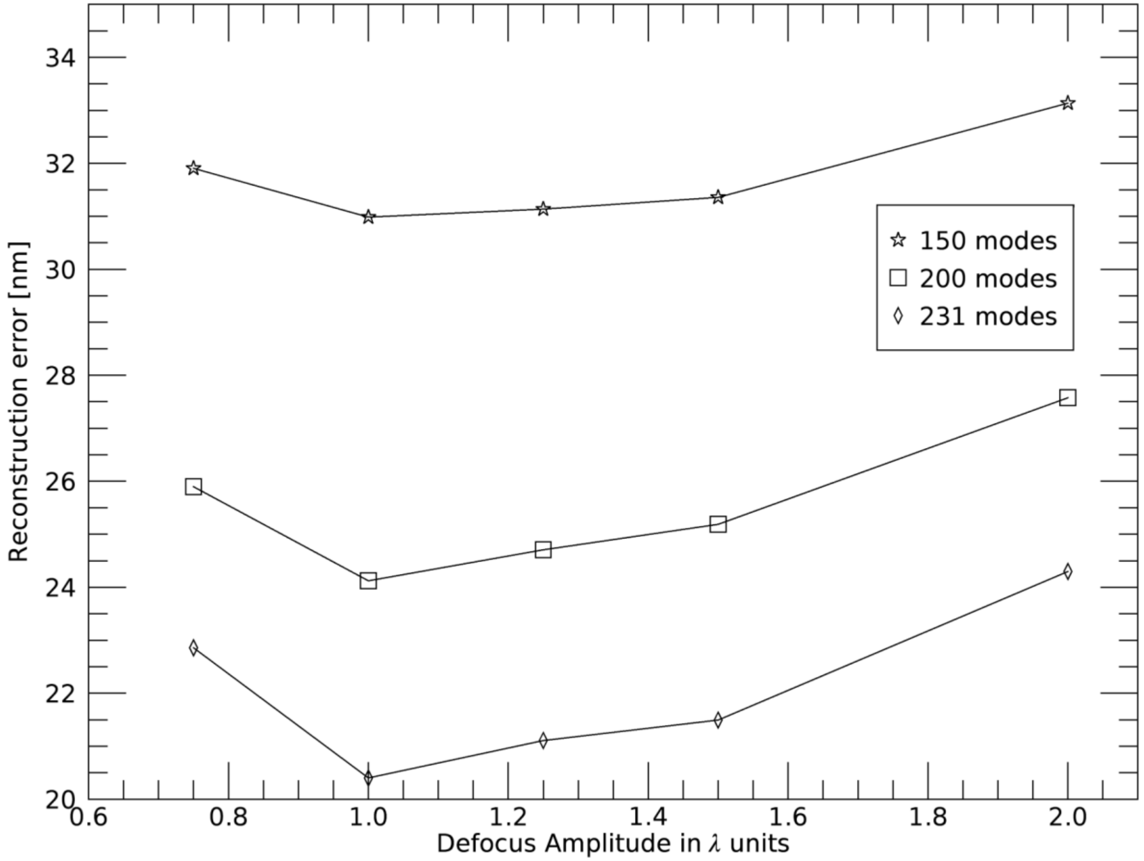
R = 8   H = 6

Seeing = 0.4”

DIT = 30 s

Residual jitter: 10 mas rms

Wavelength: 1.558 μm



SIMULATIONS

Chromatism

R = 8

H = 6

Seeing = 0.4”

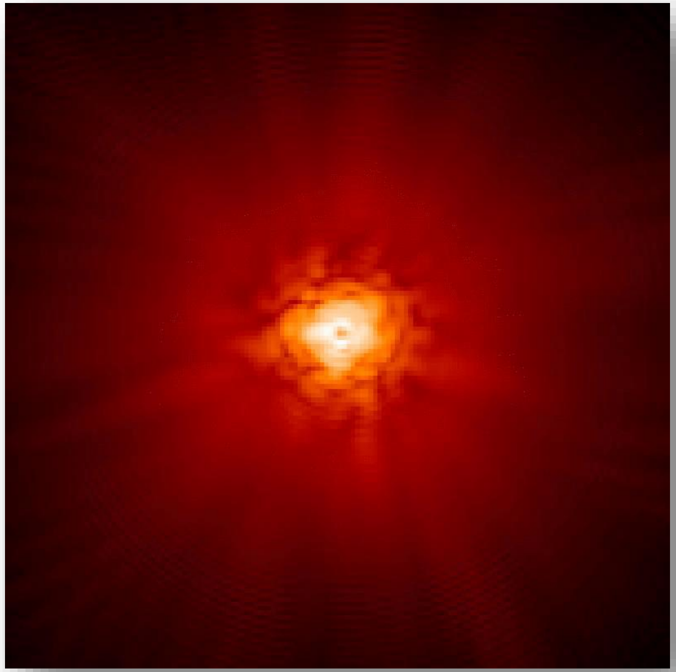
DIT = 10 s

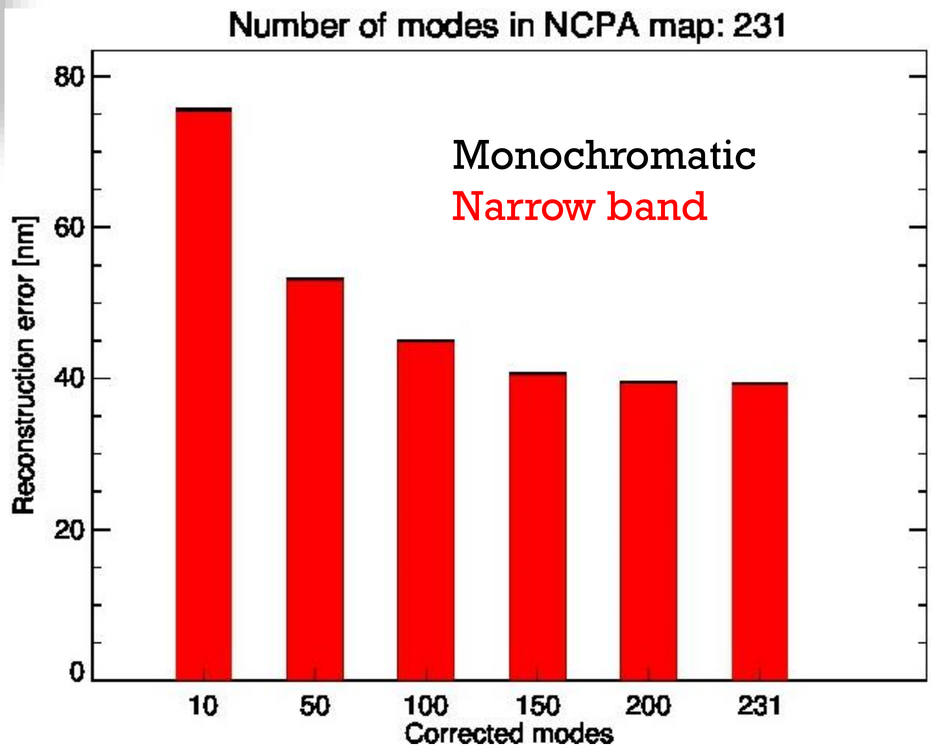
Residual jitter: 10 mas rms

Band: H

Bandwith: 25 nm

Defocus: 1.8 rad rms





IMPACT OF INTEGRATION TIME

R = 8

H = 6

Seeing = 0.4”

DIT = 1-5-10-20-30 s

Residual jitter: 10 mas rms

Wavelength: 1.558 μm

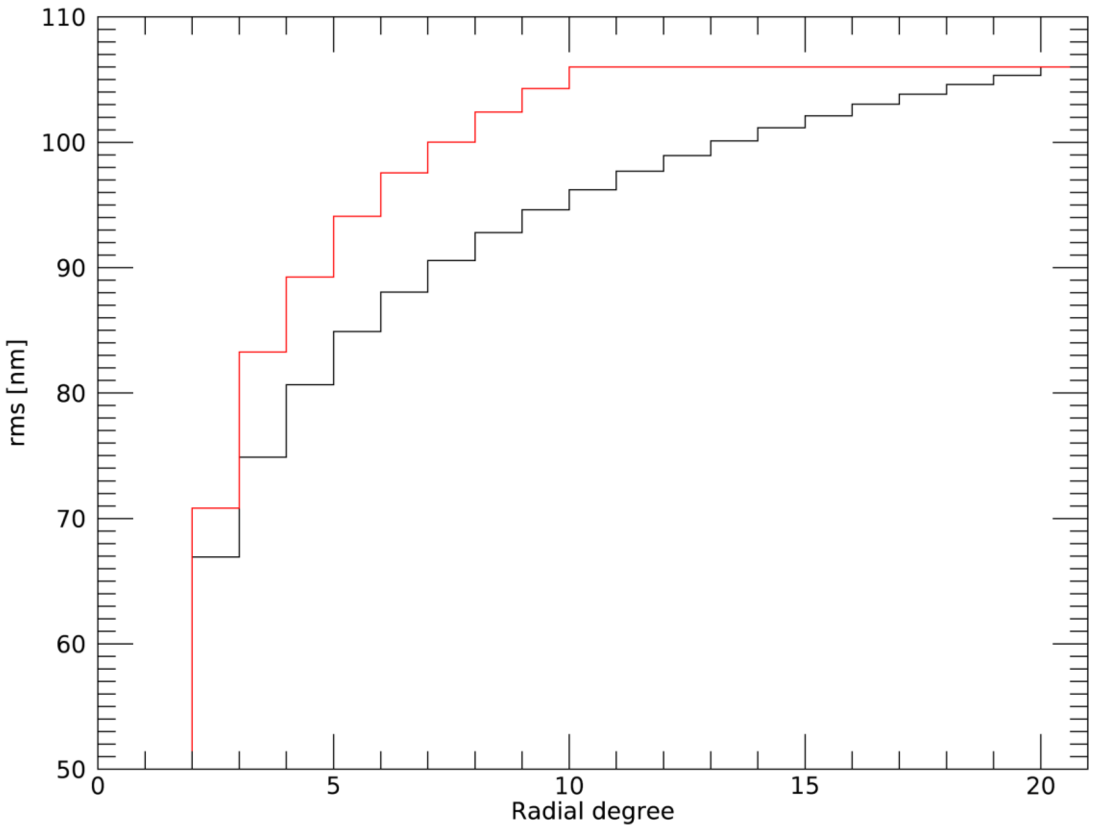
Defocus: 1 λ

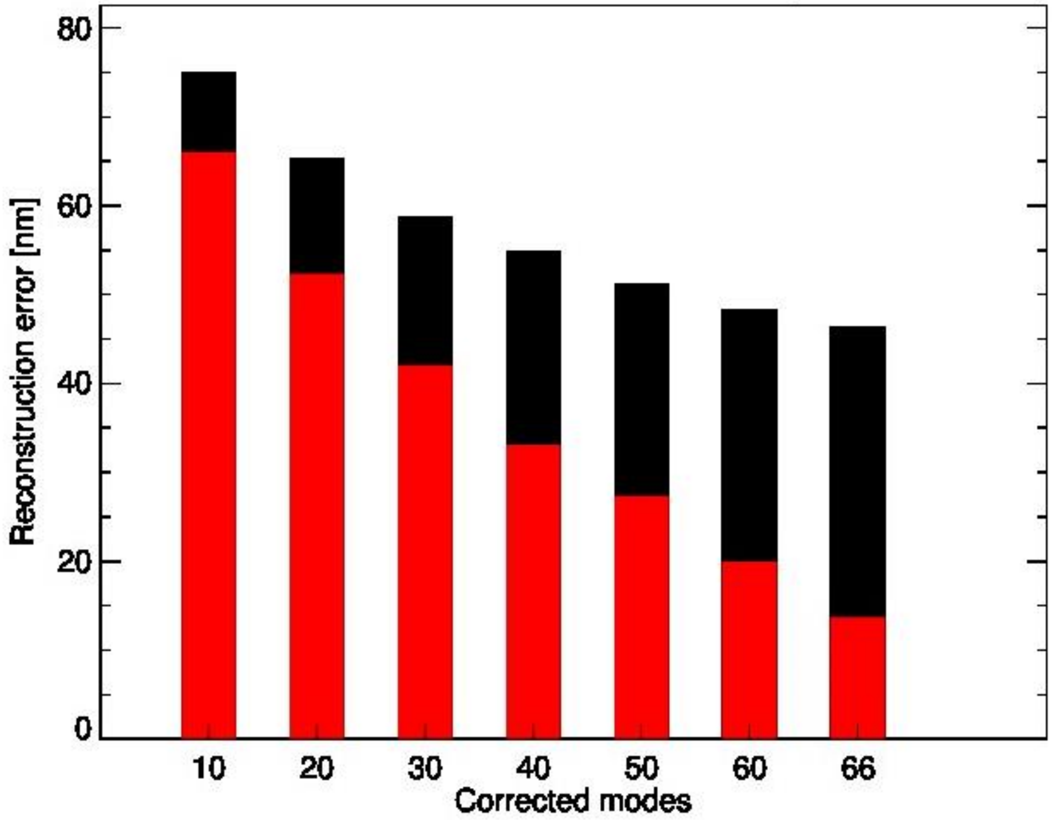
# modes	σ_{DIT} [nm]	σ_{Rand} [nm]
50	0.11	0.11
70	0.17	0.16
100	0.17	0.22
150	0.26	0.21
200	0.37	0.36
231	0.28	0.47

- Differences can be attributed to random fluctuations…
- 1 second of integration looks to be a reasonable compromise

IMPACT OF NCPA SPECTRUM

High or low orders? **10** vs **20** radial degrees… the impact on reconstruction is huge!





IMPACT OF TELESCOPE VIBRATIONS

R = 12

H = 10

Seeing = 0.6”

DIT = 1 s

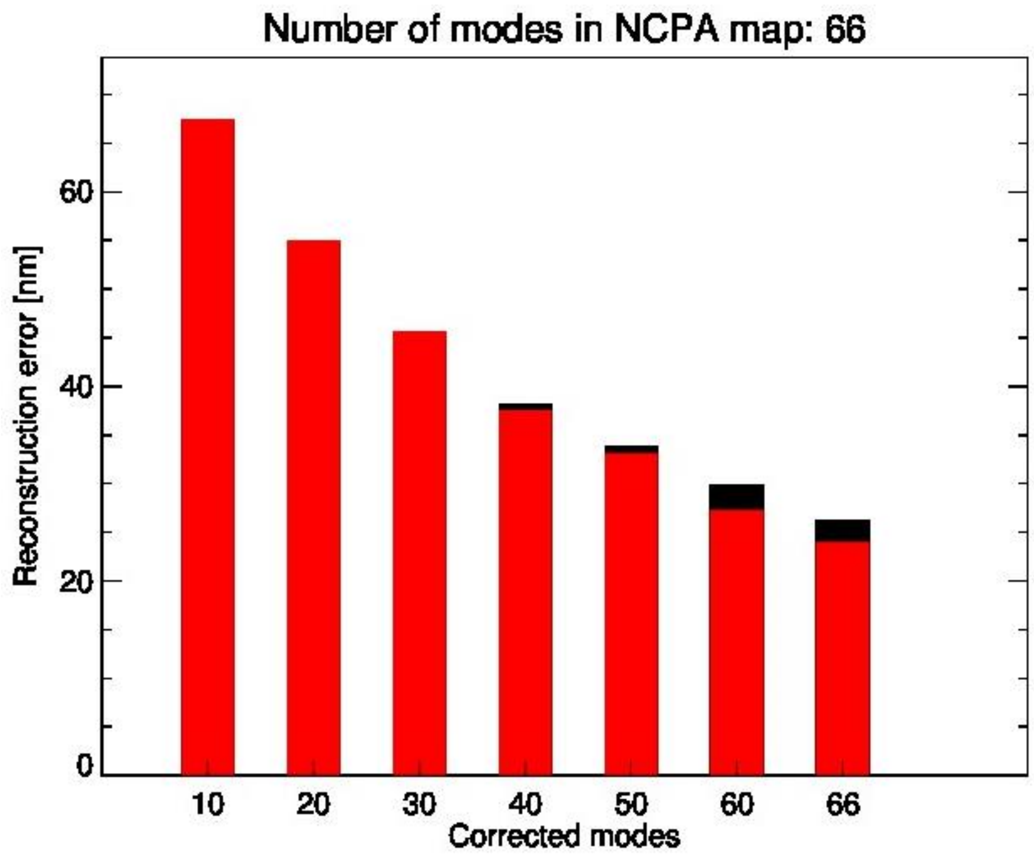
Residual jitter rms: 0 / 20 mas

Band: H

Bandwith: 0

Defocus: 1 λ

Very robust to jitter!



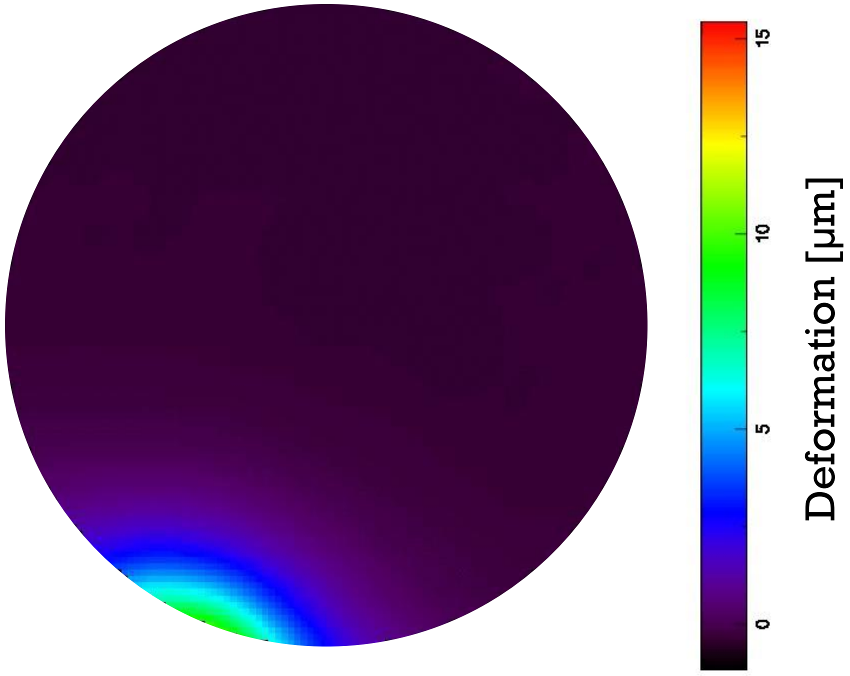
	0 mas	**20 mas**
Error [nm]	24	26.2
Time [min]	1.78	2.6

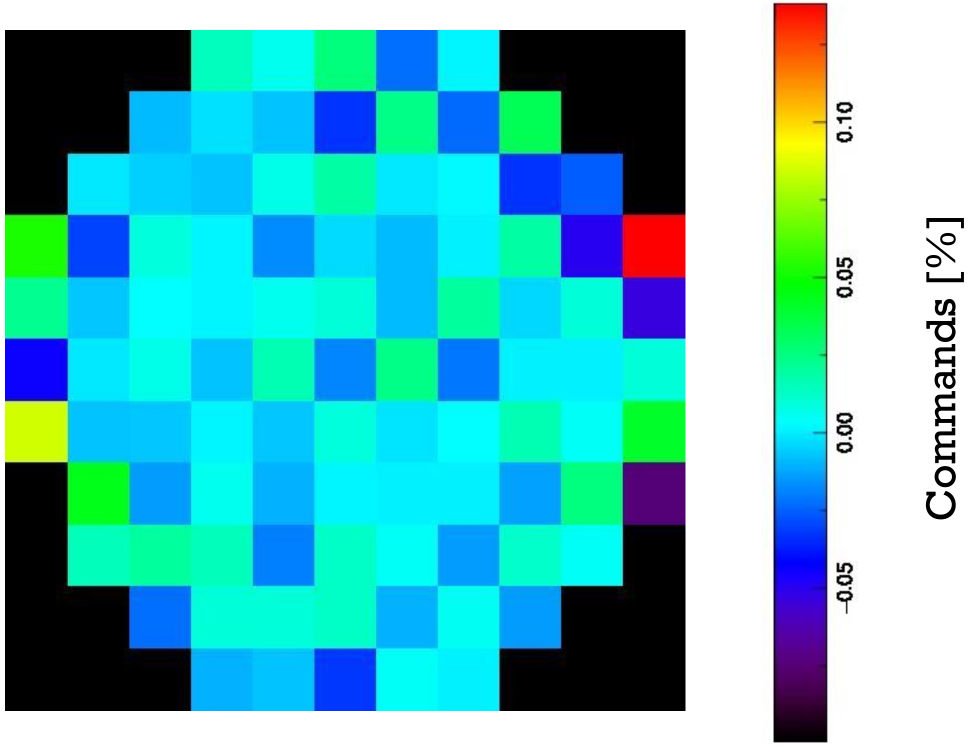
FITTING ERROR

Fit of the reconstructed map with ALPAO DM97-15

Reconstructed wavefront ➡ DM commands ➡ Best DM shape

High orders: 37 nm rms ➡ compatible with **100** modes





FINAL REMARKS AND CONCLUSIONS

- The algorithm works very close to its theoretical monochromatic limit with NB filter currently foreseen.
- Reconstruction is fast: DIT ~1s and computational time ~1-2 minutes
- The algorithm is robust to telescope vibrations and works well also in low Strehl regime
- Phase diversity could be a valuable option for SHARK-NIR. Considering the expected amount of aberrations (~100 nm), the estimated residual is between 20-40 nm with ALPAO DM97-15.

THANK YOU!