Calibration of the low-wind effects: experimental validation of wavefront control on Subaru/SCExAO

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AO4ELT5, Tenerife, June 29th, 2017

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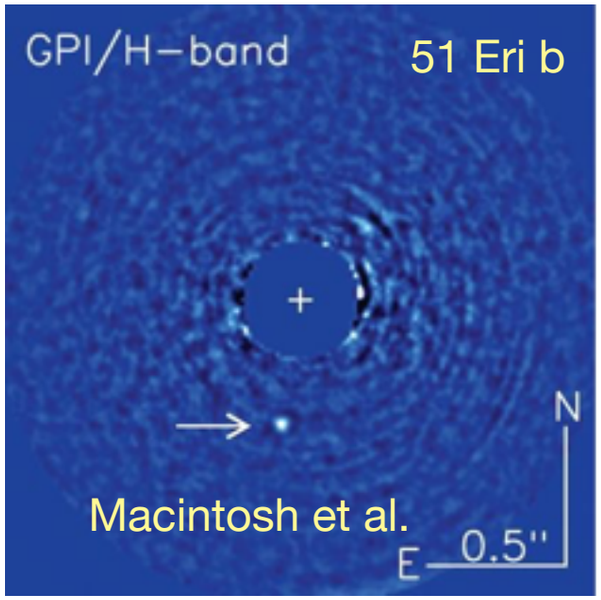
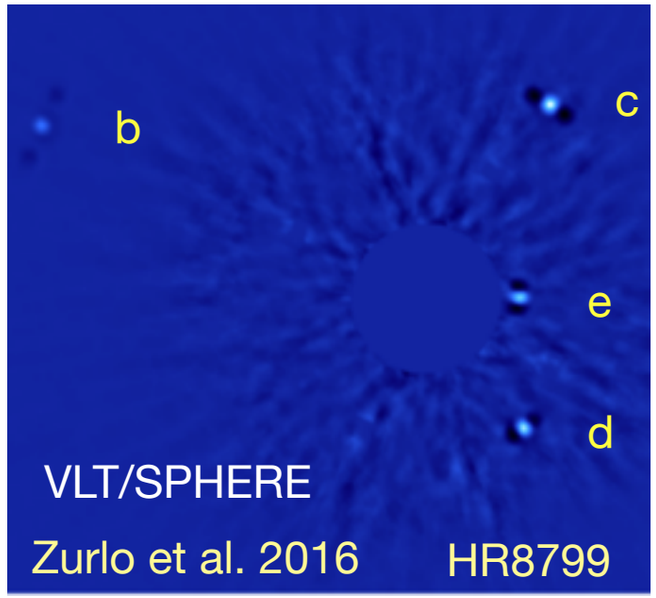
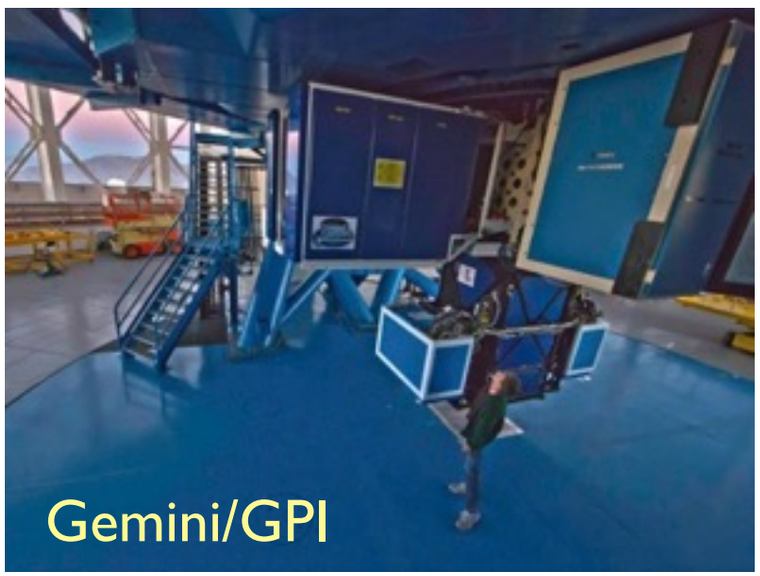
(KERNEL, PI: F. Martinache)

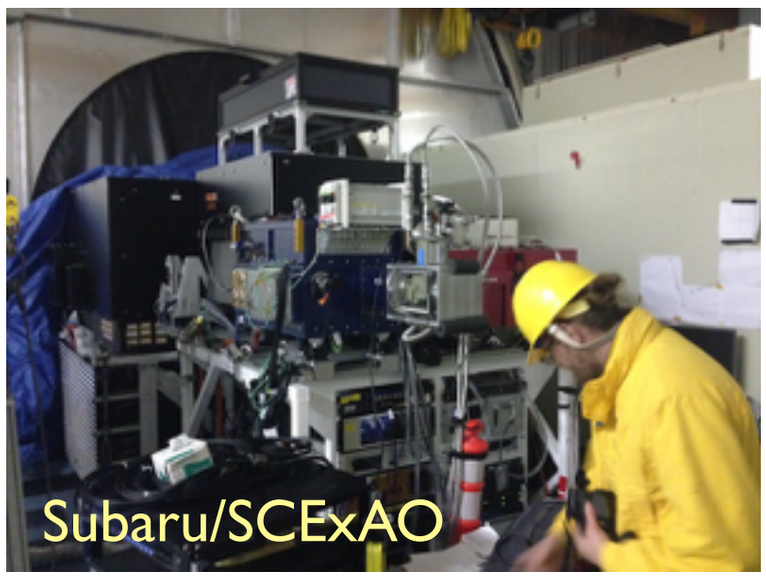
Exoplanet imagers for warm or massive gaseous planets



- Extreme adaptive optics
- Coronagraphy
- Image post-processing
  - 10^6-10^7 raw contrast
  - 0.2” in H-band







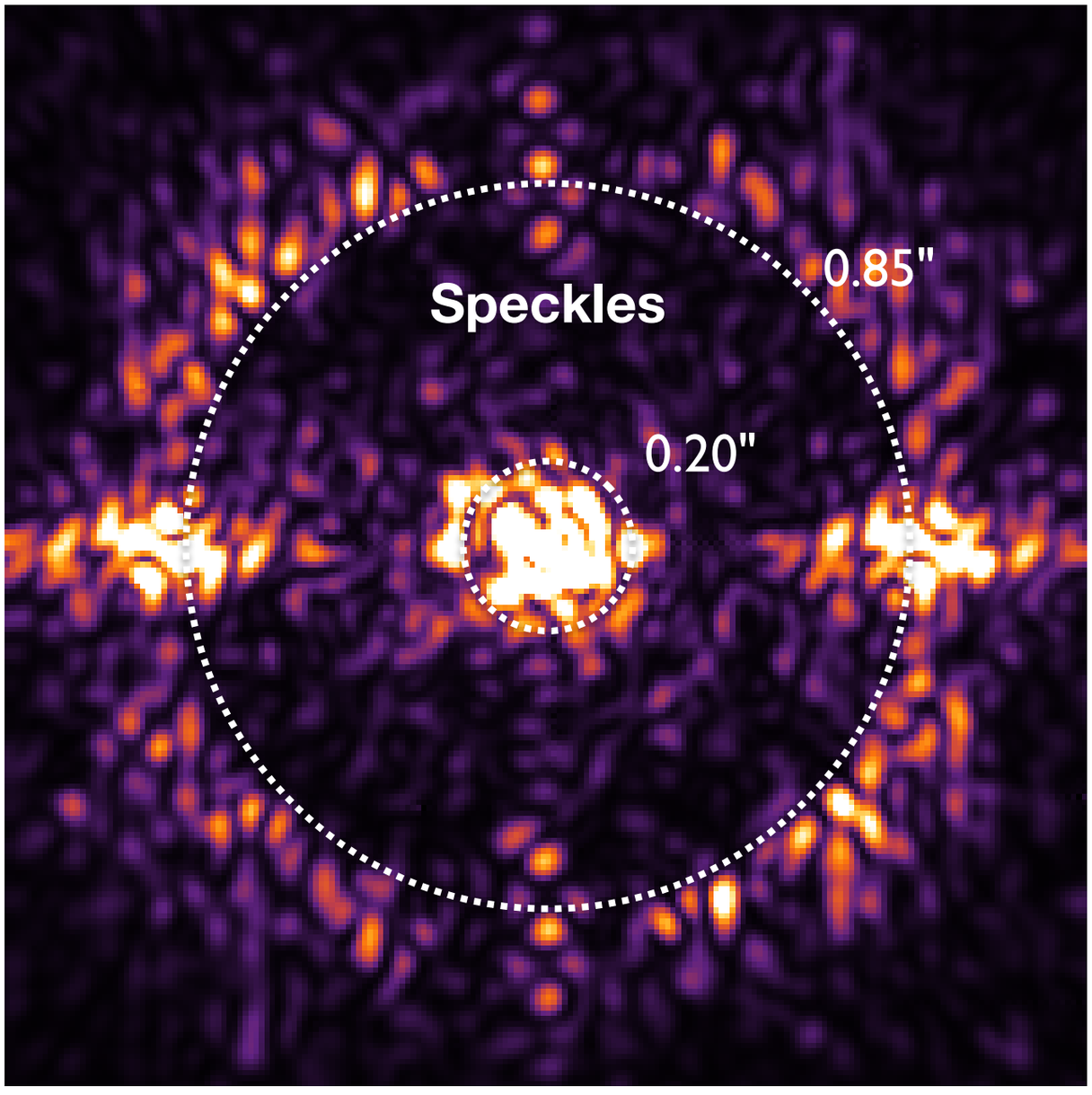
➔ Current contrast limitations

Observing colder or lighter gaseous planets?

- Main limitations:
  - instrumental aberrations, jitters, drifts
  - non common path aberrations
  - low-wind effects (LWE)
    - *C. Correia's talk yesterday*

- Focus on LWE

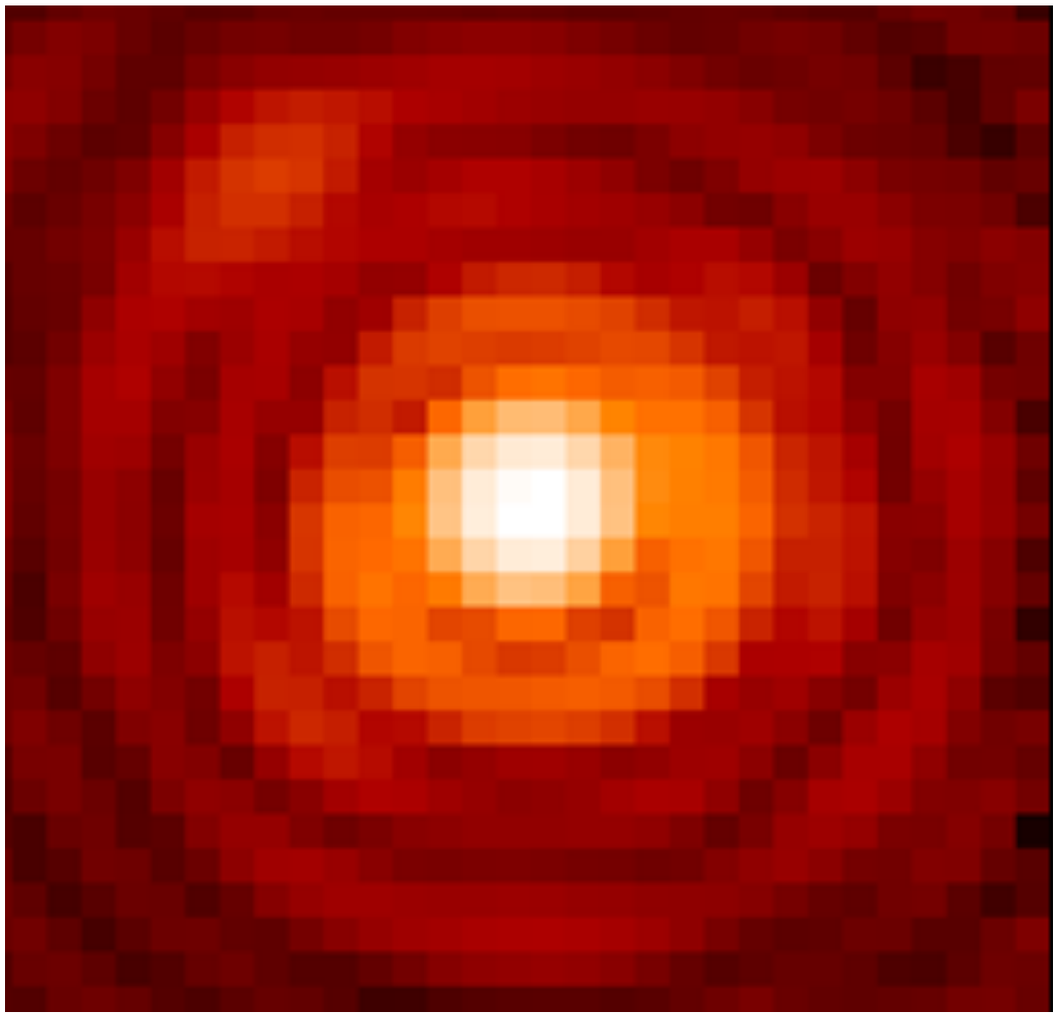
Coronagraphic image on VLT/SPHERE



10^5-10^6 contrast limit

Ideal clean star image

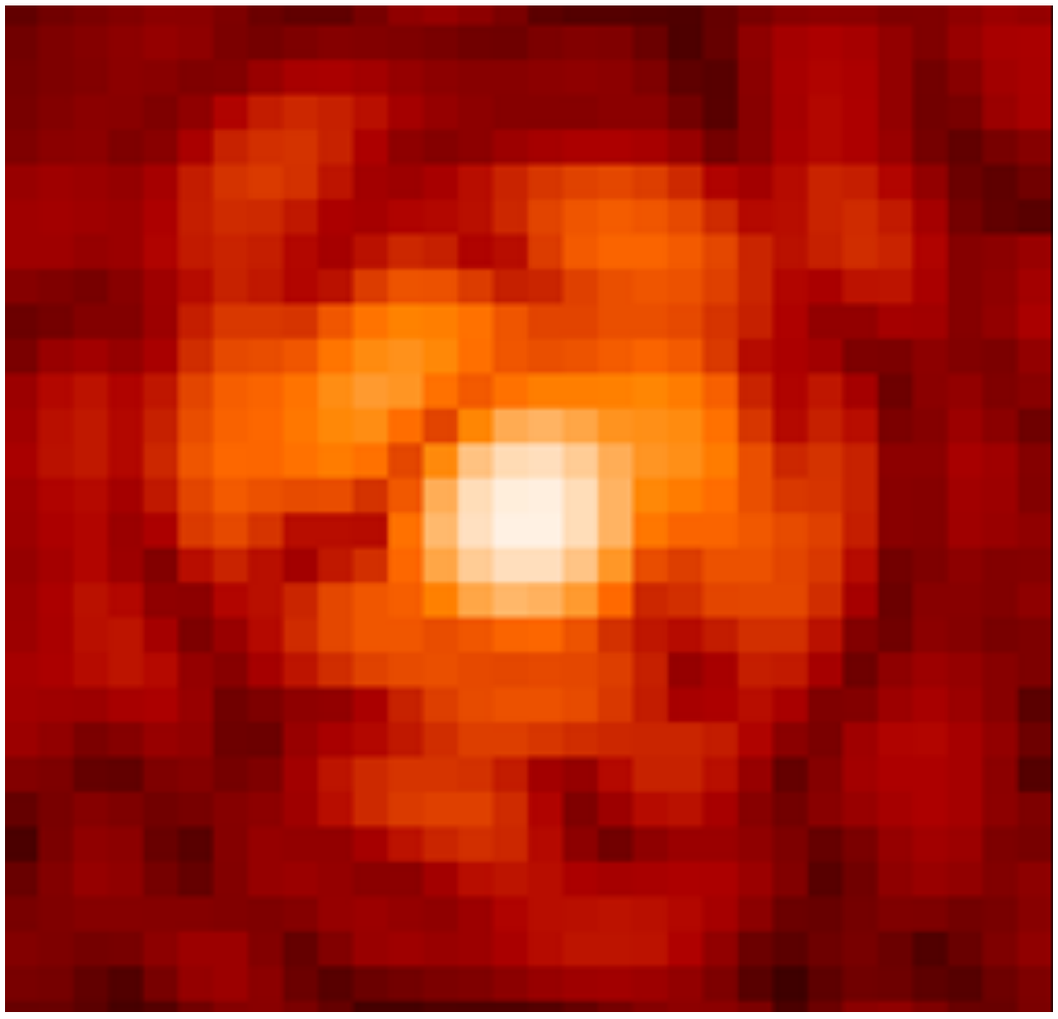
Star image (no coronagraph)



N'Diaye et al. A&A 2013, 2016
Sauvage et al. AO4ELT 2015

Low-wind effects (LWE)

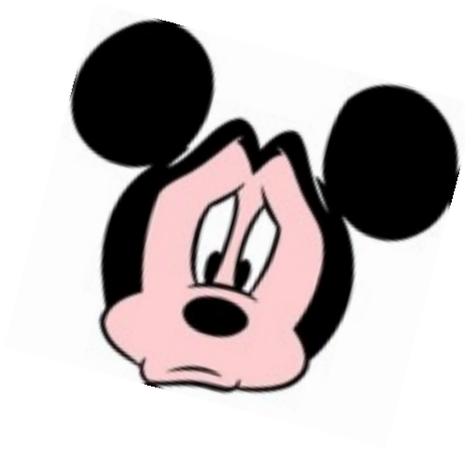
Star image (no coronagraph)



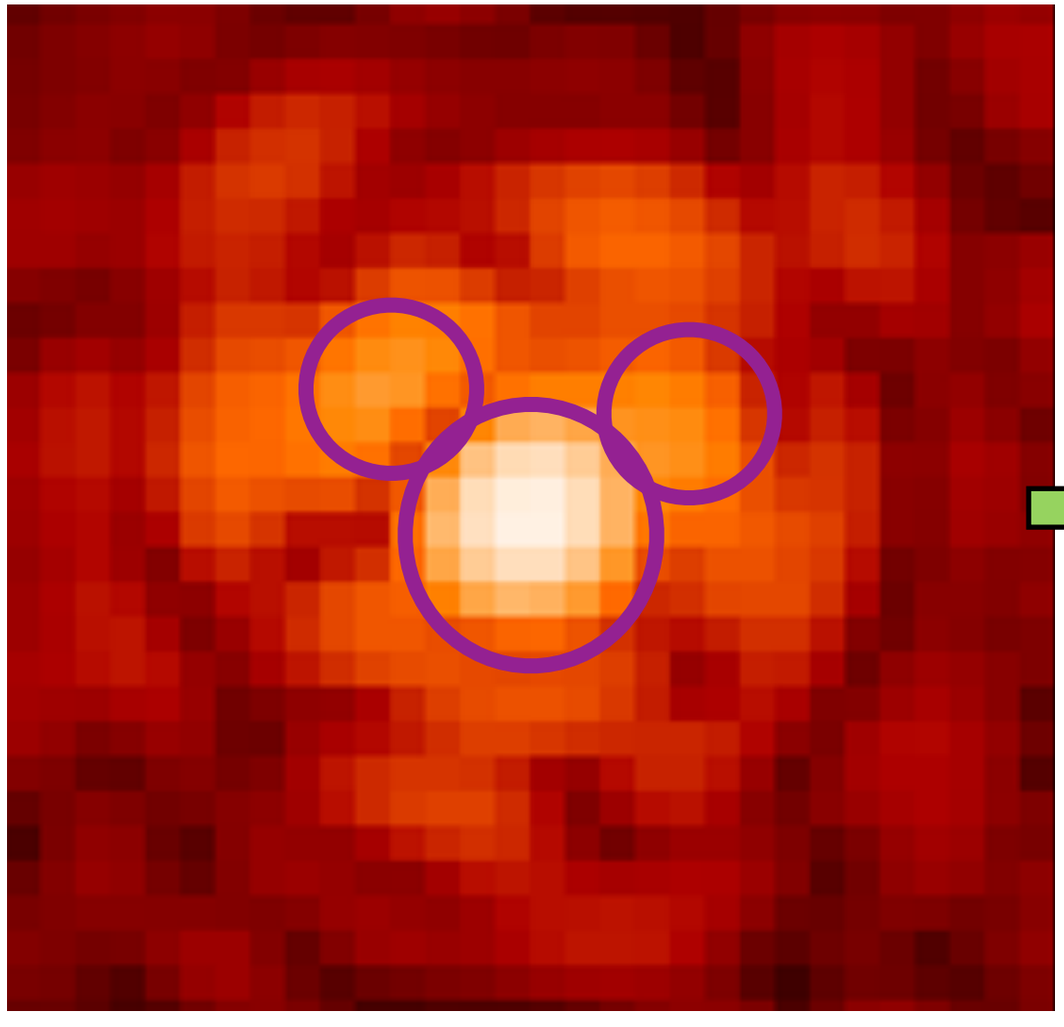
Time loss: up to 20% during
the best observing conditions

N'Diaye et al. A&A 2013, 2016
Sauvage et al. AO4ELT 2015

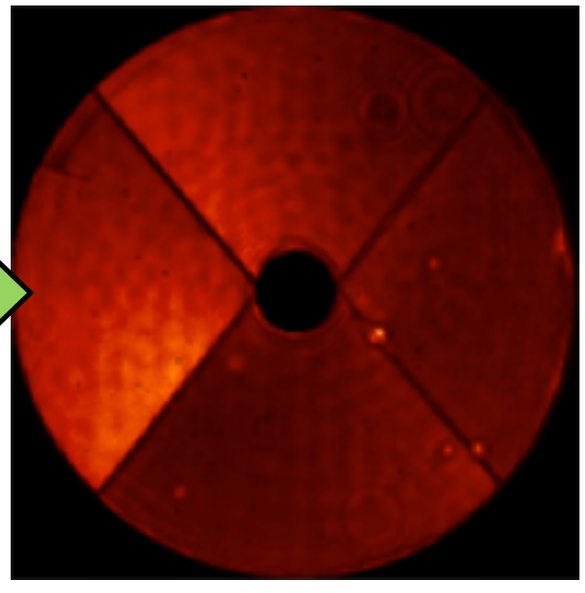
First diagnostic with ZELDA



Star image (no coronagraph)



ZELDA diagnostic on SPHERE



Differential pistons between quadrants

N'Diaye et al. A&A 2013, 2016
Sauvage et al. AO4ELT 2015

Compensation for the low-wind effects

- Issue
  - no control of these effects

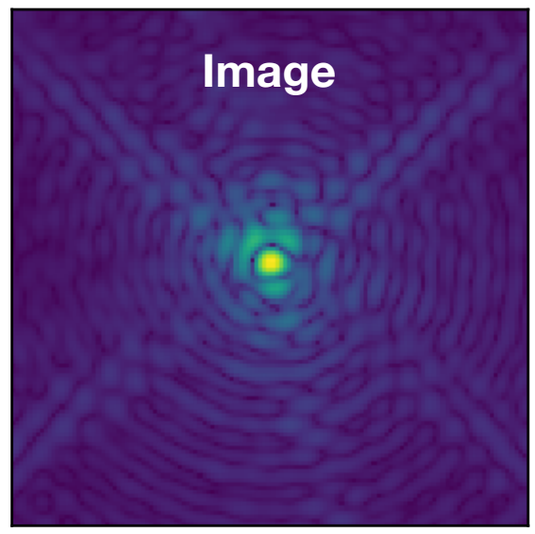
- Our solution
  - focal plane wavefront control using ZAP wavefront sensor
    - *Martinache et al. 2013, 2016*
    - *N'Diaye et al. 2017 in prep*

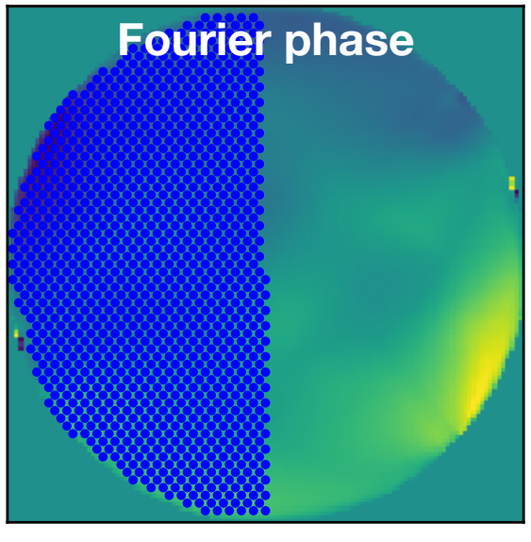
ZAP: a Fourier sensor for focal plane metrology

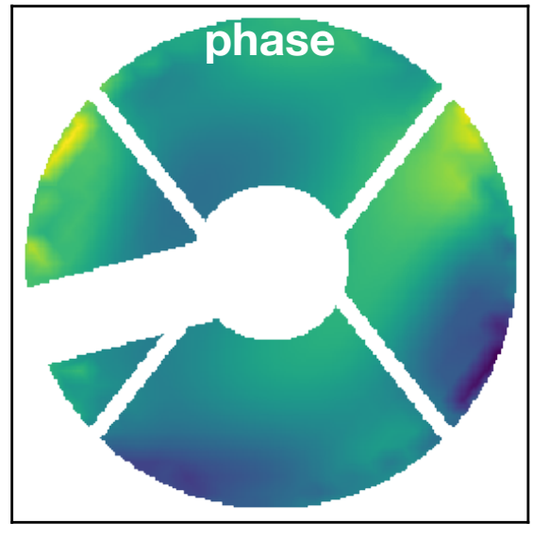
European Research Council
Established by the European Commission

KERNEL

- Fourier analysis of science images
  - Asymmetric pupil mask (ZAP)
  - Interferometric analysis of images
  - Extraction of residual aberrations



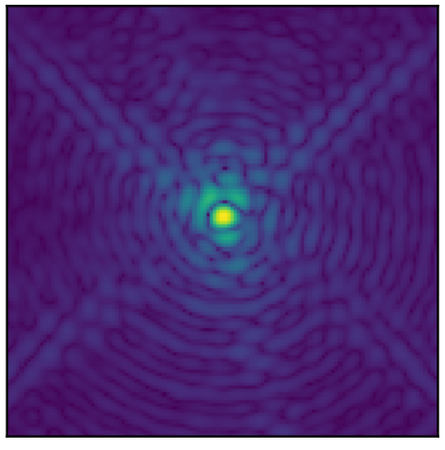




Martinache et al. 2013, 2016

ZAP formalism for phase extraction

Pupil phase φ
with asymmetric mask

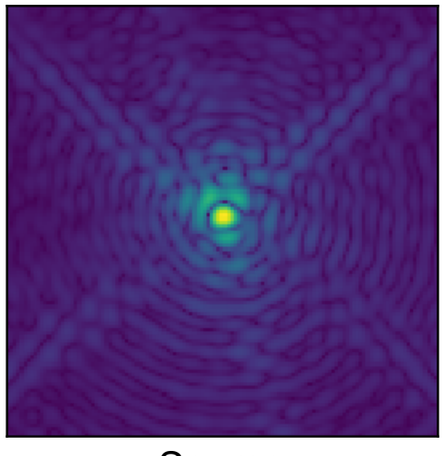


Source
image

ZAP formalism for phase extraction

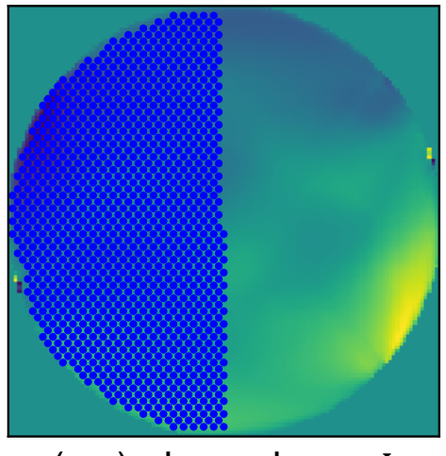
Pupil phase φ
with asymmetric mask

Light
propagation



Source
image

Fourier transform
and argument



(u,v) plane phase Φ
with subapertures

Linear regime

Phase in Fourier Plane — Phase in the pupil

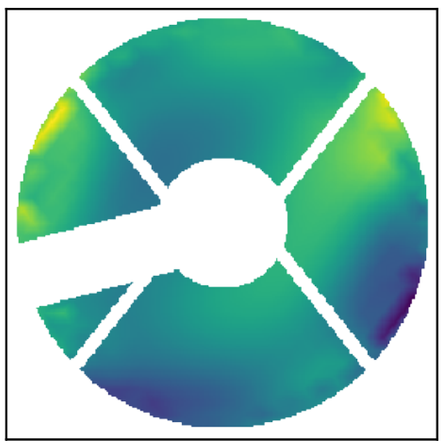
$$\Phi = A \times \varphi$$

ZAP formalism for phase extraction

Pupil phase φ
with asymmetric mask

Closed loop
control

Reconstructed
phase $\hat{\varphi}$



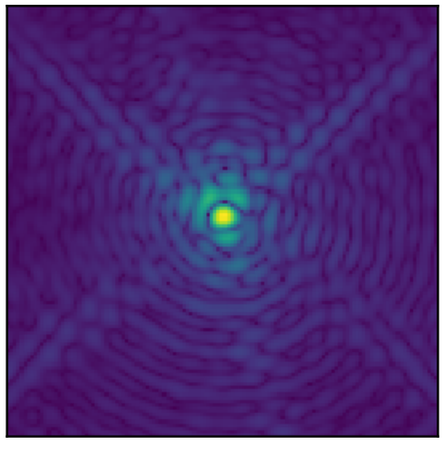
Phase in the pupil — Phase in Fourier Plane

$$\varphi = A^{+} \times \Phi$$

Light
propagation

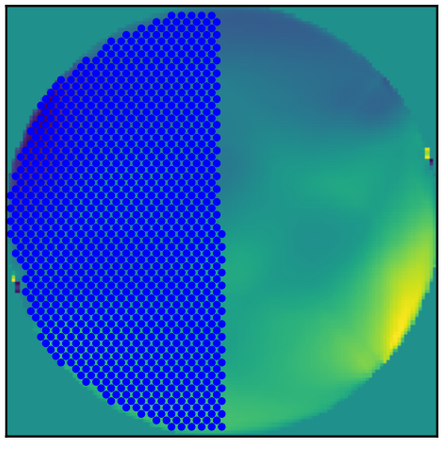
Projection on
pseudo-inverse
matrix A^{+}

Linear regime



Source
image

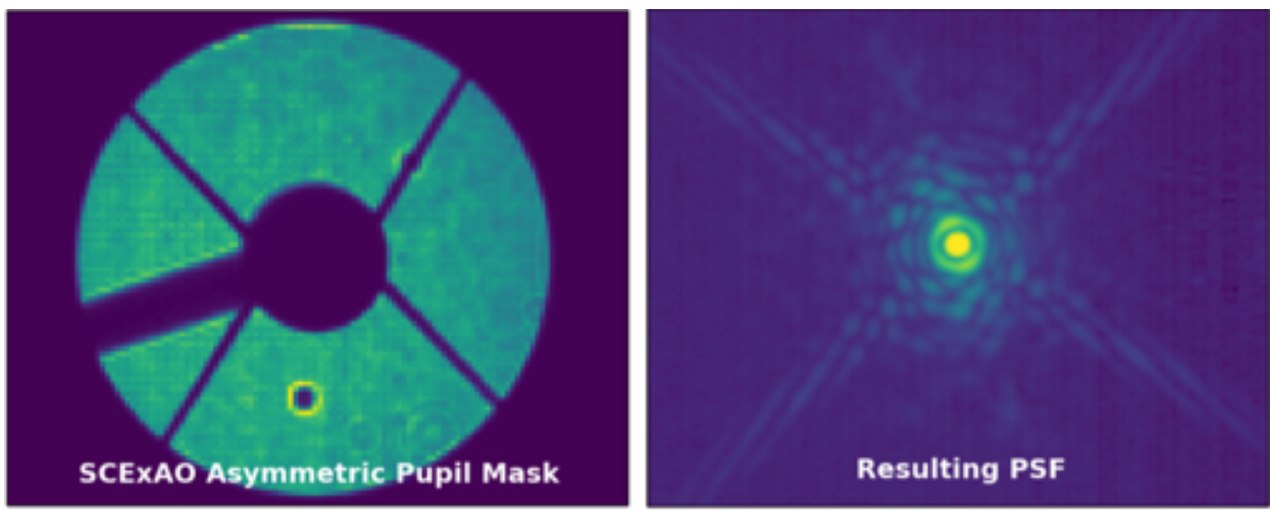
Fourier transform
and argument



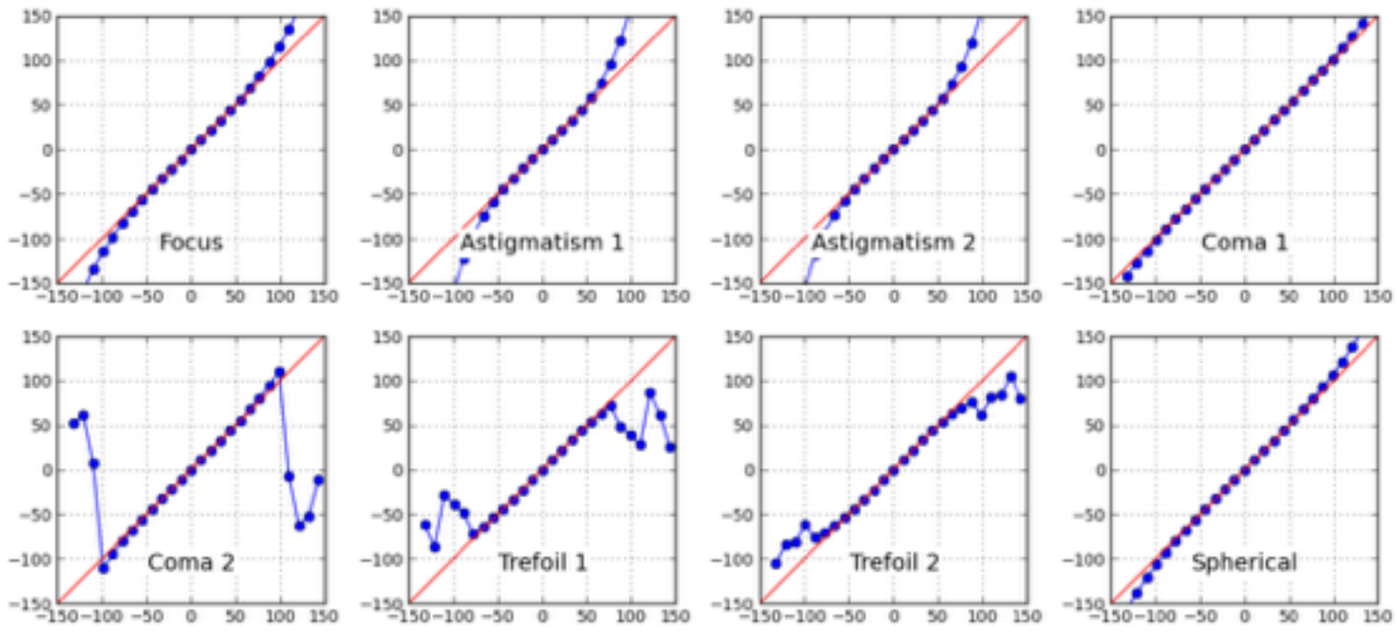
(u,v) plane phase Φ
with subapertures

ZAP: control of the first Zernike modes on Subaru/SCExAO

- ZAP
  - Conversion of the image into an unambiguous and unbiased wavefront sensor



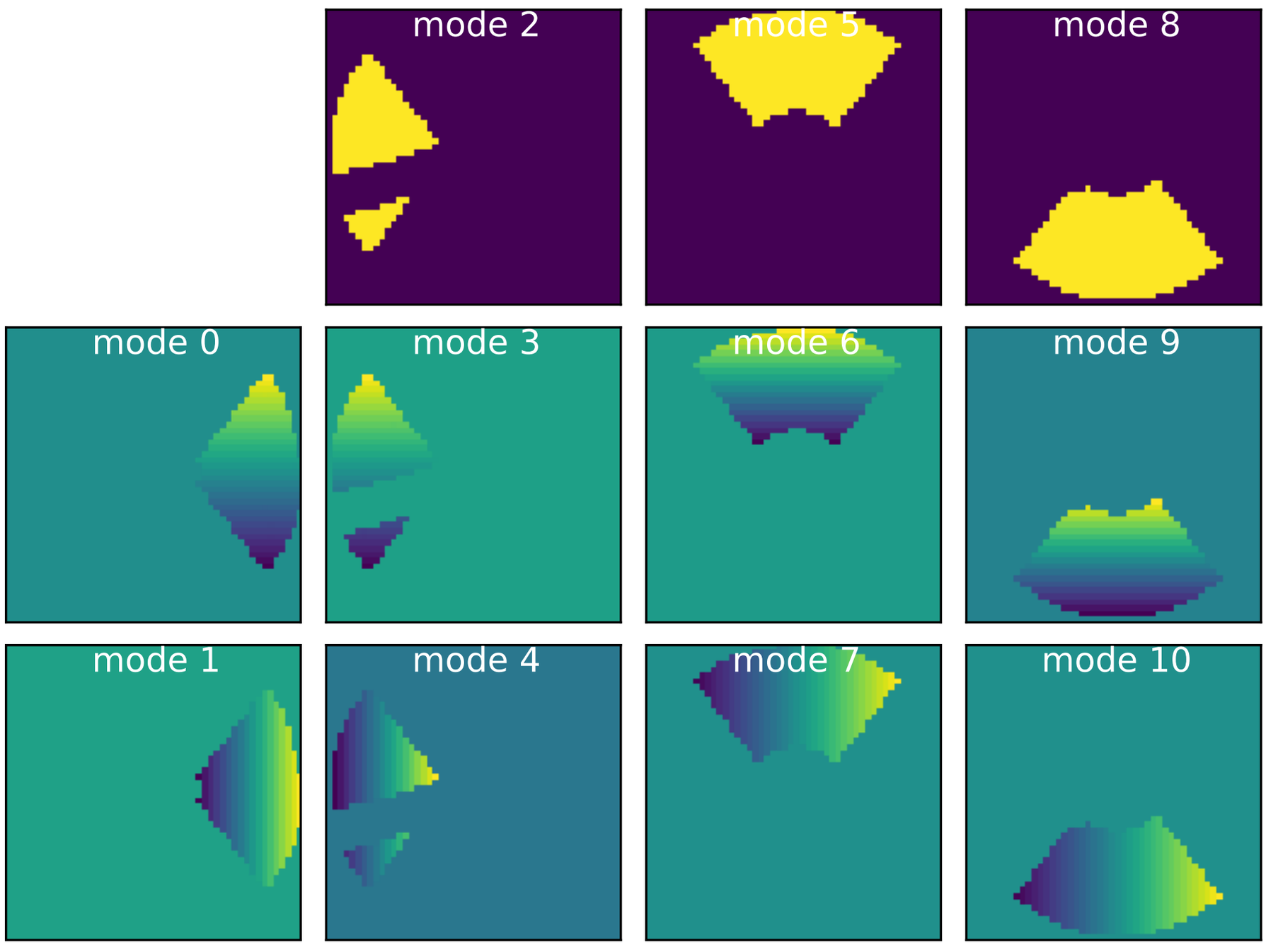
Test with Zernike modes



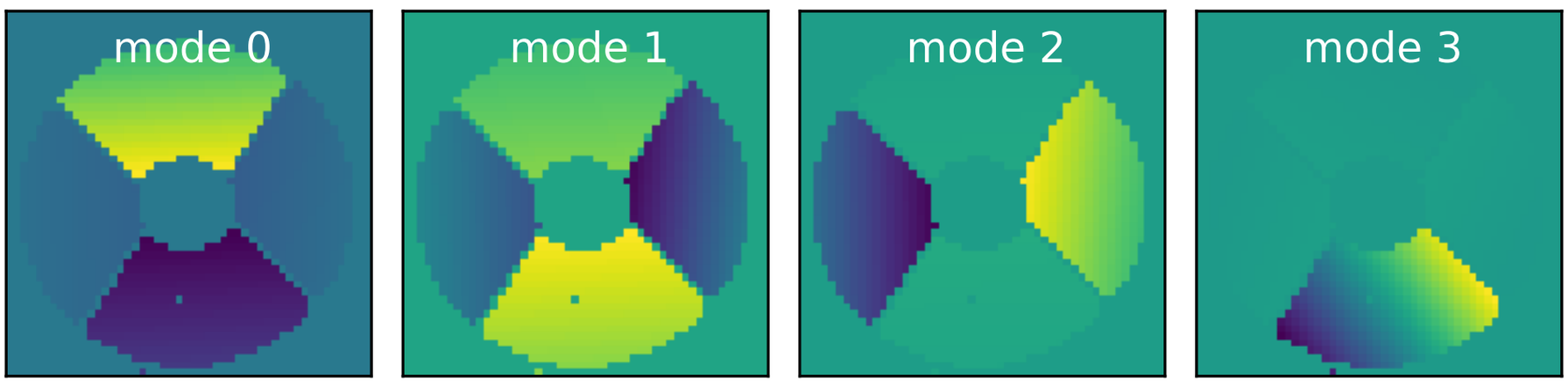
- Use of science detector to correct for the non common path errors
- Linearity of the sensor: ±200nm rms in H-band

Jovanovic et al. 2015, Martinache et al. 2016

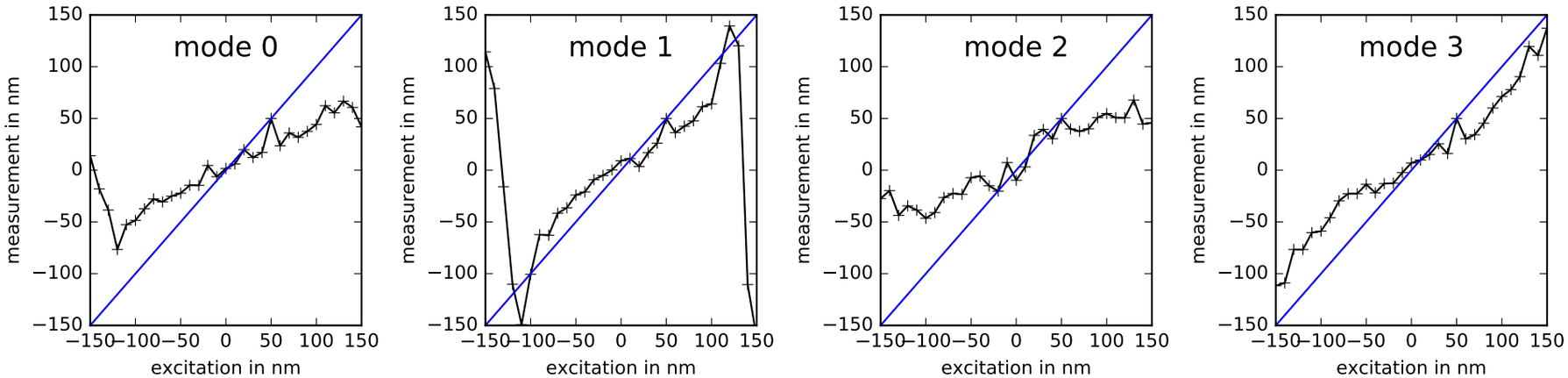
Set up of a LWE basis mode



Orthogonalization of the LWE mode set



Sensor response to the LWE modes

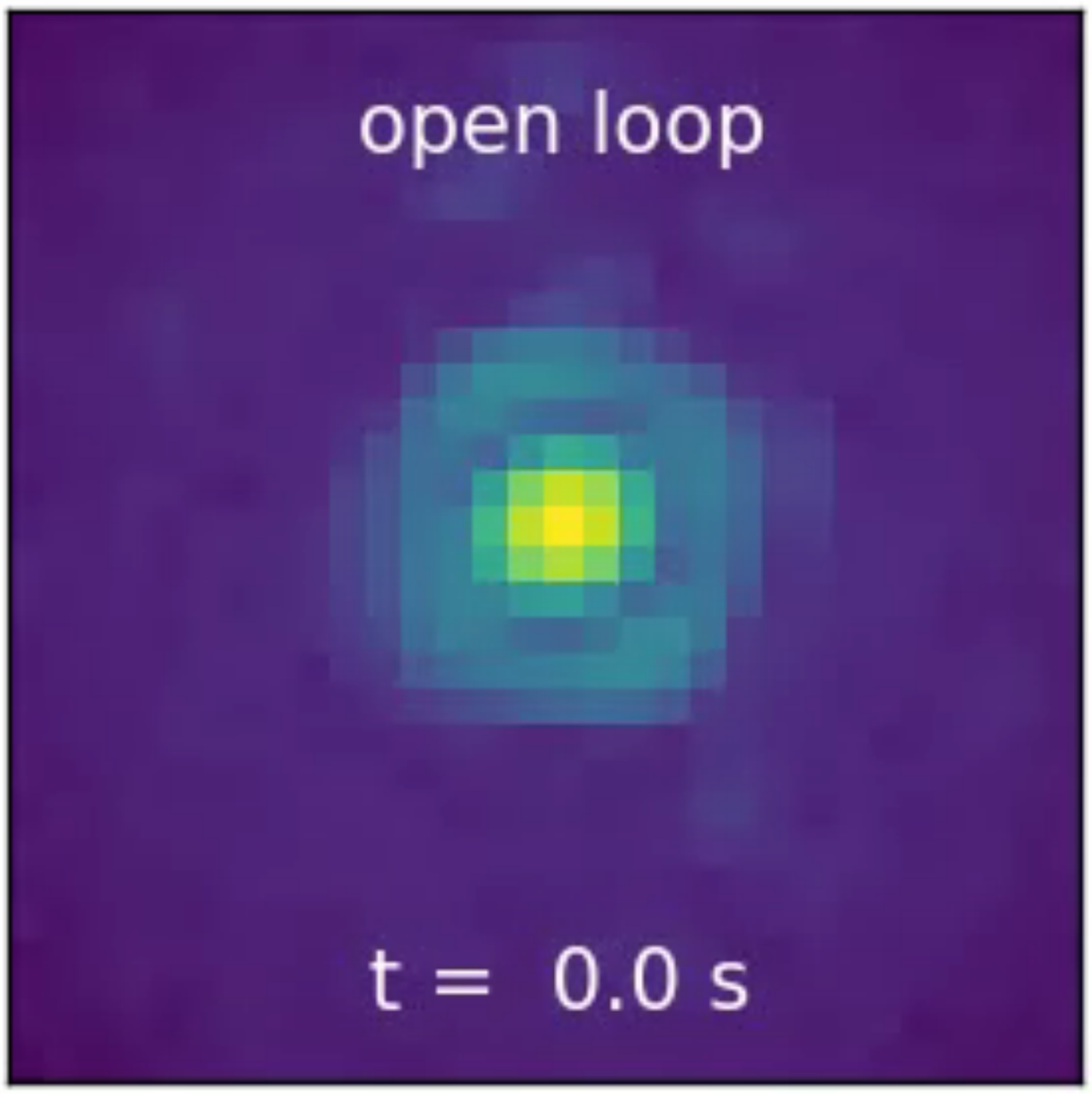


Up to ±100 nm rms linear range

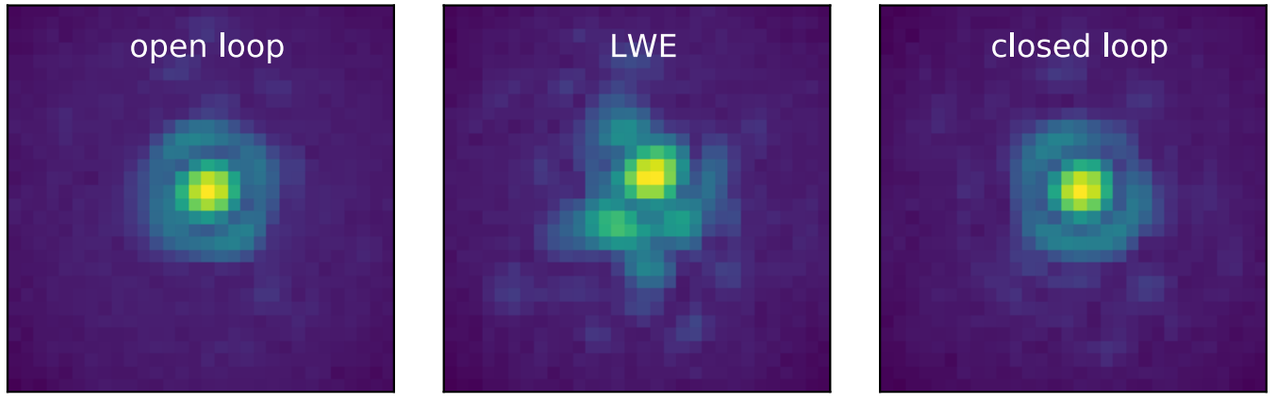
Limitations:

- discontinuous DM phase
- readout noise (160e- rms)

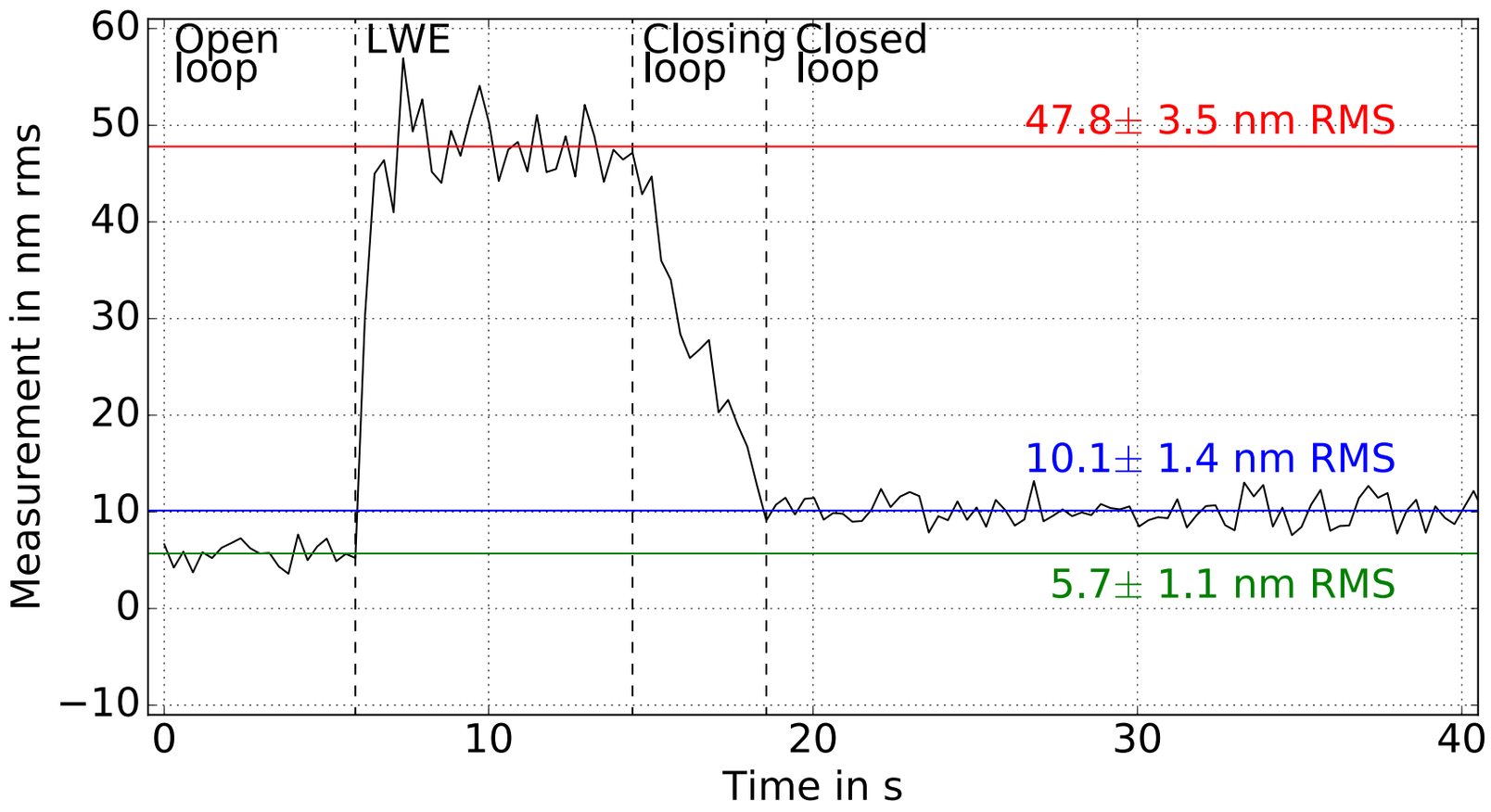
LWE control using ZAP



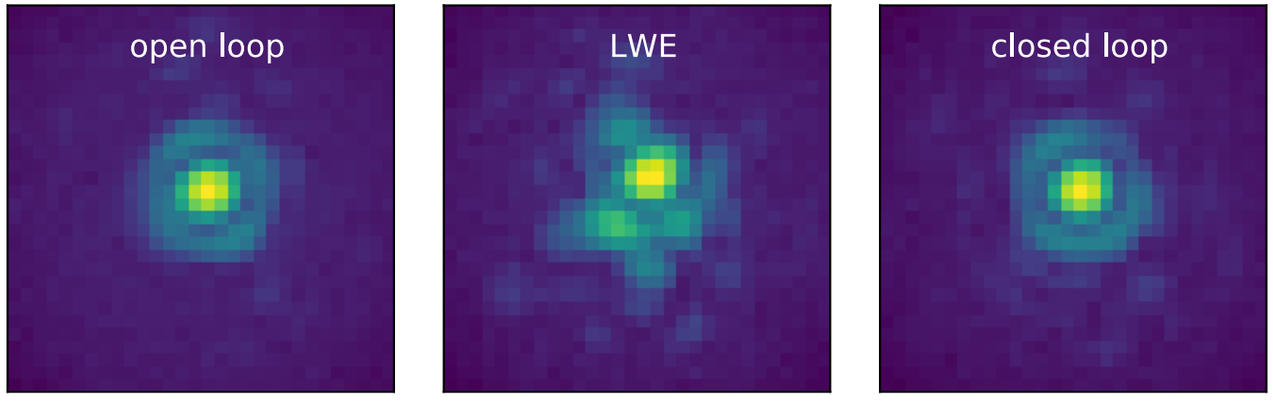
LWE control using ZAP



Temporal evolution of the wavefront error



LWE control using ZAP



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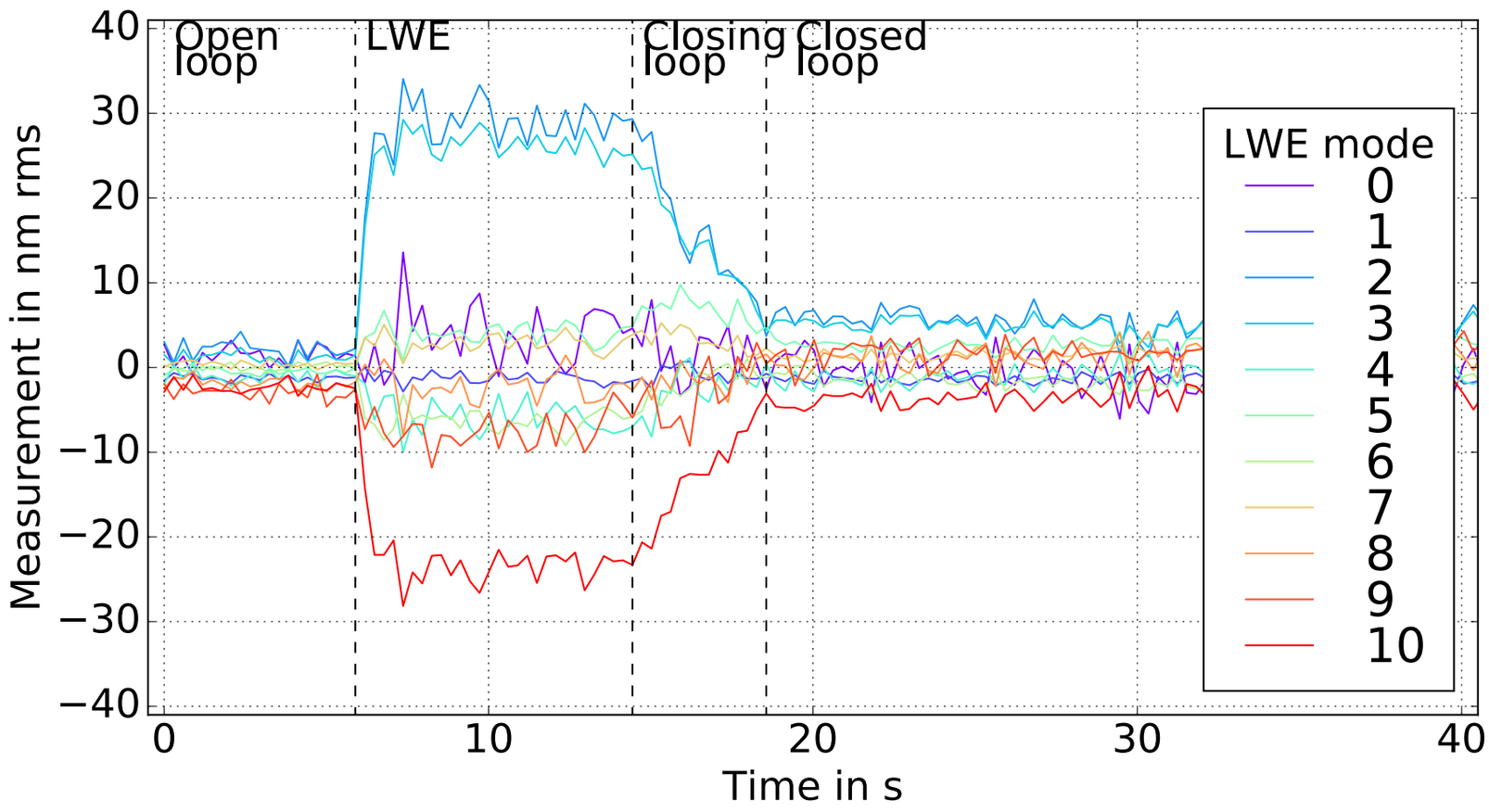
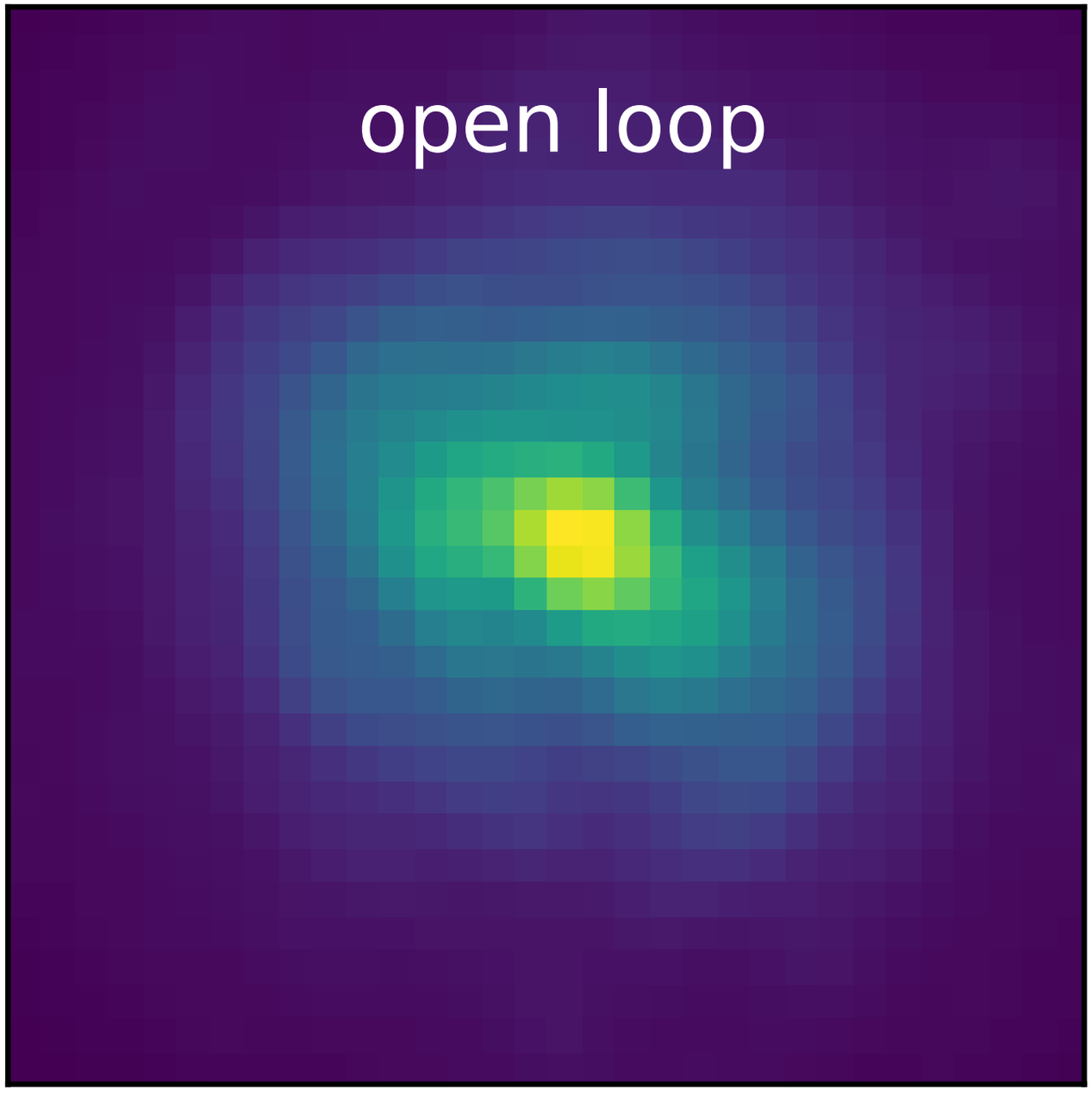


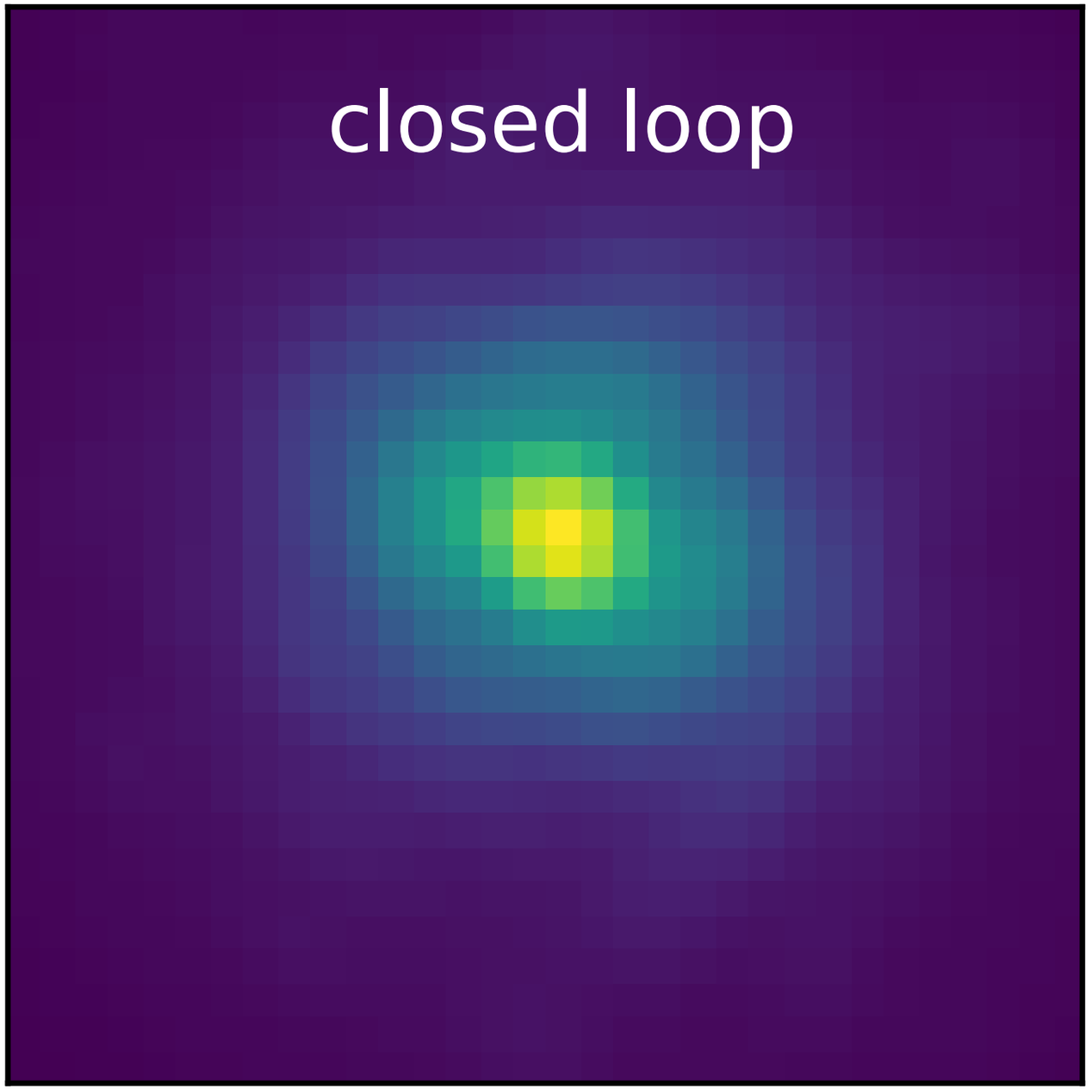
On-sky results in the visible

UT 2017-03-12
3.2 m/s wind speed
0.45” seeing



VAMPIRES, Norris et al. 2015

On-sky results in the visible



UT 2017-03-12
3.2 m/s wind speed
0.45” seeing

VAMPIRES, Norris et al. 2015

x2 gain in resolution

Conclusions & prospects

- First focal plane LWE control loop
  - In-lab compensation up to ± 100nm rms WFE
  - x2 on-sky gain in resolution in the visible

- Wavefront control algorithm improvements
  - Simultaneous correction of LWE and Zernike modes
  - Introduction of noise covariance matrix

- Forthcoming testbed to push the ultimate limits further
  - First Light C-Red One camera (<1e- rms at high frequency)
  - BMC segmented DM for the generation of segmented phase
  - **Feedback for ELTs**

Thanks for your attention!

Postdoc available on the KERNEL project
Feel free to contact Frantz Martinache:
frantz.martinache@oca.eu