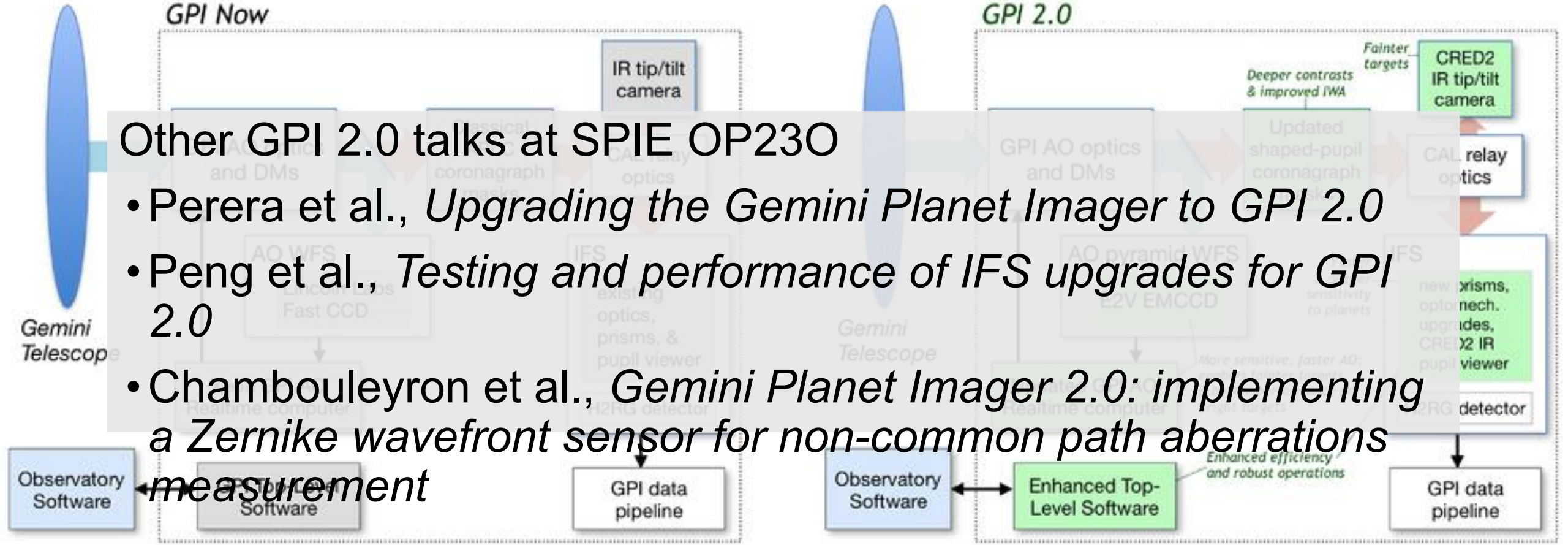
Focal plane wavefront control for the Gemini Planet Imager 2.0 calibration system (CAL 2)

Duan Li [a], Dmitry Savransky [a], Christian Marois [bc] and William Thompson [bc]

[a] Cornell University
[b] NRC Canada - Herzberg Astronomy & Astrophysics
[c] University of Victoria

Background

Upgrade to Gemini Planet Imager 2.0 (GPI 2.0)



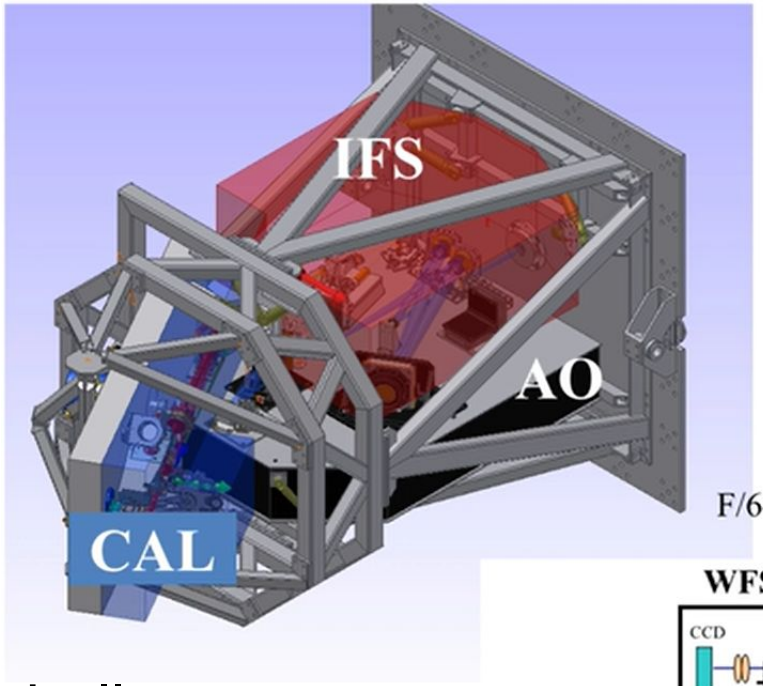
Other GPI 2.0 talks at SPIE OP23O

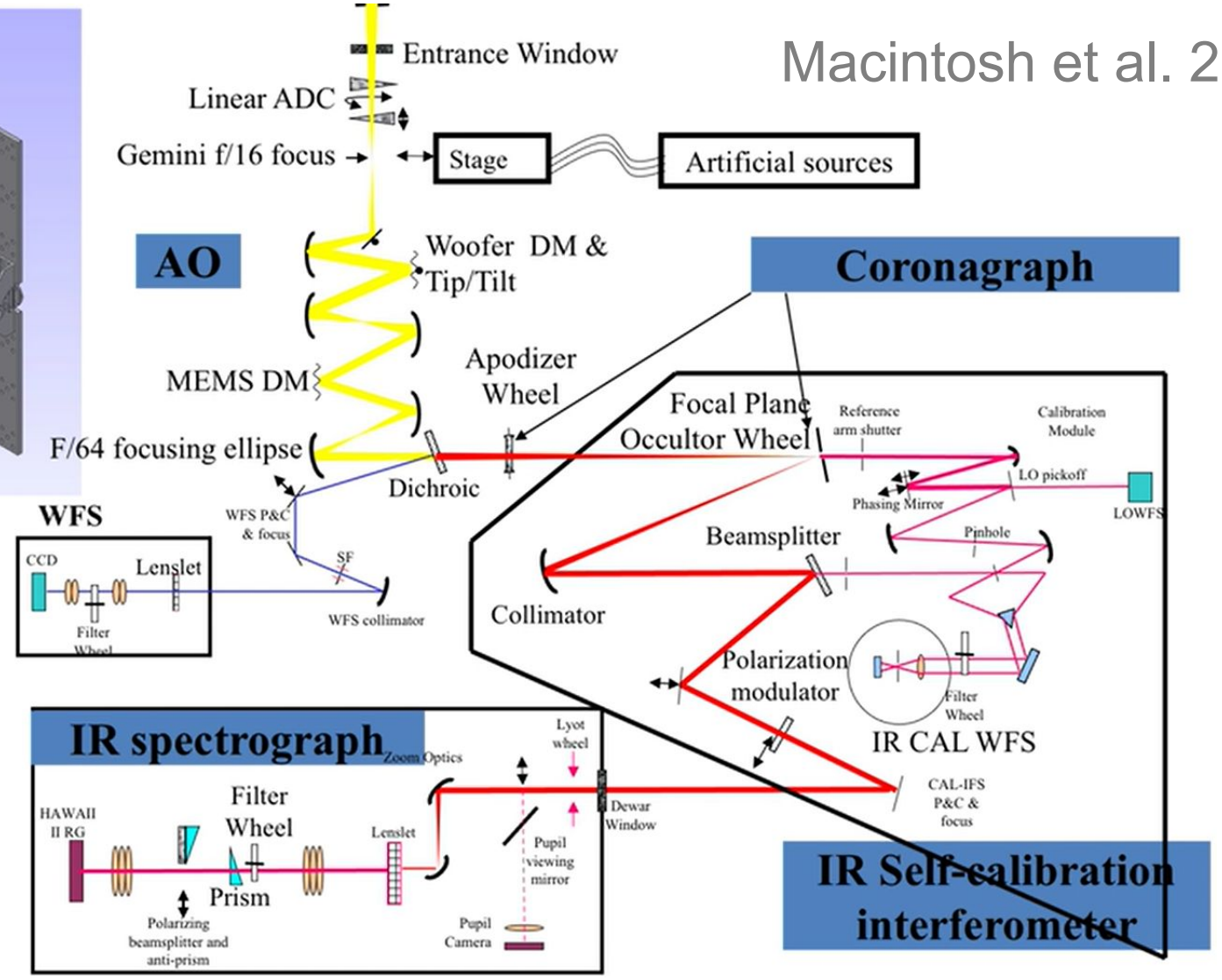
- Perera et al., *Upgrading the Gemini Planet Imager to GPI 2.0*
- Peng et al., *Testing and performance of IFS upgrades for GPI 2.0*
- Chambouleyron et al., *Gemini Planet Imager 2.0: implementing a Zernike wavefront sensor for non-common path aberrations measurement*

Chilcote et al. 2020

Background

Speckle Nulling on GPI IFS





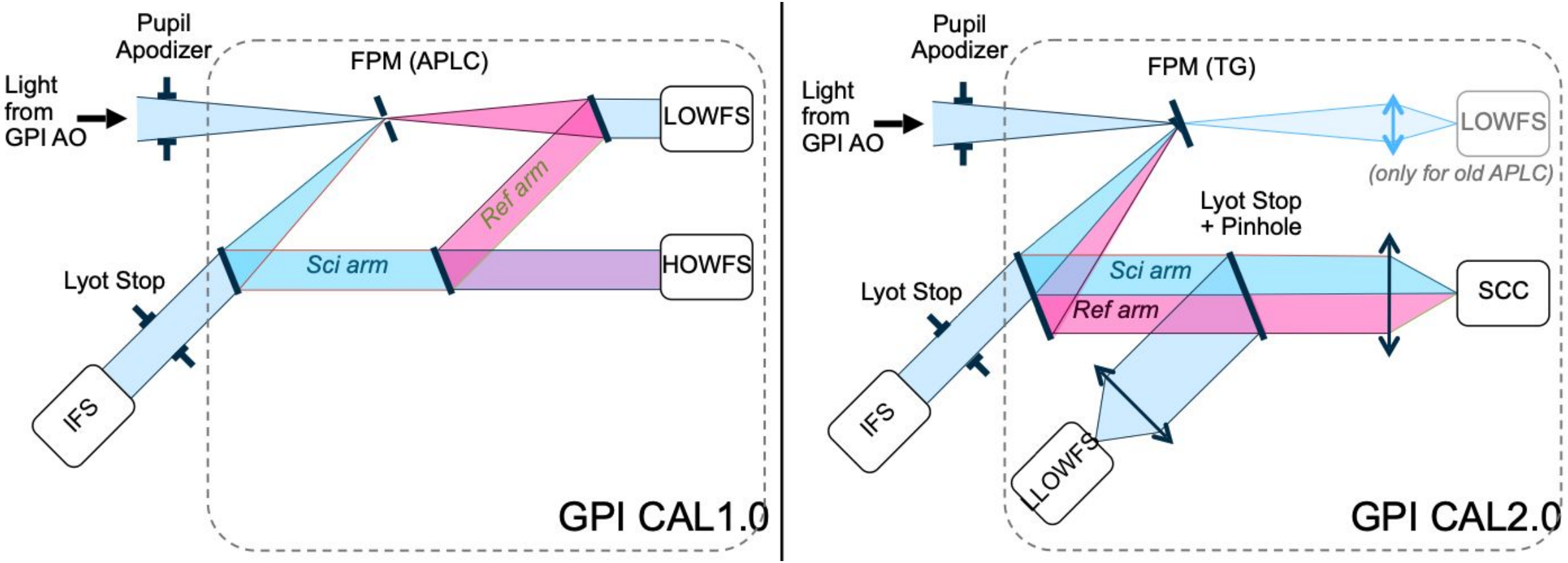
Macintosh et al. 2007

Previous challenges:

- High time cost
- Non-common path vibrations in CAL
- Limited contrast improvement

Background

GPI CAL 2.0



Marois et al. 2020

Theory

Speckle Nulling

Electric field at the deformable mirror plane

$$E_0 = Ae^{\alpha+i\beta}e^{i\psi}$$

Electric field at the science camera plane

$$E_f = C\{E_0\}$$

Intensity of light in the science camera plane

$$I_k = |E_f|^2 = \left|C\left\{Ae^{\alpha+i\beta}e^{i\psi_k}\right\}\right|^2$$

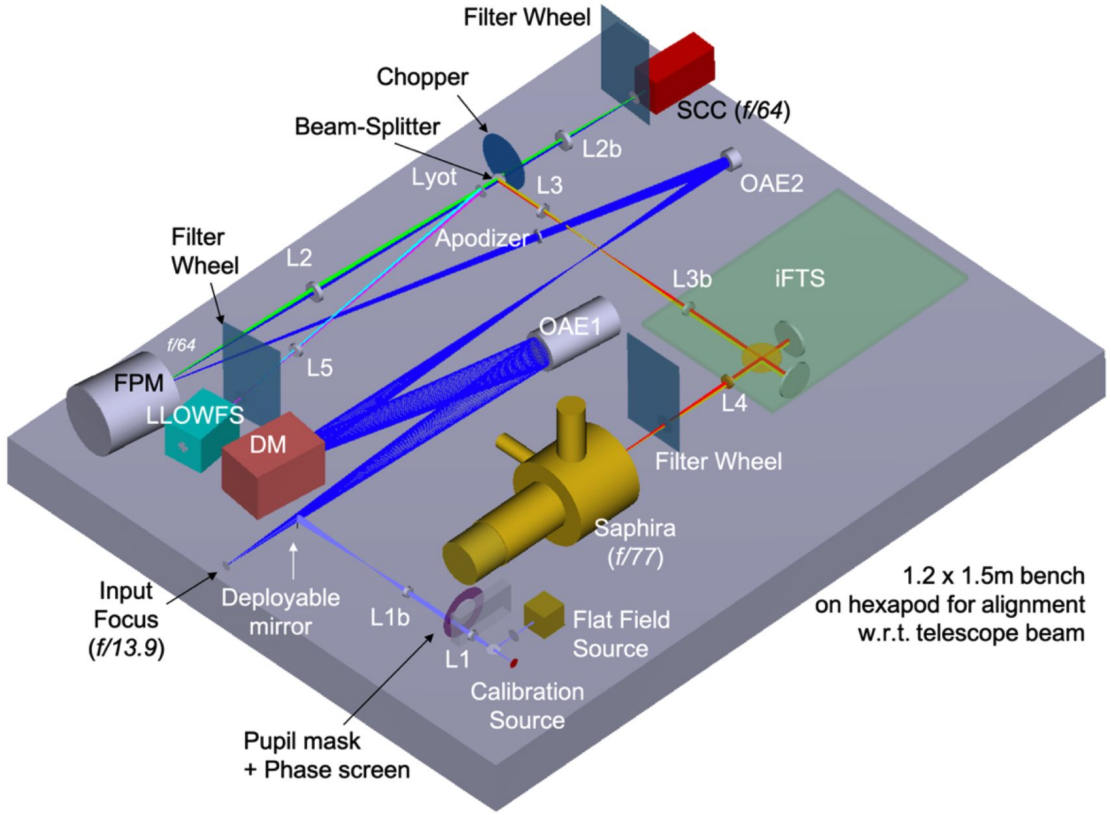
Advantage: no model required

Preliminary experiments

Subaru Pathfinder Instrument for Detecting Exoplanets & Retrieving Spectra (SPIDERS)

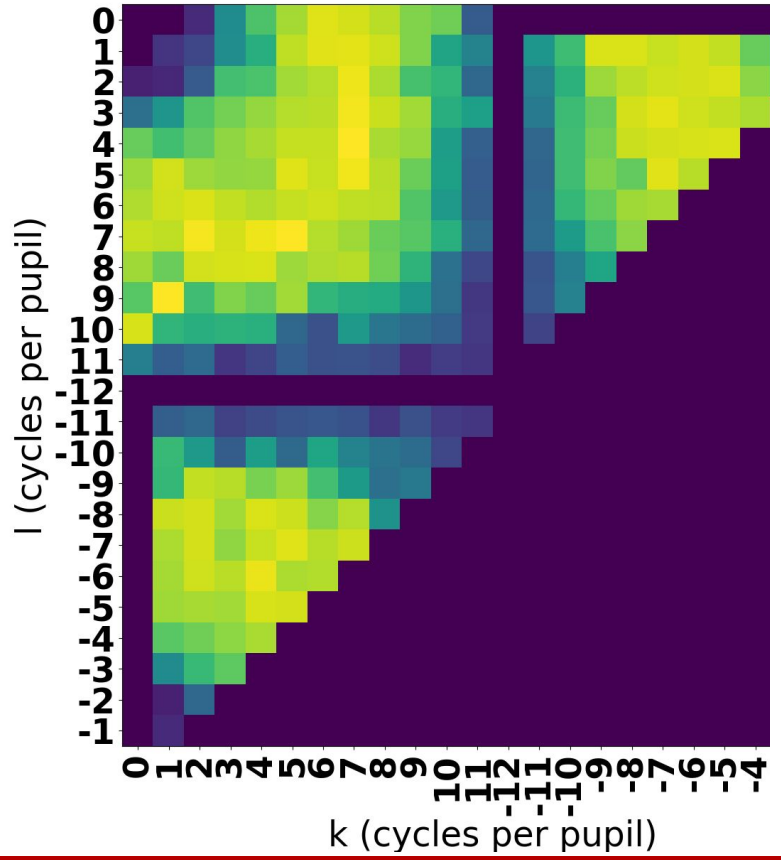
- Wavelength: 1.65 μm
- Bandwidth: 2%
- Deformable mirror (DM): 24 x 24 actua
- Wavefront control: low-order WFS, SC
- Residual vibrations: 200 Hz

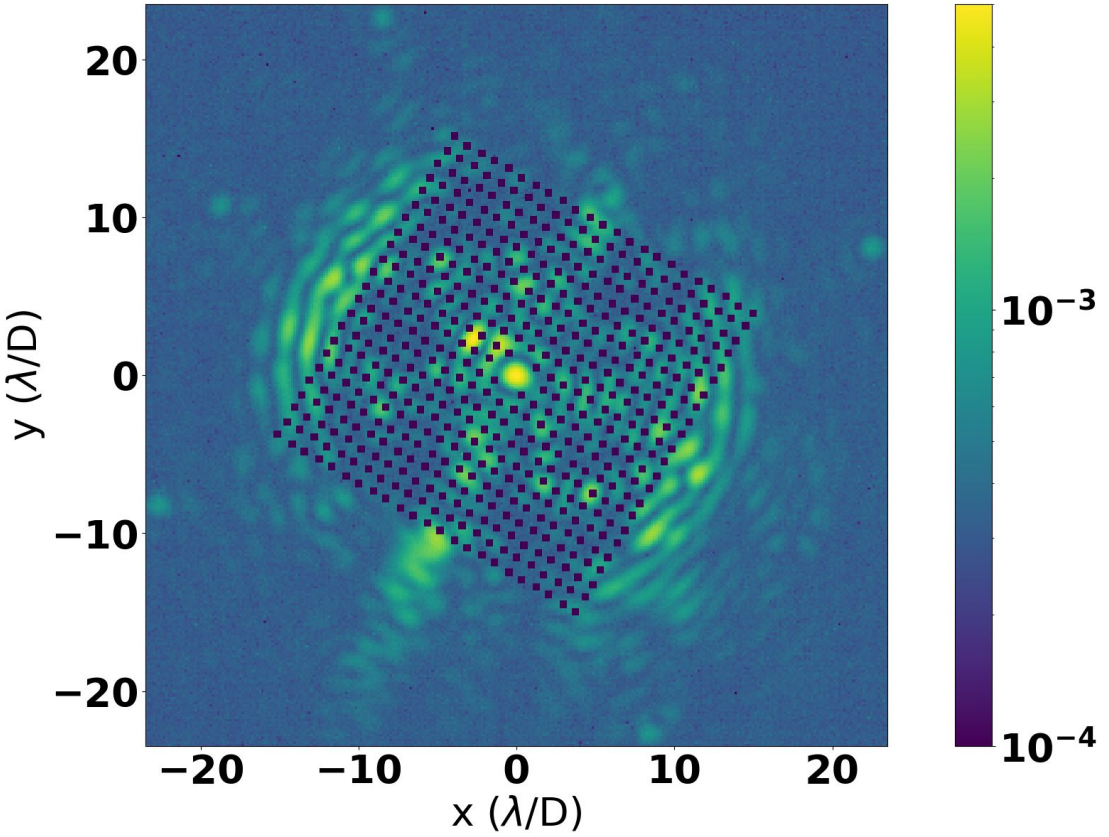
Lardière et al. 2022



Methodology

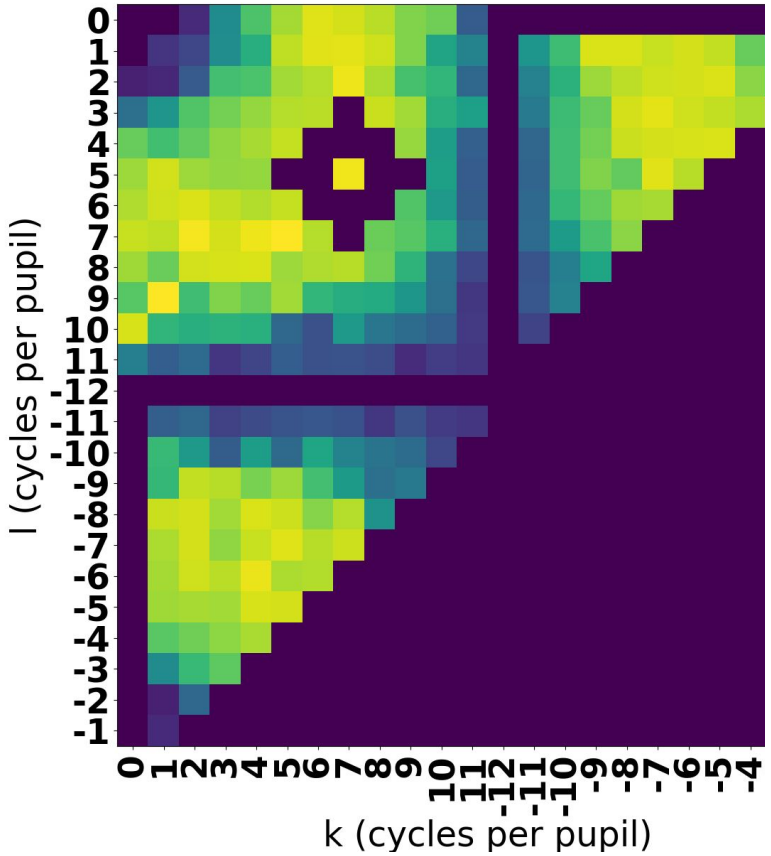
Modal control with intensity calibration

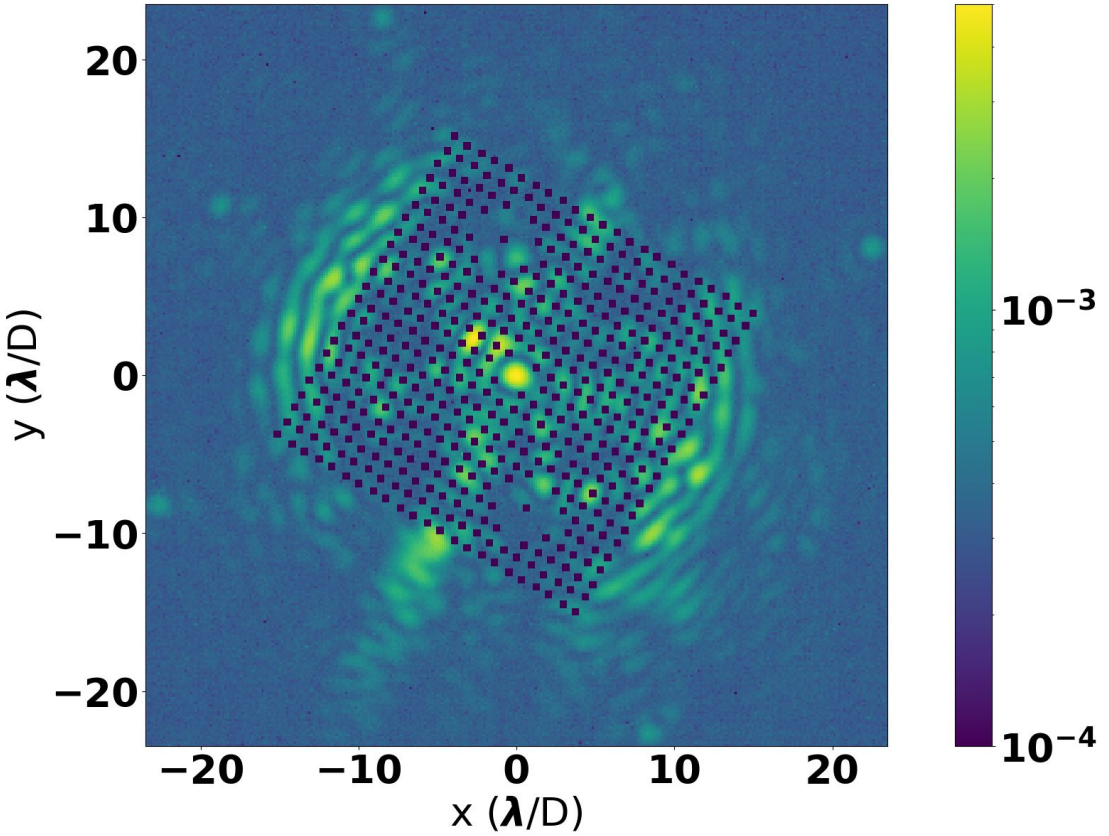




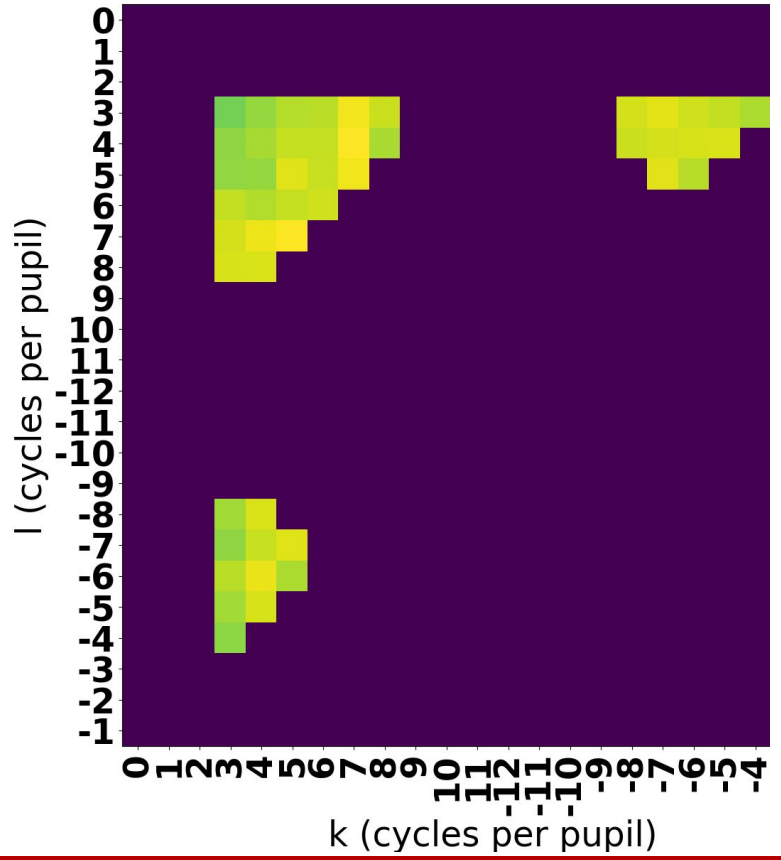
Methodology

Crosstalk



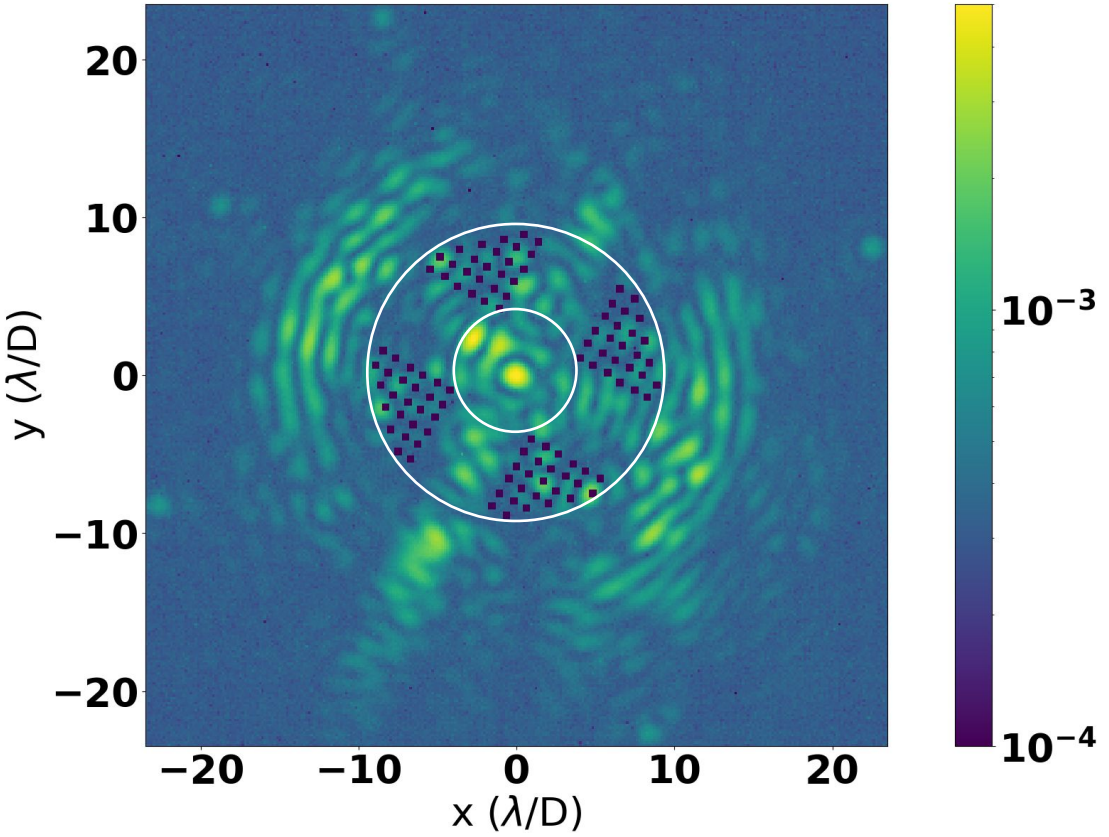


Methodology



IWA: $4\,\lambda/D$

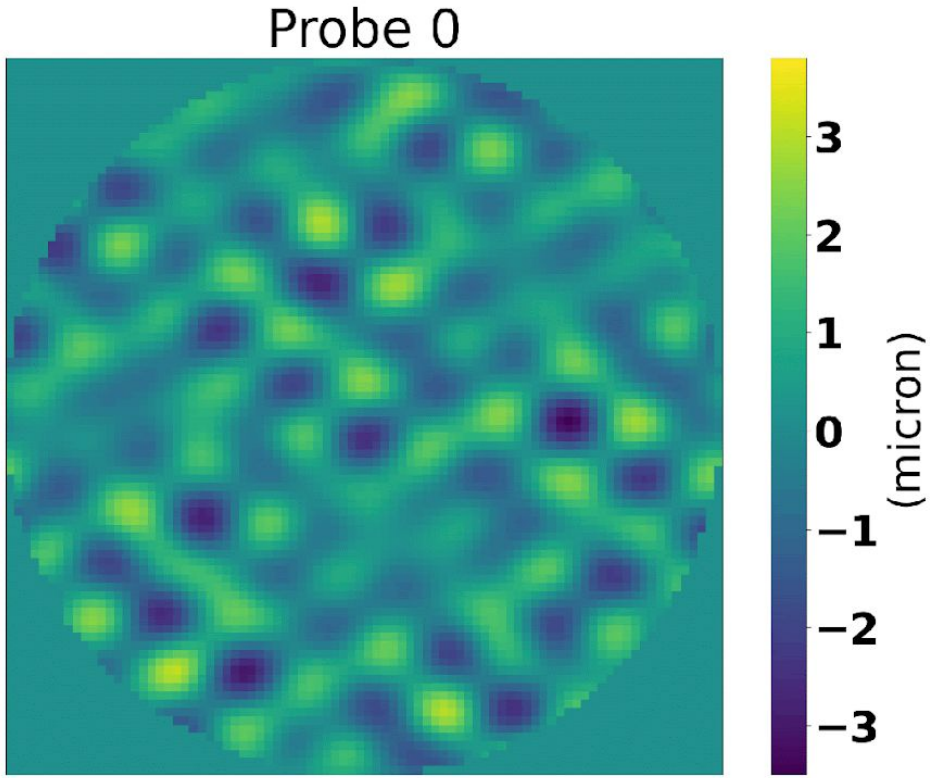
OWA: $9\,\lambda/D$



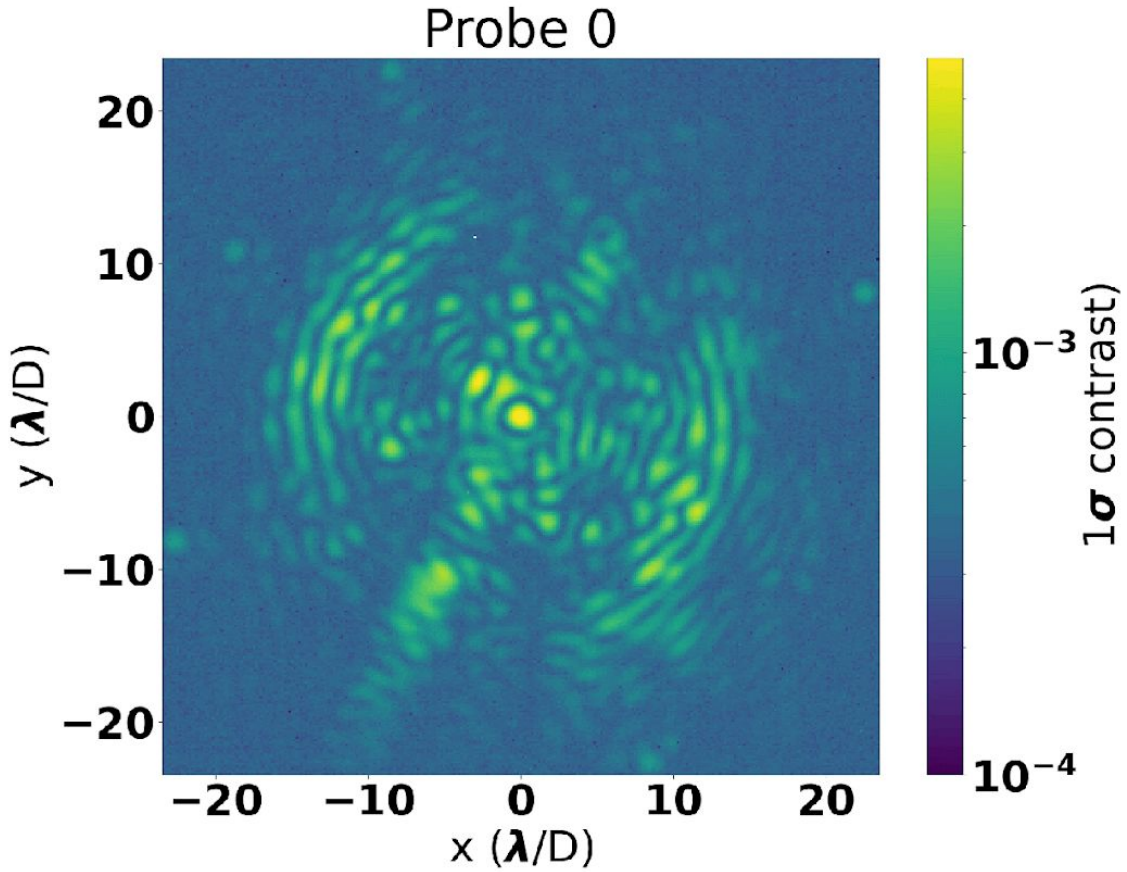
Methodology

Phase probing

DM phase

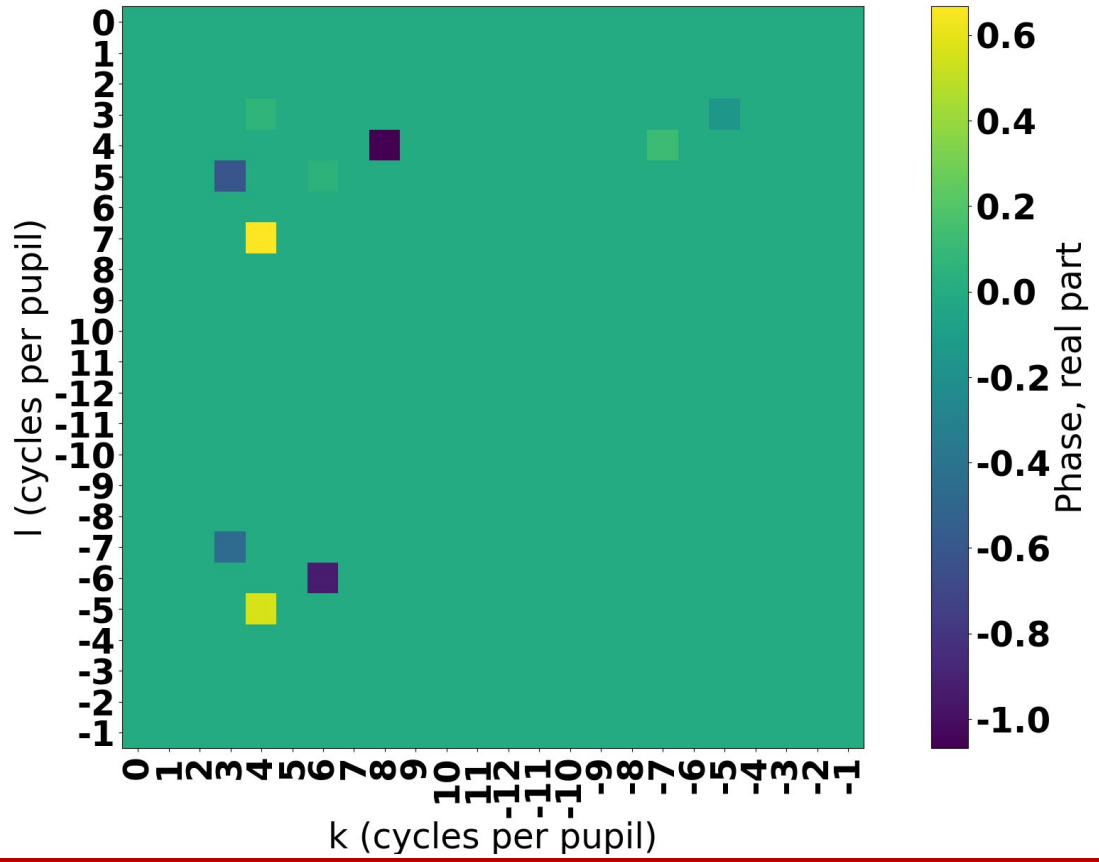


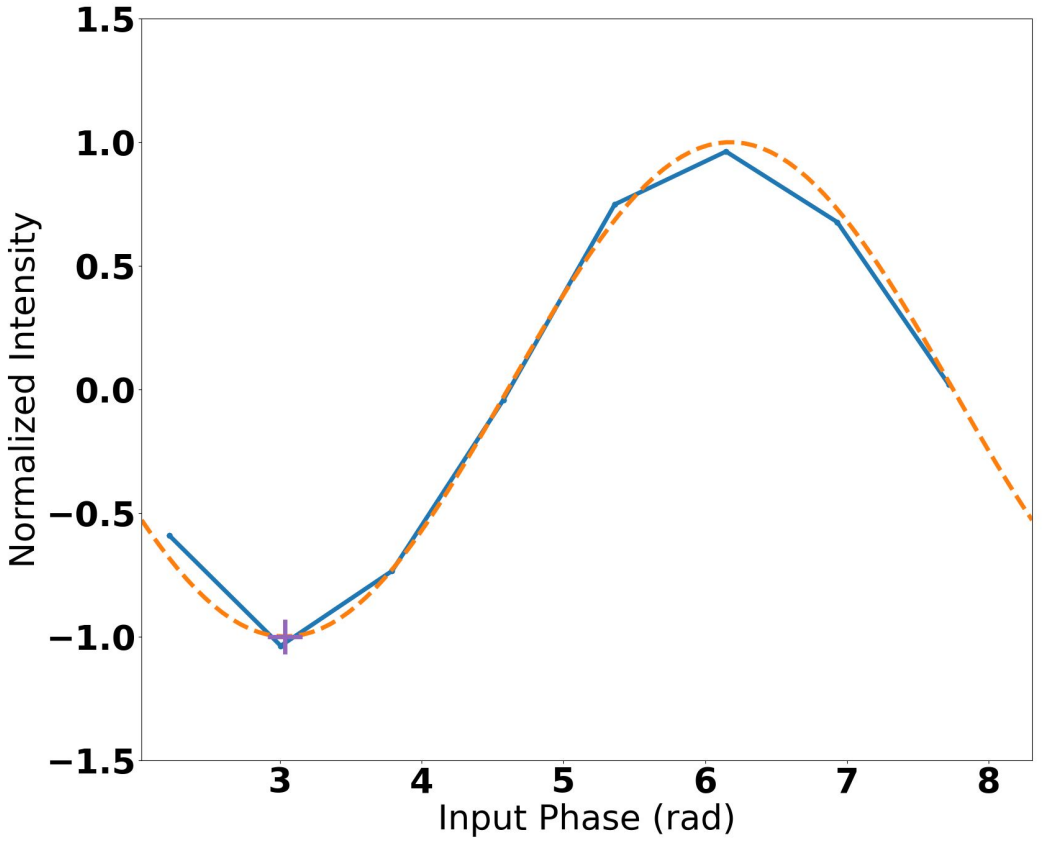
PSF



Methodology

Phase probing

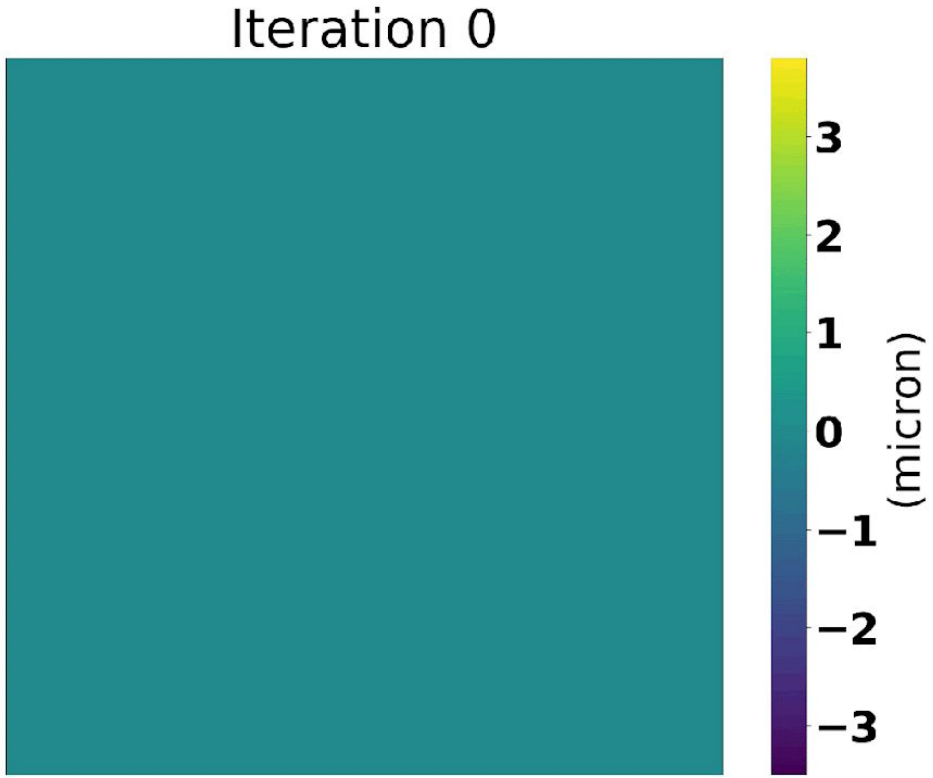




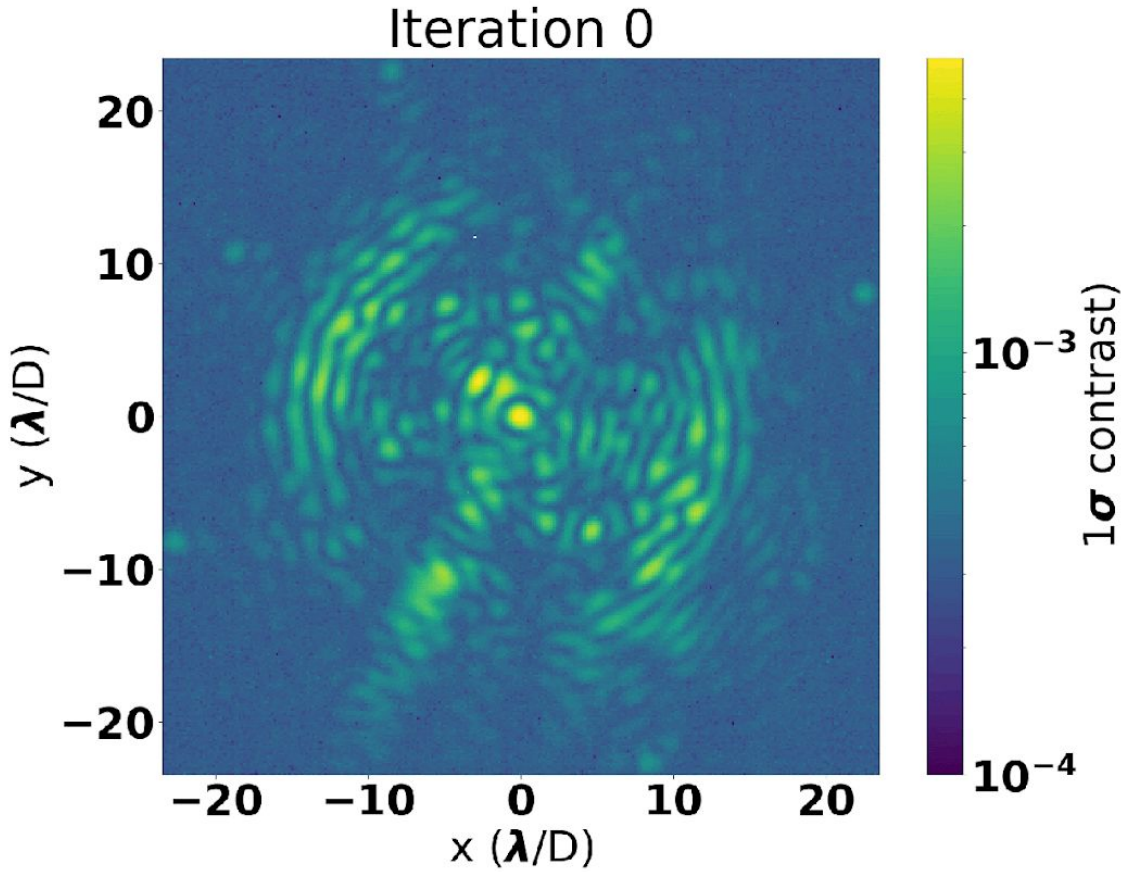
Results

Point spread function

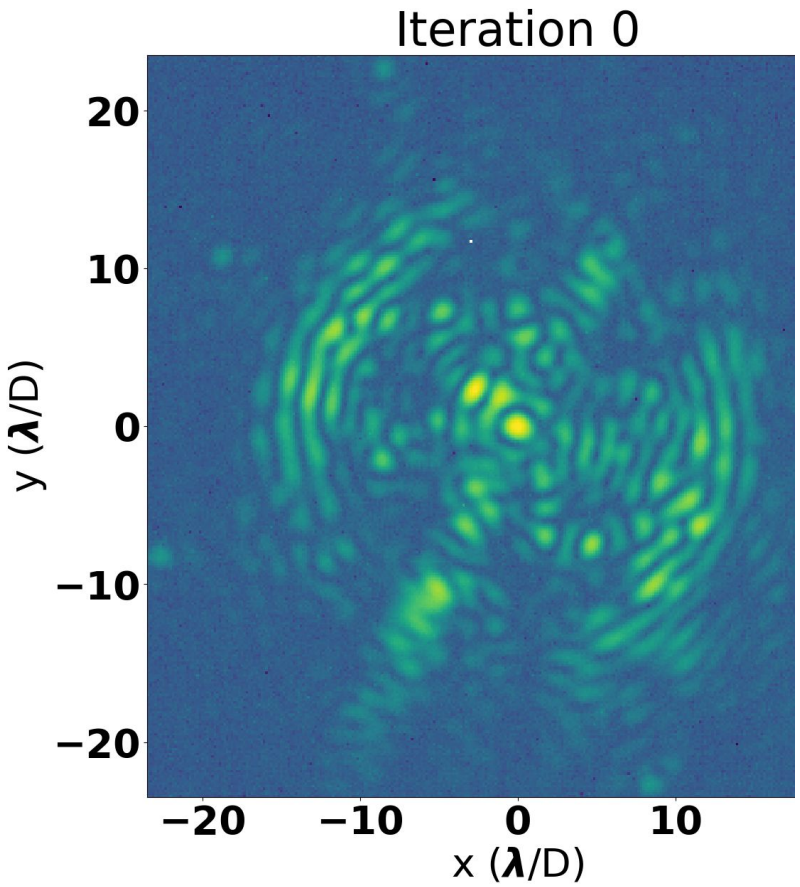
DM phase

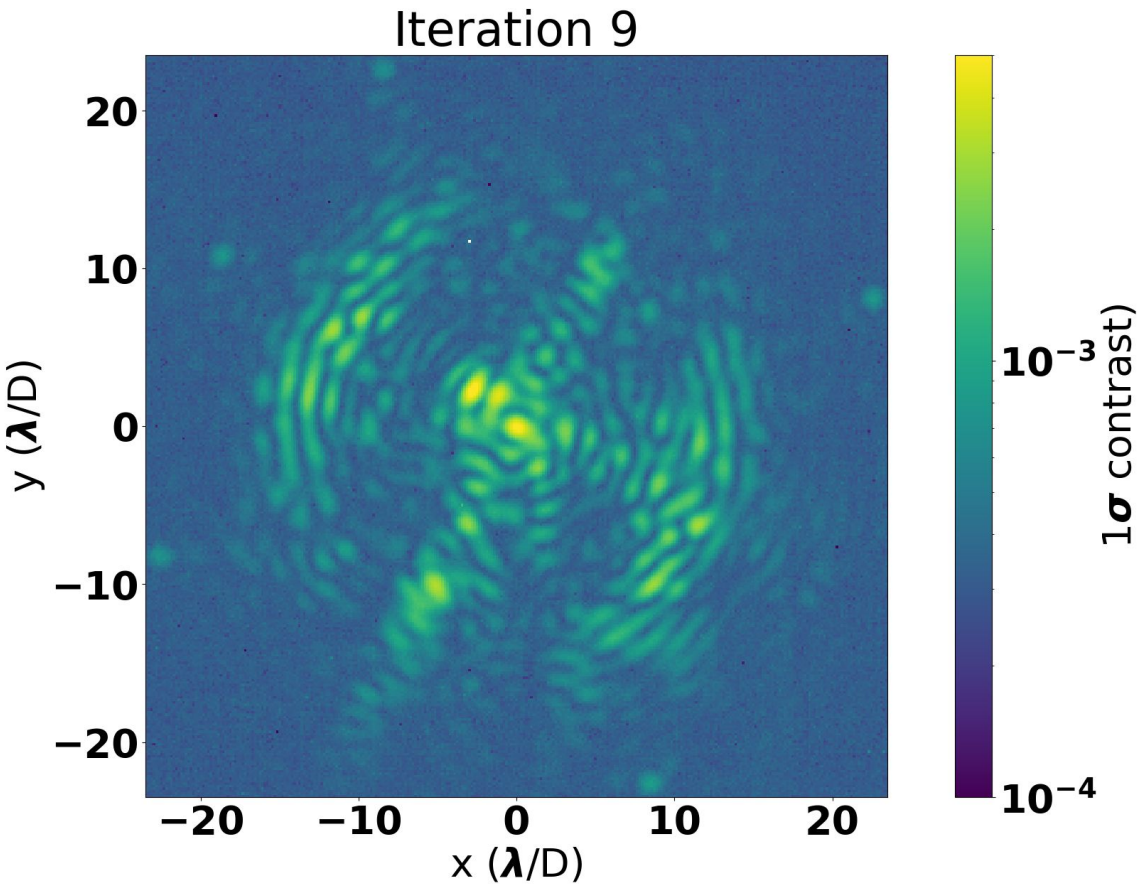


PSF



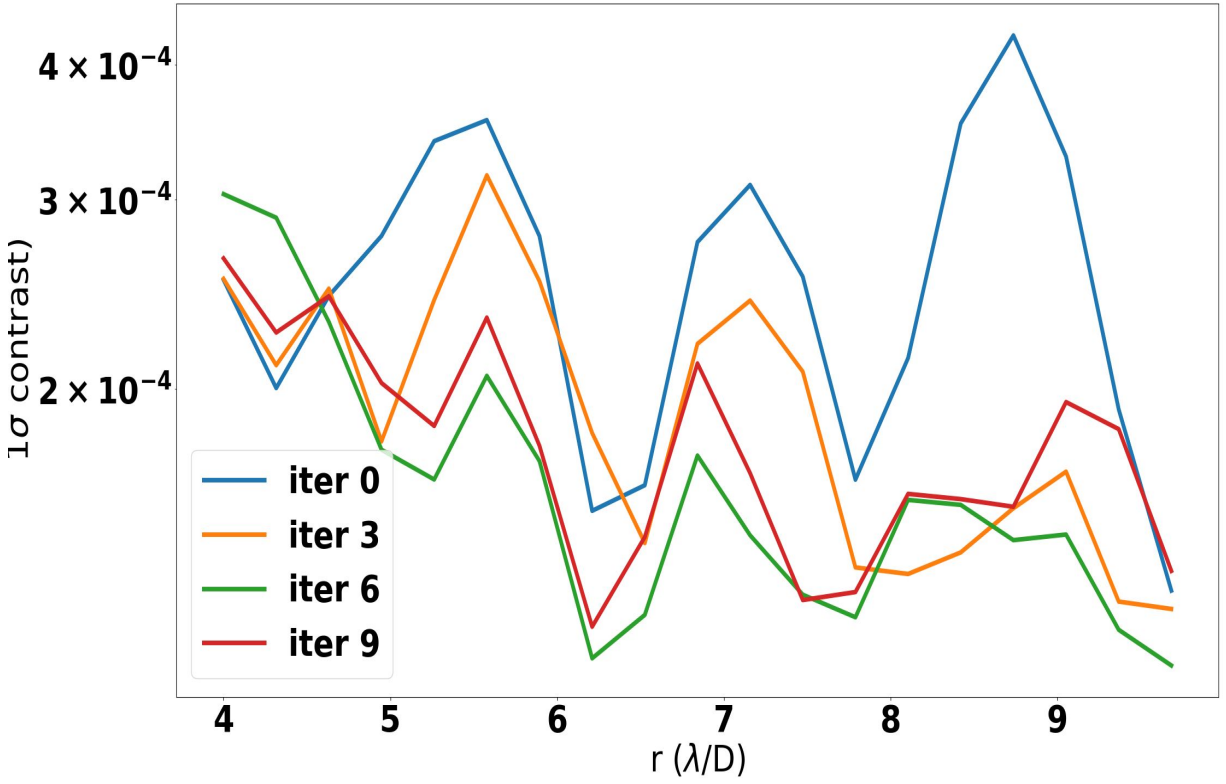
Results

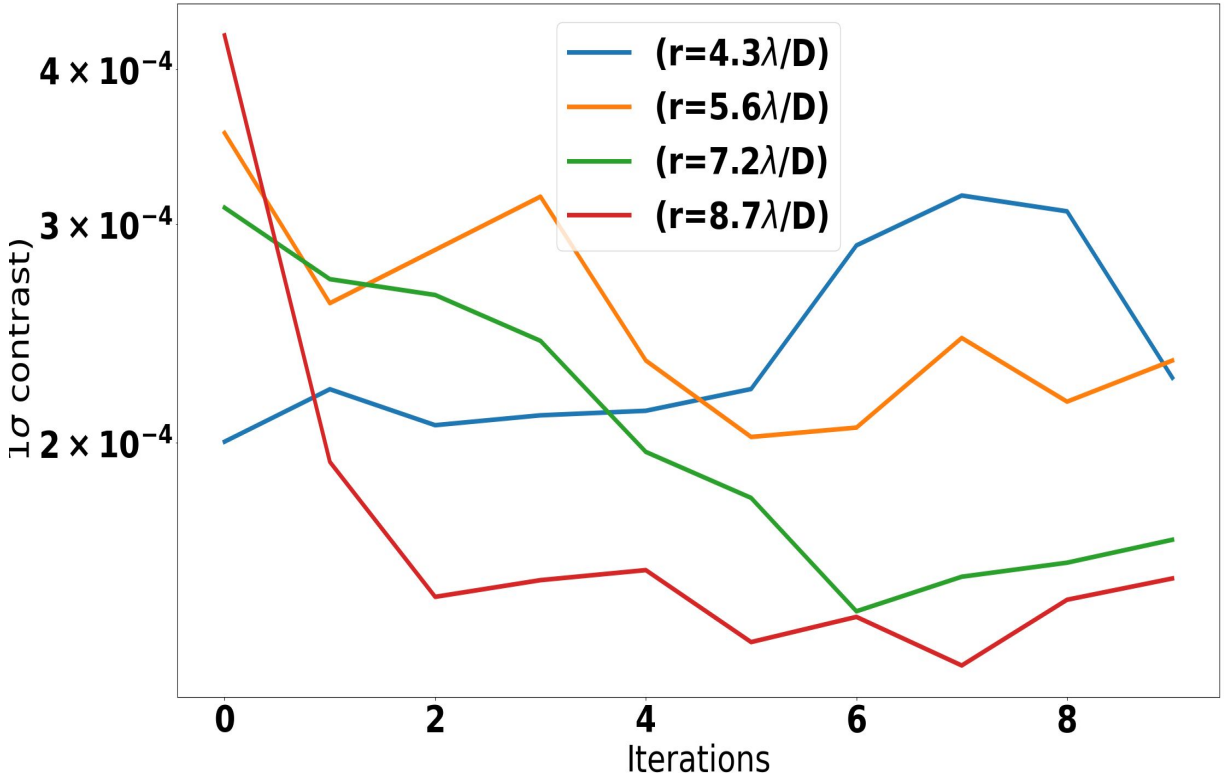

Iteration 0
20
10
0
−10
−20
y (λ/D)
−20
−10
0
10
x (λ/D)


Iteration 9
20
10
0
−10
−20
y (λ/D)
−20
−10
0
10
20
x (λ/D)
10^{-3}
10^{-4}
1σ contrast)

Results

Contrast

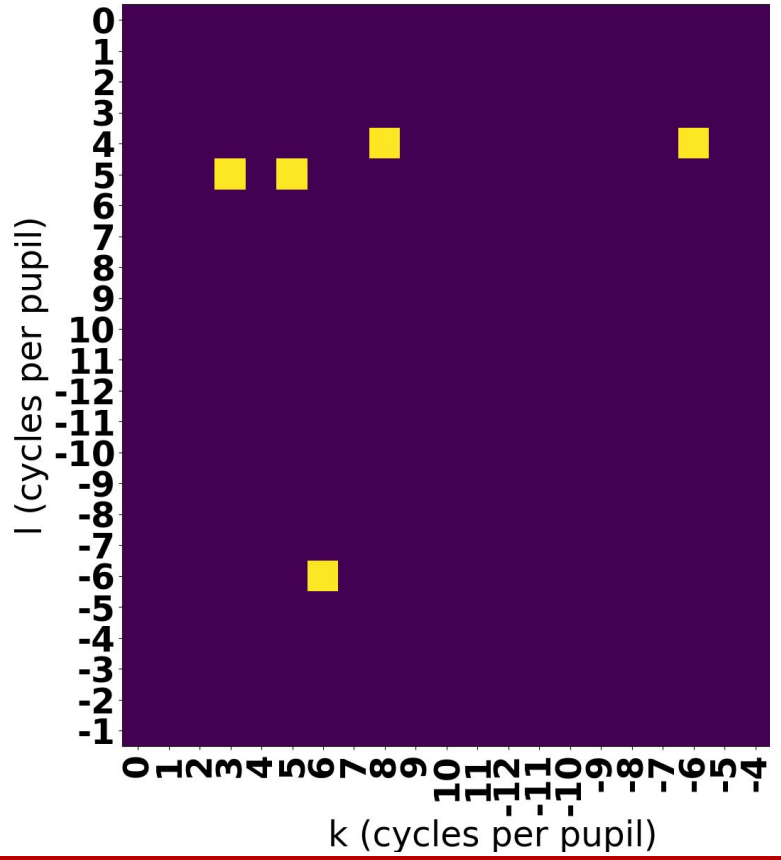




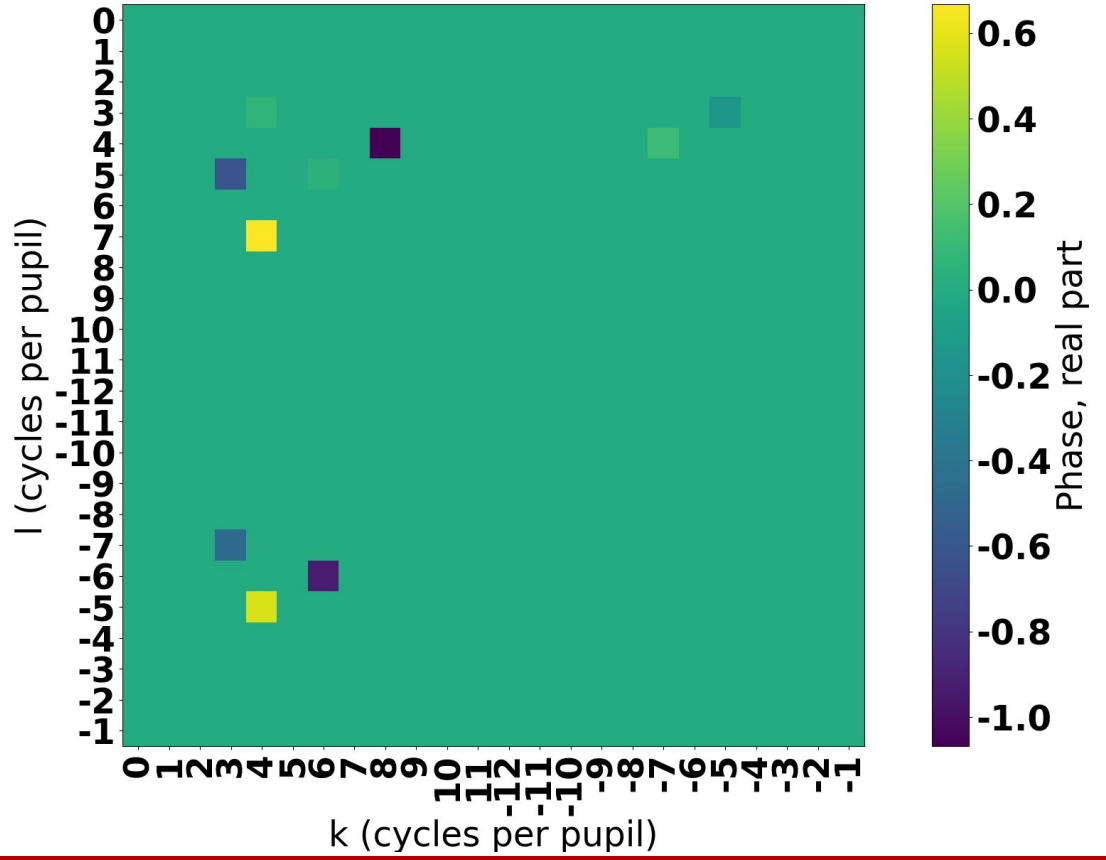
Discussion

Phase probing

Injected speckles

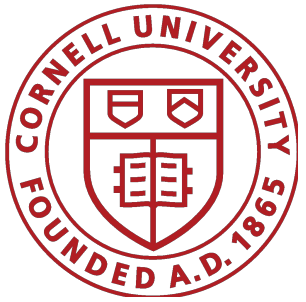


Phase corrections, real



Conclusion

- Methodology (speckle nulling):
  - Improvement in intensity calibration, image processing
- Preliminary experiments
  - Significantly faster integration time 10 nanoseconds
  - Contrast improvement by up to a factor of 3.2 for injected noise
  - Limitations: amplitude error, calibration precision
- Computational framework
  - Adapted to both SCC and IFS
- Future work
  - Algorithm optimization
  - Implicit electric field conjugation
  - Simulation on GPI optical model

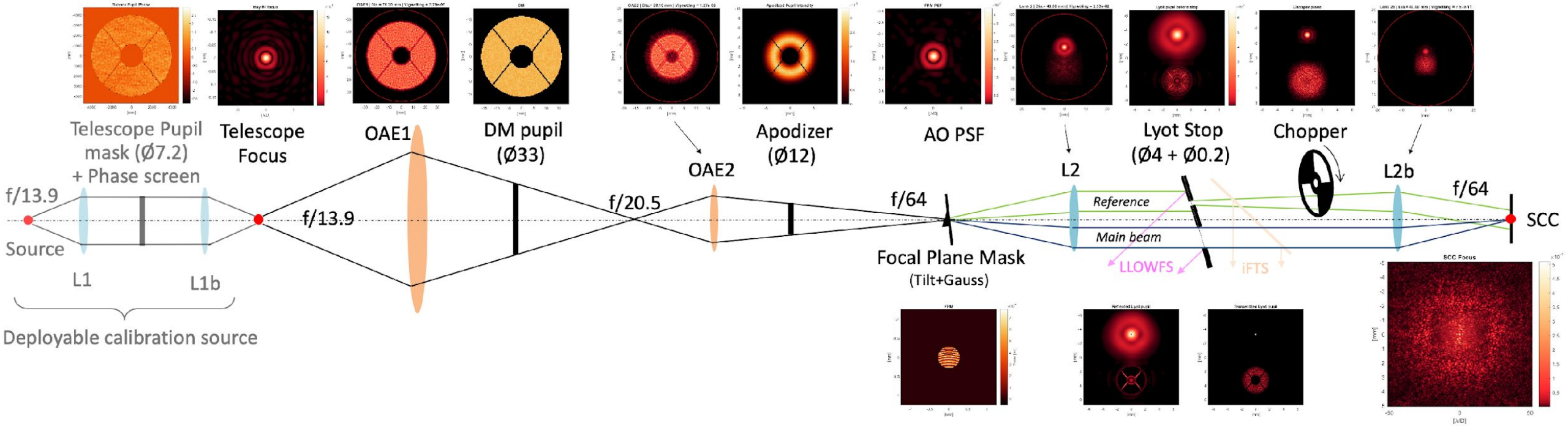


Thank You!

Contact: dl943@cornell.edu

Background

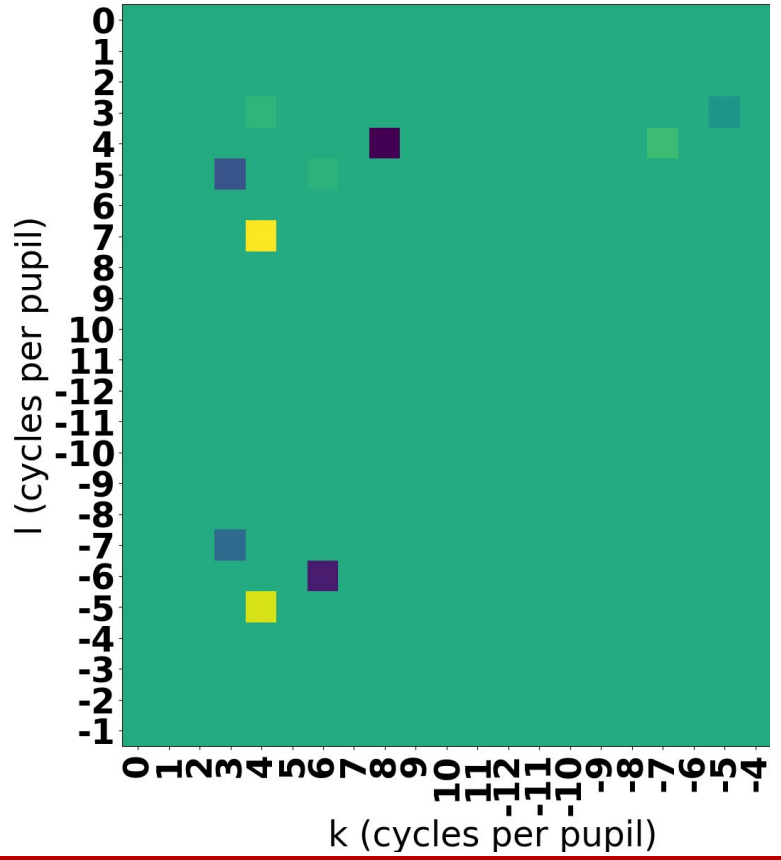
Subaru Pathfinder Instrument for Detecting Exoplanets & Retrieving Spectra (SPIDERS)



Discussion

Phase probing

Phase corrections, real



Phase corrections, imaginary