Nonlinear wavefront sensing & control with machine learning

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WFS in the VLT/ELT era 2022, Porto

Collaborators:
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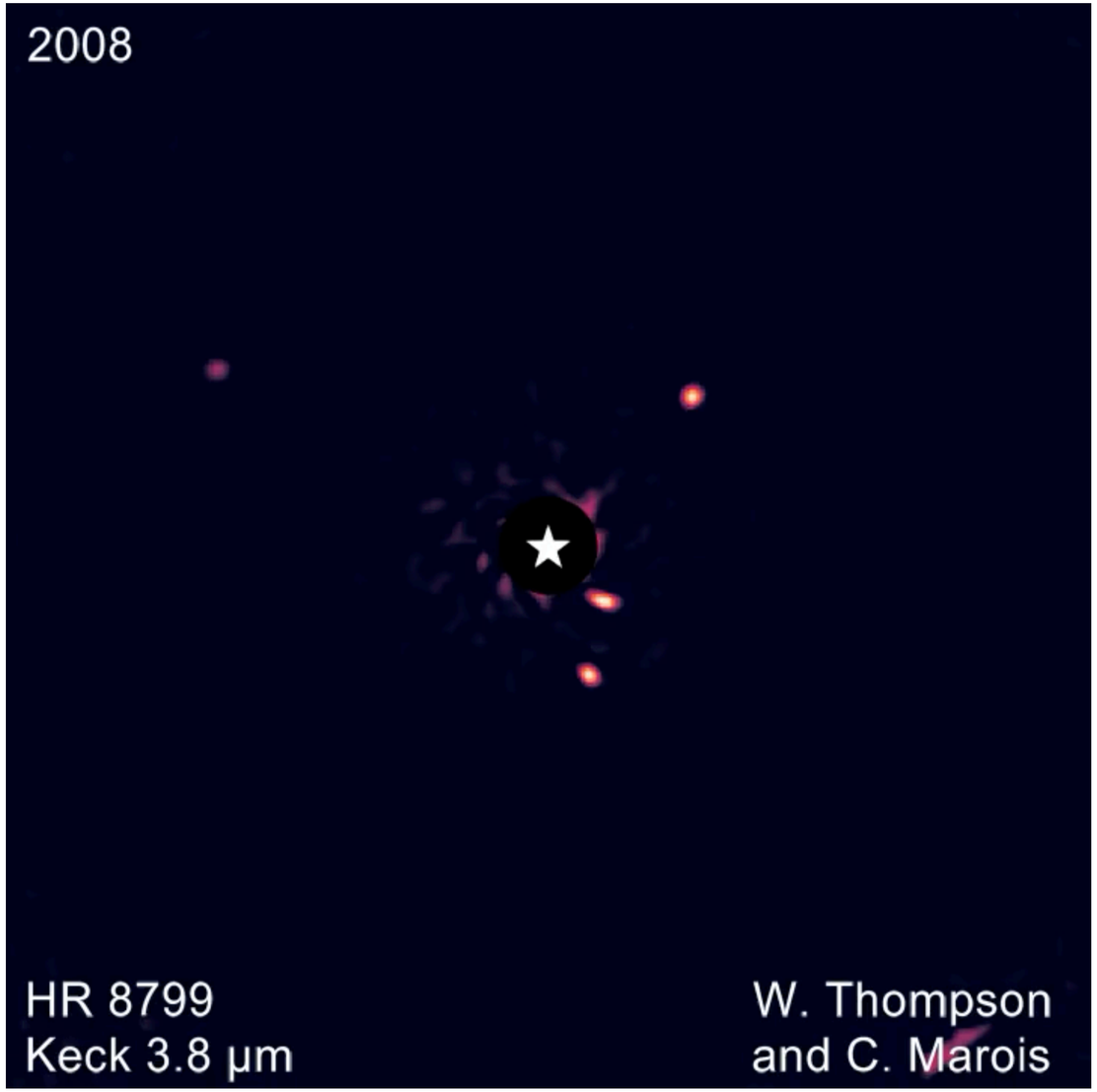
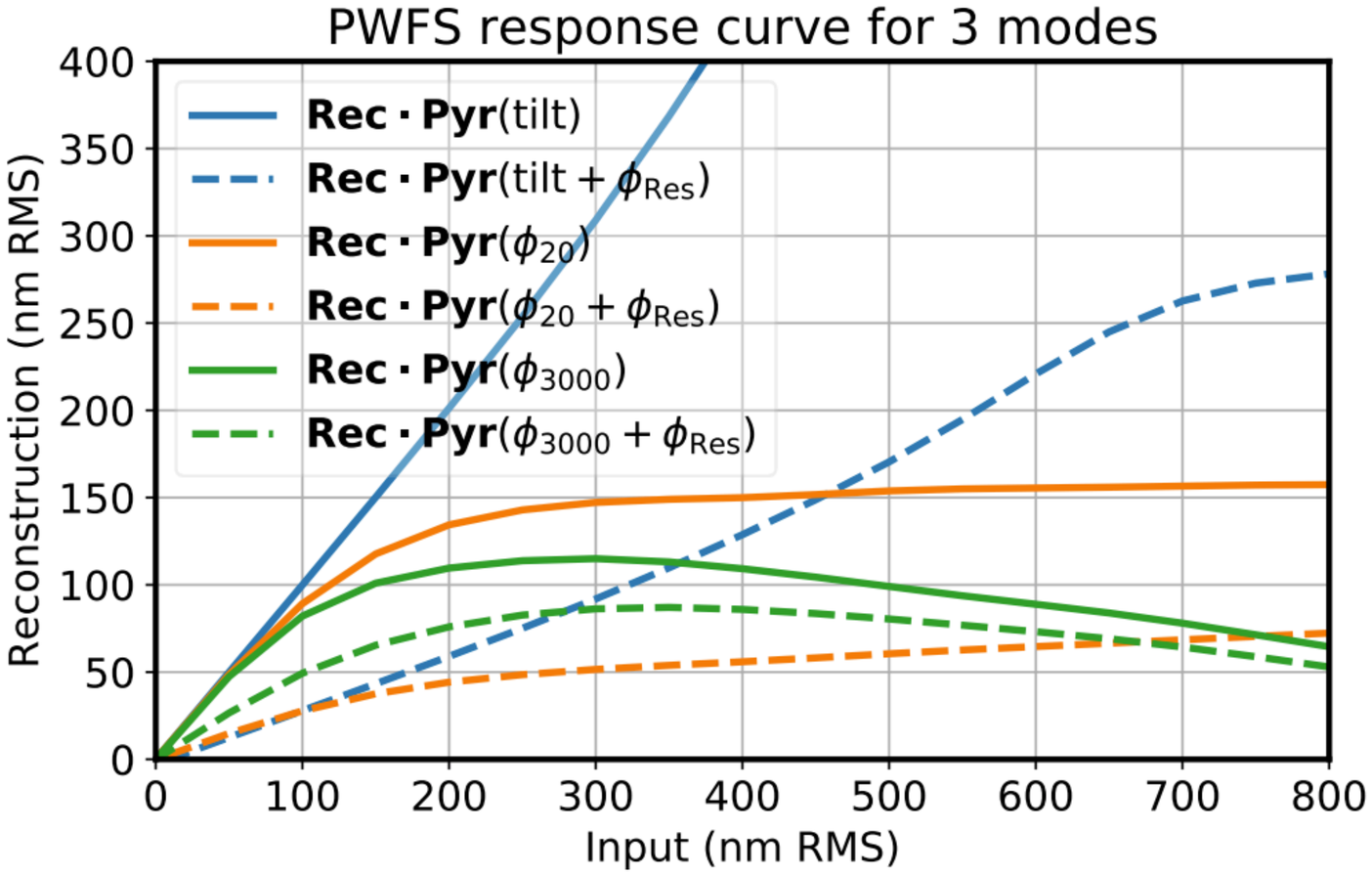
Background image credit: ESO/M. Kornmesser

Some XAO limitations for exoplanet imaging on ELT's



1. Wavefront sensor nonlinearity
2. Temporal wavefront errors
3. Wavefront sensor sensitivity (in general and to specific modes)
4. Non-common path aberrations

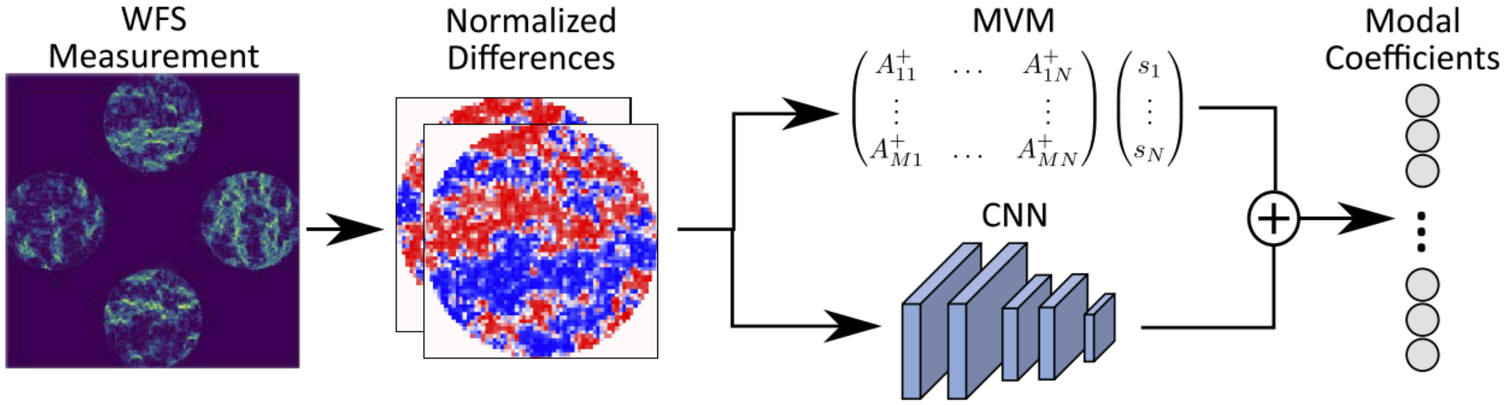
1. Fourier-filtering WFS's (e.g. Pyramid) are nonlinear



Deo+ 2019

Neural Networks as nonlinear reconstructors

Landman & Haffert 2020



See also: Swanson+2018, Allan+2020, Wong+2021, Pou+2022

Neural Networks as nonlinear reconstructors

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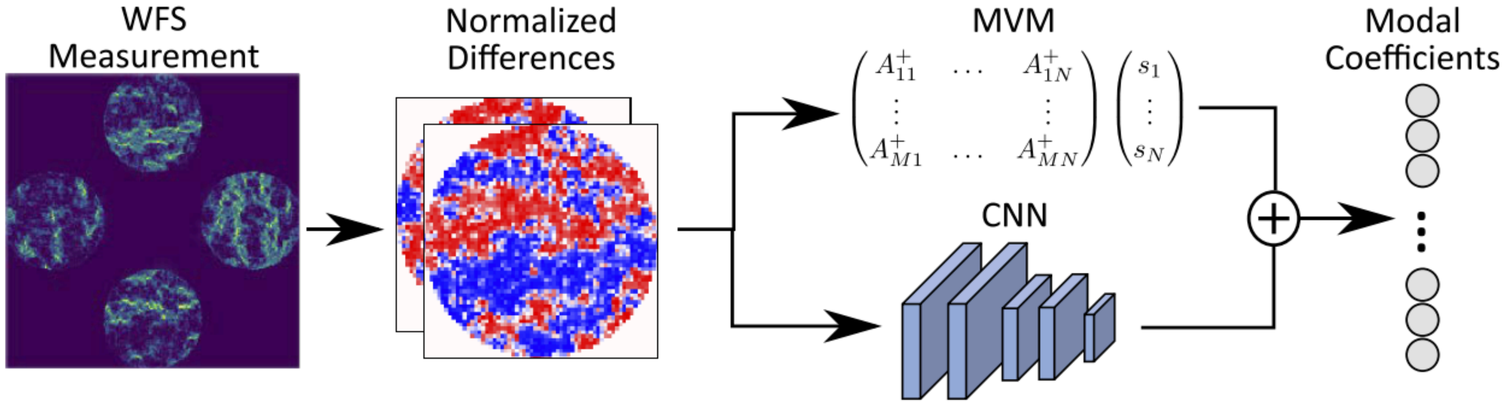
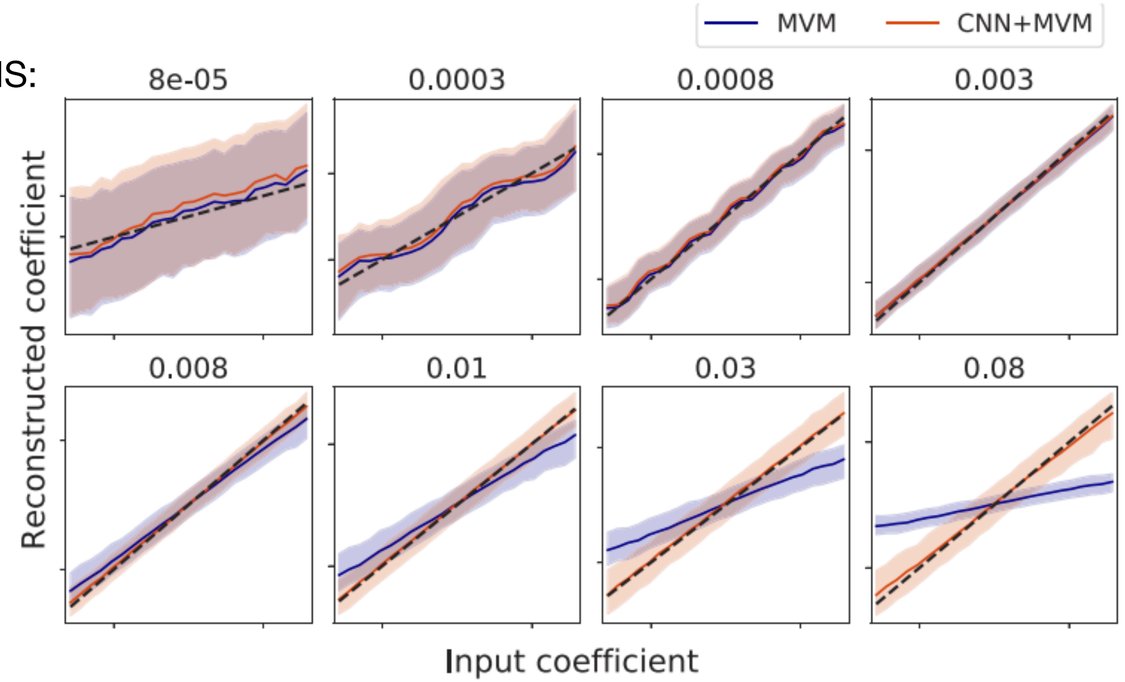


Lab results with the g-ODWFS:



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Neural Networks as nonlinear reconstructors

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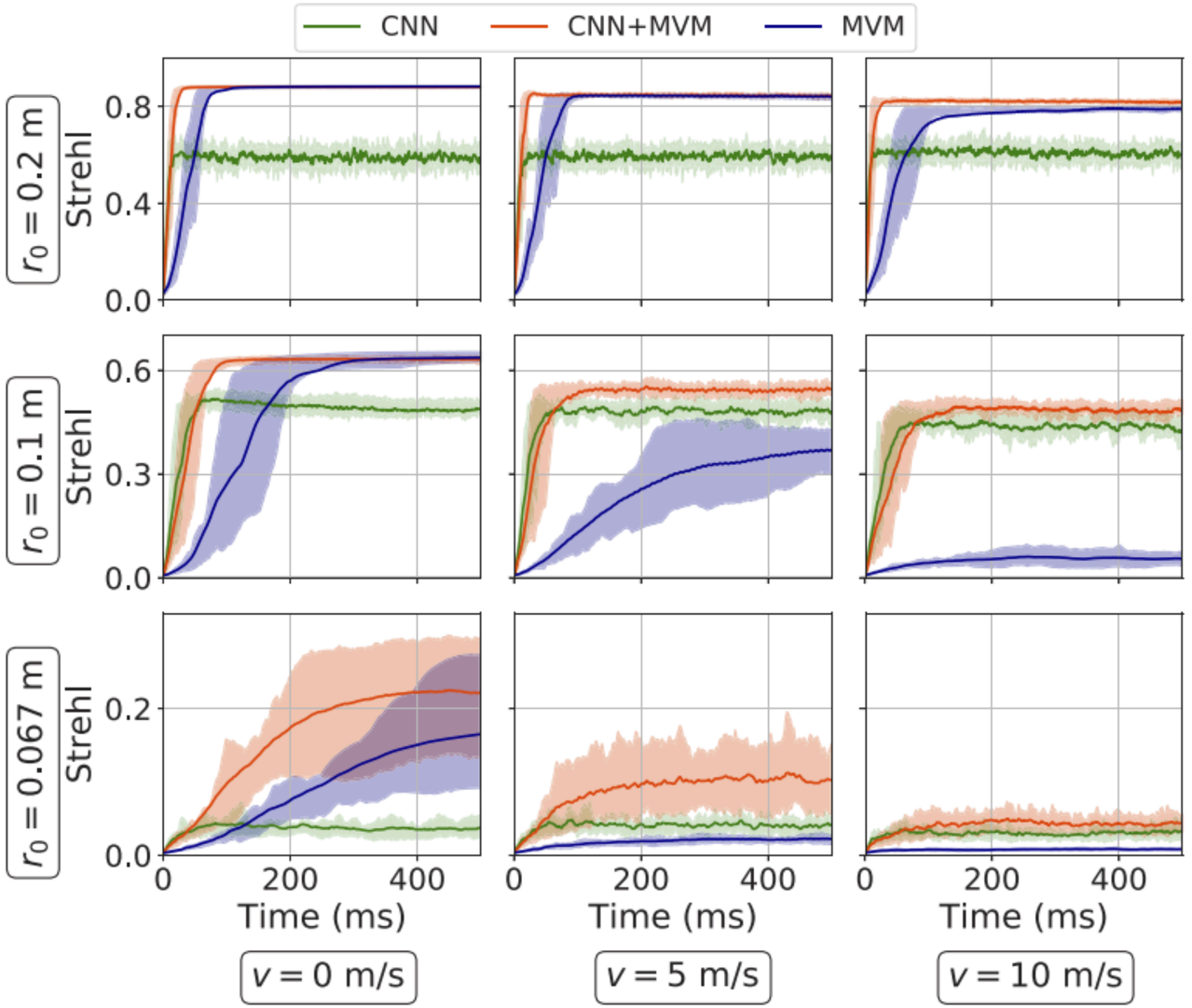
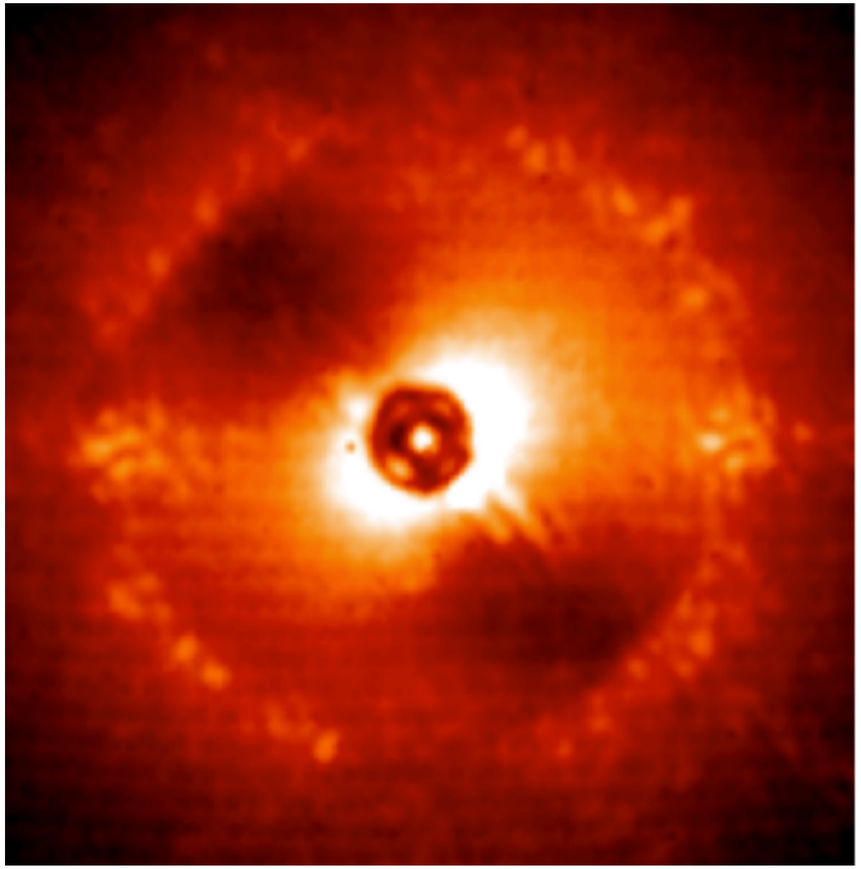


See also: Swanson+2018, Allan+2020, Wong+2021, Pou+2022

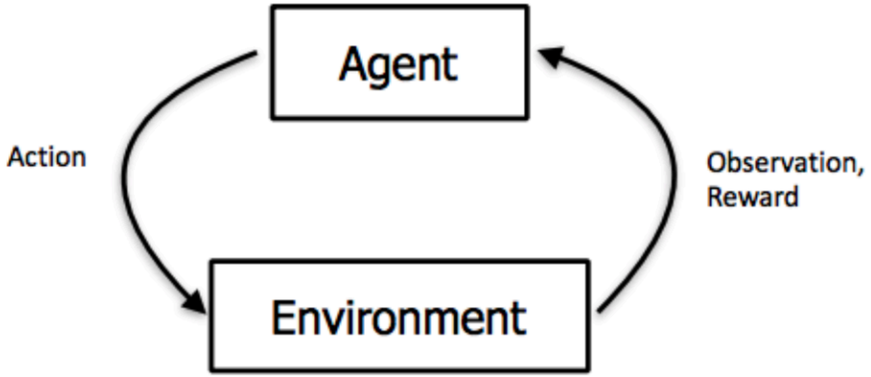
2. Temporal wavefront errors



Cantalloube+ 2020

Reinforcement Learning control

Landman+ 2021



See also: Landman+2020, Nousiainen+2021, 2022, Pou+2021,2022

Reinforcement Learning control

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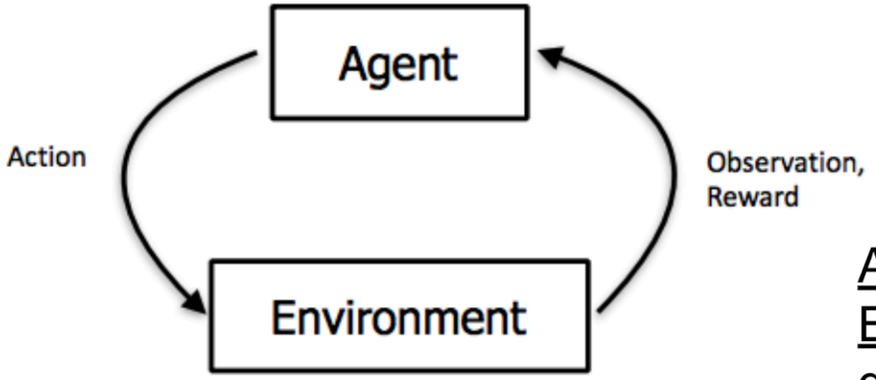
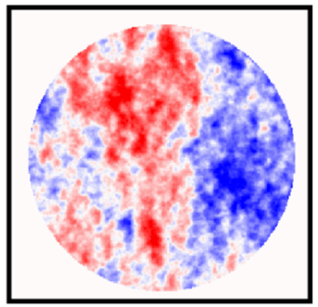


Agent: Deformable Mirror controller
Environment: Atmosphere + system dynamics

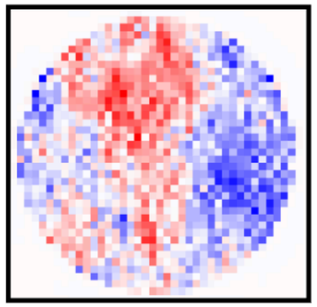
Observation

Reconstructed wavefront

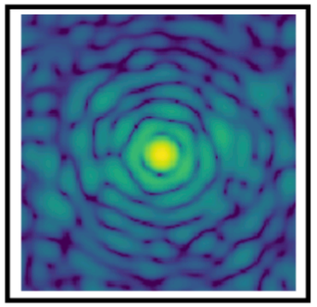


Action

DM commands



Reward



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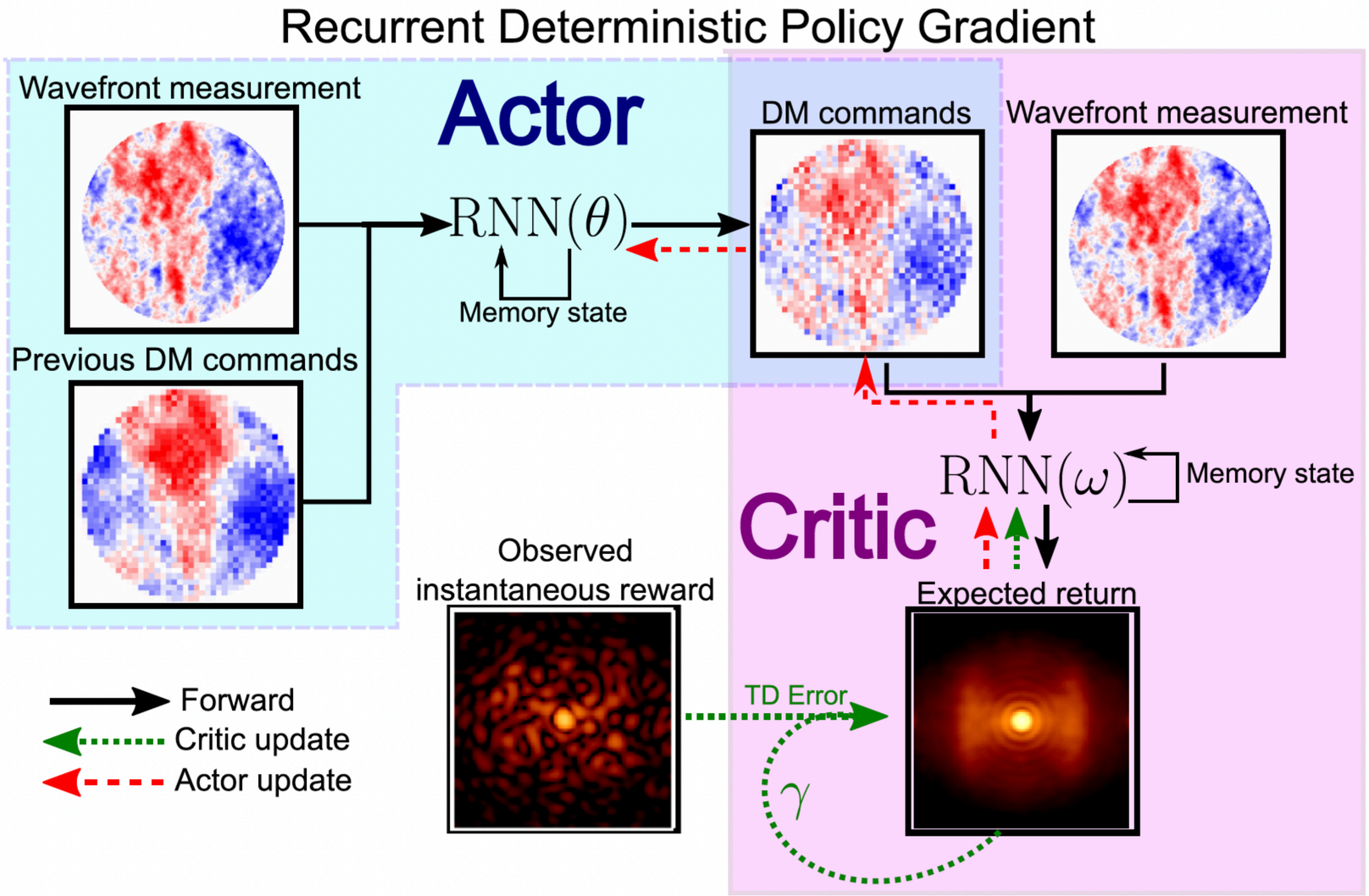

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Reinforcement Learning control

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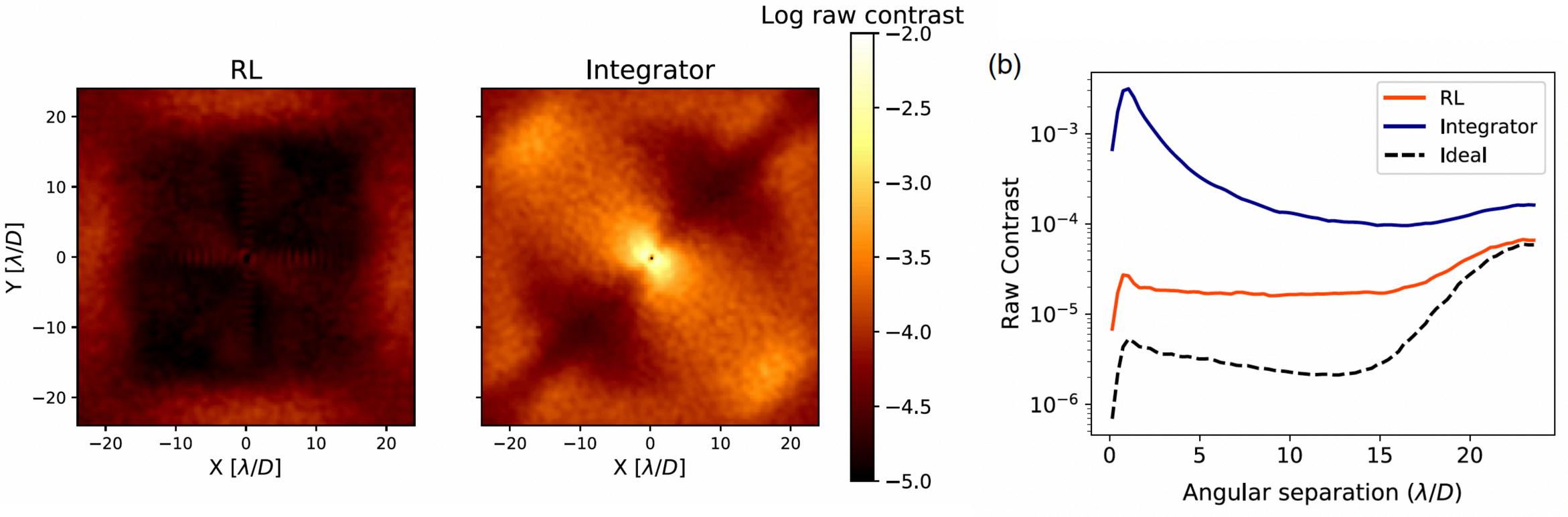
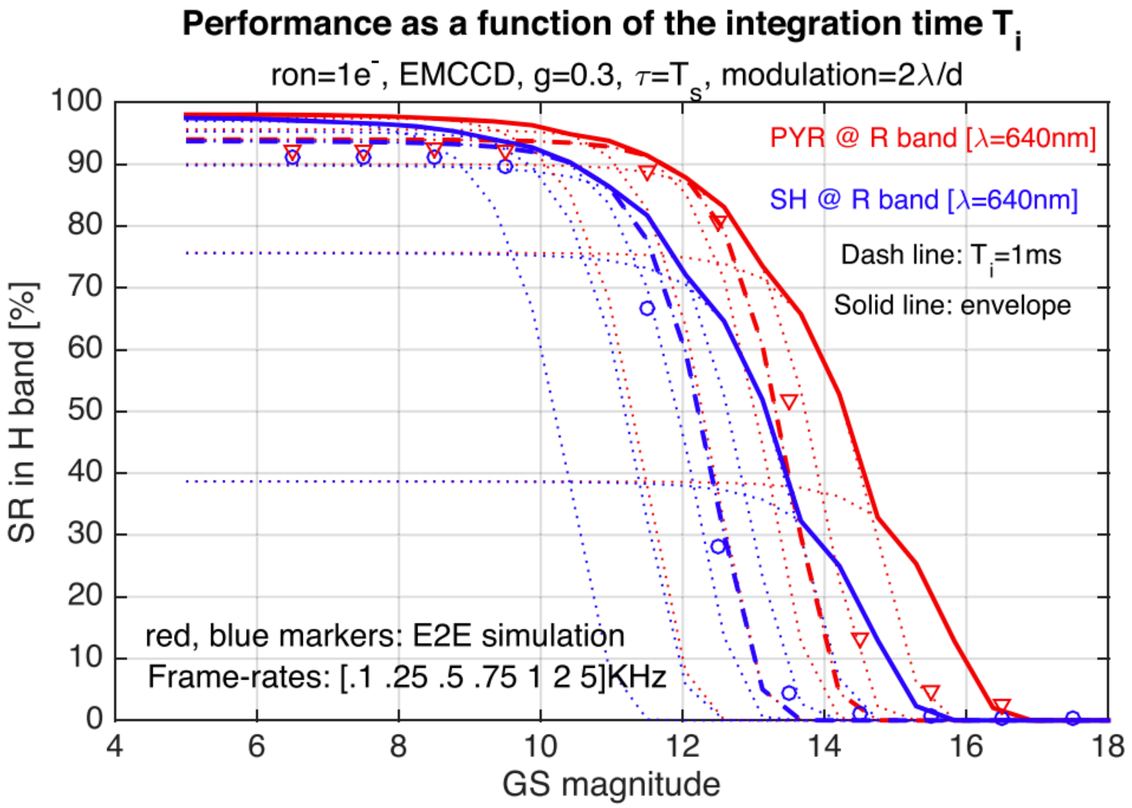
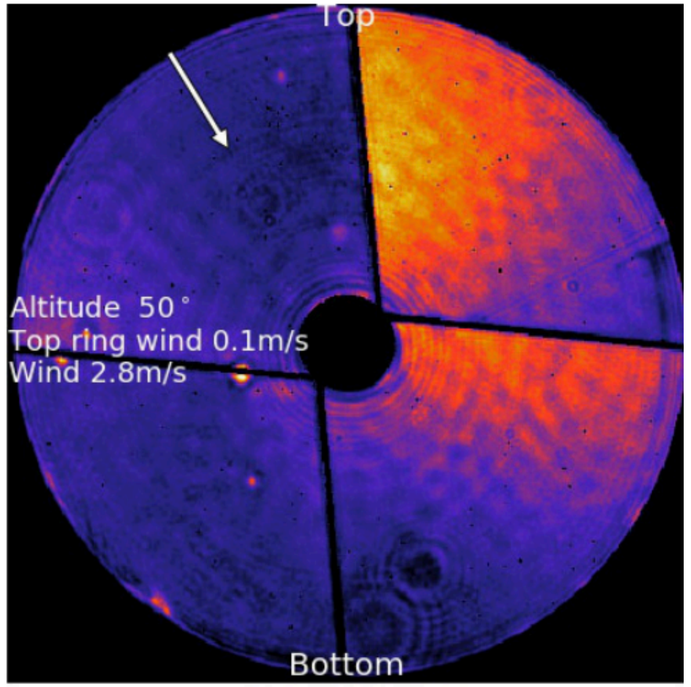


See also: Landman+2020, Nousiainen+2021, 2022, Pou+2022

3. Wavefront sensor sensitivity



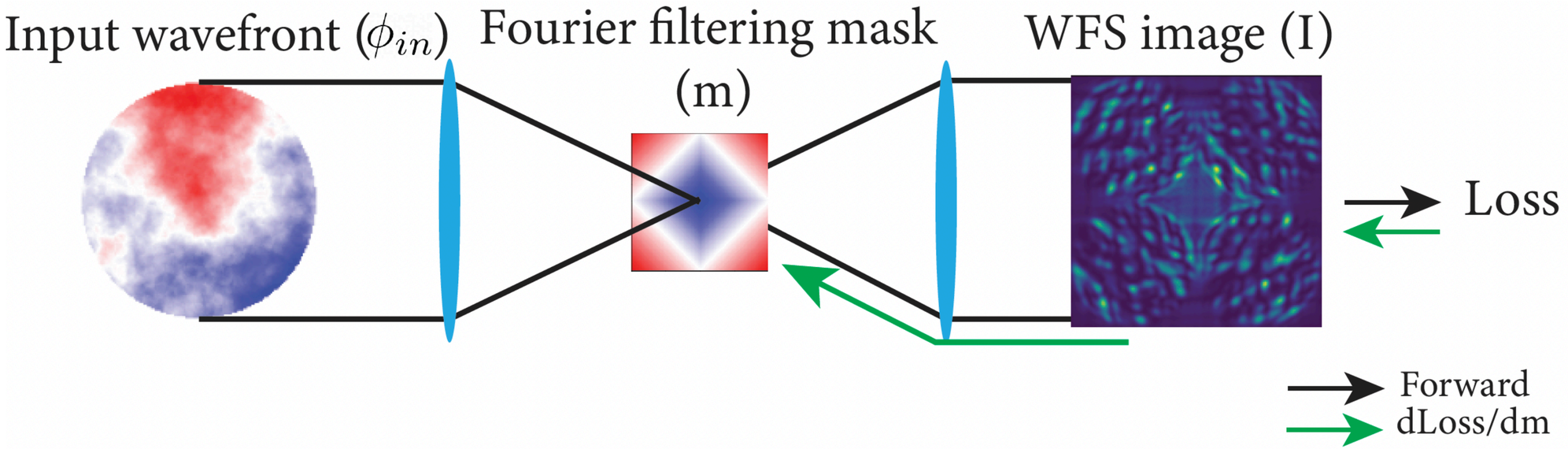
Correia+ 2020



Milli+ 2018

Optimizing wavefront sensor designs

Landman+ 2022

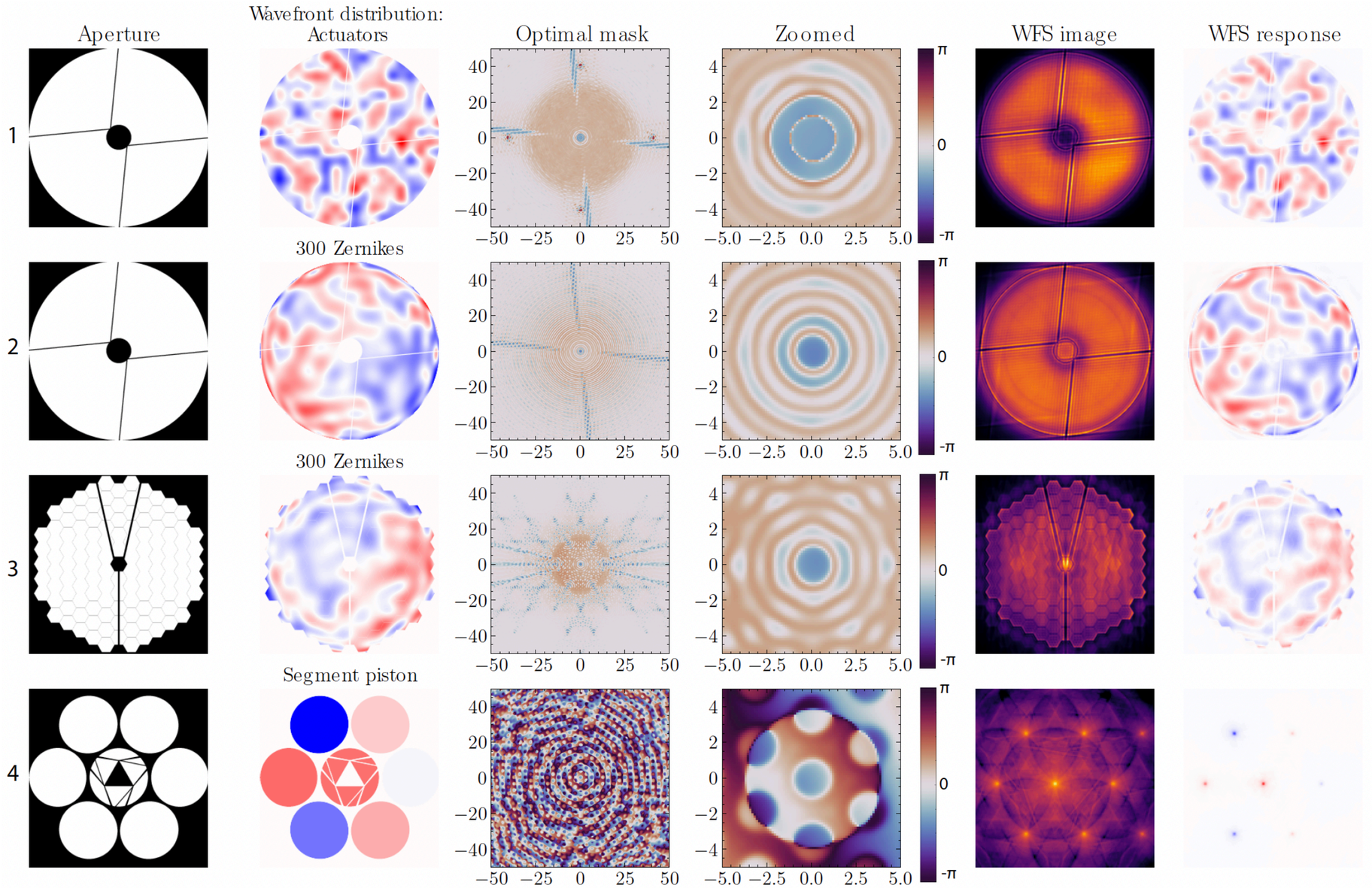


$$\textbf{Loss}(m) = \mathbb{E}_{\phi}\left[\frac{||\delta I(\phi; m)||^2}{||\delta\phi||^2}\right]$$

See also: Chambouleyron+2022

Optimizing wavefront sensor designs

Landman+ 2022



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Optimizing wavefront sensor designs

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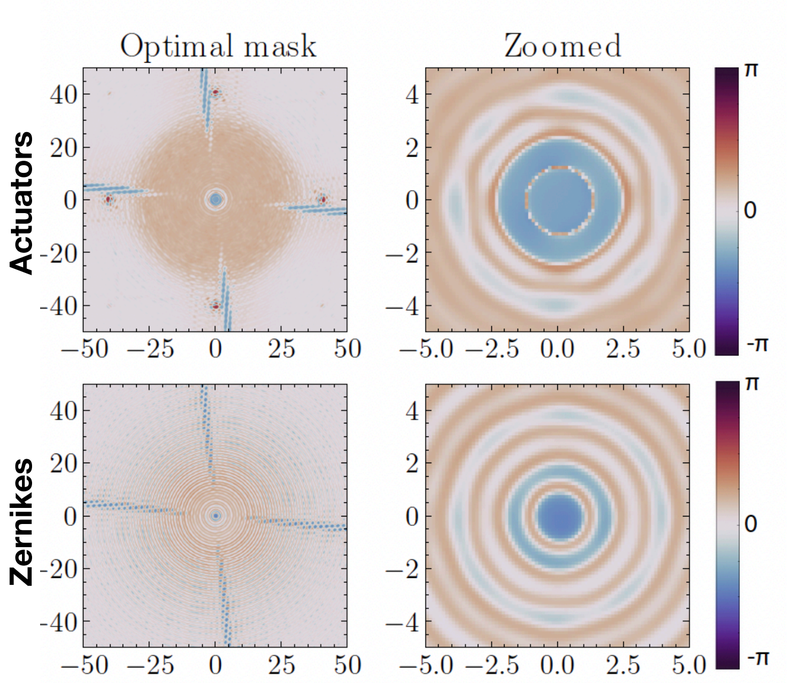
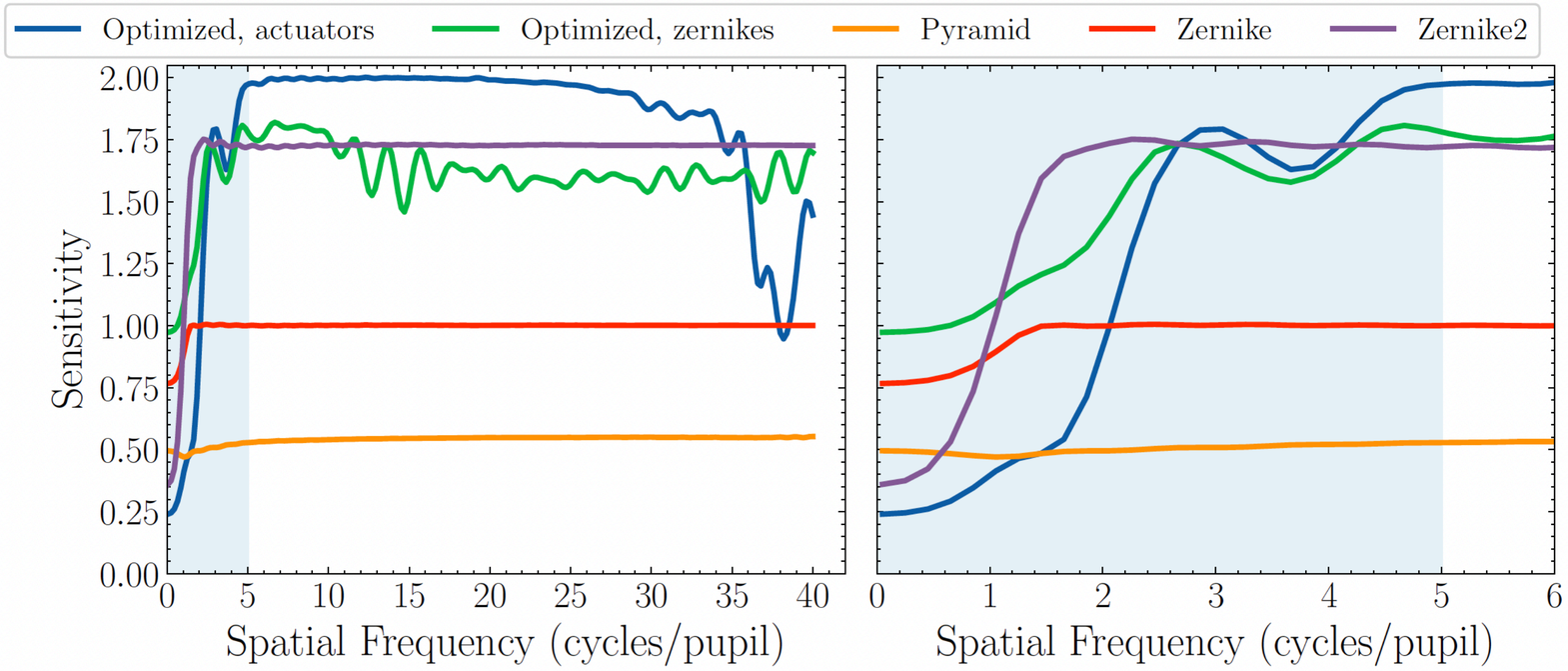
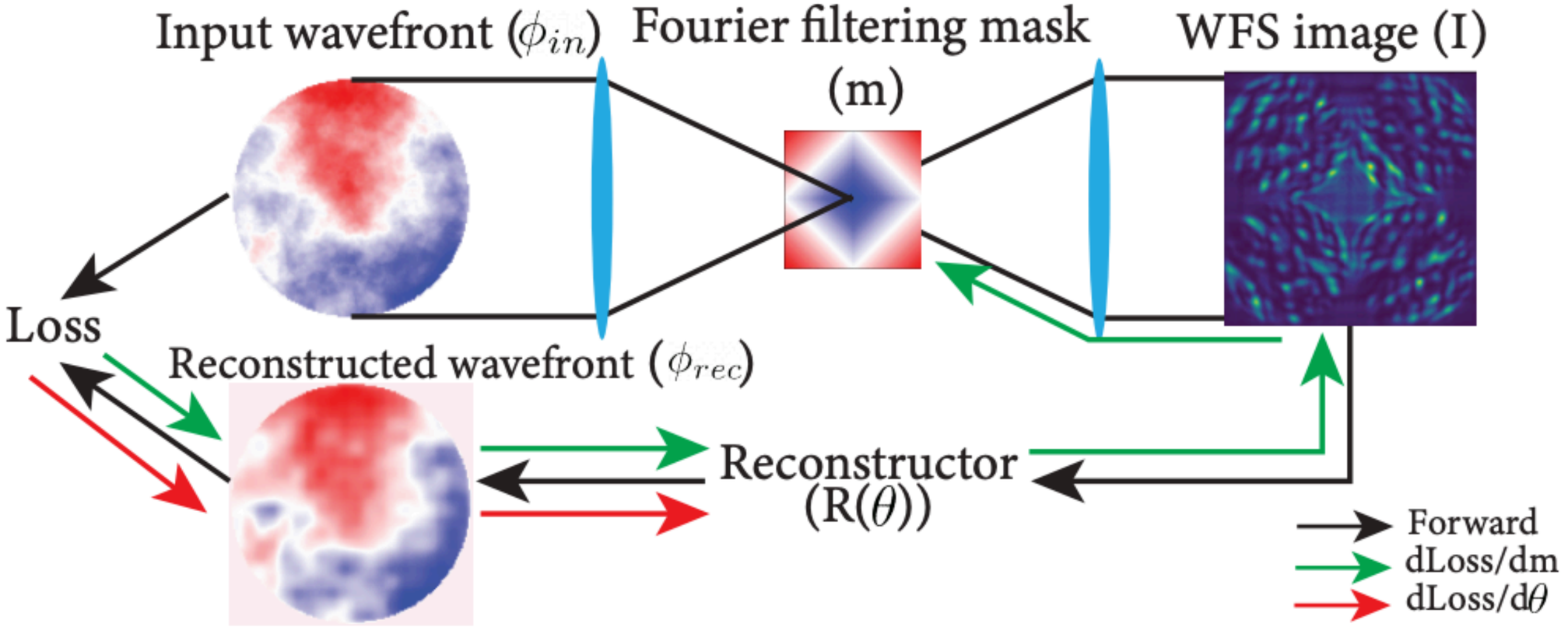




See also: Chambouleyron+2022

Joint sensor and reconstruction optimization

Landman+ 2022

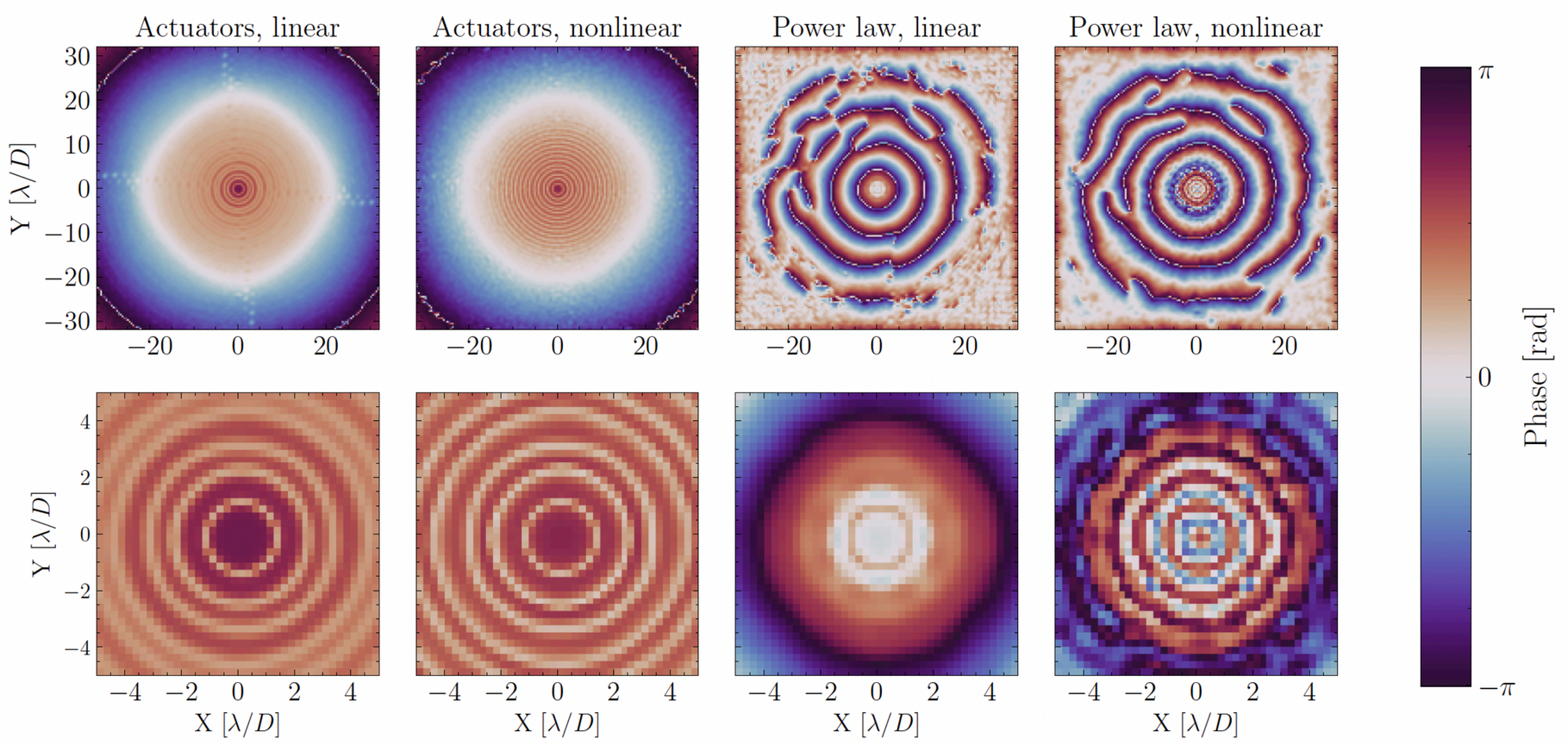


See also: Esteban Vera's talk from yesterday

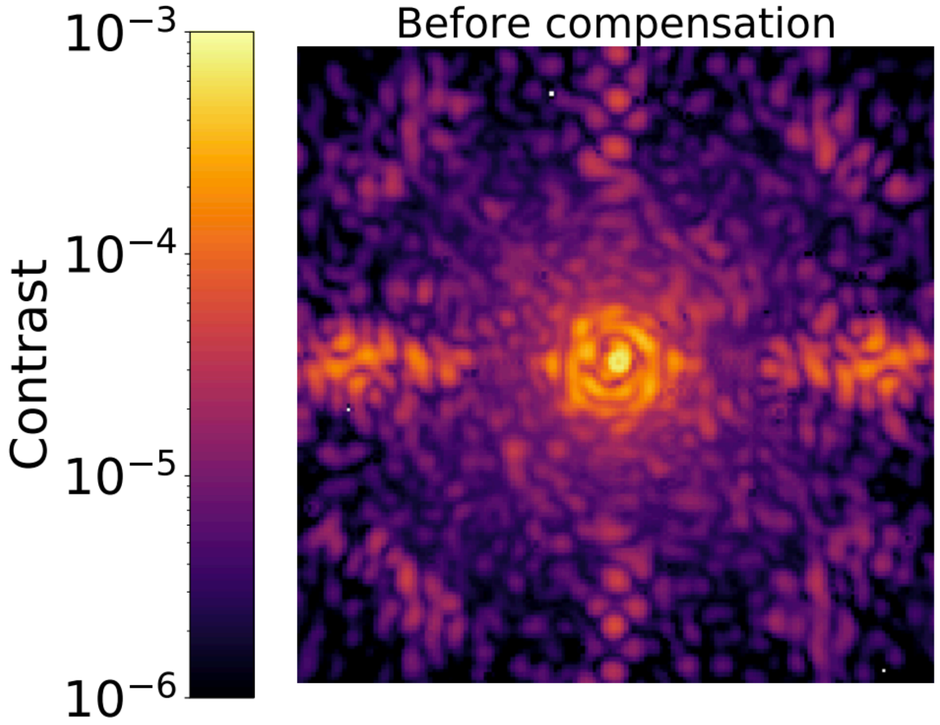
Joint sensor and reconstruction optimization

Landman+ 2022

Work in progress!



4. Non-common path aberrations



Vigan+ 2019

See next two talks to see how machine learning can help!

Summary

- Machine Learning methods can help us with:
  1. Mitigating nonlinearities of the wavefront sensor
  2. Predictive/optimal control
  3. Optimizing wavefront sensor designs
  4. Focal plane wavefront sensing

- Future:
  - Trade-off: increase in complexity vs. performance
  - Heavy use of AI in many other fields helps TRL, but on-sky validation of these concepts will be crucial!