

Exploring reinforcement learning to enhance METIS focal plane wavefront correction

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1. Introduction

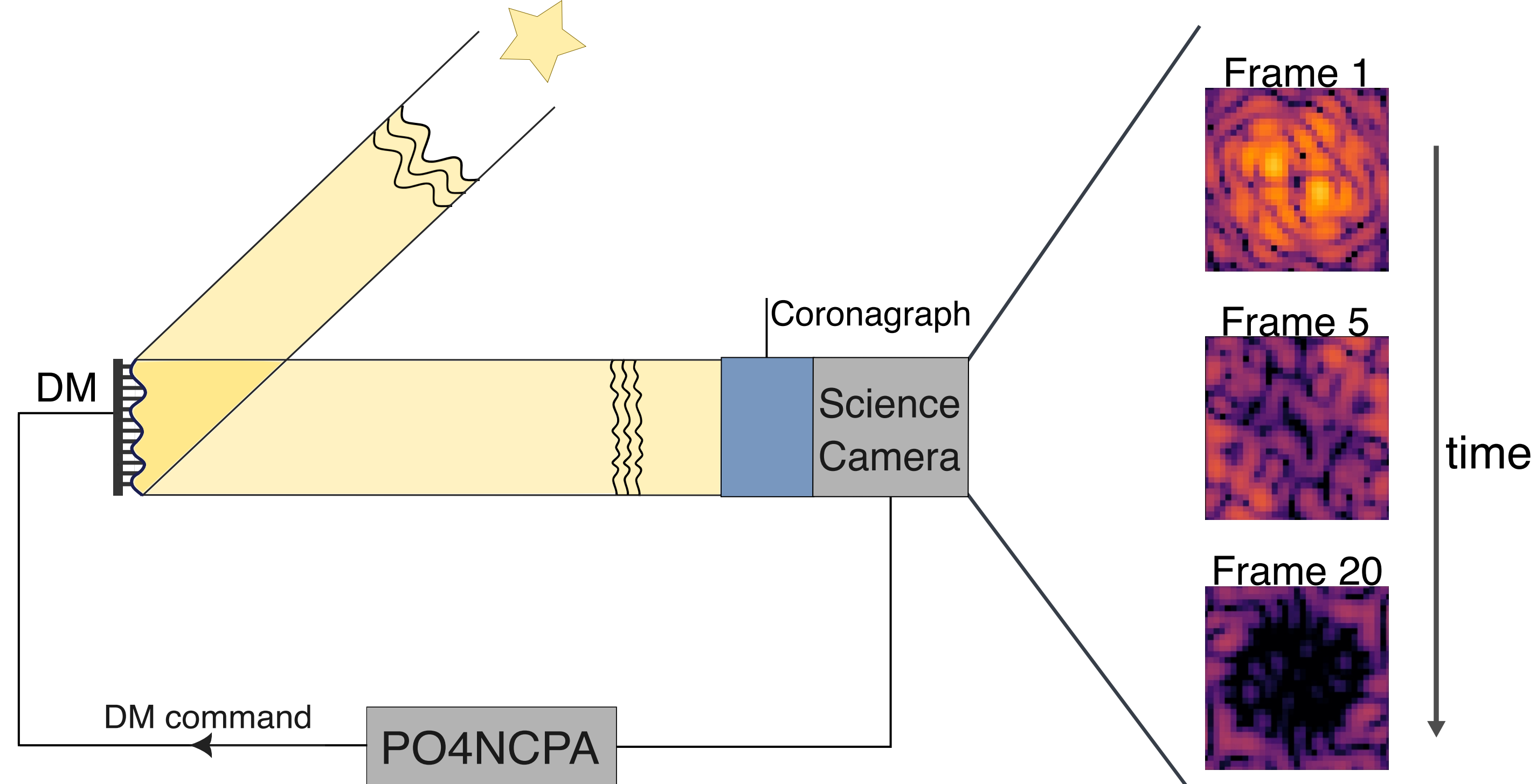


Fig 1.1: The secondary Adaptive Optics (AO) system, fine-tuned to correct NCPAs.

Non-common path aberrations (NCPAs)

- Path difference between science camera & wavefront sensor
- Chromatic aberrations

→ Focal plane wavefront sensing (FPWFS)

- Nonlinear relationship between focal plane & pupil plane
- Phase ambiguities

→ Sequential Phase Diversity + Reinforcement Learning

2. Reinforcement Learning

PO4AO^[2.1] algorithm applied to NCPA: **PO4NCPA**

1. Running the policy by controlling DM
2. Improving the dynamics model with instrument data
3. Improving the policy by using data + dynamics model

Dynamics Model

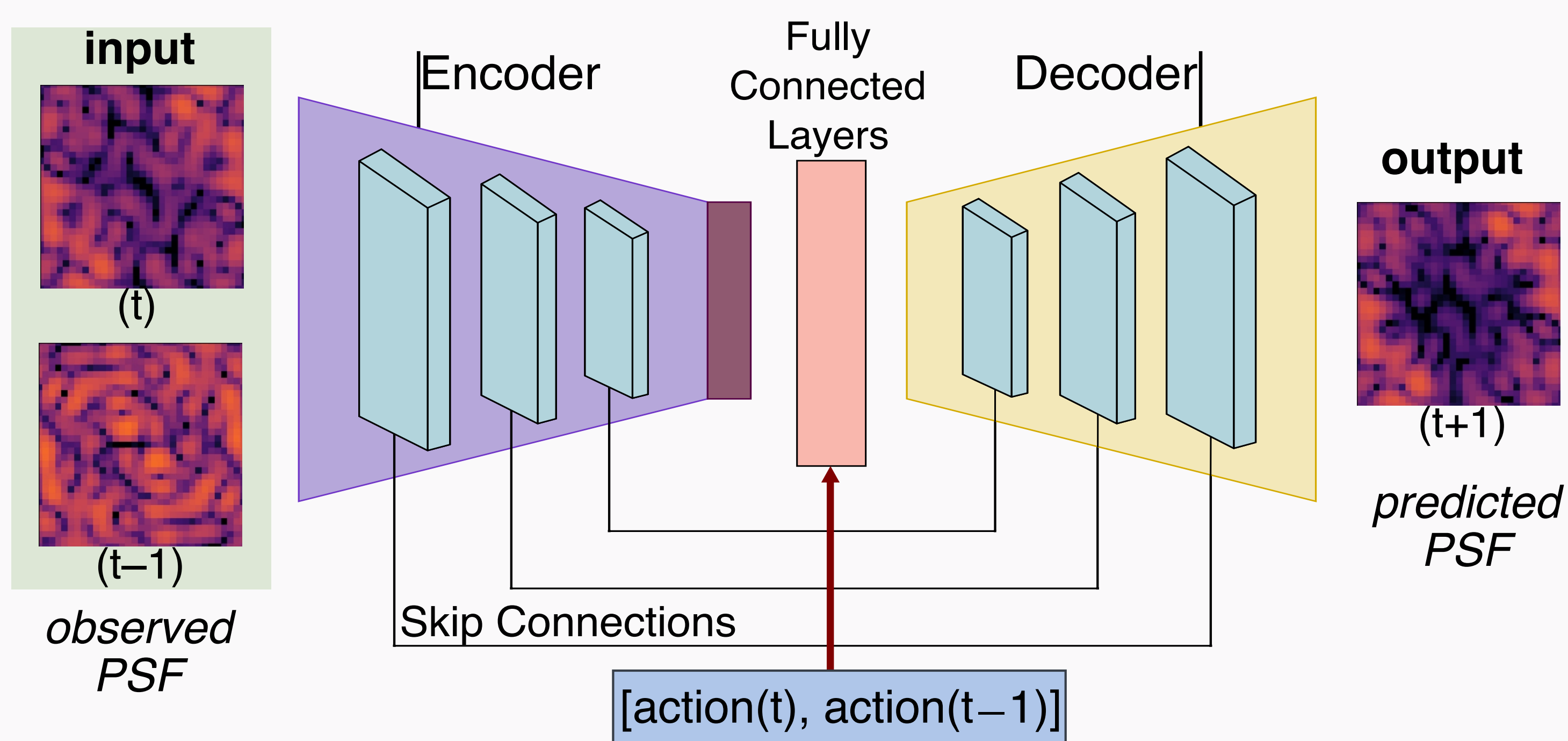


Fig 2.1: The dynamics model takes in the previous and current PSF from the science camera as inputs to predict the next PSF at the science camera. This method uses sequential phase diversity.

Policy

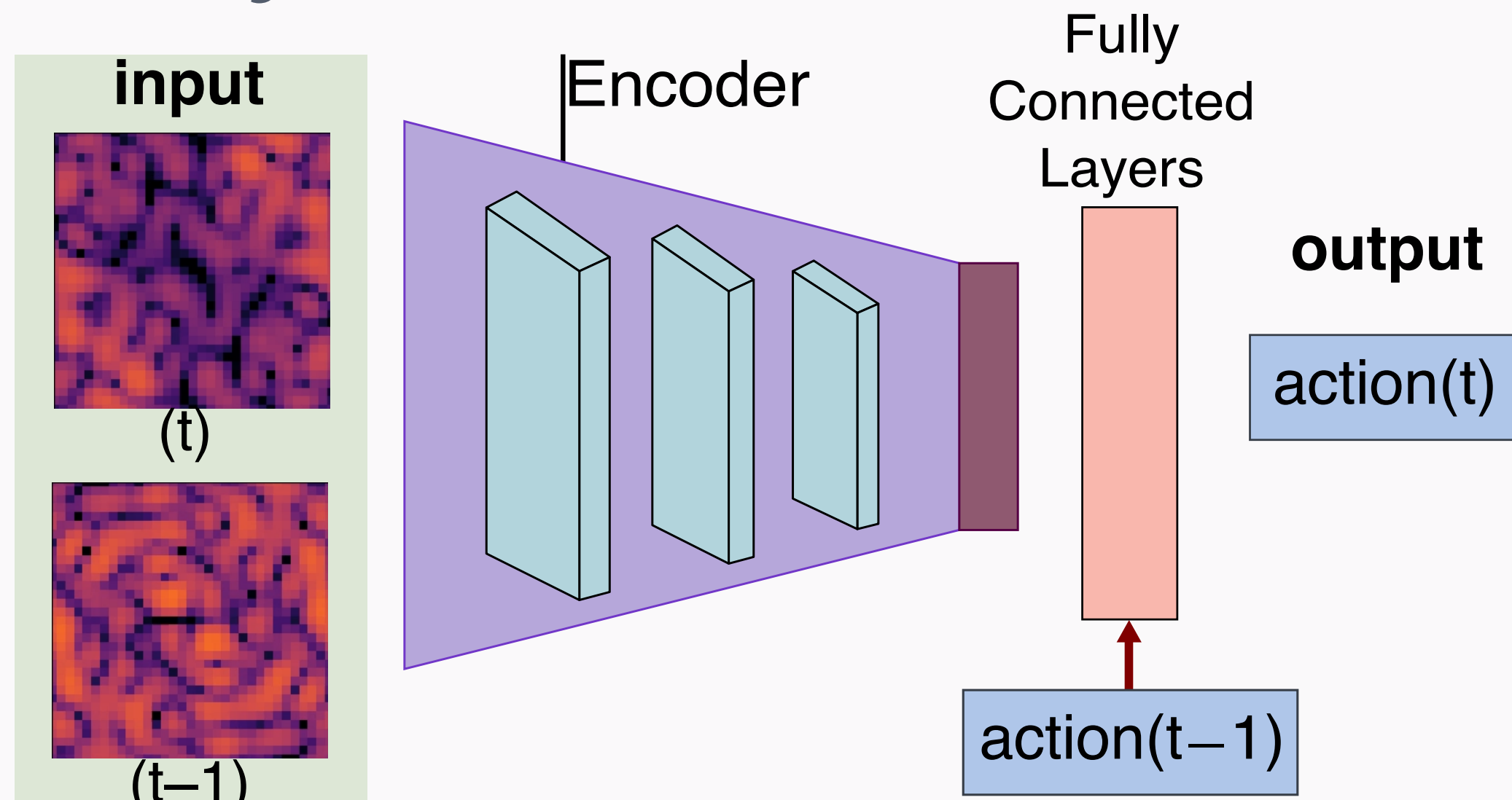


Fig 2.2: The policy uses the current PSF and the previous PSF observed by the science camera to predict the appropriate action.

3. Results

Telescope Diameter	39.3 m
Observation Band	Mid-IR (11 μ m)
# Modes Corrected	55
Frame Rate	10 Hz
Mean NCPA RMS	170 $\pm$ 34 nm

Tab 3.1: METIS-like PO4NCPA simulation parameters.

Static NCPA: Single frame of aberrations, constant throughout the simulation.

Dynamic NCPA: Water vapor^[3.1] effects for METIS, evolving throughout the simulation.

Perfect Coronagraph

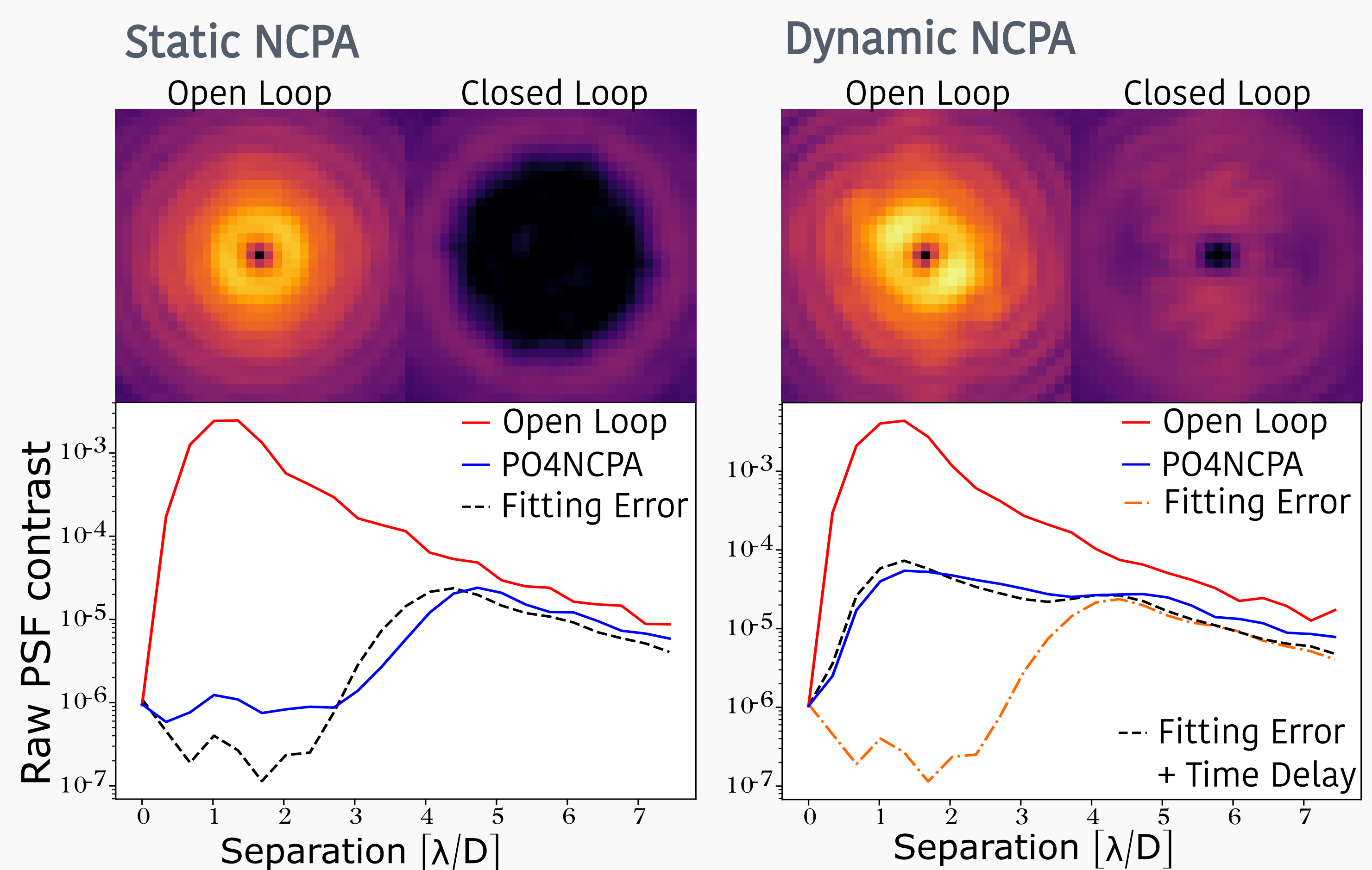


Fig 3.1: The performance of PO4NCPA in static and dynamic turbulence. The curves show the radial profile of the PSF for open and closed loop corrections.

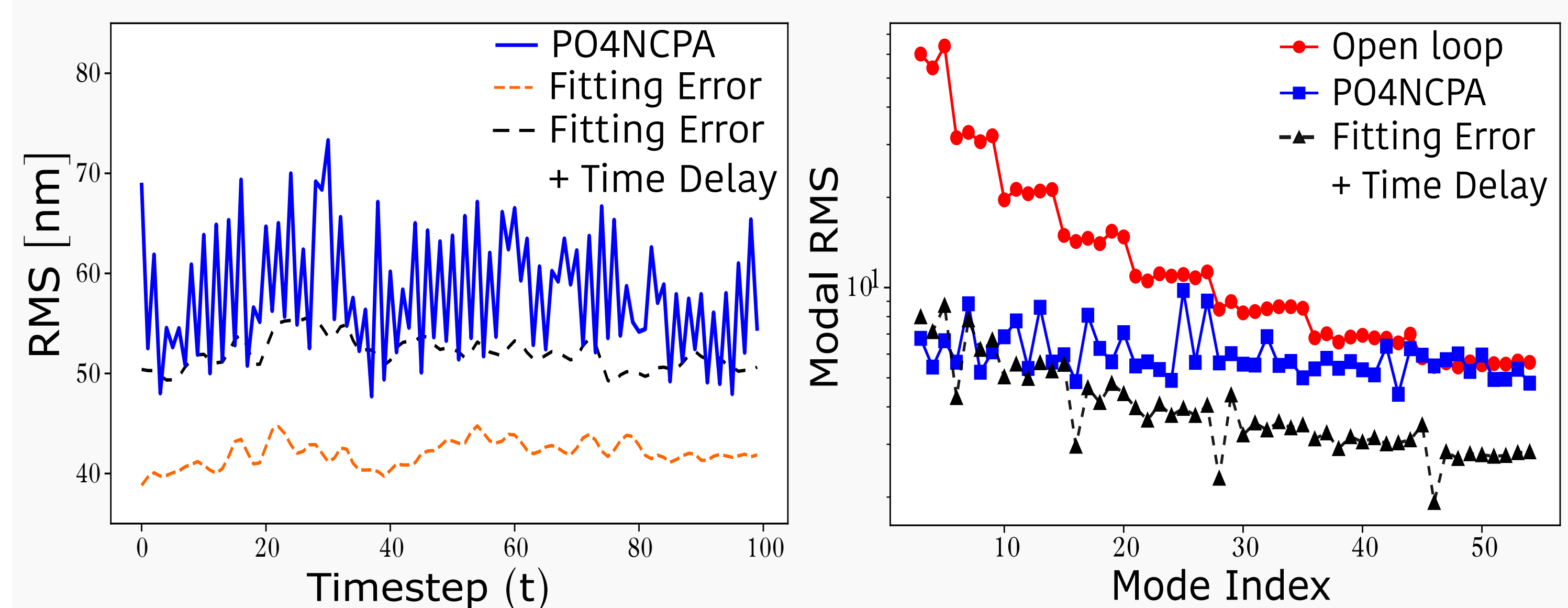


Fig 3.2: (left) PO4NCPA wavefront error RMS compared to the fitting error in dynamic NCPA simulations. PO4NCPA is able to follow what would be expected from a perfect wavefront reconstruction and an integrator. (right) RMS per mode for dynamic NCPA simulations.

For further results and videos, please check the QR code.

4. Conclusions

- Can compensate dynamic NCPA such as water vapor aberrations
- Can be applied to other types of imaging (scalar/vector vortex coronagraph, normal imaging) & instruments
- Next step: Asymmetric Lyot stop (METIS) vs sequential phase diversity, Dark-hole digging
- Future on-sky testing with SCExAO instrument, Subaru

