Autodifferentiable PSF modeling for the VLT/ERIS Vortex Coronagraph

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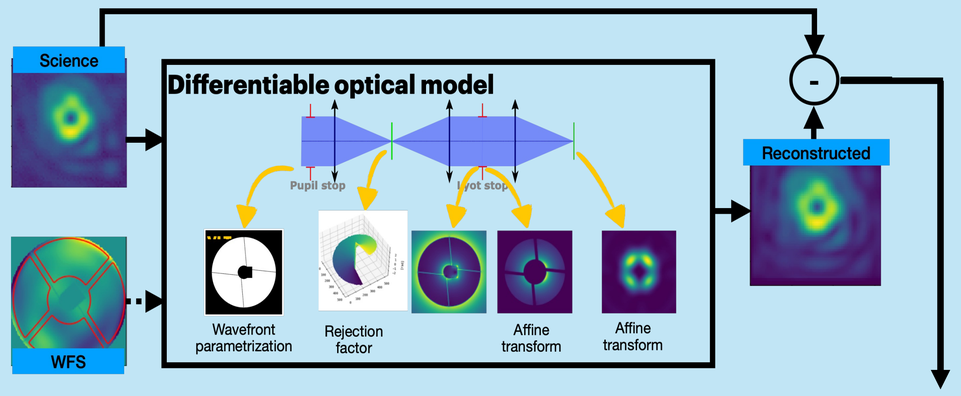
1. Overview

Direct exoplanet imaging requires accurate PSF modelling to suppress speckles at small angular separations. We introduce a differentiable optical model of the ERIS vortex coronagraph that reconstructs the PSF through gradient-based optimization informed by AO telemetry. As a first validation, we propagate wavefront-sensor measurements through a forward model of the ERIS vortex coronagraph and we **identified a discrepancy between the AO-derived PSF and the observed on-sky PSF.**

2. Motivation

We assessed the PSF reconstructed from WFS AO telemetry to determine its suitability as input to a differentiable optical model of ERIS.



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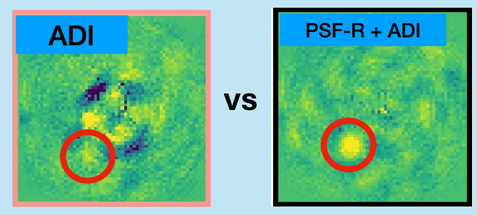

Fig 1. *Companion retrieval using a proof-of-concept differentiable optical model of VLT/ERIS compared with classical ADI. An artificial companion (Δmag = 8, separation = 0.2″) was injected into an ERIS dataset.*

3. Context

VLT/ERIS	AO	Data sequence

- L-band (3.49–4.11μm) observations.
- **Vortex** coronagraph: small inner working angle, high throughput.
- SR ~ 95 %.
- Number of actuators: 1170.
- Loop frequency: 1kHz max.

	On-axis	Off-axis
DIT	40 ms	10 ms
t_{obs}	60 s	60s

Why model based RDI?	WARP
Parameterised by physical variables.	= **W**avefront **A**ssisted **R**econstruction of the coronagraphic **P**SF.
Produces reconstructed PSF.	Includes real-time telemetry data.
Outperforms ADI.	Tracks rapid wavefront aberrations.

4. Obtaining the mode coefficients

1. The telemetry data from the Shack-Hartmann WFS provides the local wavefront slopes measured by each subaperture in the x - y direction.

2. The subaperture slopes measurements are assembled into slope vector s.

3. The slope vector is multiplied by the calibrated AO slope-to-modes (S2M) matrix to obtain the modal coefficients:

$$c_m = S2M\, s.$$

4. The reconstructed modal coefficients are injected into a forward model of the instrument to reproduce the corresponding wavefront aberrations.

Result: A discrepancy was found between the AO-derived centroid offsets and the offsets measured from the NIX science camera.

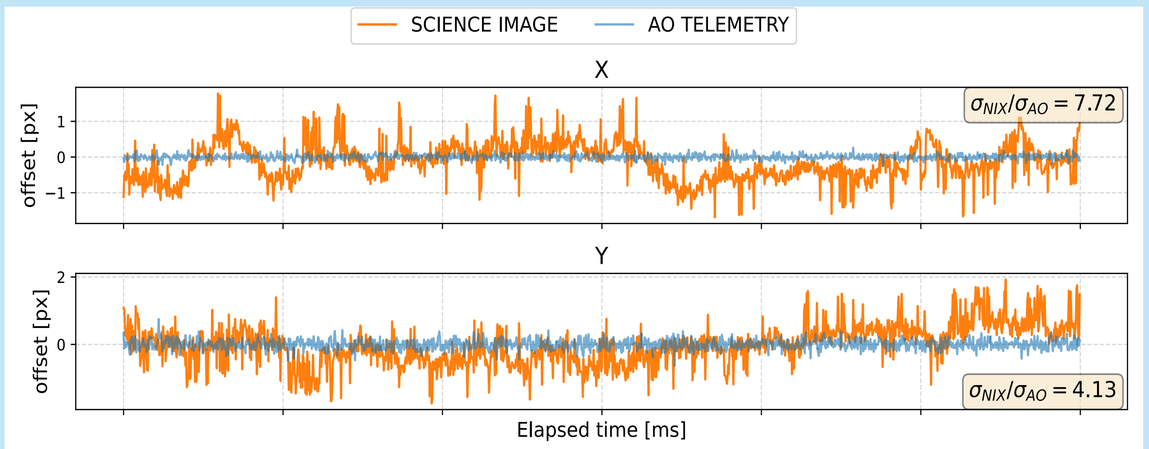

Fig 2. *Time series of the centroid offsets along the X and Y axes for the NIX PSF and the AO-derived PSF. Offsets are shown in detector pixel (spatial scale ~13 mas/pixel).*

Normalized Radial Intensity Profiles: AO vs NIX vs On-Sky

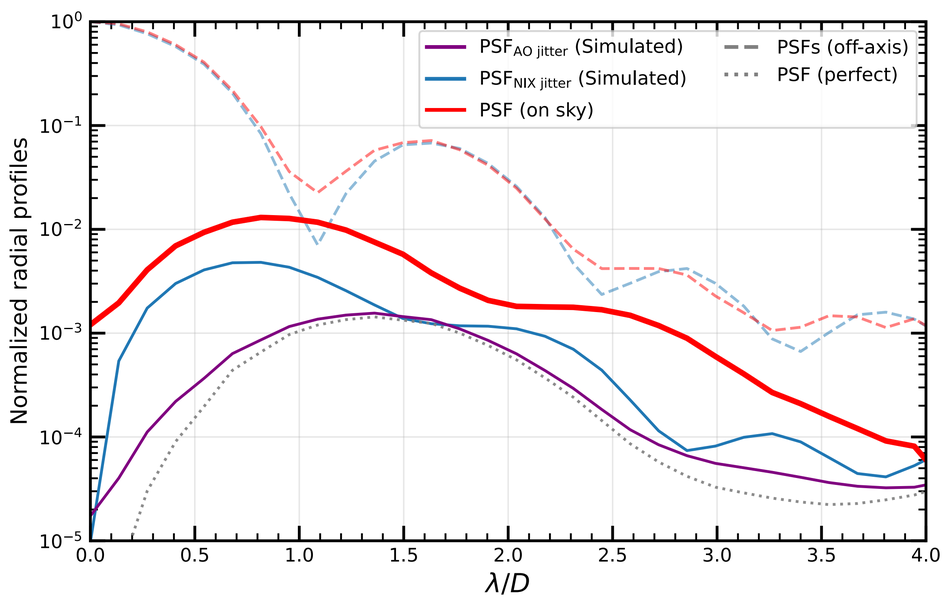

Fig 3. *Normalized radial intensity profiles as a function of λ/D, derived from NIX images and AO data. The results are compared with the on-sky vortex coronagraph profiles, as well as a simulated profile assuming perfect wavefront.*

5. AO-NIX Discrepancy

We identify a systematic discrepancy between the wavefront correction inferred from AO telemetry and the wavefront errors measured by NIX (ERIS SCI imaging camera). Because the stellar position cannot be directly inferred from the coronagraphic (vortex) science images, this NIX-jitter reconstruction instead relies on the off-axis calibration images. The centroid offsets measured in the off-axis data (Fig. 2, orange time series) are used to infer the underlying fast jitter. Modes above tip-tilt and up to the 20th Zernike coefficients are derived from the AO telemetry. The resulting wavefront (fast jitter and higher-order modes) are then propagated through a forward optical model, which includes the vortex coronagraph, to predict the resulting coronagraphic PSF. As observed in Fig.3 , the NIX-jitter reconstructed PSF (blue) reproduces the on-sky profile more accurately than the AO-jitter telemetry-based reconstruction (purple), confirming a mismatch between the wavefront aberration seen by the science camera and the wavefront correction inferred from the AO telemetry.

6. NIX PSD

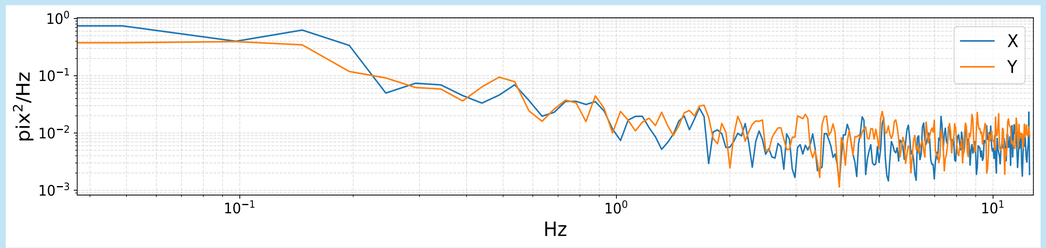

Fig4. *Power spectral density (PSD) of the NIX centroid motion measured along the detector X and Y axes. The PSDs were computed using Welch's method from the centroid time series sampled at 25 Hz.*

AO PSD

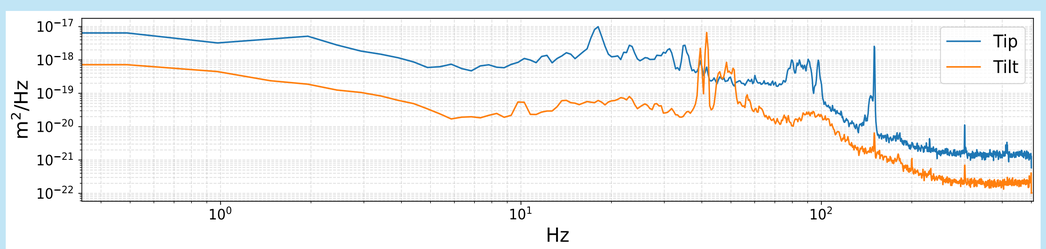

Fig5. *Power spectral density (PSD) of the reconstructed modal coefficients (tip and tilt). The PSDs were estimated using Welch's method from the modal coefficient time series sampled at 1 kHz.*

7. Next Steps