ESCAPE Project: CAPyBARA: a fast, robust Roman CGI-like simulator for exploring WFS&C, observing and post processing strategies

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1. CONTEXT

➡Direct imaging of exoplanets requires extreme contrast and precise wavefront control

➡Observing sequences and control strategies strongly impact achievable performance

➡CAPyBARA provides a flexible framework to design and test alternative observing sequence and control strategies.

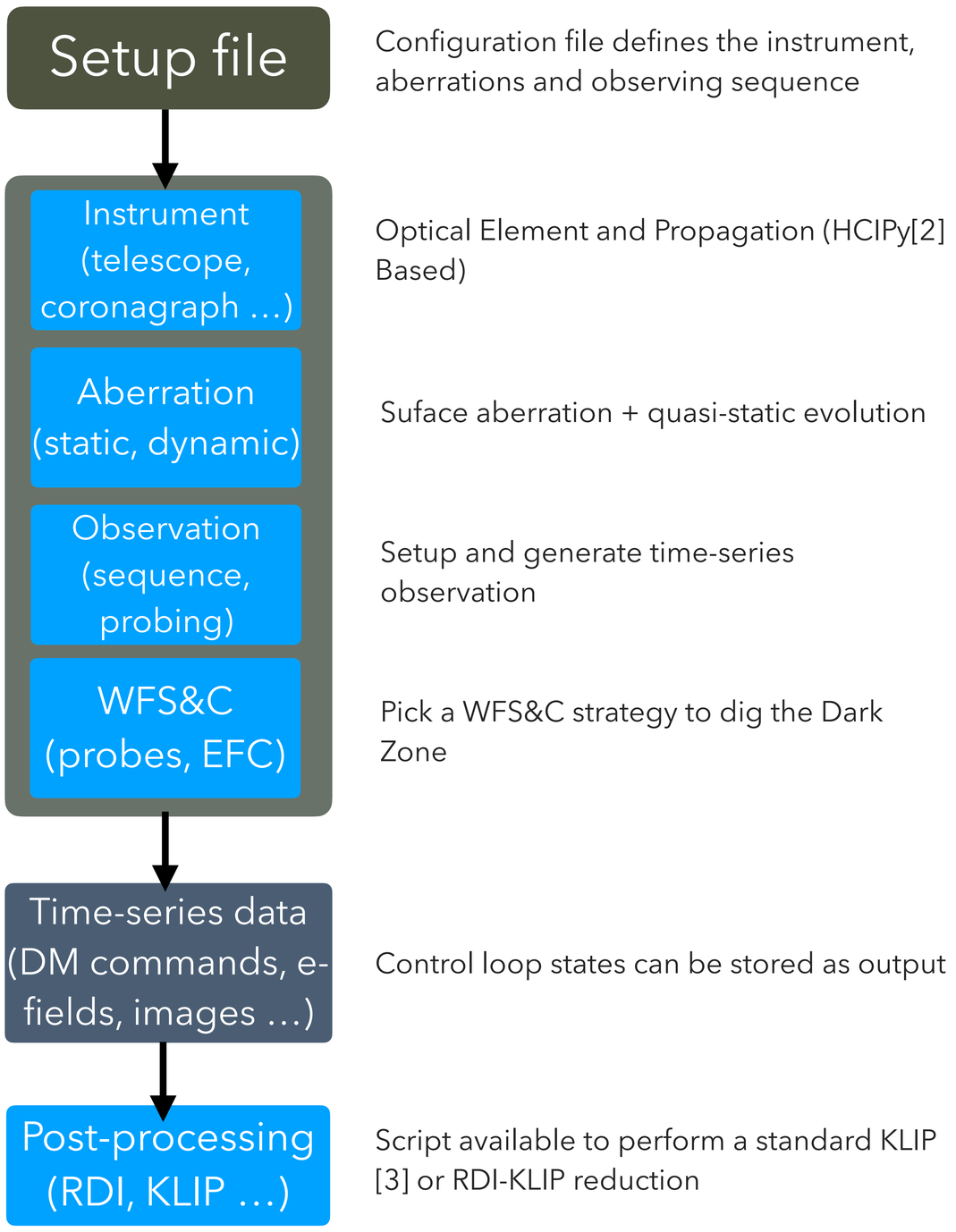
2. WHAT IS CAPyBARA

➡A modular Python package for E2E Coronagraphic simulations

➡Couple observing sequences, wavefront control and post-processing

3. CAPyBARA architecture

CAPyBARA [1] couples instrument modelling, wavefront sensing and control, and observing sequence within a single framework. All internal states are recorded, and can be used for analysis and post-processing.



Configuration file defines the instrument, aberrations and observing sequence

Optical Element and Propagation (HCIPy[2] Based)

Suface aberration + quasi-static evolution

Setup and generate time-series observation

Pick a WFS&C strategy to dig the Dark Zone

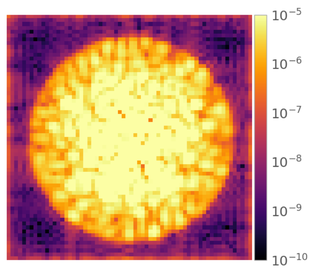
Control loop states can be stored as output

Script available to perform a standard KLIP [3] or RDI-KLIP reduction

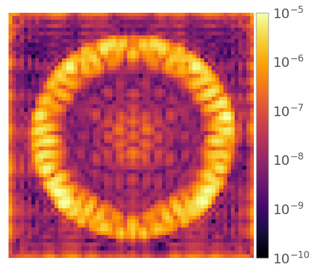
4. DATA SIMULATION AND OUTPUTS

➡ CAPyBARA produces **noiseless** coronagraphic images with full telemetry output and metadata.

➡ Able to simulate observing scenarios, like Roman-CGI (Hybrid Lyot Coronagraph)



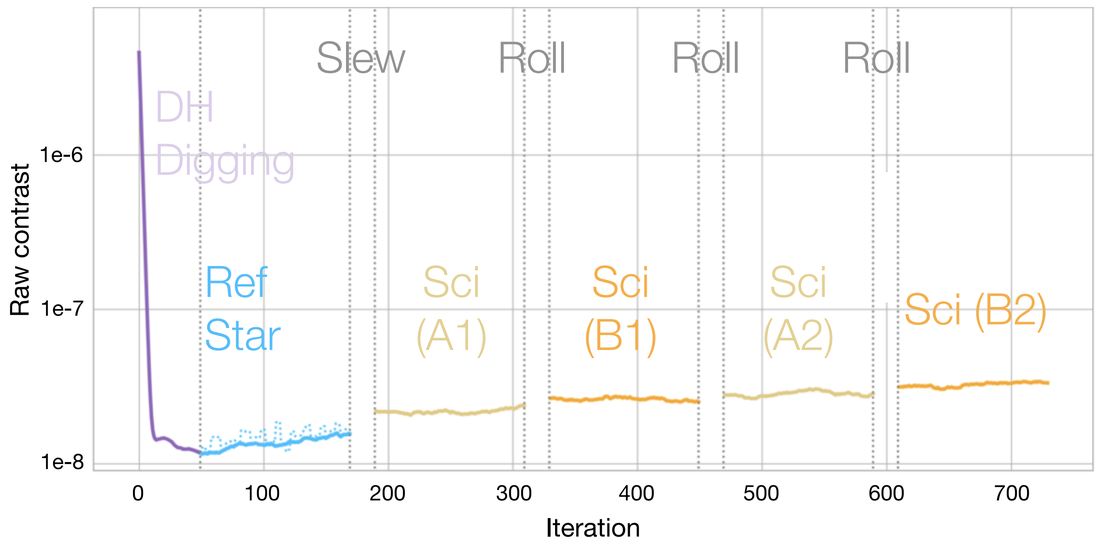
Before Dark Hole Digging

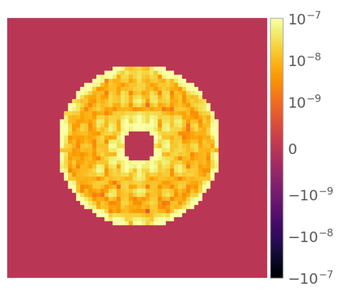


End of Dark Hole Digging

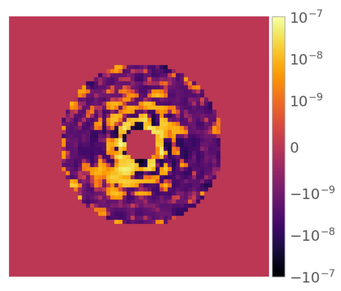
5. DEMONSTRATION (Roman-like)

Example: A Roman-like observing sequence (DH digging, reference star acquisition, science observations)





Before post-processing



After post-processing

Raw images (WFS&C + ref. + sci.), simulation metadata and commands are saved to as a whole sequence after each run. Along with basic post-processing (RDI-KLIP) + contrast information + log

Key points:

1. Enables rapid testing of alternative observing and WFS&C strategies
2. Modular framework: easier to implement and compare different methods
3. Structured output provides direct access to info required
4. Faster prototyping while preserving most of the elements, compared to a full simulator [4]

6. NEXT STEPS

➡Add Noise realisation

➡Develop Coherent Differential Imaging routine

➡Add supports to other types of coronagraph

Bibliography:

[1]Altinier et al., 13092-130, [2]Por et al. 2018, [3] Soummer et al. 2012, [4] Krist, J. https://sourceforge.net/projects/cgisim/

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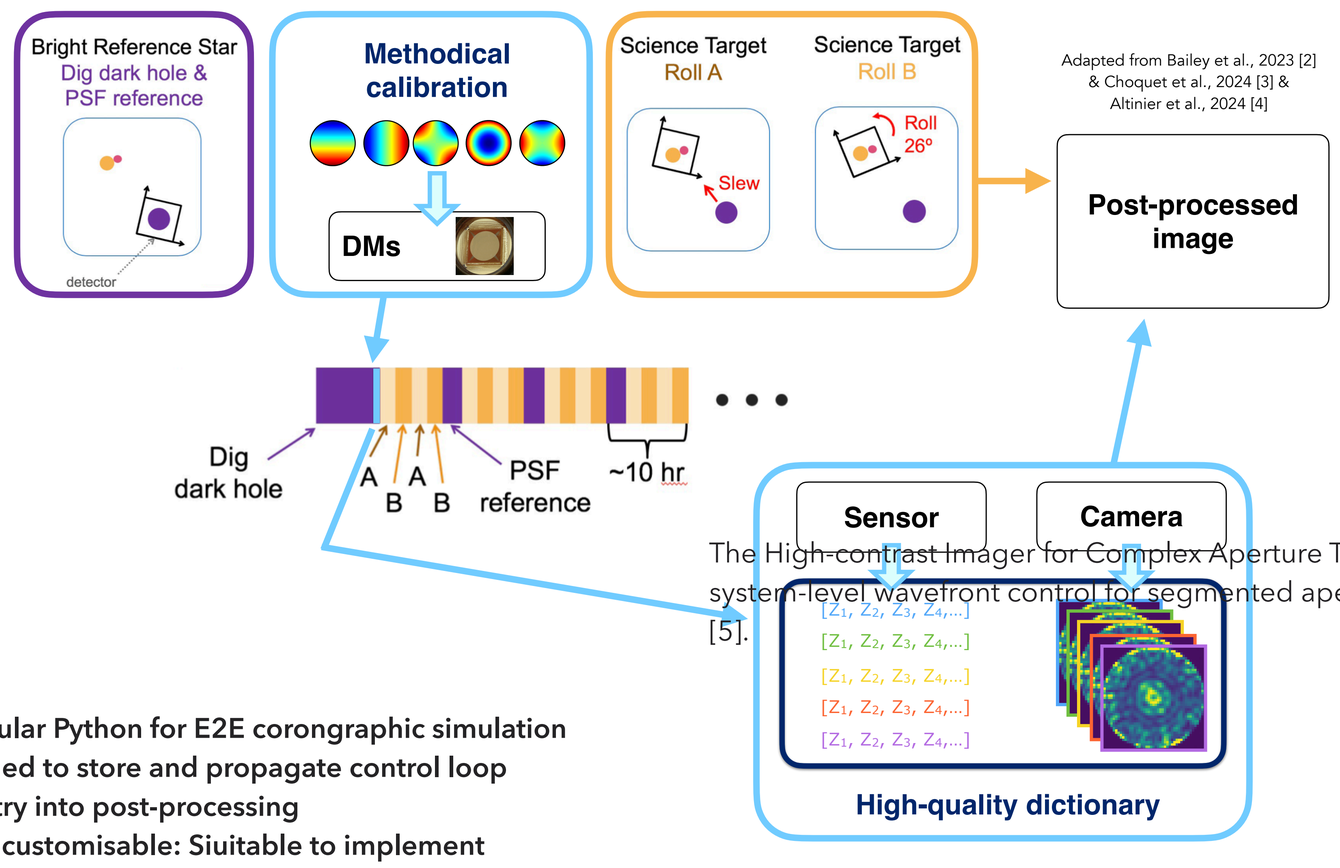
Wavefront sensing and control (WFS&C) and post-processing plays an important role in high contrast imaging.

Contrast at **10^{-7}** or better at **3 - 9 λ / D [1]** (with **active wavefront control for the first time in space)**

- Detection limit: wavefront aberration between science target and reference star observations
- **Post-processing are not optimised with the use of DMs**

Realisation on testbed - HiCAT (cont.)

Goals :



The High-contrast Imager for Complex Aperture Telescopes (***HiCAT***) showcases system-level wavefront control for segmented apertures for high-contrast imaging [5].

➡A modular Python for E2E corongraphic simulation
➡Designed to store and propagate control loop telemetry into post-processing
➡Highly customisable: Siuitable to implement observing strategies, WFS&C algorithms
➡Generic setup: can be modified to other telescope and coronagraph

➡Enables performance study and analysis before moving to hardware experiments
➡Can help to identify which telemetry produces are required to optimise post-processing

NEXT STEPS

The sequence ***only runs in numerical simulator → Run the experiment on HiCAT***

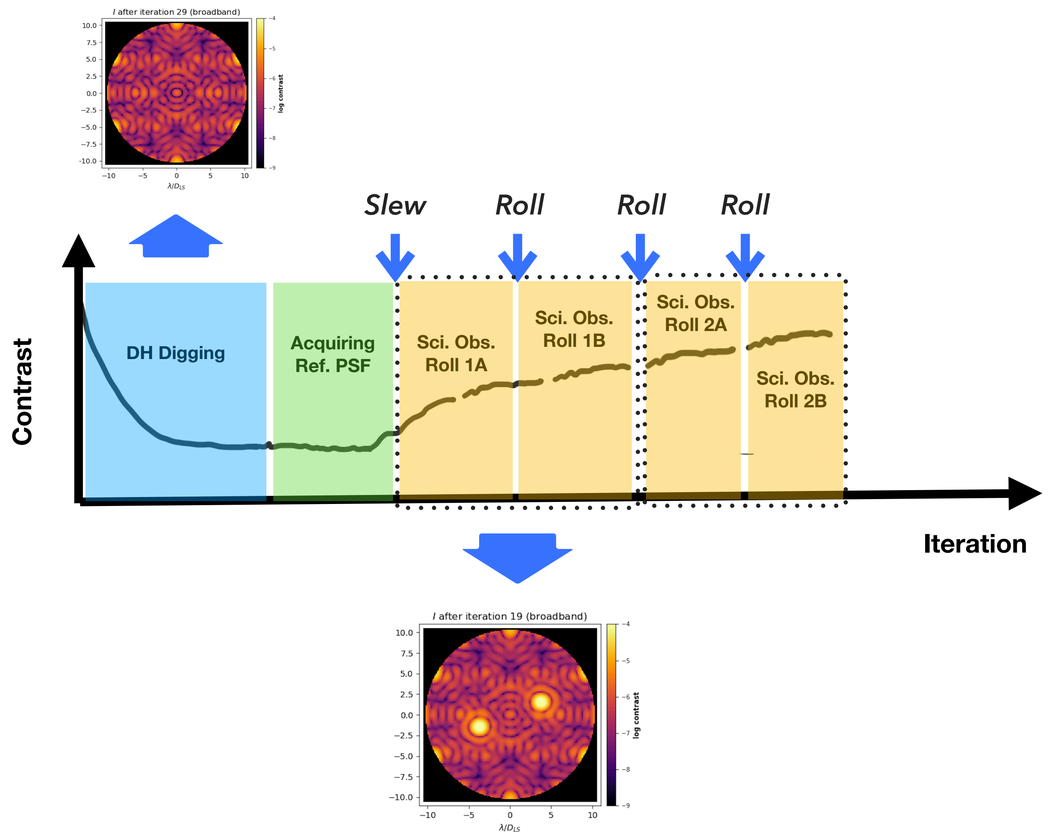
Upcoming actions - observing sequence

> Implement whole sequence w/ low order WFS&C
> Implement roll and slew of the PSFs
> Introduce additional (and controlled) aberrations (mincing *quasi-static aberration)*
> Investigate the controlled modes and their impacts on aberrations

Upcoming actions - developing post-processing technique

> Writing Telemetry class (output) for experiments
> Comparison with classical methods using experimental results
> Create telemetry libraries using experimental results

CAPyBARA


I after iteration 29 (broadband)
log contrast
λ/D_LS
Slew
Roll
Roll
Roll
Contrast
DH Digging
Acquiring Ref. PSF
Sci. Obs. Roll 1A
Sci. Obs. Roll 1B
Sci. Obs. Roll 2A
Sci. Obs. Roll 2B
Iteration
I after iteration 19 (broadband)
log contrast
λ/D_LS

Setup file

Instrument (telescope, coronagraph)

Observation (sequence, probing)

WFS&C (probes, EFC)

Time-series data (DM Commands, Focal plane images, constrast curve …)

Post-processing (RDI, KLIP …)

Setup file

Instrument (telescope, coronagraph, wavel)

Aberration (static, dynamic)

Observation (sequence, probing)

WFS&C (probes, EFC)

Time-series data (DM commands, e-fields, focal plane images, contrast …)

Post-processing (RDI, KLIP …)