LIRA Observatoire de Paris | PSL

Conférence ELBERETH
des doctorants en astronomie et astrophysique en Île de France

The Roman Coronagraph Instrument (CGI)

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Supervised by Johan Mazoyer and Axel Potier.

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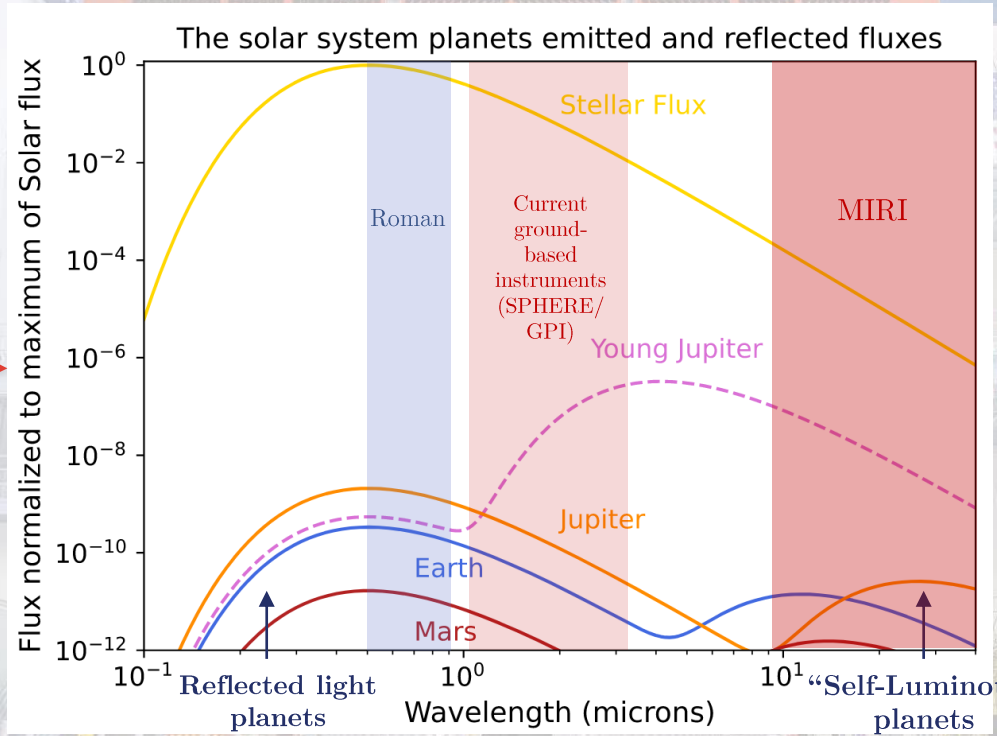
France 2030 | Académie Spatiale d'Île-de-France

NASA

ED A&A École Doctorale d'Astronomie & Astrophysique d'Île-de-France

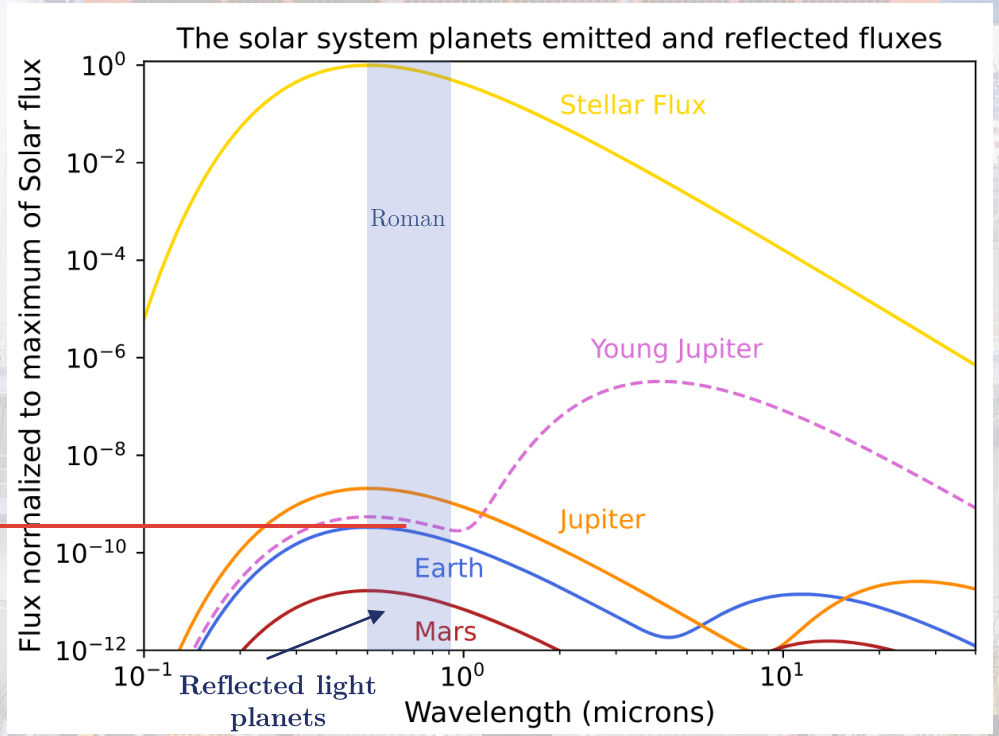
Scientific context



Adapted from Galicher & Mazoyer, 2023

Direct imaging: the challenge of contrast

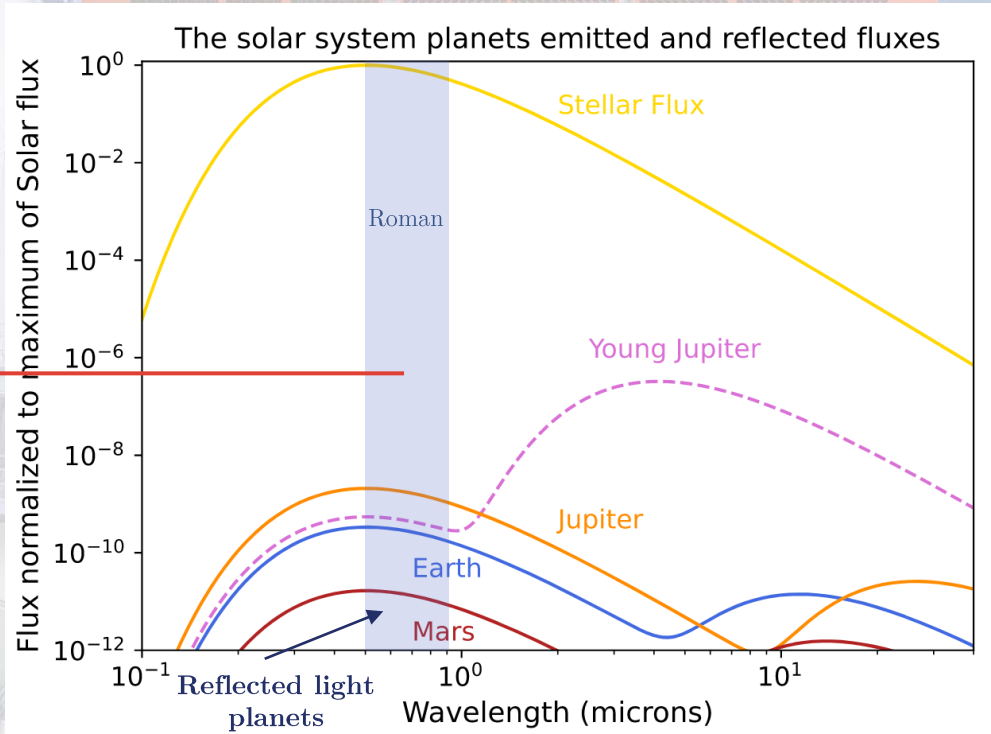
Detect an Earth-like



Adapted from Galicher & Mazoyer, 2023

Direct imaging: the challenge of contrast

Best perf in visible today



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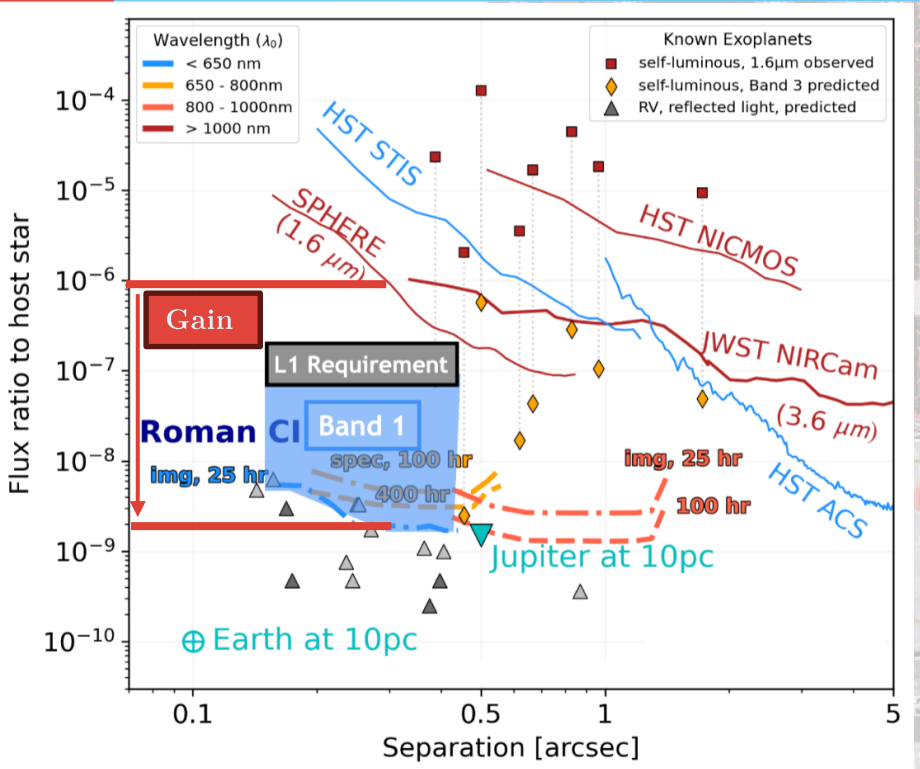
Scientific objective:

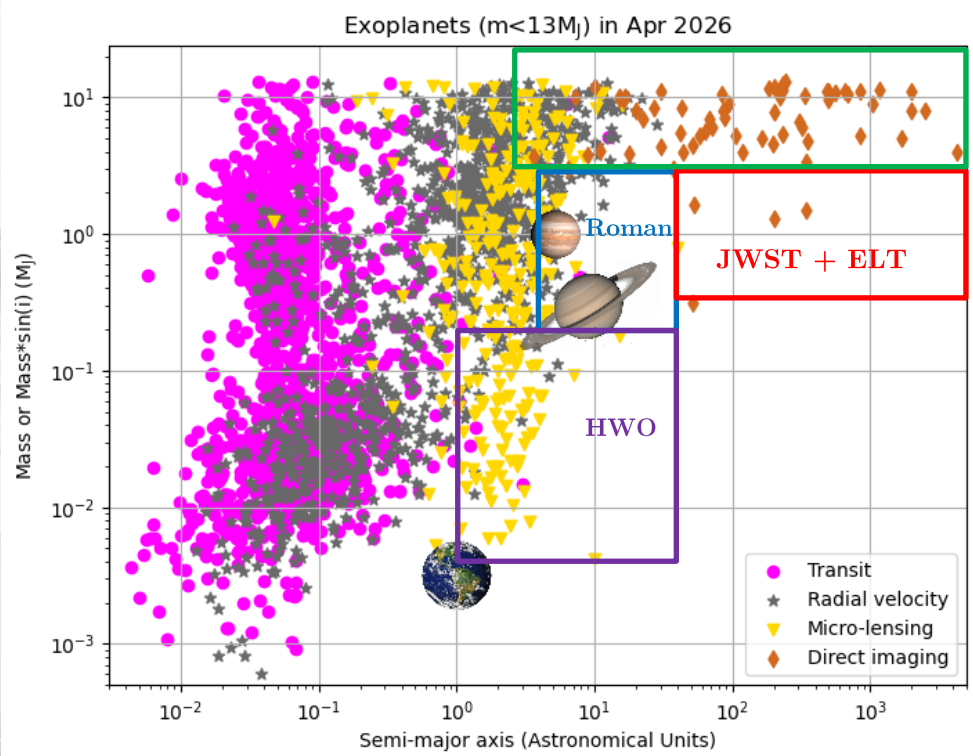


- **Roman = Flagship missions**
- For V~5 stars:
  - **Level 1 requirement (visible light):**

$$SNR \geq 5, \frac{\lambda}{D} \in (6, 9), C = 10^{-7}$$

Adapted from Altinier et al. (2024)

Scientific objective:

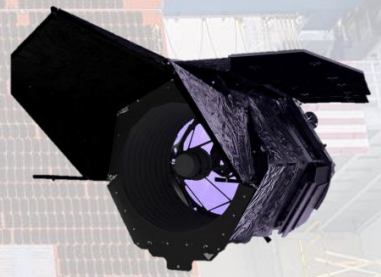


VLT, Gemini, Subaru, ...

- Method: **direct imaging**
- Detect: **solar system** analogs:
  - Young, gaseous and giant planets (Jupiter analogs, ...)
  - Debris disk
- Validate the first **active optical loop** between space and Earth:
  - Technology validation for **HWO**

= *Approximate area*

General schedule:



LAUNCH!

Observatory testing, planning, pipeline and development...

Commissioning

Observations on-sky phase

Today

September

Launch + 3 mo.

Launch + 21 mo.

Direct imaging: the challenge of contrast

How Roman works

What's the problem? In space

Telescope pupil

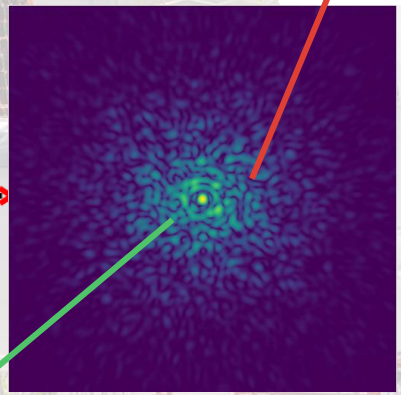
Non-common path aberrations > created by the instrument. There are quasi static/static over time.

Wavefront

Deformable mirror(s)

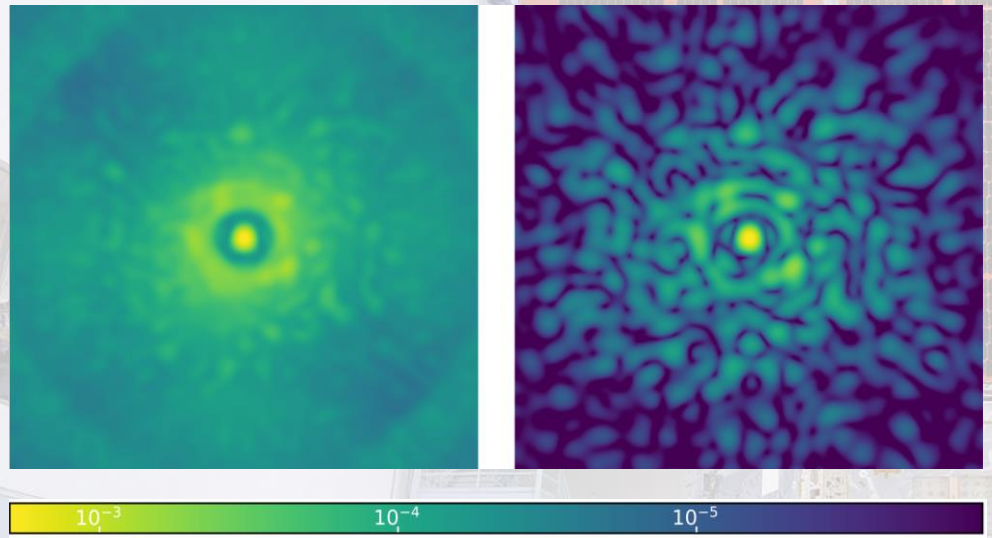
Coronagraph

Planet?



Speckles

Why yet another telescope???



SPHERE focal plane simulations: **Left (Ground like)**: Residual AO halo and speckles). **Right (space like)**: quasi-static/static speckles only (*Galicher & Mazoyer, 2023).*

- To achieve even **lower contrast,** you need:
  - to **distinguish a planet** from **stellar speckles**...
  - ... and thus **estimate stellar speckles**
  - And then **take them out! How???**

How can we estimate speckles?

Estimate = determine their **phase**

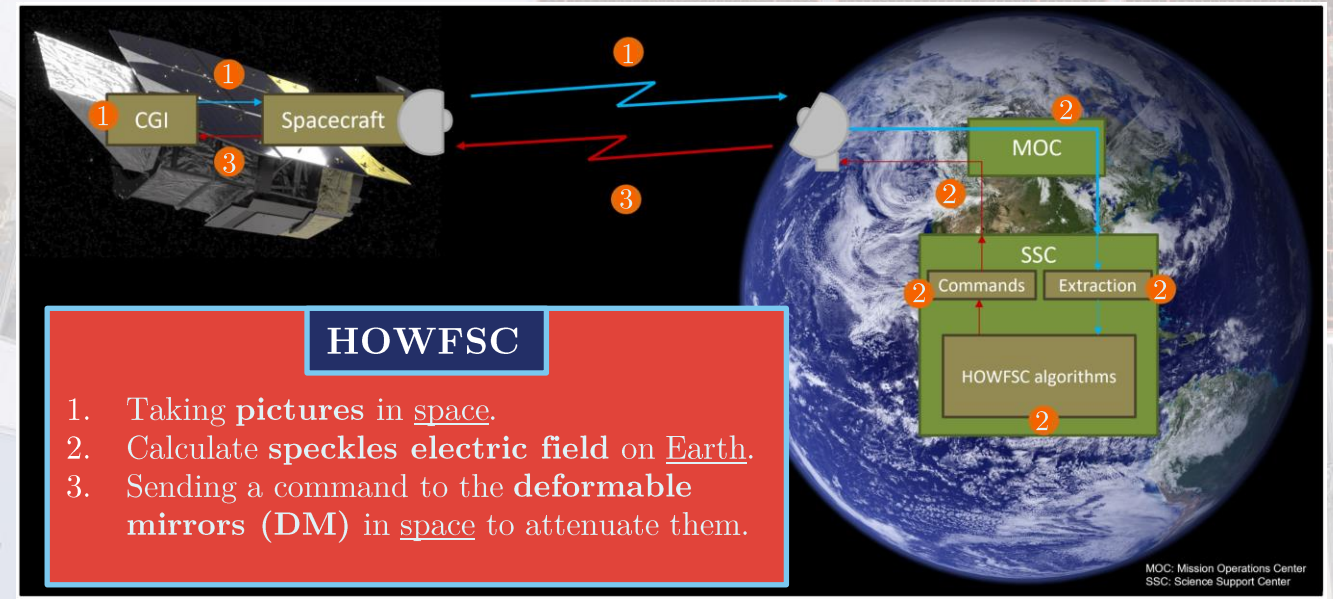
↓

Possible indirectly using the detector by **modulating** the speckles and do some **maths**! ☺

↓

Pair-wise-probing (High-order wavefront **sensing**)

With that: High-order wavefront sensing and control



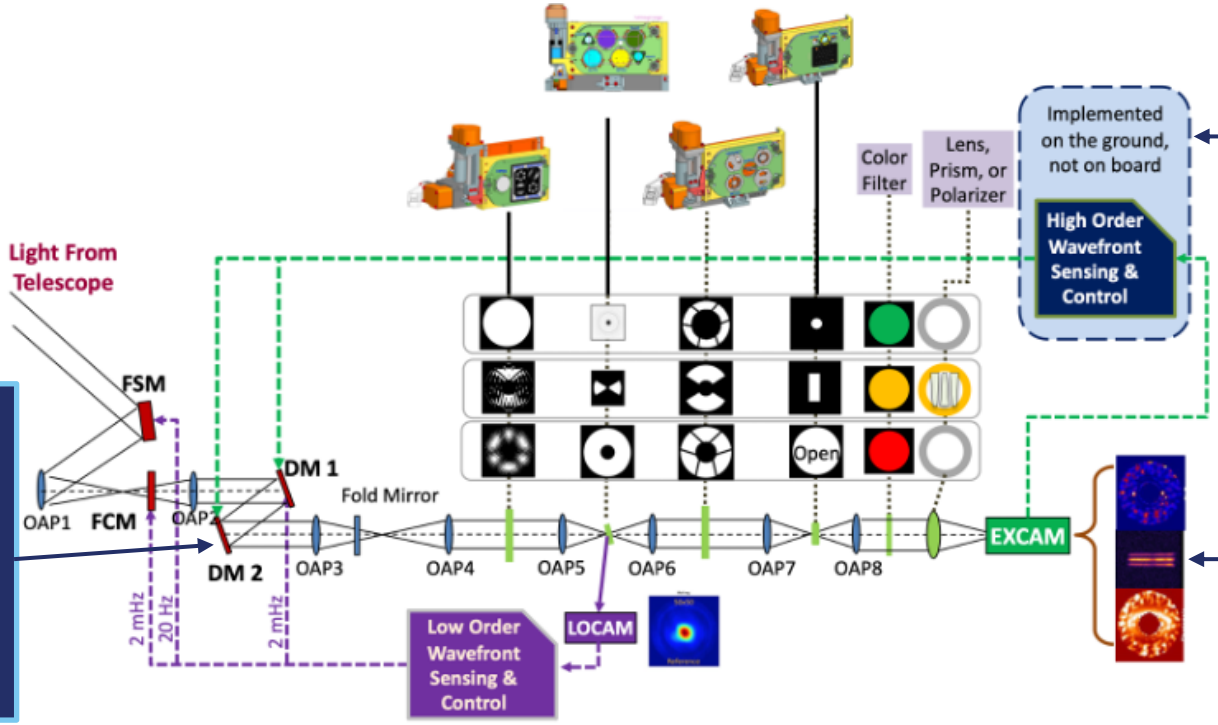
HOWFSC

1. Taking **pictures** in space.
2. Calculate **speckles electric field** on Earth.
3. Sending a command to the **deformable mirrors (DM)** in space to attenuate them.

- We deliberately **modulate** the **images in focal plane.**
- We use these to **estimate the phase of the speckle.**
- We **attenuate them** using the DMs of Roman (creation of the **opposite electric field**).

Cady et al. (2025)

The optical bench of Roman CGI

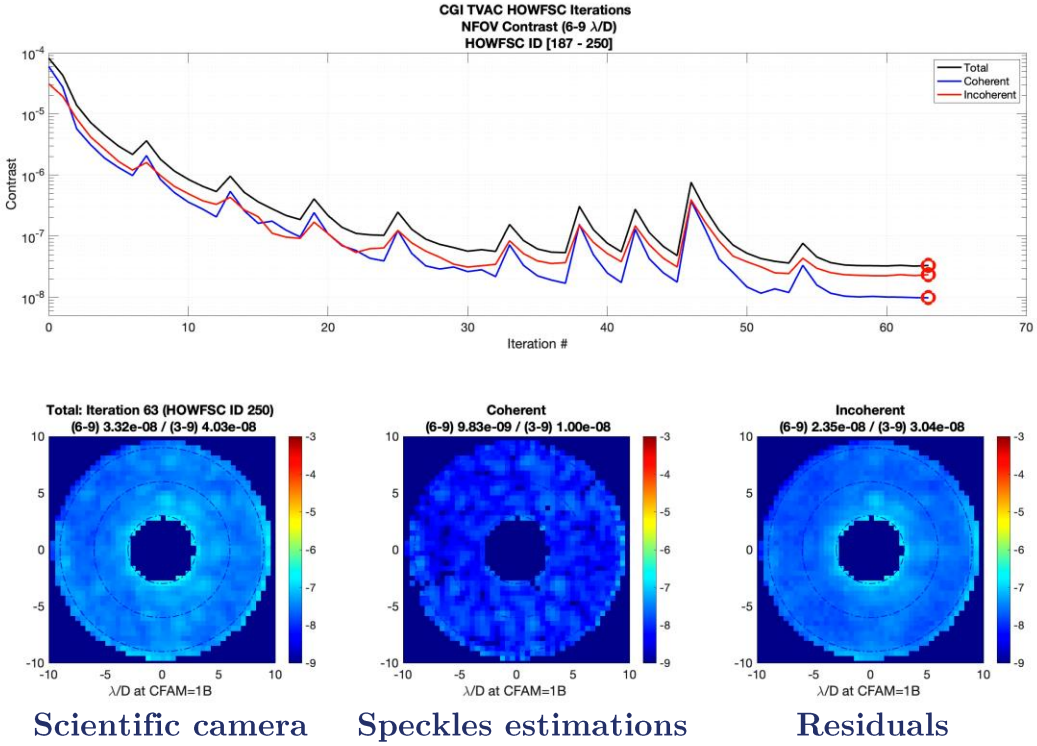


2 - We use these to **estimate the phase of the speckle.**

3 - We **attenuate them** using the DMs of Roman (creation of the **opposite electric field).**

1 - We deliberately **modulate** the **images in focal plane.**

Technological demo



- The **contrast decreases** at each iterations!
- The **speckles** being corrected are **static/quasi-static.**

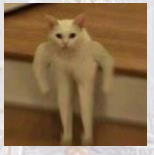
The **expected contrast** is:
$< 10^{-7}$ (L1 requirement)
$\sim 10^{-8}$ - 10^{-9} (predicted/goal)

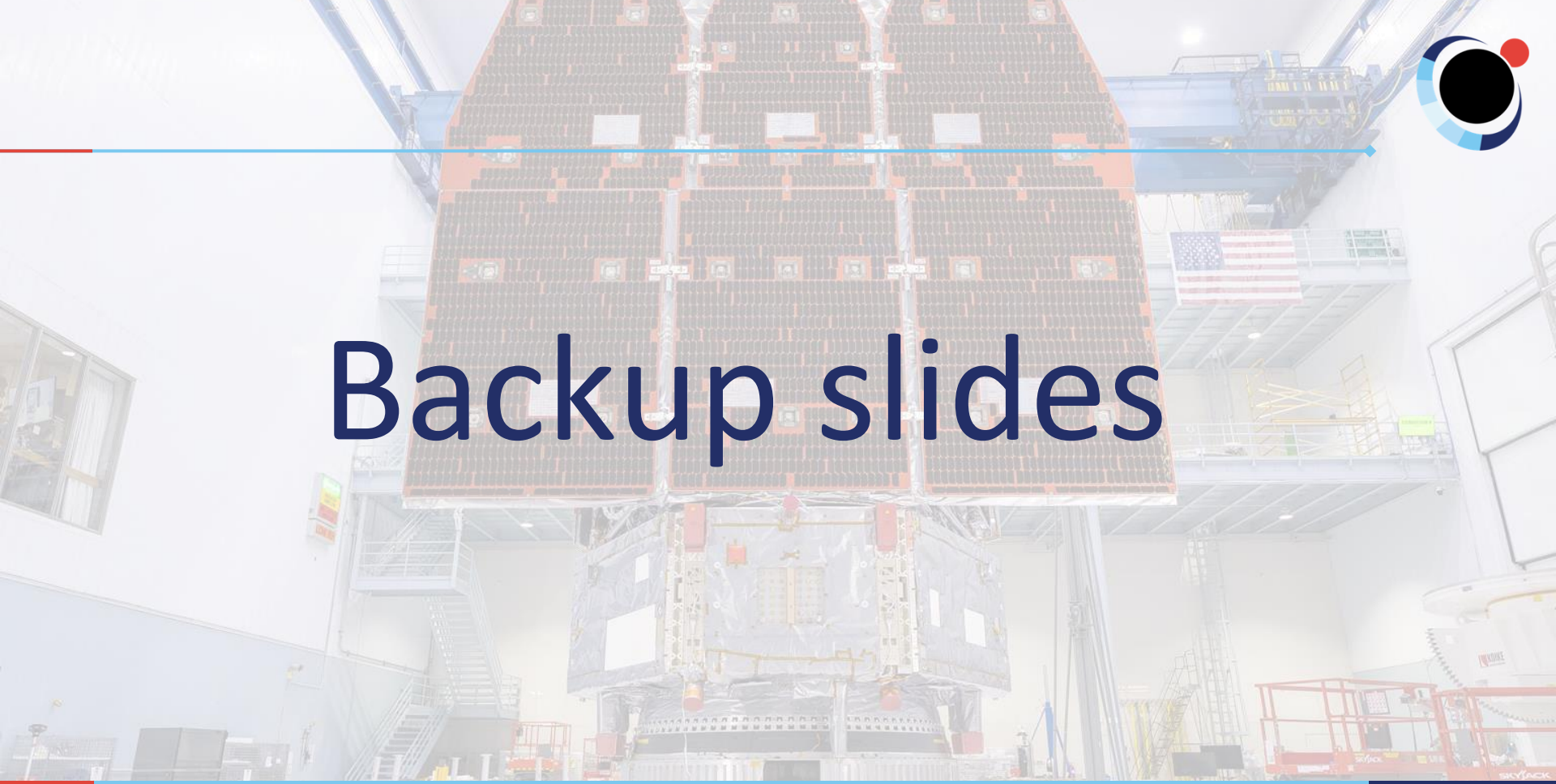
Cady et al. (2025)

To conclude…

- Roman CGI aims to image **Jupiter-like planets and debris disk.**
- It's a **technology demonstrator** for HWO which will attempt to image the **first Earth-like exoplanet** in the future.
- **Stay tuned: launching in early September!!!**

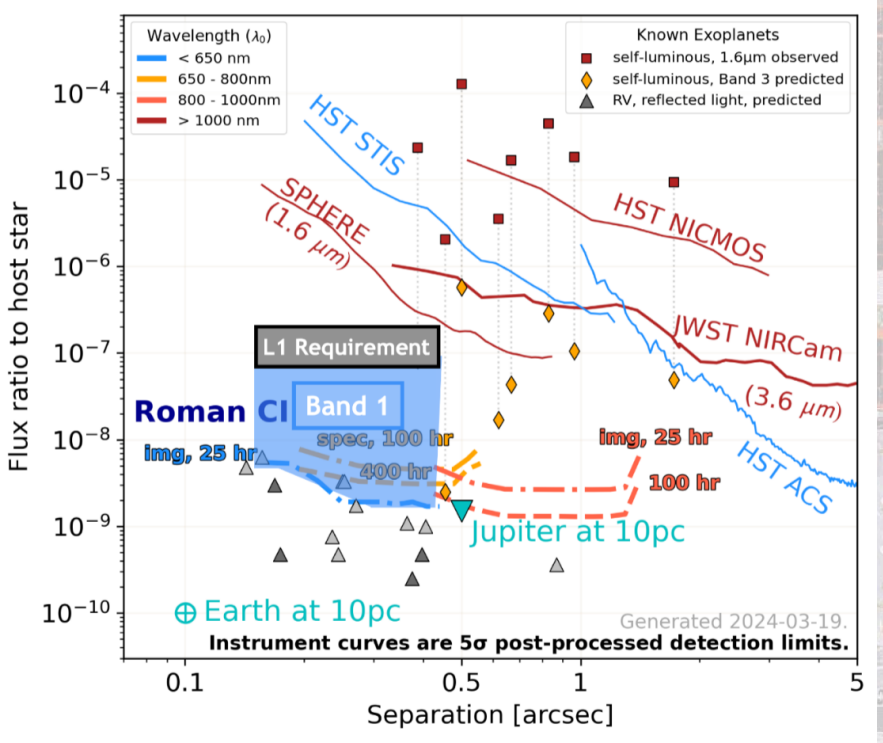
Questions???





Backup slides

Scientific objective:



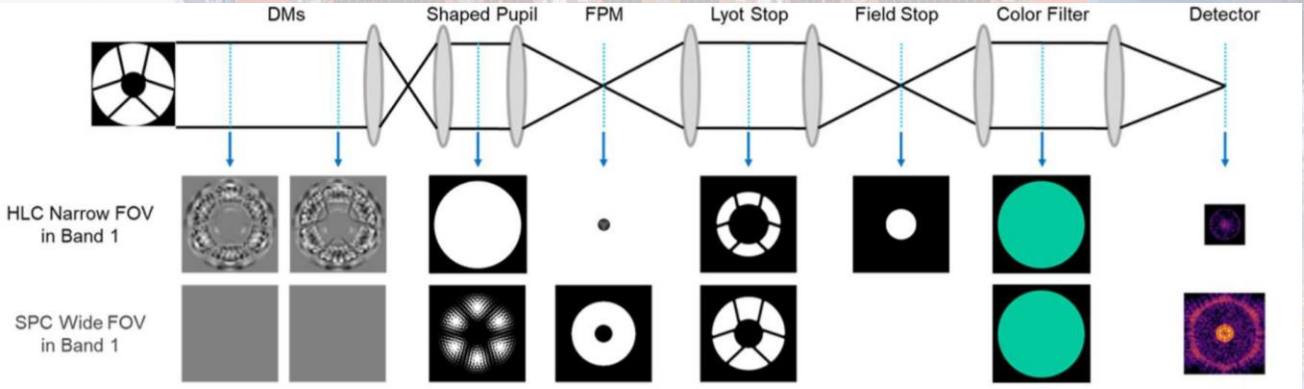
- For V~5 stars:
  - Level 1 requirement (band 1):

$$SNR \geq 5, \frac{\lambda}{D} \in (6, 9), C = 10^{-7}$$

Band	Mode	λ (nm)	BW	Corona.	λ/D
1	**NFOV**	**575**	**10%**	**HLC**	**3-9 (360°)**
2	Spectro	660	15%	SPC	3-9 (2x65°)
3	Spectro	730	15%	SPC	3-9 (2x65°)
4	WFOV	825	10%	SPC	3-9 (360°)

Adapted from Altinier et al. (2024)

Scientific objective:



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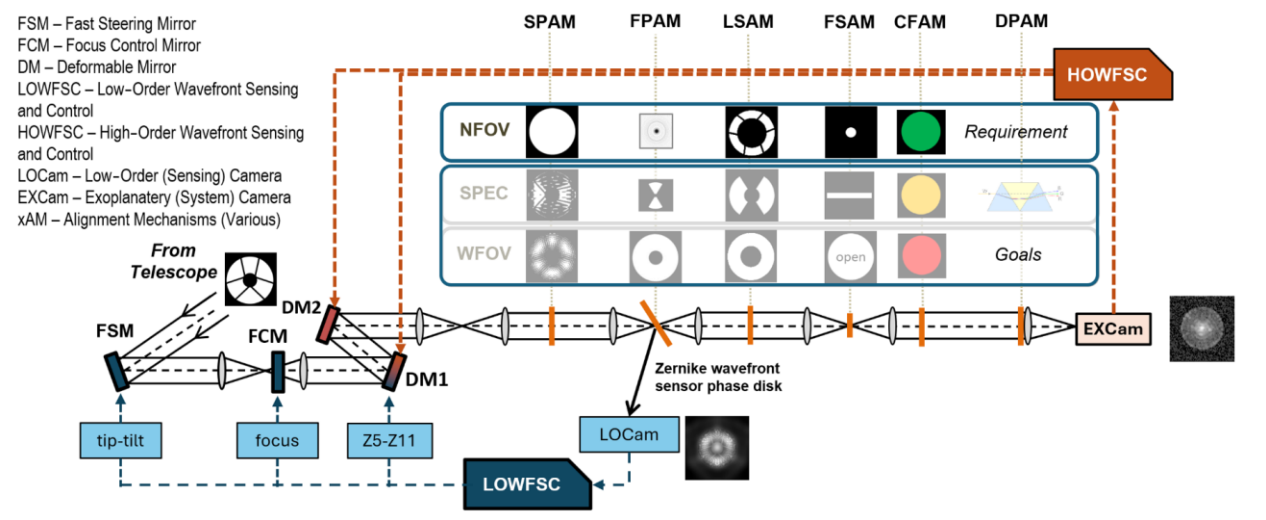
Cady et al. (2025)

Technological demo

- **HOWFSC** is part of a complex coronagraph instrument with a lot of sub-systems:
  - **Coronagraphs, 2 DMs, LOWFSC** (internal loop) and **HOWFSC** (Earth-instrument loop), **EMCCDs** for ultra-low noise photon detections, ...



Cady et al. (2025)

Technological demo: simplified problem

- How can we estimate speckles intensity on earth? $|E_s|^2$
  - We make temporal modulations on the DM (Pair-Wise-Probing).

  = Apply pairs of known phase probes $\pm\psi_m$
  - Linearize the intensity measurement for +/- probes

$$\Delta I_m = I^+ - I^-$$

  - Then, solve inverse problem:

$$\underbrace{\Delta I_m}_{\text{Measurement}} = \underbrace{\mathcal{M}_{\text{model}}}_{\text{Modulation}} \cdot \underbrace{E_s}_{\text{Speckles}}$$

Technological demo: simplified problem

- How can we kill the speckles in space?
  - Linearize the problem around a DM position $\vec{a}$:

$$E_s(S,\vec{a}) \approx E_s(S,\vec{a}_0) + \frac{\partial E_s(S,\vec{a})}{\partial \vec{a}}|_{\vec{a}=\vec{a}_0}(\vec{a}-\vec{a}_0)$$

  - Solve:

$$min_{\Delta\vec{a}}\left(||\vec{E}_s + J\Delta\vec{a}||^2\right)$$

  - Solution = apply on the DM:

$$\Delta\vec{a} = -(J^T J)^{-1} J^T \vec{E}_s$$

  - *(After: regularization, …)*

Alternates probes

A&A, 698, A130 (2025)
https://doi.org/10.1051/0004-6361/202553797

Astronomy & Astrophysics

Extended linearity in the high-order wavefront sensor for the Roman Coronagraph

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- **Alternate** modulations:
  - Can extend **linearity** of the algorithm.
  - Can achieve better **contrast.**
  - **Enhance** HOWFSC strategies.