Roman Space Telescope Coronagraph Overview

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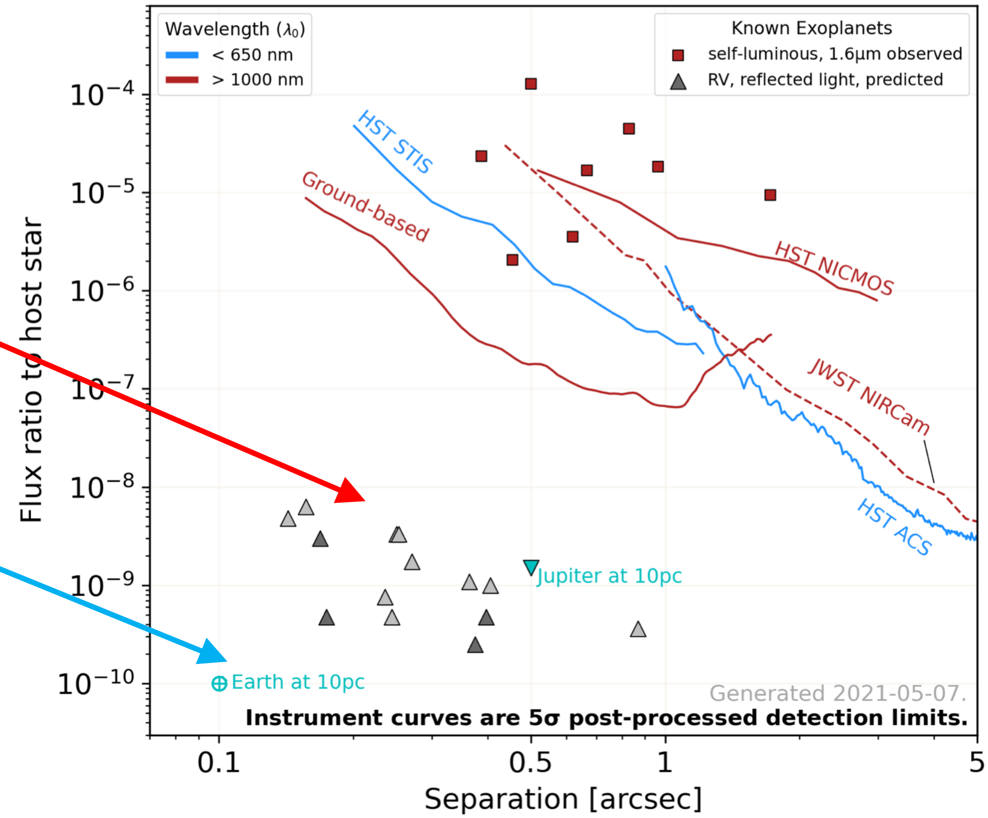
With support from many at the Jet Propulsion Laboratory, Goddard Space Flight Center, and the Science Investigation Teams

The Roman Coronagraph Instrument paves the way for future exoplanet direct imaging missions

Roman coronagraph

Future exo-Earth missions



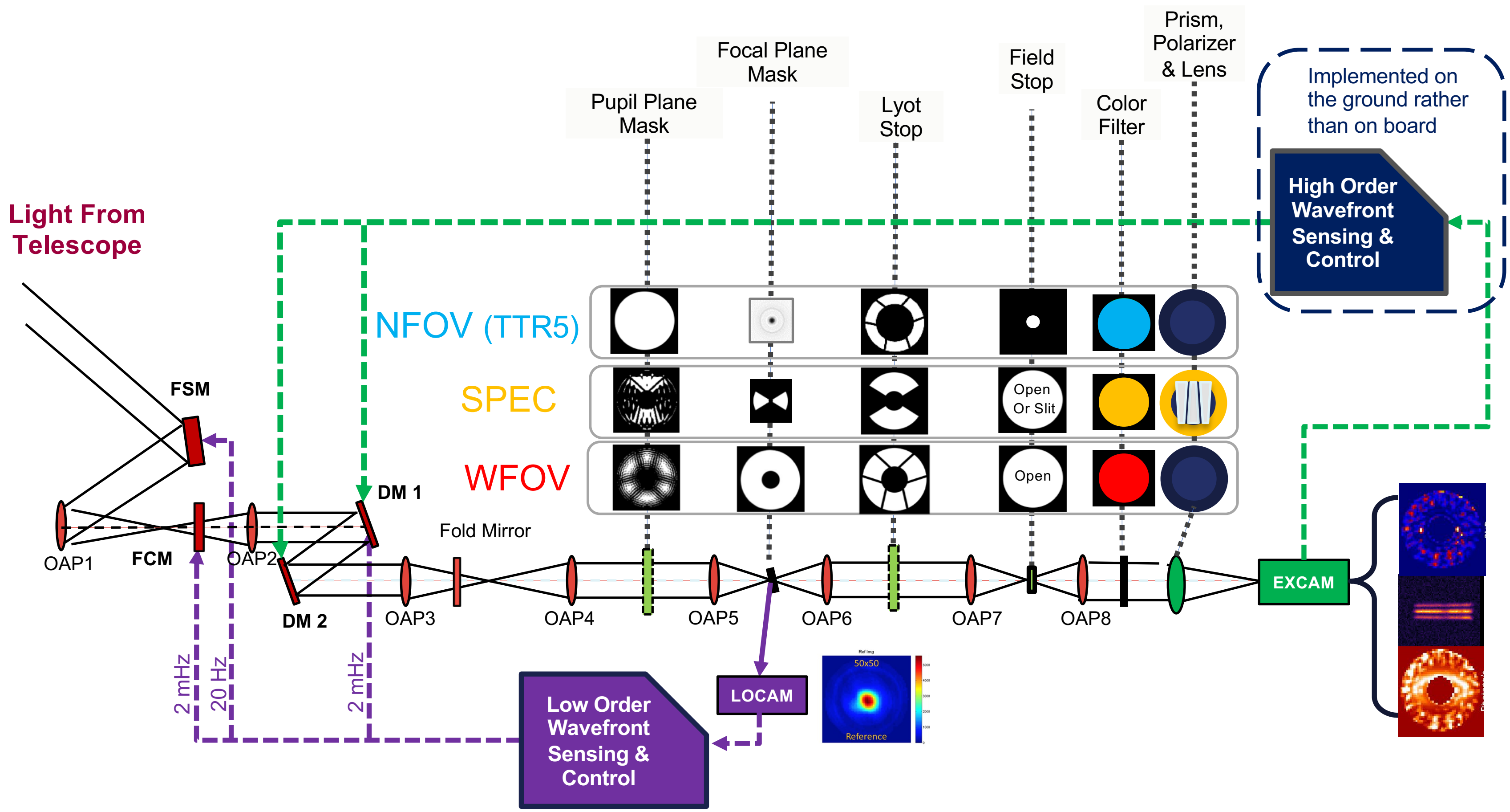
Threshold Technology Requirement #5 (TTR5)

- **TTR5:** Roman shall be able to measure brightness of an astrophysical point source w/ SNR ≥ 5 located 6 – 9 λ/D from an adjacent star with $V_{AB} \leq 5$, flux ratio $\geq 10^{-7}$; bandpass shall have a central wavelength ≤ 600 nm and a bandwidth ≥ 10%.

- TTR5 supporting observing mode (narrow field of view imaging) is the only mode to be fully tested (lab + simulations) before instrument delivery

- Other modes available on best effort basis (see Vanessa Bailey's talk)
  - Spectroscopy, "wide" field of view imaging, polarimetry
  - The optics for the other observing modes should be available and aligned but not end-to-end performance-tested before delivery.

Key technologies work together as a system to deliver high performance

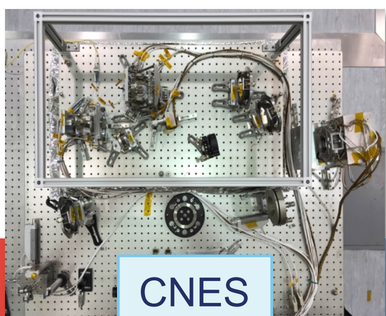


OAP = Off-Axis Parabolic [Mirror]

CGI will demonstrate key technologies for future missions

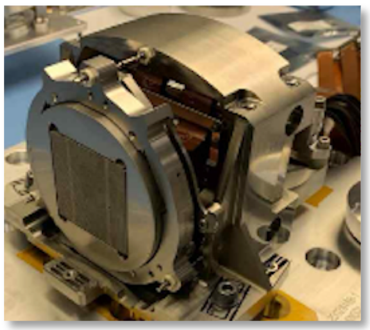
Other areas:
CNES, MPIA, JAXA

Ultra-Precise Wavefront Sensing & Control (now Ground-In-The-Loop)

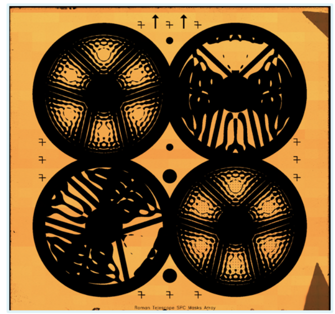


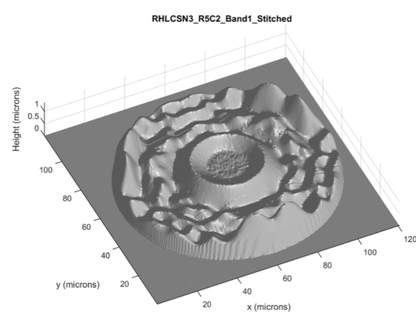
CNES

Large-format Deformable Mirrors



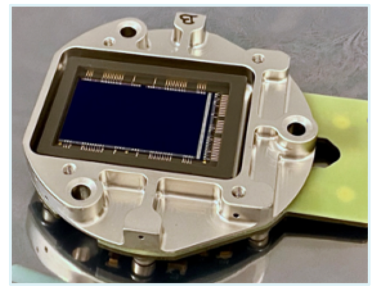
High-contrast Coronagraph Masks





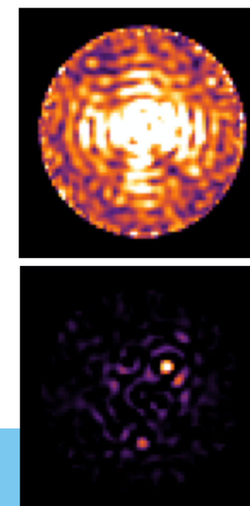
JAXA

Ultra-low-noise Photon-counting EMCCDs



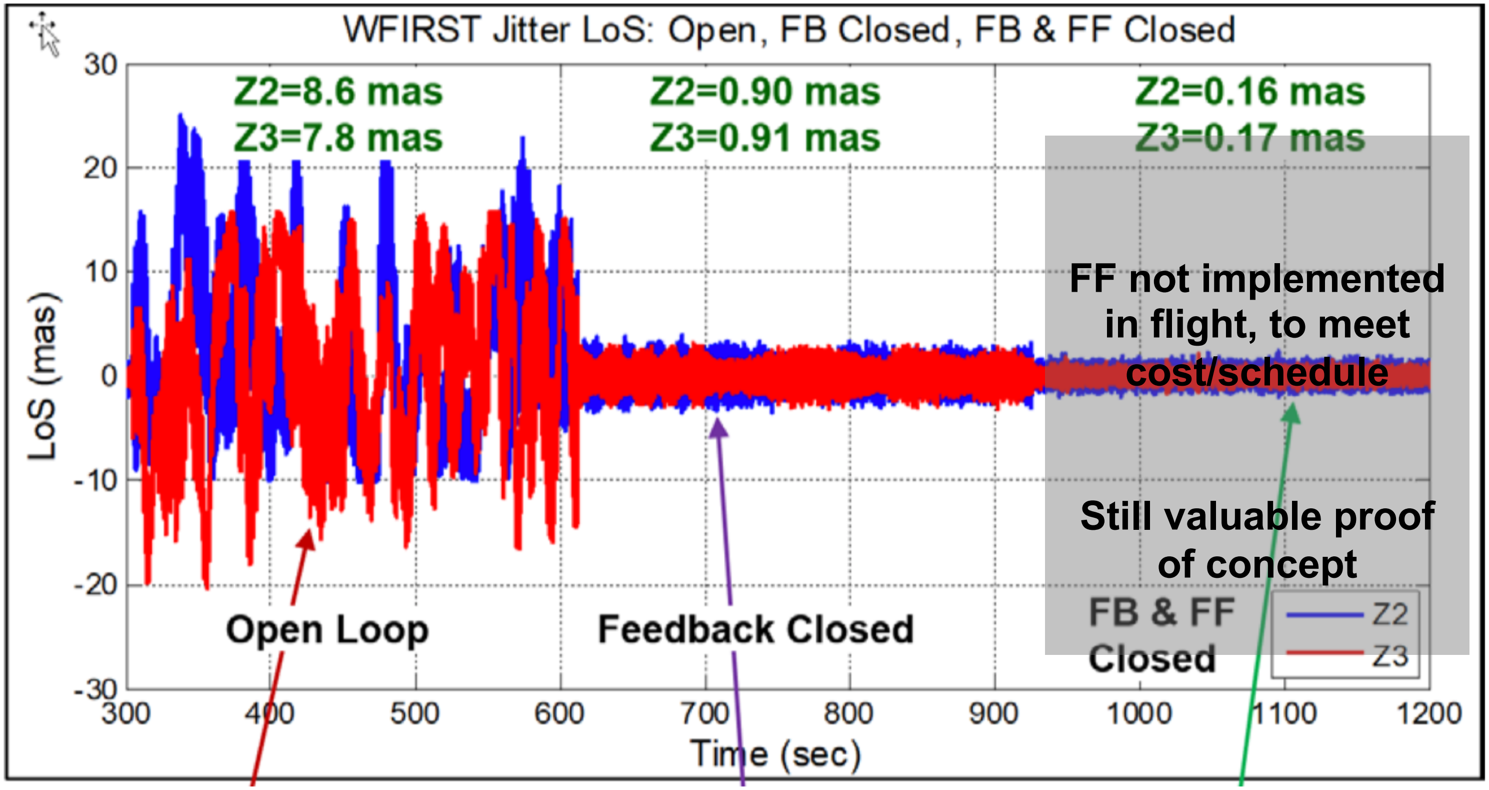
ESA

Data Post-Processing



All hardware now at TRL ≥ 6

Low Order Wavefront Sensing and Control rejects flight-like tip/tilt disturbances



Shi+2019

LOWFS/C also continuously senses and controls Z4 – Z11 (~2 mHz bandwidth)

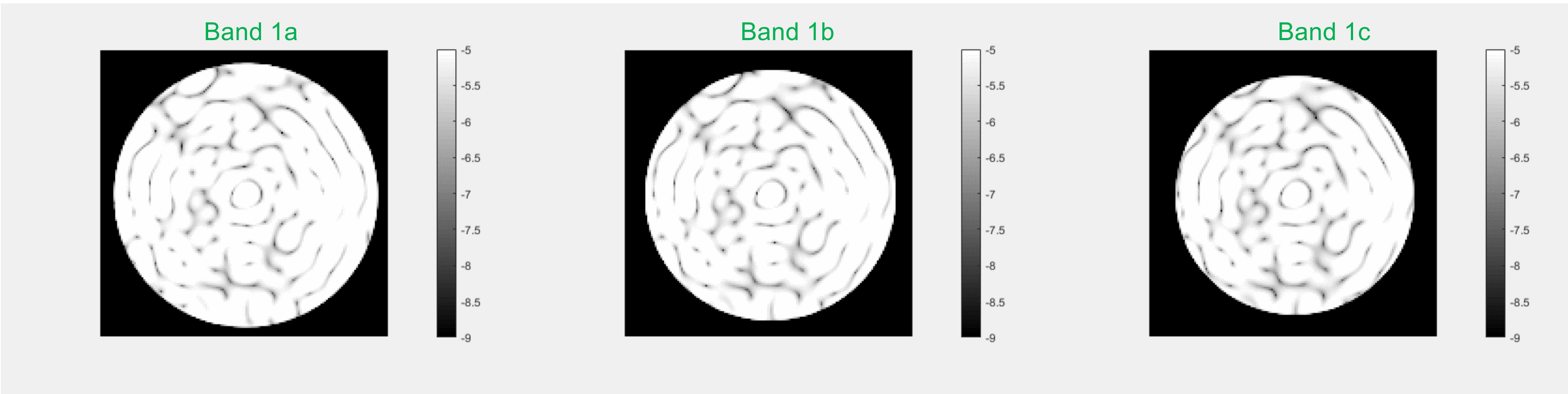
What is High-Order Wavefront Sensing and Control (HOWFSC)?

HOWFSC "digs the dark hole" by cycling periodically through iterations of:

Wavefront sensing at primary camera EXCam ("focal plane wavefront sensing")

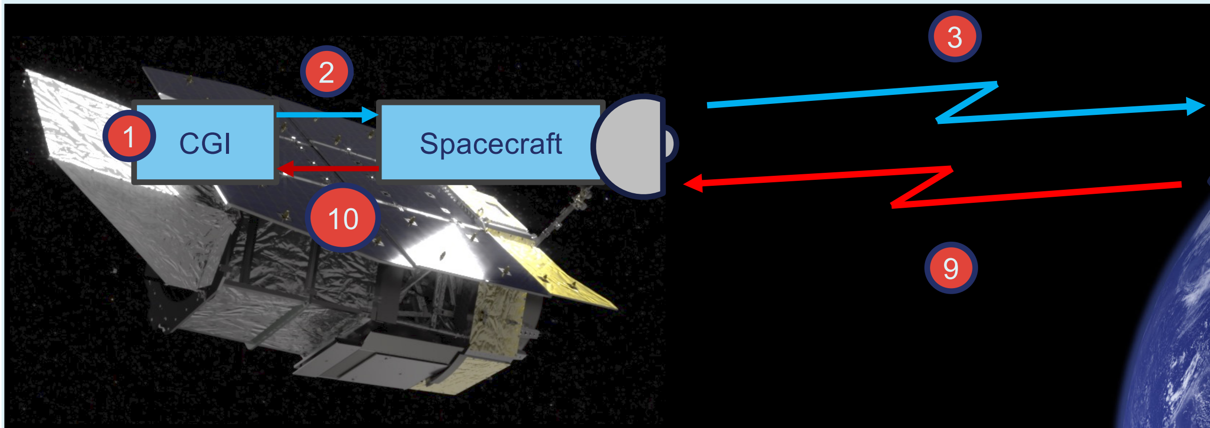
Wavefront control, by using a model to solve for the next set of DM settings

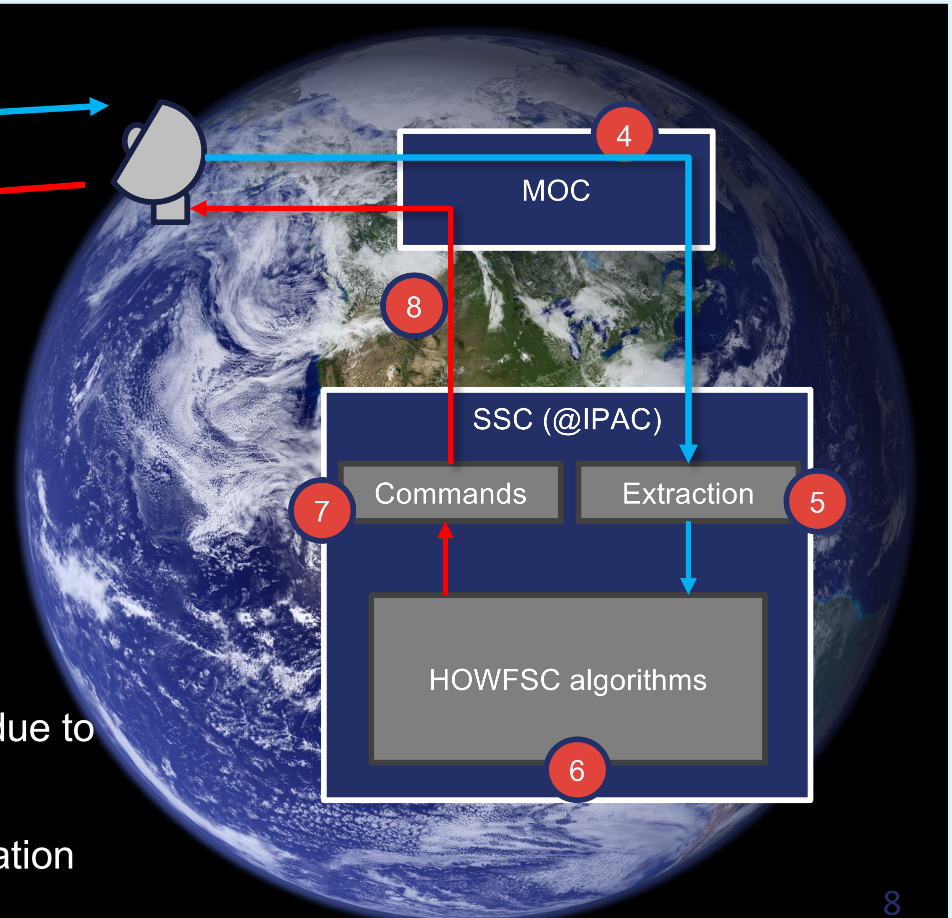
These cycles are repeated to reduce the residual starlight level and permit the detection of faint astrophysical signals in the vicinity of the star.



See HOWFSC talk by Neil Zimmerman this afternoon. Ref SPIE?

HOWFS Operates “Ground In the Loop” (GITL) (see Neil Zimmerman’s talk)





Roman Coronagraph Dark Hole Algorithms Interest Group

Neil Zimmerman neil.t.zimmerman@nasa.gov

Computation offloaded to ground

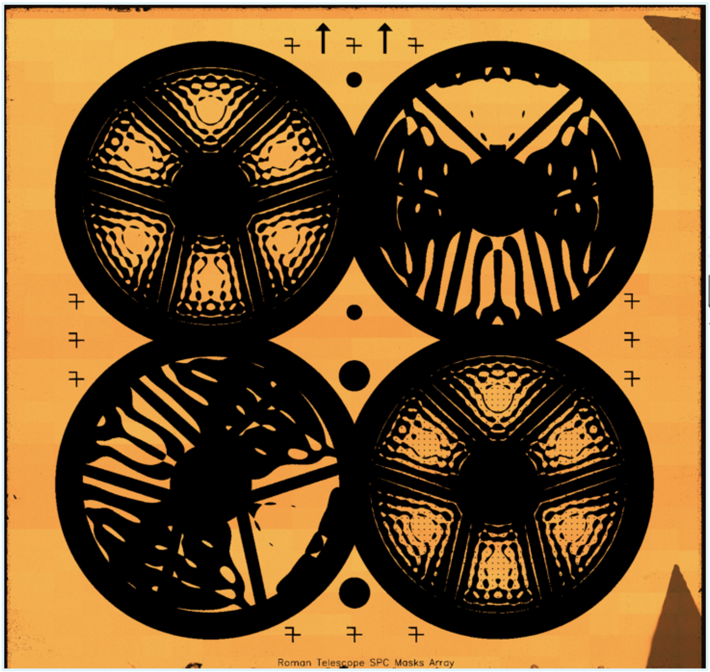
~Daily contacts; Small number of iterations per contact

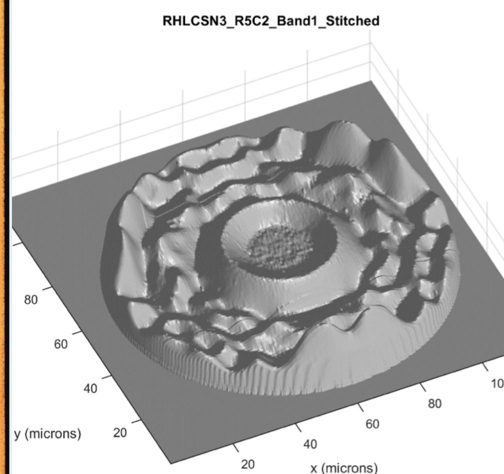
tens of minutes / iteration (22 min CBE ; 30 min Req) due to comm’s bandwidth

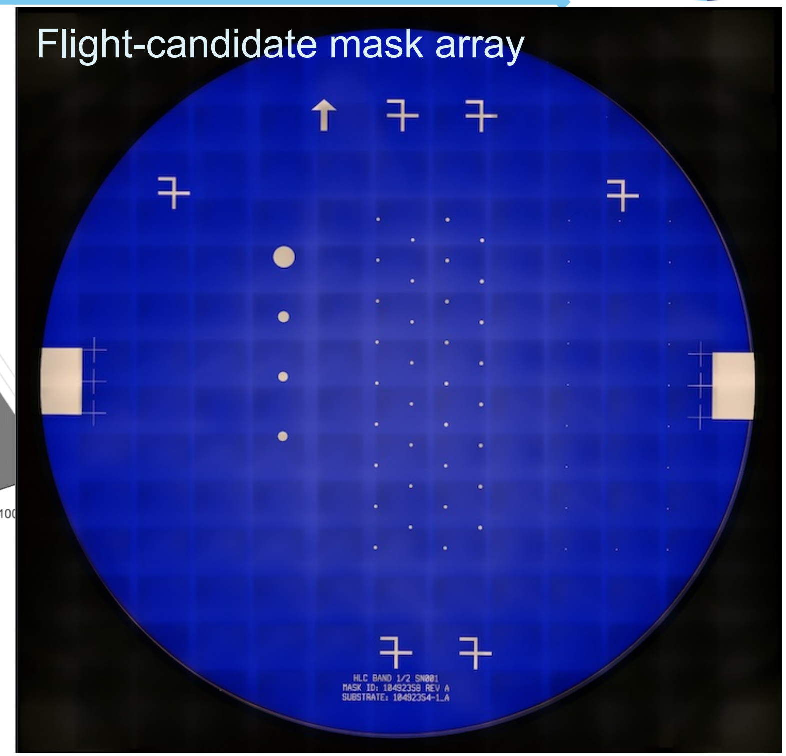
Potential for contributed HOWFSC algorithms. Testing/validation support TBD

Coronagraph masks for challenging pupils

(see 2021 SPIE paper by A.J. Eldorado Riggs)







3 sets of HLC band 1 flight masks already manufactured and characterized.

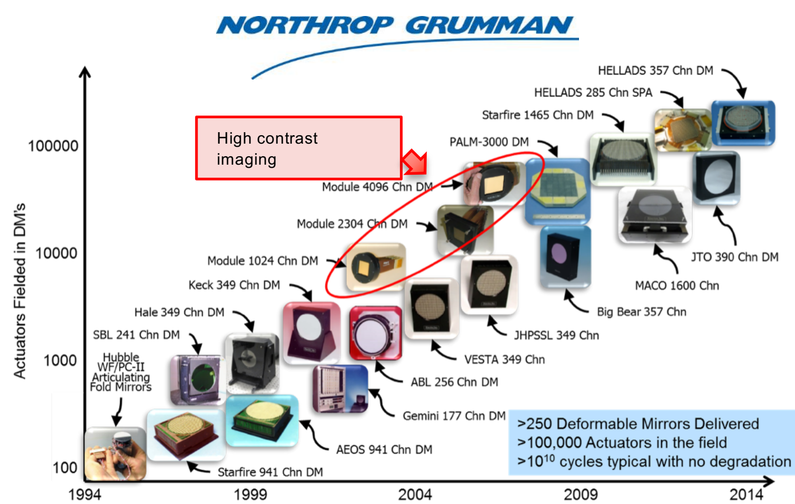
Balasubramanian+2019
Riggs+ 2019

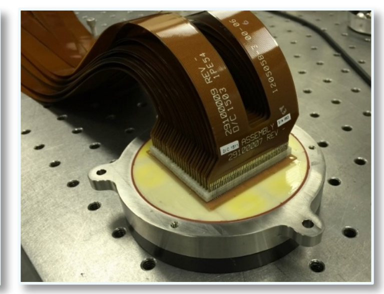
Xinetics deformable mirrors have a long lab track record, but needed modifications for flight

- Northrop Grumman Xinetics Deformable Mirrors
  - 48X48 PMN (lead magnesium niobate) electro-strictive ceramics actuators

- Lab performance:
  - Several DMs working in the lab 5 – 10 years without failures
  - Reached ~10^{-10} level of contrast
  - DMs Reached TRL 6 in Nov 2020

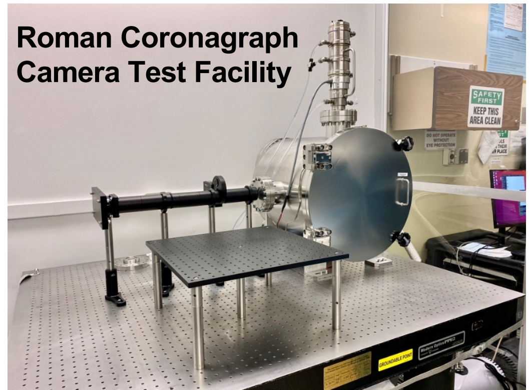
- DMs + electronics now flight-qualified

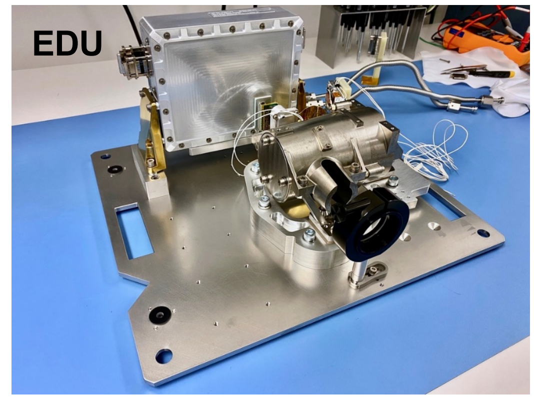


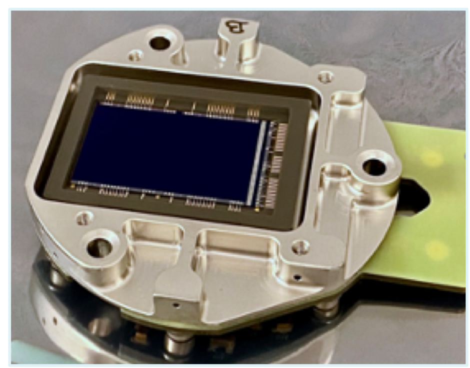


Electron-Multiplying CCDs count photons

- Jupiter analogs V ~ 27
  - < 1 planet photon per minute
- Teledyne e2v, two 1k×1k EMCCDs
  - EM => no read noise
- Tech & data processing development
  - Mitigation and characterization of charge traps from radiation damage (“notch” channels)
  - Mitigation of cosmic ray effects (overspill)
- Flight EMCCD delivery sensor expected in Nov. 2021 (Teledyne-e2V/UK)
- ABB/Nuvu electronics expected in November 2021 (ABB/Canada)

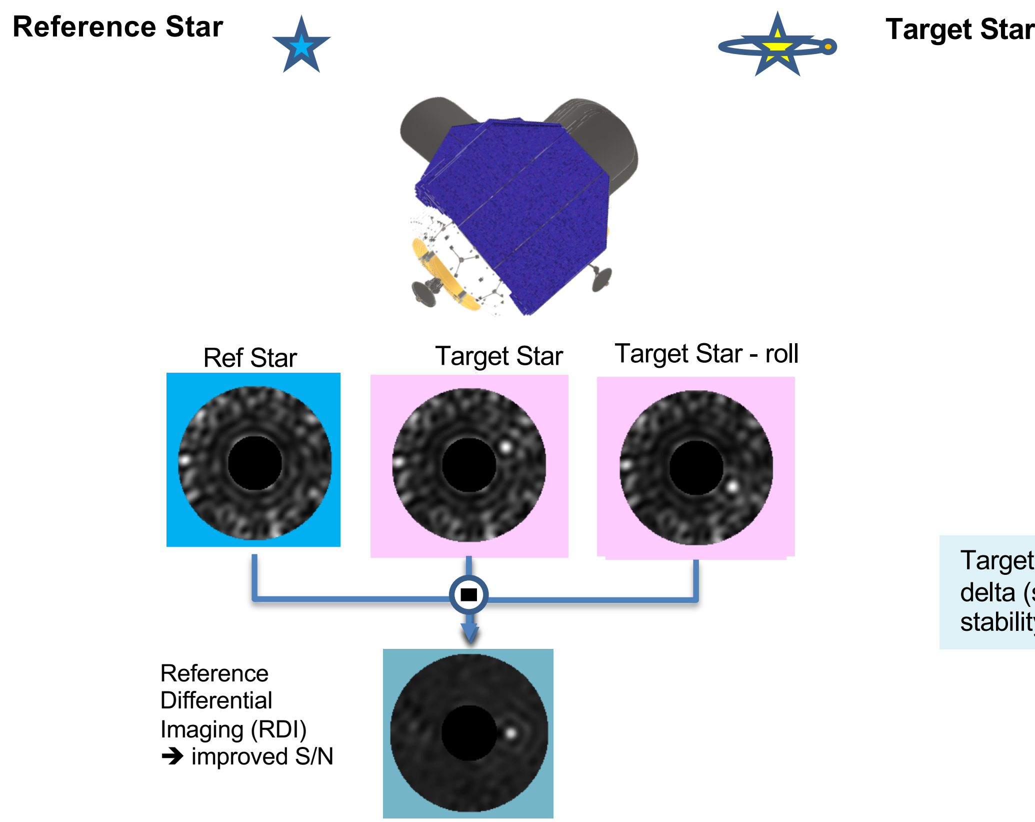






Pictures courtesy of Patrick Morrissey

Nominal operations: target & reference star



Target vs Reference should have small delta (spacecraft) pitch for better thermal stability

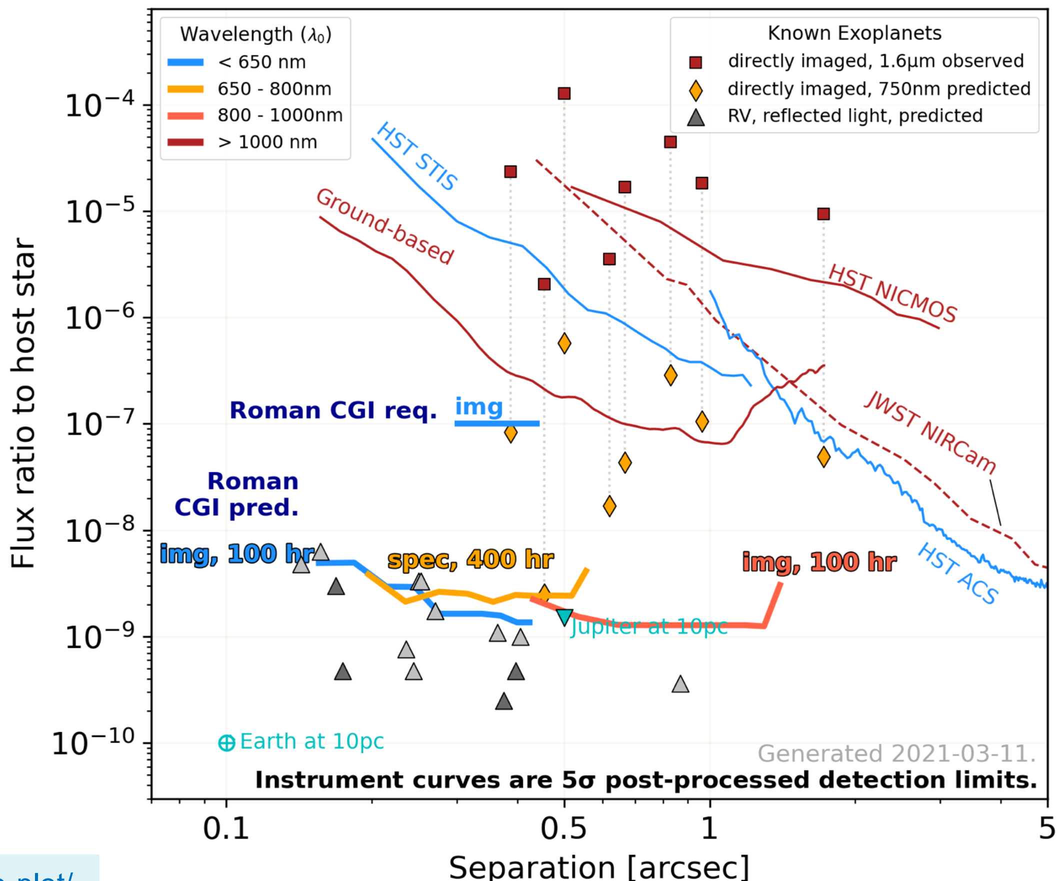
Adapted from J. Krist

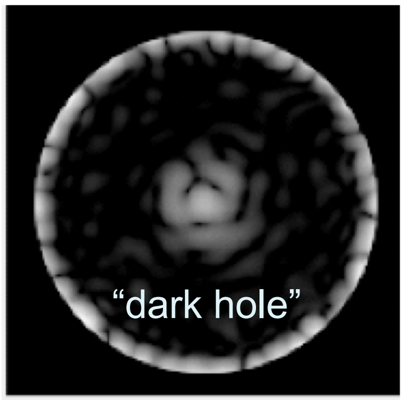
Need both active wavefront control and optimized in-orbit operations to meet L1 requirements

Observing Scenarios Performance Simulations

- See John Krist's overview talk about Observing Scenarios and their Simulated Datasets
- See Marie Ygouf's talk about Working with Simulated Datasets (Post processing)

Predicted detection limit is 100-1000x better than State-of-the-Art





Based on lab demonstrations as inputs to high-fidelity, end-to-end thermal, mechanical, optical models.

NASA terminology: Most Model Uncertainty Factors set to 1

github.com/nasavbailey/DI-flux-ratio-plot/

Brian Kern (JPL)
John Krist (JPL)
Bijan Nemati (UA Huntsville)
A.J. Riggs (JPL)
Hanying Zhou (JPL)
Sergi Hildebrandt-Rafels (JPL)

Resources about Roman (Coronagraph)

- Nancy Grace Roman Space Telescope at GSFC: https://roman.gsfc.nasa.gov
- Nancy Grace Roman Space Telescope at JPL:
  - https://www.jpl.nasa.gov/missions/the-nancy-grace-roman-space-telescope
- Nancy Grace Roman Space Telescope at IPAC https://roman.ipac.caltech.edu
- Nancy Grace Roman Space Telescope at STScI: https://www.stsci.edu/roman/
- Roman Coronagraph performance vs HabEx/LUVOIR requirements: https://arxiv.org/pdf/2008.05624.pdf
- Instrument overview, Coronagraphic Masks design and modes: Riggs et al. 2021 SPIE ; Bendek et al. SPIE 2021; Mennesson et al. SPIE 2021

Backup Slides

Technology Objectives for Coronagraph Instrument

- Demonstrate Coronagraphy with Active Wavefront Control
- Advance Engineering & Readiness of Coronagraph Elements
- Develop and Demonstrate Advanced Coronagraph WFSC Algorithms
- Collect Data to Enable Integrated Observatory Performance Characterization
- Demonstrate Advanced High-Contrast Data Processing

The Roman Coronagraph Instrument in a nutshell

- Coronagraph Instrument is:
  - a technology demonstration instrument on Roman
  - the first space-based coronagraph with active wavefront control
  - a visible light (545-865nm) imager, polarimeter and R~50 spectrograph
  - a 100-1,000 times improvement in performance over current ground and space facilities
  - capable of exoplanetary system science
- Instrument entering Build, Integration & Test phase now