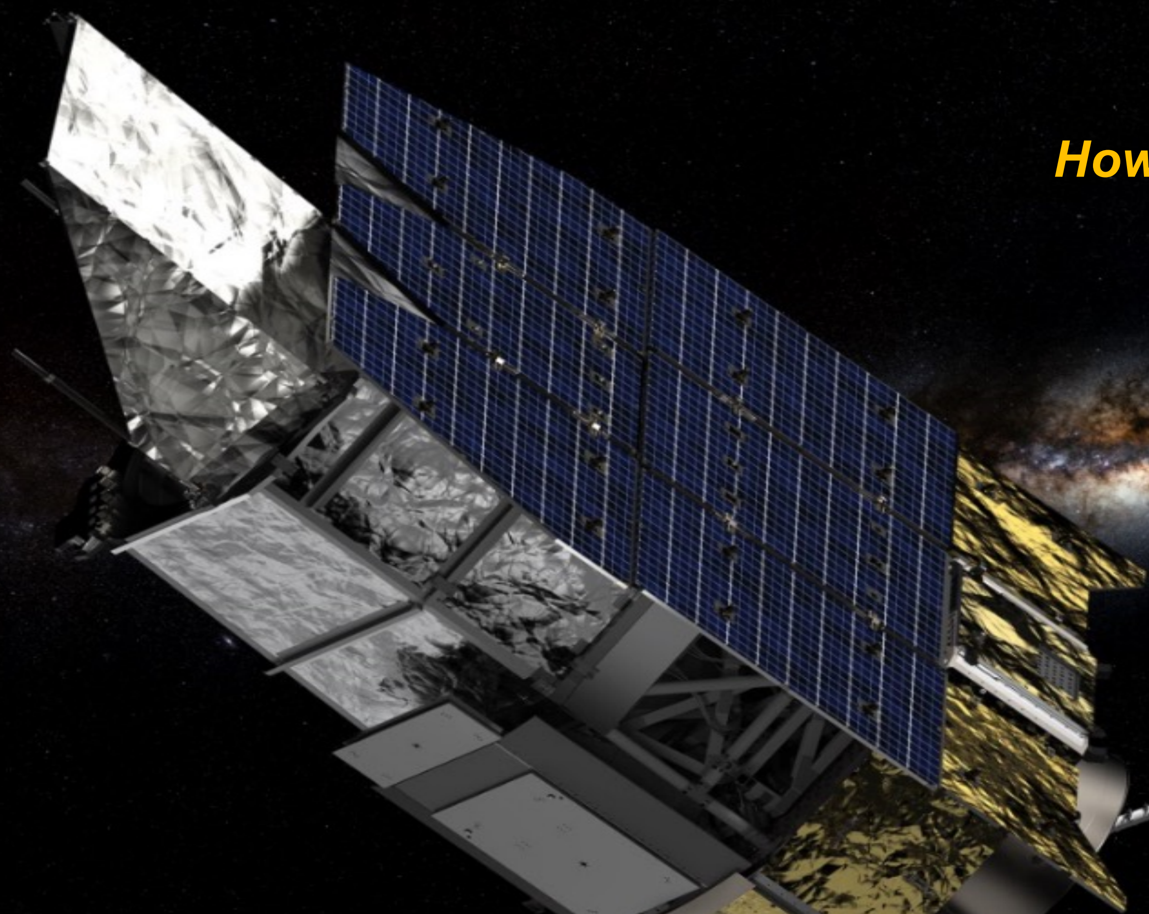

Jet Propulsion Laboratory
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How far will the Roman coronagraph get us on the way to HWO?

Bertrand Mennesson

Jet Propulsion Laboratory,

California Institute of Technology

Roman Coronagraph Test Results Info Session, Caltech/ IPAC August 26 – 27, 2024

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Could be a very short talk 😁 !

- HWO science and corresponding technical requirements have not yet been defined

- The Roman coronagraph TVAC results aimed to meet minimum requirements
  - Time-limited rather than performance-limited
  - In-flight results will differ from TVAC!

- Yet, we do have:
  - Knowledge of the Roman coronagraph elements (LOWFS, HOWFS, DMs, Masks, Detectors) and functionalities (Imaging, point source spectroscopy, polarimetry)
  - A reasonable idea of:
    - HWO's minimum requirements (HabEx and LUVOIR studies, 2020 Decadal Survey report, recent HWO-related JATIS papers: Mennesson et al. 2024, Stark et al. 2024)
    - CGI minimum expected performance (TVAC) and current best estimate of performance

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Answer needs regular updating as new information becomes available

ROMAN CORONAGRAPH

- Update 2020 community Whitepaper aiming to answer the same question before HWO recommendation and CGI TVAC results https://arxiv.org/pdf/2008.05624

Paving the Way to Future Missions: the Roman Space Telescope Coronagraph Technology Demonstration

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Abstract

This document summarizes how far the Nancy Grace Roman Space Telescope Coronagraph Instrument (Roman CGI) will go toward demonstrating high-contrast imaging and spectroscopic requirements for potential future exoplanet direct imaging missions, illustrated by the HabEx and LUVOIR concepts. The assessment is made for two levels of assumed CGI performance: (i) current best estimate ("CBE") as of August 2020, based on laboratory results and realistic end-to-end simulations with JPL-standard Model Uncertainty Factors (MUFs); (ii) CGI design specifications inherited from Phase B requirements. We find that the predicted performance (CBE) of many CGI subsystems compares favorably with the needs of future missions, despite providing more modest point source detection limits than future missions. This is essentially due to the challenging pupil of the Roman Space Telescope; this pupil pushes the coronagraph masks' sensitivities to misalignments to be commensurate with future missions. In particular, CGI will demonstrate active low-order wavefront control and photon counting capabilities at levels of performance either higher than, or comparable to, the needs of future missions.

CGI Top-level performance vs. HWO's notional needs

Comparison of CGI top-level characteristics (from TVAC and from CBE) to ***notional range*** of requirements envisioned for a ***visible*** HWO coronagraph

Top Level Characteristics	CGI TVAC	CGI CBE	HWO Range	Notes & Caveats
Inner Working Angle (in λ/D)	3	3	2 to 3	
Raw Contrast near IWA	~5 x 10^{-8}	10^{-8}	10^{-10} - 10^{-9}	Averaged [IWA; IWA + λ/D]
5σ Detection Limit at IWA	2.5 x 10^{-8}	5x10^{-9}	~10^{-10}	
Raw Contrast Stability* (1σ) at IWA	A few 10^{-9} over 5h (OS10)	2 x 10^{-9} (OS11)	~10^{-11} to a few 10^{-10}	HWO needs are TBD
Core Throughput at IWA	3% (DH max = 4.5%)	3% (DH max = 4.5%)	>~ 30%	HWO needs are TBD
Spectral Bandwidth	10%	10% to 15%	20%	
Spectral Resolution	50	50	> 100	R > 1,000 being explored
Planet Spectroscopic Capability	Slit Spectrograph	Slit Spectrograph	Multi-planet spectrograph (likely an IFS)	MOS ?
Aperture Type	Heavily obscured on-axis monolith	Heavily obscured on-axis monolith	Segmented off-axis or on-axis	
PM linear obscuration %	28	28	0 to ~10?	
F/#	1.3	1.3	2-2.5	
Con Ops		Ref/Tgt & Tgt rolls (+/-13 deg)	TBD	
Speckle subtraction (PP) Method	RDI/ ADI	RDI/ADI	RDI, ADI, SDI, CDI, PDI, WFS	HWO: many options open

CGI Subsystems characteristics vs. HWO's notional needs (I)

Subsystems	CGI TVAC	CGI CBE	HWO Range *(or HabEx/LUVOIR B)*	Notes & Caveats
Pointing Jitter Control	< 0.45 mas rms per axis	< 0.5 mas rms per axis	*~ 0.3 mas rms per axis*	Will depend on HWO coronagraph sensitivity to pointing jitter
LOWFSC: Defocus (pm rms)	12 (OS10 WFE(t) in TVAC, Joon Seo)	12 (OS11, Krist et al. 2023, MUF=2)	*7 to 1315*	Will depend on HWO coronagraph sensitivity to defocus
LOWFSC: Astigmatism (pm rms)	20 (OS10)	12 (OS11)	*14 to 157*	Will depend on HWO coronagraph sensitivity to astigmatism
LOWFSC: Coma (pm rms)	8 (OS10)	9 (OS11)	*8 to 94*	Will depend on HWO coronagraph sensitivity to coma
LOWFSC: Spherical (pm rms)	6 (OS10)	1 to 14 (OS11)	*4 to 76*	Will depend on HWO coronagraph sensitivity to spherical
HOWFSC (rms temporal drift of all Zernikes with n+|m| >=6)	$<2\times10^{-9}$ Δcontrast over 5 hours (OS10)	5 (OS11)	*< 5*	GITL every 30 min may also work for HWO for EFC. EFC iteration times dominated by probe time for the longest last iterations
DMs	2	2	>= 2 per TBD channels	Hwo Coronagraph may have several parallel observing simultaneously at different wavelengths and/or polarization states
DMs format	48x48	48x48	48x48 to 96x96	CGI uses 1 mm picth Xinetics AOX DMs
DMs Stroke Range (microns)	0.5	0.5	*> 0.5*	
DMs stroke resolution	7.5	7.5	*2*	
Nb of Dead Actuators	1 (on DM1)	1	TBD	CGI: impact of DM dead actuator(s) strongly depends on location

CGI Subsystems characteristics vs. HWO's notional needs (II)

Subsystems	CGI TVAC	CGI CBE	HWO Range *(or HabEx/LUVOIR B)*	Notes & Caveats
Coronagraph Masks	NFOV HLC WFOV SPC	NFOV HLC WFOV SPC SPEC SPC	To be selected. Likely higher throughput than HLC or SPC	Exact relevance to HWO will depdn on selected mask technology, but abiity to model, manufacture and characterize and meet tolerance
Precision Alignment Mechanisms Translation accuracy and repeatability in x,y	<2 microns	<2 microns	?	Met reqts in terms of resolution, range and translation precision. (2 um in x,y translation) was demonstrated
Detectors type	Photon counting EMCCD		EMCCD or CMOS or Skipper CCD, etc.	May even consider energy resolving detectors for HWO
Detectors format	1024	1024	*1024 to 2048*	
Read out noise* (e- rms/pix/read)	<0.1	< 0.1	*< 0.1*	Dependence on chosen EM gain.
Dark Current (e-/pix/s)	1×10^{-3} (185 K)	1.3×10^{-4}	*3×10^{-5} to 4×10^{-4}*	Strong function of EMCCD operating temperature. TVAC quoted value is 185 K. Reduces to 3.8×10^{-5} at 168 K.
CIC (e-/pix/frame)	8.8×10^{-3}	5×10^{-3}	*1.3×10^{-3} to 6×10^{-2}*	Function of EM gain. Quoted value is at 90 % detective quantum efficiency for photon counting mode, corresponding to a gain of ≈8000 for ExCam. CIC is reduced for lower EM gains.
Detector Lifetime	5 years	5 years	5 years minimum	CGI detectors and shielding designed and qualified for 5 years.

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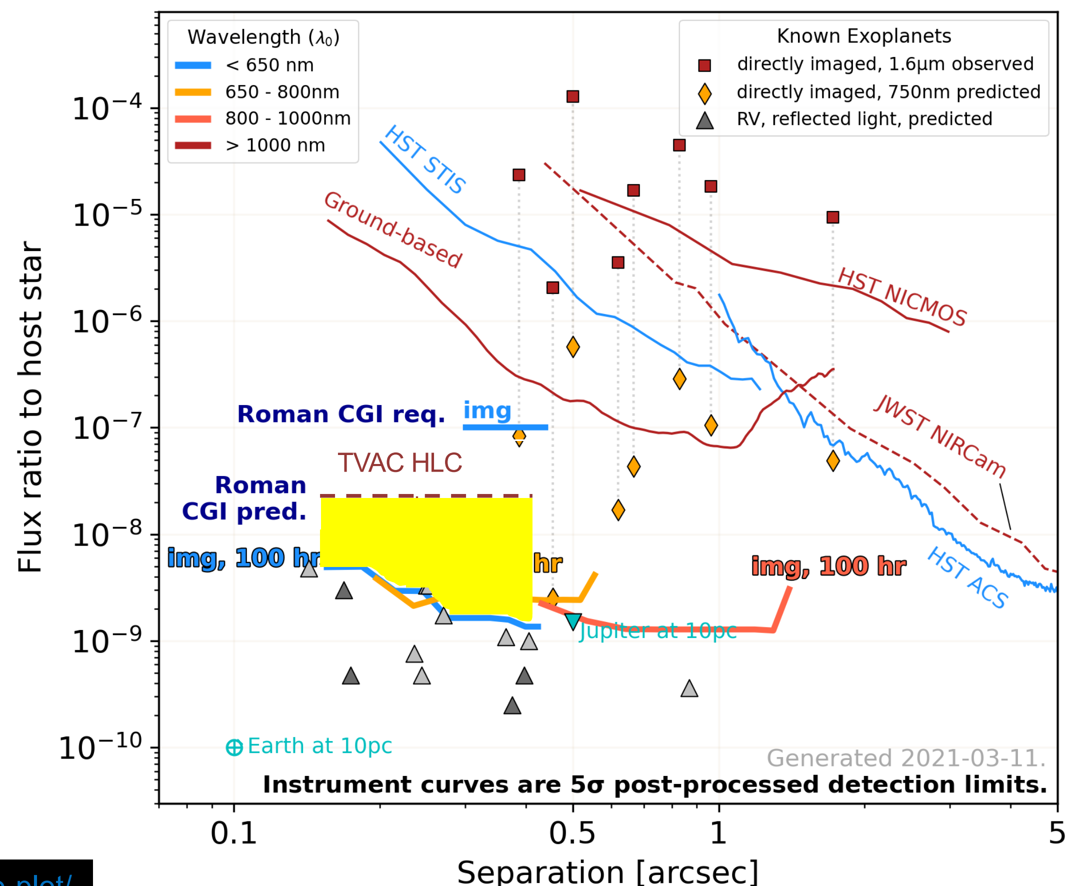
Predicted Detection Limit is 100-1000x Better than State-of-the-Art
Yet will barely skim the top of the exoplanet population around mature stars

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

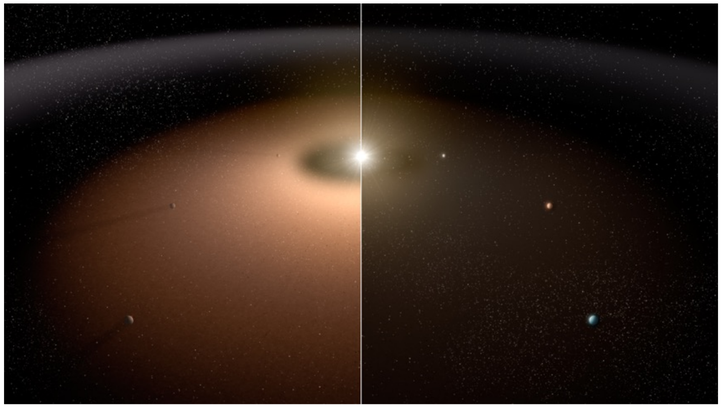


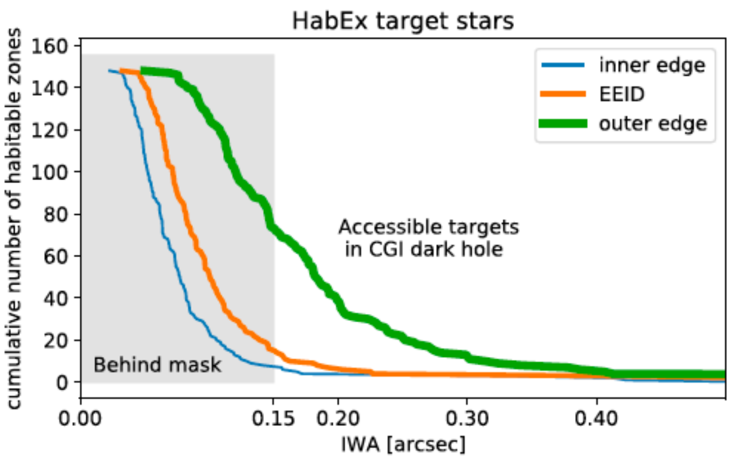
But a fantastic machine for producing the first images of exozodiacal dust around HWO targets at HWO wavelengths

- At better than 10^{-7} contrast, the Roman coronagraph will enter a new regime in disk physics, where structures are dominated by transport phenomena & disk-planet resonances rather than collisions

- The Roman coronagraph could probe low surface density disks (10-100 zodis) in the habitable zone of ~75 HWO sun-like targets in 1 month of *total* exposure time

- This will tell us how bigth exozodi light is in scattered light and how it may affect exo_earth characterization with HWO (Mennesson et al. 1997, 2010, 2018, 2019, Beichman et al. 1997, Defrere et al. 2010, Douglas et al. 2022)





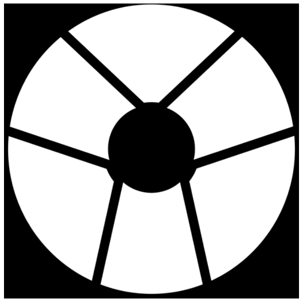
Conclusions

Cons:

- The ultimate planet-to-star flux ratio detection limit of the Roman coronagraph is typically 100x worse than needed by HWO (~10^{-8} vs ~10^{-10})
- This will only skim the top of the mature exoplanet population
- Roman's aperture is monolithic vs segmented primary considered for HWO.
- Roman coronagraph does not have an IFS

Pros:

- Many Roman coronagraph subsystems have expected performance in family with the ancitipated needs of HWO
  - E.g., pointing sensing and control, low-order wavefront sensing and control, braod-band imaging detectors
- Many functionalities in line with HWO anticipated needs
  - high-order wavefront sensing and control, precision optics and masks manufacturing, ultra-low noise photon couting detectors
- Will test speckles calibration methods applicable to HWO (ADI, RDI) in a relevant contrast regime (A,ϕ)
- Will provide unparalleled sensitivity to exozodi at HWO wavelengths, and the potential for a powerful exozodi survey (if TD performance confirms it and time available post TD).



"A pupil that only a mother could find beautiful"
David Spergel, circa 2015