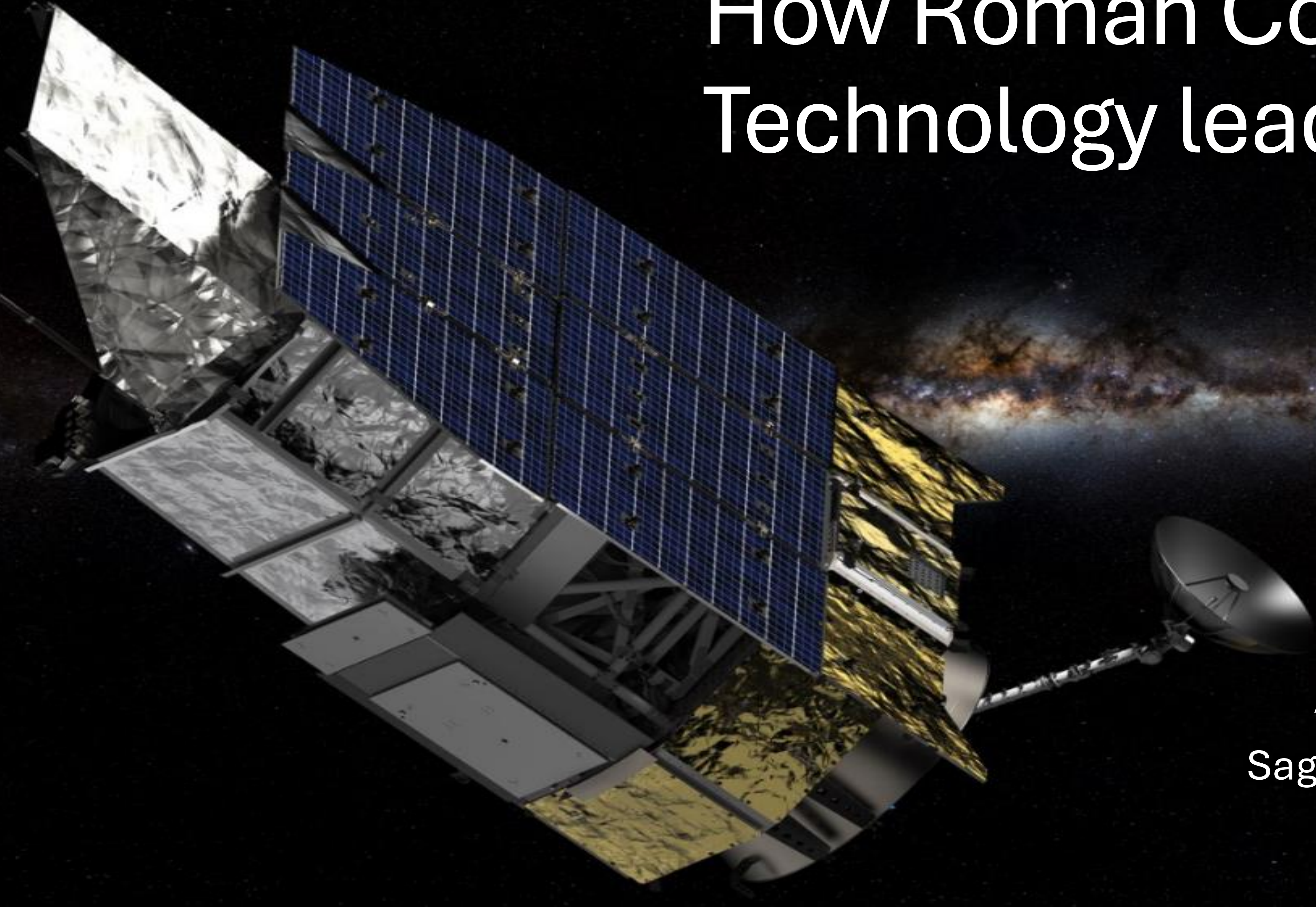
How Roman Coronagraph Technology leads to HWO



Alexandra Greenbaum

Sagan Summer Workshop

July 24, 2026

Nancy Grace Roman Envisioned Imaging Reflected Light Planets in Space

NASA's First Chief Astronomer, appointed 1959

1959 October THE ASTRONOMICAL JOURNAL

Roman, Nancy Grace. *Planets of other suns.*

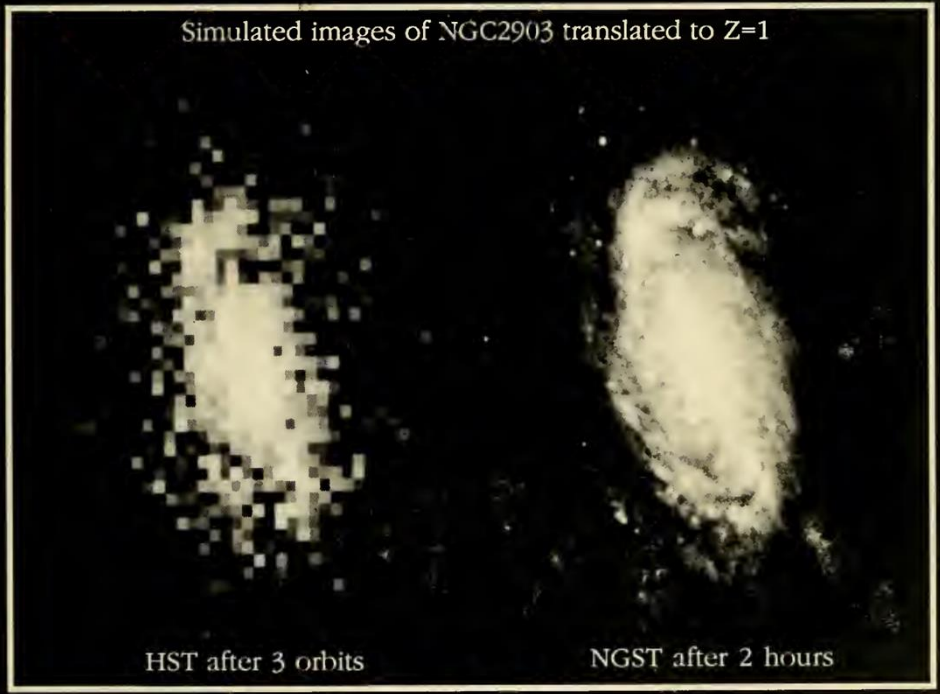
As seen from the distance of Alpha Centauri, Jupiter, at its maximum apparent separation from the sun, $3''.94$, would be a star of $23^{m}.4$ (assuming that its phase function is that of Venus); it would brighten to a maximum of $22^{m}.0$ at exterior conjunction. For Venus, Earth, Saturn, the maximum brightnesses and separations are, respectively: $22^{m}.5$ and $0''.55$, $23^{m}.4$ and $0''.76$, and $22^{m}.7$ and $7''.23$ (with the rings at moderate inclination).

Thus, a similar planetary system around Alpha Centauri would be within the reach of our largest telescopes and our current photoelectric techniques if our terrestrial atmosphere did not limit our resolution. At a separation of more than $2''$, it does not seem to be a serious problem to get rid of the light of the primary in the absence of an atmosphere.

NANCY GRACE ROMAN SPACE TELESCOPE

Image credit: NASA, ESA

THE NEXT GENERATION SPACE TELESCOPE



Proceedings of a Workshop held at the Space Telescope Science Institute Baltimore, Maryland, 13-15 September 1989

USE OF A 16 M TELESCOPE TO DETECT EARTHLIKE PLANETS

Roger Angel
Steward Observatory
University of Arizona
Tucson, AZ

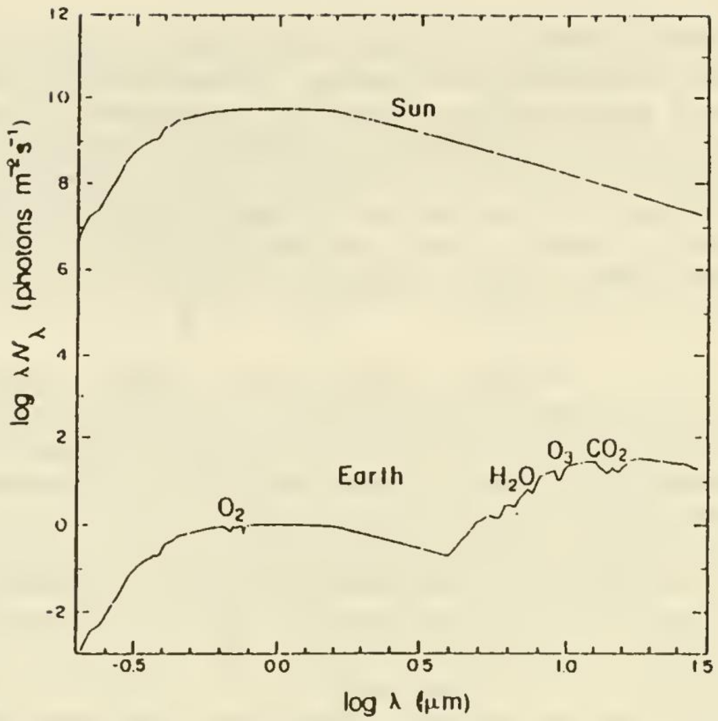


Figure 2 Fluxes of the sun and Earth as seen from 4 pc distance. From Angel, Cheng and Woolf, 1986.

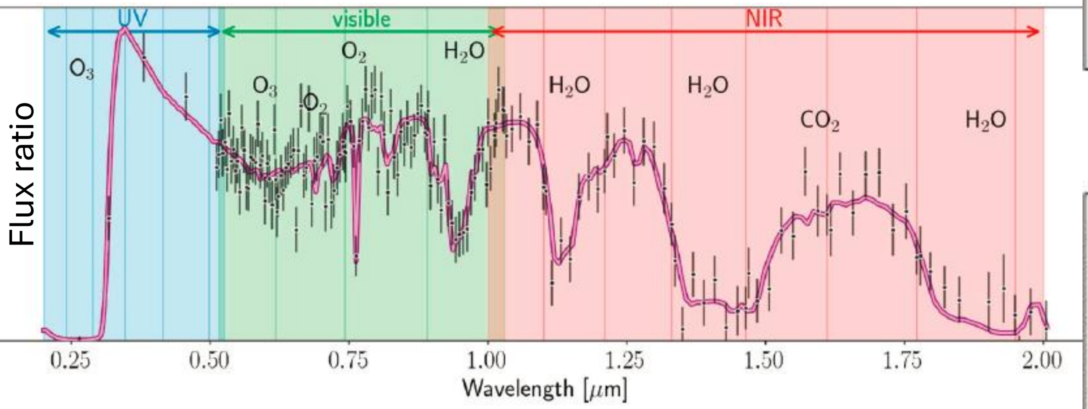

Voyager 1
February 14, 1990

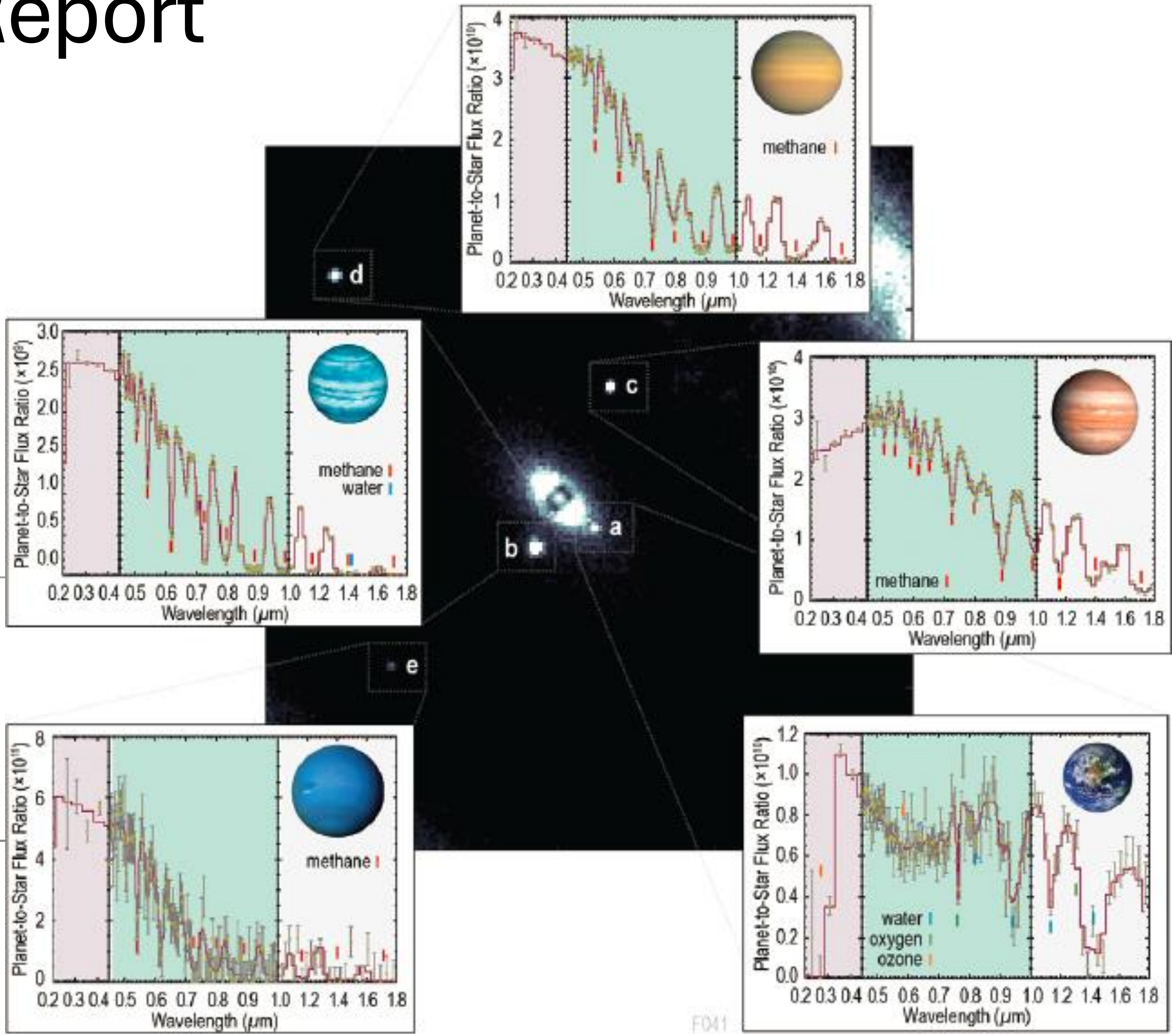
Astro2020 Decadal Report

SOURCE: NASA, HabEx report

“… priority recommendation in the frontier category for space is a large (~6 m diameter) **IR/O/UV telescope with high-contrast (10^{-10}) imaging and spectroscopy…”**

SOURCE: NASA LUVOIR report





National Academies of Sciences, Engineering, and Medicine. 2023. **Pathways to Discovery in Astronomy and Astrophysics for the 2020s**. Washington, DC: The National Academies Press. https://doi.org/10.17226/26141.

Imaging planets is hard

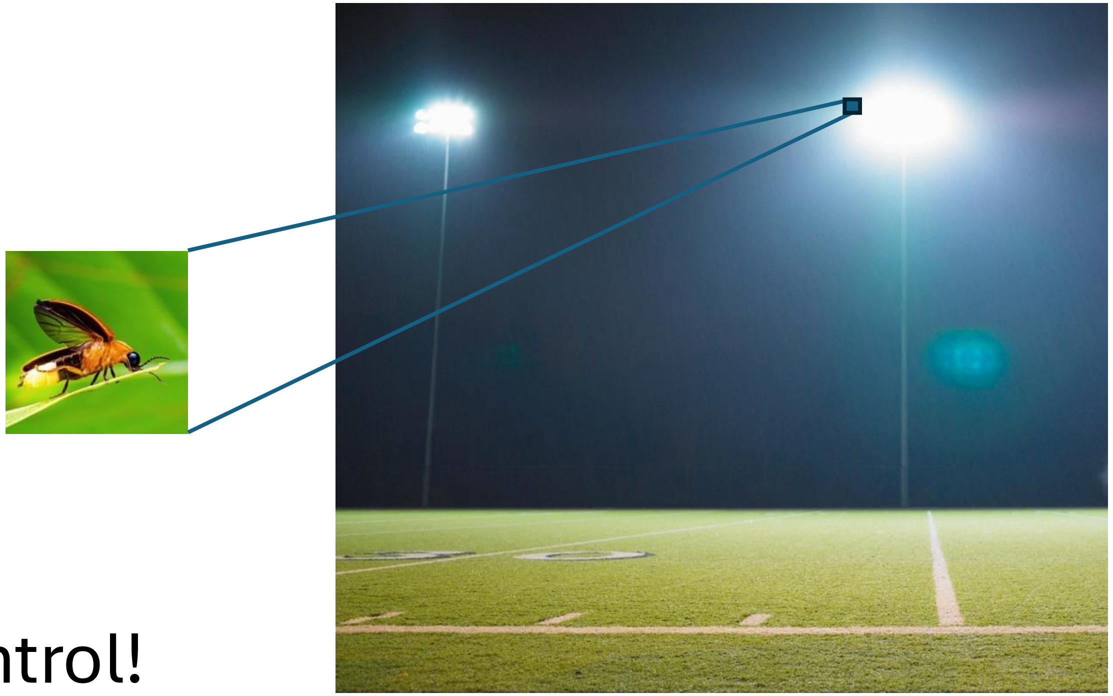
Consider young Jupiters, 1 million x fainter than their star

For typical solar system distances for a near-ish star:

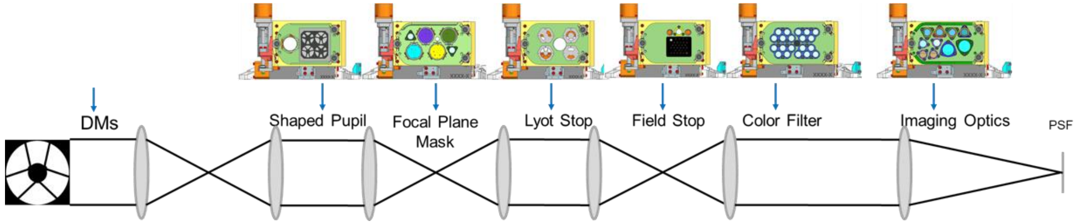
- ➢ Imaging a firefly next to floodlights from the next state over!

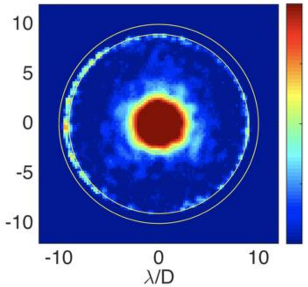
Earth-analogs are 10 billion times fainter than their parent stars in the visible!

Stadium lights



Solution: coronagraph and wavefront control!

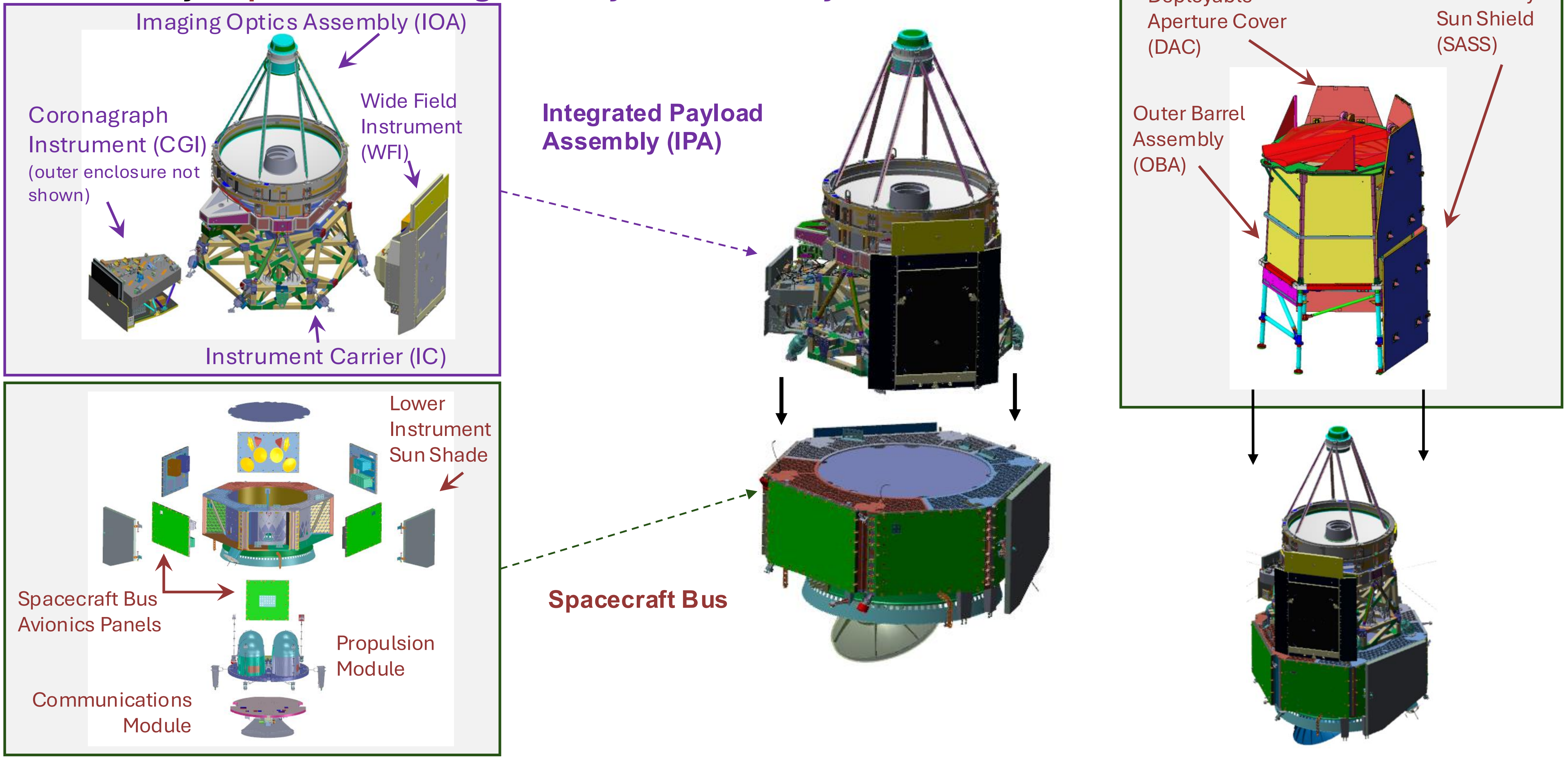




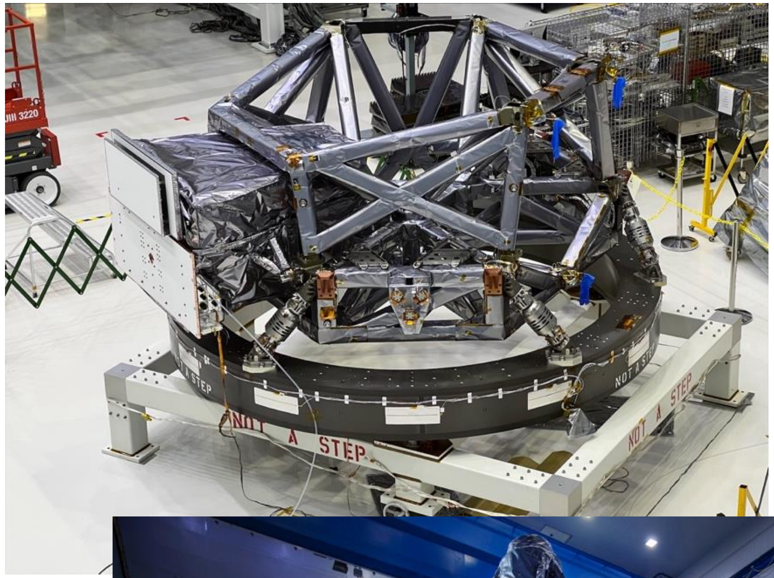
https://science.nasa.gov/astrophysics/programs/exep/technology/coronagraph-video/

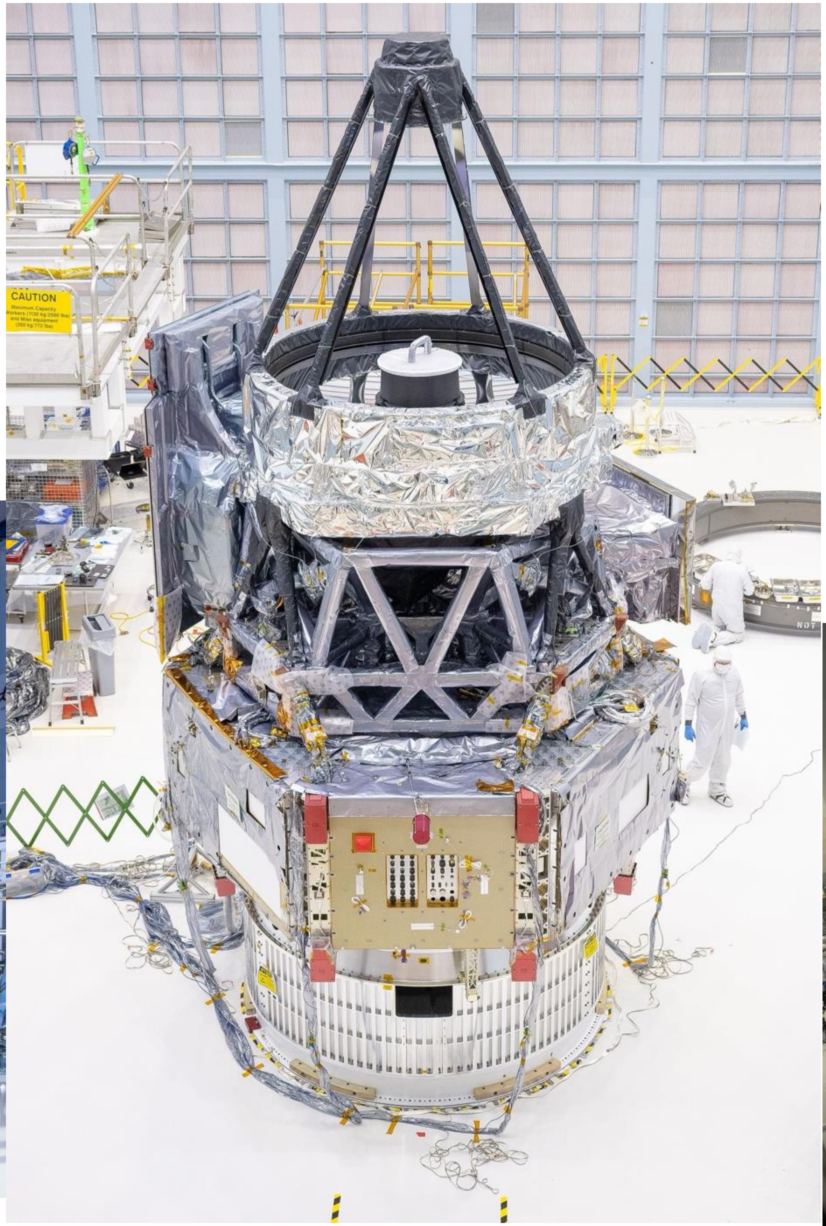
Roman Observatory

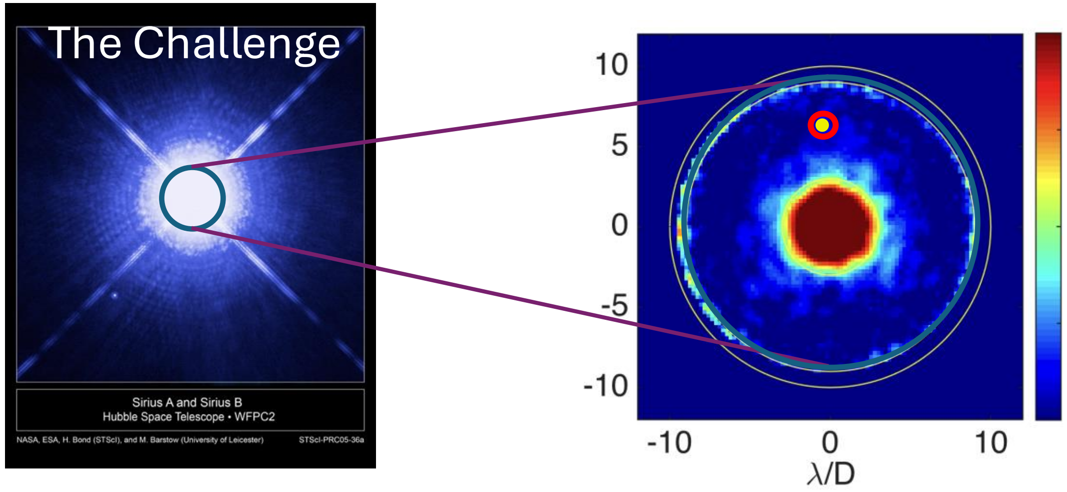
Observatory = Spacecraft + Integrated Payload Assembly

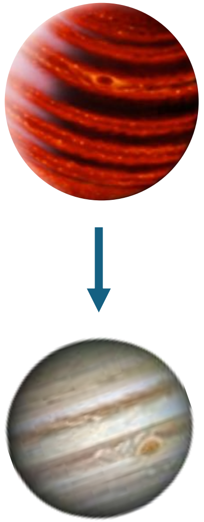


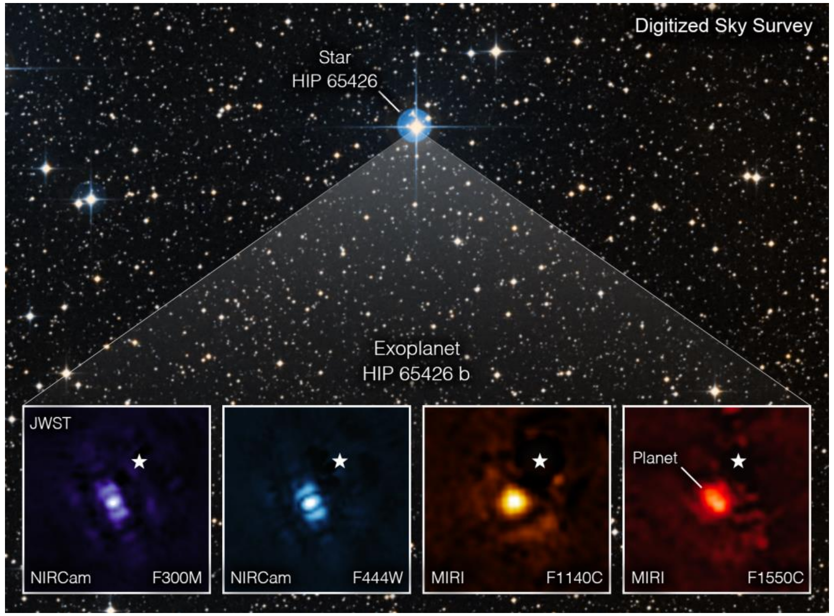
Roman Observatory









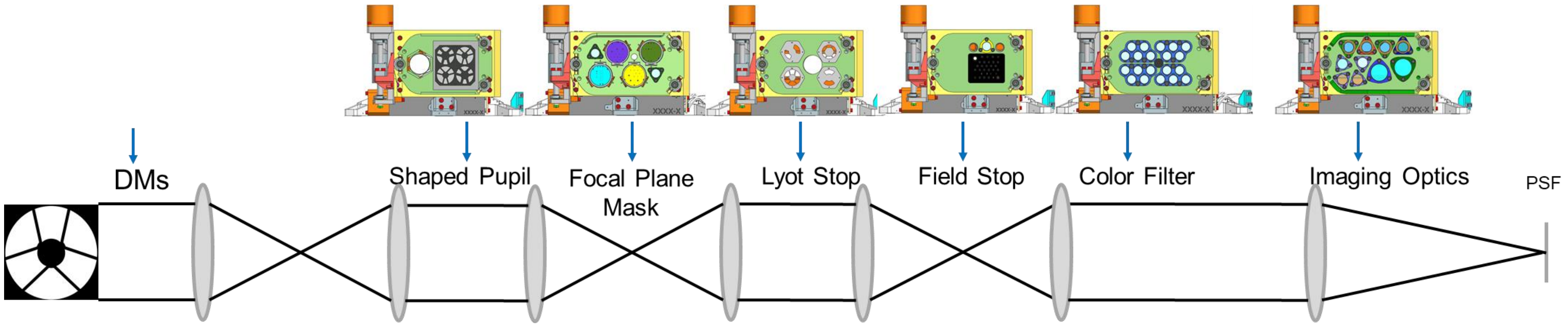


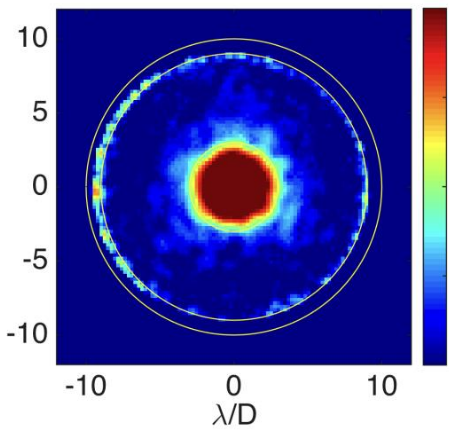
Credit: NASA/ESA/CSA, A Carter (UCSC), the ERS 1386 team, and A. Pagan (STScI)

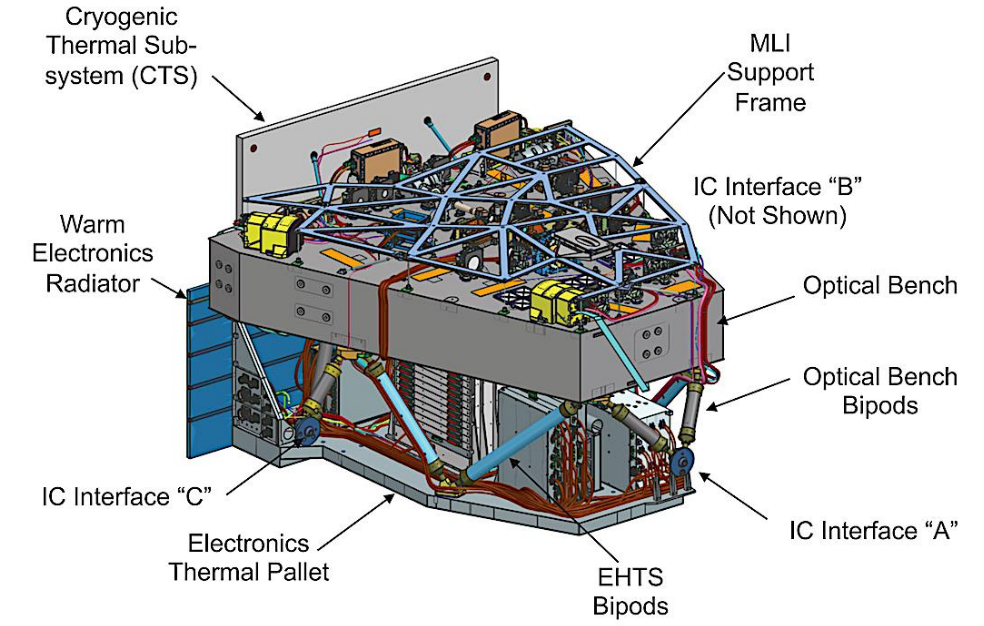
The Coronagraph Tech Demo

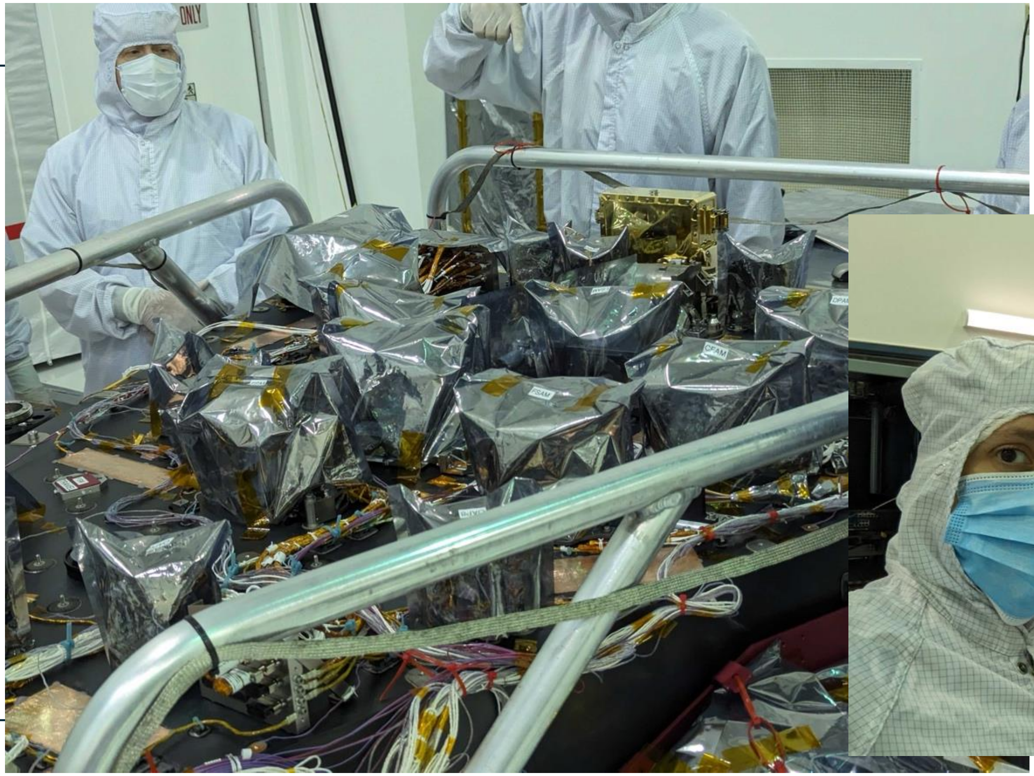
Paving the way towards imaging an Earth-like Planet around a Sun-like star

The Roman Coronagraph Instrument





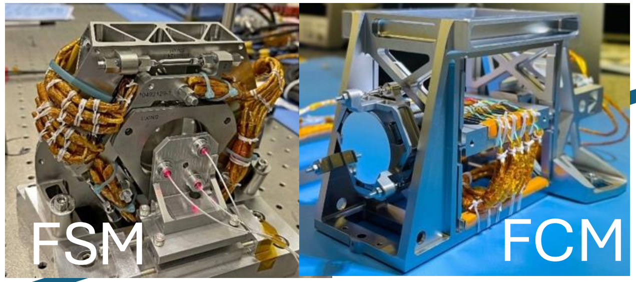




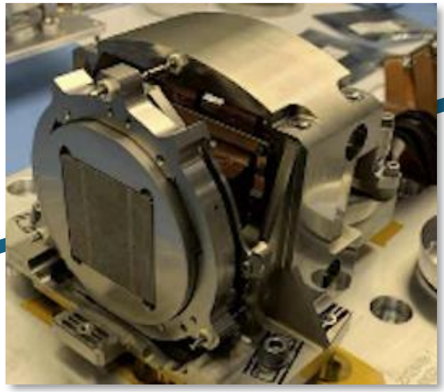
Critical Technologies

The Roman Coronagraph is an advanced technology demonstrator for NASA's future flagship mission that will directly image Earth-like exoplanets.

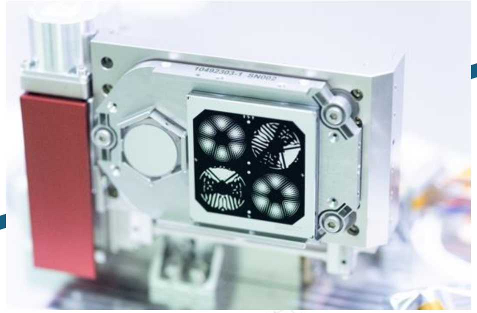
Ultra-Precise Wavefront Sensing & Control

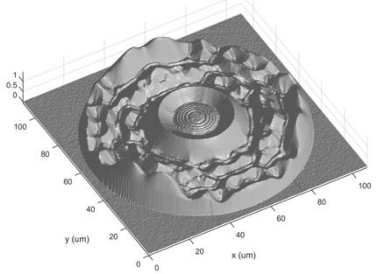


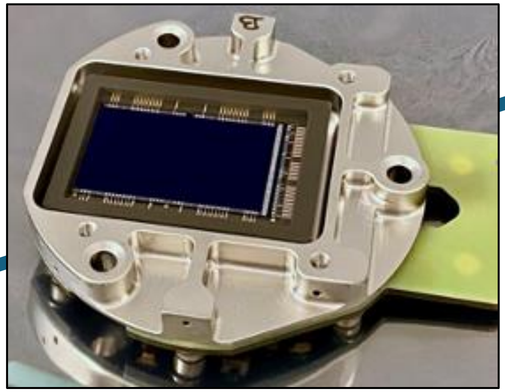
Large-format Deformable Mirrors



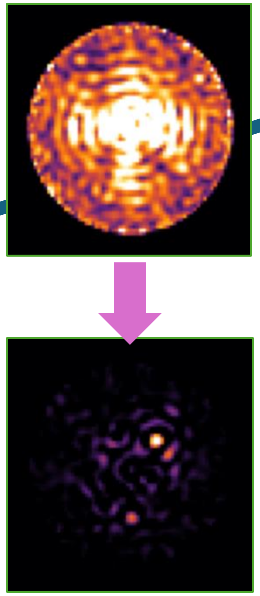
High-contrast Coronagraph Masks







Ultra-low noise photon-counting EMCCD Detectors



Data Post-Processing

The first space-based demo of tech needed to image and characterize rocky planets in the habitable zones of nearby stars.

Coronagraph Observing Modes

Band	λ_{center}	BW	Mode	FOV radius	FOV Coverage	Pol?	Coronagraph Mask Type	Support
1	**575 nm**	**10%**	**Narrow FOV Imaging**	**0.15” – 0.45”**	**360°**	**Y ****	**Hybrid Lyot**	**Req’d**
1	575 nm	10%	“Wide” FOV Imaging	0.45” – 1.4”	360°	Y	Hybrid Lyot	Best Effort
2	660 nm	17%	Slit + R~50 Prism Spectroscopy	0.17” – 0.52”	2 x 65°	-	Shaped Pupil	Best Effort
3	730 nm	17%	Slit + R~50 Prism Spectroscopy	0.18” – 0.55”	2 x 65°	-	Shaped Pupil	Best Effort
4	825 nm	11%	“Wide” FOV Imaging	0.45” – 1.4”	360°	Y	Shaped Pupil	Best Effort

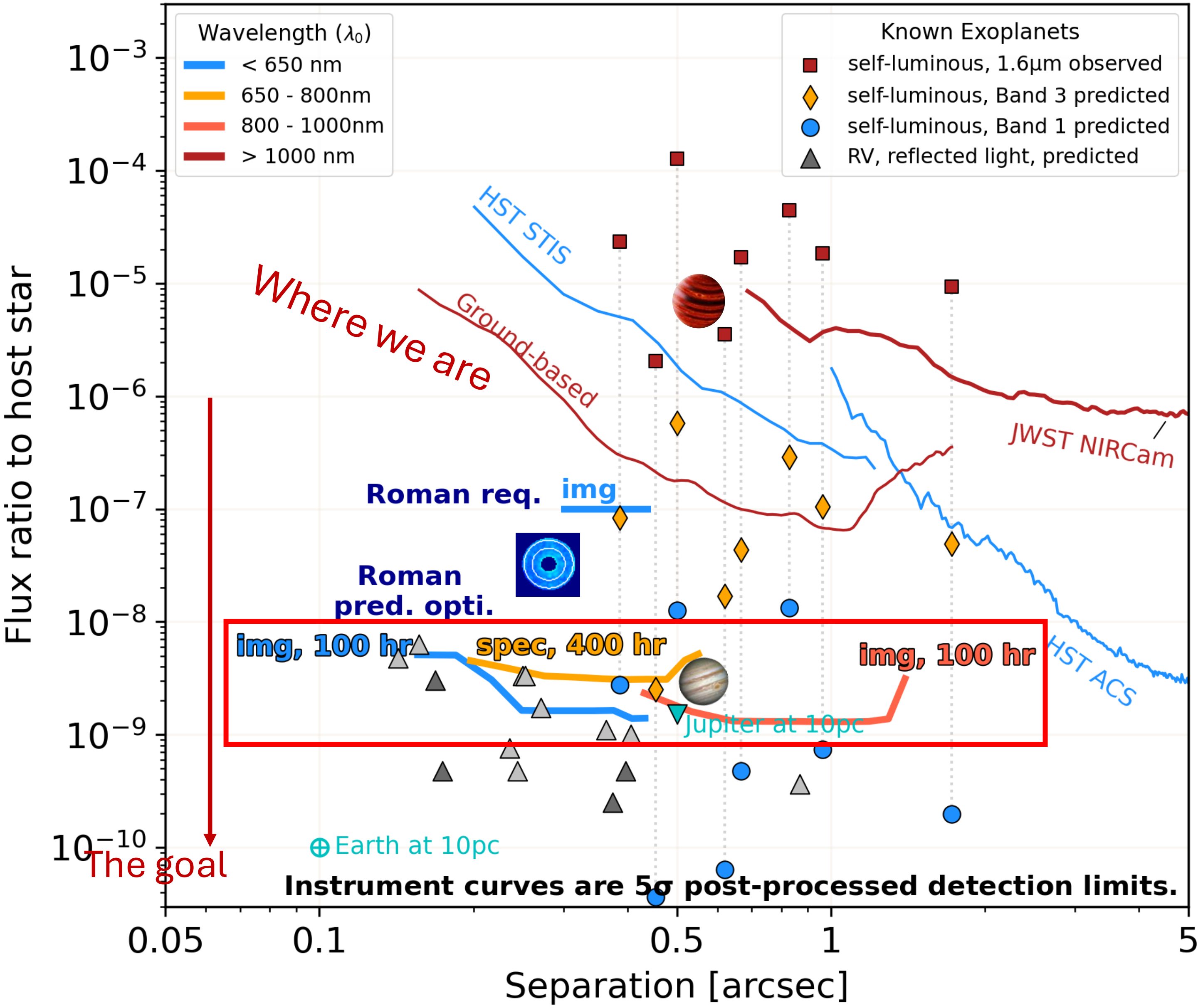
B1 HLC NFOV is fully supported, B4 imaging, spectroscopy & polarimetry are best effort
Even more contributed modes: see Riggs et al. 2025

Pathway to exo-earth imaging

TTR5 requirement: 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} ≤ 5, flux ratio ≥ 10^{-7}; bandpass shall have a central wavelength ≤ 600 nm and a bandwidth ≥ 10%.

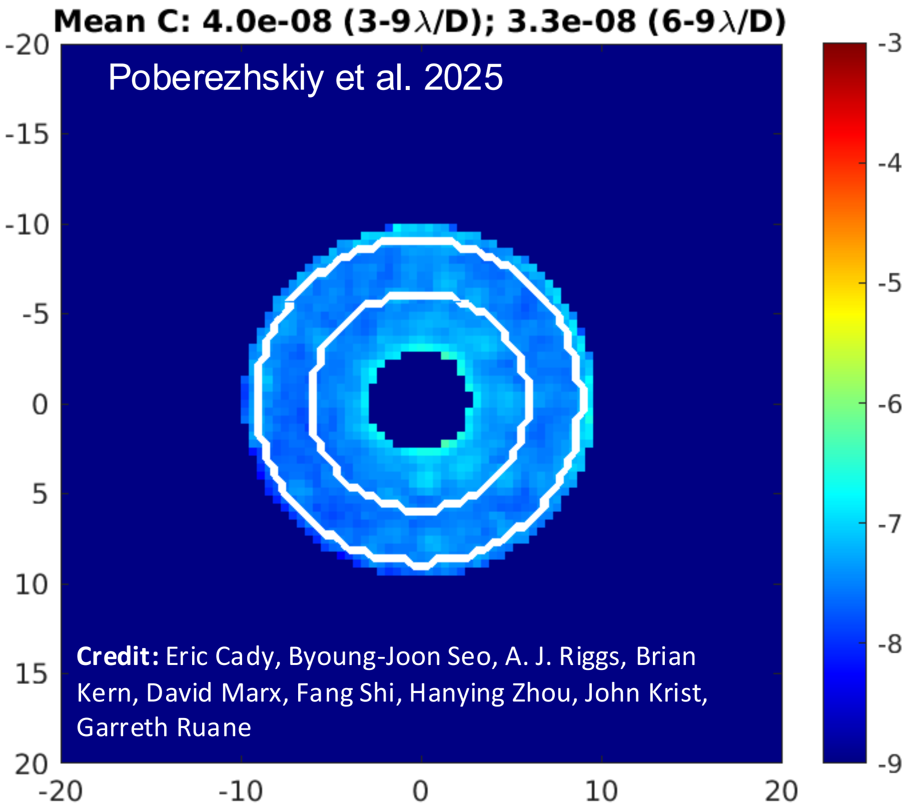
The Roman Coronagraph could take the first images of mature Jupiter analog **exoplanets** and circumstellar **disks** seen **in visible reflected starlight**

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



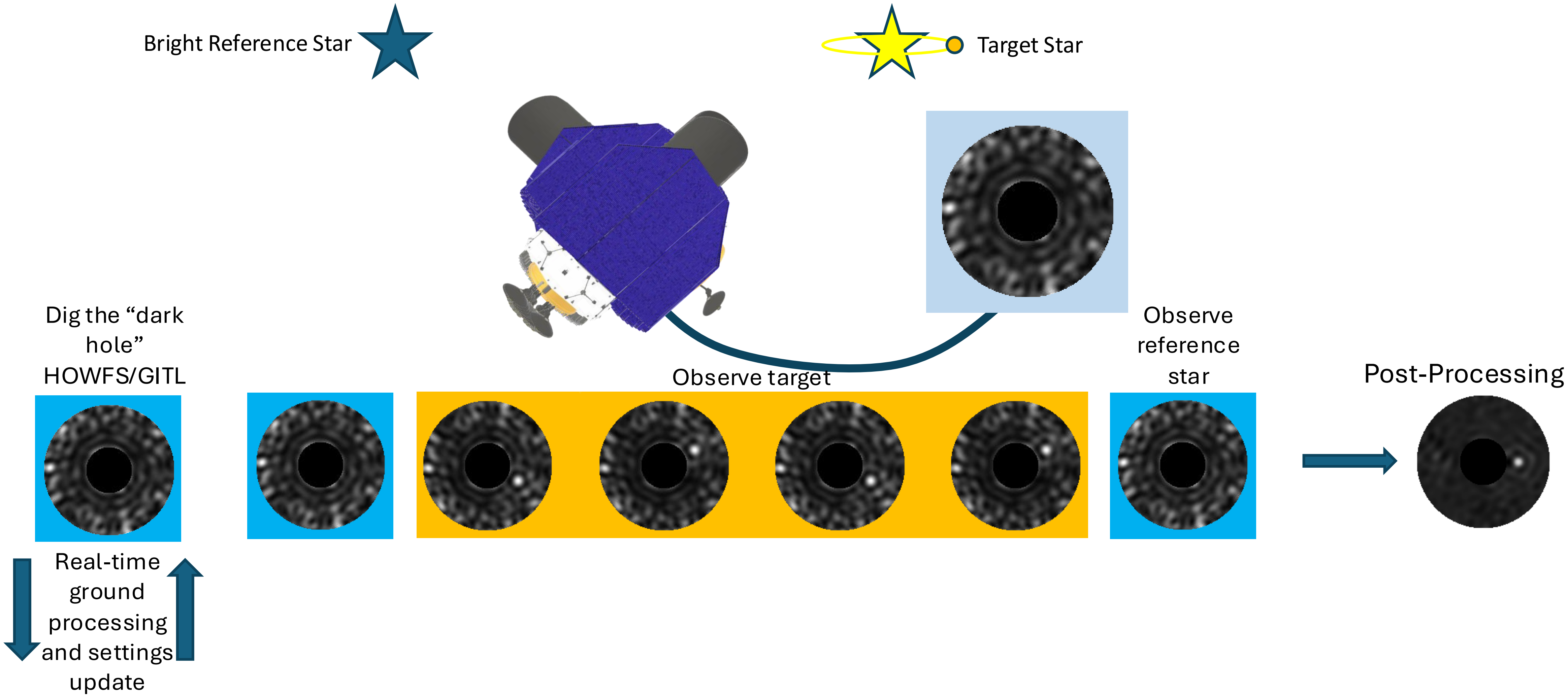
Roman Coronagraph Instrument Status

- First space-based coronagraph with active wavefront control
- **Requirement: 10^{-7} flux ratio 5σ detection limit in a single photometric band**
  - Designed to outperform requirement
  - Predicted performance ≥4x beyond req
- Delivered to GSFC on May 19, 2024
- Attached to SCIPA & S/C
- Completed Observatory TVAC + I&T
- Launch readiness date: Aug 2026



See JATIS special issue 2025

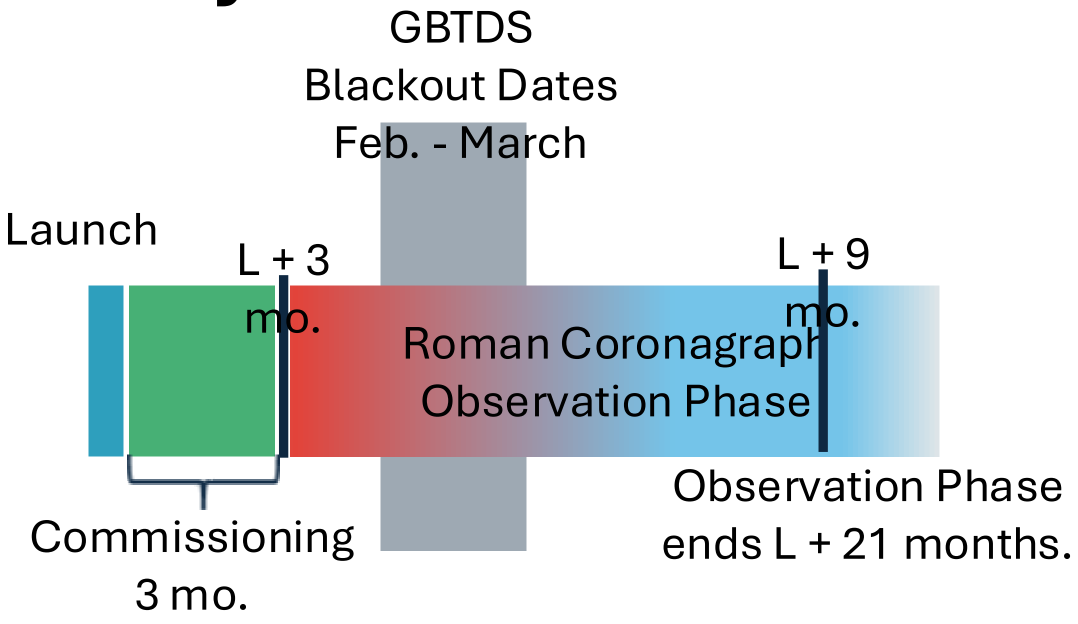
Observing Scenario

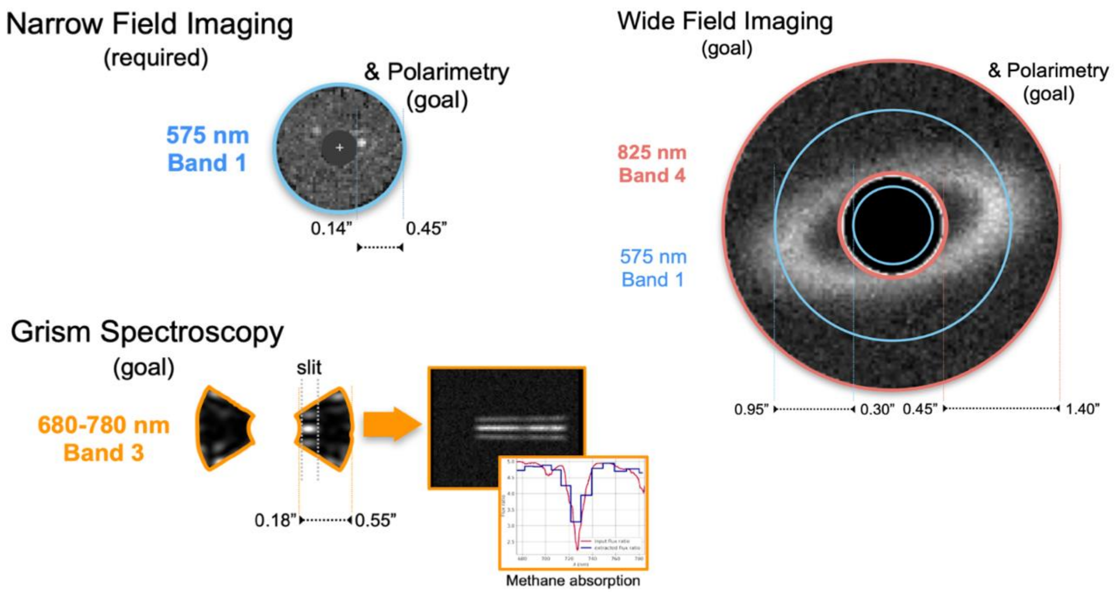


Many players – distributed ground system

- Instrument team & Coronagraph Technology Center at JPL
- Mission Operations Center at GSFC
- Science Support Center at IPAC
- Science Operation Center at STScI
- Project science
- Community Participation Program

Early *technical demonstration* goals in operations





- Check out baseline mode (HLC B1 NFOV), demonstrate TTR5
- Deep dark hole digging in HLC B1 & WFOV B1 polarimetry
- Wavefront sensing: probe with wollaston, different probes
- Check out goal modes (spectroscopy, polarimetry, WFOV)
- Understand faint star performance
- Screen reference stars (valuable for HWO too!)

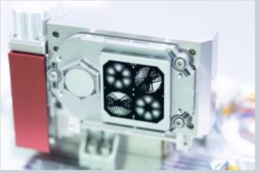
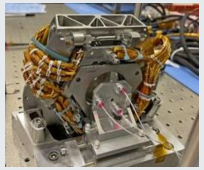
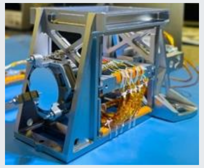
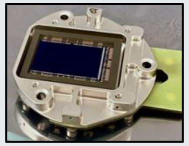
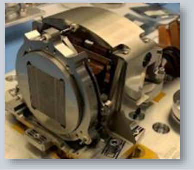
HWO technical challenges that Roman addresses

- Starlight suppression at small IWA
- Contrast stability
- Large format deformable mirrors
- Finite bandwidth
- Low noise detectors
- Spectroscopy & Polarimetry
- *Post-processing*

ID	Technology Lane	Estimated Current TRL	Gap Type
T1	Starlight Suppression	3-4	Tech
T2	Contrast Stabilization	3-5	Tech
T3	Deformable Mirrors	4	Tech
T4	Low-noise / Noiseless Detectors	3-4	Tech
E5	Spectroscopy	4	Eng
E6	Post-Processing	3-4	Eng
T7	Near-UV High-contrast Capability	2 / 4	Tech
T8	Ultra-stable Mirrors	4-5	Tech
E9	Ultra-stable Structures	4-5	Eng
E10	Thermal Control System	4	Eng
T11	Telescope Sensing & Control	3-4	Tech
T12	Low-Vibration & Pointing Control Systems	4	Tech
E13	Deployable Systems	3-5	Eng
T14	Far-UV Mirror Coatings	4	Tech
E15	Near-UV / Visible Detectors	4	Eng
E16	Far-UV Detectors	3-5	Eng
T17	Multi-Object Selection	3-5	Tech
E18	UV Gratings & Filters	4-6	Eng
T19	Cryogenic / Superconducting Detectors	N/A	Tech
T20	Quantum Sensors	N/A	Tech
T21	Meta Surfaces	N/A	Tech
T22	Photonic Integrated Circuits	N/A	Tech
T23	Artificial Intelligence / Machine Learning	N/A	Tech

Bolcar et al. 2026

Technology gap list – CGI sets state of the art

Technology	State of the Art	Needs
Contrast 	1.6×10-9 raw contrast at 10% bandwidth across angles of 3-9 λ/D (**Roman CGI** Lab Demos) with obstructed pupil	≤ 10-10 raw contrast, >30% core throughput, inner working angle ≤ 3 λ/D, 20% bandwidth; obscured/segmented pupil
Coronagraph stability  	**RST CGI** demonstrated ~10-8 contrast in a simulated dynamic environment using LOWFS (which obtained 12 pm focus sensitivity)	This stability is likely to require wavefront error stability at the level of 10-100 pm per control step (of order 10 minutes).
Integrated modeling	**RST CGI** IM demonstrated contrast in TVAC (TRL 6)	Automate/streamline integrated modeling
Detection Sensitivity (visible) 	**RST CGI** EMCCDs; low noise, photon counting	Similar sensitivity / noise requirements across, vis+NIR
Deformable mirrors 	**RST CGI** has 48x48 actuator DMs, surface quality does not limit contrast (1e-9)	96x96 actuator, surface quality does not limit contrast (1e-10)

https://assets.science.nasa.gov/content/dam/science/astro/programs/exep/technology/gap-lists/files/The_2024_Exoplanet_Exploration_Program_Technology_Gap_List_v2.pdf

How CGI compares to HWO concept studies

Parameter	CGI vs. Future Missions (FM) with unobscured apertures: HabEx & LUVOIR B
10σ Flux Ratio Detectable at 3 λ/D	10^{-8} vs 10^{-10} Roman Space telescope Pupil is challenging
Wavefront error sources	Comparable Phase & "new physics" (amplitude and polarization)
Pointing Jitter Control	Comparable CGI lab: ~ 0.35 mas rms V=5 star, CBE = 0.49 mas rms FM: 0.3mas NTE*
Low-order Control	~ 100x better than required for HabEx better than LUVOIR needs Complex Roman Space Telescope pupil: trading low-order sensitivity for overall throughput
High-order drift	Comparable (~5pm) CGI: 1σ prediction** FM: NTE*
# of DMs	Same (2)
DM Stroke Resolution	~4X worse (7.5pm vs 2pm) Engineering problem, not physics problem
DM Actuator Count	48x48 vs 64x64
EMCCD	Comparable at V-band Bit better: dark current, clock-induced charge Bit worse: QE at UV/red at 5 years (rad hard)

Top Level Characteristics	CGI (CBEs)	CGI (Design Specifications)
Inner Working Angle (in lambda/D)	3 NFOV @ 575 nm SPEC @ 730 nm	4 NFOV @ 575 nm SPEC @ 730 nm
Flux Ratio Detection Limit at IWA	10^{-8} (10σ)	5 x 10^{-8} (10σ)
Spectral Bandwidth	10% (NFOV) - 15% (SPEC)	10% (NFOV) - 15% (SPEC)
Spectral Resolution	50 (SPEC)	50 (SPEC)
Multiplanet Spectroscopy Capability	No	No
Polarimetric Capability	Yes 4 linear states, 2 at a time	Yes 4 linear states, 2 at a time
Low Flux Detection at 500 - 900nm		
Photon counting	Y	Y
Detector Format	1024 x 1024 (imaging and spectroscopy)	1024 x 1024 (imaging and spectroscopy)
dQE at 550nm	0.50	> 0.47
Read-out-noise (amplified read noise divided by gain, in e- rms/ pix /read)	0.015	< 0.02
Dark Current (e-/pix/s)	1.3x 10-4	< 5.2 x 10-4
Clock-induced Charge (e-/pix/read)	5.00E-03	< 0.01
Lifetime at specified detector parameters	5 years	> 21 months
Minimum point source flux detectable per PSF core (e-/s)	0.14 (NFOV around 575 nm) 0.027 (SPEC around 730 nm)	< 0.3 (NFOV around 575 nm) < 0.04 (SPEC around 730 nm)

Mennesson et al. 2020 https://arxiv.org/pdf/2008.05624.pdf

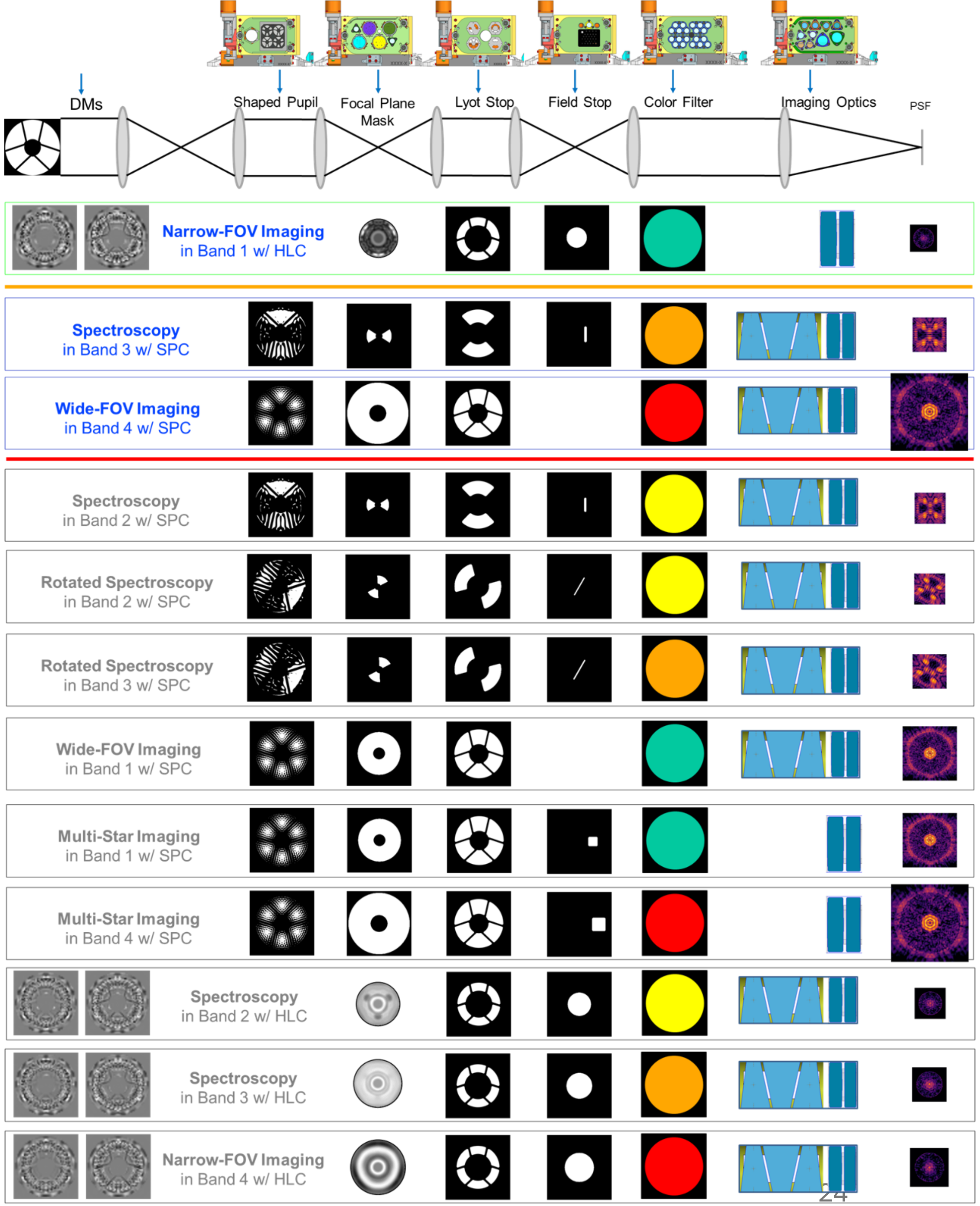
Habitable Worlds Observatory
Simulated Solar System Time-lapse
Observed from 33 light-years away
Time = 10 years, 1 second = 72 days

Credit: R. Juanola Parramon, N. Zimmerman, A. Roberge (NASA GSFC)
See https://habitableworldsobservatory.org/technology

Additional (backup)

Contributed modes include

- **High order ZWFS**
- **Multi-star demo**
- *SPC & HLC orientations & filter combinations*
- *Classical Lyot coronagraphs*



See Riggs et al. 2025

Not shown: low-contrast classical coronagraph ‘contributed modes’