

# HABITABLE WORLDS OBSERVATORY

## *TECHNOLOGY ROADMAPS*

*2025 January 16*

*245<sup>th</sup> Meeting of the AAS*

*Habitable Worlds Observatory Splinter Session*

*Matthew R. Bolcar (GSFC) & Feng Zhao (JPL)*

*HWO Chief Technologists*

H A B I T A B L E  
W  R L D S  
O B S E R V A T O R Y

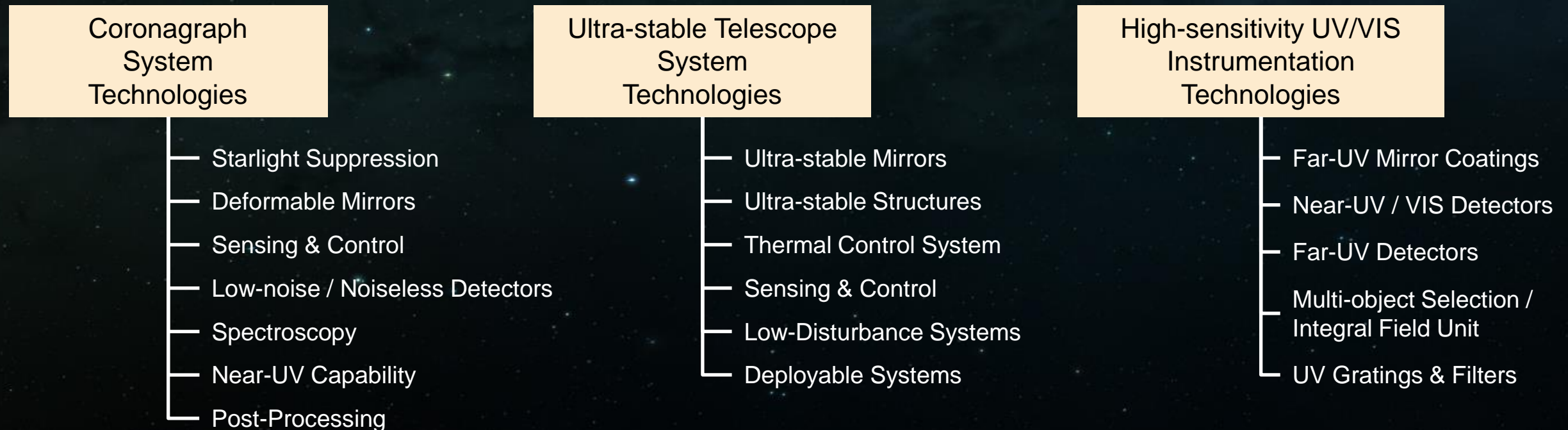
# OBJECTIVES

1. Identify technology, engineering, modeling, and facility/testbed gaps associated with the formulation and implementation of the Habitable Worlds Observatory.
2. Define roadmaps, milestones, and success criteria for the development of technologies and capabilities to close the identified gaps.
3. Scope the cost, schedule, and human resources needed to implement the roadmaps to achieve TRL 5 by March 2029, ahead of Mission Concept Review (MCR).
4. Execute the roadmaps.

# ORGANIZATION

The HWO Technology Plan is organized along three *tracks*:

Each track is further divided into *lanes* associated with specific technology components or capabilities



# GAP IDENTIFICATION & PRIORITIZATION

Gaps are classified as **Technology, Engineering, Modeling or Testbed / Facility**

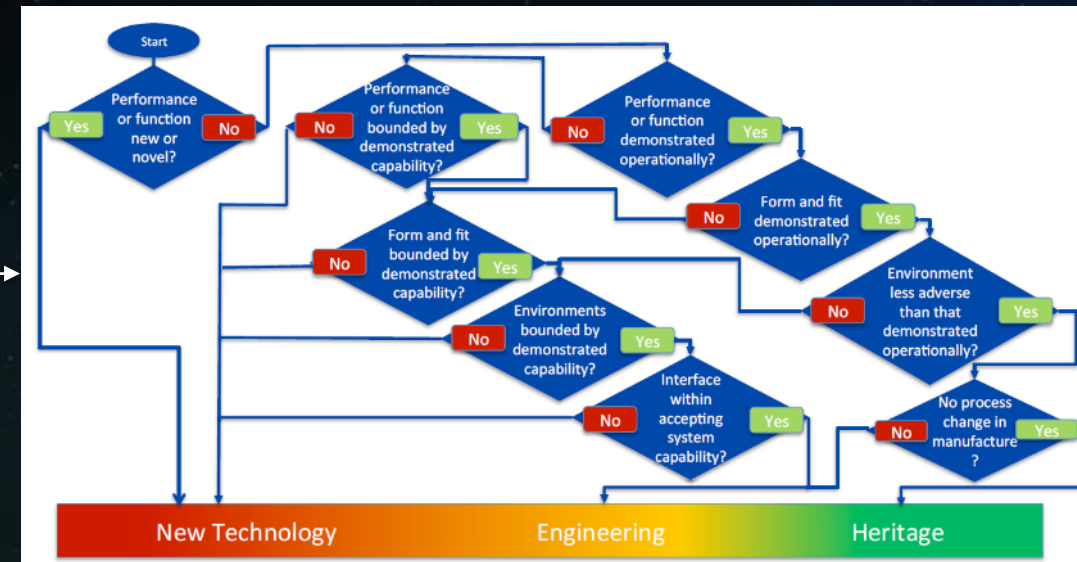
**Modeling Gaps** capture computational, software, or analytical capabilities needed to adequately verify & validate an element's performance.

**Testbed / Facility Gaps** capture capabilities needed to support the development of a critical technology element or improve the manufacturability, testability, yield, or reliability of an element.

Gaps are then prioritized based on **Importance** and **Urgency**:

**Importance** gauges how enabling the technology is for HWO.

**Urgency** gauges impact to critical path or mission design.



SP-20205003605: Technology Readiness Assessment Best Practices Guide

<b>Urgency</b>	Critical	6	3	1
	Urgent	8	4	2
	Long Term	9	7	5
		Enhancing	Baseline	Threshold
		<b>Importance</b>		

# CURRENT GAPS – CORONAGRAPH SYSTEM

## 1. Starlight Suppression (TRL ~3-4)

Overall ability to achieve desired raw contrast, bandwidth, inner working angle, etc.

## 2. Deformable Mirrors (TRL ~4)

High actuator count; stable smooth surface; robust, precision electronics and interconnects

## 3. Coronagraph Sensing & Control (TRL ~3-5)

Achieve and maintain contrast stability during observations

## 4. Low-noise/Noiseless Detectors (TRL ~3-4)

Photon-counting, low-noise, rad-hard capability with high QE at biomarker wavelengths

## 5. Spectroscopy (TRL ~3-4)

Resolve questions about speckle chromaticity; achieve desired R for key biomarkers

## 6. Near-UV Capability (TRL ~2)

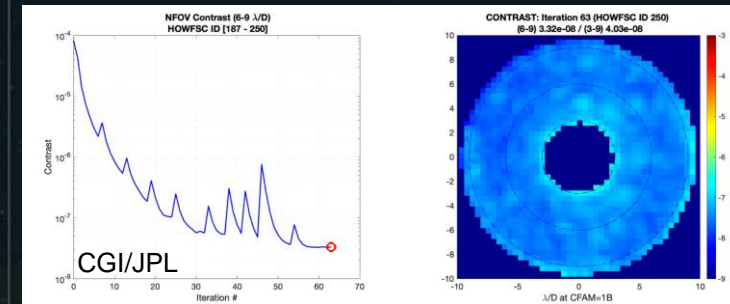
Achieve high contrast between 250-450 nm for key ozone features

## 7. Post-processing (TRL ~3-4)

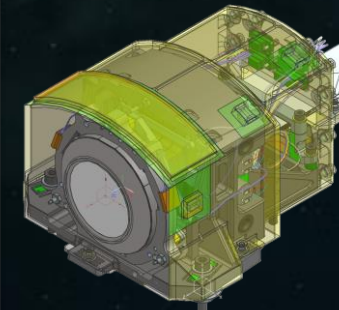
Achieve desired SNR in context of observatory stability and sensing & control

## State-of-the-Art: Roman CGI

		1,3
6		2,4,7
		5



4.0e-8  
Raw Contrast  
3-9 λ/D



48x48 DM

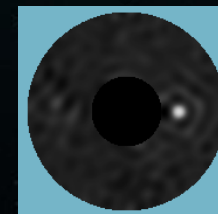
Measurement	Requirement	ExCam
Read Noise (e <sup>-</sup> )	200	108
Image Area Full Well Capacity (ke <sup>-</sup> )	50	78
Serial Register Full Well Capacity (ke <sup>-</sup> )	90	105
Parallel Charge Transfer Inefficiency	< 5x10 <sup>-5</sup>	1.29 x 10 <sup>-6</sup>
Serial Charge Transfer Inefficiency	< 5x10 <sup>-5</sup>	1.45 x 10 <sup>-5</sup>
Thermal Dark Current 188 K (e <sup>-</sup> /pix/hr) (req. applies to 95 % of pixels at BOL)	< 1.65	1.65
Average Thermal Dark current (188 K) e <sup>-</sup> /pix/hr	--	1.11
Unity Gain Non-linearity (%)	< 4	< 0.5
Clock Induced Charge e <sup>-</sup> /pix/frame	0.01	0.0129

CGI/JPL

Ref Star    Target Star    Target Star - roll



CGI/JPL



**Con-ops and Post Processing:**  
Reference Differential Imaging (RDI)  
→ FRN = 3.94x10<sup>-9</sup>  
(Courtesy of B. Kern)

# CURRENT GAPS – ULTRA-STABLE TELESCOPE

		8, 11
		9, 10
		12, 13

## 8. Ultra-stable Mirrors (TRL ~4-5)

Mirror cell that meeting required stability and optical performance

## 9. Ultra-stable Structures (TRL ~4-5)

Composites and joints with low creep and high-stiffness

## 10. Thermal Control System (TRL ~4)

Milli-kelvin control with compact Flight electronics, low-vibe thermal control systems

## 11. Telescope Sensing & Control (TRL ~3-4)

Sense and control segment-level and global telescope alignment at picometer level

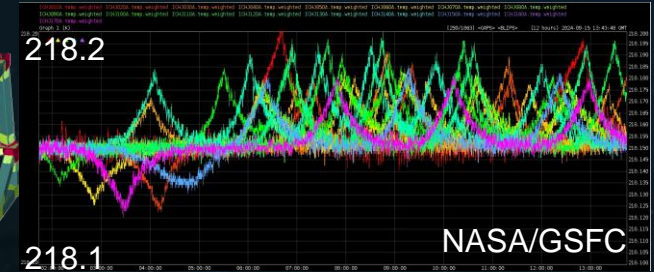
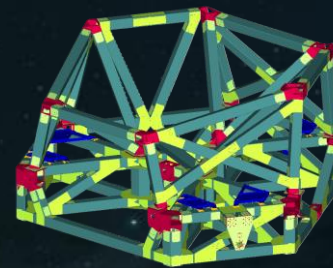
## 12. Low-disturbance Systems (TRL ~4)

Active and passive isolation, Microthrusters, and low-disturbance mechanisms

## 13. Deployable Systems (TRL ~3)

Large deployable baffle, stable hinge and latch systems

## State-of-the-Art: JWST, Roman

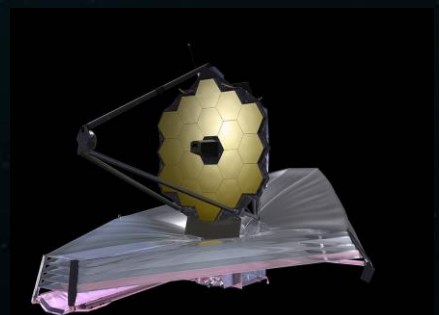


Roman Instrument Carrier achieves 10 mk stability



L3Harris

Roman Telescope thermal vacuum test results consistent with 10s of pm wavefront error stability.



JWST continues to exhibit extraordinary on-orbit passive stability.

# CURRENT GAPS – HIGH-SENSITIVITY UV/VIS INSTRUMENTS

	15, 16, 17	14
	18	

## 14. Far-UV Mirror Coatings (TRL ~3-5)

Broadband with high reflectivity down to 100 nm; high-uniformity and low scattering

## 15. Near UV/VIS Detectors (TRL ~4)

Large format, low noise, high-QE

## 16. Far-UV Detectors (TRL ~4-5)

Large format and high-QE, with high solar-blindness

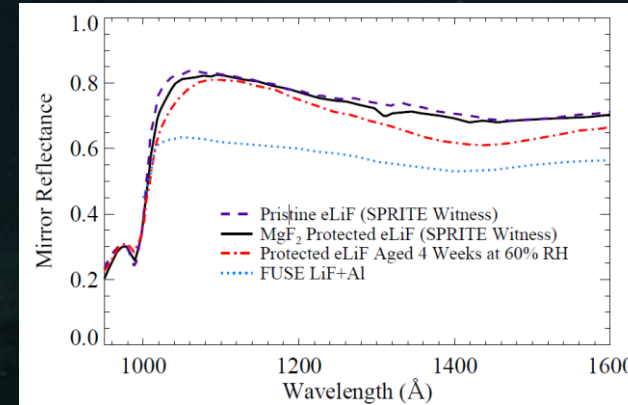
## 17. Multi-object Selection (TRL ~3-5)

Microshutters, micro-mirrors, or slicers for multi-object or integral field spectroscopy

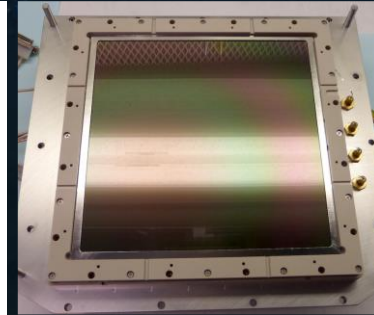
## 18. UV Gratings and Filters (TRL ~4-6)

High out-of-band rejection; curved substrates for aberration control

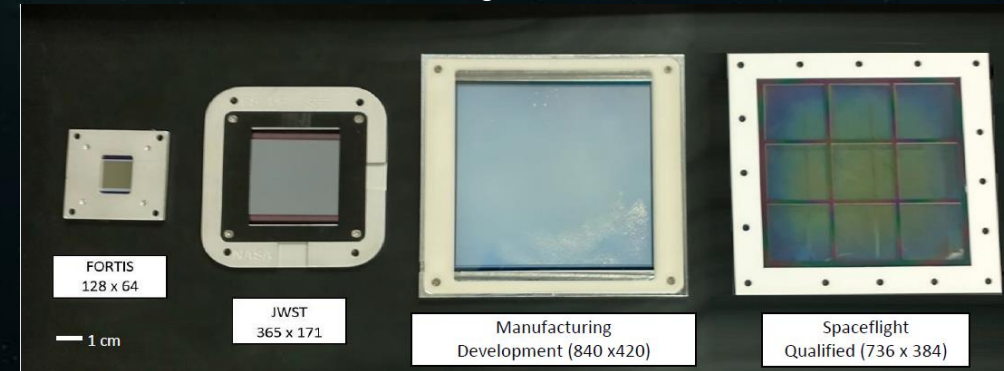
**State-of-the-Art:  
Sub-orbital & Lab**



SPRITE mirror coating



20x20 cm MCP for DEUCE



FORTIS & JWST microshutters (left) with next gen devices (right)

See: Tuttle, et al. 2024 for comprehensive review of state-of-the-art.



2025

Coronagraph Testbeds Available For Use

Keck Sensing & Control Demo

Ultra-stable & System Testbeds Available For Use

Critical Technology Demonstration Milestone

## Ultra-stable Telescope System



## Coronagraph System



Near-UV Coronagraph Science & Technology Investigation

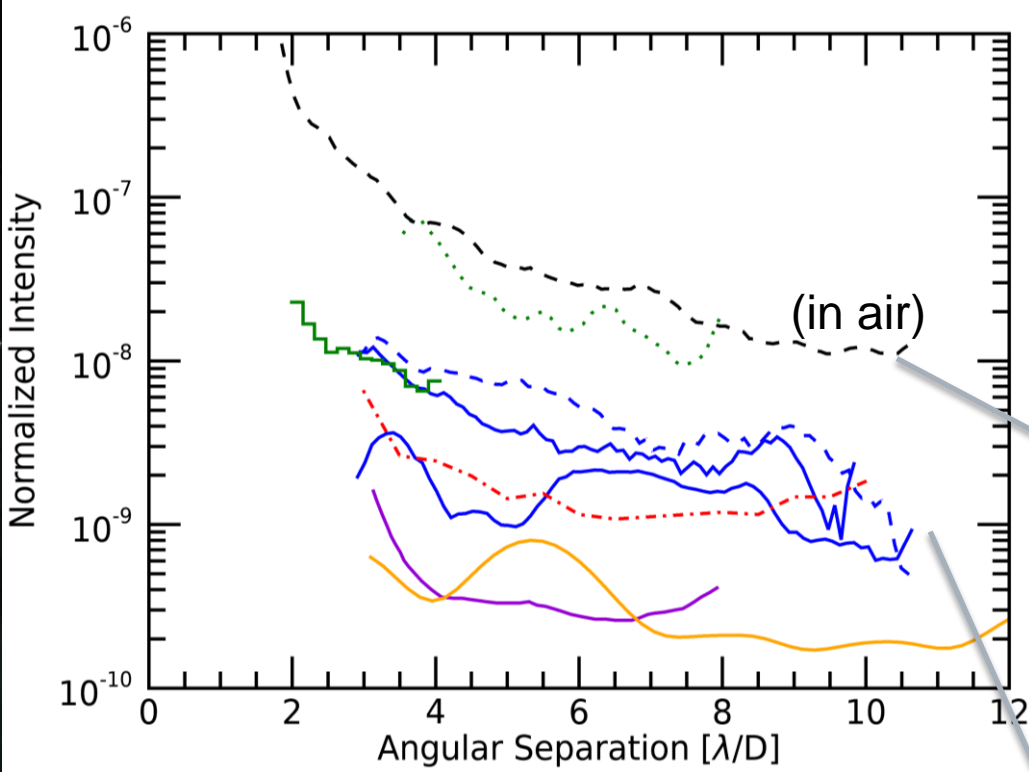
Currently Funded	Development / Fabrication
Design and Analysis	Characterization / Demonstration

## High-Sensitivity UV & Instrument Technologies



# RECENT TECHNOLOGY ADVANCEMENT \*HIGHLIGHTS\*

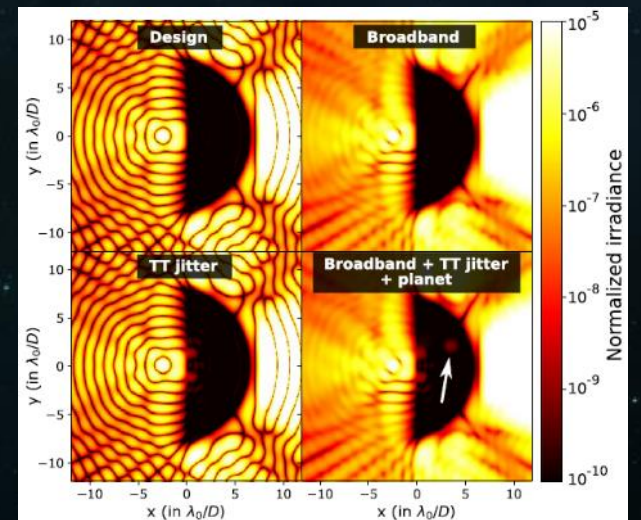
# STARLIGHT SUPPRESSION – LAB RESULTS



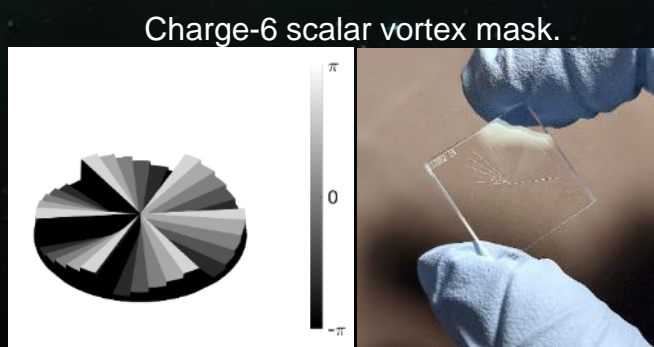
- PAPLC off-axis segmented 1DM (in air)
- ..... PIAACMC on-axis segmented 1DM
- PIAA off-axis monolith 1DM
- - - VVC4 off-axis segmented 1DM
- VVC4 off-axis monolith 1DM (above)
- VVC4 off-axis monolith 2DMs (below)
- . - CGI HLC on-axis monolith 2DMs
- HLC off-axis monolith 1DM
- CLC off-axis monolith 2DMs

Menesson, et al. *JATIS*, 2024

PAPLC design trades broadband dark hole with half-plane coverage.



PAPLC contrast maps [Por et al. 2020]



Scalar vortex will have similar performance as vector vortex, without requiring additional polarization optics.

Simulation results indicate raw contrasts better than 1e-10 with 20% bandpass at 2 λ/D.

# ULTRA-STABLE SYSTEMS

In early 2024, three industry teams were selected under FY23 ROSES Appendix D.19 “Critical Technologies for Large Telescopes”

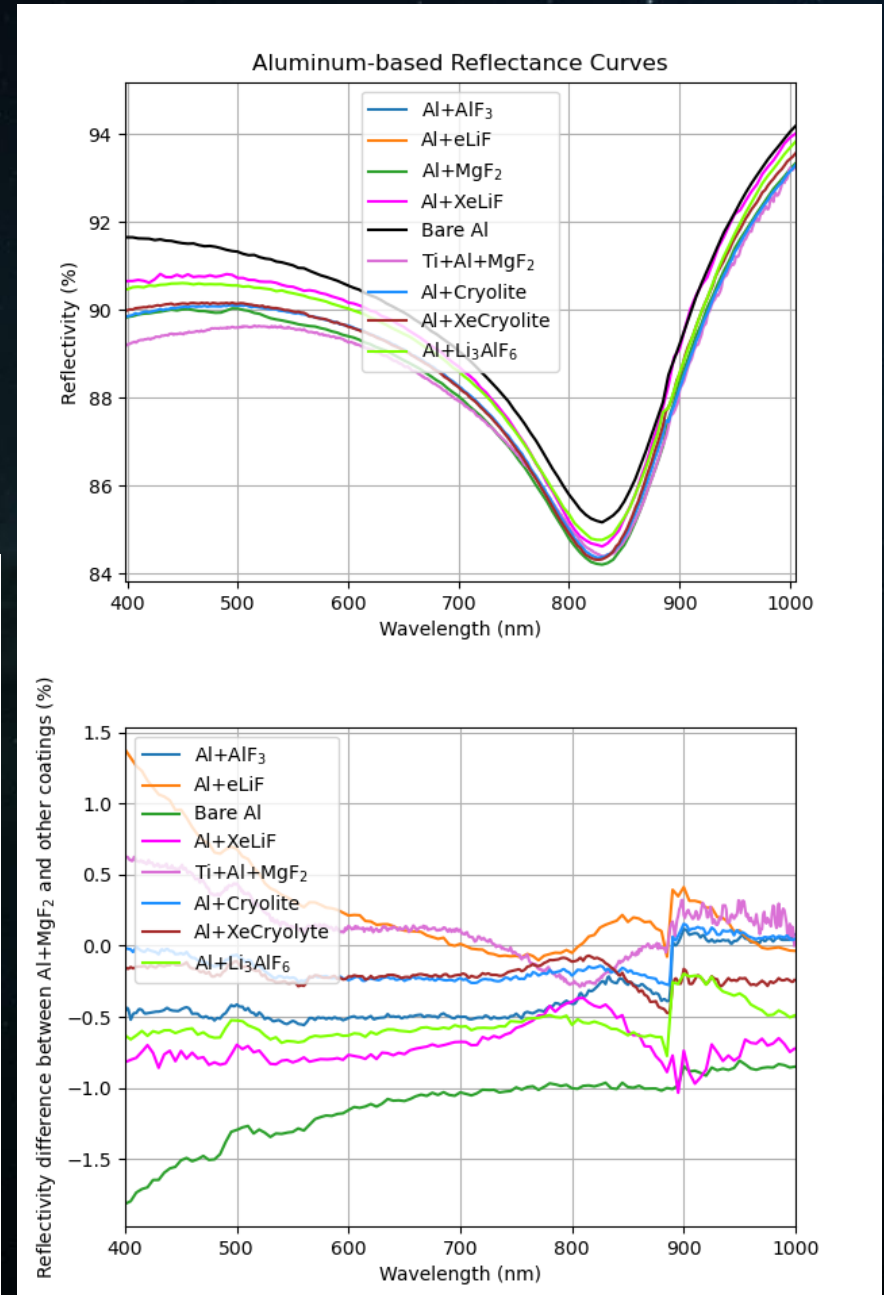
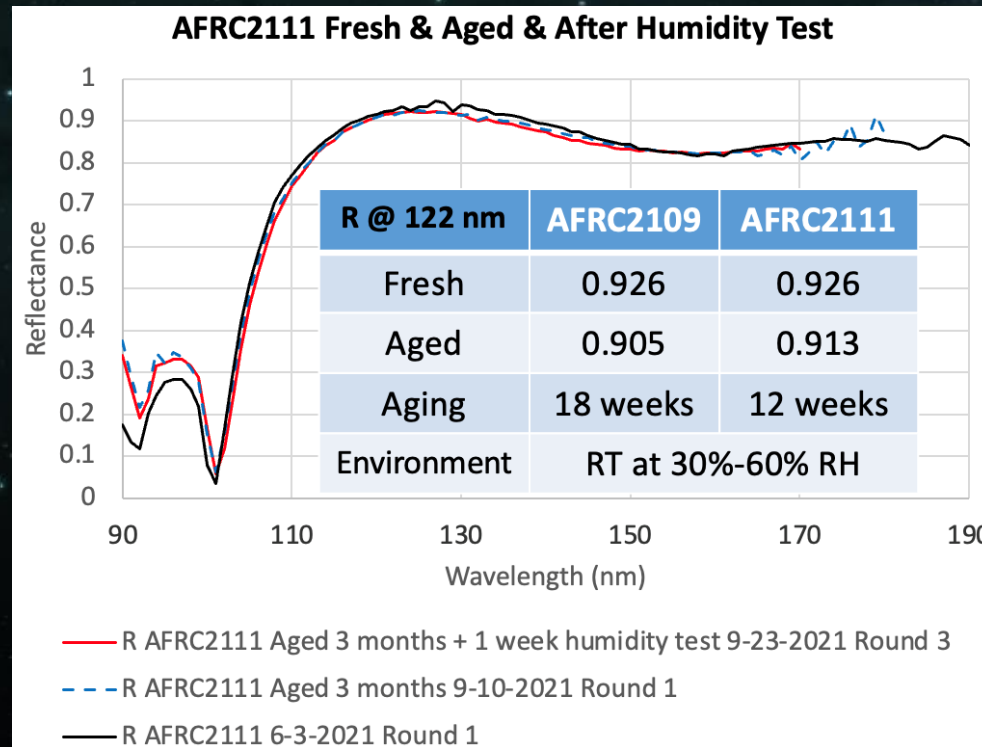
- **Alain Carrier / Lockheed Martin:** Technology Maturation for Astrophysics Space Telescopes (TechMAST)
- **Laura Coyle / BAE Systems:** Ultra-stable Telescope Research & Analysis – Critical Technologies (ULTRA-CT)
- **Tiffany Glassman / Northrop Grumman:** Systems Technologies for Architecture Baseline (STABLE)

All teams are now under contract and have held kick-off reviews

*See panel discussion from all industry team members at HWO Splinter Session:  
Tomorrow, 1/16, 9:00 AM in Potomac C*

# FAR-UV BROADBAND COATINGS

- Aluminum-based coatings can provide high reflectance in the UV (i.e., Al+XeLiF) with excellent aging statistics
- Key Challenges:
  - Scaling up while maintaining high uniformity (2-3%) between segments
- Need to test surface roughness and coating-induced stresses
- Full characterization of polarization-induced aberrations

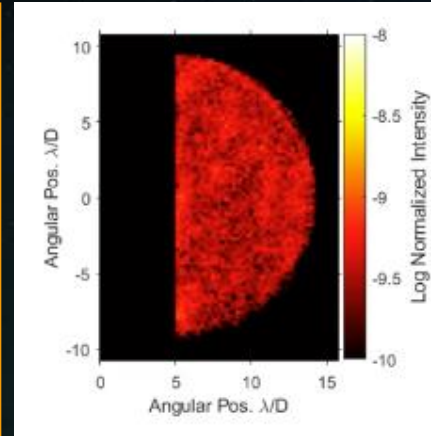
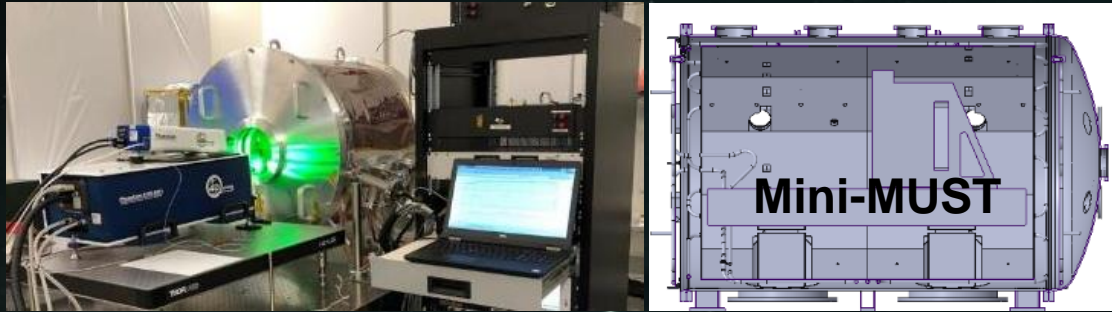


# GOVERNMENT TESTBEDS FOR TECHNOLOGY DEVELOPMENT

EXISTING

## Ultra-Stable Structures Lab (USSL) + Mini-MUST (GSFC)

- Picometer-stable metrology to advance TRL of critical flight-like hardware including mirrors, structures, etc.
- Demonstrated thermal stability of  $\pm 75 \mu\text{K}$  over an hour
- Mini-MUST fits 1-m class test articles



4e-10 contrast over 20% BW from 5 – 13.5  $\lambda/D$  for a one-sided dark hole (Allan et al. in 2023)

## High-contrast Imaging Testbed (HCIT, JPL)

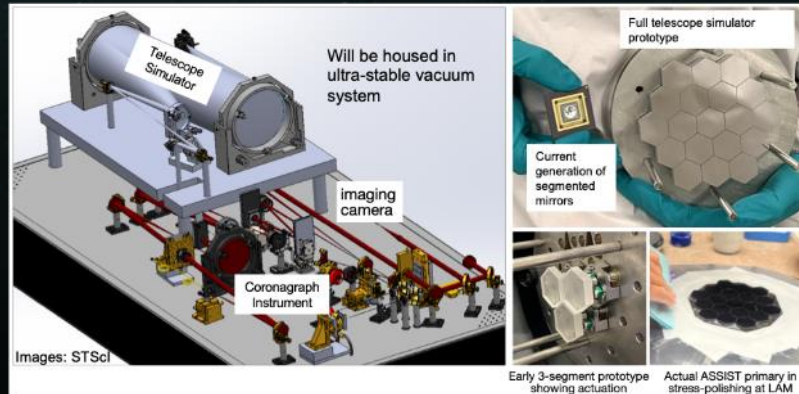
- Achieved 4e-10 raw contrast in 20% BW in vacuum for 1-sided dark hole
- Supports many SATs and coronagraph development efforts
- Provide DM characterization capability



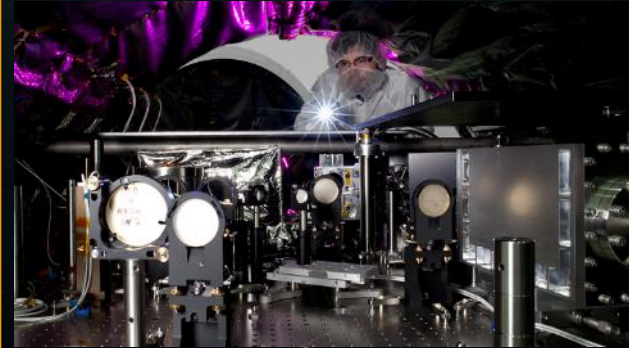
PROPOSED

## HWO Observatory System Testbed (HOST, STScI + GSFC)

- System-level TRL 5 demo with dedicated telescope simulator and coronagraph
- High-contrast model validation is key product



## Exoplanet Imaging Coronagraph for TRL 5 (EPIC5, JPL)



- TRL 5 demonstration of HWO coronagraph performance
- Leverages HCIT expertise to build testbed capable of qualifying HWO coronagraph designs
- Integrated modeling involvement for model validation.

**Proposed testbeds are complementary to industry investments and will be made available to external groups for future technology development calls.**

# SUMMARY

The Habitable Worlds Observatory Technology Development effort is underway

We've identified, organized, and prioritized an initial set of technology gaps to enable to HWO mission

We are currently developing roadmaps to guide the development of those technologies to TRL 5 by Mission Concept Review in 2029

Detailed roadmap will be available by the July HWO Science & Technology Workshop