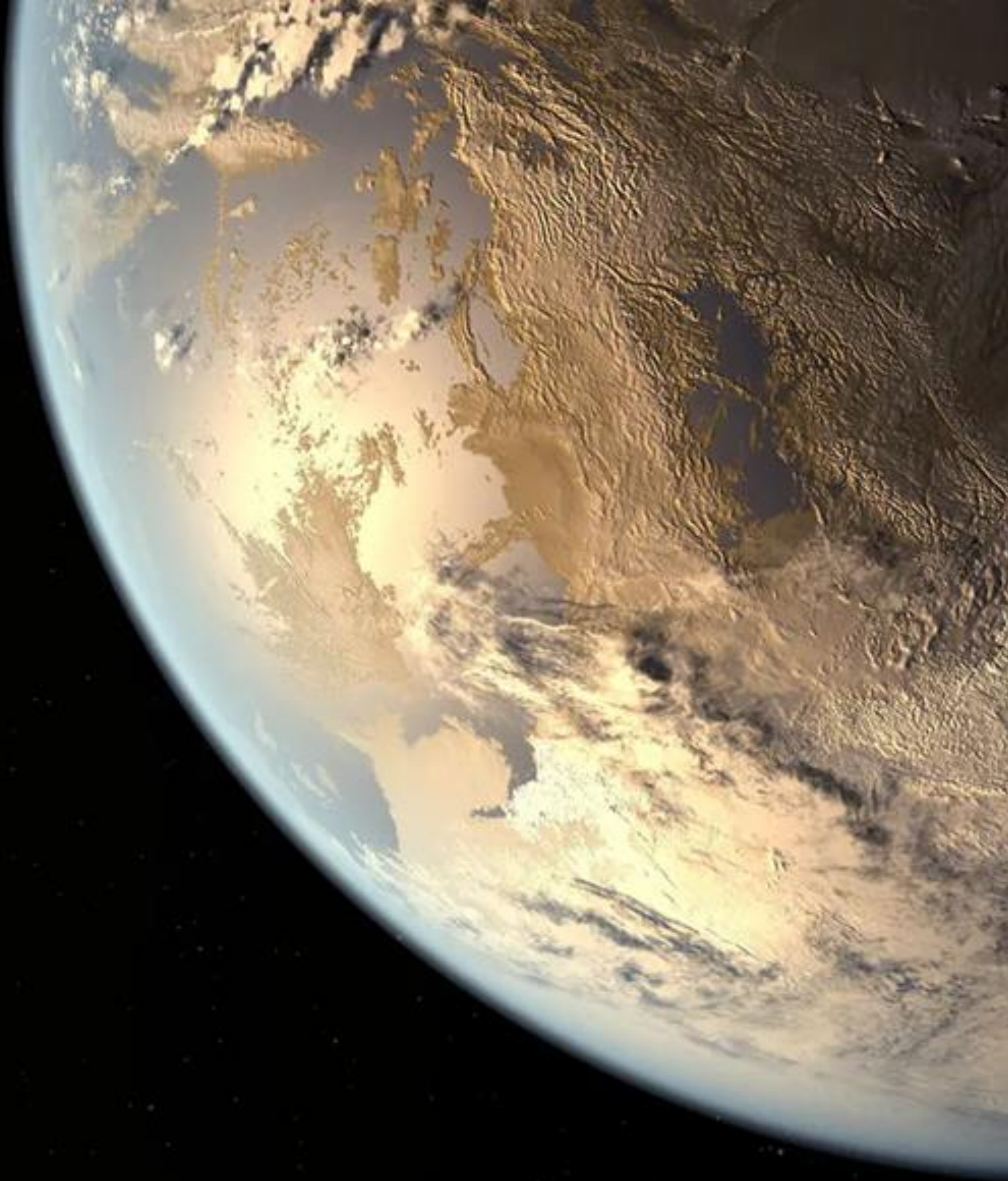
National Aeronautics and Space Administration

HABITABLE WORLDS OBSERVATORY



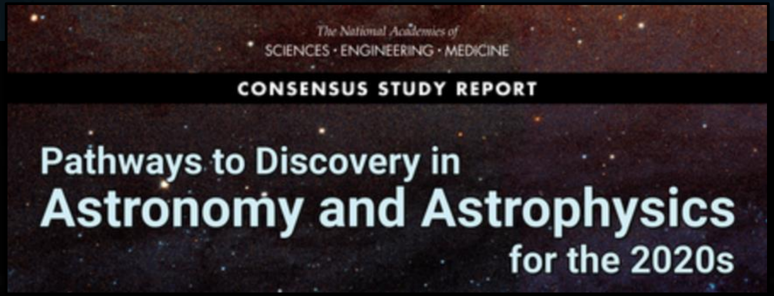
Habitable Worlds Observatory (HWO) Technology Maturation Project Office Status

Lee Feinberg, HWO Principal Architect,
NASA Goddard Space Flight Center

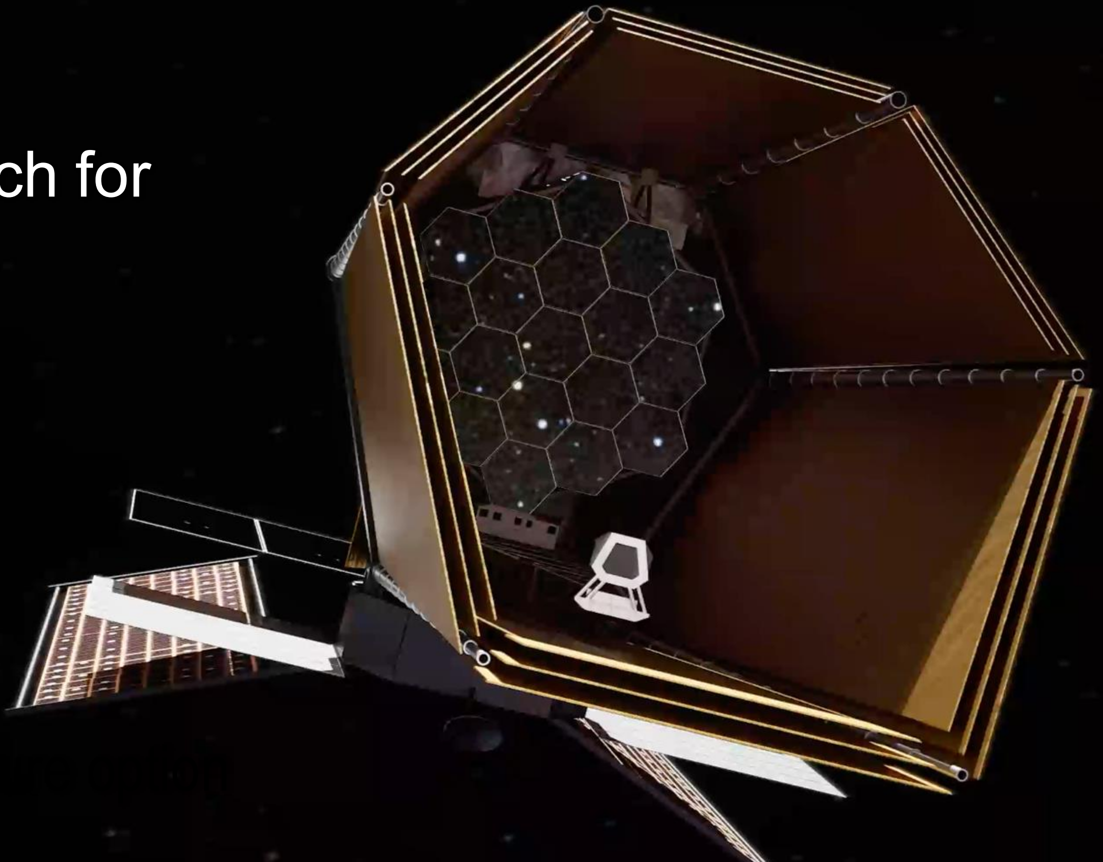
*on behalf of the HWO Technology Maturation Project Office,
and 1000+ community members*

What is the Habitable Worlds Observatory?

NASA's next flagship mission concept recommended by Astro2020 Decadal Survey



A mission to search for life and perform transformative astrophysics



Key Improvements needed:

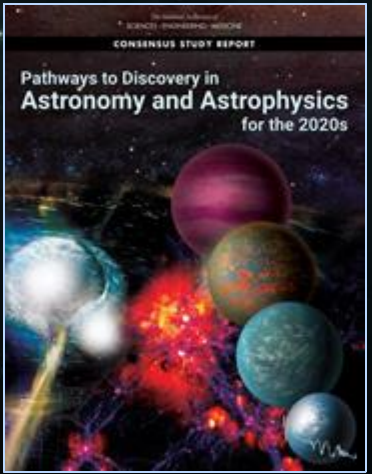
- ~10x in telescope stability vs. RST (1000x vs JWST)
- ~100x in contrast vs RST/CGI
- Large aperture (>=6m)

CHANGING HOW WE DO FLAGSHIP MISSIONS

"Design problems are baked into the cake at the start, and not uncovered until you have eaten half the cake."

JWST Lessons Learned:

"Mature the architecture, technology science holistically early on, Build in Large System Margins from the Start"



"Prior to commencing mission formulation, a successful Great Observatories Mission and Technology Maturation program must be completed.."

Architected for success, Roman Space Telescope Continues to Meet Cost and Schedule

New Project Office

- New Project Office at Goddard Started August 1st
- Priority this first year has been organizing, planning, and leading science, technology and architecture efforts in an integrated way
  - Technology roadmap and pre-formulation plans are key deliverables in May
- Community Science and Instrument Team selection to be in the next few weeks
- Dialog and communication with potential international partners has begun
  - Contributions can include full instruments, subsystems, etc

HWO Project Office

* JPL ex-officio
° Interim

Project Leadership

L. Feinberg, Principal Architect
S. Smith, Project Manager°
J. Ziemer, Pre-Formulation Architect*

Financial: P. Butler
Pub Affairs: C. Andreoli
Community Engagement:
Rob Zellem & Raissa Estrella*
Mentoring +Int., N. Latouf, T.Kataria*
Chief Optical Scientist, B. Saif

Science

G. Arney, Project Scientist°
A. Roberge, Pre-formulation Scientist°
B. Mennesson, Pre-formulation Scientist*

Deputy PS: Mike McElwain
Deputy PFS: Erin Smith
Deputy PFS: Pin Chen*
Coronagraph Instr Sci: Vanessa Bailey*
High-Contrast Spectr. Sci: Neil Zimmerman
Camera Instr. Scientist: Jessie Dotson/Ames
UV Instrument Scientist: Paul Scowen
Exoplanet Theme Ld: Chris Stark
Exoplanet Theme Ld: Renyu Hu*
Astrophysics Theme Ld: Tzu-Ching Chang
Astrophysics Theme Ld: Allison Youngblood
Solar Systems Ld: Lynnae Quick
Astrobiology: Niki Parenteau

Testbeds

B. Sitarski, Deputy Principal Architect
C. Baker* JPL Testbed Lead*

NASA HOST Lead: M. McElwain
HOST Systems: T. Groff
Keck Demo: M. Troy*

Systems

A. Liu, Acting Mission Systems Engineer
M. Levine*, Systems Modeling

Servicing & Instrument Systems: J. Van Campen
High Contrast Sys: C. Noecker
Payload Systems: J. Abel
High Contrast Error Budgets: Brian Kern
Systems Design and Modeling teams

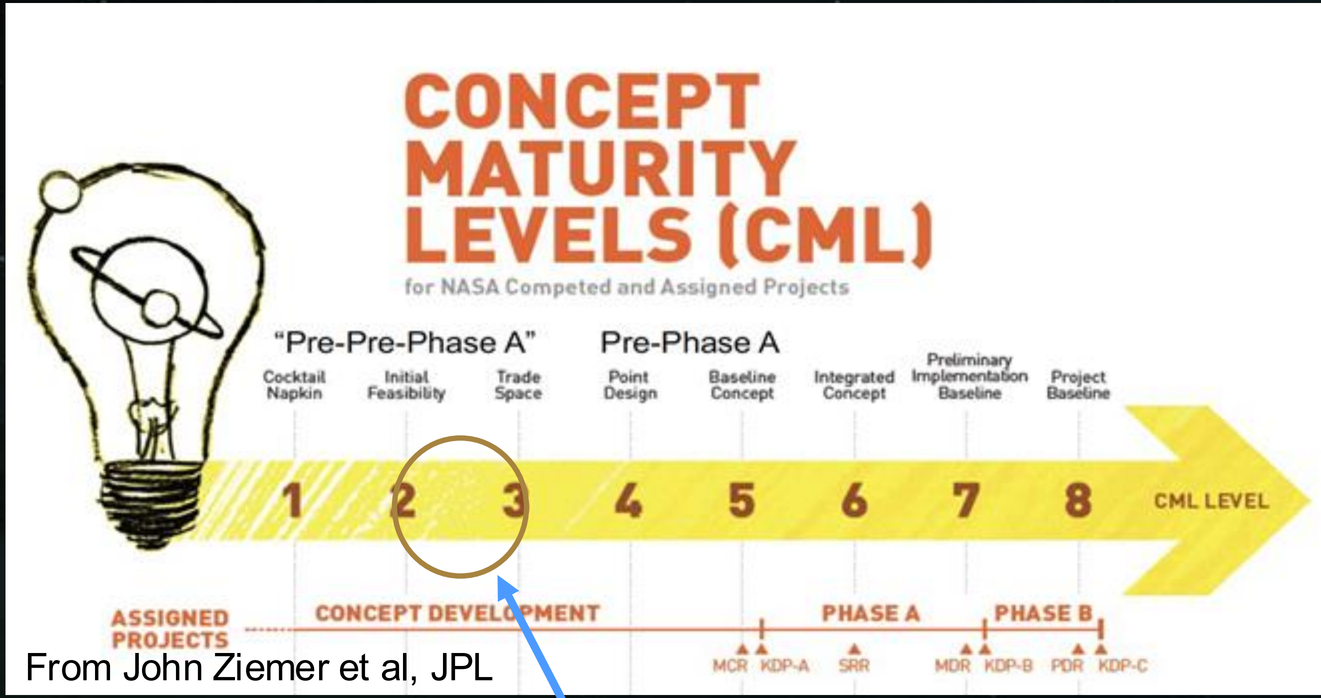
Technology

M. Bolcar, Chief Technologist
F. Zhao, Deputy Chief Technologist*

Coronagraph Technology: Ilya Poberezhskiy/TBD
Telescope Technology: TBD
UV/Instrument Technology: Paul Scowen
SME: D. Redding*
SME: P. Stahl, MSFC
SME: R. Belikov, Ames

Larger Science and Engineering Project Development Team supporting various studies

Concept Maturation



From John Ziemer et al, JPL

We are here

MCR Requirements via GSFC – STD – 1001A

Category	MCR Criteria
Review Process	A preliminary Systems Review Plan (SRP) including an Engineering Peer Review Plan (EPRP) is available and deemed compliant with all applicable requirements.
Technical Management	Mission objectives are clearly defined and unambiguous. Potential technology needs are identified and the gaps between such needs and the current and/or planned technology readiness levels have been assessed with acceptable results. The evaluation criteria and trade space for candidate systems that fulfill the conceptual design requirements have been identified and prioritized. Technical planning is sufficient to proceed to the next phase.
System Design and Demonstration	An operations concept and system architecture is provided that meets these requirements, demonstrating the feasibility of the mission and technical solution. A search was conducted to identify existing assets or products that have a potential to be implemented to satisfy the mission or parts of the mission. The preliminary set of requirements meeting the objectives is provided and is consistently stated within the project.
Safety & Mission Assurance	Safety and mission assurance activities (i.e., safety, reliability, maintainability, quality, and Electrical, Electronic and Electromechanical [EEE] parts) related to the mission and conceptual design have been adequately addressed.
Project Management	Initial risk identification and mitigation strategies have been provided and are acceptable. A rough order of magnitude cost estimate is provided and is both credible and within an acceptable cost range. The schedule estimates are credible.

From Mike Menzel

EXPLORATORY ANALYTIC CASES (EACS) (FROM DECEMBER 2023)

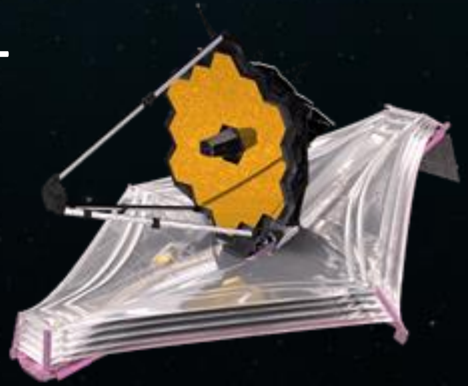
1st round mission architectures are being developed to explore the HWO trade space.

- Practice end-to-end modeling, from science to engineering. Develop initial models & codes to ”pipeclean” the process using representative examples, understand end to end modeling capabilities and needs
- Use EACs to identify key technology gaps and guide maturation of potential technology solutions
- Explore key architectural options/breakpoints in the context of rockets to help guide future point design choices
- Provide feedback to rocket vendors as soon as possible to help influence their direction

We don’t expect any of the cases studied will become a baseline design going forward.
These are only intended to explore and practice.

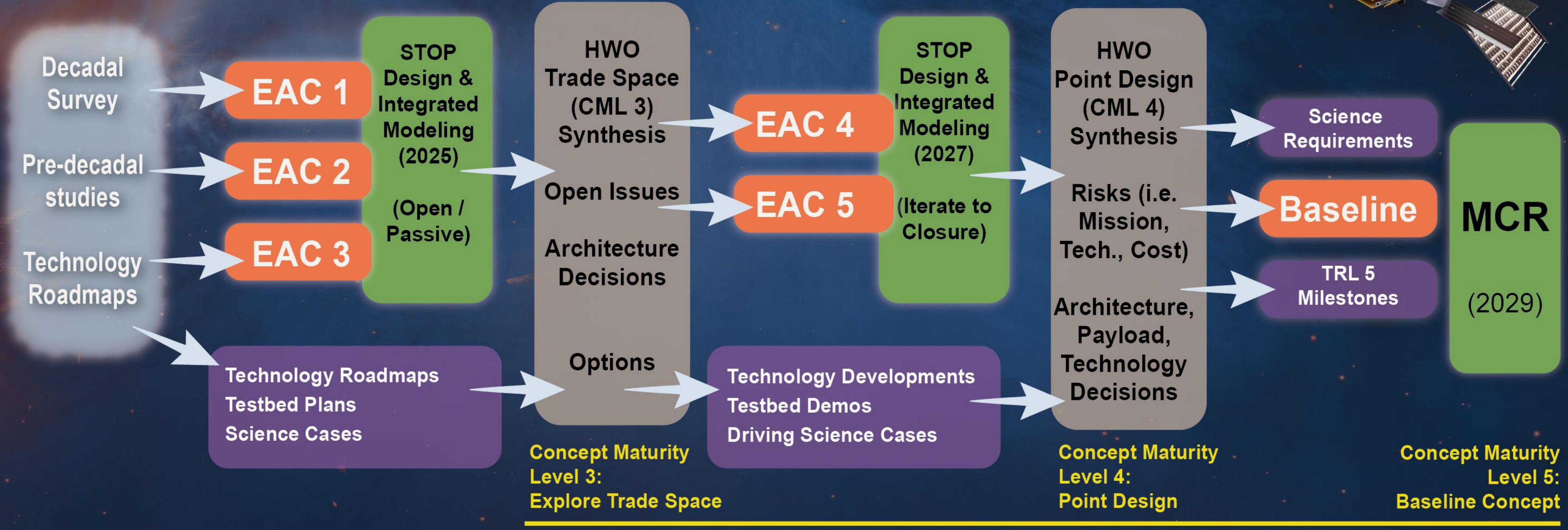
Early JWST

Final JWST
CML 9+



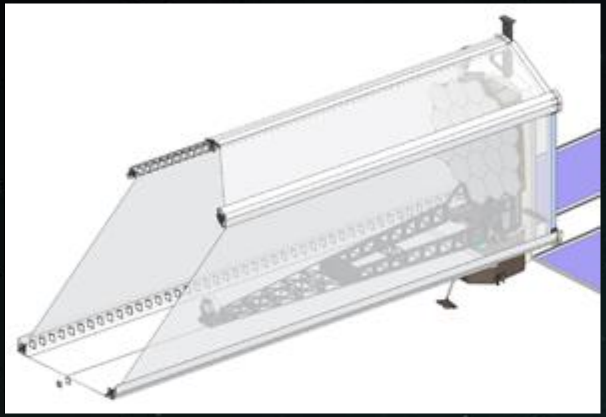
HABITABLE WORLDS OBSERVATORY

Iterative Design of Exploratory Analytic Cases (EAC's)



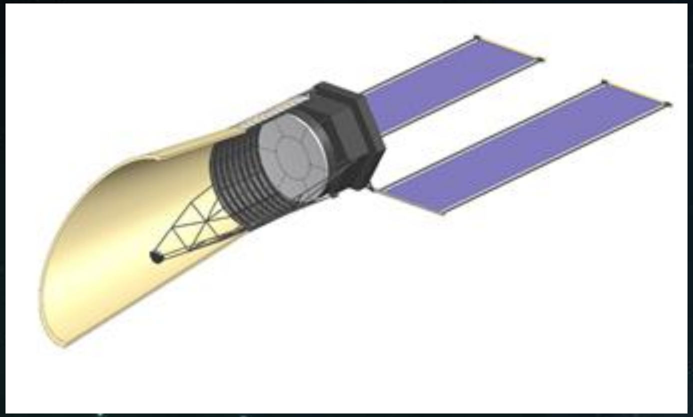
CML – Concept Maturity Level EAC – Exploratory Analytical Case CEC – Coronagraph Exploratory Case STO – Structure / Thermal / Optical

NOTIONAL EXPLORATORY ANALYTIC CASES



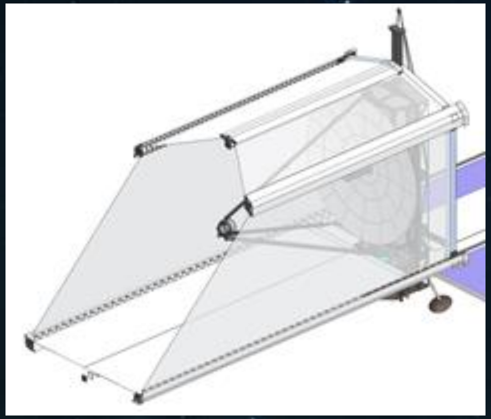
Case 1:

- 6m ID/7.2m OD off-axis
- 19 hex segments
- PM faces horizontal in rocket
- JWST like wing deployment
- Fits in New Glenn, Starship Standard
- Unique attributes:
  - Meets volume of New Glenn, mass was a goal but to be evaluated
  - Low Areal Density Mirrors
  - Requires unique baffle and SM tower



Case 2:

- 6m ID (round) off-axis
- Non-deployed Primary mirror
- Central 3 m round mirror + 6 keystone
- PM faces up in rocket
- Fits in Starship Standard and SLS
- Unique attributes:
  - Higher areal density mirrors with unique thermal stability case
  - Less metrology, unique coronagraph performance vs Case 1



Case 3:

- 8m ID (round) on-axis
- 34 keystone segments, low areal density mirror
- PM Faces horizontal in rocket
- JWST like wing deployment
- Fits in Starship Standard and SLS for mass
- Unique attributes:
  - On-axis (w/obscuration and struts)
  - Unique deployment
  - Key comparison point for performance (e.g., yield), mass, volume

Deployment Architecture Types Studied

NASA
Space Launch System

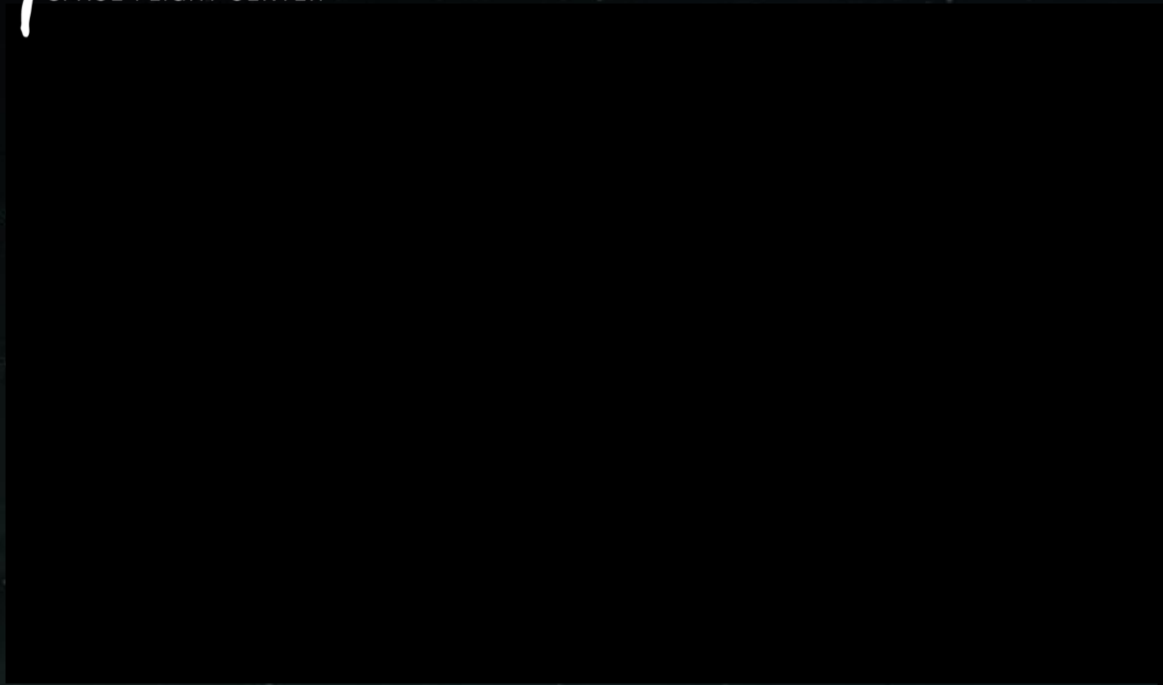
Space-X
Starship

Blue Origin
New Glenn

Webb-like wings, secondary with barrel unfolding

Roman-like Hard Barrel w/"Camping Cup" Deployment

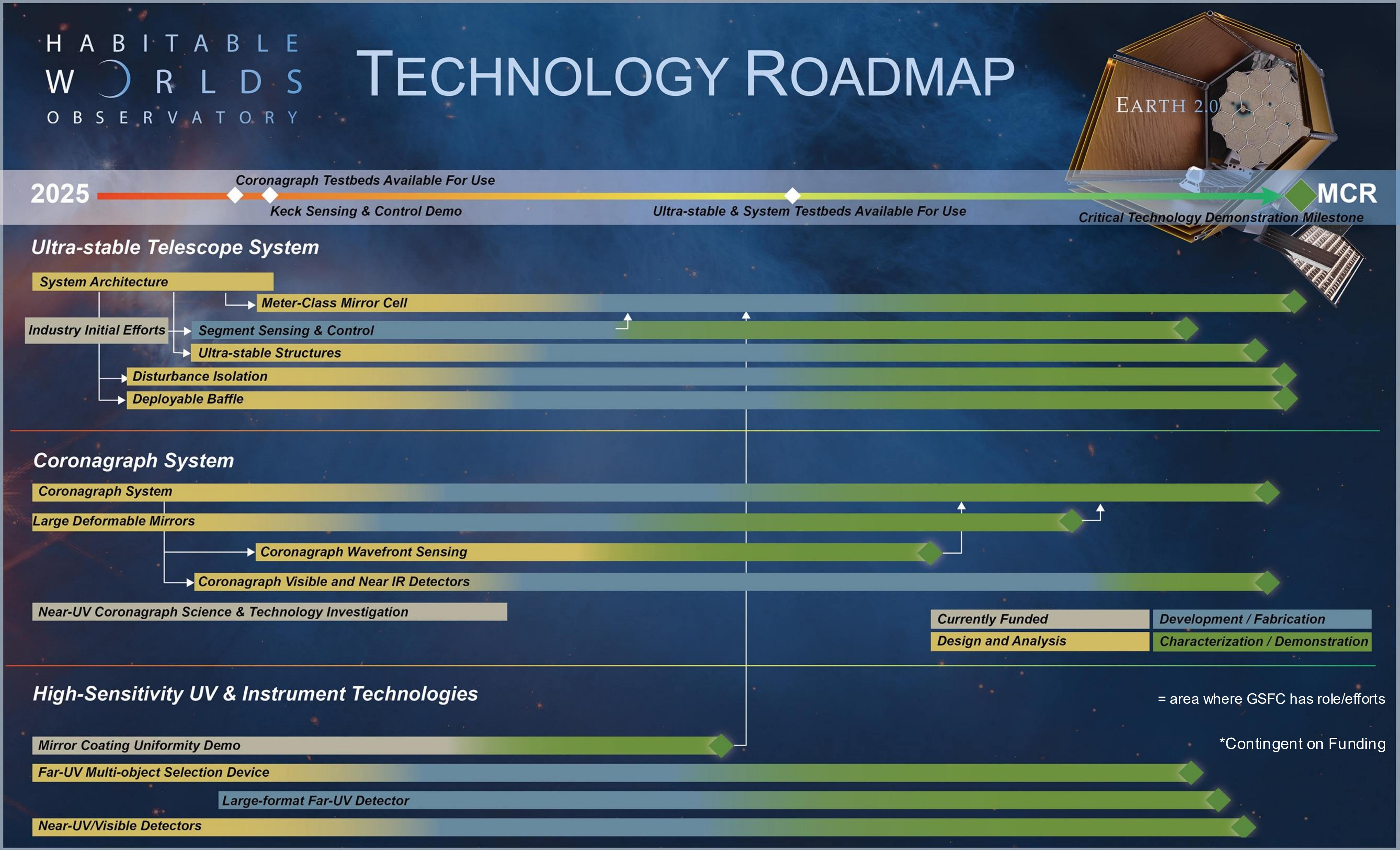
HWO In-space servicing concept



Shuttle/Starship Approach

Separate Servicer with Carrier

- Allows multiple generations of Instruments
- Enables earlier launch date by focusing on minimum needs initially
- Architecting for Serviceability helps Integration and Testing



HABITABLE WORLDS OBSERVATORY
TECHNOLOGY ROADMAP
EARTH 2.0
2025
Coronagraph Testbeds Available For Use
Keck Sensing & Control Demo
Ultra-stable & System Testbeds Available For Use
MCR
Critical Technology Demonstration Milestone
Ultra-stable Telescope System
System Architecture
Meter-Class Mirror Cell
Industry Initial Efforts
Segment Sensing & Control
Ultra-stable Structures
Disturbance Isolation
Deployable Baffle
Coronagraph System
Coronagraph System
Large Deformable Mirrors
Coronagraph Wavefront Sensing
Coronagraph Visible and Near IR Detectors
Near-UV Coronagraph Science & Technology Investigation
Currently Funded
Development / Fabrication
Design and Analysis
Characterization / Demonstration
High-Sensitivity UV & Instrument Technologies
= area where GSFC has role/efforts
*Contingent on Funding
Mirror Coating Uniformity Demo
Far-UV Multi-object Selection Device
Large-format Far-UV Detector
Near-UV/Visible Detectors

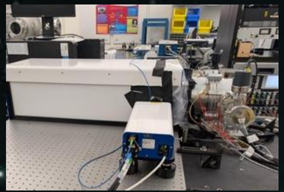
Testbeds For Technology Development

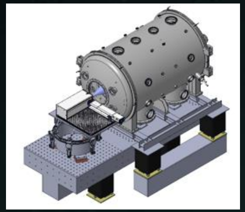
Ultra-Stable Structures Lab (USSL) + Mini-MUST (GSFC)

B. Sitarski (GSFC), C. Baker (JPL)

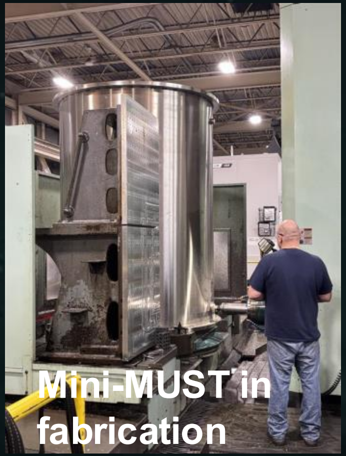
ONGOING

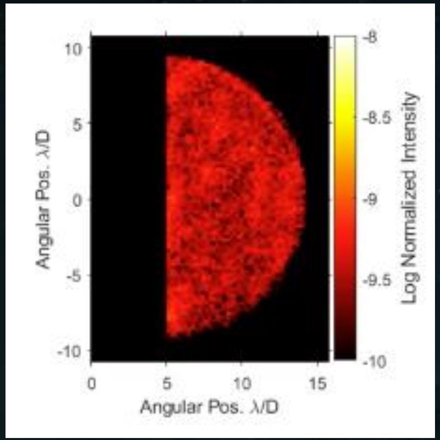
- Picometer-stable metrology to advance TRL of critical flight-like hardware including mirrors, structures, etc.
- Demonstrated thermal stability of ±75 μK over an hour
- Mini-MUST fits 1-m class test articles





	All	0.033 - 0.01 Hz	0.01 - 1 Hz	1 - 10 Hz	10+ Hz	
Weighted σ Comparison (2 Days)	18.36	4.86	8.25	3.43	13.46	ULE
	23.58	11.46	15.85	7.79	7.90	0.03 Hz
	19.33	7.85	13.19	7.37	7.89	0.07 Hz
	32.14	14.28	24.14	8.70	8.07	2 Hz
	24.76	9.65	18.48	8.04	8.02	7 Hz
	PICOMETERS					





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

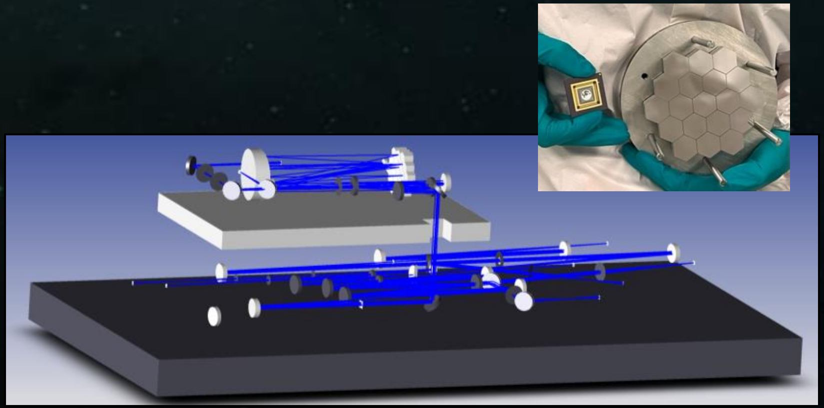
High-contrast Imaging Testbed (HCIT, JPL)

- 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

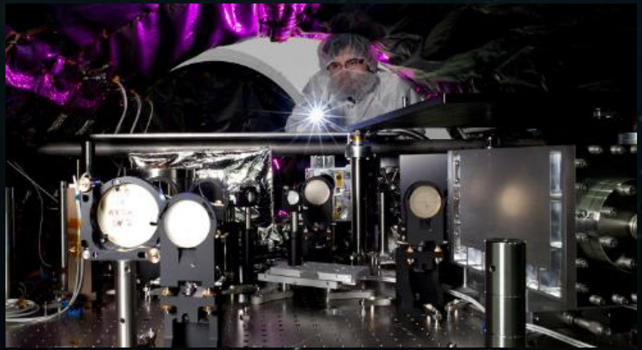
HWO Observatory System Testbed (HOST, STScI + GSFC)

PROPOSED

- System-level TRL 5 demo with dedicated telescope simulator and coronagraph
- Leverages advances in segmented coronagraphs on HICAT and on simulators



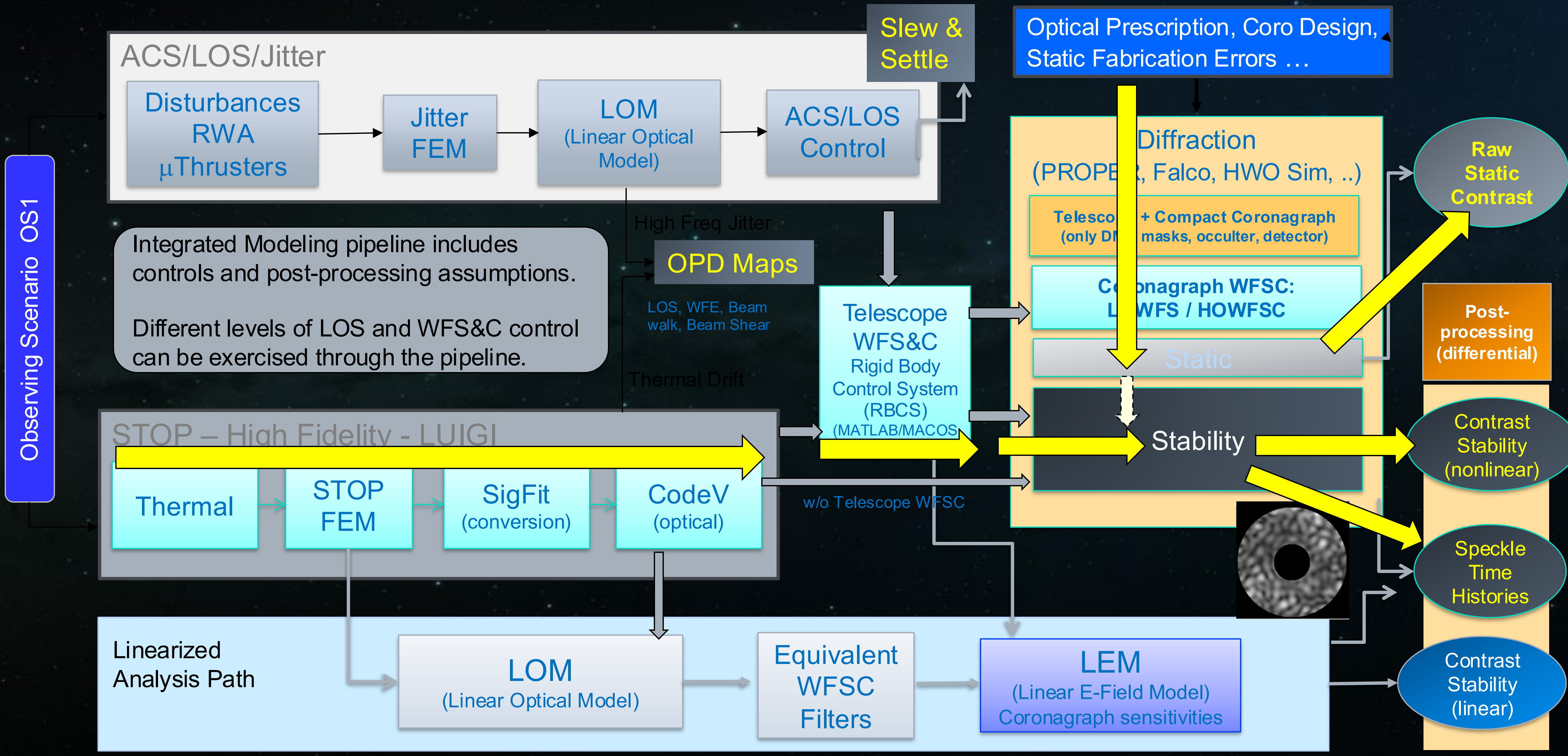
Exoplanet Imaging Coronagraph for TRL 5 (DST2/EPIC5, JPL)



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

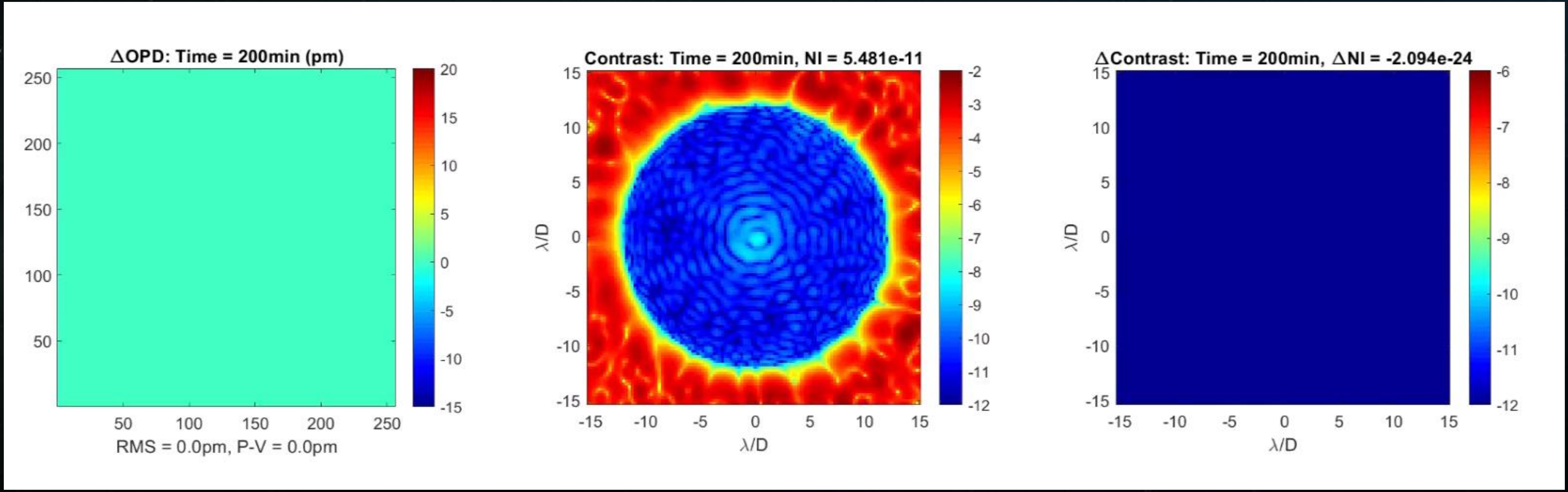
Proposed testbeds are complementary to industry investments and will be made available to external groups for future technology development calls.

HWO IM Pipeline (A. Liu/GSFC, M. Levine/JPL)



Example of output: WFSC Residual Alignment WFE & Contrast Stability : Movie Monochromatic through OS1 – PRELIMINARY RESULTS, Work in progress

Left: residual OPD post Met WFSC (unit = pm). Includes static surface errors but no surface figure change.
Middle: raw contrast. Coronagraph at Time = 200 min is the starti initial raw contrast ~5.5 e-11.
Right: Delta contrast compared to Time = 200 min starting point. RMS contrast stability 8 e-12
(Note: Yield analyses assume a baseline Raw Contrast of 3e-12)

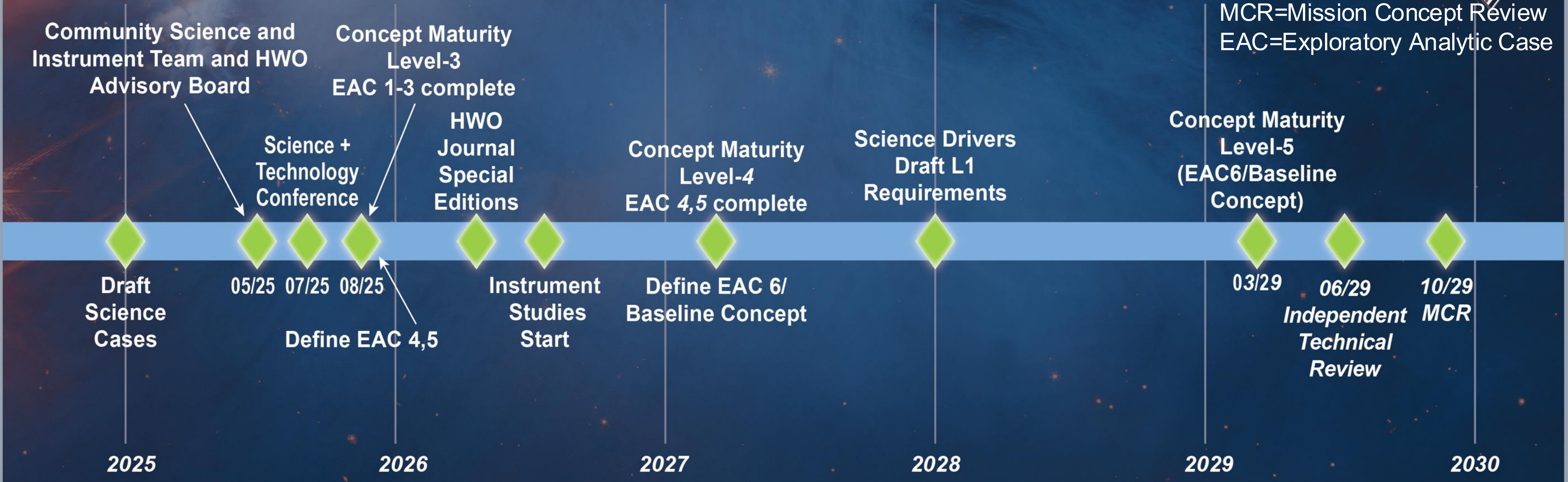


HABITABLE WORLDS OBSERVATORY

Notional

Habitable Worlds Observatory Plan to MCR

MCR=Mission Concept Review
EAC=Exploratory Analytic Case



Contingent on Funding

HWO25 | JULY 28 – 31, 2025

Towards the

HABITABLE WORLDS OBSERVATORY

VISIONARY SCIENCE AND TRANSFORMATIONAL TECHNOLOGY

JOHNS HOPKINS BLOOMBERG CENTER, WASHINGTON DC

STScI | SPACE TELESCOPE SCIENCE INSTITUTE

JOHNS HOPKINS UNIVERSITY

NExScI

Habitable Worlds Observatory Community Is growing