

Roman Space Telescope Optical System:

Overview, Test, and Verification

SPIE Astronomical Telescopes +
Instrumentation

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Montreal, Quebec, CA

Matthew R. Bolcar (GSFC)

Optical Systems Lead

Alice Liu (GSFC)

Wavefront Error Budget & Integrated Modeling

John Hagopian (ATA)

Optical Alignment

Tom Casey (ATA)

Integrated Payload Assembly Lead

Bear Witherspoon (ATA)

Integrated Payload Assembly Systems

Liz Daly (ATA)

Integrated Payload Assembly I&T Lead

• NASA GODDARD SPACE FLIGHT CENTER • JET PROPULSION LABORATORY •
• L3HARRIS TECHNOLOGIES • BALL AEROSPACE • TELEDYNE • NASA KENNEDY SPACE CENTER •
• SPACE TELESCOPE SCIENCE INSTITUTE • IPAC • EUROPEAN SPACE AGENCY •
• JAPAN AEROSPACE EXPLORATION AGENCY • LABORATOIRE D'ASTROPHYSIQUE DE MARSEILLE •
• CENTRE NATIONAL d'ÉTUDES SPATIALES • MAX PLANCK INSTITUTE FOR ASTRONOMY •

Roman Space Telescope Reviewed – Not Subject to Export Control

Who Is Nancy Grace Roman?



- Early astronomy research in stellar classification
- NASA's first Chief of Astronomy
- NASA's first woman executive
- Oversaw the development of many NASA astronomy programs between 1960 – 1980
 - Orbiting Solar Observatories, Orbiting Astronomical Observatories, Uhuru, Small Astronomy Satellite
- Foundational to the development and success of the Hubble Space Telescope
- Ensured NASA science missions were for the astronomical community

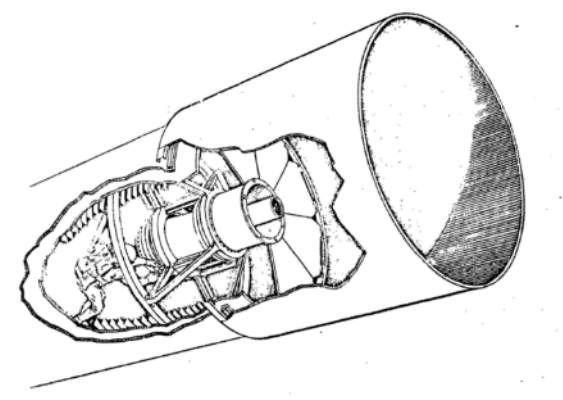
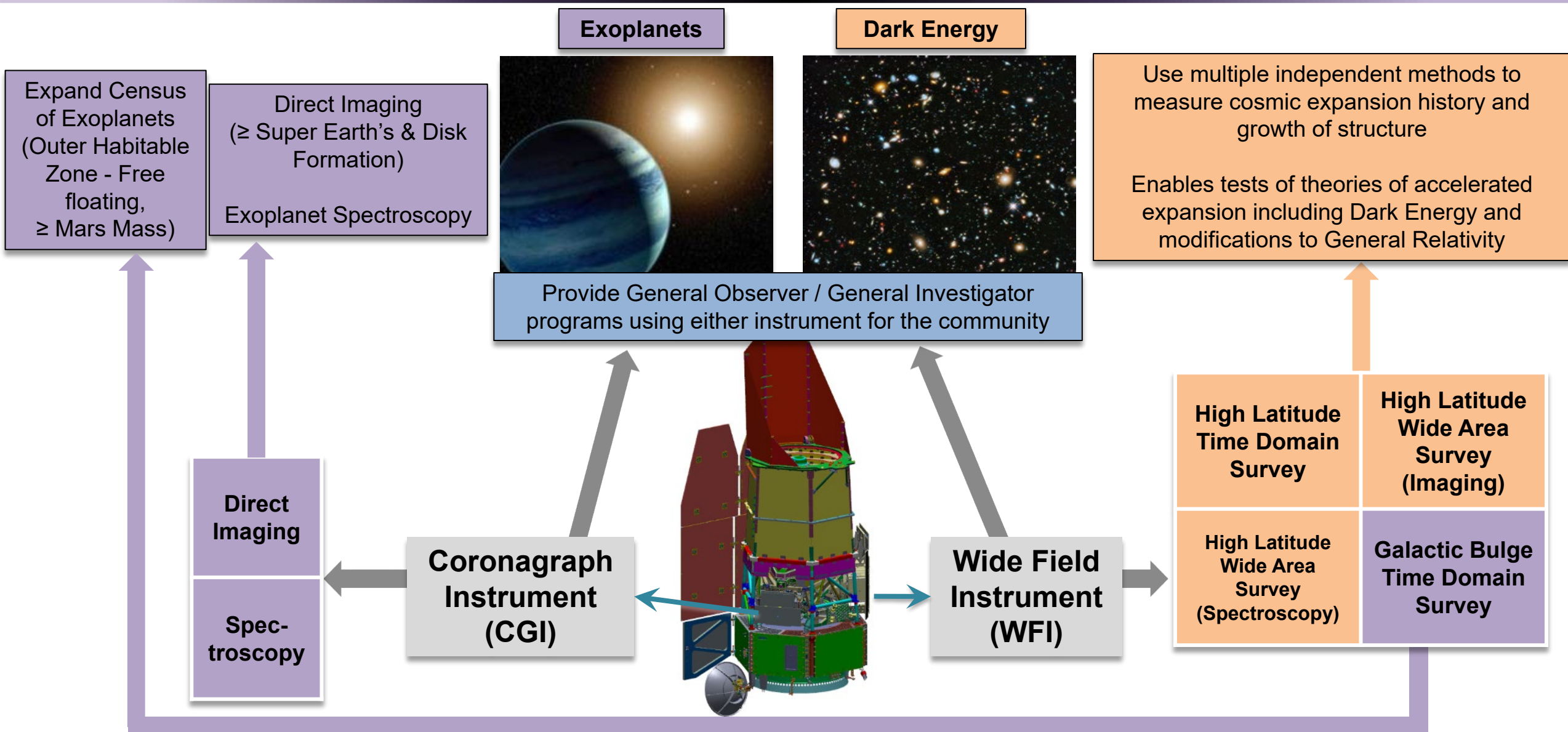


Figure 4 - 51. Extravehicular Checkout Operations



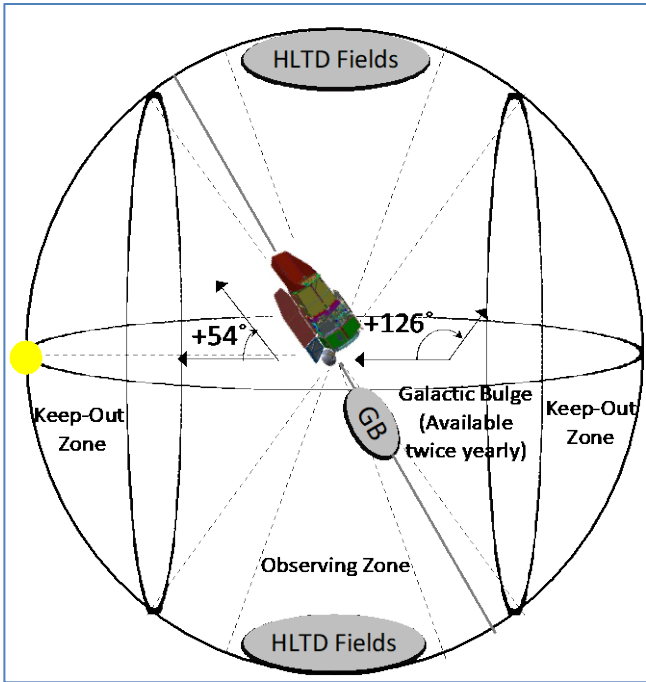
Emilio Segre
Visual
Archives

What is the Roman Space Telescope?



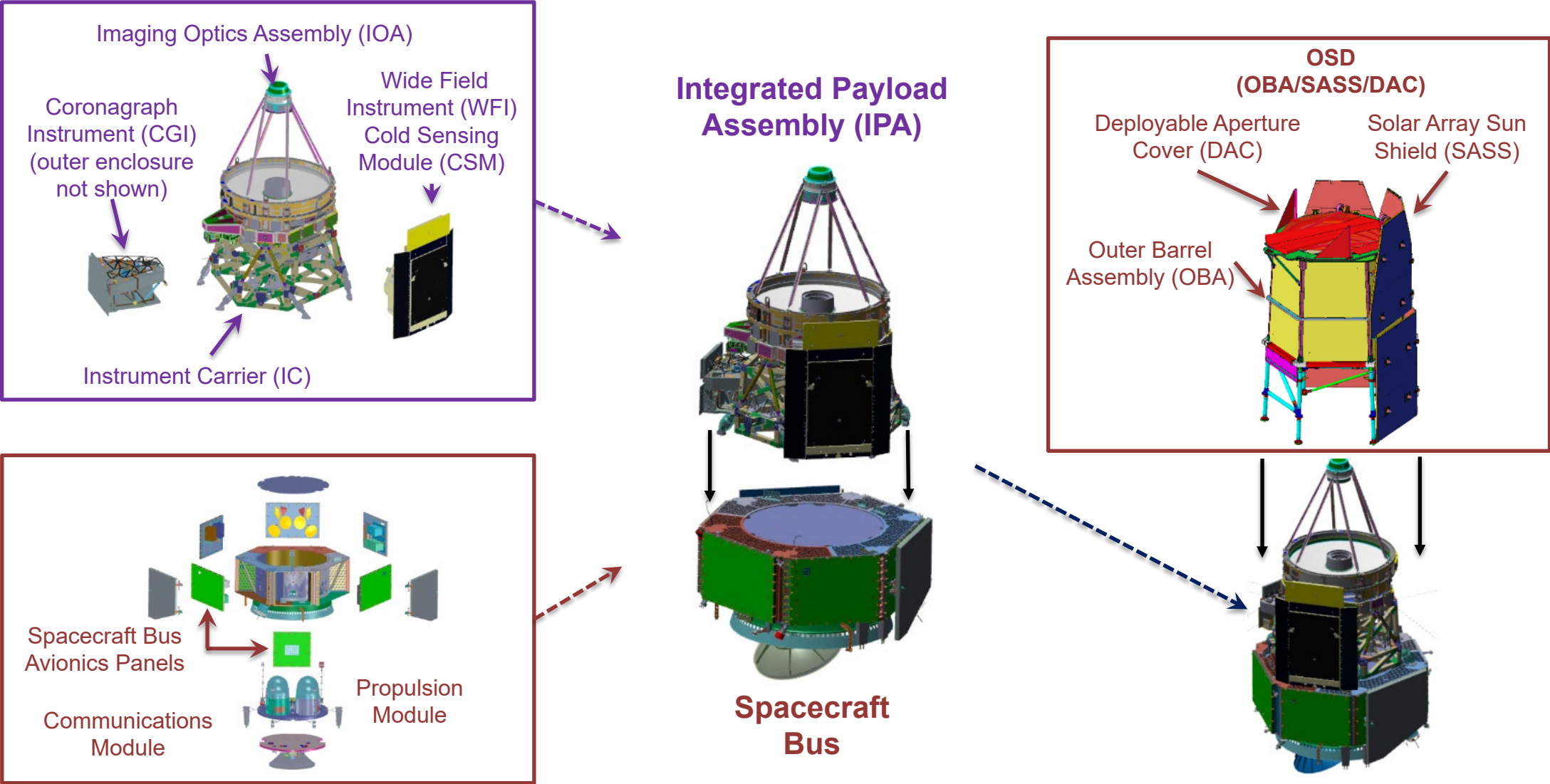
- **Mission Description**
 - 2.4m primary mirror @ 265 K
 - Class A, with tailoring
 - 5-year primary mission, 10-year goal
- **Mission Orbit**
 - Quasi-Halo Orbit about Sun-Earth L2, with no Moon or Earth Shadows

		Mission Elements	Responsibility
Flight Segment	Launch Vehicle	Launch Vehicle & Services	NASA Launch Services Program (LSP)
	Observatory	Spacecraft (S/C)	NASA Goddard Space Flight Center (GSFC)
		Optical Telescope Assembly (OTA)	L3Harris
		Wide Field Instrument (WFI)	NASA GSFC & Ball Aerospace
		Coronagraph Instrument (CGI)*	NASA Jet Propulsion Laboratory (JPL)
		Instrument Carrier (IC)	NASA GSFC
Ground Segment		Ground Stations/Networks	NASA SCan / International Contributors
		Mission Operations Center (MOC)	NASA GSFC
		Flight Dynamics Operations Area (FDOA)	NASA GSFC Flight Dynamics Facility (FDF)
		Science Operations Center (SOC)	Space Telescope Science Institute (STScI)
		Science Support Center (SSC)	Infrared Processing and Analysis Center (IPAC)
		Coronagraph Technology Center (CTC)	NASA Jet Propulsion Laboratory (JPL)
NASA GSFC (Greenbelt, MD); L3Harris (Rochester, NY); Ball Aerospace (Boulder, CO); NASA JPL (Pasadena, CA); STScI (Baltimore, MD); IPAC (Pasadena, CA)			
*CGI is managed by NASA HQ			

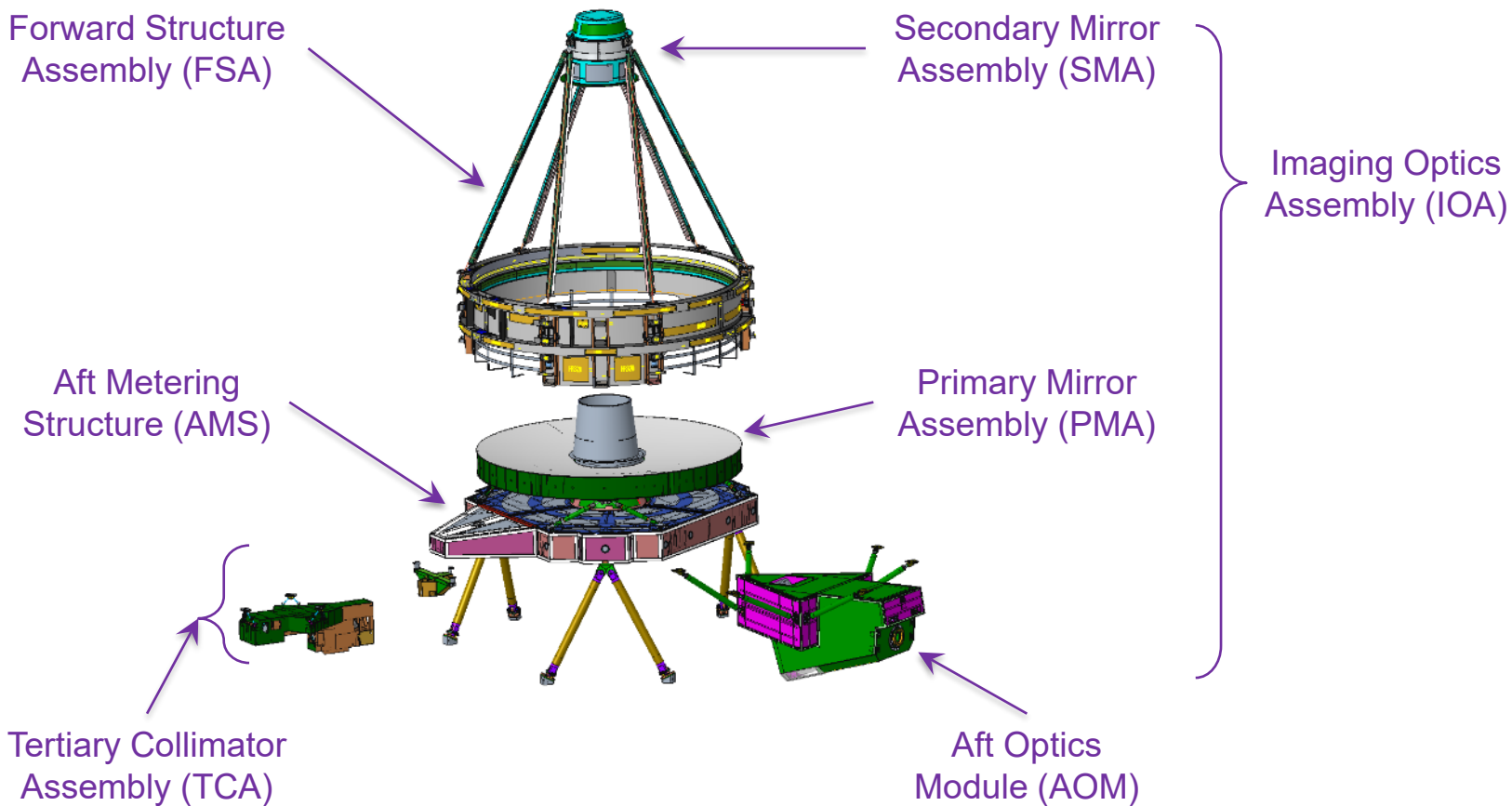


The Roman field of regard provides ~60% total sky coverage each day (72° swath with 360° rotation)

Observatory = **Spacecraft** + **Integrated Payload Assembly**



Integrated Payload Assembly (IPA)

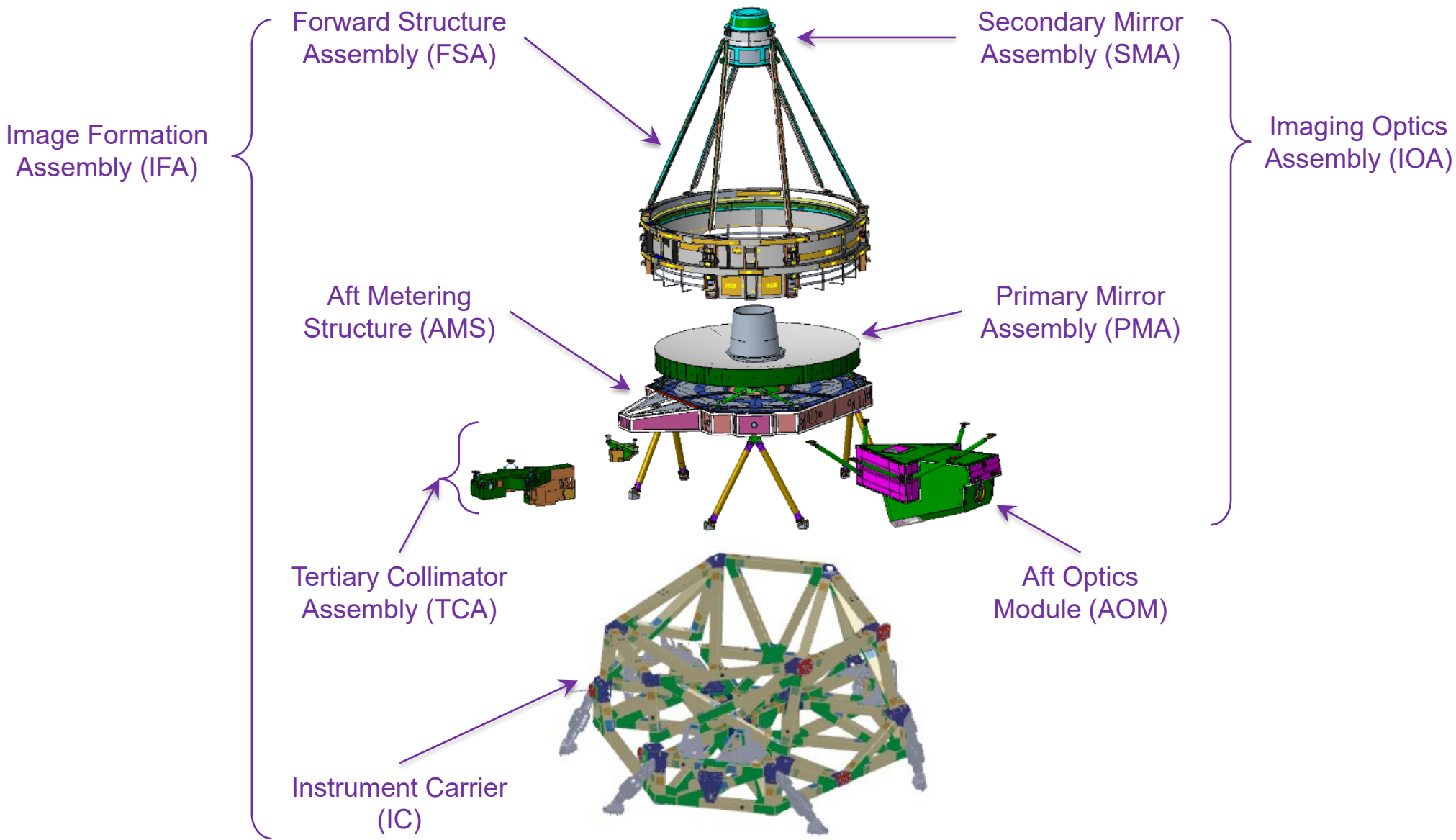


See Talks:

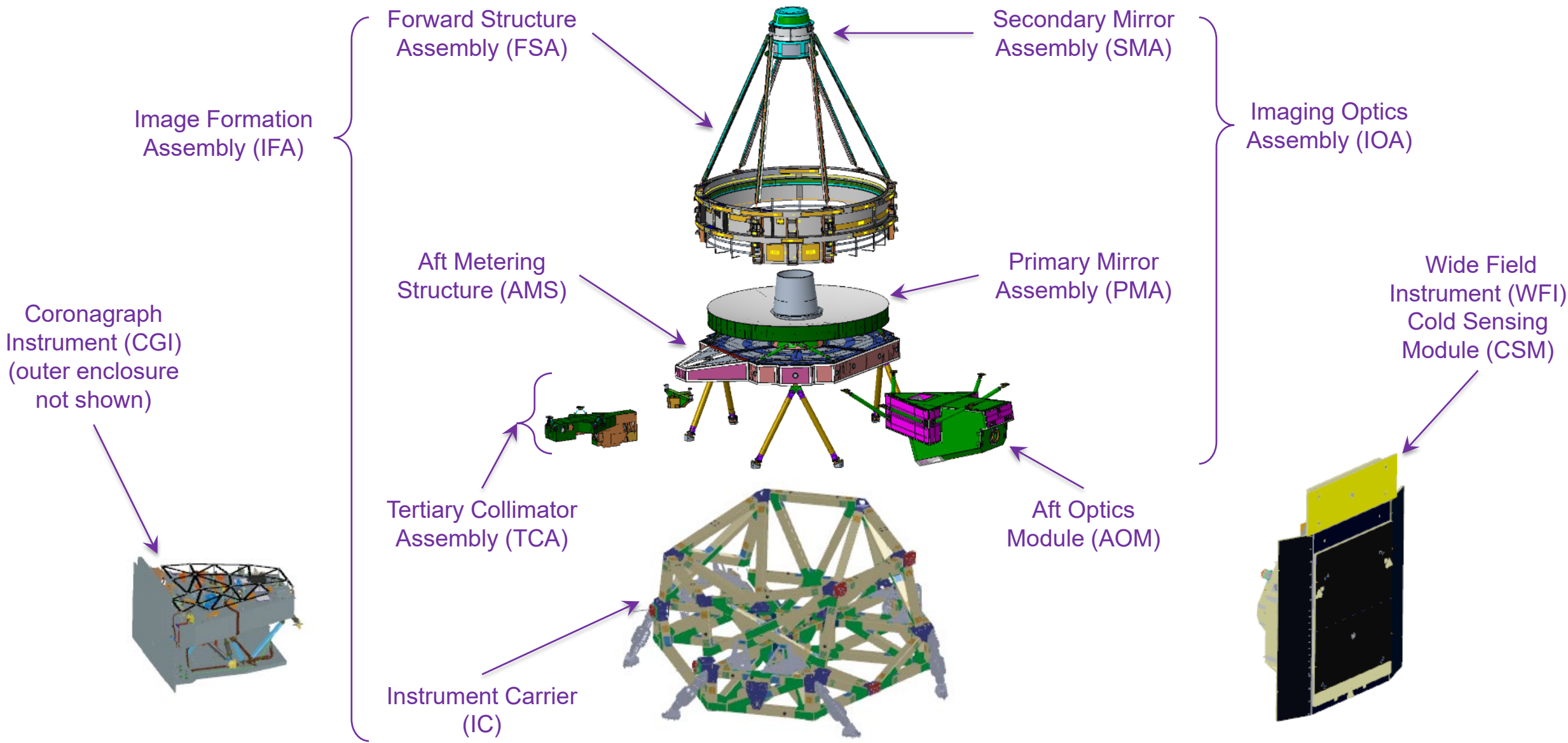
12180-60: Roman OTA Build & Integration Progress

12188-54: RST – Demonstration of integrated thermal control system test for the OTA

Integrated Payload Assembly (IPA)



Integrated Payload Assembly (IPA)



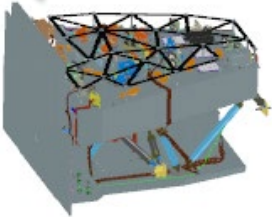
Integrated Payload Assembly (IPA)

See Talks:

- 12180-70: RST Coronagraph Technology Demonstration: Current Status & Relevance to Future Missions
- 12180-71: Roman CGI: Post-CDR Engineering Overview & Status
- 12180-109: RST CGI: Characterizing Prism & Polarizer Flight Units
- 12180-74: Nancy Grace Roman Space Telescope CGI Observation Calibration Plan

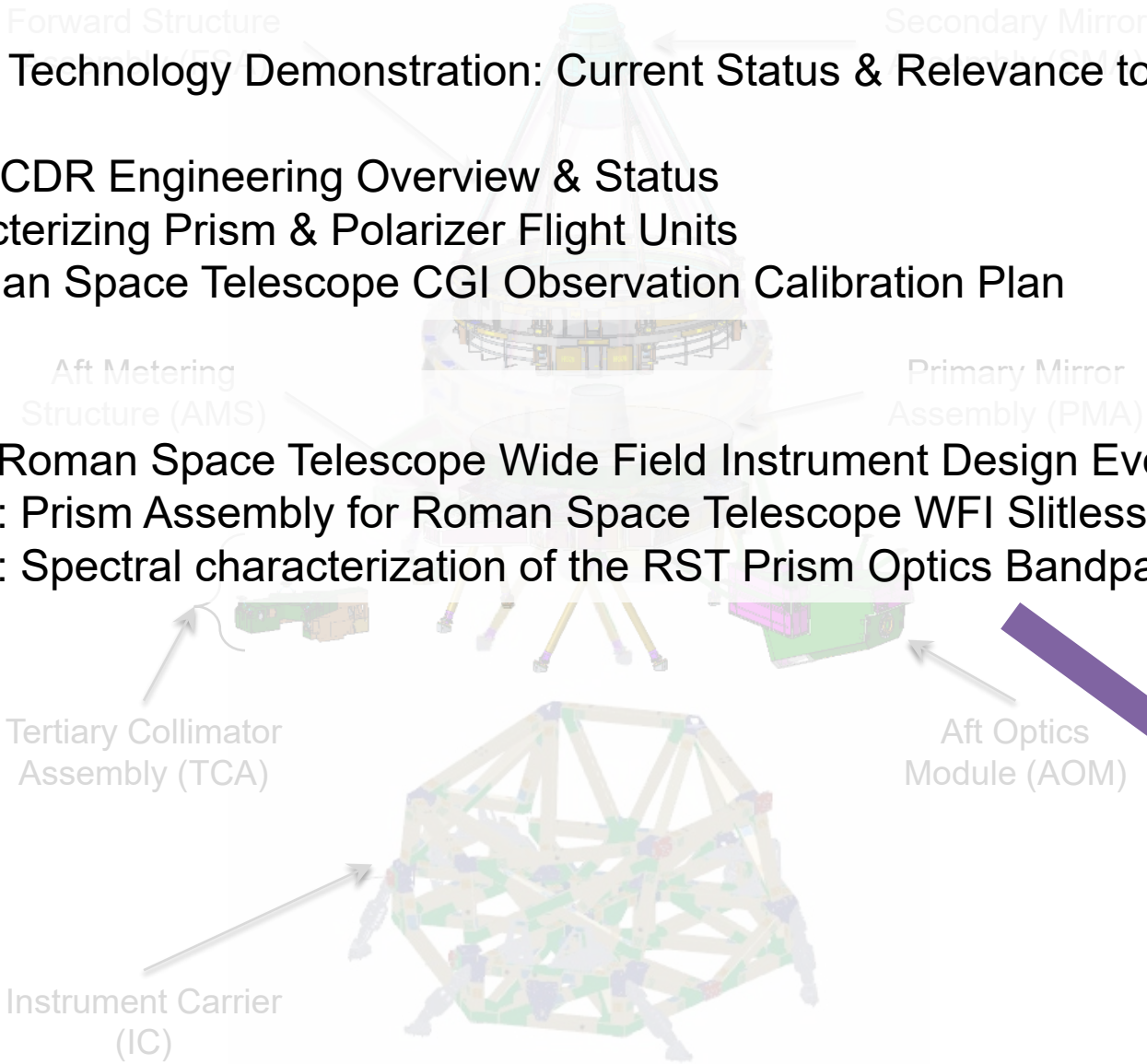


Coronagraph Instrument (CGI)
(outer enclosure not shown)



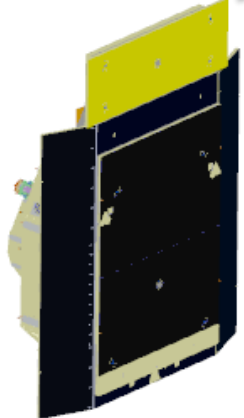
See Talks:

- 12180-61: Roman Space Telescope Wide Field Instrument Design Evolution
- 12180-226: Prism Assembly for Roman Space Telescope WFI Slitless Spectroscopy
- 12188-170: Spectral characterization of the RST Prism Optics Bandpass Filters



Imaging Optics Assembly (IOA)

Wide Field Instrument (WFI)
Cold Sensing Module (CSM)



Optical System Block Diagram

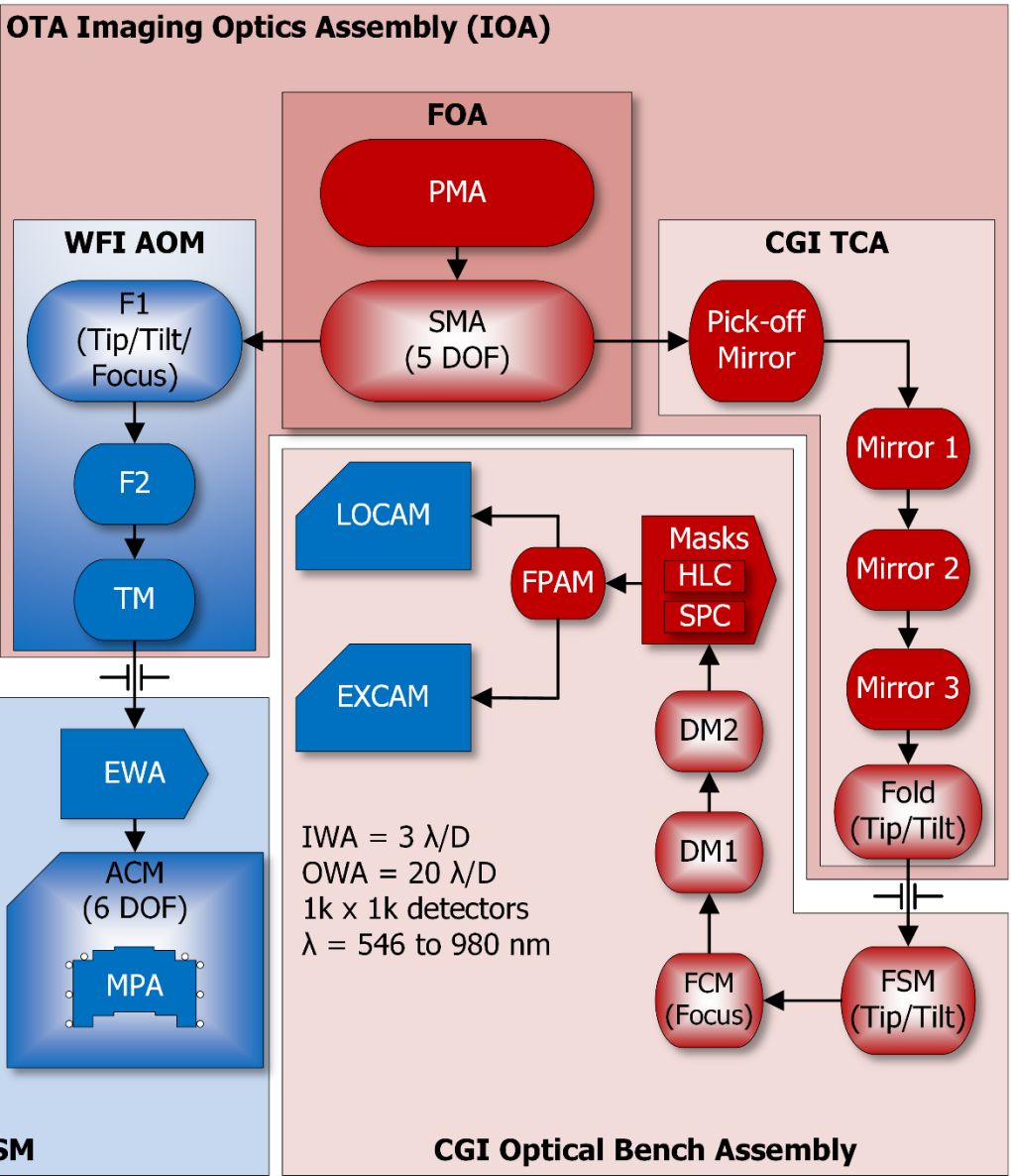
LEGEND

- Optic
- Flight Compensator
- Focal Plane
- Mechanism
- Optical Path
- Optical Pupil

2022-06-03

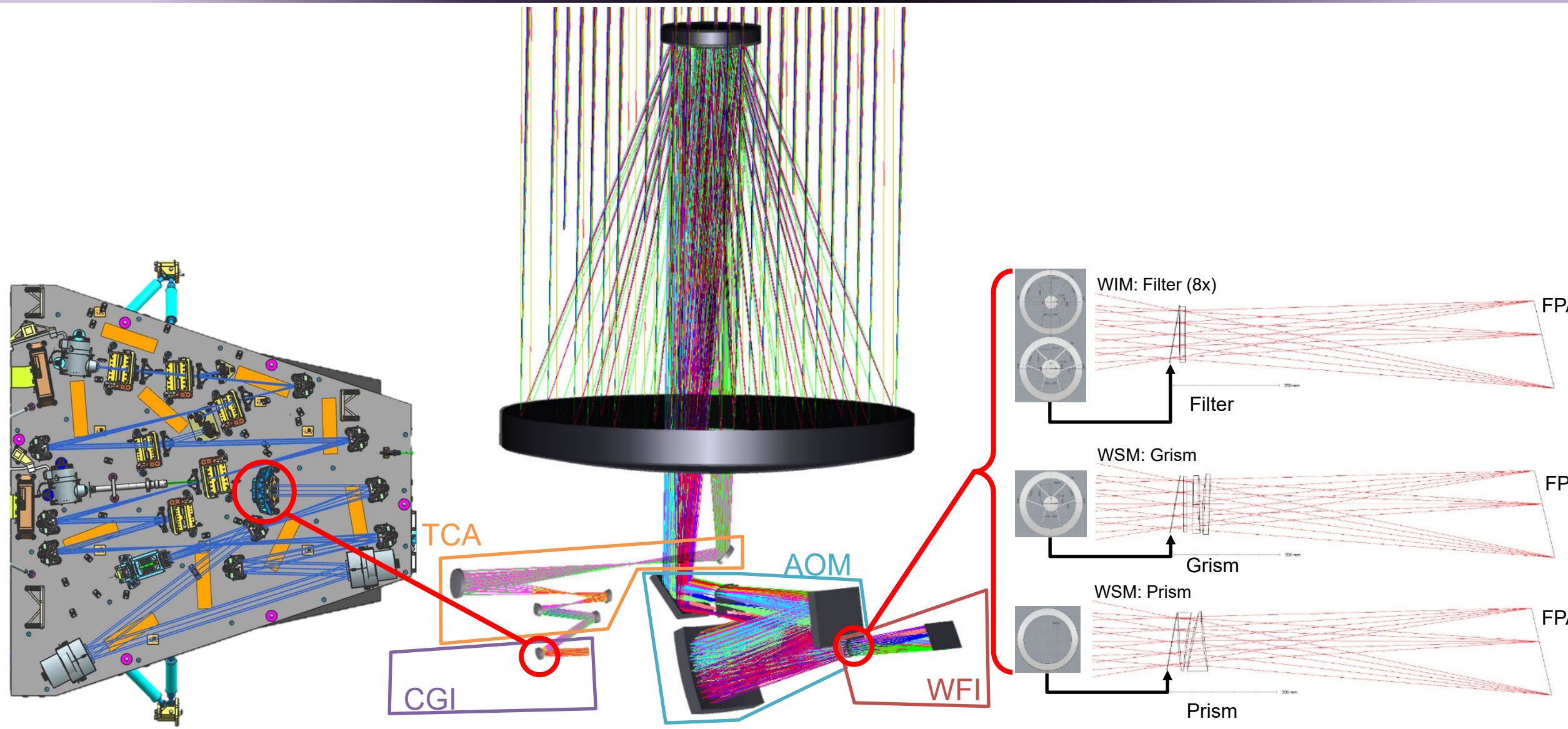
8 Filters
1 Grism
1 Prism
1 Cold Dark
18 H4RG detectors
10 μm pixel size
288 Megapixels
 $\lambda = 0.48$ to $2.3 \mu\text{m}$
 0.28 deg^2 active area
110 mas/pixel
f/7.9

WFI CSM

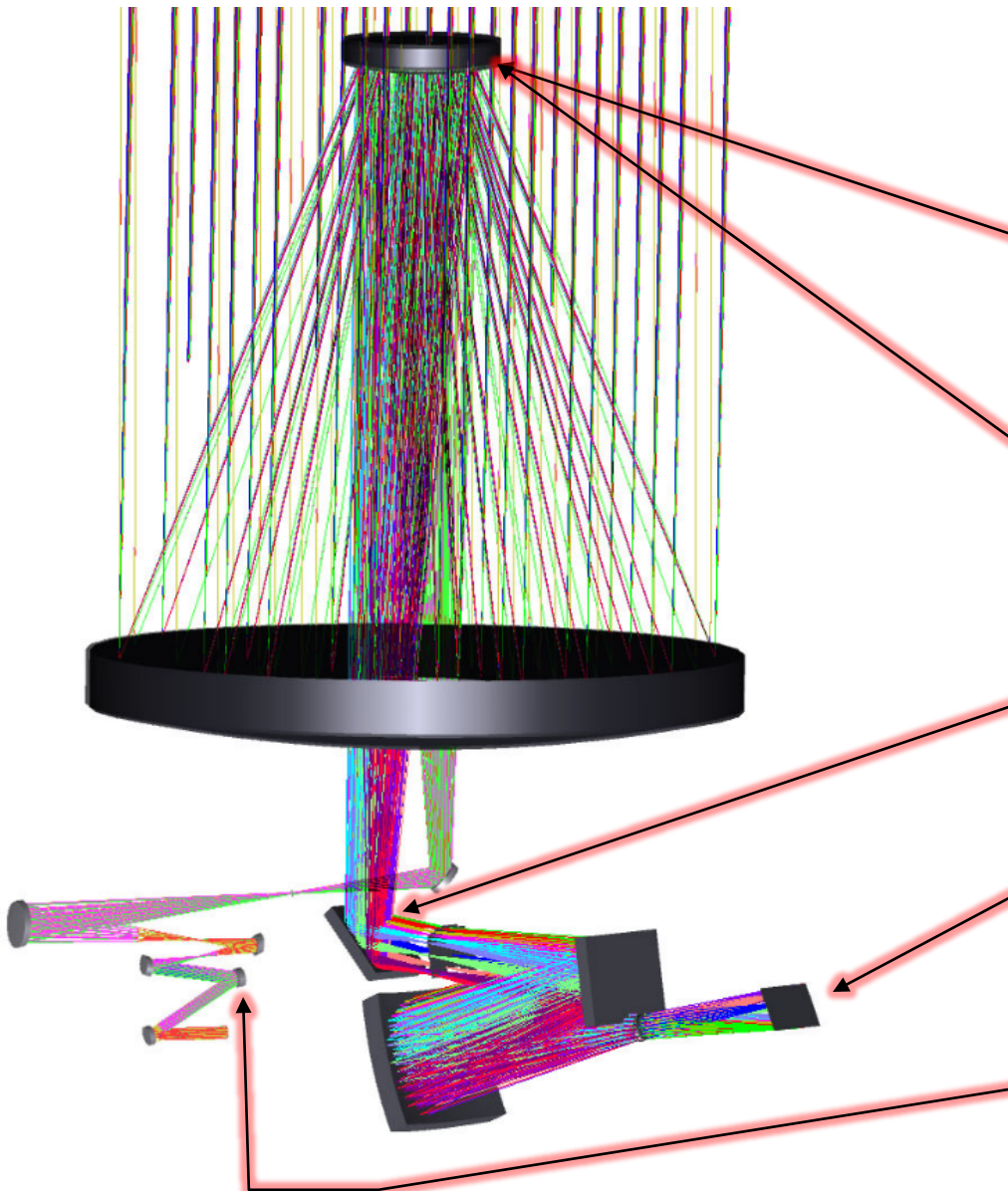


- AOM = Aft Optics Module
- ACM = Alignment Compensation Mechanism
- CGI = Coronagraph Instrument Assembly
- CSM = Cold Sensing Module
- DM = Deformable Mirror
- DOF = Degree of Freedom
- EWA = Element Wheel Assembly
- EXCAM = Exoplanet Camera
- FOA = Forward Optics Assembly
- FCM = Focus Control Mechanism
- F1/F2 = Fold Mirror 1/2
- FOA = Forward Optics Assembly
- FPAM = Focal Plane Mask Precision Alignment Mechanism
- FSM = Fast Steering Mirror
- HLC = Hybrid Lyot Coronagraph
- IOA = Imaging Optics Assembly
- IWA = Inner Working Angle
- LOCAM = Low Order Wavefront Sensing Camera
- MPA = Mosaic Plate Assembly
- OTA = Optical Telescope Assembly
- OWA = Outer Working Angle
- PMA = Primary Mirror Assembly
- RCS = Relative Calibration System
- SPC = Shaped Pupil Coronagraph
- TCA = Tertiary Collimator Assembly
- TM = Tertiary Mirror
- WFI = Wide Field Instrument

Optical Path



Optical Compensators



Compensator	Optical Degree of Freedom
SM Focus Drives (FD)*	Defocus
SM Alignment Drives (AD)*	Decenter (x)
	Decenter (y)
	Defocus
	Tip
	Tilt
AOM Fold Mirror 1 (FM1)	Defocus
	Tip
	Tilt
WFI Alignment Compensation Mechanism (ACM)†	Defocus
	Tip
	Tilt
TCA Tip/Tilt Fold (TTF)	Tip
	Tilt

*Heritage actuators from previous program
†Heritage JWST actuators

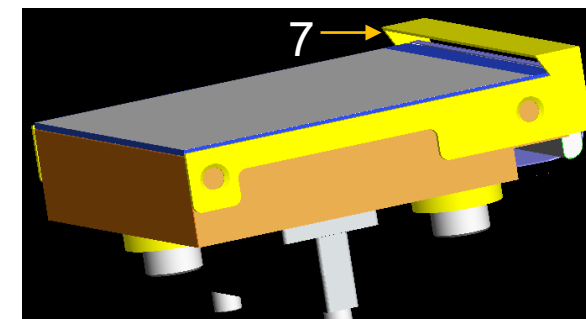
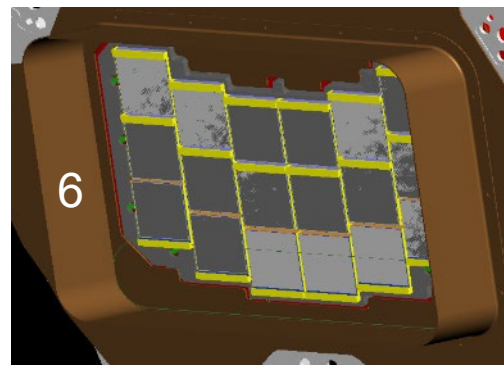
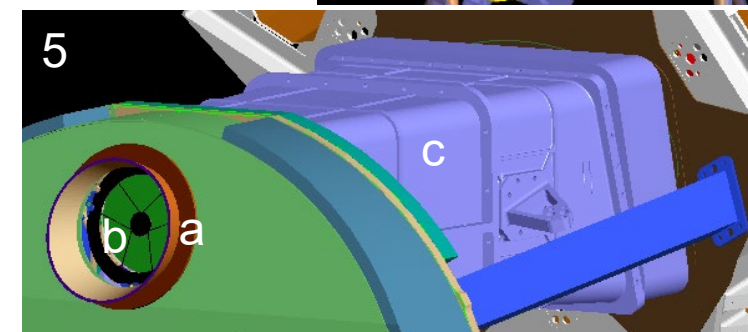
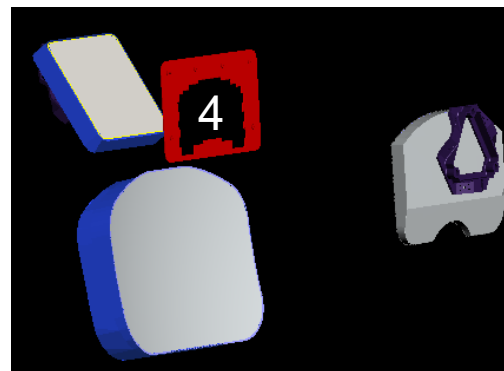
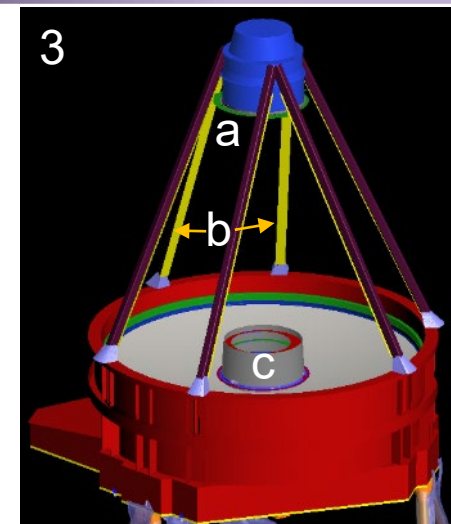
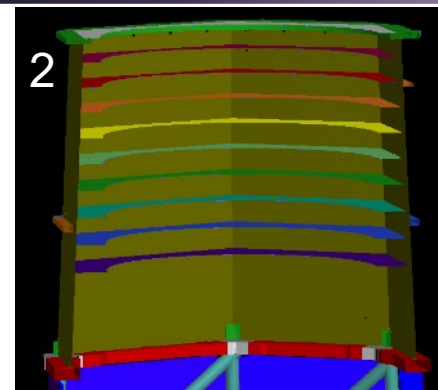
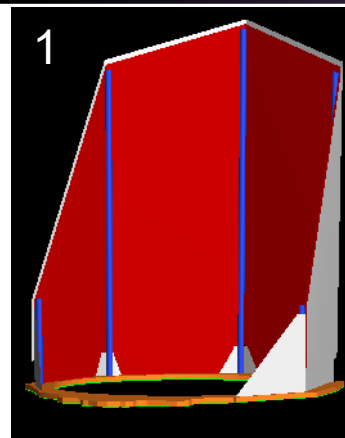
Compensate Wavefront Error (WFE) Errors Common to Each Channel

Compensate Focus & Pupil Shear in WFI Channel

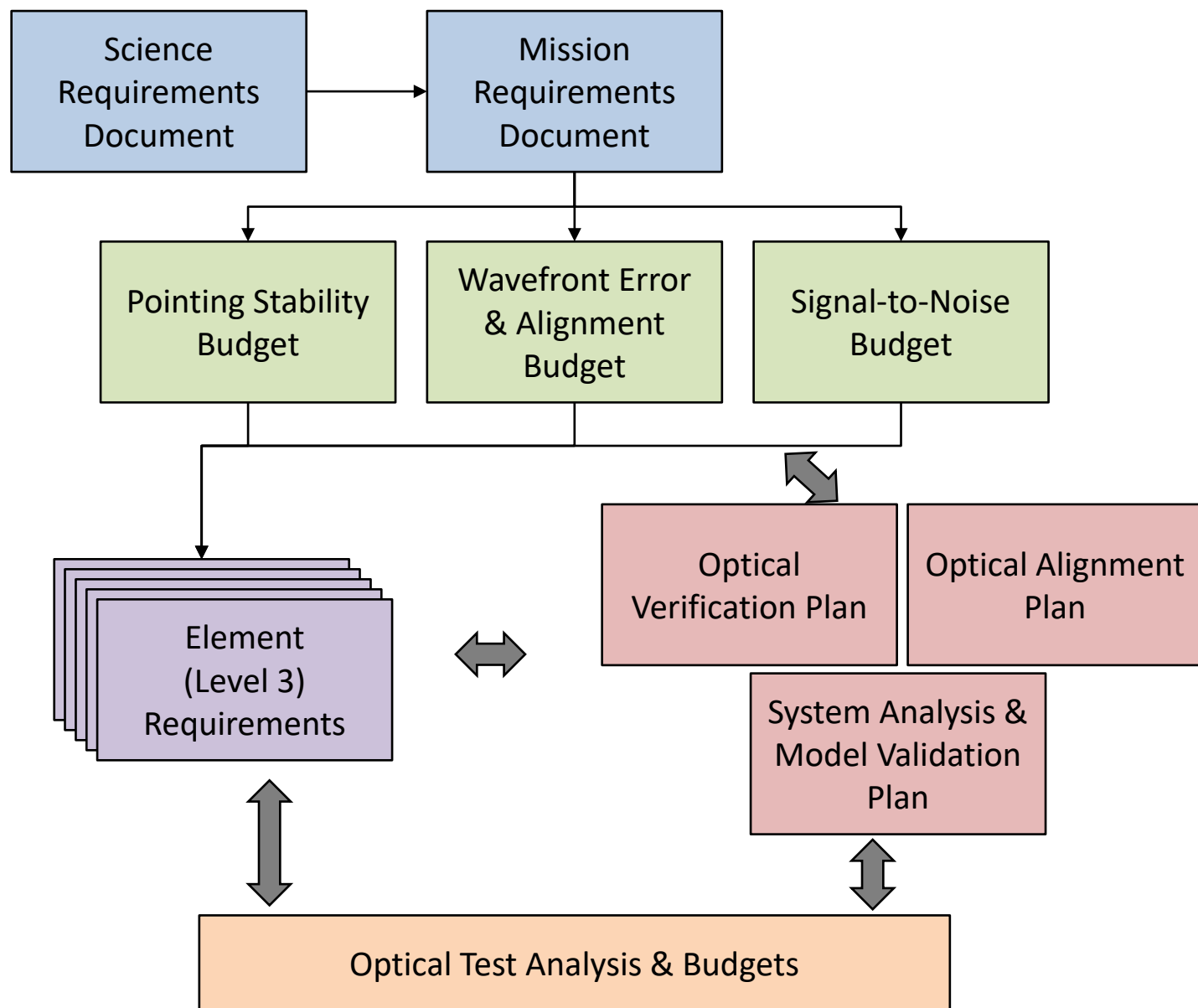
Compensate Pupil Shear in CGI Channel

Stray Light Controls

1. **Deployable Aperture Cover** keeps direct sun from entering the **Outer Barrel Assembly (OBA)** aperture
2. **OBA** baffle vanes limit simultaneous view of OBA walls from the sky and the primary mirror
3. **a) Secondary Mirror Shade & Scraper** limit grazing angle scattering from SM housing blankets
b) Secondary Mirror Support Tube (SMST) Scrapers limit grazing reflection from SMST thermal blankets
c) Primary Mirror Baffle limits direct view of aft-optics module (AOM) F1 from the sky
4. **Entrance Aperture Plate (EAP)** limits out-of-field light from getting into WFI (similar EAP in TCA channel not shown)
5. **a) WFI Stray Light Guard** mostly seals gap between AOM and WFI (similar stray light guard between TCA & CGI not shown)
b) Pupil Masks block thermal emission from warm telescope hardware
c) Cold Optics Baffle Assembly provides a dark and cold environment for the focal plane
6. **Labyrinth** allows on-orbit movement of focal plane while closing off stray light paths from warmer WFI electronics, etc.
7. **Sensor Chip Assembly wirebond shields** block out-of-field light from hitting shiny gold wires and wire bonds



Optical Requirement Allocation & Verification

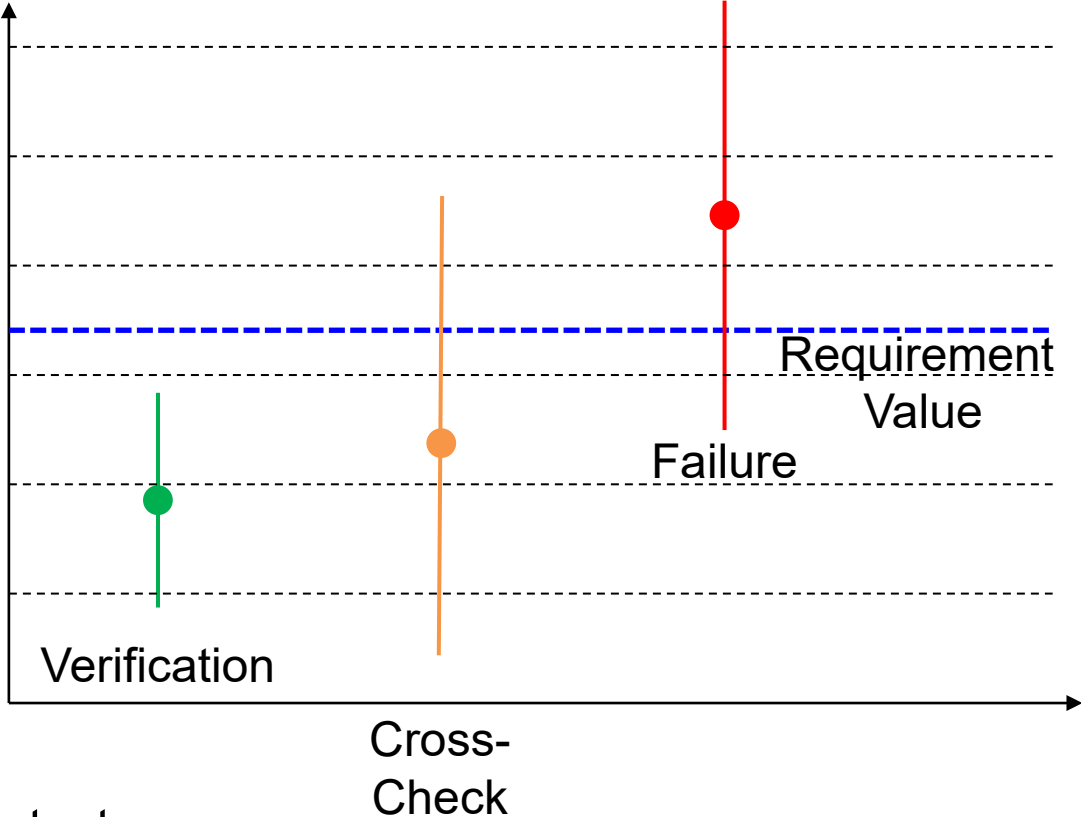


- **Budgets sub-allocate optical performance requirements to each element**
- **Requirements and budget allocations are verified by test and analysis**
 - Documented in Optical Verification Plan, Optical Alignment Plan, and System Analysis and Model Validation Plan
 - Analyses include integrated modeling*, stray light, optical Monte Carlo, and wavefront sensing & control
- **Optical test analysis and budgets are under development for supporting optical verification**

*See: 12187-33: Integrated Modeling Activities for NASA's Roman Space Telescope

- **Early in the Roman lifecycle, lessons learned from the Hubble Space Telescope Optical Systems Failure report (“Allen Report”) were used to establish a robust verification program**
- **Roman optical verification approach built upon 5 “pillars”:**
 1. Independent two-factor verification for mission critical components and assemblies
 2. Test-As-You-Fly verifications at the lowest possible level of assembly
 3. Independent technical reviews throughout alignment, integration, and test
 - Periodic Optical Verification Peer Reviews (at least 1 per mission phase)
 - Reviews of all analytical back-outs and pre-flight biases (Model Validation & Integrated Modeling Peer Reviews)
 - Optical test plans and procedure reviews; Test Readiness Reviews
 - Design reviews for all optical ground support equipment (null correctors, holograms, test sets, etc.)
 4. Independent review of element level verifications
 - Element Pre-Ship Reviews
 - Subject Matter Expert / Signature Authority agreement on Level 3 verification artifacts for Level 2 verification
 5. Rigorous, formal risk management of the optical fabrication and test program

- **Optical cross-checks of key mission critical components and assemblies minimize the risk of an uncompensatable error making it to orbit undetected**
- **Optical Cross-Checks:**
 - Independent means of measuring same quantity as verification test
 - Larger uncertainties that must envelope the primary verification measurement
- **Examples:**
 - Cross-check PMA gravity figure
 - **Verification:** PMA gravity-offloaded test
 - **Cross-check:** PMA horizontal multi-orientation
 - End-to-end wavefront error
 - **Verification:** IFA-level full-aperture interferometry test
 - **Cross-check:** IPA-level sub-aperture focus-diverse phase retrieval (FDPR) test



WFI Channel End-to-End Optical Verification



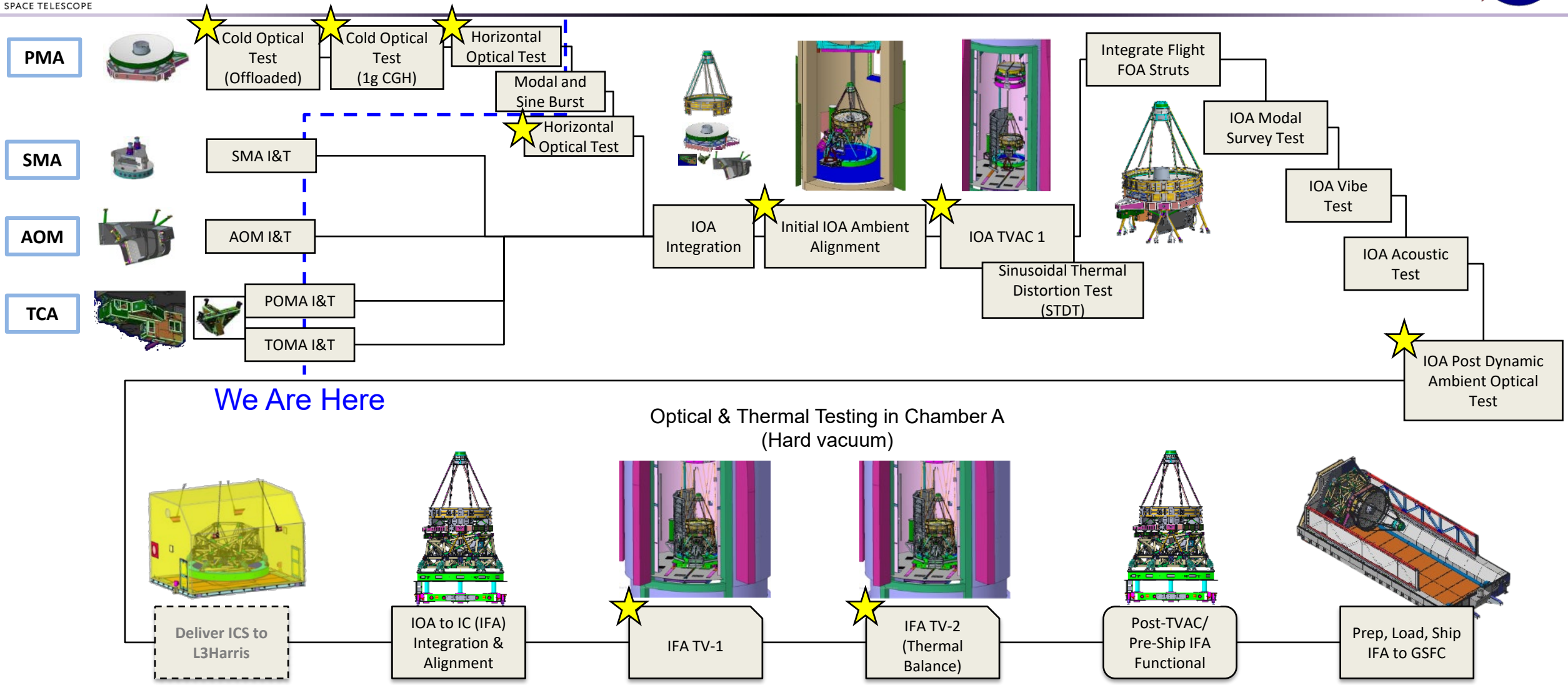
Element:		OTA										WFI								
Sub-System:		FOA		AOM						EWA				MPA						
= Flight hardware present		PM		SM		FM1		EAP		FM2		TM		Filter+Mask	Prism+Mask	Grism+Mask	Dark		SCAs	
= Non-flight hardware present																				
V = Final Verification Event																				
Test Activity	PM (Offloaded, Offner, Ambient)																			
	PM (Offloaded, CGH, OpTemp)																			
	PM (Offloaded, Offner, Ambient)																			
	PMA (Offloaded, CGH, OpTemp)																			
	PMA (1g CGH, OpTemp)																			
	PMA (Horizontal, Pre & Post Env., Ambient)																			
	SM (Coated, Ambient)																			
	SMA (Pre & Post Env., Ambient)																			
	FM1 (Coated, Ambient)																			
	FM1A (Pre & Post Env., Ambient)																			
	FM2 (Coated, Ambient)																			
	FM2A (Pre & Post Env., Ambient)																			
	TM (Coated, Ambient)																			
	TMA (OpTemp)																			
	TMA (Pre & Post Env., Ambient)																			
	Filter (Uncoated Substrate, Vendor + Ball X-check)																			
	Filter (Coated, Unmounted)																			
	Filter (Coated, Mounted, Pre & Post Env.)																			
	Prism (WFE, OpTemp)																			
	Prism(WFE, Spec., Pre & Post Env., Ambient)																			
	Grism (WFE, OpTemp)																			
	Grism (WFE, Spec., Pre & Post Env., OpTemp)																			
	IOA (Pre-Vibe OpTemp, I/F)																			
	IOA (Pre-Vibe OpTemp, FDPR)																			
	IOA (Post-Vibe Ambient, I/F)																			
	IOA (Post-Vibe Ambient, FDPR)																			
	IFA (Surrogate Filter, Offloaded, I/F, OpTemp)	V																		
	IFA (Surrogate Filter, Offloaded, FDPR, OpTemp)																			
	IFA (Surrogate Filter, FDPR, OpTemp)																			
	EWA (OpTemp)																			
WFI (SORC, OpTemp, Pre & Post Env.)													V							
IPA (Sub-ap WFE Test, OpTemp)																				
IPA (LED System Test, OpTemp)	V																			

CGI Channel End-to-End Optical Verification



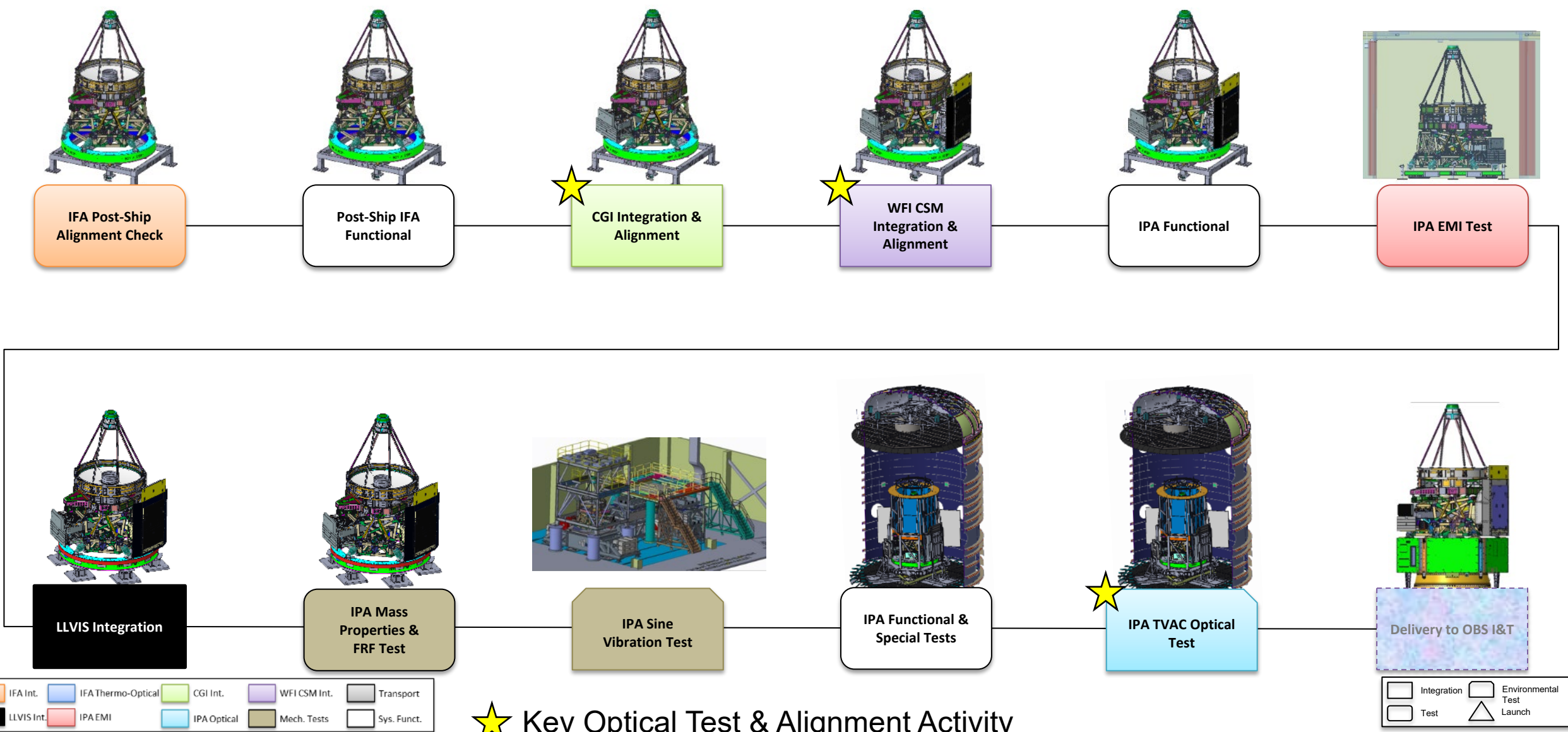
Element:		OTA														CGI		
Sub-System:		FOA			TCA													
= Flight hardware present		PM			SM		POMA		EAP		M3		M4		M5		TTF	
= Non-flight hardware present																		
V = Final Verification Event																		
Test Activity	PM (Offloaded, Offner, Ambient)																	
	PM (Offloaded, CGH, OpTemp)																	
	PM (Offloaded, Offner, Ambient)																	
	PMA (Offloaded, CGH, OpTemp)																	
	PMA (1g CGH, OpTemp)																	
	PMA (Horizontal, Pre & Post Env., Ambient)																	
	SM (Coated, Ambient)																	
	SMA (Pre & Post Env., Ambient)																	
	POMA (on Reaction Struct., Pre & Post Env.)																	
	M3 (on Reaction Struct., Pre & Post Env.)																	
	M4 (on Reaction Struct., Pre & Post Env.)																	
	M5 (on Reaction Struct., Pre & Post Env.)																	
	TTF (on Reaction Struct., Pre & Post Env.)																	
	TOMA (Ambient Alignment)																	
	IOA (Pre-Vibe OpTemp, I/F)																	
	IOA (Post-Vibe Ambient, I/F)																	
	IFA (Surrogate Filter, Offloaded, I/F, OpTemp)																	
	CGI (Instrument Alignment, Ambient)																	
	CGI (Post Env. Functional Test, OpTemp)																	
	IPA (FSA Fiber Test, OpTemp)																	

Optical Test & Verification Plan – OTA



★ Key Optical Test & Alignment Activity

Optical Test & Verification Plan – IPA



Optical Verification Summary



- WFI-level:
 - **Verify** instrument-level optical wavefront error with FDPR & Stimulus of Ray Cones (SORC)
 - SORC is optical ground-support equipment that provides a telescope-like stimulus to the WFI instrument
 - **Verify** instrument-level alignment allocations with metrology & SORC
- IFA-level (IOA+IC with T-Bar and V-Bar alignment GSE):
 - **Verify** optical wavefront error with double-pass interferometry (both channels)
 - **Risk reduction** for IPA wavefront error measurements with FDPR (WFI channel only)
 - **In-process** optical alignment measurements with interferometry (both channels) and FSA Fiber sources (CGI channel only)
- IPA-level:
 - **Cross-check** optical wavefront error with sub-aperture FDPR (WFI channel only)
 - **Verify** optical alignment with LED System and sub-aperture FDPR (WFI channel)
 - **Verify** optical alignment with FSA Fiber sources (CGI channel)
- Observatory level (contingency only):
 - **Cross-check** optical wavefront error with sub-aperture FDPR (WFI channel only)
 - **Trend** optical alignment with LED System (WFI channel only)

NOTE: Cross-check measures a change in the verified wavefront that would correspond to an optical performance that would violate the tightest **threshold** Level 1 science requirement.

- **Nancy Grace Roman Space Telescope has recently passed its Mission Critical Design Review, and is proceeding to Flight build**
- **Roman Flight optics all in hand and in assembly-level I&T**
- **The optical verification plan is effective, technically achievable, and well-understood**
 - Two-factor verification of mission-critical components / assemblies
 - Verification complete at lower levels of assembly, with cross-checks at higher levels
 - End-to-end verification activities are documented
 - All optical interfaces are verified