ROMAN
SPACE TELESCOPE

Roman Space Telescope Integrated Modeling

7/19/2022

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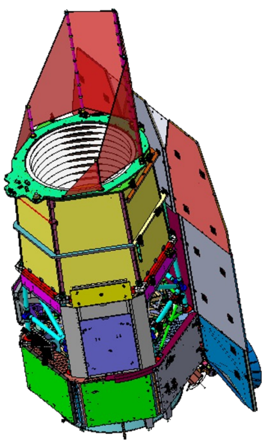
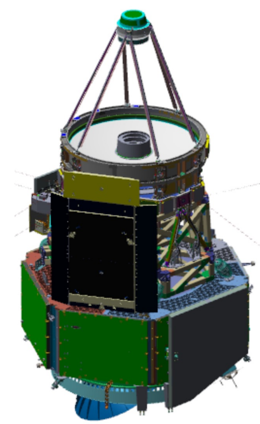
Introduction

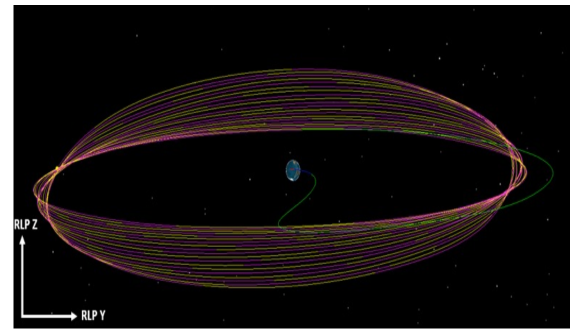
- The Nancy Grace Roman Telescope (Roman) is a NASA observatory designed to unravel the secrets of dark energy and dark matter, search for and image exoplanets, and explore many topics in infrared optics.
- Scheduled to launch in the mid-2020s, this 2.4-meter aperture telescope has a field of view 100 times greater than the Hubble Space Telescope.
- The mission is currently in its construction phase, where integrated modeling between thermal, structural, and optical models of the observatory is necessary to demonstrate science quality images over the range of operational parameters.
- This presentation discusses integrated modeling results from the Roman mission Critical Design Review.
- Outline:
    1. RST Mission and Model Overview
    2. Observatory Models and Processes
    3. Analyses and Example Results
    4. Cross-checks
    5. Monte-Carlo and End-to-End modeling



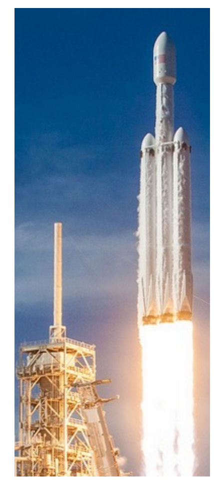


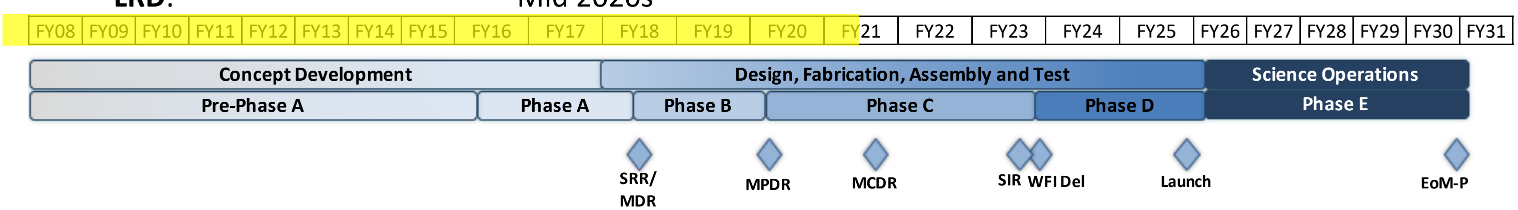
Roman Mission Overview

- **RST:** Nancy Grace Roman Space Telescope (Class A)
- **Mission:** Wide-Field Infrared Survey
- **Objectives:**
  - Characterize the history of cosmic acceleration and structure growth
  - Understand how planetary systems form and evolve and determine the prevalence of planets in the colder outer regions
  - Provide a peer-reviewed General Observer & Archival Research program
  - Develop and fly a technology demonstration of advanced starlight suppression technology, which could be used for direct imaging and spectroscopy of planets and debris disks.
- **Mission Duration:** 5 years science
- **Orbit:** Quasi-Halo Orbit about Sun-Earth L2
- **Launch Vehicle:** Falcon Heavy *OR* Vulcan
- **Launch Site:** Eastern Range
- **Mission Budget:** $3 Billion
- **Mass:** 10.9 metric tons
- **LRD**: Mid 2020s



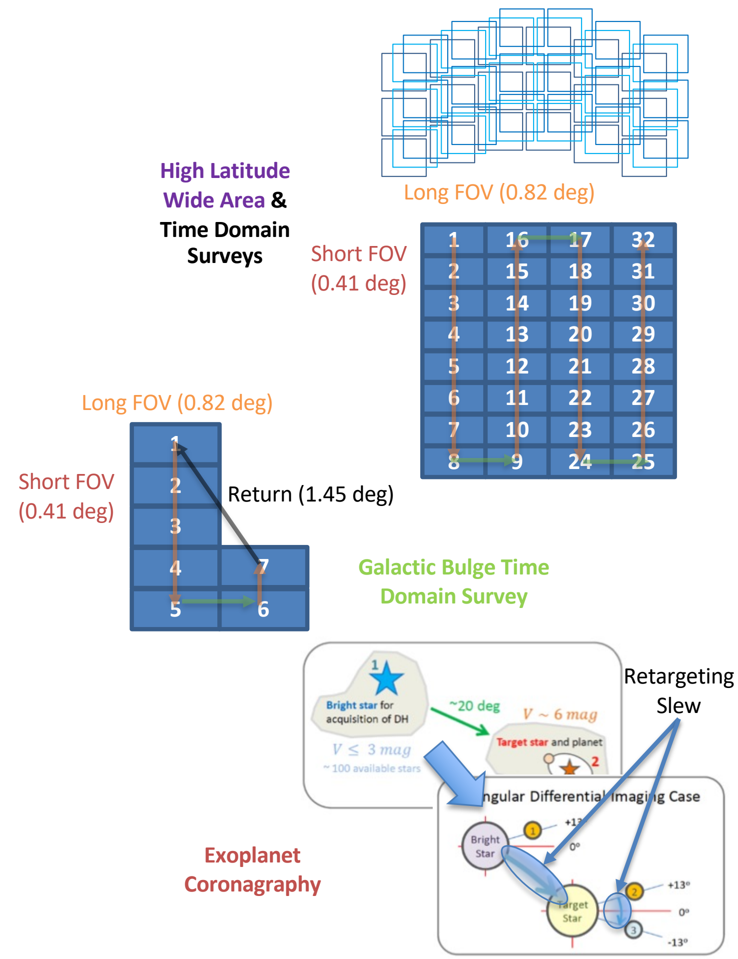
VIEW FROM EARTH TO L2



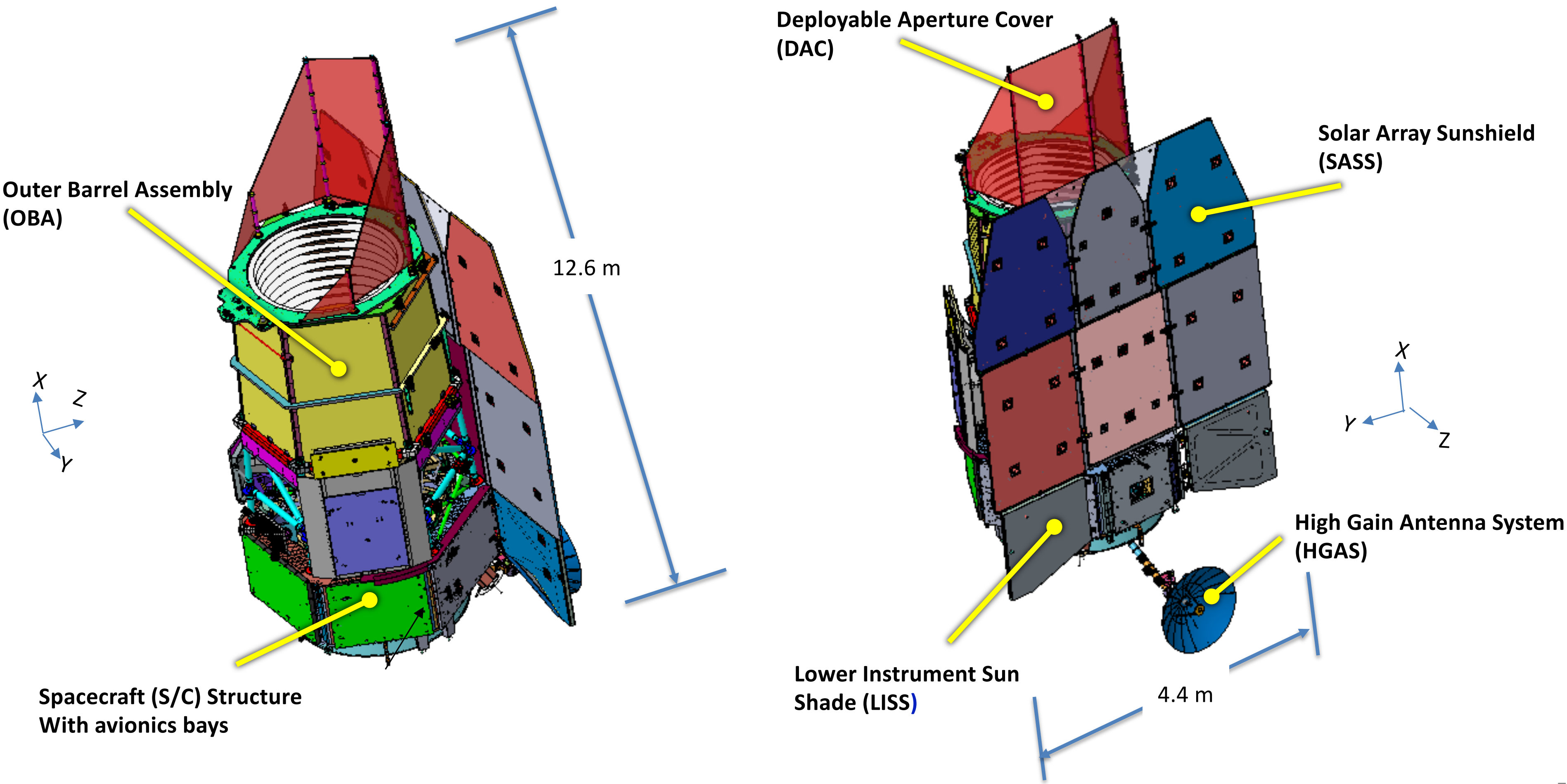


Roman Mission Observing Programs

- **The Roman Mission consists of a five-part observing program:**
  1. **High Latitude Wide Area Survey:** Spectroscopic & Imaging sky survey for Baryon Acoustic Oscillation (BAO) / Redshift space distortion (RSD) & Weak Lensing/Galaxy Clustering
     - Mapping >1,700 deg2, observations of ~140 sec (imaging) or ~300 sec (spectroscopy)
  2. **High Latitude Time Domain Survey:** Multiple visits to fields at high ecliptic latitudes to discover and track Supernova
     - 30 hours of imaging and spectroscopic observations every 5 days
  3. **Galactic Bulge Time Domain Survey:** Repeated visits to fields near the Galactic bulge to monitor planetary microlensing events
     - Repeated viewing of 7 fields every 15 minutes for 60 days
  4. **Exoplanet Coronagraphy:** Targeted observations of nearby stars for technology demonstration of high-contrast imaging and spectroscopy
  5. **General Investigator:** Allocated time for proposers to observe targets anywhere within the field of regard
     - All portions of the sky in the FOR are visible during otherwise-unallocated time

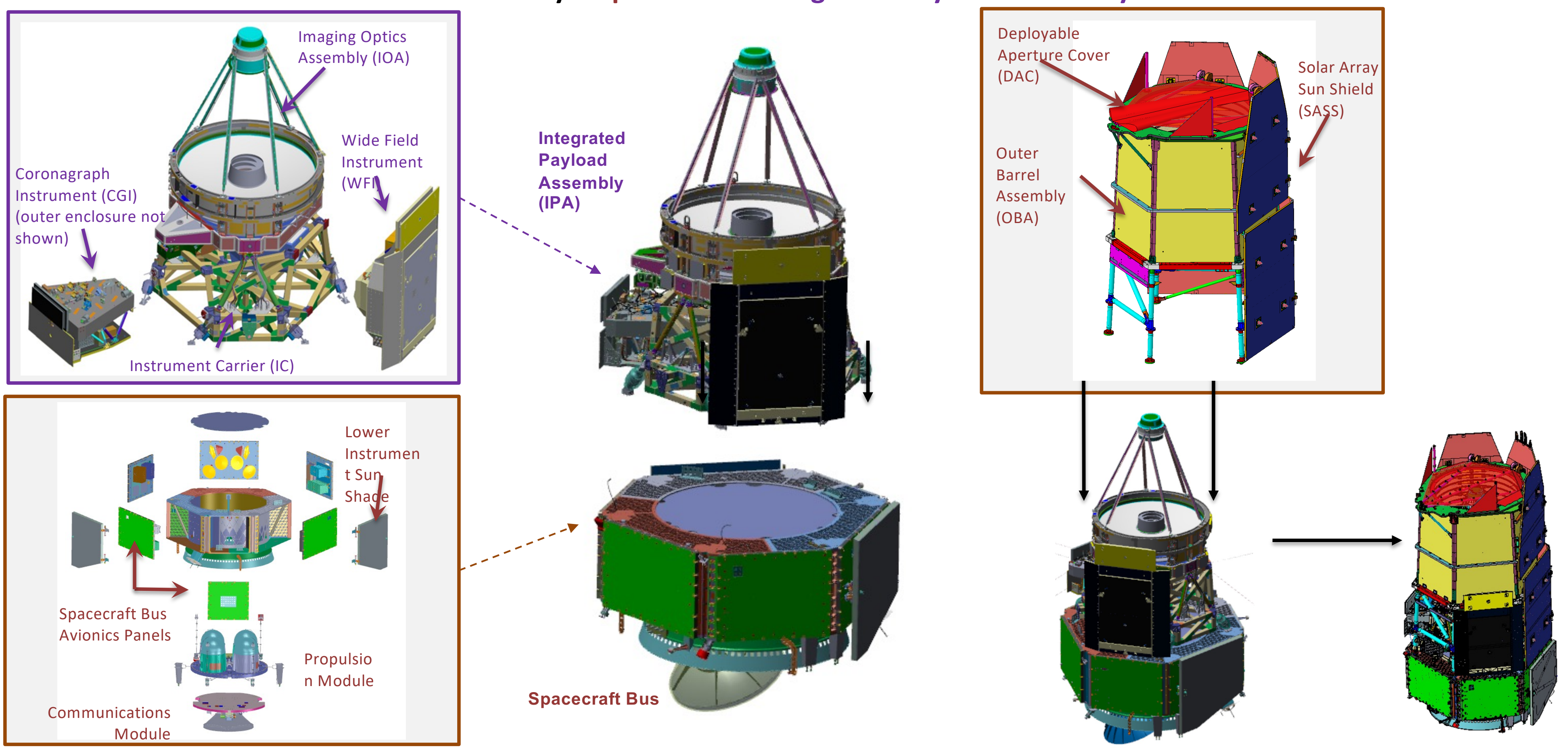


Roman Model Overview, Observatory Deployed

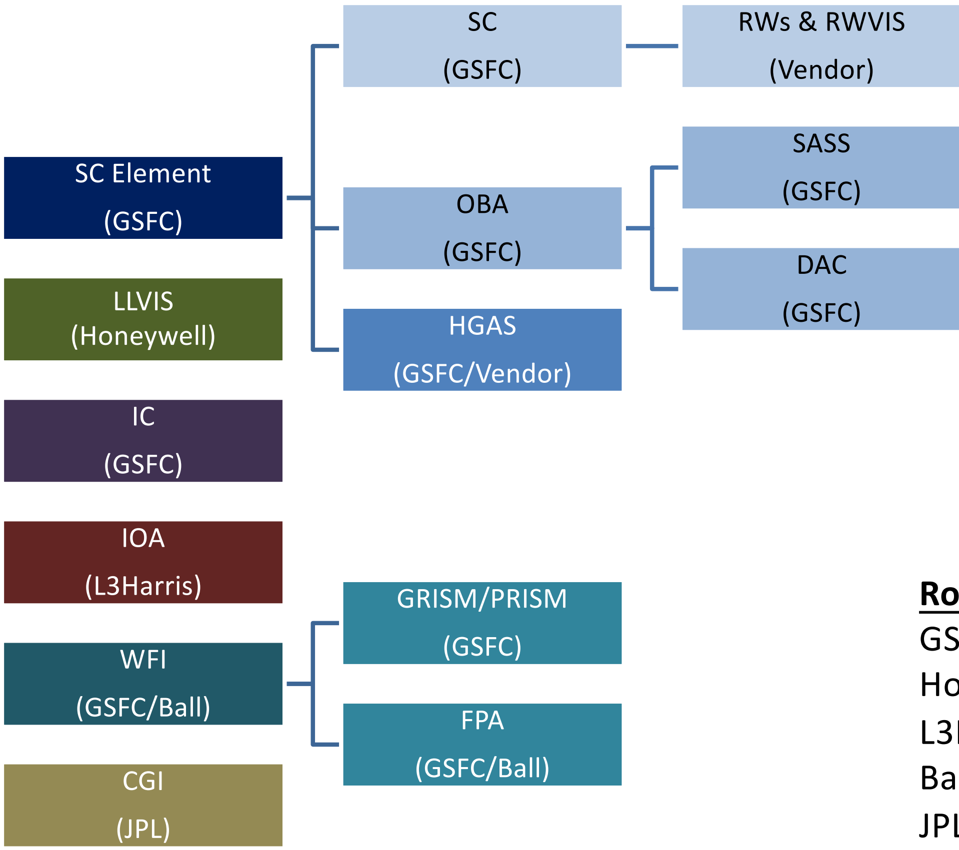


Roman Observatory Model Expanded View

Observatory = Spacecraft + Integrated Payload Assembly



Roman Observatory Model Components



- **Component models are delivered to GSFC**
- **Each component is individually checked out against the Math Model Guidelines**
- **Components are integrated into the overall Observatory Integrated Model**
- **Observatory model is modular**
  - Constructed using INCLUDE files
  - Any component(s) can be removed or run separately

<u>Roman Space Telescope Contributors</u>

GSFC = NASA Goddard Space Flight Center
Honeywell = Honeywell Aerospace
L3Harris = L3Harris Corp, Rochester NY
Ball = Ball Aerospace
JPL = NASA Jet Propulsion Lab

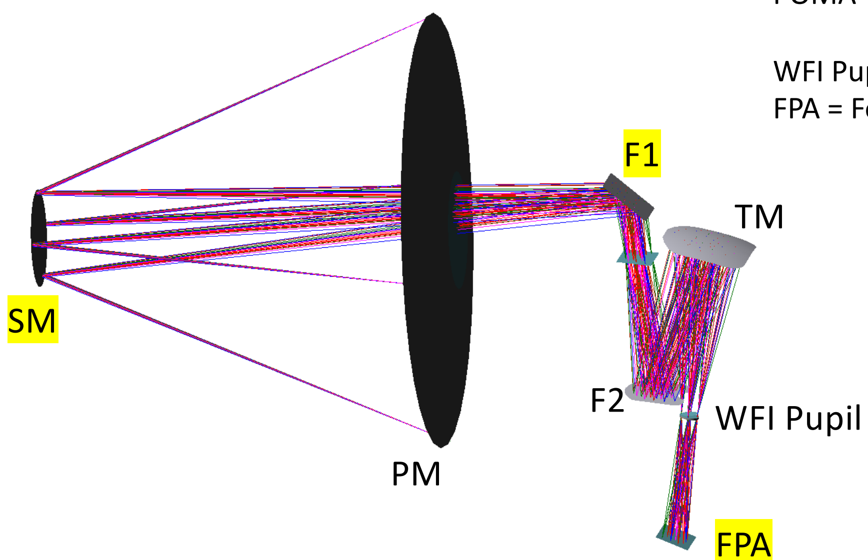
Roman Observatory Optical Models (CODE V)

One Telescope, Two instruments: Wide Field Instrument (WFI), and Coronagraph Instrument (CGI)

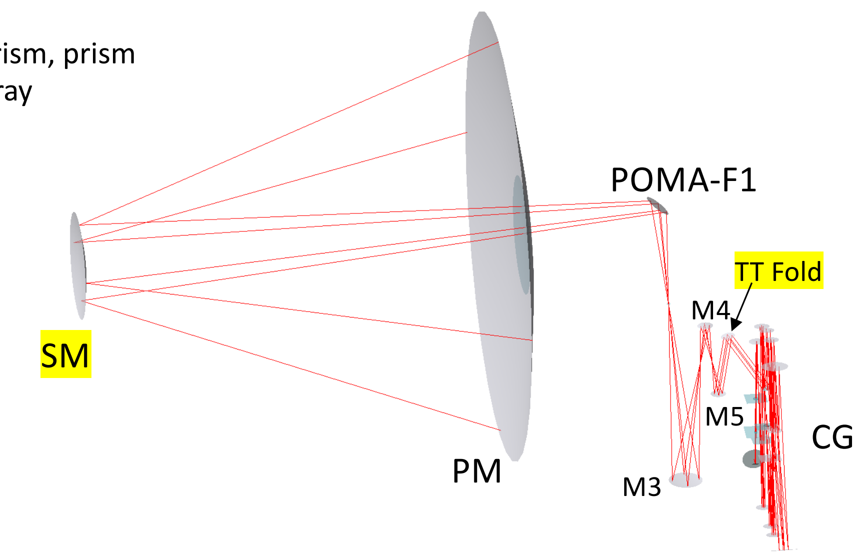
PM = Primary Mirror
SM = Secondary Mirror
F1 = Fold 1
F2 = Fold 2
TM = Tertiary Mirror
POMA = Pickoff Mirror Assembly

WFI Pupil = filters, grism, prism
FPA = Focal Plane Array

Wide Field Instrument (WFI)



Coronagraph Instrument (CGI)



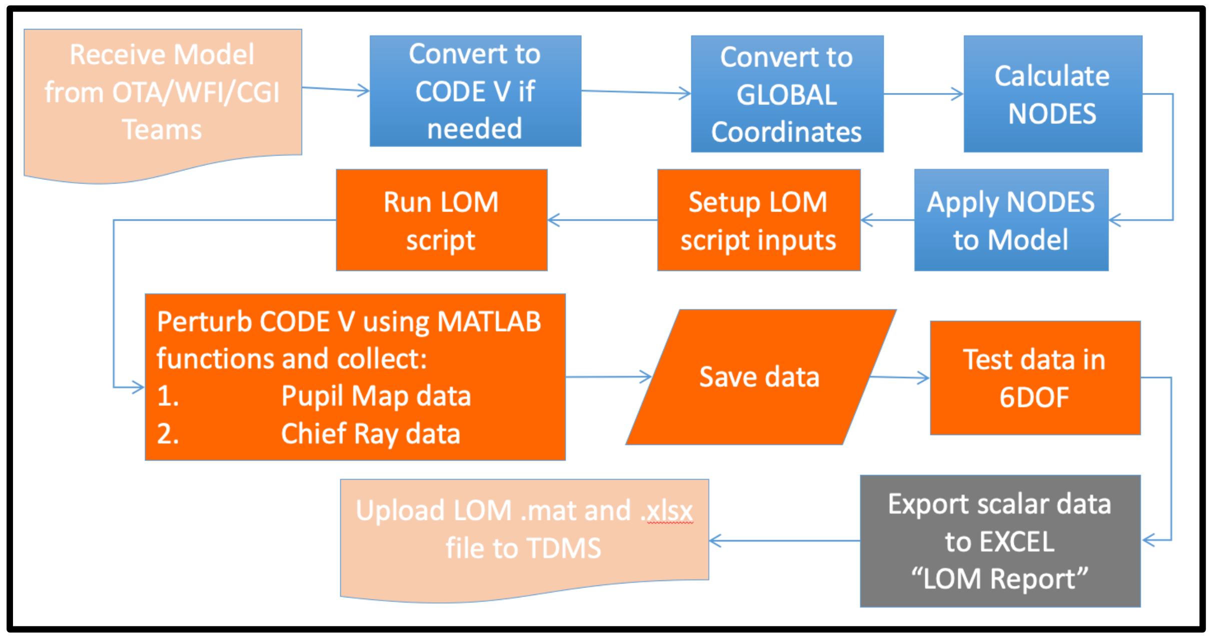
Movable Optics: SM (5dof), F1 (3dof), FPA (3dof), TT Fold (2dof)

Roman Observatory Linear Optical Models (LOMs)

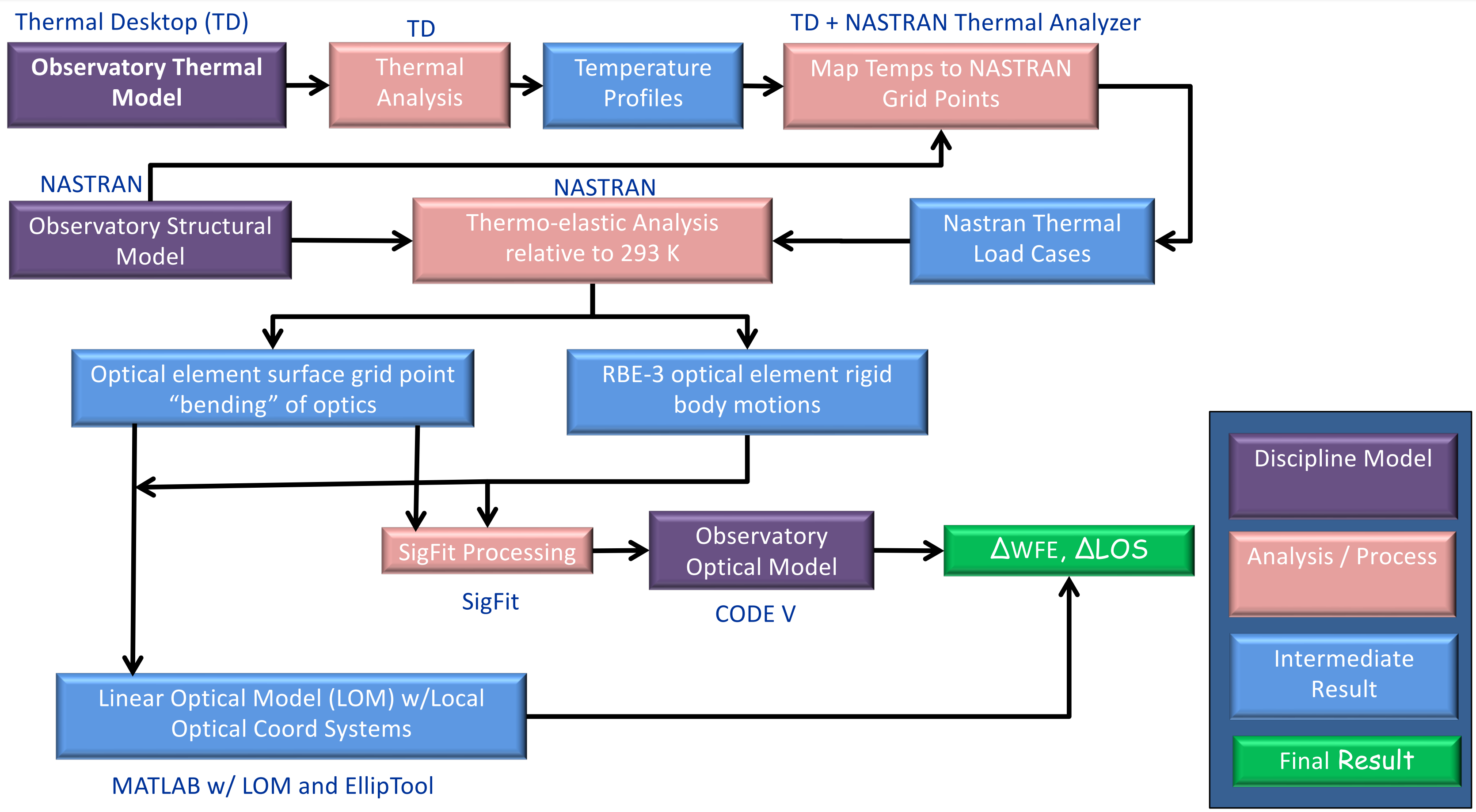
- **Linear Optical Models (LOMs) are built in MATLAB for each of the configured optical models**
- **The LOMs are used for:**
  1. Integrated Modeling analyses as a kernel for "EllipTool" (jitter, LOS, alignment, wavefront performance)
  2. End-to-End modeling of science image predictions
  3. Compensation/optimization analysis

LOMs have an optical model worst case estimation error < 2% when compared directly to CODE V for most uses on RST. Thermal cooldown is generally considered to have the highest error.

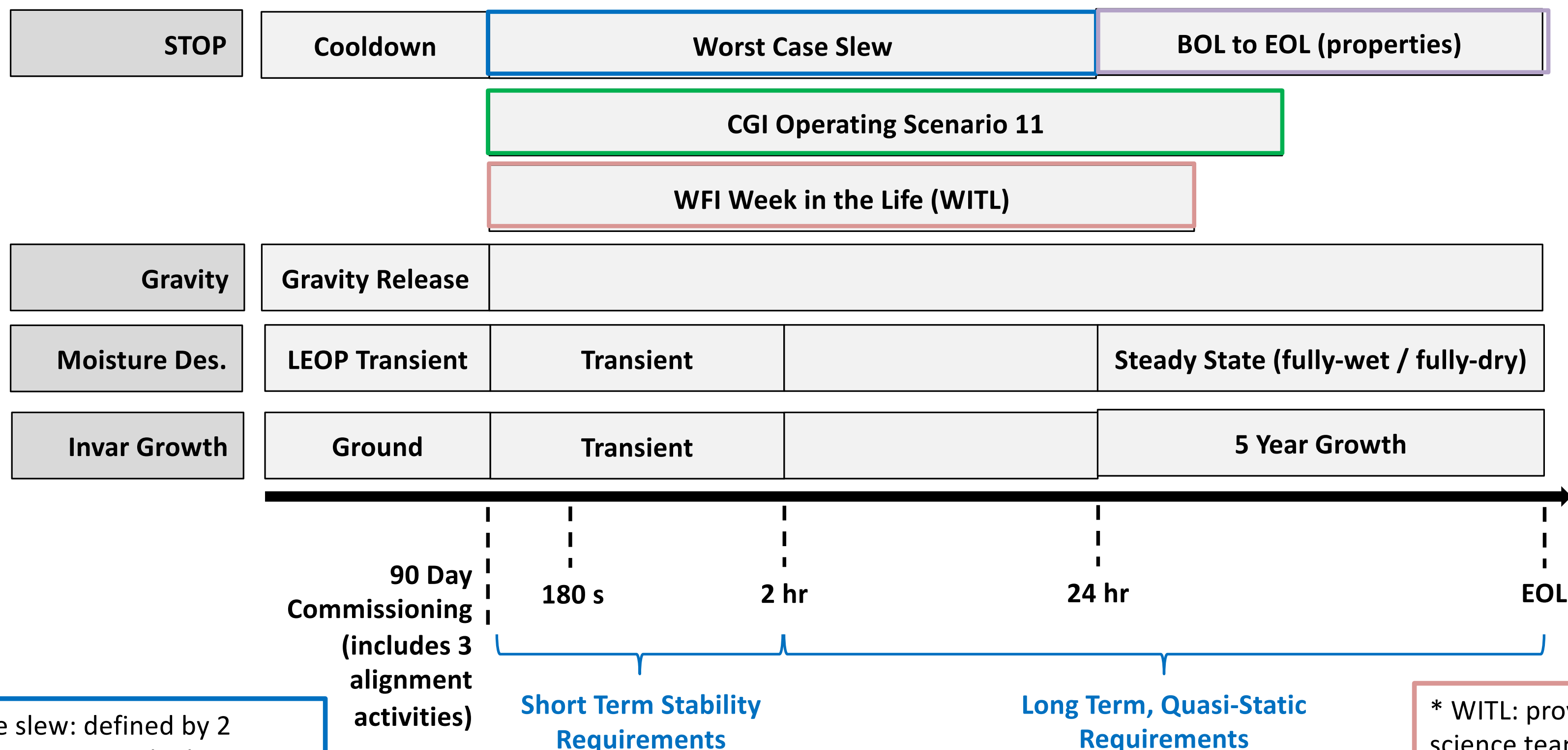
LOM "build" process



Roman STOP Process



Roman Space Telescope Analysis Cases



* Worst case slew: defined by 2 attitudes that generate the largest WFE difference
* Use sliding windows to predict stability performance

BOL to EOL: capture effects due to thermal property changes from BOL to EOL

OS-11: scenario defined by CGI team for verifying CGI stability requirements

* WITL: provided by WFI science team to represent realistic survey scenario
* Use this case to show margin against worst case slew

EXAMPLE STOP Analysis: Cooldown Results vs. allocations

Cooldown Results

Cycle 2.0	RMS WFE [nm] Cooldown (Uncompensated)				RMS WFE [nm] Cooldown (Compensated)							
	FILTER (FOV95%)	GRISM (FOV95%)	PRISM (FOV90%)	CGI (WF)	FILTER (@1200nm) (FOV95%)		GRISM (@1550nm) (FOV95%)		PRISM (@1200nm) (FOV90%)		CGI (@685nm) Worst Field	
					Alloc.	CBE	Alloc.	CBE	Alloc.	CBE	Alloc.	CBE (@ CGI focus)
OBS (SE_MUF)	423.3	419.2753	401.9	319.8		15.5		18.3		18.3	19.3	9.4
OBS (SE_MUF + TO)						15.3		22.29		18.1		
OBS (SE_MUF + TO _MUF)						15.3		25.5		18.2		
Element Level (SO_MUF)						0.3		0.3		7		
RSS {OBS (SE_MUF + TO _MUF), Element Level (SO_MUF)}					23.5	15.3	53.3	25.5	33.7	19.5		

Roman Modeling Cross-Checks

- **Cross-checks between analysis teams and institutions are important to verify consistent predictions and results and provide opportunities to improve processes.**
- **The RST approach toward cross-checks is to perform independent analyses that show consistency between whether requirements are met or not, and the general margin levels that result.**
- **In this context, independent analyses rely on the same models but different analysis processes, techniques, and assumptions.**
- **EXAMPLE Cross-checks performed:**
  1. Cooldown of the Telescope (GSFC and L3Harris)
  2. Wide Field Instrument (WFI) Cooldown alignment (GSFC and BATC)
  3. WFI Thermo-Optic performance predictions (GSFC and BATC)
  4. Coronagraph Instrument (CGI) Line of Sight analysis (GSFC and JPL)

Roman Optical Monte-Carlo Analysis

The Optical Monte-Carlo (MC) analysis has multiple uses:

- Simulate Alignment step by step
- Verify sufficient margin to tolerances and actuator ranges
- Provides input for to End-to-End performance estimates

The MC procedure is documented in a spreadsheet, where perturbations, optimization, and compensators are defined for each of the following 10 steps:

1-New Nominal Design
2-TOMA Box
3-IOA Alignment
4-IOA Cold Testing
5-IFA Alignment
6-WFI Integration
7-CGI Integration
8-IPA Vibration Test
9-Ground-to-Orbit
10-EOL

1: New Nominal Design

1a: Perturbations Applied

Sub-system	Component	Radius of Curvature Tolerance*	Radius of Curvature Uncertainty	Conic Constant Tolerance	Conic Constant Uncertainty	Rigid Body Position X/Y	Rigid Body Position Z	Rigid Body Position Tip/Tilt	Rigid Body Position Clock
		+/- mm	+/- mm	+/-	+/-	+/- mm	+/- mm	+/- arcsec	+/- arcsec
FOA	PM	0.7112	-	0	-	-	-	-	-
	SM	0.254	-	0.0002	-	-	-	-	-
	SM AD	-	-	-	-	-	-	-	-
	SM FD	-	-	-	-	-	-	-	-
	SMST	-	-	-	-	-	-	-	-
AOM	FM1	1.1e-8 mm^{-1}	-	-	-	-	-	-	-
	EAP	-	-	-	-	-	-	-	-
	FM2	6.67e-8 mm^{-1}	-	-	-	-	-	-	-
	TM	0.508	-	0.0001	-	-	-	-	-
POMA	F1	-	-	-	-	-	-	-	-
TOMA	EAP	-	-	-	-	-	-	-	-
	M3	0.508	-	0.0002	-	-	-	-	-
	M4	0.508	-	0.0002	-	-	-	-	-
	M5	0.508	-	0.0002	-	-	-	-	-
	TTF	-	-	-	-	-	-	-	-
	TCA-EXP	-	-	-	-	-	-	-	-
	Bench	-	-	-	-	-	-	-	-
IOA	FOA Struts	-	-	-	-	-	-	-	-
WFI	Lyot Mask	-	-	-	-	-	-	-	-
	Filter	-	-	-	-	-	-	-	-
	EWA	-	-	-	-	-	-	-	-
	FPA	-	-	-	-	-	-	-	-
	SIIP/Latch	-	-	-	-	-	-	-	-
CGI	CGI-ENP	-	-	-	-	-	-	-	-
	FSM	-	-	-	-	-	-	-	-
	DI Camera	-	-	-	-	-	-	-	-
	SIIP/Latch	-	-	-	-	-	-	-	-
TCA STE	TCA PRF	-	-	-	-	-	-	-	-
	TCA CGH	-	-	-	-	-	-	-	-
	TCA I/F	-	-	-	-	-	-	-	-
AOM STE	AOM PRF	-	-	-	-	-	-	-	-
	AOM ISRF	-	-	-	-	-	-	-	-
	AOM I/F	-	-	-	-	-	-	-	-
OBS	ACF	-	-	-	-	-	-	-	-
	Sky Angle	-	-	-	-	-	-	-	-

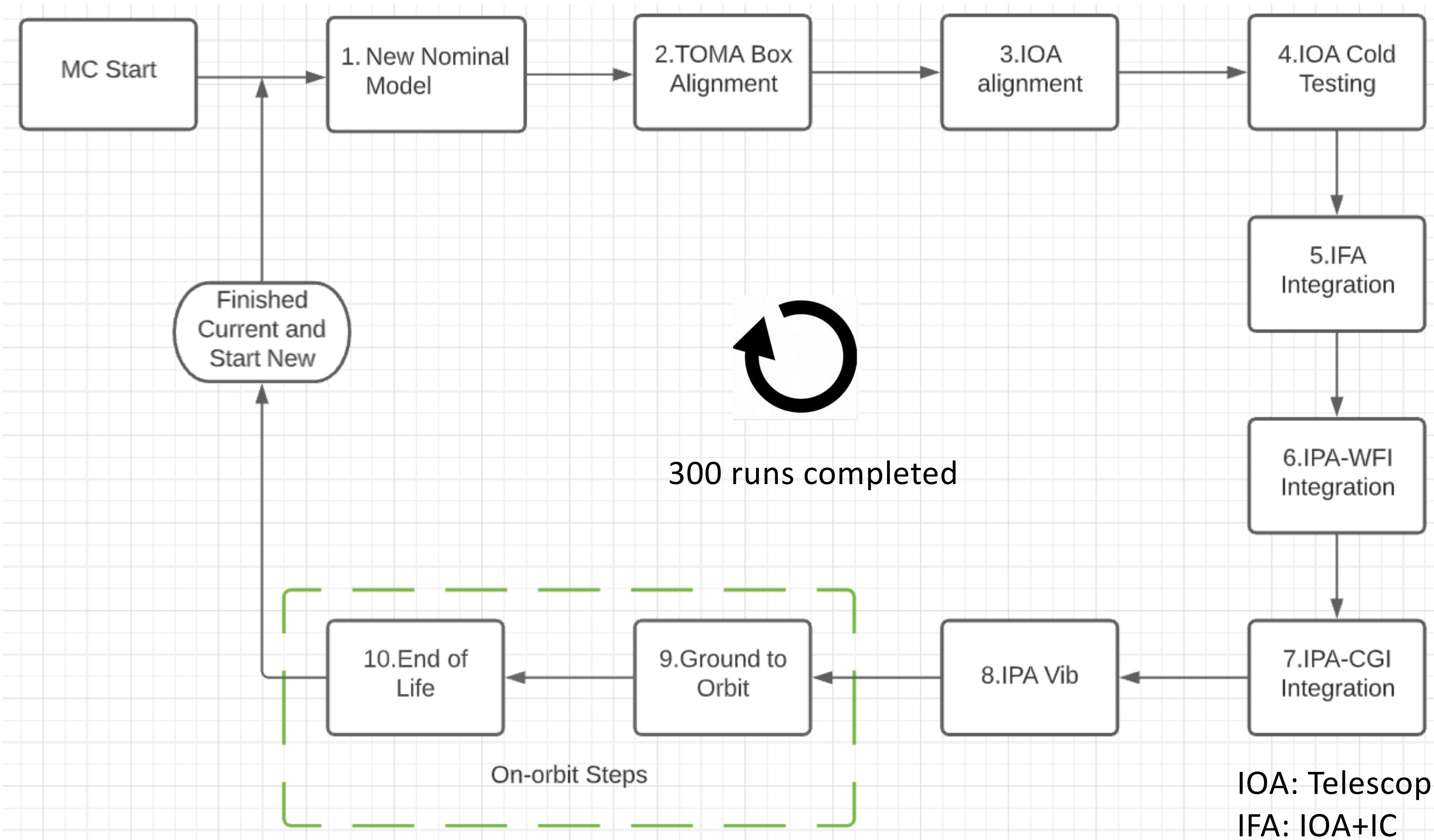
1b: Optimization

Metric	Channel: WFI	Channel: CGI
WFE	Match design residual	Match design residual
Pupil Shear	Chief ray location at Lyot Mask = 0	Chief ray location at TCA-EXP = 0
Pupil Clocking	-	-
Focal Surface	-	-
Img. Boresight	Chief ray angle at Lyot Mask = nominal	Chief ray angle at TCA-EXP = nominal
Obj. Boresight	-	-
Position in EAP	-	-

1c: Compensators Used & Compensator Range

Sub-system	Component	Compensator Range X/Y	Compensator Range Z	Compensator Range Tip/Tilt	Compensator Range Clock
		+/- mm	+/- mm	+/- arcsec	+/- arcsec
FOA	PM	-	-	-	-
	SM	-	[no limit]	-	-
	SM AD	-	-	-	-
	SM FD	-	-	-	-
	SMST	-	-	-	-
AOM	FM1	-	0.508	144	-
	EAP	-	-	-	-
	FM2	-	0.508	144	-
	TM	0.254	0.508	144	-
POMA	F1	-	0.508	144	-
TOMA	EAP	-	-	-	-
	M3	0.254	0.508	144	-
	M4	0.254	0.508	144	-
	M5	0.254	0.508	144	-
	TTF	-	-	144	-
	TCA-EXP	-	-	-	-
	Bench	-	-	-	-
IOA	FOA Struts	-	-	-	-
WFI	Lyot Mask	-	-	-	-
	Filter				
	EWA	-	-	-	-
	FPA	-	-	-	-
	SIIP/Latch	-	-	-	-
CGI	CGI-ENP	-	-	-	-
	FSM	-	-	-	-
	DI Camera	-	-	-	-
	SIIP/Latch	-	-	-	-
TCA STE	TCA PRF	-	-	-	-
	TCA CGH	-	-	-	-
	TCA I/F	-	-	-	-
AOM STE	AOM PRF	-	-	-	-
	AOM ISRF	-	-	-	-
	AOM I/F	-	-	-	-
OBS	ACF	-	-	-	-
	Sky Angle	-	-	[no limit]	-

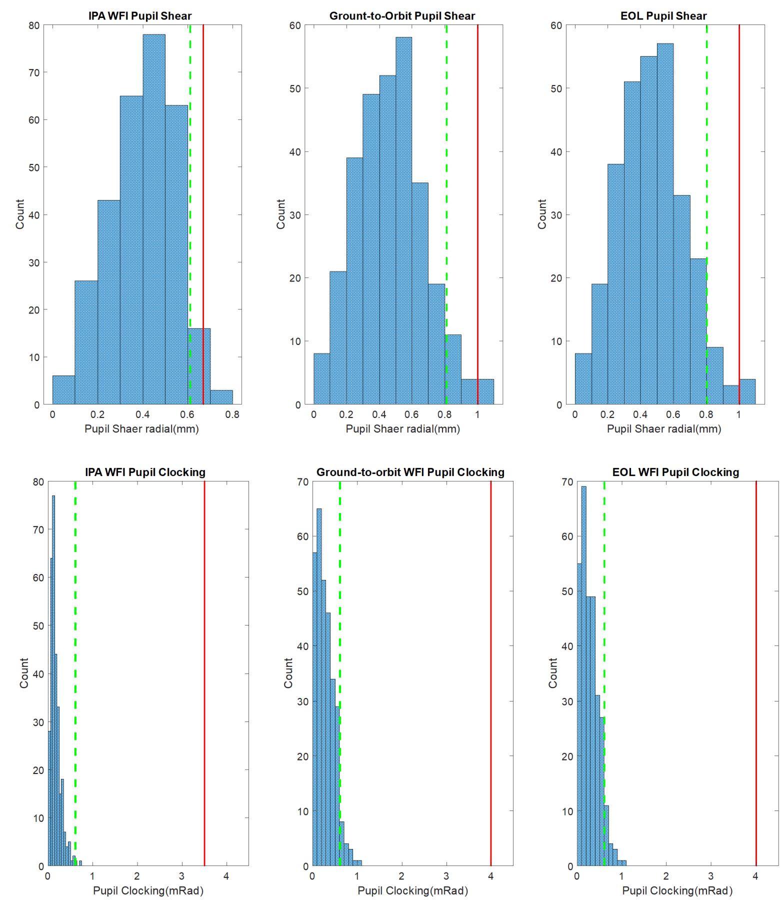
10 Steps in the Optical Monte-Carlo



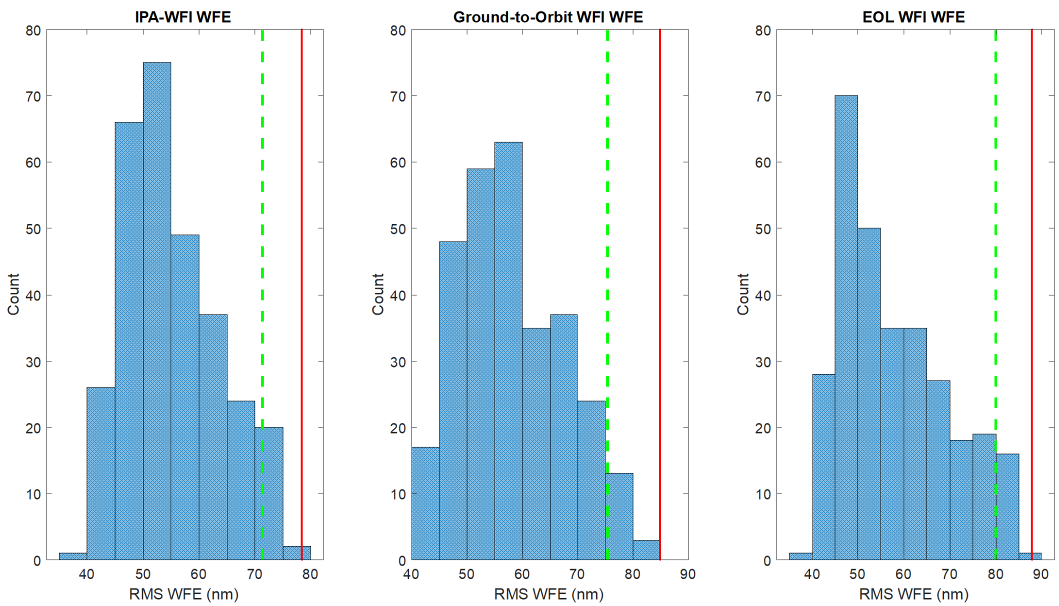
IOA: Telescope + AOM, and TCA
IFA: IOA+IC
IPA: IPA+WFI+CGI

Monte Carlo Results: WFI

PUPIL Alignment

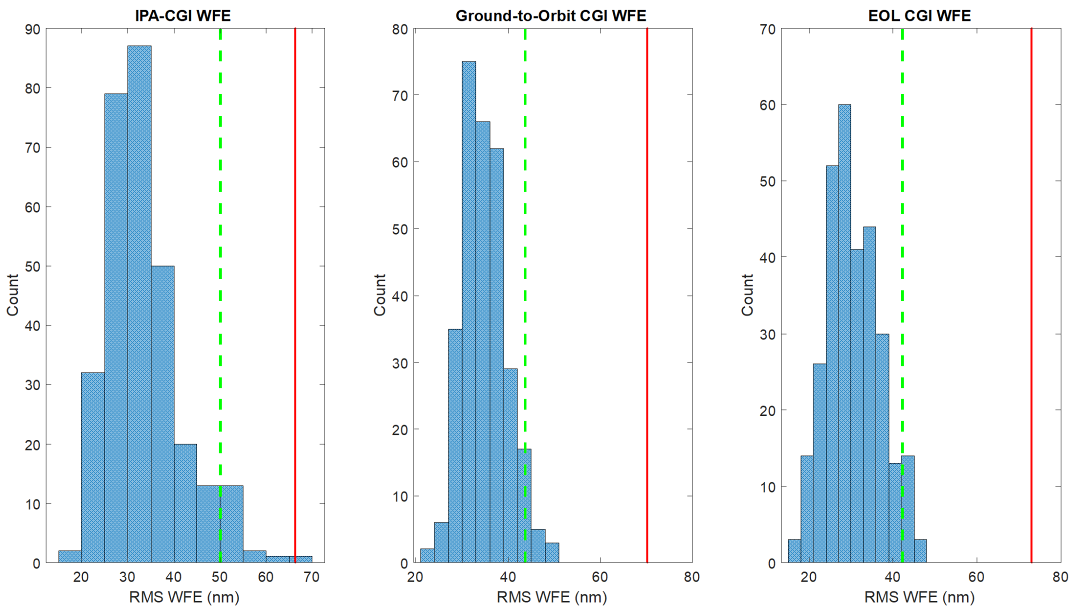


RMS Wavefront Error

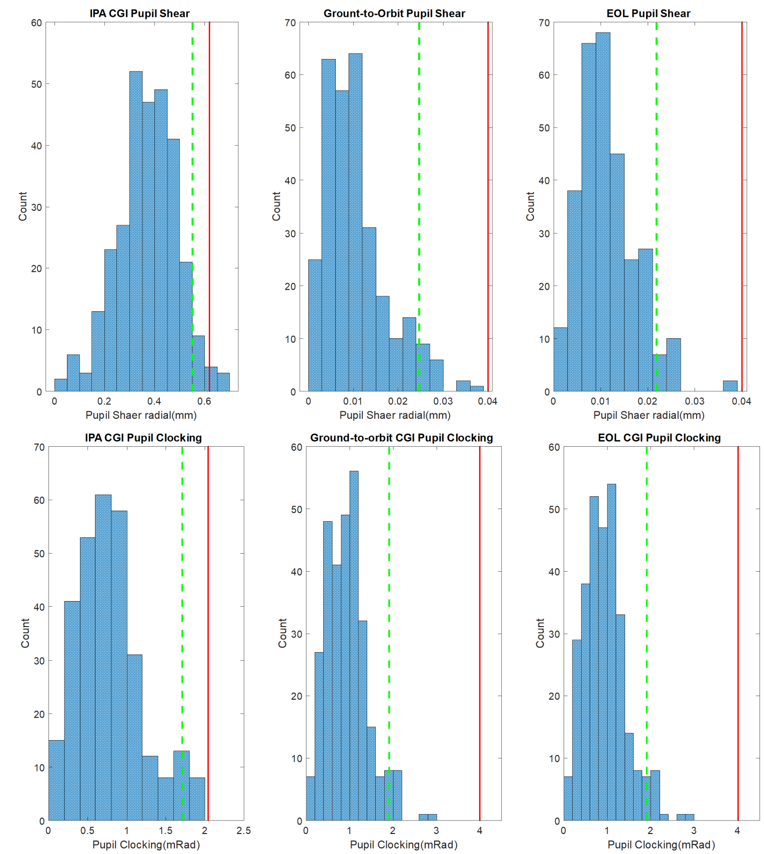


Monte Carlo Results: Coronagraph Instrument

RMS Wavefront Error

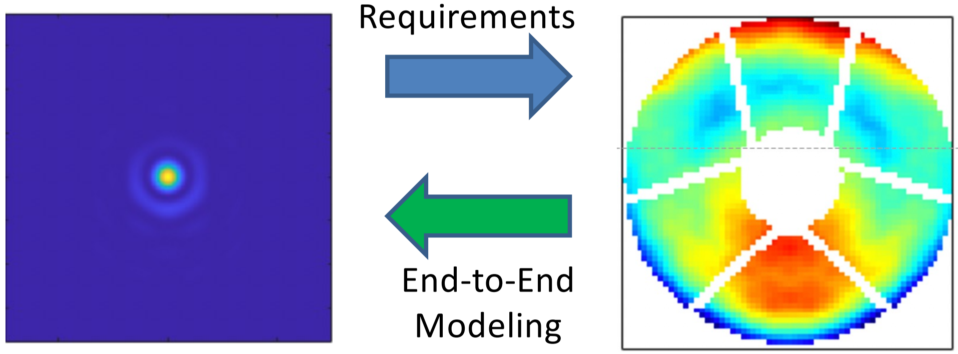


PUPIL Alignment



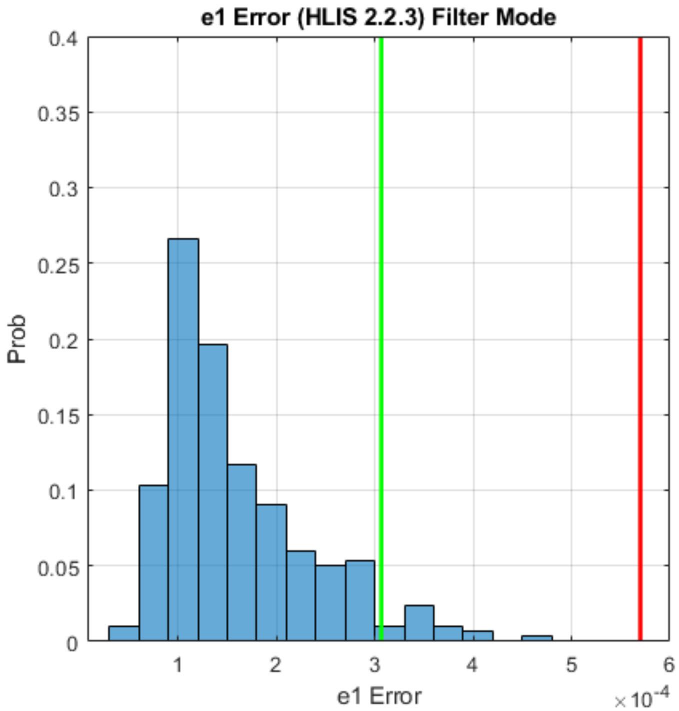
Roman End-to-End modeling

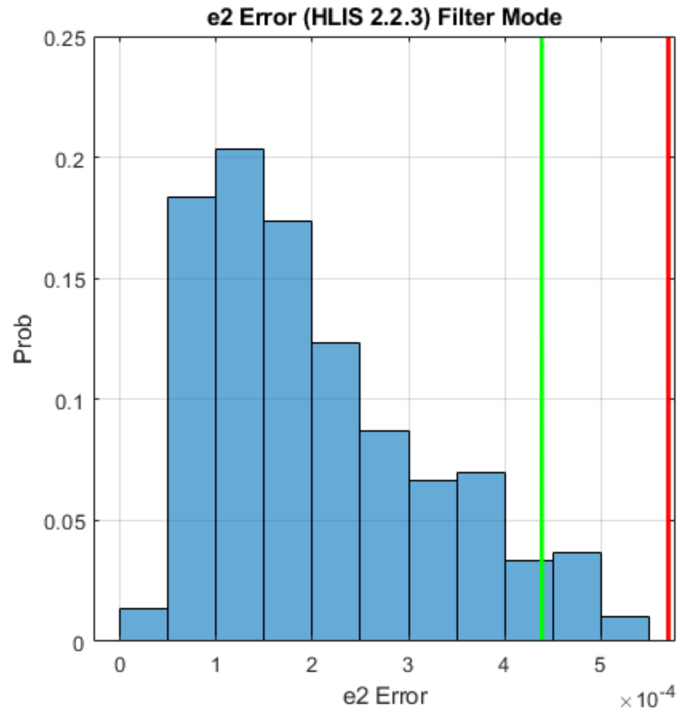
- Science requirements are primarily written with the detected image in mind, such as how much blur can be acceptable to achieve the desired science objectives.
- When these requirements are flowed down to the Mission level, however, the optical performance metrics of interest are expressed as exit pupil wavefront error and system alignments, which include pupil shear/clocking and focal surface position.
- The End-to-end modeling effort "closes the loop" with Science requirements from the Mission level predictions by evaluating the image point spread function (PSF), providing current best estimates on the PSF size and shape based on Integrated Modeling and Optical Monte Carlo results. This effort confirms our conservative assumptions in the requirements flow-down to the Mission level.



EXAMPLE End-to-End modeling Results

Image PSF Ellipticity (important for gravitational lensing science)





Concluding Remarks

- **Integrated Modeling** for Roman is a complex activity with many teams contributing from various institutions across the US.
- **Cross-checks** help ensure uniformity of process and consistency between the teams.
- **Monte-Carlo analysis and End-to-End modeling** bring in the Integrated Modeling results to predict performance against our science requirements.

The Mission Critical Design Review of the Integrated Modeling results predict that Roman will be a success!