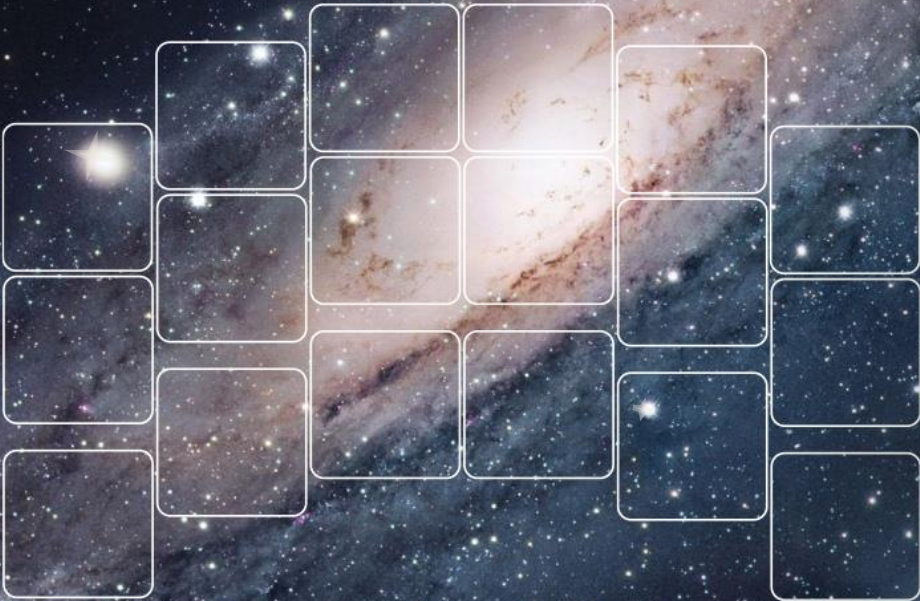


NANCY GRACE ROMAN



SPACE TELESCOPE

Optical Performance of Roman Optical Telescope Assembly

SPIE conference
August 4th, 2025

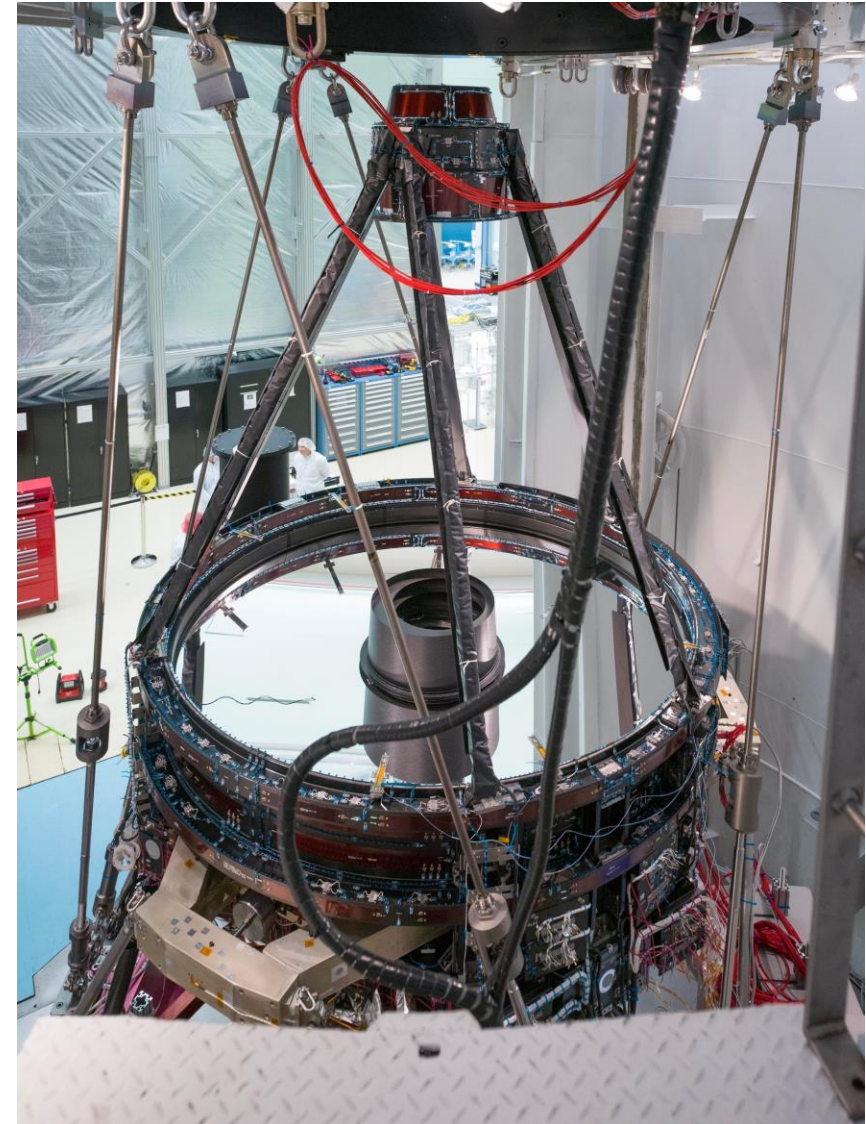
Presented by Josh Johnson
L3Harris

Josh Johnson, L3Harris
Peter Miller, L3Harris
Bill Castle, L3Harris
Pete McCarthy, L3Harris
Elise Michaels, L3Harris
Scott Paine, L3Harris
Malcolm O'Sullivan, L3Harris
Karen Gorski, L3Harris

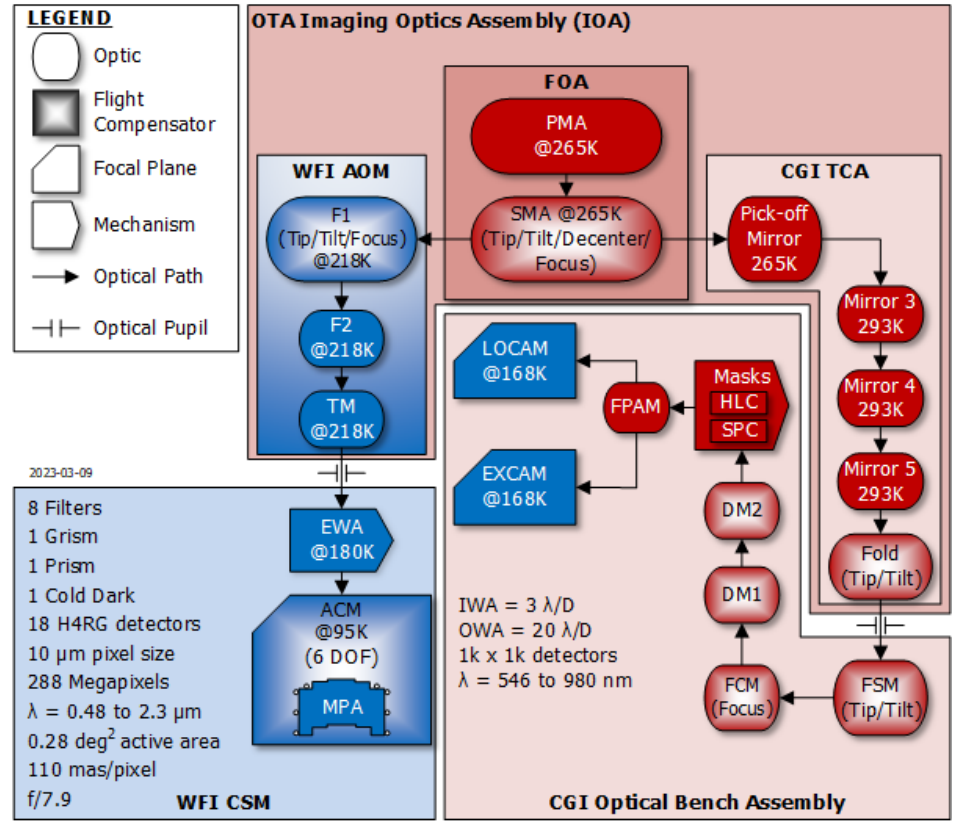
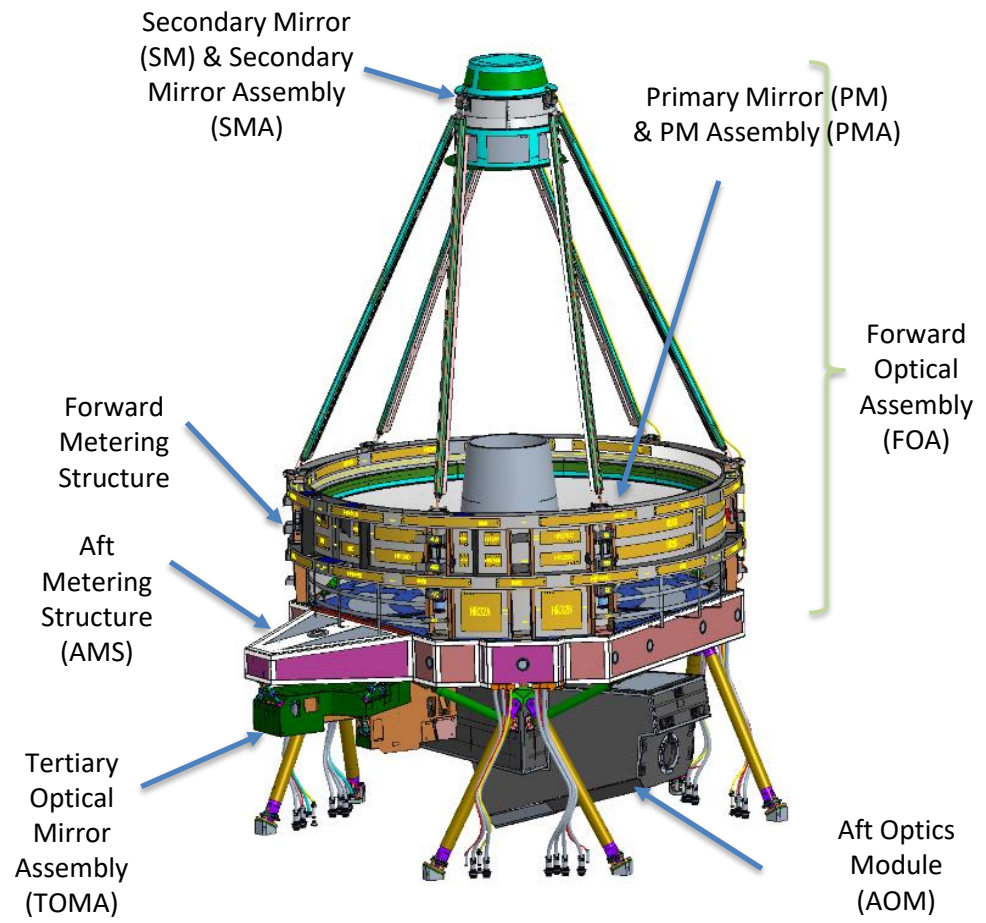
Bente H. Eegholm, NASA Goddard Space Flight Center
Josh Abel, NASA Goddard Space Flight Center
Matt Bolcar, NASA Goddard Space Flight Center
Boris Glebov, Peraton
Alden Jurling, NASA Goddard Space Flight Center
Jeffrey Scott Smith, NASA Goddard Space Flight Center

- **The Roman optical telescope assembly and subsystem alignment was completed in 2023**
- **The test campaigns in 2024 consisted of**
 - Ambient vacuum optical alignment in Chamber IIIB
 - Mechanical environmental testing, including
 - Modal, Acoustic, Vibration
 - Thermal vacuum optical performance test in Chamber A
 - STDT testing Sinusoidal Thermoelastic Distortion Testing
 - On-orbit optical performance
 - This presentation describes the test campaigns and their results

Telescope testing and analysis was successfully completed at L3Harris, and the telescope was delivered to NASA GSFC



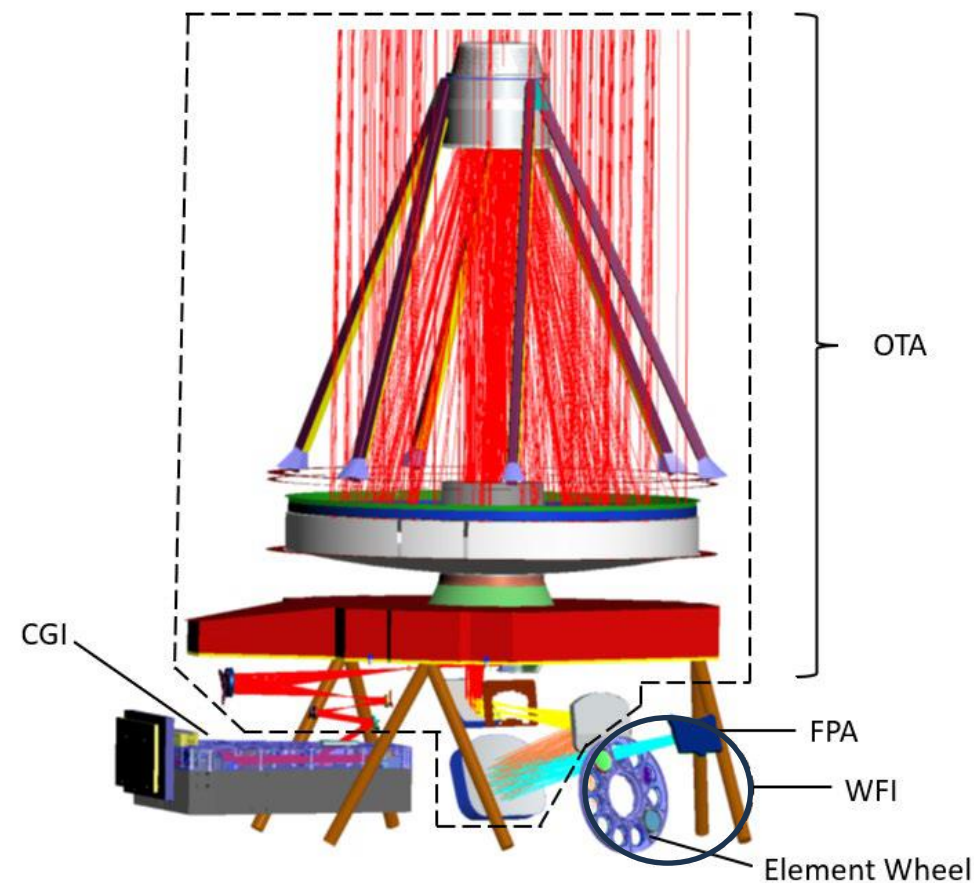
Roman Optical System Block Diagram



Block diagram of the Roman optical system

Telescope with Actuated Mirrors

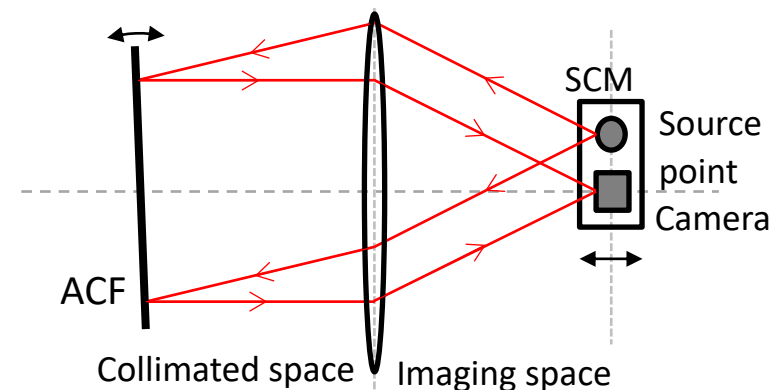
- The telescope has two optical paths, one for the Wide Field Instrument (WFI) and one for the Coronagraph Instrument (CGI).
- The common elements for the two paths are the Primary Mirror and the Secondary Mirror
- Secondary Mirror actuated in 5 Degrees Of Freedom (DOF)
 - Piston, tip, tilt, x-decenter, y-decenter
- WFI receives its input via the Aft-Optics Module (AOM)
 - AOM has 3 mirrors: 2 flat fold mirrors and a tertiary mirror
 - Fold Mirror 1 is actuated in 3-DOF (piston, tip, and tilt)
 - Compensates focus and pupil shear
- CGI receives input via the Tertiary Collimator Assembly (TCA)
 - TCA has 5 mirrors
 - Flat pick-off mirror (POMA)
 - Powered optics, M3, M4, and M5
 - 2-DOF Tip/Tilt Fold mirror
 - Compensates pupil shear
- The telescope mirror actuator range is dimensioned to be used both in ground alignment, as well as on orbit through EOL.



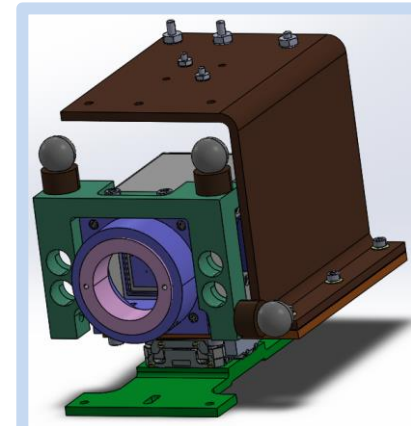
OTA within the dashed lines.
Optical ray trace through the system with the CGI channel to the left and the WFI channel to the right

Double Pass Testing with Interferometry and FDPR

- All testing was double-pass
- Large flat mirror (ACF) placed in top of chamber
- Test signal injected and received at the entrance to the science instruments
 - Science instruments not present
- An interferometer in each of the WFI and CGI test paths
 - Used to measure optical performance in the Ambient Alignment test
 - Used for pupil imaging in the TVAC test
- Focus Diverse Phase Retrieval used both during the Ambient Alignment as well as in the TVAC test.



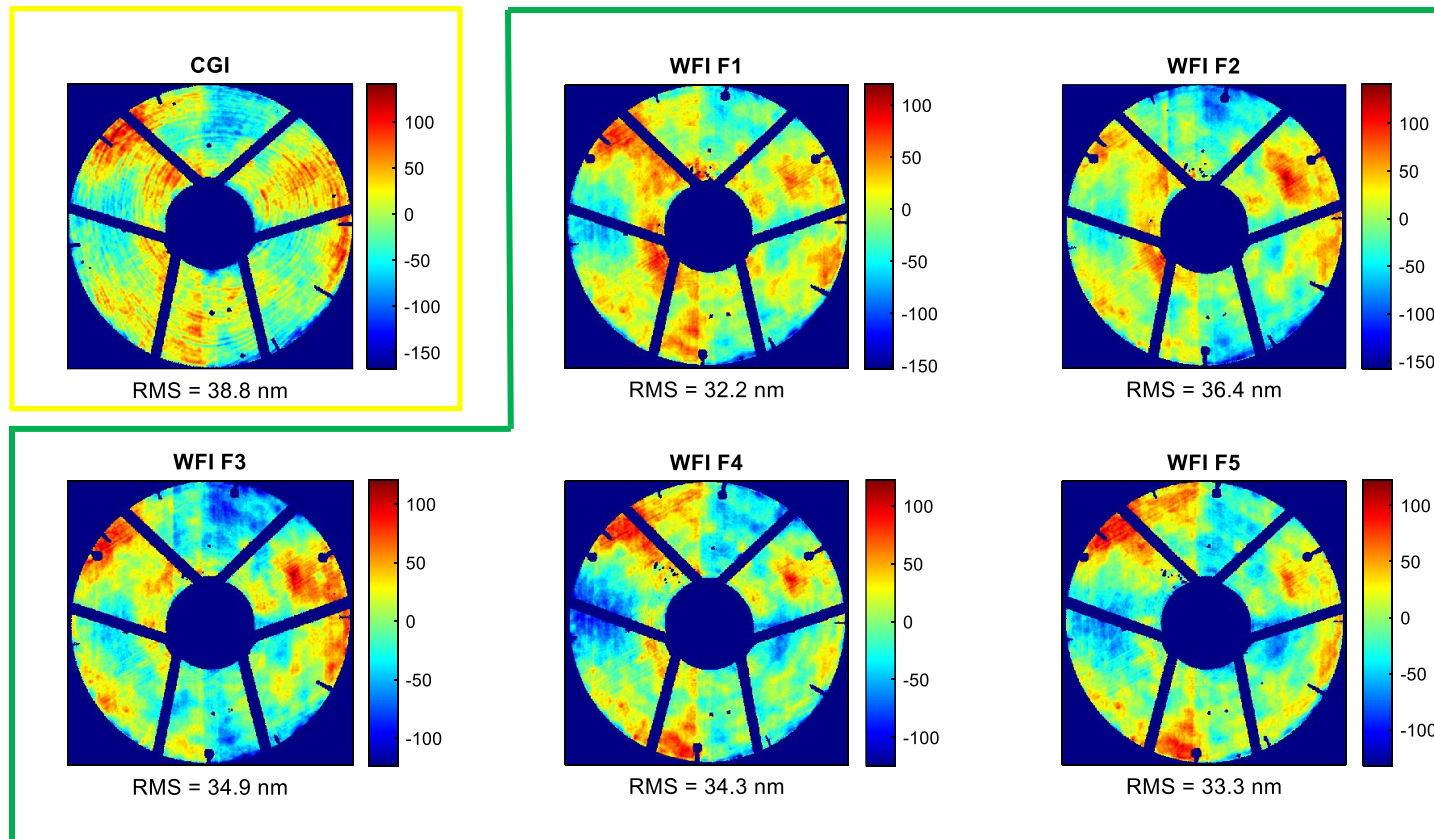
- **FDPR data acquisition in double-pass**
- **FDPR dataset comprises a series of images acquired at varying amounts of defocus.**
- **Data Analysis yields the wavefront**
- **Combining recovered wavefront with optical model to get optical performance info**



- TVAC-compatible, no enclosure required
- Single-mode fiber-coupled 633 nm CW laser source, chopped to 1 ms pulses
- **Source Camera Module (SCM)**
- Camera: 2048x2048 sensor, 5.5 μm pixel
- Motion: 10 mm range, 1 μm accuracy

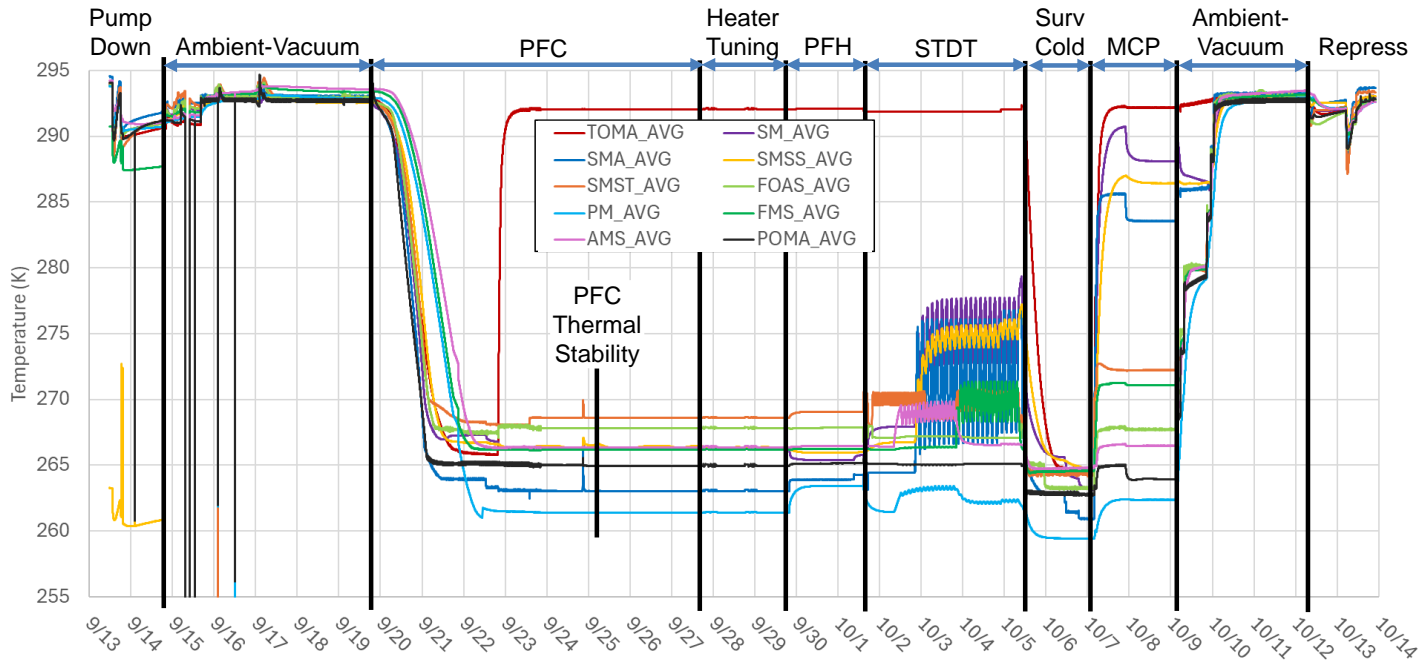
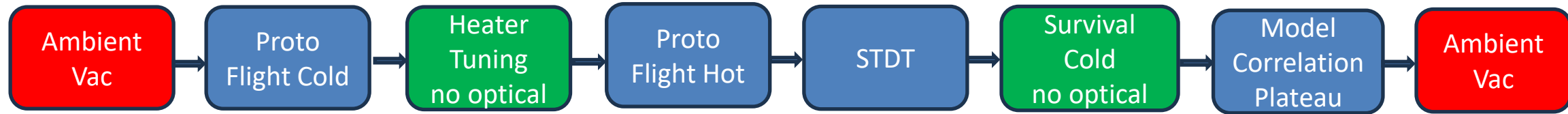
Ambient Alignment Results

- CGI channel
- WFI channel field points 1-5



Final ambient measured wavefront error of the IOA.
Values do not include uncertainty.

Telescope TVAC Test Flow



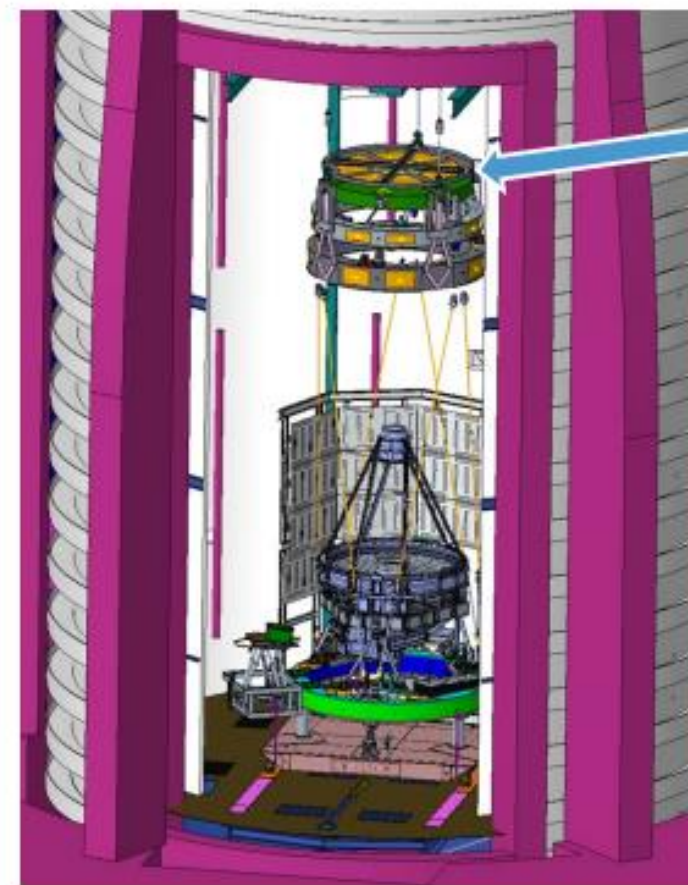
STDT = Sinusoidal Thermoelastic Distortion Testing

As-run thermal data showing component average temperatures
AOM temperature reached 220 K (not shown)

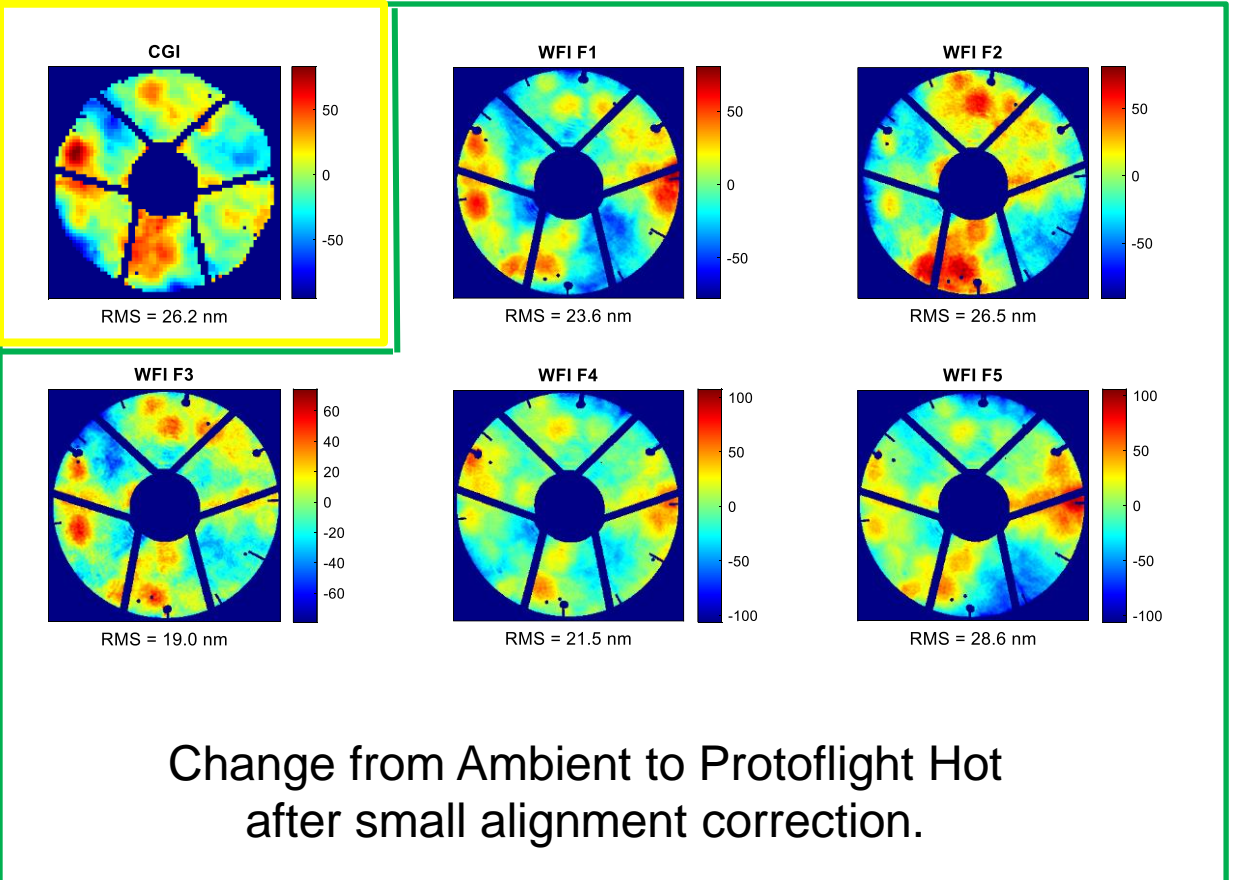
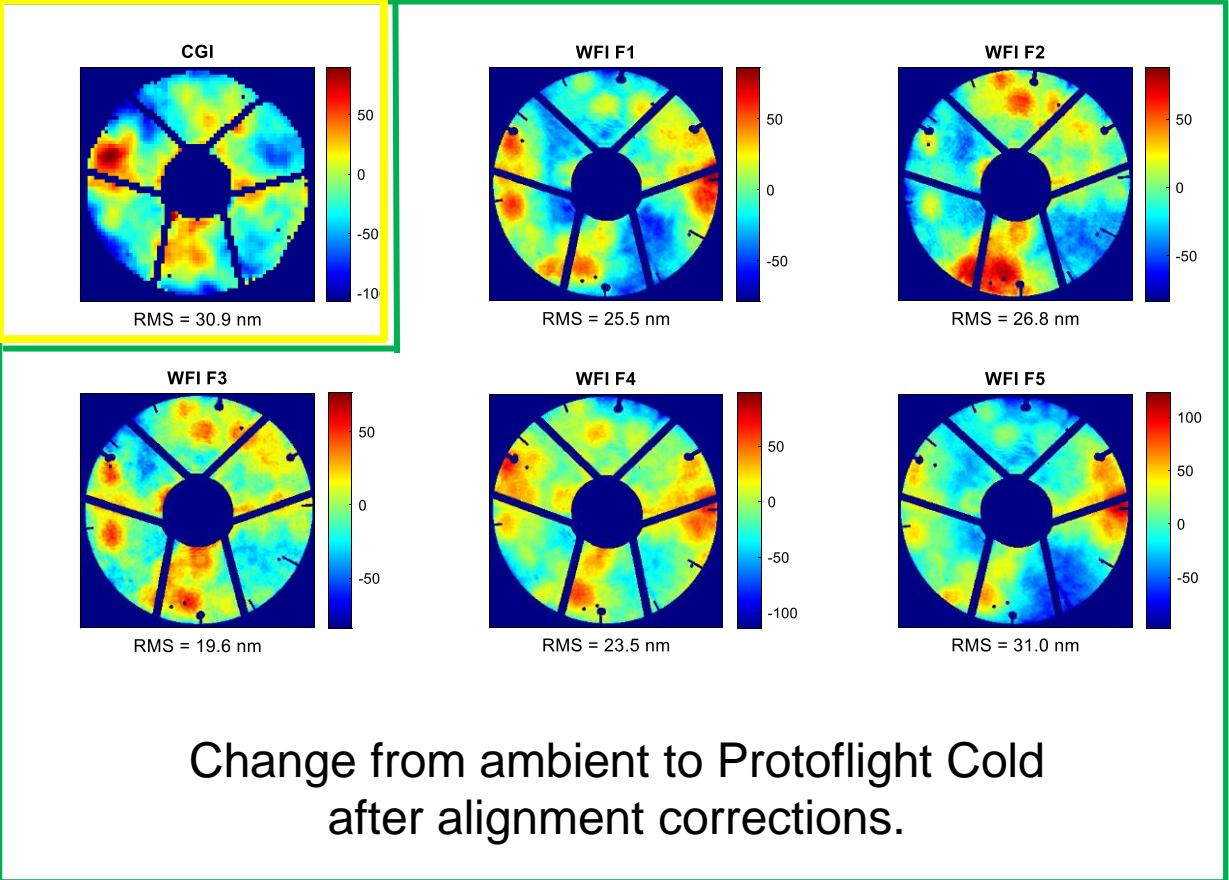
The best estimate of a typical environment for Roman is an average of the Proto Flight Hot and Cold (PFC, PFH) environments

- **The TVAC wavefront error measurements were performed using**
 - Double-pass testing (ACF in top of chamber), employing
 - FDPR for WFI channel
 - Shack-Hartman Wave front sensing (SH-WFS) for CGI channel
 - The gravity sag of the Primary Mirror prohibited use of interferometry for wavefront error testing
- **The TVAC optical testing had two main goals**
 - Simultaneously confirm no optical changes occurred as a result of mechanical environments AND
 - Link the data taken in the (soft vacuum) ambient chamber to the hard vacuum chamber
 - Measure the optical “cold shift” as a delta
 - The predicted on-orbit performance is the ambient WFE from the alignment campaign, subtracted the average cold environment performance

ACF

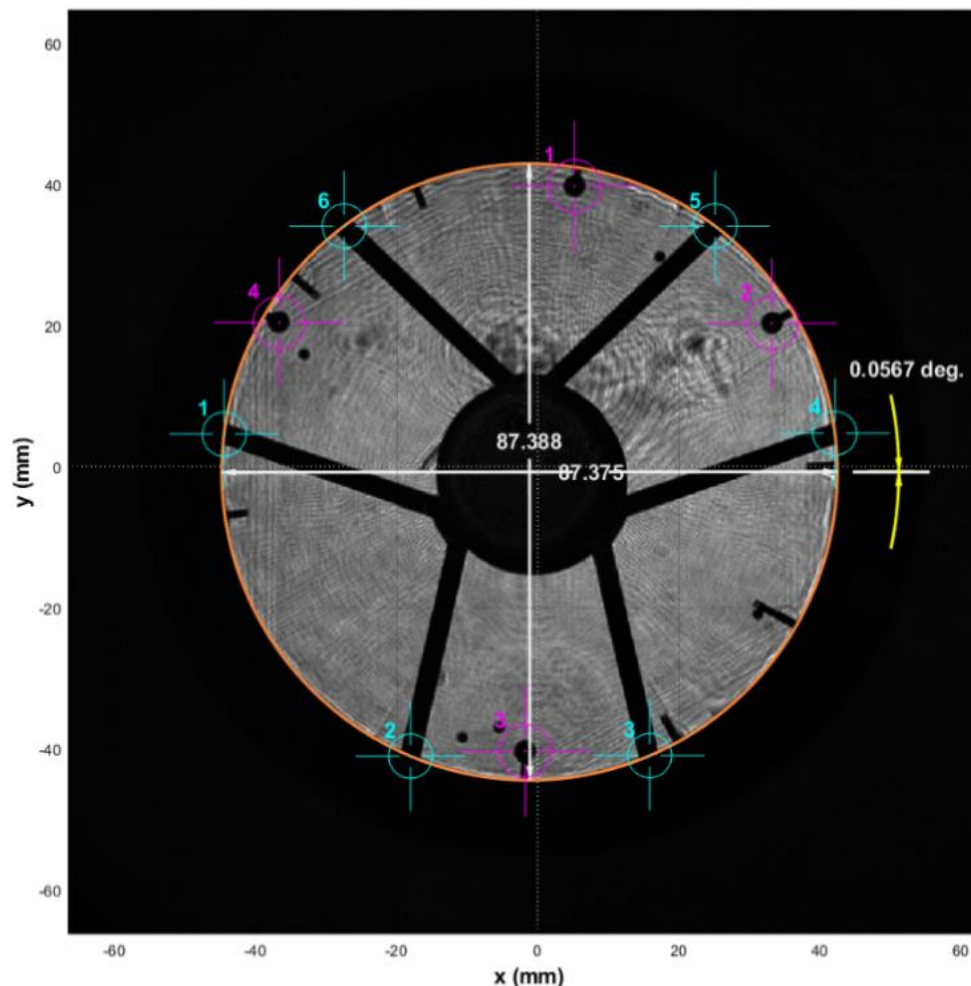


Change from Ambient to Cold Temperature



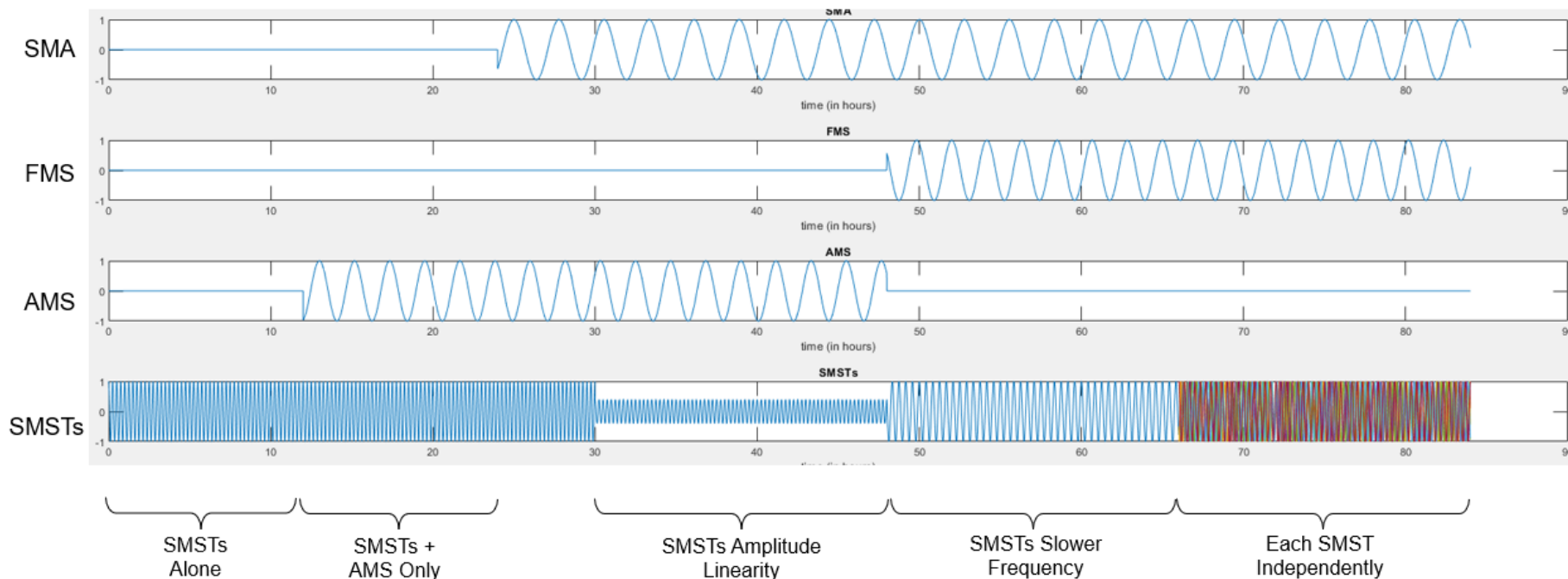
- Protoflight Cold and Protoflight Hot are two different environmental simulating on-orbit environments.

- In both the Ambient Alignment and the TVAC test campaigns the two interferometers were used to collect pupil images.
- Pupil location, clocking, shear and diameter results for both the CGI path and the WFI path were determined from the boresight intensity images in subsequent data analysis.
- All system requirements were met.



Example WFI pupil calculation result (from PFC)

Sinusoidal Thermoelastic Distortion Testing (STDT)

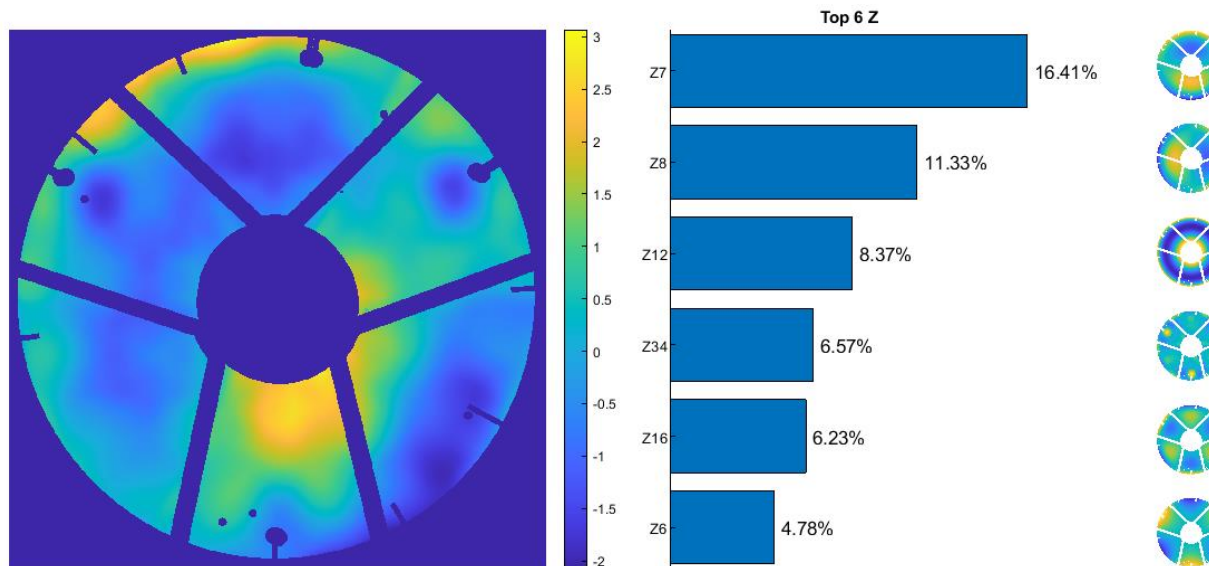


Thermal stimulus plan over the active duration of STDT.

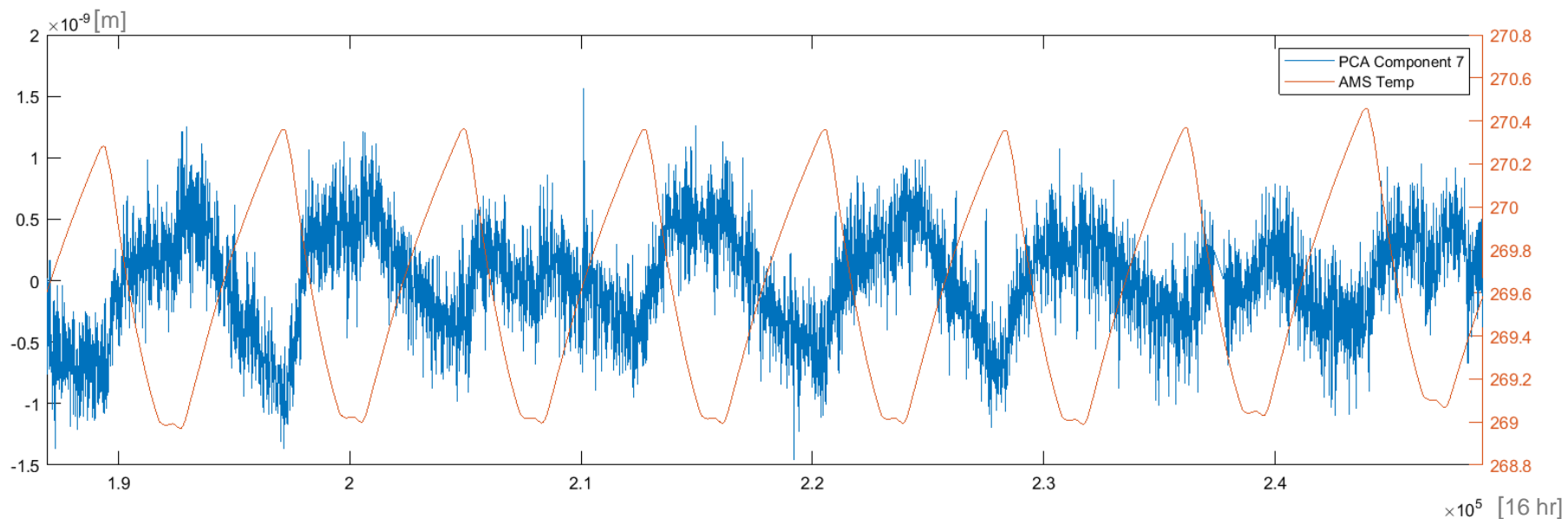
- **Both the WFI and CGI light paths have requirements for sub-nanometer wavefront stability over periods of minutes to hours to enable their science objectives**
- **L3Harris and NASA developed a novel test (STDT) to measure the optical response of OTA in the presence of small amplitude thermal stimuli**
- **The optical response was monitored while OTA's thermal control system generated repeated thermal disturbances**
- **Signal processing techniques used to extract the optical response from the background noise**

Example of STDT Test Results

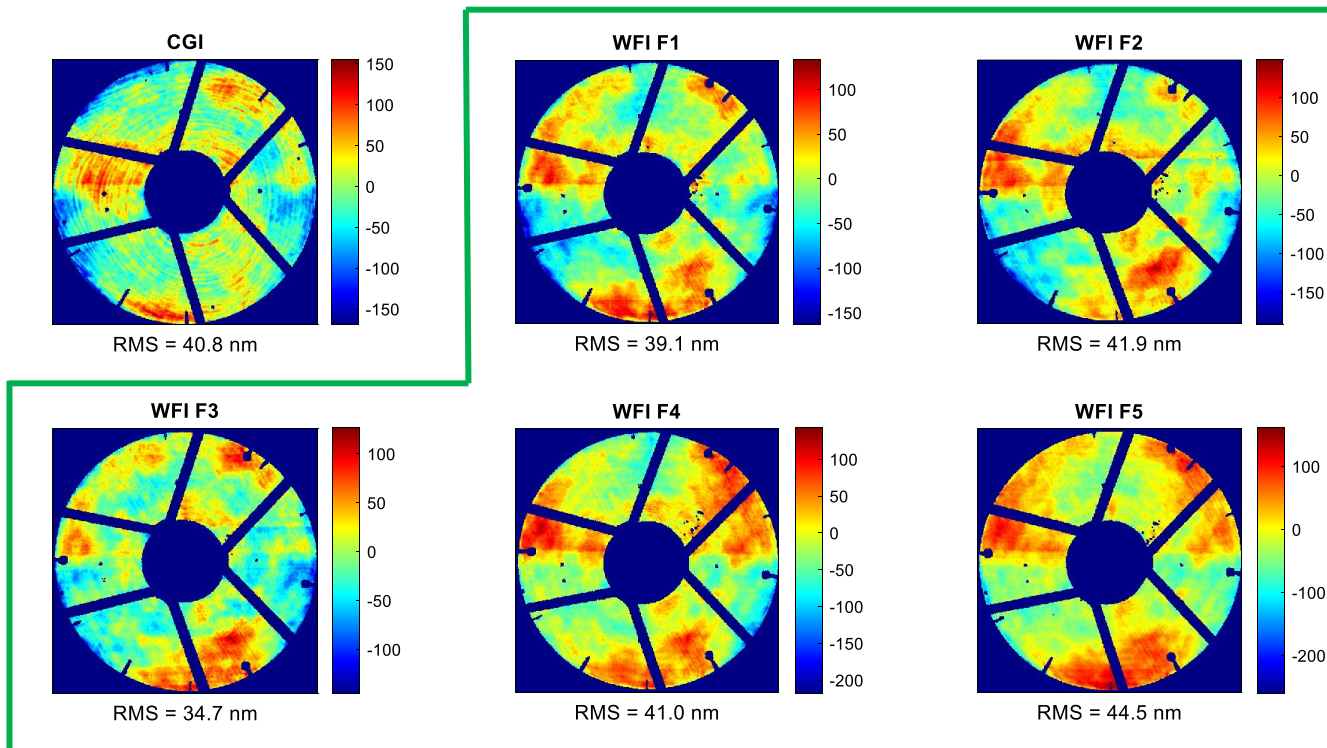
- **Unique AMS wavefront signature**
- **The Principal Component Analysis (PCA) component with the top 6 corresponding wavefront shapes**



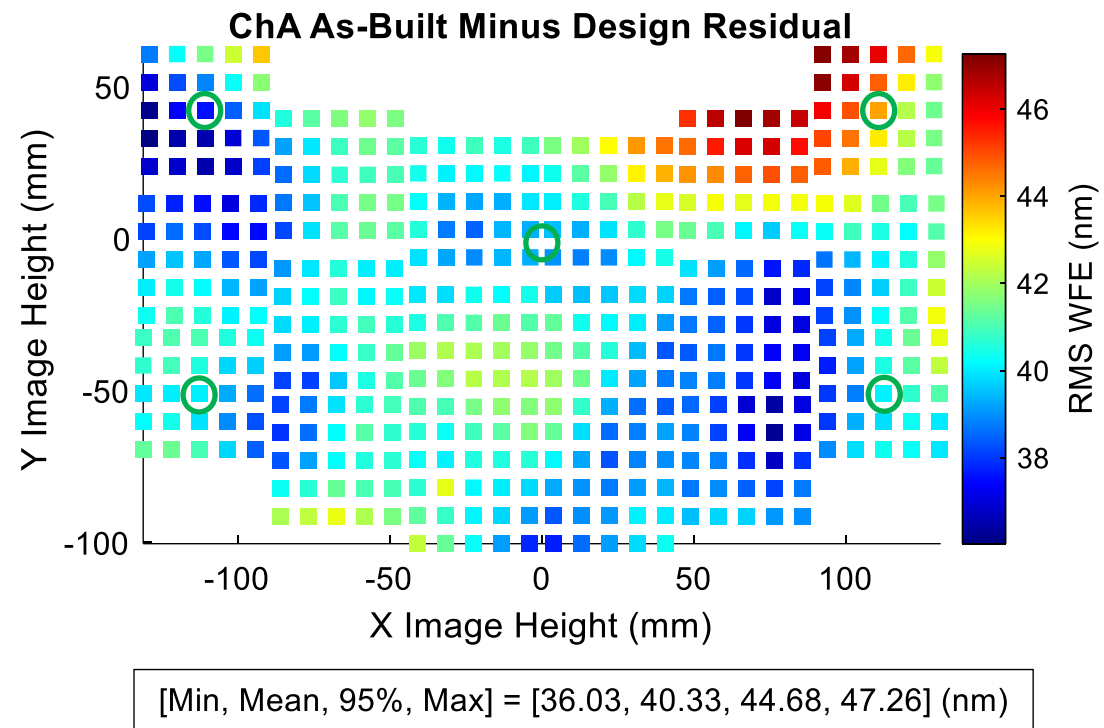
- **The time series plot showing change in this term in blue alongside AMS temperature in orange.**
- **The PCA component has been multiplied by -1 to clearly show the correlation with temperature**



On-orbit optical performance (measured field points)

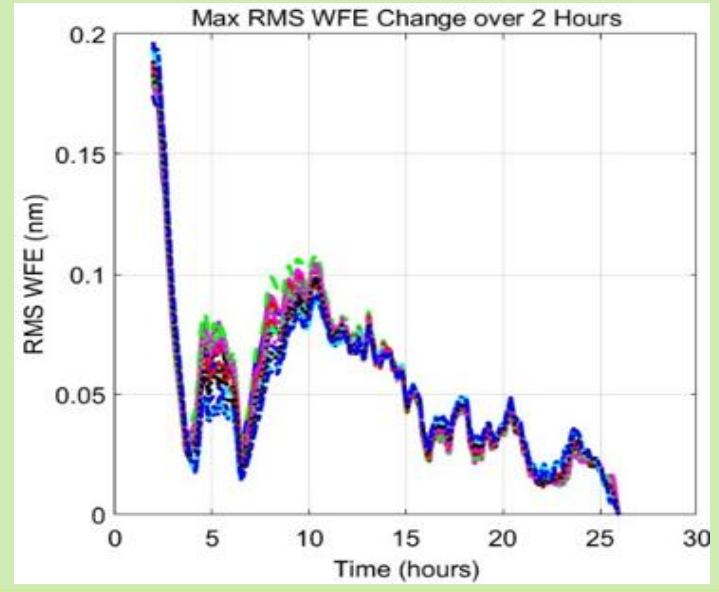
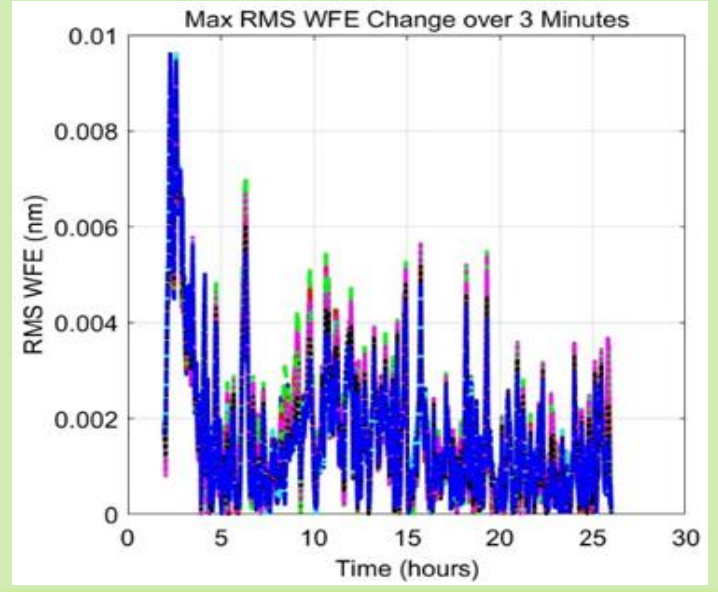


Test-correlated model WFI WFE vs Field of View



- **Measurement of selected, five representative field points for WFI (left)**
- **Test correlated model including 450 field points to cover entire field (right)**
 - Field of view on the sky 0.8 deg x 0.4 deg
 - Field point location on the detector = ○

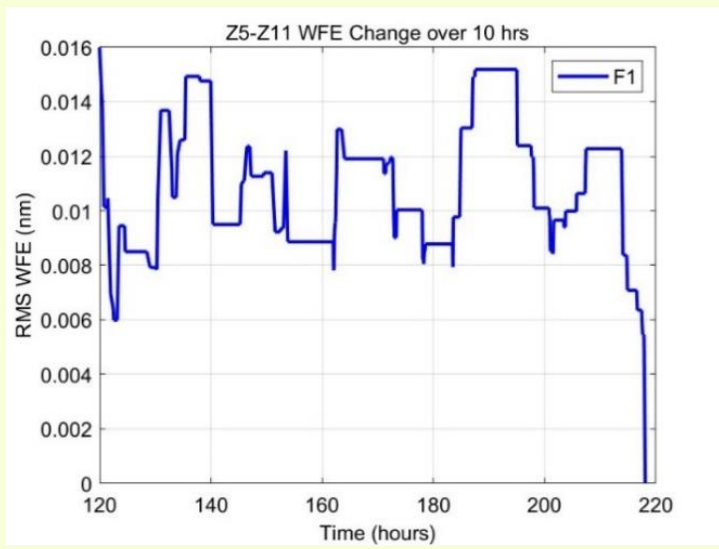
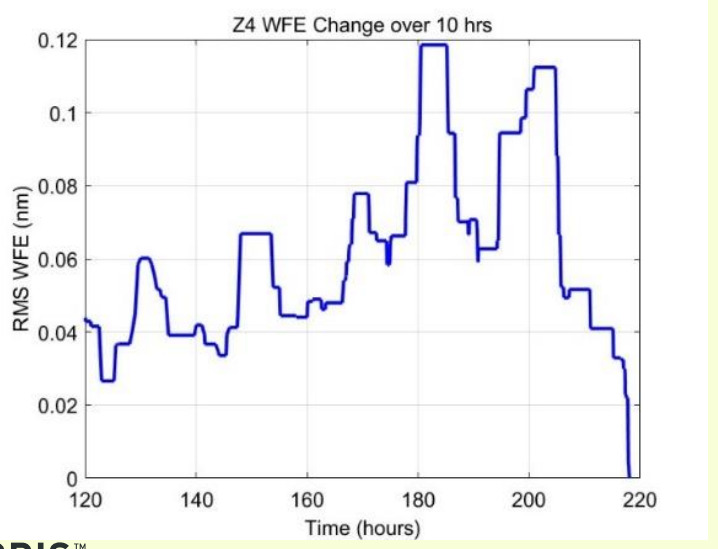
On-Orbit Optical Stability Predictions



Peak to valley WFE change during a “Worst Case Slew” operational scenario:

- **< 10 picometers** RMS over 3 minutes
- **< 200 picometers** RMS over 2 hours
- Note: There is no thermal settling time after the slew

Results are an order of magnitude better than requirement



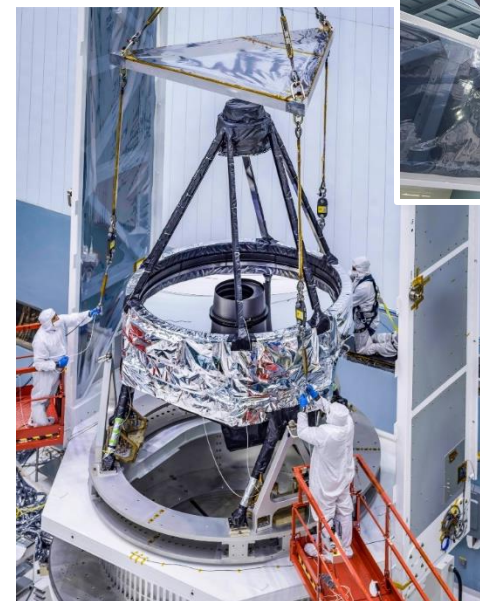
Peak to valley WFE change during “OS11” day in the life **Coronagraph** operational scenario:

- **< 120 picometers** RMS defocus over 10 hours
- **< 16 picometers** RMS of Z5-Z11 over 10 hours
- Note: Results show WFE changes before CGI focus and DM correction

Conclusion and Summary

- The Roman Optical Telescope Assembly was completed and tested at L3Harris' facilities in Rochester, NY.
- Successful alignment at ambient temperature in a vacuum chamber
- Optical performance, wavefront error, and pupil alignment were successfully tested at cold operating temperatures in a TVAC chamber.
- The telescope's predicted On-Orbit, End of Life quasi-static optical wave front error performance is well within the required 67.3 nm RMS for the WFI channel, 74.2 nm RMS for the CGI channel.
- The new Sinusoidal Thermoelastic Distortion Test (STDT) test, was performed during the TVAC test.
- The result of the test campaign is a well-aligned telescope, stable to milli-Kelvin with picometer level wavefront error stability – an order of magnitude better than requirement.
- The telescope has margin in the error budget, and ample actuator range on-orbit throughout End-Of-Life.

The telescope was delivered to NASA Goddard Space Flight Center, for science instrument, spacecraft, and other flight hardware integration. The combined payload and space craft assembly will undergo final TVAC performance testing at NASA GSFC.



Photos: NASA/Chris Gunn