

# Nancy Grace Roman Space Telescope Grism and Prism: Flight As-built Models

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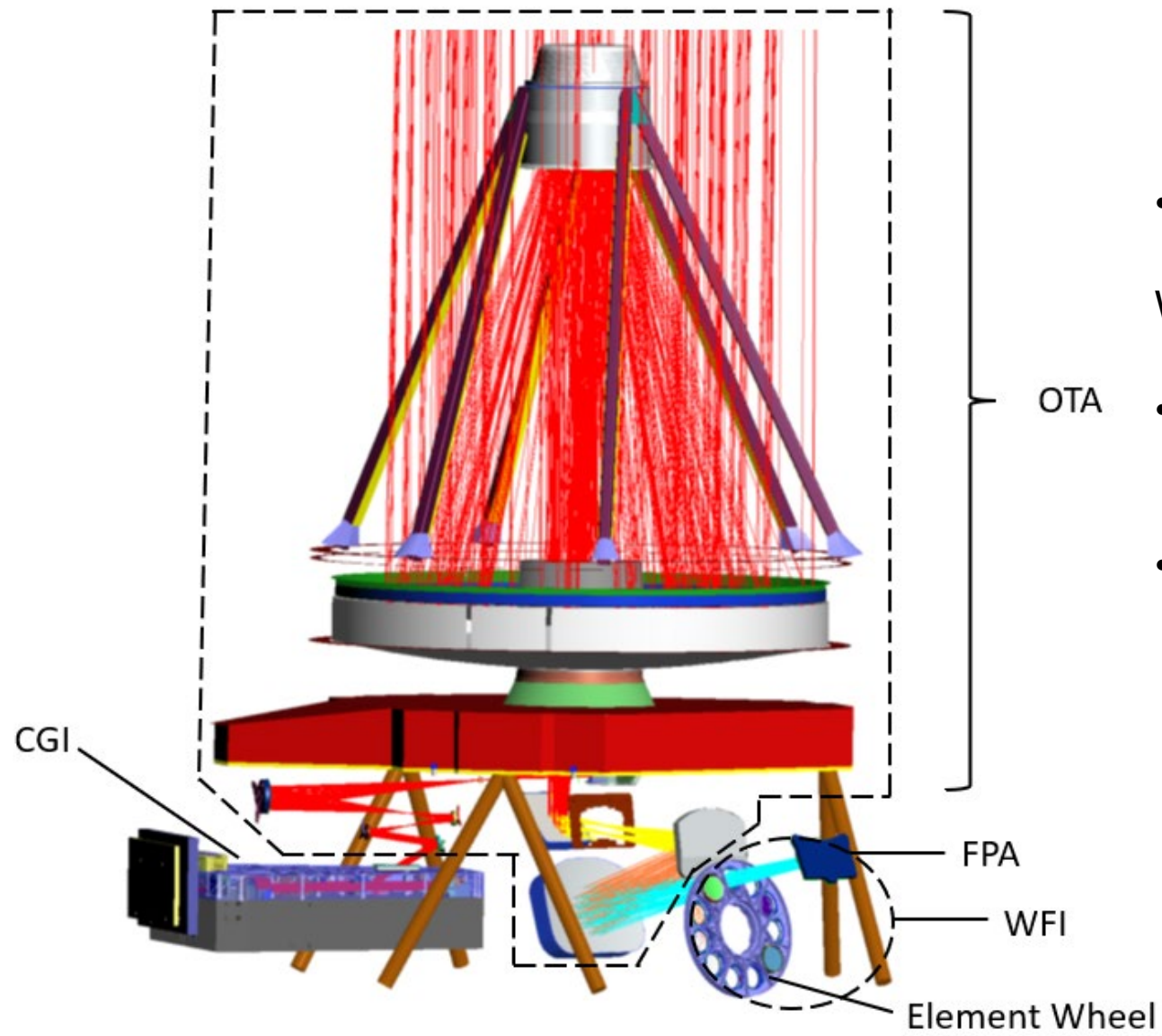
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1. KBR, Inc.
2. Alcyon Technical Services, LLC

# Outline

- **Brief Introduction of Roman Space Telescope (RST) and Wide Field Instrument (WFI)**
- **WFI Grism and Prism As-built Modeling**
  1. **Inputs and process of Grism/Prism as-built modeling**
  2. **Results of as-built modeling work and comparison to test**
- **Integration to Telescope and end-of-life (EOL) on-orbit performance prediction**
  1. **Element-Wheel level adjustment**
  2. **Flow Chart of on-orbit performance prediction**
  3. **Observatory level EOL on-orbit performance of Grism and Prism**
- **Summary**

# Brief Introduction of RST

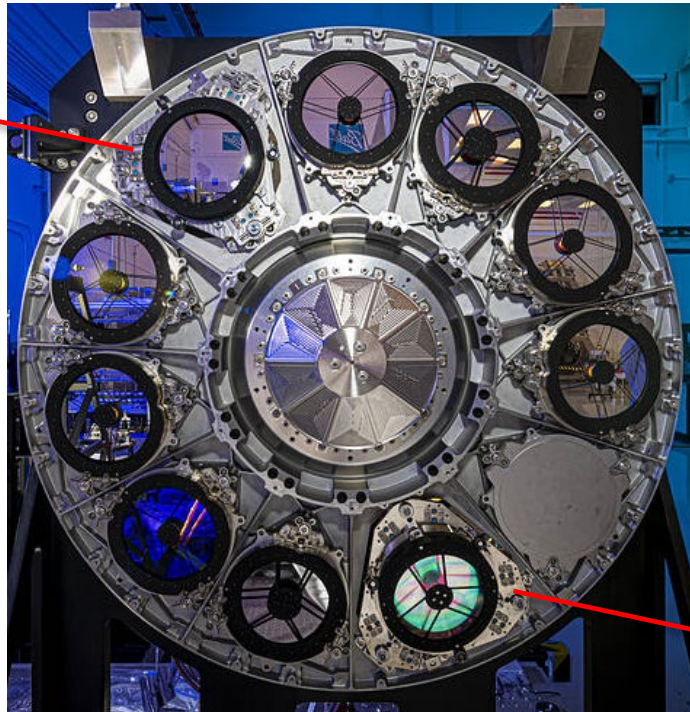


- RST Payload is composed of the Optical Telescope Assembly (OTA), Coronagraph Instrument (CGI), and Wide Field Instrument (WFI)
- CGI and WFI share the same Primary and Secondary Mirrors
- RST WFI channel has field  $0.8 \times 0.4 \text{ deg}^2$ , which is about 100x larger than the Hubble Space Telescope!

# Brief Introduction of Wide Field Instrument

- WFI includes Element Wheel Assembly (EWA), Focal Plane Assembly (FPA), and Calibration system

Element Wheel Assembly

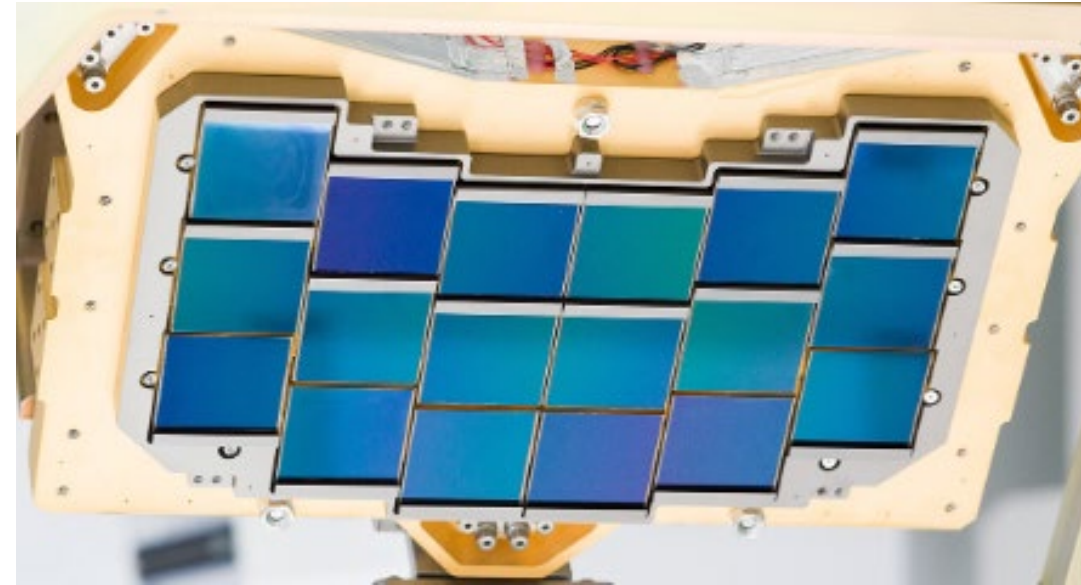


Grism

EWA houses:

- 8 science filters, Grism, Prism, and a dark element
- All elements are confocal
- Element operating temperature is  $\sim 175\text{K}$

Focal Plane Assembly



FPA integrates 18 H4RG detectors  
Each detector is a  $4096 \times 4096$  array of  $10 \mu\text{m}$  pixels  
FPA is mounted on a hexapod to allow tip/tilt/focus adjustment

## Data used in this modeling effort

1. Room temperature Grism and Prism nominal models (on-orbit design model taken warm)
2. Fabrication values of Grism and Prism optical elements (from vendors and internal element testing)
3. Room temperature testing metrology data, and room temperature interferometric testing data\*
4. Spectral verification results\*\*
5. Grism/Prism room temp-to-cryo change (from STOP analysis)
6. Cryo testing metrology data, and cryo interferometric testing data\*

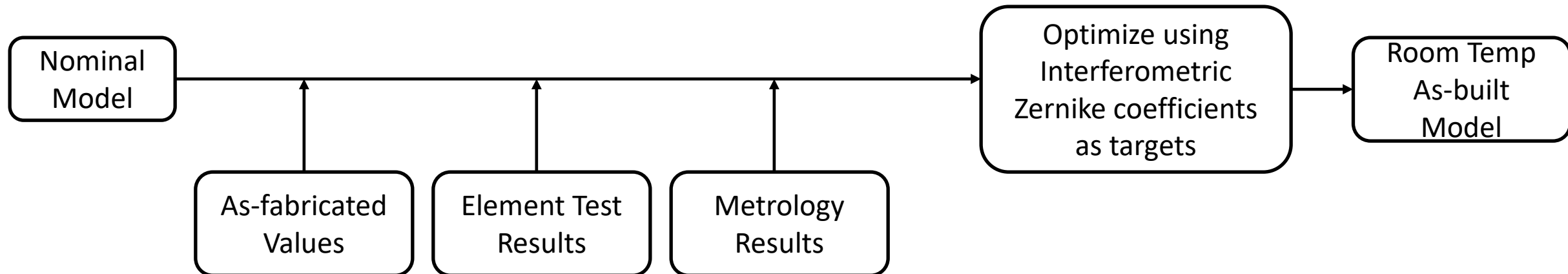
\* Details for element level testing and interferometric testing, see presentation “Alignment and Wavefront testing results of the Nancy Grace Roman Space Telescope Grism and Prism assemblies “ by Dr. Margaret Dominguez

\*\* Details for spectral calibration results, see presentation “Measured Spectral Properties of the Grism and Prism Spectrometers for the Nancy Grace Roman Space Telescope - Deviations From Model Expectations “ by Dr. Evan Bray, and “In-situ Index Determination for the Nancy Grace Roman Space Telescope (NGRST) Wide-field, Slitless, Imaging Prism Spectrometer” by Dr. John Lehan

**Grism and Prism as-built modeling work simulates the lab alignment and testing activities of Grism and Prism assemblies by the following steps on optical models:**

- 1. Apply as-fabricated values of each optical elements**
- 2. Apply metrology data**
- 3. Tweak/optimize alignment/fabrication parameters within uncertainty range to let Zernike coefficients of each field match to the coefficients from interferometric testing**
- 4. Double check the spectral dispersion performance of as-built models to make sure it matches to the results from spectral verification testing**

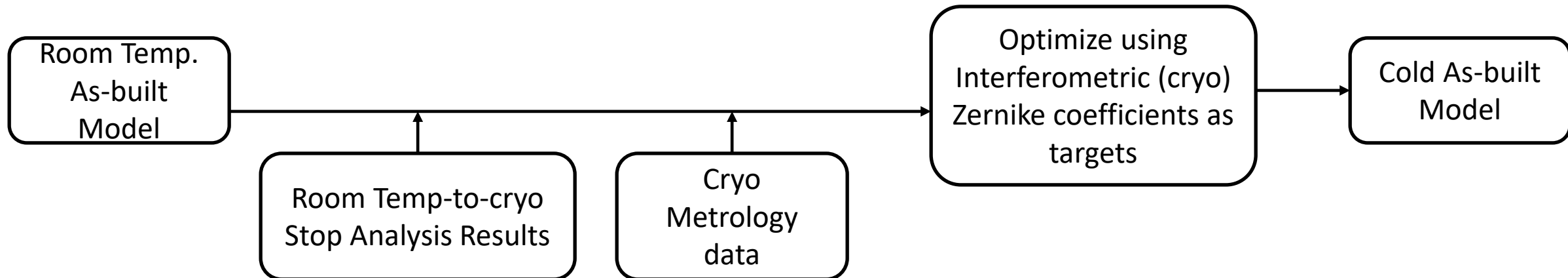
**After steps 1~4, we got room temperature as-built models of Grism/Prism**



**Starting from room temperature as-built model:**

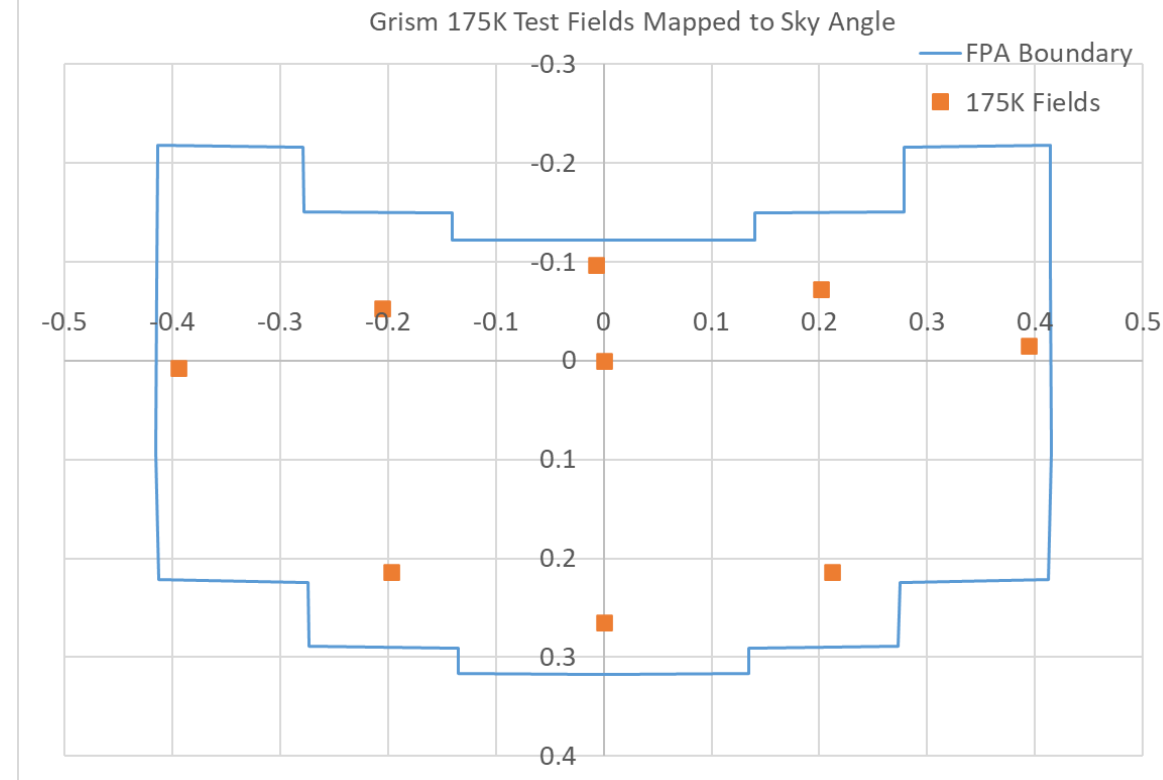
- 5. Apply room temp-to-cryo changes from STOP analysis and cryogenic metrology data**
- 6. Adjust/optimize elements' positions within the ancillary metrology uncertainty ranges to let models WFE matches to the cryo interferometric testing result by comparing low-order Zernike coefficients**
- 7. Adjust higher-order Zernikes determined by STOP modeling based on cryogenic interferometric measurements**
- 8. Add mid-spatial SFE if needed**

**After step 8, the cryo as-built Grism/Prism models are ready**



- Cryogenic (175K) modeling and testing results
- Wavelength of 1053 nm
- Maximum difference 10 nm (0.0095  $\lambda$  RMS)

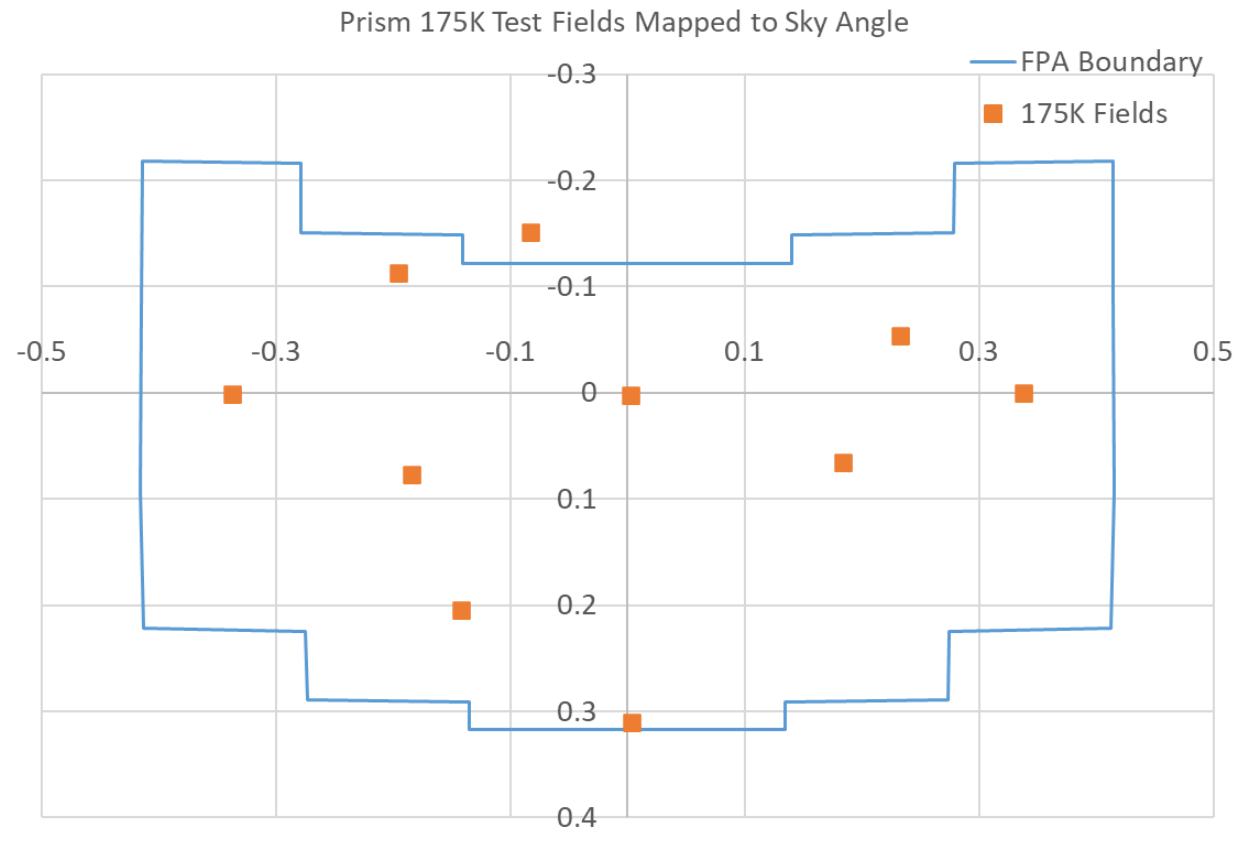
RMS ZFR [nm]	Delta (Model-Test)								
	Field 1	Field 2	Field 3	Field 4	Field 5	Field 6	Field 7	Field 8	Field 9
Z3*(Power)	-3	-10	0	-3	4	-8	-4	0	8
Z4(X-Astig)	-1	-2	-1	-1	-3	-2	-3	-4	0
Z5(Y-Astig)	0	0	-1	7	-3	2	1	3	-2
Z6(X-Coma)	0	0	-1	-2	2	-2	1	-1	1
Z7(Y-Coma)	0	0	-1	1	-1	1	0	1	0
Z8(Spherical)	3	3	5	4	4	3	3	3	5
ZFR9	0	-1	-1	-3	0	-2	0	-1	1
ZFR 10	-1	-1	0	1	-3	0	-2	1	1
ZFR 11	-2	-2	0	-1	1	-2	-1	0	0
ZFR 12	0	1	-1	-1	1	0	1	-1	0
ZFR 13	1	1	1	2	-1	2	0	1	0
ZFR 14	1	2	0	1	2	2	2	1	1
ZFR 15	3	3	-1	3	3	3	4	1	0



\*Z3 data is a combination of 2 measurements so has ~ 3x more uncertainty

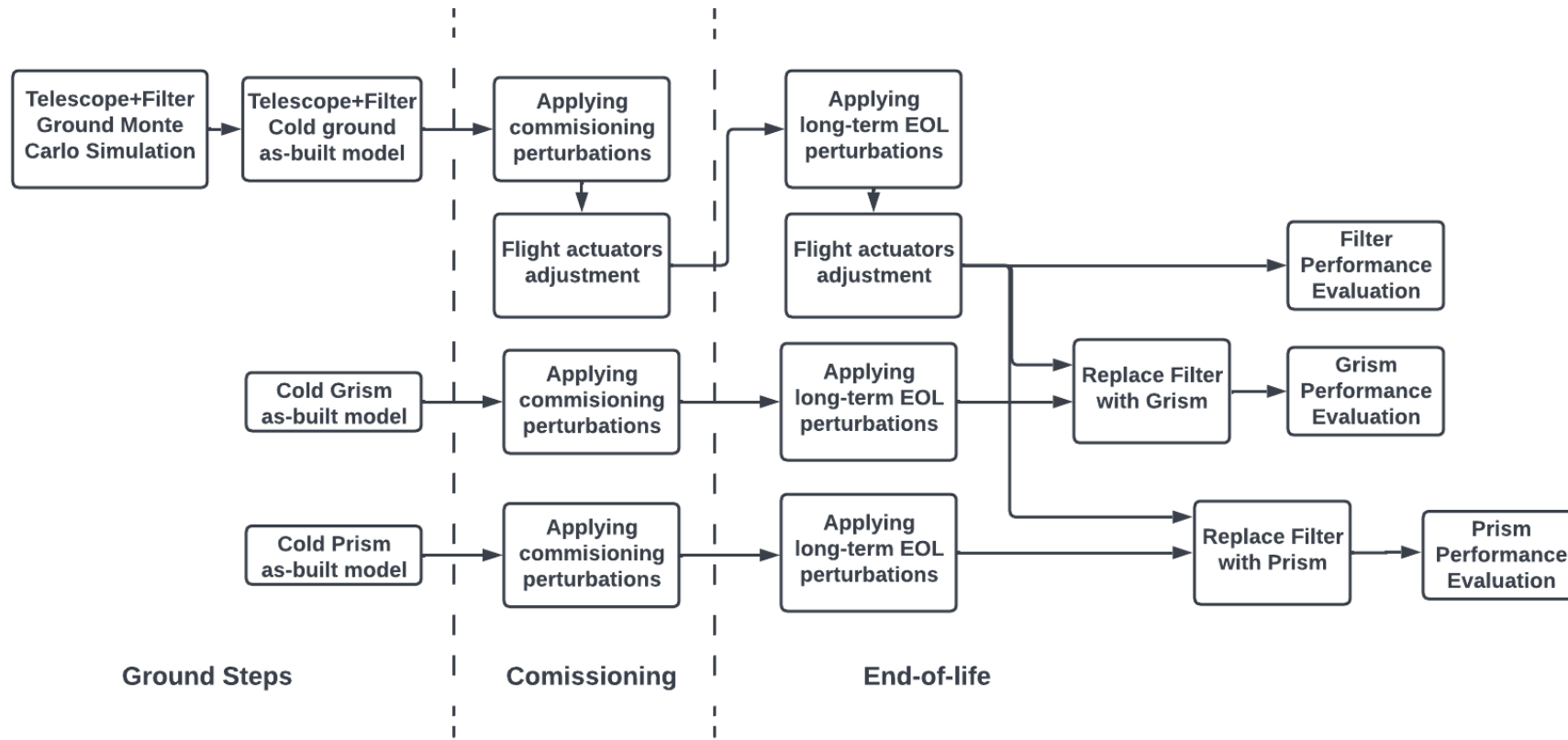
- Cryogenic (175K) modeling and testing results comparison
- 1053 nm comparison wavelength
- 13 nm (0.0123λ) RMS maximum difference

RMS ZFR [nm]	Delta (Model-Test)									
	Field 1	Field 2	Field 3	Field 4	Field 5	Field 6	Field 7	Field 8	Field 9	Field 10
Z3*(Power)	-11	-9	0	-5	11	6	-13	-1	5	-4
Z4(X-Astig)	2	3	-3	6	6	2	0	2	1	4
Z5(Y-Astig)	3	0	-2	-4	3	4	1	-1	-2	1
Z6(X-Coma)	1	2	-3	3	0	0	2	0	-1	2
Z7(Y-Coma)	1	6	2	4	2	3	2	3	2	4
Z8(Spherical)	0	1	-2	0	1	1	0	0	-1	-1
ZFR9	-1	0	0	1	-2	0	-1	-1	0	1
ZFR 10	-1	1	-1	0	1	0	0	1	0	1
ZFR 11	-1	1	1	-1	-1	-1	1	-2	-2	1
ZFR 12	-2	1	0	-1	-1	-1	0	-1	1	0
ZFR 13	1	2	2	4	0	1	0	3	2	4
ZFR 14	1	2	2	1	2	2	2	1	2	2
ZFR 15	2	2	2	3	0	0	1	1	2	2



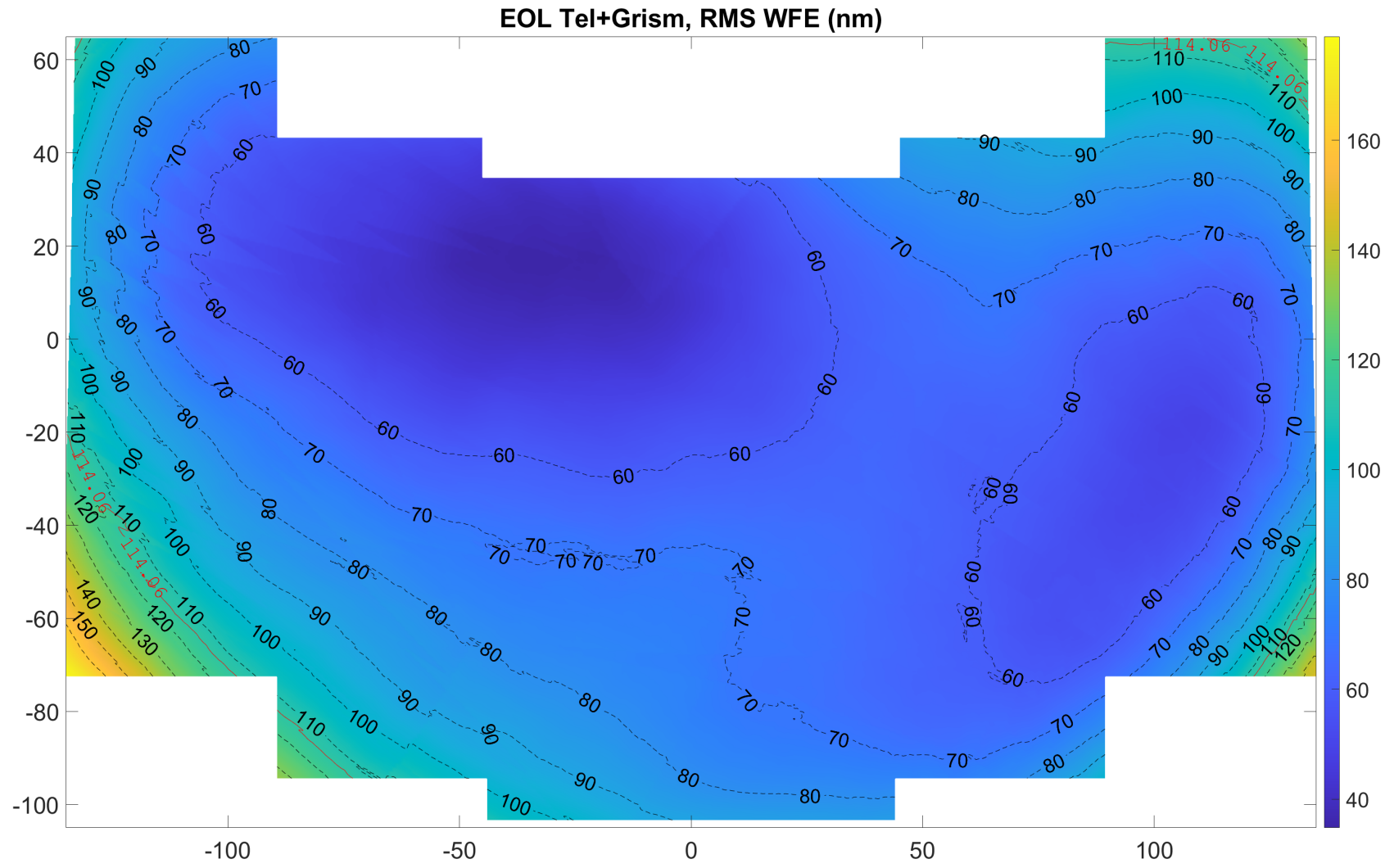
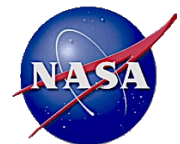
\*Z3 data is a combination of 2 measurements so has ~ 3x more uncertainty

# Flow Chart of Flight Performance Prediction - EDIT



- Currently, no as-built telescope but telescope component information
- So, we perform a Monte Carlo of a *pseudo* as-built telescope which includes telescope mirrors' as-fabricated information, alignment errors and compensators' adjustment, plus on-orbit perturbations and on-orbit refocus performed in Telescope+Filter operational mode.
- Grism and Prism mode follow a simplified procedure without any refocus adjustments and inheriting the FPA position from Filter mode

# Grism End of Life Performance Prediction

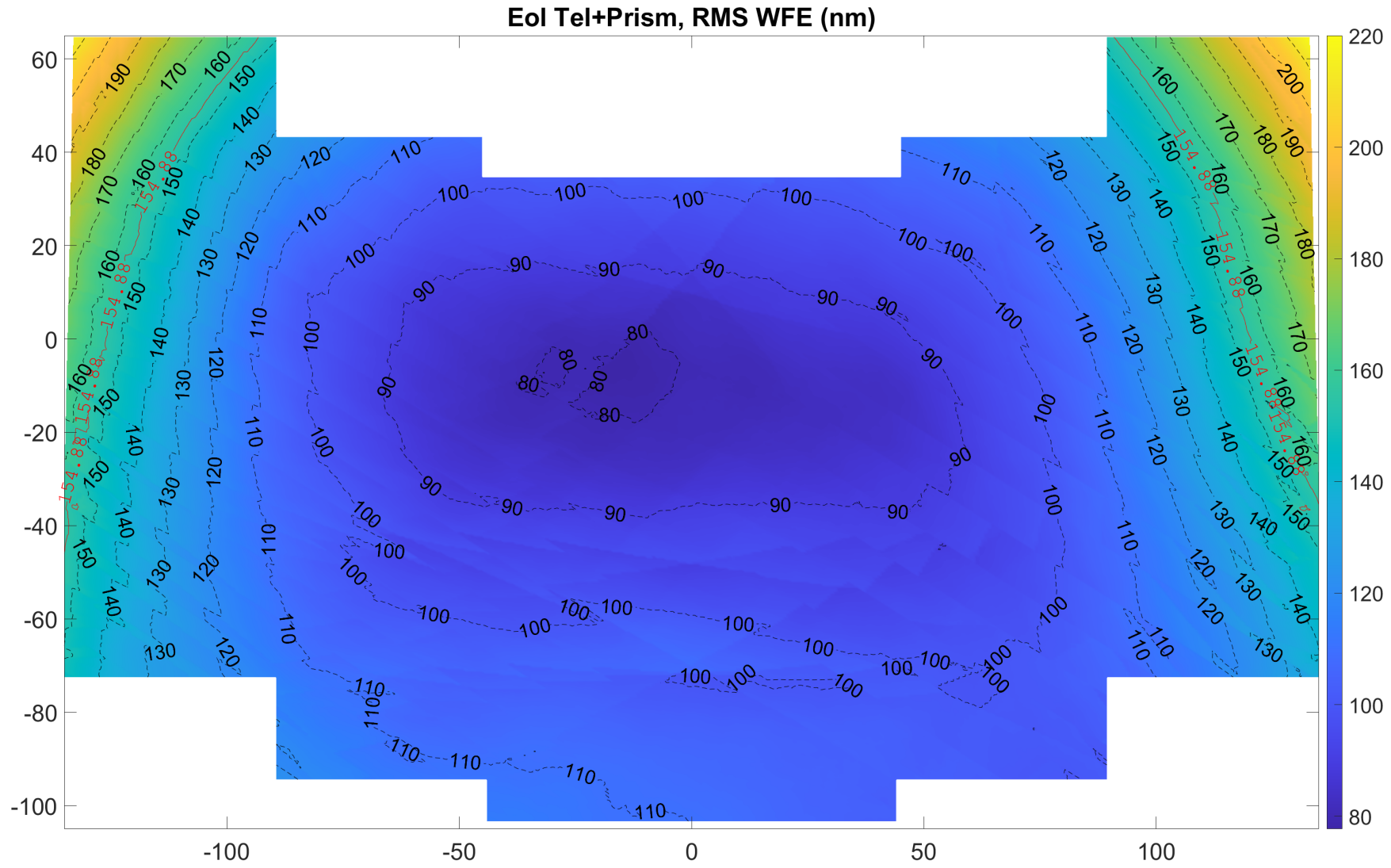


After an EOL Monte Carlo simulation, the 95<sup>th</sup> percentile trial is selected; then we find the maximum RMS WFE at the boundary of the lowest RMS 95% of the focal plane area.

95% field RMS WFE is 114.06nm, which meets the requirement (160nm).

Figure shows performance at 170K, 1550nm

# Prism EOL Performance Prediction - EDIT



After an EOL Monte Carlo simulation, the 95<sup>th</sup> percentile trial is selected; then we find the maximum RMS WFE at the boundary of the lowest RMS 90% of the focal plane area.

90% field RMS WFE is 154.88nm, which meets requirement (160nm).

Figure shows performance at 170K, 1200nm

- **We generated as-built Grism and Prism models based on data at the component and assembly level and augmented the data with STOP results to inform and bound them**
- **We have both room temperature and cryogenic models that mimic the test results within the tests' experimental errors**
- **We predicted the observatory level end-of-life performance of Grism and Prism, both meet requirements with adequate margin**
- **Going forward, these models will be further refined as the testing progresses and will serve as starting points for on orbit models that can be used for science simulations**

**Thank you for your attention!**

## Room Temp (293K) modeling and testing results comparison

RMS ZFR [nm]	Test Results										Model Results									
	Field 1	Field 2	Field 3	Field 4	Field 5	Field 6	Field 7	Field 8	Field 9	Field 10	Field 1	Field 2	Field 3	Field 4	Field 5	Field 6	Field 7	Field 8	Field 9	Field 10
Z3(Power)	-3	0	-8	-4	-7	-4	-7	-3	-8	-	-6	-10	-8	-7	-3	-12	-11	-3	0	-
Z4(X-Astig)	15	37	-45	-29	-2	13	26	-44	-35	-	14	35	-46	-30	-5	11	23	-48	-35	-
Z5(Y-Astig)	19	17	27	8	27	-12	44	10	39	-	19	17	26	15	24	-10	45	13	37	-
Z6(X-Coma)	-3	-4	-2	-21	14	-11	4	-14	8	-	-3	-4	-3	-23	16	-13	5	-15	9	-
Z7(Y-Coma)	6	8	10	8	12	7	9	7	9	-	6	8	9	9	11	8	9	8	9	-
Z8(Spherical)	-7	-8	-7	-7	-7	-7	-7	-5	-7	-	-4	-5	-2	-3	-3	-4	-4	-2	-2	-
ZFR9	-2	-1	-2	-6	5	-3	1	-4	-1	-	-2	-2	-3	-9	5	-5	1	-5	0	-
ZFR 10	-4	-8	6	-7	-1	-9	-6	3	5	-	-5	-9	6	-6	-4	-9	-8	4	6	-
ZFR 11	3	3	1	2	0	3	2	1	1	-	1	1	1	1	1	1	1	1	1	-
ZFR 12	-1	-2	-1	-3	0	-3	-1	-2	0	-	-1	-1	-2	-4	1	-3	0	-3	0	-
ZFR 13	-1	-1	-1	-2	1	-2	0	-1	0	-	0	0	0	0	0	0	0	0	0	-
ZFR 14	2	2	3	2	1	2	2	2	2	-	3	4	3	3	3	4	4	3	3	-
ZFR 15	-2	-2	2	-2	-2	-2	-3	0	1	-	1	1	1	1	1	1	1	1	1	-

RMS ZFR [nm]	Delta (Model-Test)									
	Field 1	Field 2	Field 3	Field 4	Field 5	Field 6	Field 7	Field 8	Field 9	Field 10
Z3(Power)	-3	-10	0	-3	4	-8	-4	0	8	-
Z4(X-Astig)	-1	-2	-1	-1	-3	-2	-3	-4	0	-
Z5(Y-Astig)	0	0	-1	7	-3	2	1	3	-2	-
Z6(X-Coma)	0	0	-1	-2	2	-2	1	-1	1	-
Z7(Y-Coma)	0	0	-1	1	-1	1	0	1	0	-
Z8(Spherical)	3	3	5	4	4	3	3	3	5	-
ZFR9	0	-1	-1	-3	0	-2	0	-1	1	-
ZFR 10	-1	-1	0	1	-3	0	-2	1	1	-
ZFR 11	-2	-2	0	-1	1	-2	-1	0	0	-
ZFR 12	0	1	-1	-1	1	0	1	-1	0	-
ZFR 13	1	1	1	2	-1	2	0	1	0	-
ZFR 14	1	2	0	1	2	2	2	1	1	-
ZFR 15	3	3	-1	3	3	3	4	1	0	-

Data from: RST-WFI-ANYS-0612-.xlsx

## Cryo (175K) modeling and testing results comparison

RMS ZFR [nm]	Test Results										Model Results									
	Field 1	Field 2	Field 3	Field 4	Field 5	Field 6	Field 7	Field 8	Field 9	Field 10	Field 1	Field 2	Field 3	Field 4	Field 5	Field 6	Field 7	Field 8	Field 9	Field 10
Z3(Power)	-3	0	-8	-4	-7	-4	-7	-3	-8	-	-6	-10	-8	-7	-3	-12	-11	-3	0	-
Z4(X-Astig)	15	37	-45	-29	-2	13	26	-44	-35	-	14	35	-46	-30	-5	11	23	-48	-35	-
Z5(Y-Astig)	19	17	27	8	27	-12	44	10	39	-	19	17	26	15	24	-10	45	13	37	-
Z6(X-Coma)	-3	-4	-2	-21	14	-11	4	-14	8	-	-3	-4	-3	-23	16	-13	5	-15	9	-
Z7(Y-Coma)	6	8	10	8	12	7	9	7	9	-	6	8	9	9	11	8	9	8	9	-
Z8(Spherical)	-7	-8	-7	-7	-7	-7	-7	-5	-7	-	-4	-5	-2	-3	-3	-4	-4	-2	-2	-
ZFR9	-2	-1	-2	-6	5	-3	1	-4	-1	-	-2	-2	-3	-9	5	-5	1	-5	0	-
ZFR 10	-4	-8	6	-7	-1	-9	-6	3	5	-	-5	-9	6	-6	-4	-9	-8	4	6	-
ZFR 11	3	3	1	2	0	3	2	1	1	-	1	1	1	1	1	1	1	1	1	-
ZFR 12	-1	-2	-1	-3	0	-3	-1	-2	0	-	-1	-1	-2	-4	1	-3	0	-3	0	-
ZFR 13	-1	-1	-1	-2	1	-2	0	-1	0	-	0	0	0	0	0	0	0	0	0	-
ZFR 14	2	2	3	2	1	2	2	2	2	-	3	4	3	3	3	4	4	3	3	-
ZFR 15	-2	-2	2	-2	-2	-2	-3	0	1	-	1	1	1	1	1	1	1	1	1	-

RMS ZFR [nm]	Delta (Model-Test)									
	Field 1	Field 2	Field 3	Field 4	Field 5	Field 6	Field 7	Field 8	Field 9	Field 10
Z3(Power)	-3	-10	0	-3	4	-8	-4	0	8	-
Z4(X-Astig)	-1	-2	-1	-1	-3	-2	-3	-4	0	-
Z5(Y-Astig)	0	0	-1	7	-3	2	1	3	-2	-
Z6(X-Coma)	0	0	-1	-2	2	-2	1	-1	1	-
Z7(Y-Coma)	0	0	-1	1	-1	1	0	1	0	-
Z8(Spherical)	3	3	5	4	4	3	3	3	5	-
ZFR9	0	-1	-1	-3	0	-2	0	-1	1	-
ZFR 10	-1	-1	0	1	-3	0	-2	1	1	-
ZFR 11	-2	-2	0	-1	1	-2	-1	0	0	-
ZFR 12	0	1	-1	-1	1	0	1	-1	0	-
ZFR 13	1	1	1	2	-1	2	0	1	0	-
ZFR 14	1	2	0	1	2	2	2	1	1	-
ZFR 15	3	3	-1	3	3	3	4	1	0	-

RST-WFI-ANYS-0612-.xism

## Room Temp (300K) modeling and testing results comparison

RMS ZFR [nm]	Test Results										Model Results									
	Field 1	Field 2	Field 3	Field 4	Field 5	Field 6	Field 7	Field 8	Field 9	Field 10	Field 1	Field 2	Field 3	Field 4	Field 5	Field 6	Field 7	Field 8	Field 9	Field 10
Z3(Power)	-9	-2	-6	-8	-10	10	4	5	2	3	0	0	-1	6	6	0	0	0	-1	0
Z4(X-Astig)	-9	7	-201	164	141	59	3	19	-77	69	-9	14	-191	155	130	65	4	18	-73	66
Z5(Y-Astig)	-5	18	-15	-83	82	25	66	-79	-121	15	-1	18	-17	-84	81	33	68	-85	-118	10
Z6(X-Coma)	6	7	5	16	-5	0	2	11	9	8	5	9	3	21	-12	-5	-4	13	11	14
Z7(Y-Coma)	28	18	19	28	24	20	20	21	26	23	24	23	16	24	20	22	22	24	21	24
Z8(Spherical)	7	7	11	9	10	8	8	9	9	8	4	3	6	4	5	5	5	4	5	3
ZFR9	-10	-9	-13	-4	-19	-15	-12	-6	-13	-6	-11	-9	-9	-1	-21	-19	-14	-7	-9	-4
ZFR 10	18	16	20	13	11	13	12	13	14	18	17	24	13	14	11	15	13	14	13	21
ZFR 11	3	5	5	3	1	4	4	4	2	5	1	1	-1	0	1	1	1	0	-1	1
ZFR 12	2	2	5	3	2	3	3	4	6	3	3	2	3	2	3	3	3	2	3	2
ZFR 13	-2	0	0	-6	-3	2	1	-1	-4	-2	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
ZFR 14	-1	0	2	-1	0	1	1	0	1	-4	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
ZFR 15	-6	-1	-3	-3	-2	-2	-3	-3	-4	-4	0	0	0	0	0	0	0	0	0	0
RMS ZFR [nm]	Delta (Model-Test)																			
	Field 1	Field 2	Field 3	Field 4	Field 5	Field 6	Field 7	Field 8	Field 9	Field 10										
Z3(Power)	8	2	5	14	16	-10	-4	-5	-3	-3										
Z4(X-Astig)	0	7	10	-9	-11	6	1	0	5	-3										
Z5(Y-Astig)	4	0	-3	-1	-1	8	2	-7	3	-5										
Z6(X-Coma)	-1	2	-2	5	-6	-5	-6	3	3	6										
Z7(Y-Coma)	-4	5	-2	-3	-4	2	2	3	-5	1										
Z8(Spherical)	-3	-4	-5	-6	-5	-3	-3	-5	-4	-5										
ZFR9	-1	1	5	2	-2	-5	-2	-1	4	2										
ZFR 10	-1	8	-6	1	0	2	0	1	-1	3										
ZFR 11	-3	-4	-6	-3	0	-3	-4	-4	-2	-5										
ZFR 12	0	0	-2	-2	2	0	0	-1	-3	-1										
ZFR 13	1	0	-1	5	2	-3	-2	0	3	1										
ZFR 14	0	-1	-3	0	-1	-2	-2	-1	-2	3										
ZFR 15	5	1	3	3	2	2	3	3	4	4										

## Cryogenic (175K) modeling and testing results comparison

RMS ZFR [nm]	Test Results										Model Results									
	Field 1	Field 2	Field 3	Field 4	Field 5	Field 6	Field 7	Field 8	Field 9	Field 10	Field 1	Field 2	Field 3	Field 4	Field 5	Field 6	Field 7	Field 8	Field 9	Field 10
Z3(Power)	10	8	0	5	-11	-7	12	0	-5	4	0	0	0	-1	-1	0	0	0	0	0
Z4(X-Astig)	-13	6	-195	144	131	66	7	11	-79	58	-11	9	-198	149	137	68	7	13	-78	61
Z5(Y-Astig)	-2	16	-14	-80	80	29	70	-84	-115	9	1	16	-16	-84	83	32	72	-85	-117	10
Z6(X-Coma)	7	7	9	13	-3	1	0	12	12	10	8	9	6	16	-3	1	2	12	11	12
Z7(Y-Coma)	23	17	15	19	20	20	21	21	19	19	24	23	16	23	22	23	23	24	21	23
Z8(Spherical)	10	9	11	9	10	10	10	9	10	11	10	10	9	9	11	11	10	9	9	10
ZFR9	-11	-9	-10	-3	-19	-19	-13	-8	-10	-5	-12	-9	-10	-2	-20	-19	-15	-8	-11	-4
ZFR 10	18	21	21	14	9	15	14	15	17	19	18	22	19	14	11	15	14	16	17	20
ZFR 11	4	1	3	4	5	4	3	5	5	2	3	3	3	3	4	3	3	3	3	3
ZFR 12	5	2	4	5	4	3	3	4	3	3	3	3	4	4	3	3	3	4	4	3
ZFR 13	0	-1	0	-2	2	1	2	-1	0	-2	2	2	1	2	2	2	2	2	2	2
ZFR 14	2	1	1	3	1	1	1	2	2	1	3	3	3	4	3	3	3	3	3	4
ZFR 15	-2	-2	-2	-3	0	0	-1	-1	-2	-2	0	0	0	0	0	0	0	0	0	0

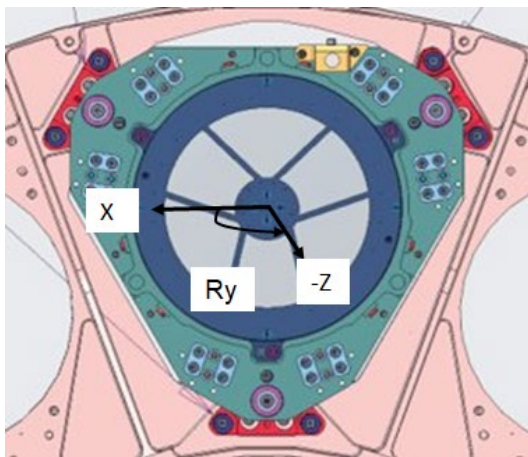
RMS ZFR [nm]	Delta (Model-Test)									
	Field 1	Field 2	Field 3	Field 4	Field 5	Field 6	Field 7	Field 8	Field 9	Field 10
Z3(Power)	-11	-9	0	-5	11	6	-13	-1	5	-4
Z4(X-Astig)	2	3	-3	6	6	2	0	2	1	4
Z5(Y-Astig)	3	0	-2	-4	3	4	1	-1	-2	1
Z6(X-Coma)	1	2	-3	3	0	0	2	0	-1	2
Z7(Y-Coma)	1	6	2	4	2	3	2	3	2	4
Z8(Spherical)	0	1	-2	0	1	1	0	0	-1	-1
ZFR9	-1	0	0	1	-2	0	-1	-1	0	1
ZFR 10	-1	1	-1	0	1	0	0	1	0	1
ZFR 11	-1	1	1	-1	-1	-1	1	-2	-2	1
ZFR 12	-2	1	0	-1	-1	-1	0	-1	1	0
ZFR 13	1	2	2	4	0	1	0	3	2	4
ZFR 14	1	2	2	1	2	2	2	1	2	2
ZFR 15	2	2	2	3	0	0	1	1	2	2

Test data from: 20220531\_WOA2095\_Prism\_Cryo2 with BFL.xlsx

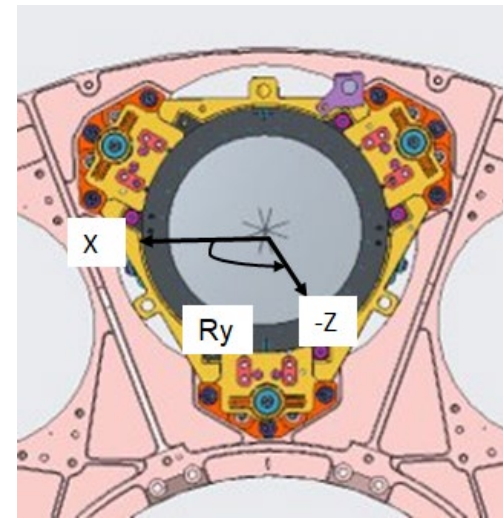
# Integration to Element Wheel Assembly (EWA)

- When the as-built Grism and Prism assemblies are finished, they are integrated to the EWA, and EWA integrated to WFI bench which located at the exit pupil of RST telescope
- In this step, the Grism and Prism assemblies are adjusted to furtherly reduce the observatory-level wavefront error. Adjustments on assembly lever are listed below.

Grism on the EWA



Prism on the EWA



	Dz (mm)	Rx(deg)	Ry(deg)
Grism	--	0.5	-0.5
Prism	-0.27	0.5	-0.28