ROMAN SPACE TELESCOPE

Roman Space Telescope
Wide Field Instrument

Grism and Prism Overview, Design, and As-Built Models

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Bente Eegholm, Ph.D.
NASA Goddard Space Flight Center

with C. Marx, V. J. Chambers, M. Dominguez, G. Gao, Q. Gong, E. Bray[1], J. Hagopian[2], J. P. Lehan, B. Pasquale, J. Schlieder, and L. Seide[1]

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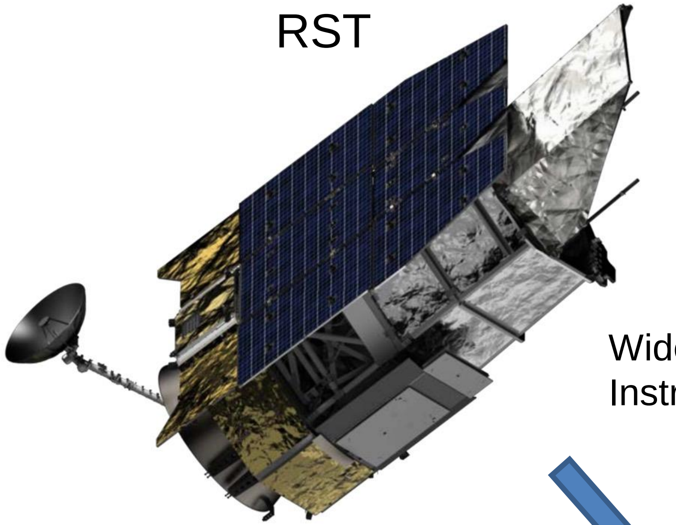
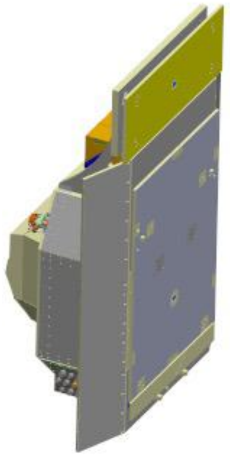
Outline

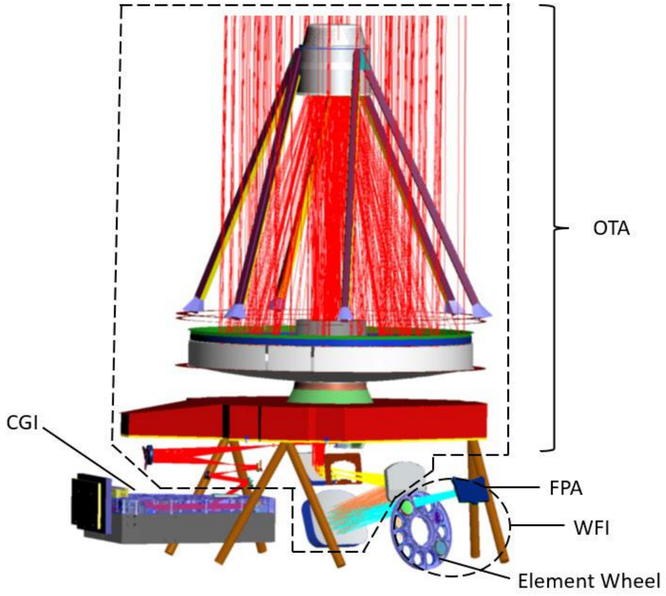
- Brief Introduction of Roman Space Telescope (RST) and Wide Field Instrument (WFI)
- Grism and Prism roles in RST science
- Design challenges
- Grism and Prism As-built Models
- Spectral verification, dispersion and refractive index lessons learned
- Results of as-built modeling work and comparison to test
- Integration to Telescope and end-of-life (EOL) on-orbit performance prediction
- Summary

RST



Wide Field Instrument

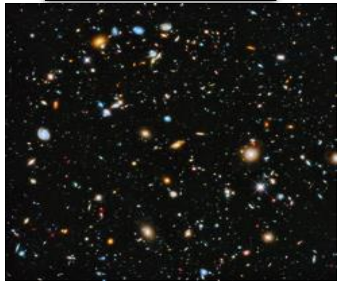




2.4 m primary
L2 orbit

Grism and Prism Roles in RST Wide Field Instrument Science

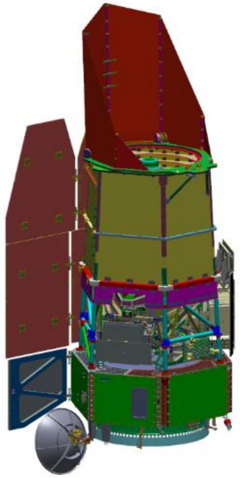
Dark Energy



Use multiple independent methods to measure cosmic expansion history and growth of structure

Enables tests of theories of accelerated expansion including Dark Energy and modifications to General Relativity

Provide General Observer / General Investigator programs using either instrument for the community



Wide Field Instrument (WFI)

High Latitude Time Domain Survey	**High Latitude Wide Area Survey (Imaging)**
High Latitude Wide Area Survey (Spectroscopy)	**Galactic Bulge Time Domain Survey**

Grism

Full field, slitless spectroscopy

High Latitude Spectroscopic Survey (HLSS)

Acquires galaxy spectra to measure the redshift to measure the Expansion of the universe to achieve Dark Energy information

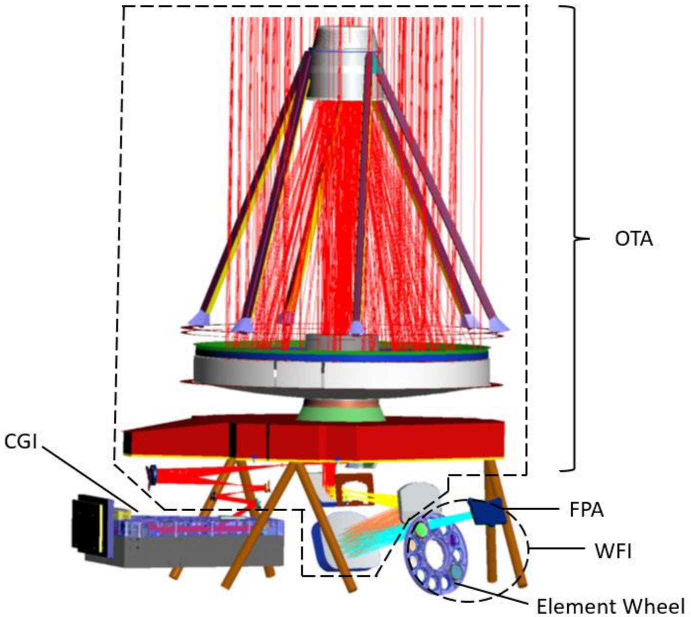
Prism

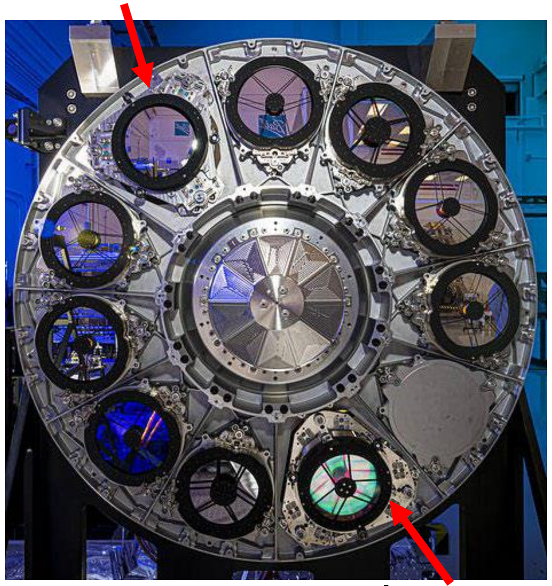
Full field, slitless spectroscopy

High Latitude Time Domain Survey (HLTDS)

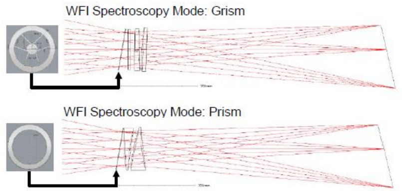
Acquires spectra of supernova Type Ia (explosion of white dwarf which exceed threshold mass by accretion). Measures distance to explosion for info about universe Expansion over cosmic history

Wide Field Instrument (WFI) Introduction





Grism



F/8 beam yields 9x tighter focus tolerance as compared to Webb/Hubble F/24

Focal Plane Assembly

Element Wheel Assembly (EWA) houses:

- 8 science filters, Grism, Prism, and a dark element
- All elements are confocal
- Facilitates direct imaging, spectral imaging, and calibration

Operates at 170K

- FPA integrates 18 H4RG detectors
- Each detector is a 4096 x 4096 array of 10µm x 10µm pixels
- FPA is mounted on a hexapod to allow tip/tilt/focus adjustment

Grism and Prism design challenges

Challenges for both Grism and Prism

- f/8 converging beam introduces large aberrations
- Large FOV and wavelength range introduces large field-dependent chromatic aberrations
- Zero beam deviation and parfocality requirements constrain design
- Fit into a tight space in the filter wheel
- 170K cold operation

	Grism	Prism
Wavelength (μm)	1.0-1.93	0.8-1.60
FOV at WFI pupil (degree)	22 x 13	22 x 13
Pupil mask diameter (mm)	89	95
Beam f-number	Converging, ~f/8	Converging, ~f/8
Wavefront error	diffraction limit (DL)	For wavelength λ>1um, RMS WFE < λ/10
Spectral Resolving Power (per 2 pixels)	~700	75 -- ~180
0-deviation wavelength (center of field of view)	1.550 μm	1.550 μm
Confocal	Filter/Grism/Prism have same image surface position	

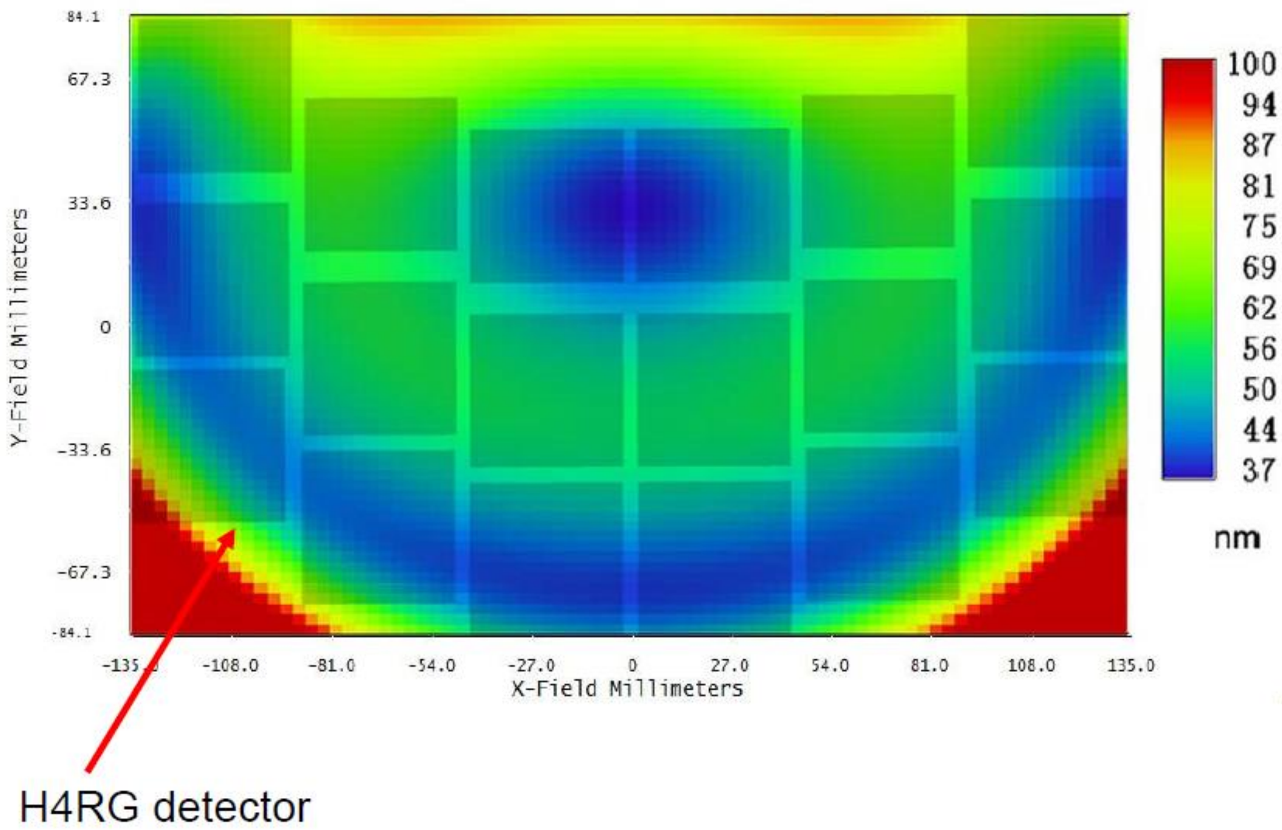
Grism

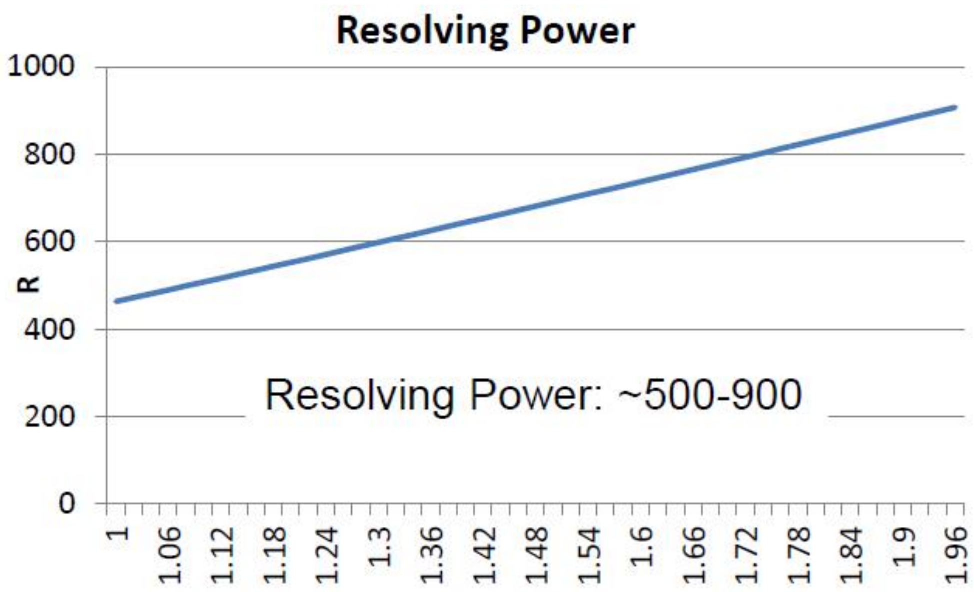
- Extra challenge: Diffractive surfaces lead to aberrations difficult to balance with refractive elements
- High dispersion leads to diffractive solution
- 2nd diffractive surface balances aberrations in diffractive disperser
- Zero chief ray beam deviation at 1550 nm requires prism-compensation of diffractive elements deviation
- 2 prisms (E2,E3) after the diffractive element (E1) balance defocus, field and chromatic ab.
- Using 2 prisms allowed diffraction-limited performance over the large field of view and bandwidth using only spherical surfaces
- Material: Fused SIlica

Prism

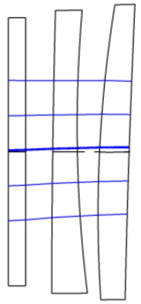
- High-index, high-dispersion glass (S-TIH1, n=1.71695, v=29.75) for 1st element (P1) because dispersion yields optimal R vs λ for the science.
- 2nd element, P2, (lower index and dispersion) CaF_2, n=1.43479, v=96.66)
  - Wedge placed in opposition to P1
  - Balances the aberrations from P1's tilted surfaces
  - Corrects the chief ray beam deviation
  - Maintains parfocality
- P1 controls the dispersion
- P2 is a corrector element to allow insertion into the telescope without moving the focal plane.
- All-spherical surfaces

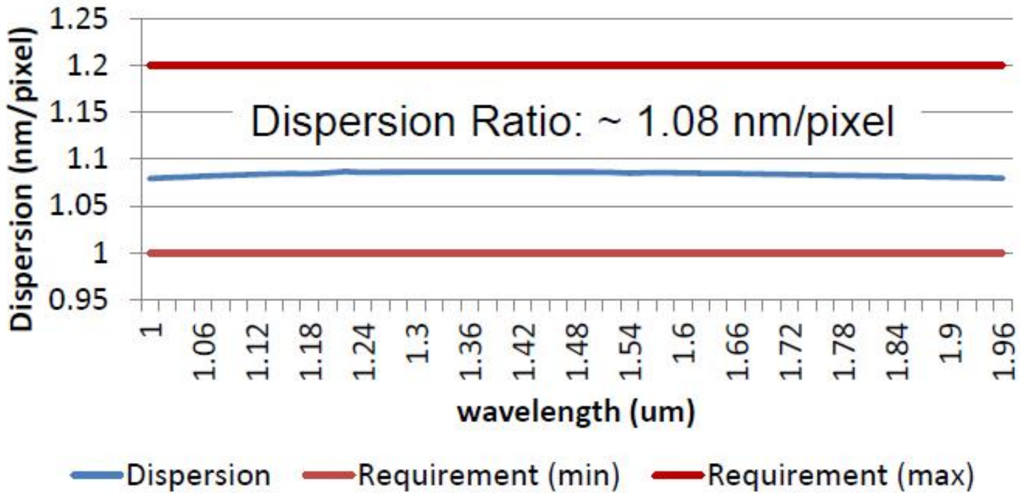
As-Designed Grism





Evaluation wavelength: 1550 nm, 95% of FPA fields have RMS WFE less than 67.2nm





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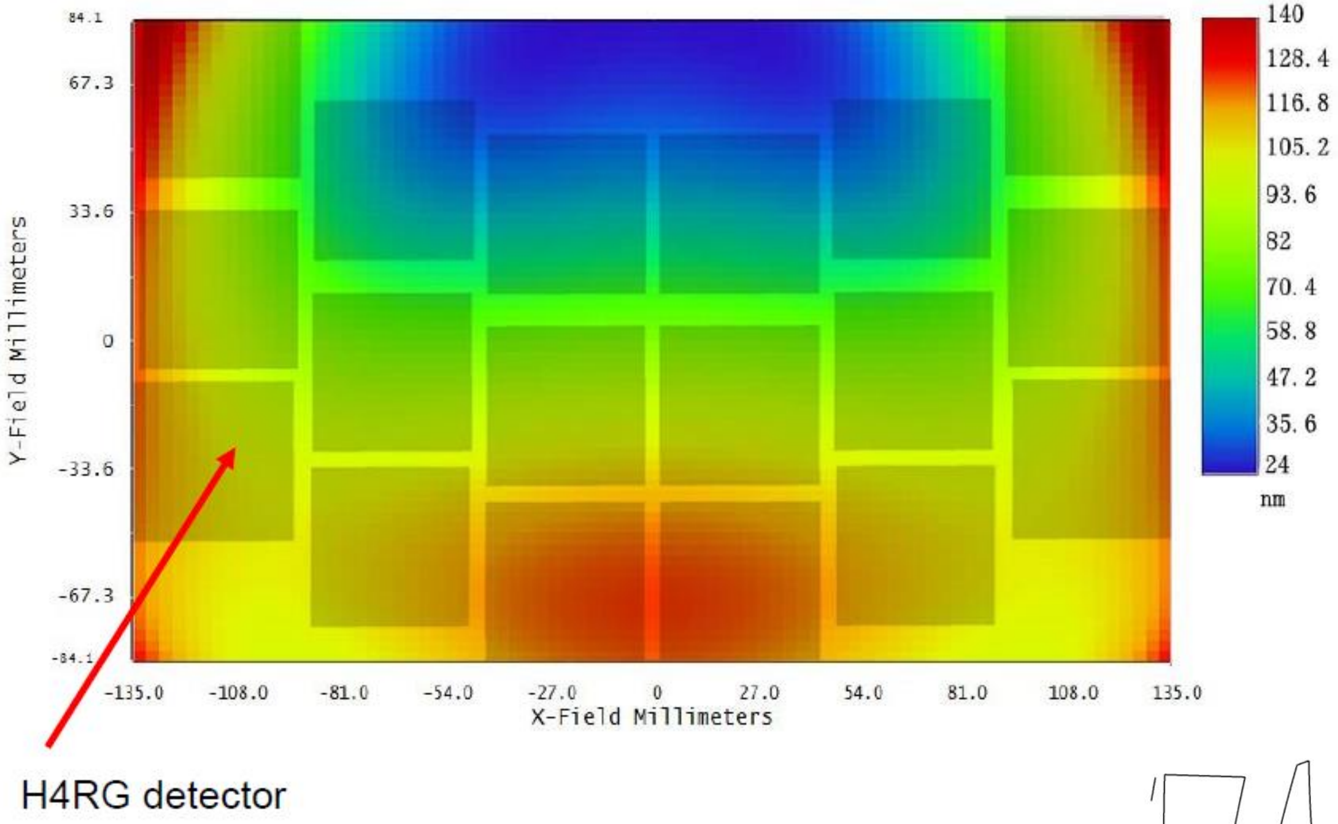
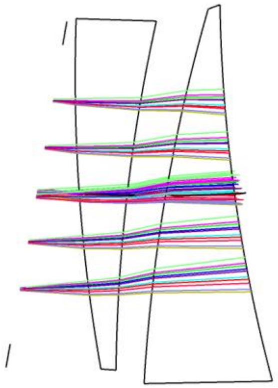
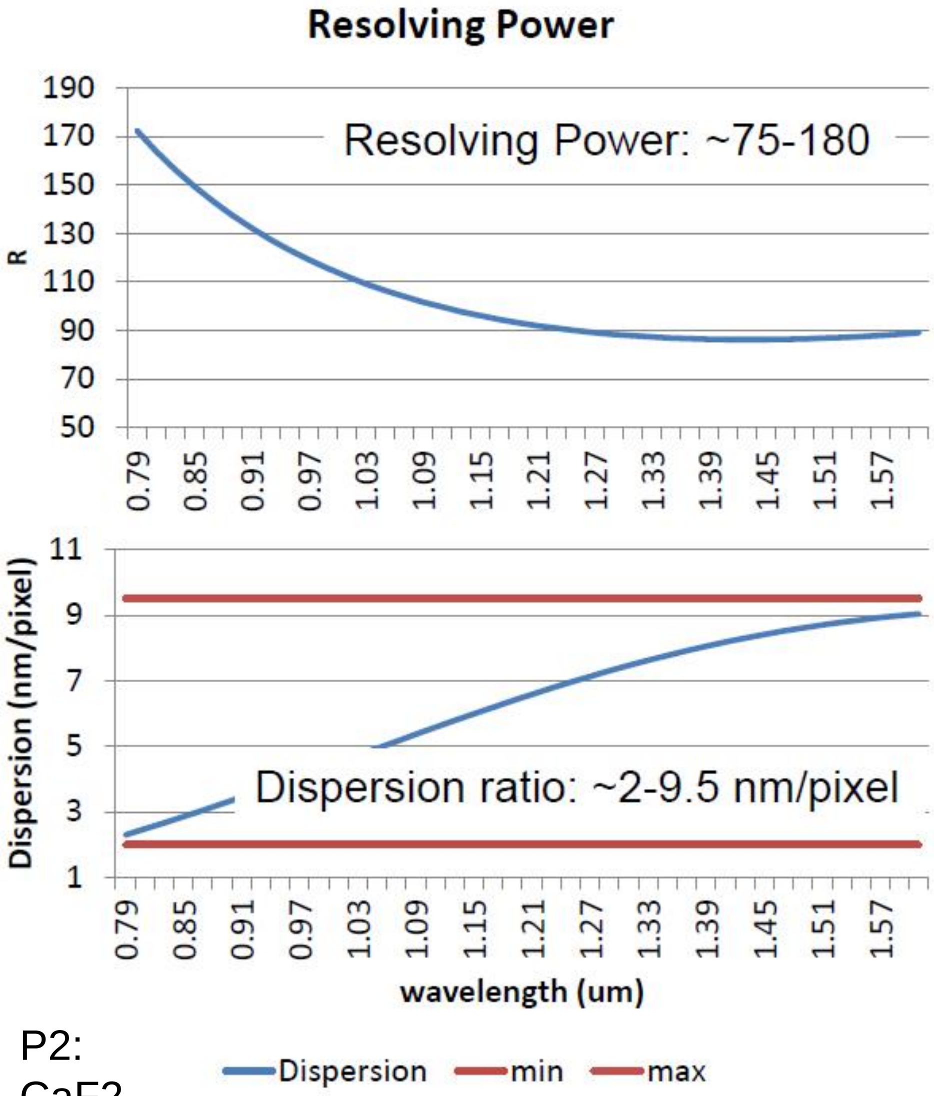
As-Designed Prism



Evaluation wavelength: 1200 nm, 90% of FPA fields have RMS WFE < 121 nm





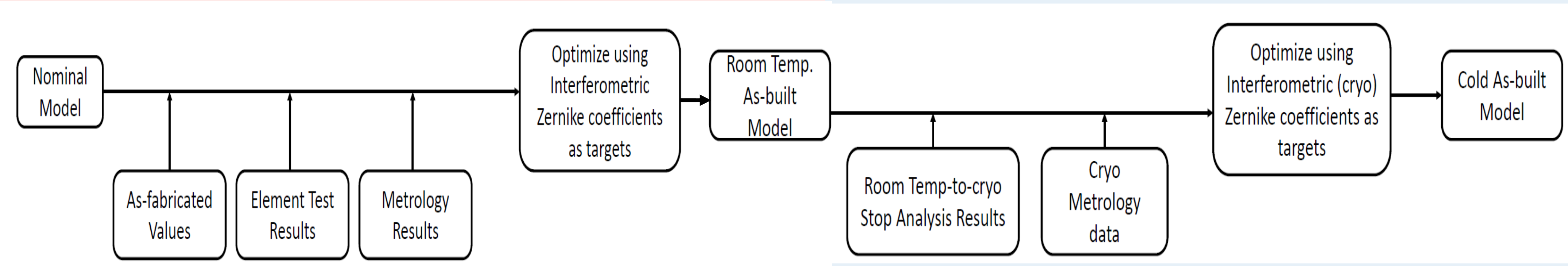
Grism and Prism As-built Models
Room and Cryogenic Temperatures

- 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 element
2. Apply metrology data
3. Optimize alignment/fabrication parameters within uncertainty ranges to match Zernike coefficients at each field to interferometric test results
4. Verify spectral dispersion performance of as-built models matches results from spectral verification testing

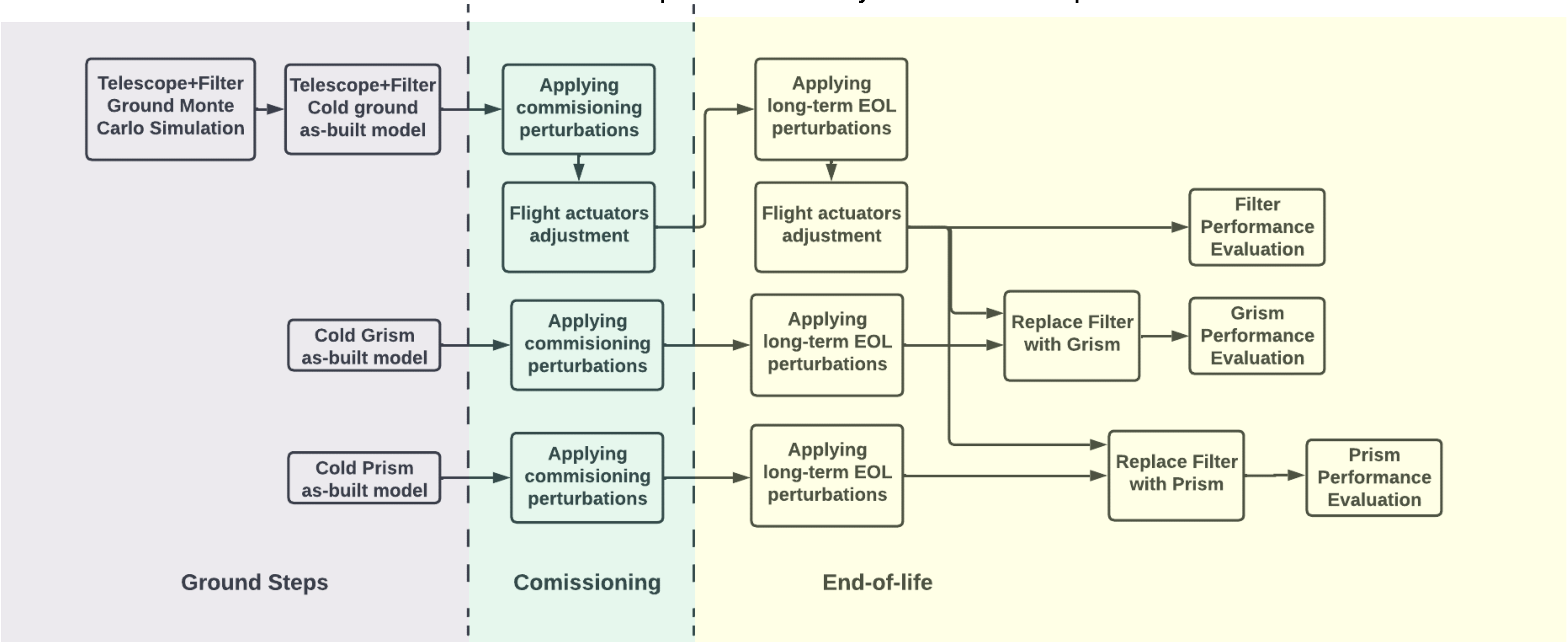
- Starting from room temperature as-built model:

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 match low-order Zernike coefficients from cryo-interferometric tests
7. Adjust higher-order Zernikes determined by STOP modeling based on cryogenic interferometric measurements
8. Add mid-spatial SFE if needed



Flow Chart of Flight Performance Prediction

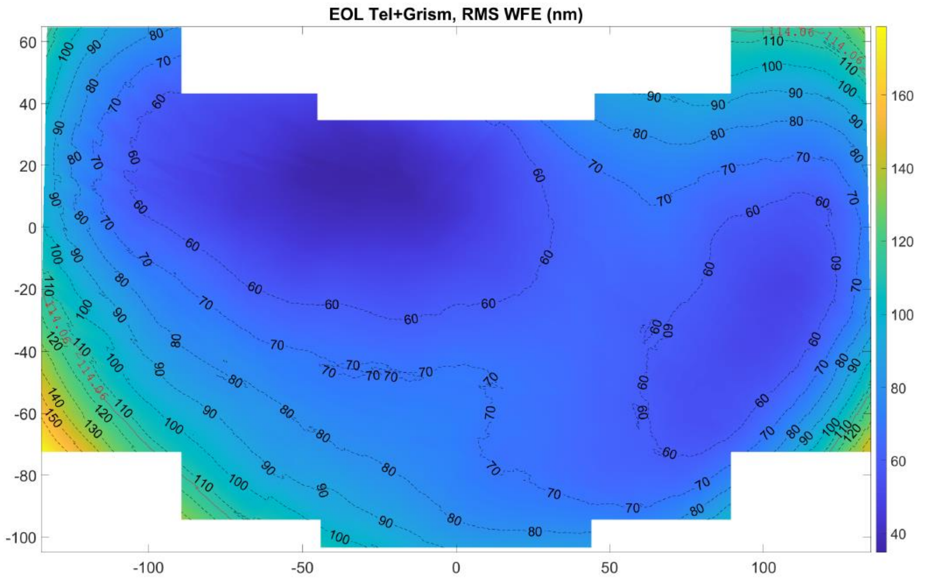
- During the Grism and Prism AI&T phase there was not yet any as-built telescope
- Monte Carlo performed based on the *Pseudo* as-built telescope which includes
  - Telescope mirrors' as-fabricated information
  - Alignment errors and compensators' adjustment
  - On-orbit perturbations and refocus performed in Telescope + Filter operational mode
- Grism and Prism mode: No telescope refocus adjustment. FPA position set for Filter mode



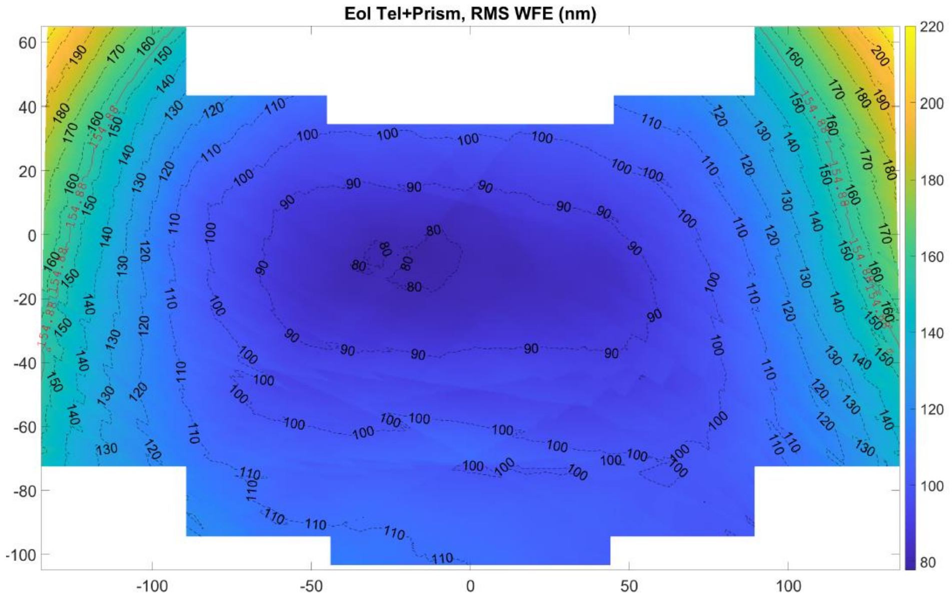
End-Of-Life Performance Prediction

EOL Monte Carlo simulation → Select the 95th percentile trial → Find max. rms WFE at boundary of required % of the focal plane

- Grism
  - 95% field RMS WFE is 114.06nm,
    - meets requirement (160nm).
  - Performance shown for 175K,1550nm



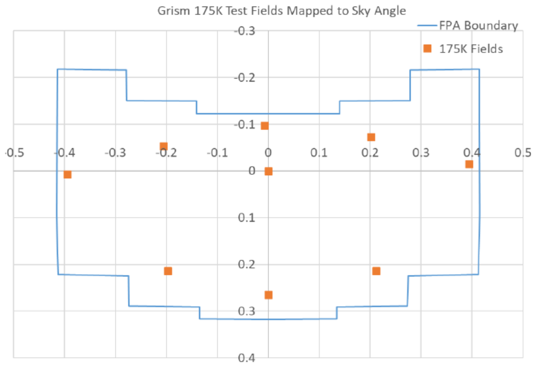
- Prism
  - 90% field RMS WFE is 154.88nm
    - meets requirement (160nm).
  - Performance shown for 175K,1200nm

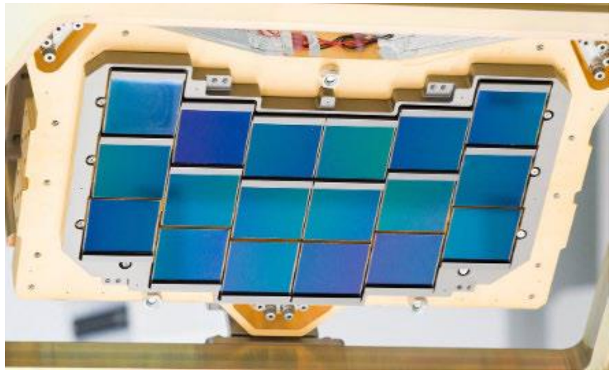


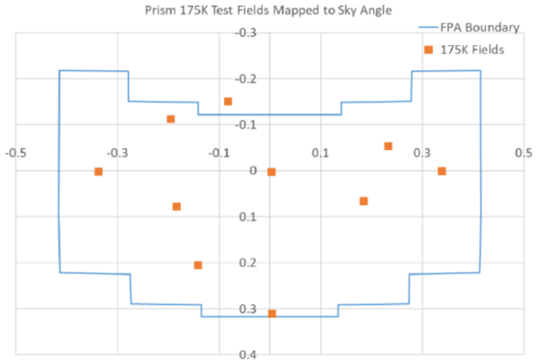
As-built Models

Cryogenic (175K) modeling and testing results comparison @1053 nm wavelength
*Z3 data is a combination of 2 measurements so has ~ 3x more uncertainty

- **Grism**
  - 10 nm (0.0095λ RMS) max. difference
- **Prism**
  - 13 nm (0.0123λ) RMS max. difference







	Delta (Model-Test)								
RMS ZFR [nm]	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

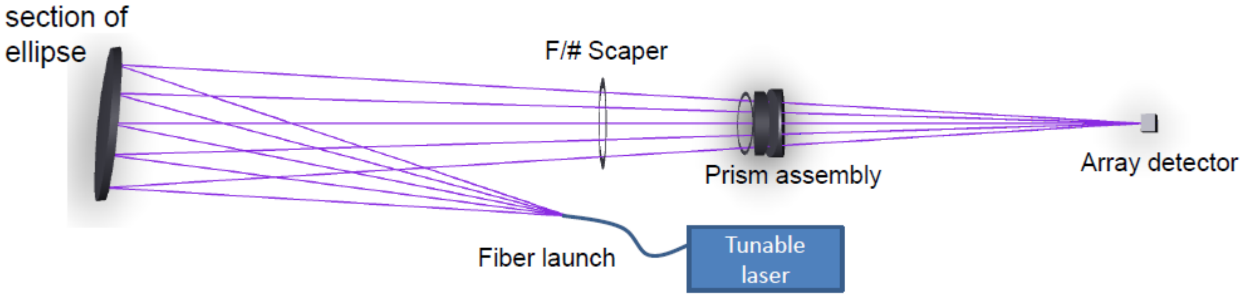
	Delta (Model-Test)									
RMS ZFR [nm]	Field 1	Field 2	Field 3	Field 4	Field 5	Field 6	Field 7	Field 8	Field 9	Field 10
Z3*(Power)	-11	-9	0	-5	11	6	-13	-1	5	-4
Z4(X-Astig)	2	3	-3	6	6	2	0	2	1	4
Z5(Y-Astig)	3	0	-2	-4	3	4	1	-1	-2	1
Z6(X-Coma)	1	2	-3	3	0	0	2	0	-1	2
Z7(Y-Coma)	1	6	2	4	2	3	2	3	2	4
Z8(Spherical)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

Calibration and Characterization

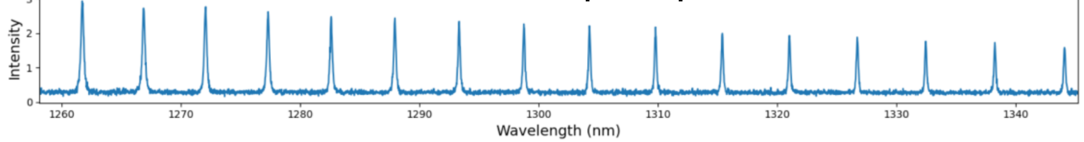
- The Ellipse Testbed was developed to test
  - Diffraction efficiency
  - Throughput
  - Radiometric calibration
  - Bandpass filter edge measurement
  - Dispersion scale

- Spectral accuracy and wavelength knowledge is the most challenging test.
- Slitless spectrometers strongly rely on the dispersion scale and BP filter edge sharpness to determine absolute λ
- Testbed provides better than diffraction limited beam for Grism/Prism
- White light laser 700 nm –2000 nm
- Comb filters: spectral line series with the desired spacing and bandwidth.
- Argon source calibrated FFT based Optical Spectral Analyzers used to calibrate source wavelengths.
- Automated data collection and analysis

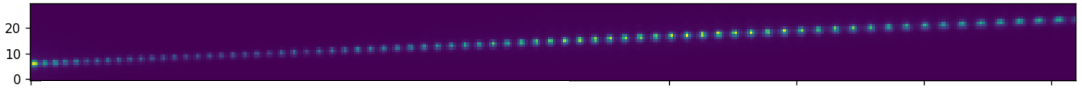
Ellipse Testbed

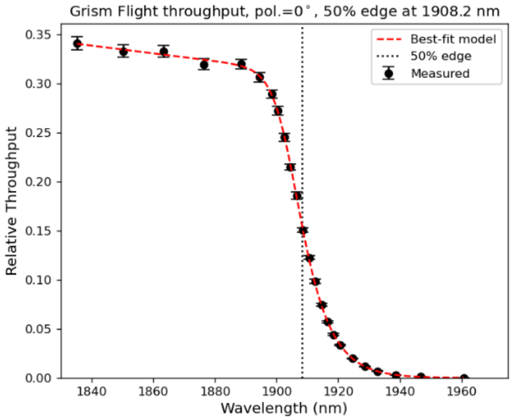


Comb filter output spectrum



Grism Flight Raw image data

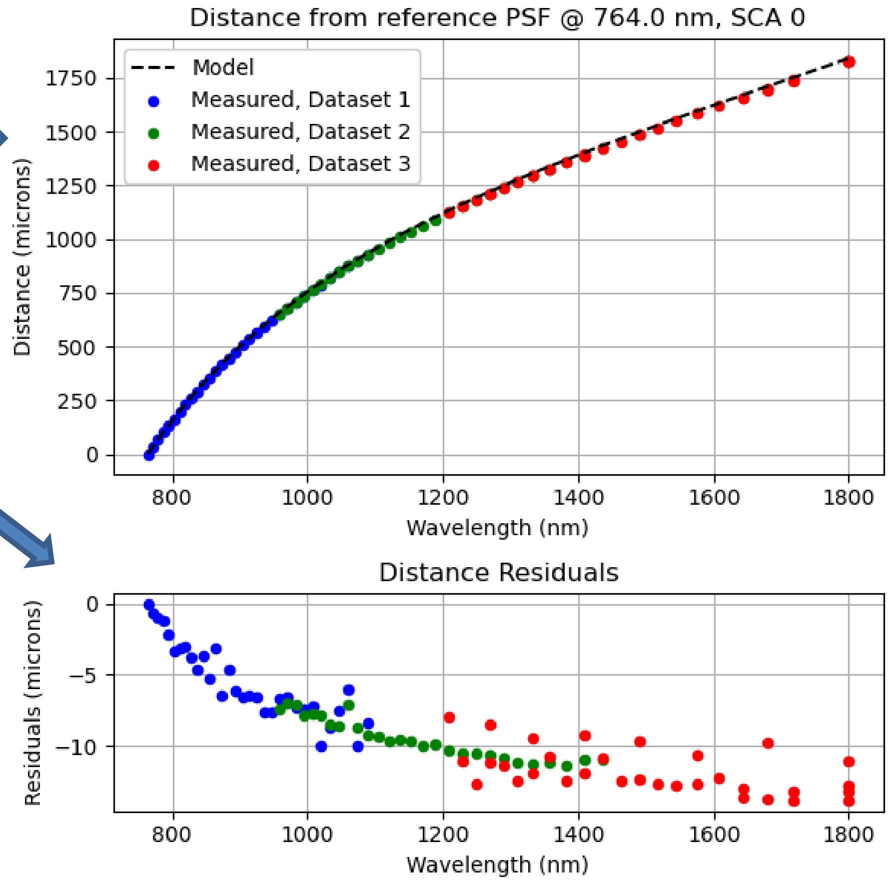




Cut-on/cut-off λ varies with:
- Field position
- Angle of incidence
- Temperature
- Polarization
- Optic position

Dispersion discrepancy and index error

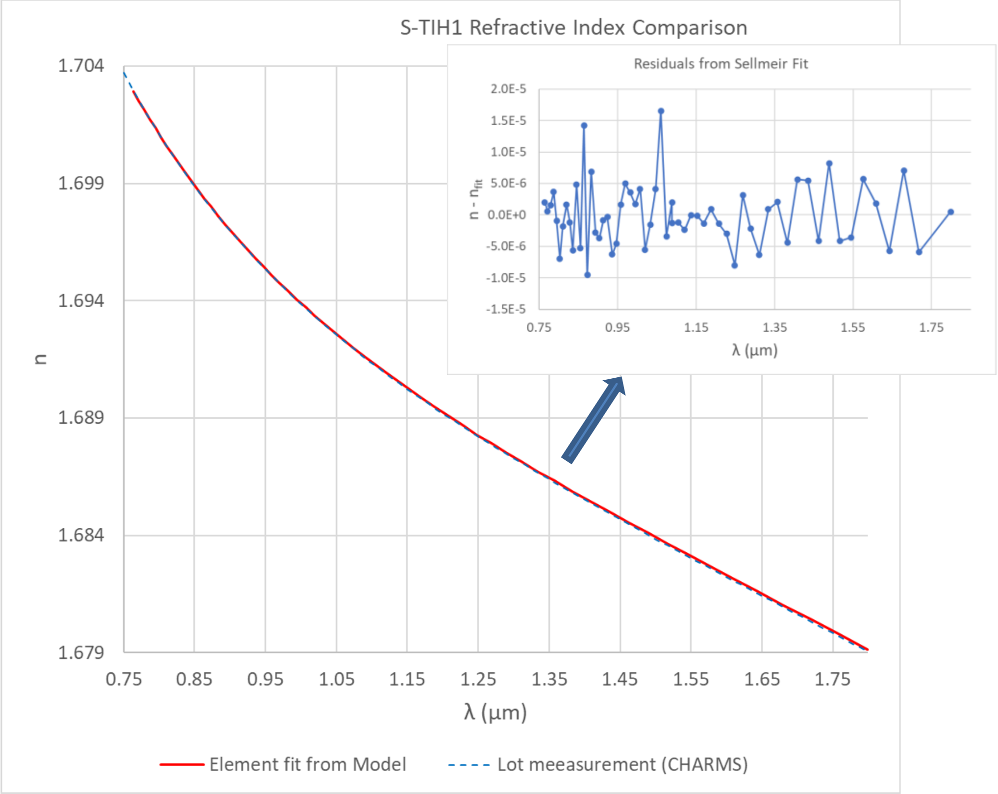
- Dispersion of Prism measured in Ellipse testbed
- Measurement geometry has to carefully match the telescope focal plane geometry for verification of the specifications
- At first, the resultant spectrum was slightly shorter than expected
- Data deviates from the model despite measuring the lot indices and careful characterization of the elements
- Dispersion still in spec but the model is not good enough for science simulations
  - Does not meet the knowledge goals
- Interferometry performed and modeled at 1053 nm and 1546 nm to optimize equipment use schedule
- The 1053nm/1046nm models suggested slightly different alignments, but individually consistent



- Trouble-shooting ruled out everything but refractive index value in the Prism
- CaF2 a pure substance with very small lot-to-lot variation, ruled out as source of error
- S-TIH-1 solid solution with small variability

Correction methodology

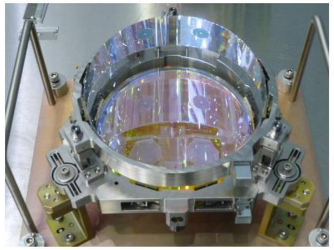
- Raw ellipse testbed data used
- Optical model-based fit
- Only employed field with performance most tolerant to alignment difference between 1053 and 1546 nm models
- Assume CHARMS lot measurement index is the same as our component's index at the short end (nearest VIS)
  - No arc-sec level angle measurement available to establish a zero deviation to high certainty
- Index a free variable at all other λ
- Interpolate resultant indices with a 3-term Sellmeier dispersion formula
- New indices determined at room temperature (Prism operates at 175K)
- New dispersion allows a single alignment to describe interferometric data and power measurements at 1053nm & 1546nm to within error bars
- Cryogenic dispersion and focus will be measured during WFI testing



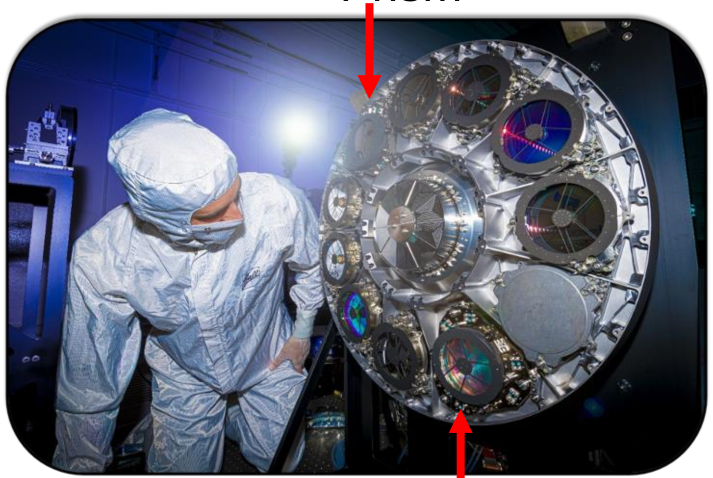
- Catalog indices get more uncertain as the spectral region deviates from VIS
- Single lot measurements are not adequate for precision work
- Sample the *exact blank*

Summary

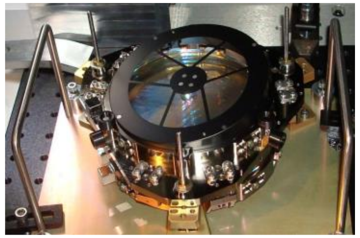
- The design and modeling efforts presented have helped overcome the many challenges in designing, implementing, testing, and calibrating the RST Grism and Prism optical instruments.
- We generated as-built Grism and Prism models based on data at the component and assembly level and augmented the data with STOP results to inform and bound them
- Both room temperature and cryogenic models mimic the test results within the tests' experimental errors
- We predicted the observatory level end-of-life performance of Grism and Prism, and 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
- The Grism and Prism have now been successfully built and tested at the instrument level, delivered and incorporated into the WFI
- The WFI is currently undergoing thermal vacuum test at Ball Aerospace in Boulder, CO.
- When WFI element level test is complete, it will be integrated to the RST telescope at NASA Goddard Space Flight Center in Greenbelt, MD.



Prism



Grism



Thank you for your attention!