NANCY GRACE ROMAN SPACE TELESCOPE

CGI Spectrometer/Polarimeter Design and Calibrations

Roman Coronagraph Instrument Test Results Info Session
8/26-27/2024

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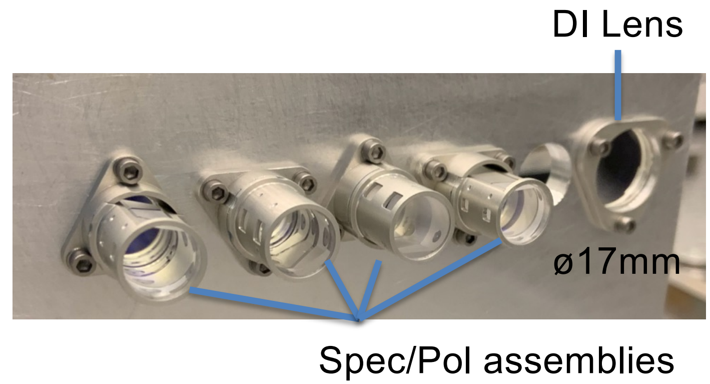
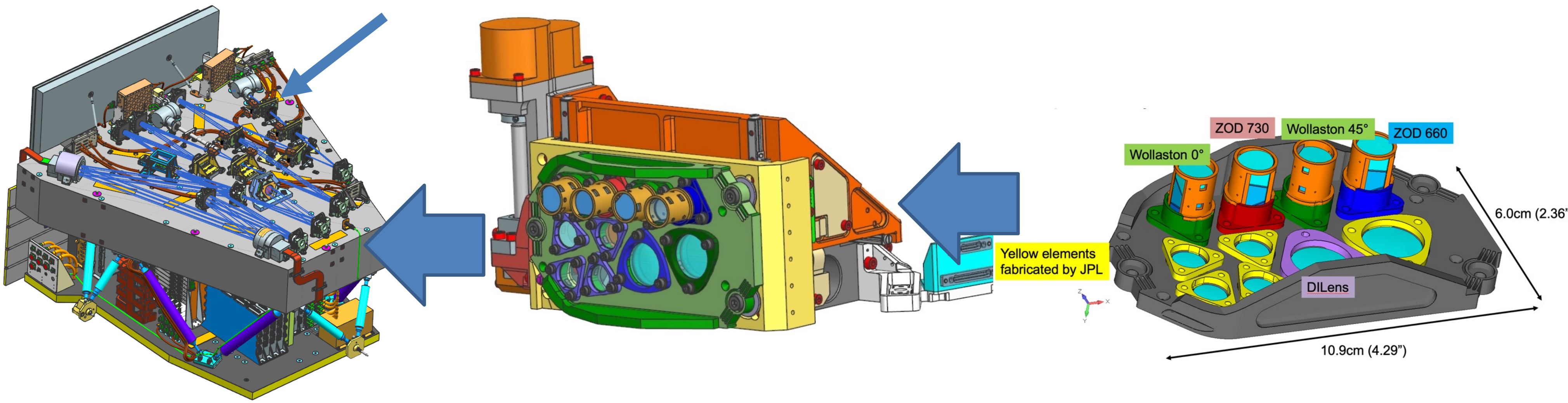
Introduction

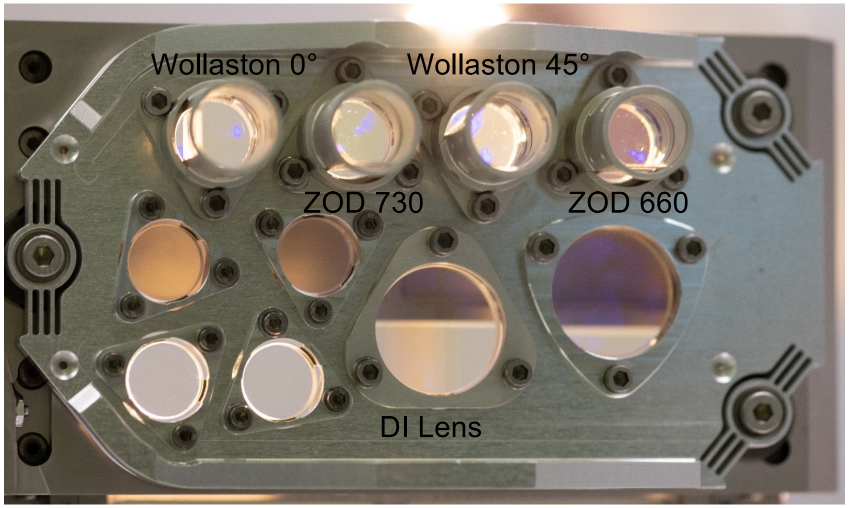


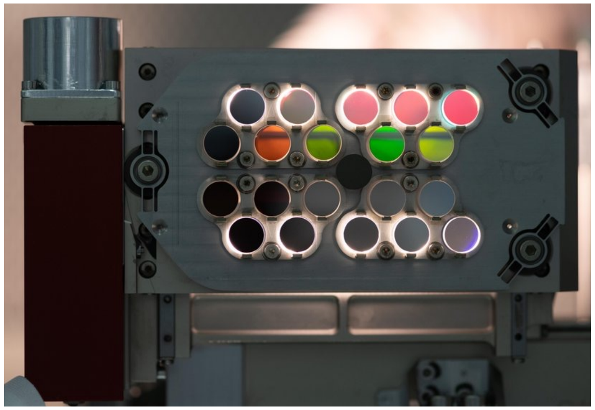
- **The Roman Coronagraph Instrument is a Class D Technology Demonstration for exoplanet direct imaging via coronagraphy**
- **Goddard delivered the final imaging modes in the Precision Alignment Mechanisms (PAMs)**
  - Direct Imaging Lens for primary dark hole imaging mode
  - Two Wollaston prism modes for disk science applications
  - Two spectroscopy zero-deviation prisms for exoplanet slit spectroscopy
- **<u>Imaging and polarization optics generously contributed by JAXA</u>**



Spectroscopy and Polarization Modules for CGI

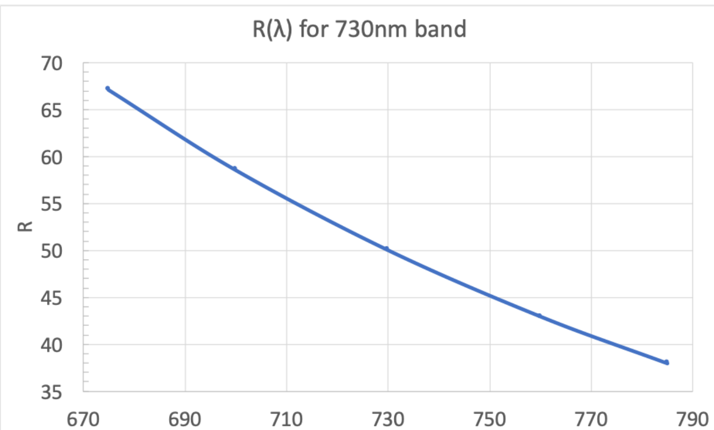
- **Zero Optical Deviation (ZOD) prisms**
  - 730nm Band 3
  - 660nm Band 2
- **Wollaston Prism Assemblies**
  - Vertically oriented (0 deg)
  - Diagonally oriented (45 deg)
- **Direct Imaging (DI) Lens**
- **Calibration and spectral extraction algorithm**
  - Required for centroiding and calibrating spectra on CGI
  - Not flight software

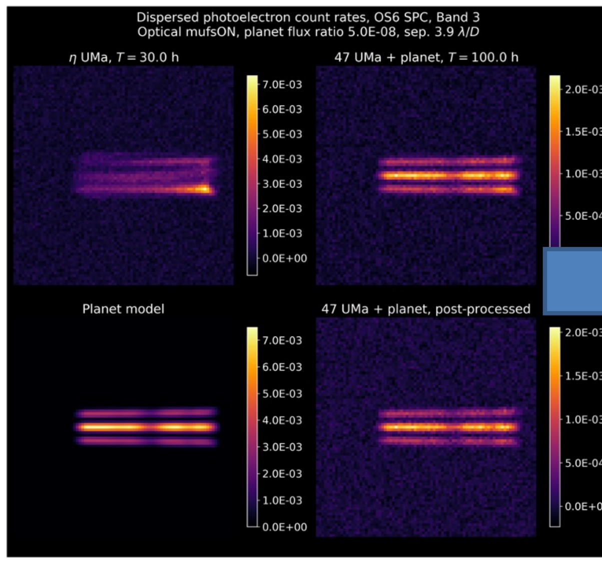


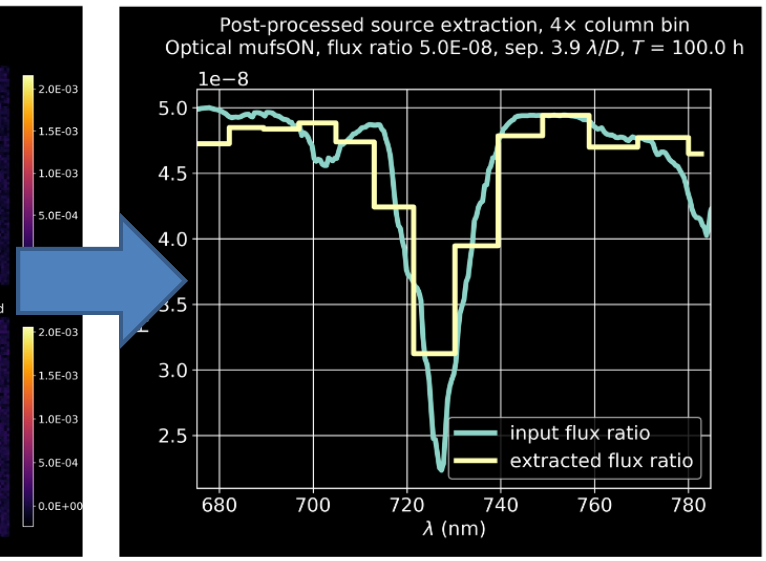


Baseline Filter Bands	Center	Cut-on	Cut-off	Bandwidth %
CGI Band 1 (Wollaston Prism)	575	546	604	10.1
CGI Band 2 (Spectroscopy Shaped Pupil)	660	610	710	15.2
CGI Band 3 (Spectroscopy Shaped Pupil)	730	675	785	15.1
CGI Band 4 (Wollaston Prism)	825	784	866	9.8

Spectroscopy with Roman Coronagraph

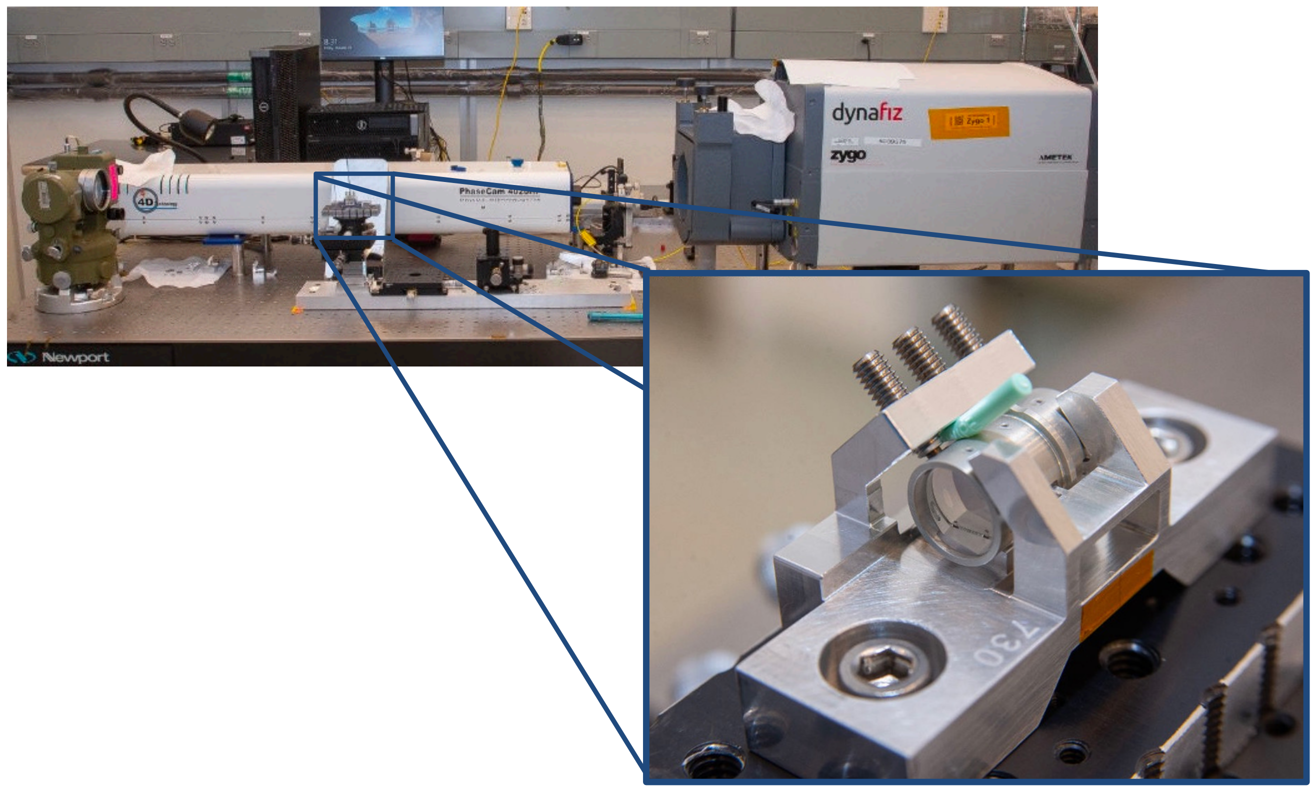




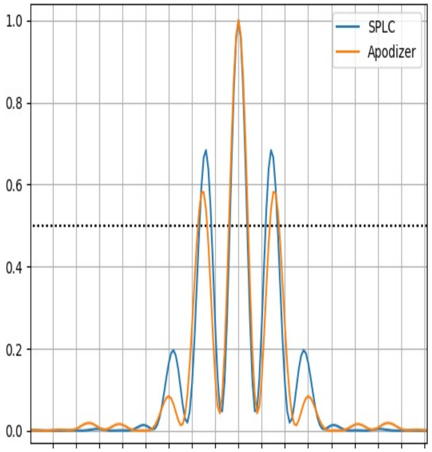


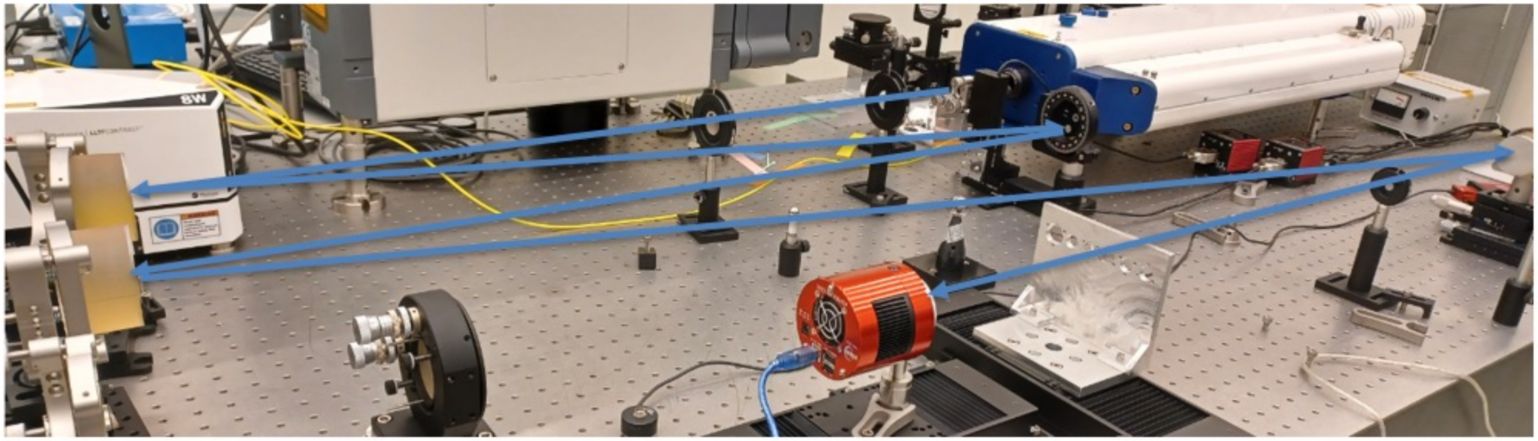
Alignment and Bonding Setup at GSFC

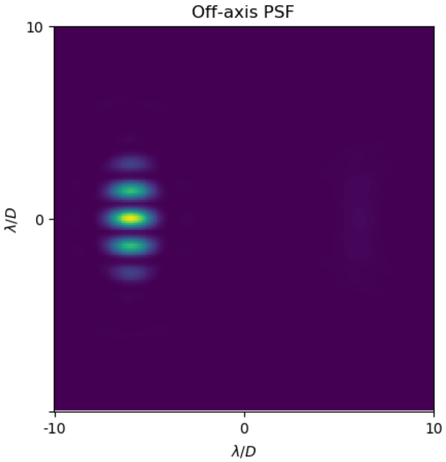
- **Theodolite co-witnesses Interferometer beam through and around prism assembly**
  - Dispersion directly verified with theodolite during alignment and bonding activities with extremely high fidelity
- **WFE Verified in double-pass during alignment**
- **Flat reference used for prisms**
- **Spherical reference and CaliBall swapped into setup for interferometric lens alignment in double-pass**
  - Focal lengths *well* within tolerance as a result

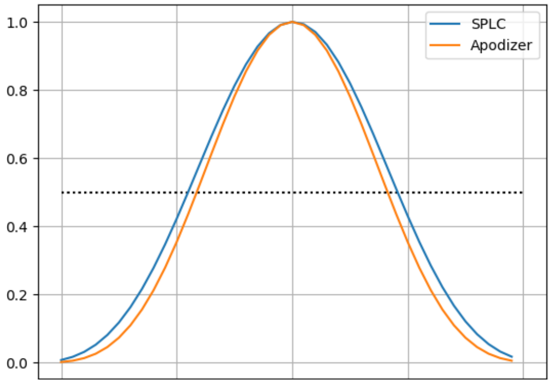


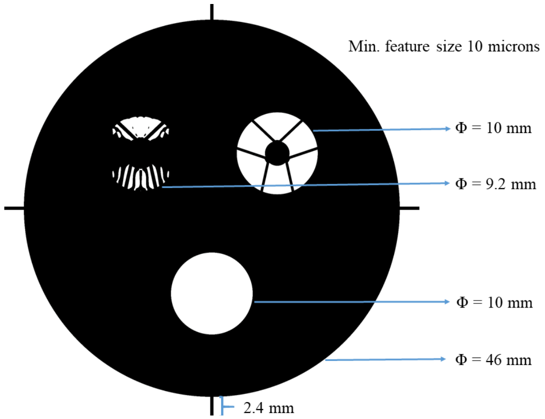
GSFC Performance Verification Lab Setup









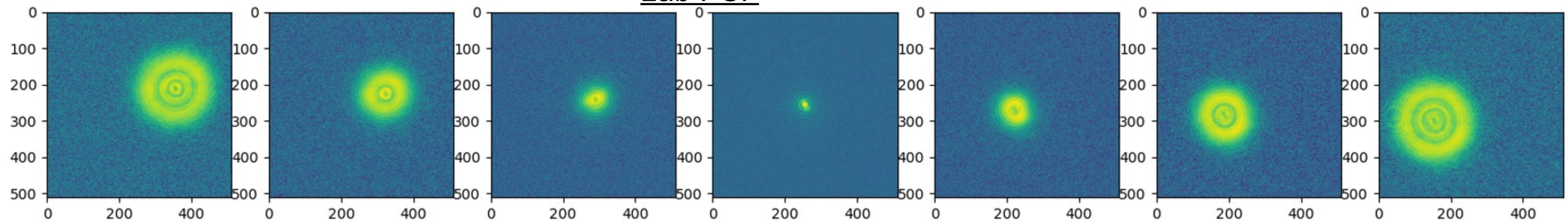


Pre and Post Environments Wavefront Error

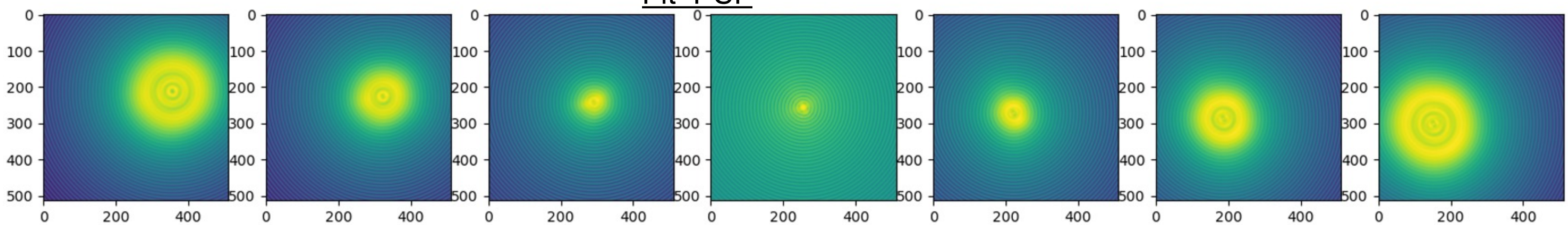
Optics	Pre (nm rms)	Post (nm rms)	Uncertainty (nm)
DI Lens	14.67	14.40	±1.91
ZOD660	14.79	13.89	±1.91
ZOD 730	7.90	5.7	±1.91
Wollaston 0	30.2	27.83	±1.91
Wollaston 45	19.10	18.02	±1.91

Sources of Uncertainty
- camera noise
- interferometer accuracy
- alignment error

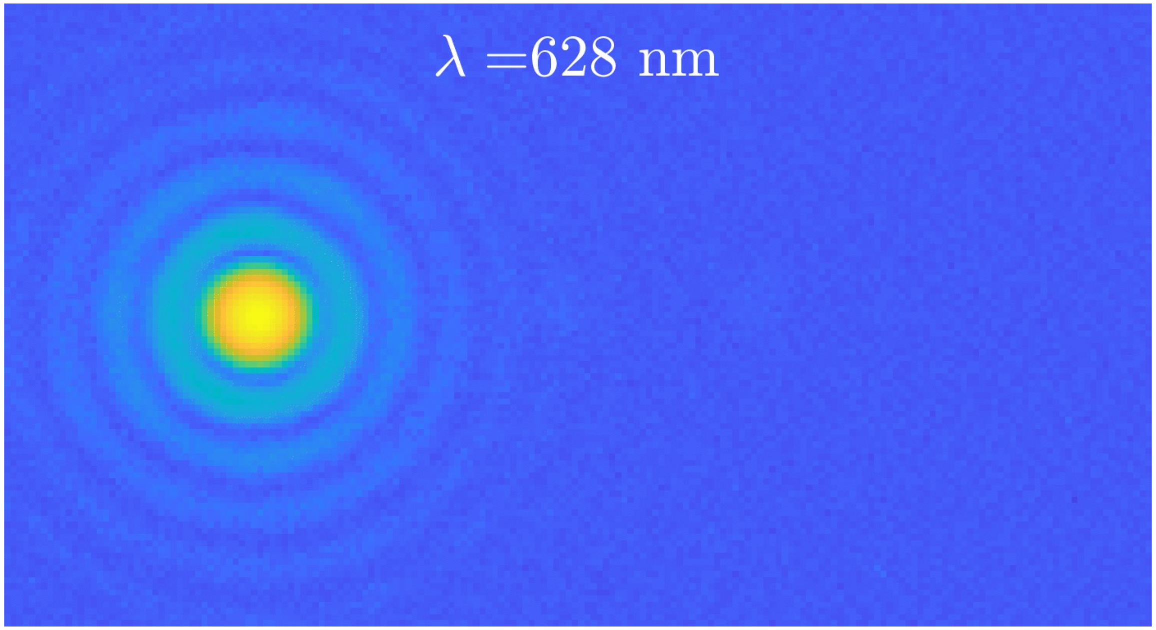
Lab PSF

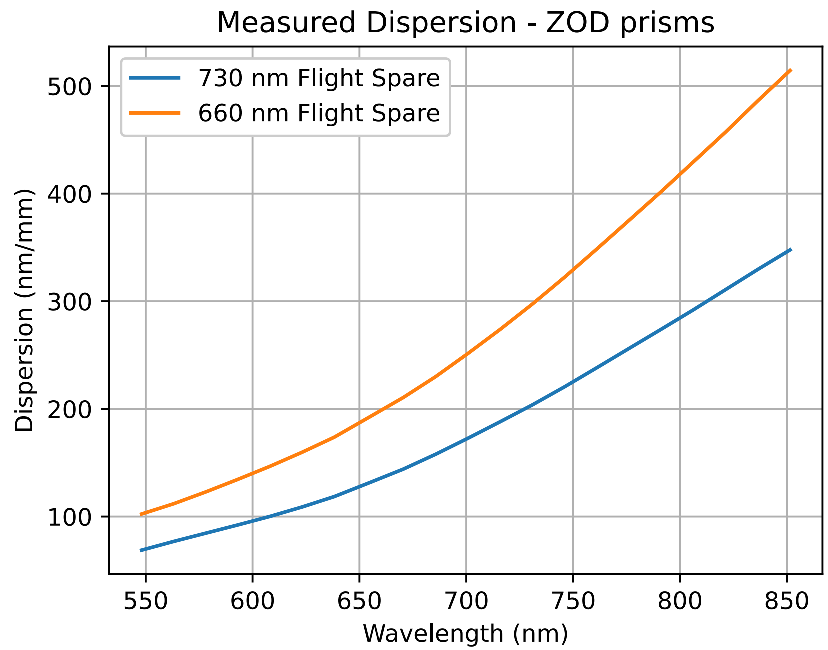


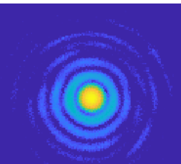
Fit PSF



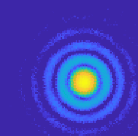
Example Tests and Calibrations at GSFC







Wollaston Extinction Tests



Ground Calibration

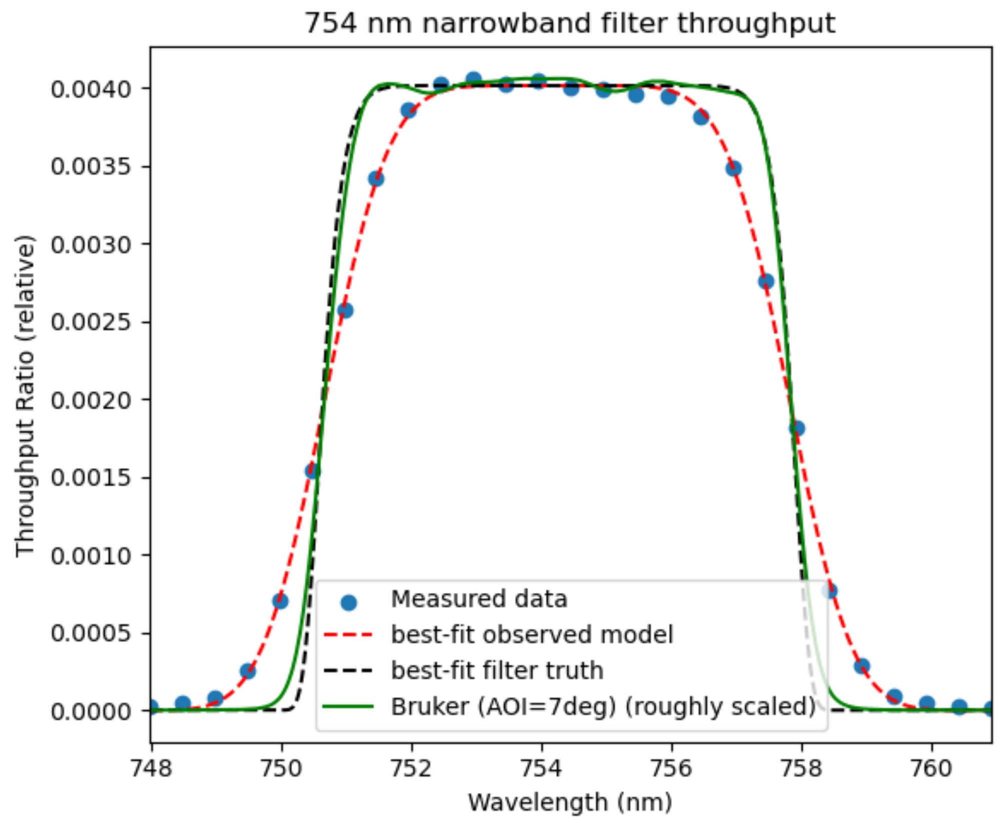
- **The spectroscopy mode has two instrument requirements to meet on-orbit performance**
  - Tolerance on final instrument spectral resolution
  - Wavelength accuracy of the spectrum located anywhere in the SPC field of view
- **Both requirements are dependent on as-built filter parameters, beam angle of incidence, slit format, and as-built pupil observed looking back from the final focal plane**
- **All subsystem level verifications and calibrations were done prior to delivery, but final instrument-level calibrations were required for final flight calibration**
  - Interesting systems engineering side effect unique to pupil apodizing coronagraph:

    Since it is designed specifically to block/apodize the entire telescope pupil it is possible do true spectral resolution verification activities at the instrument level that reflect on-orbit performance
- **Spectroscopy Tests in TVAC2**
  - Dispersion calibration with final flight pupil
  - Calibrate narrowband filter transmission profile in-situ with wavelength scans using a laser line tunable filter
    - Narrowband filter knowledge critical to wavelength accuracy; since the slit and spectrum are deployable anywhere in the field the narrowband filter observation anchors the spectrum on detector

Filter Characterization Demonstration

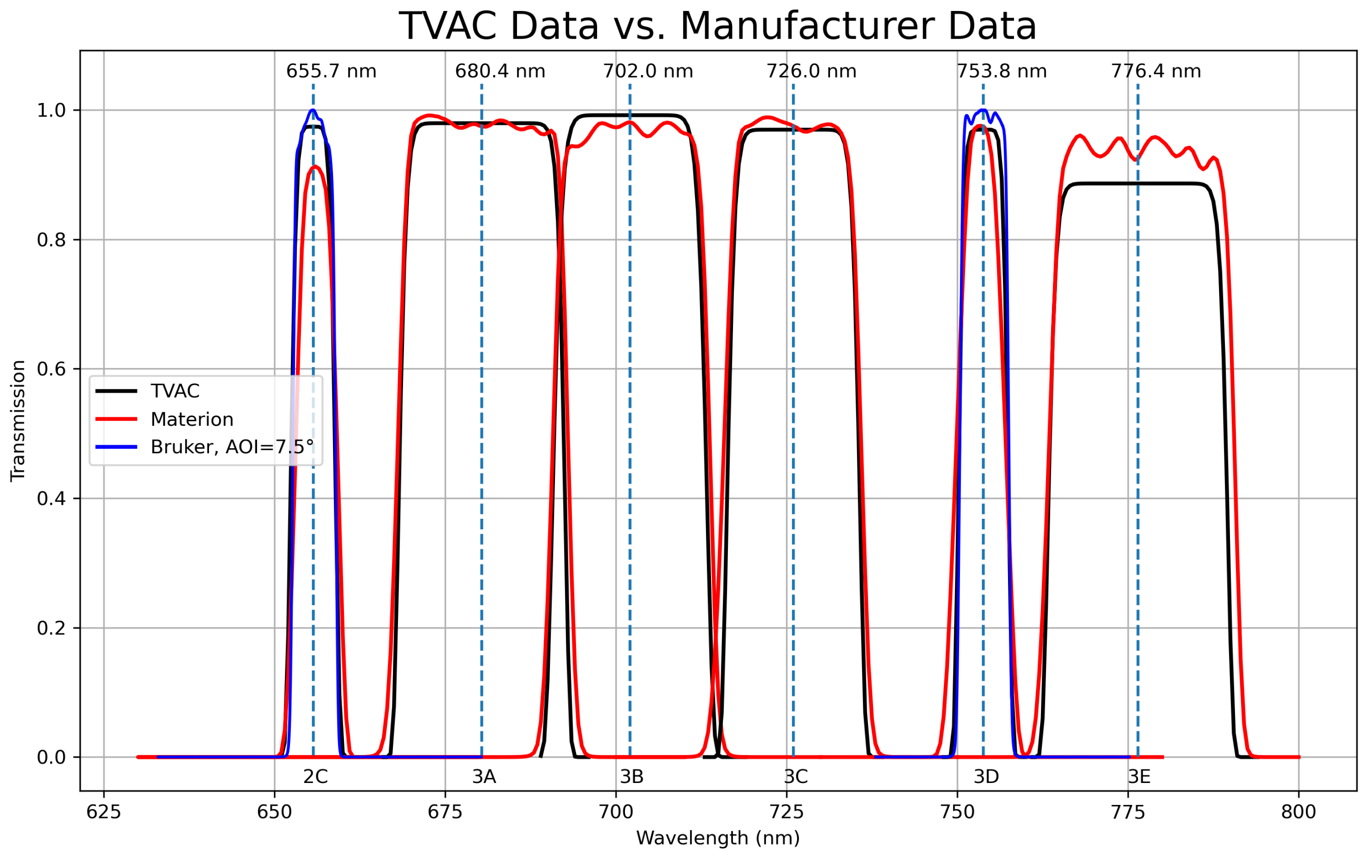
- **Wavelength accuracy requirement of 2-nm at instrument level**
  - Requires careful dispersion calibration of prism
  - Since slit deploys to arbitrary field position, also requires extremely careful calibration of the narrowband filters in as-assembled instrument configuration
- **Demonstration using flight reject filter prior to CGI I&T shows extremely precise calibration possible with designed test**
  - Tunable filter scan in CGI simulator testbed
  - Compare to independent filter measurement with calibrated GSFC Bruker Fourier Transform Spectrograph in collimated light

Method	Center (nm)	Width (nm)
CGIsim testbed	754.24 ± 0.01	7.19 ± 0.06
Bruker (AOI=7°)	754.25	7.19



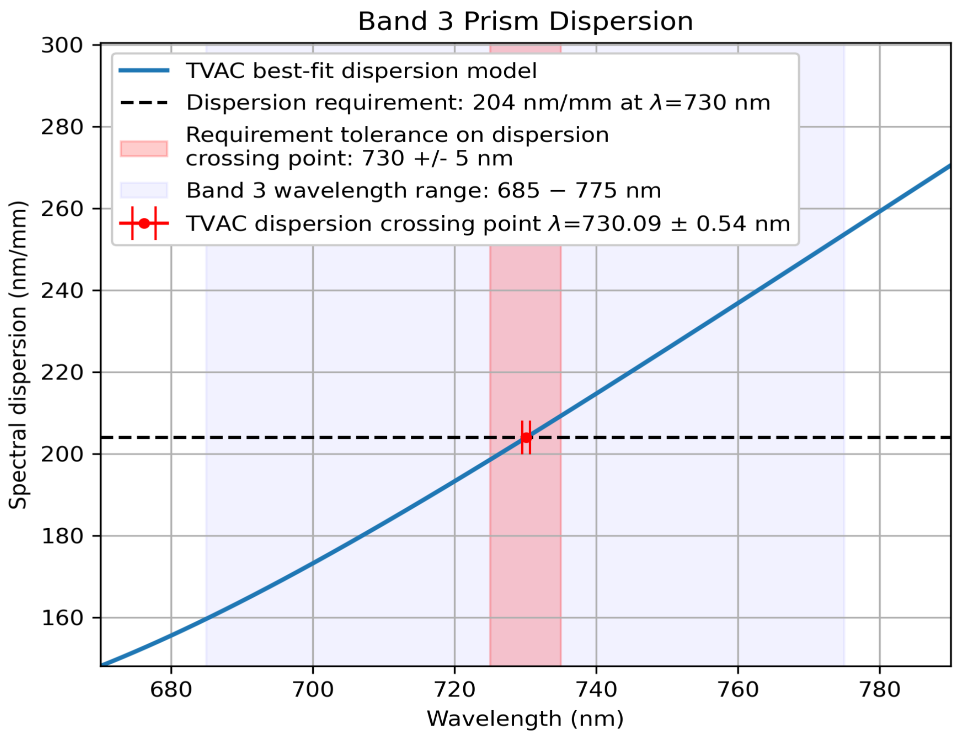
Sub-band filter transmission curves

- Overlay of transmission curves inferred from TVAC data with manufacturer scans
- Narrowband filters 2C and 3D were highest priority for TVAC measurements, since they define the wavelength zero-point of spectroscopic data taken during the tech demo.
- The other Band 3 sub-band filters will be used for HOWFS, and for confirming the prism dispersion scale an orientation in flight.



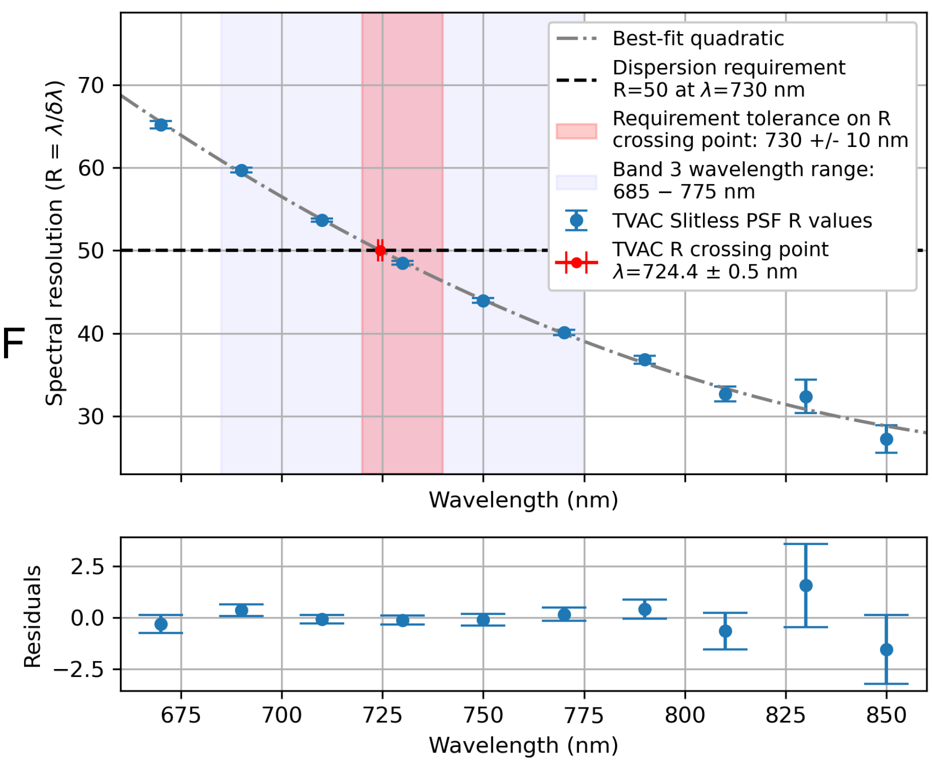
DNG 1012831
REQ: L4 OPT DESIGN - Spectral Resolution

- Band 3 dispersion
- Wavelengths measured: 10
- **L7 Requirement:** "The wavelength at which the Band 3 Prism assembly achieves a dispersion of 204 nm/mm shall be 730 +/- 5 nm"
  - Measured dispersion value: 730.09 ± 0.54 nm

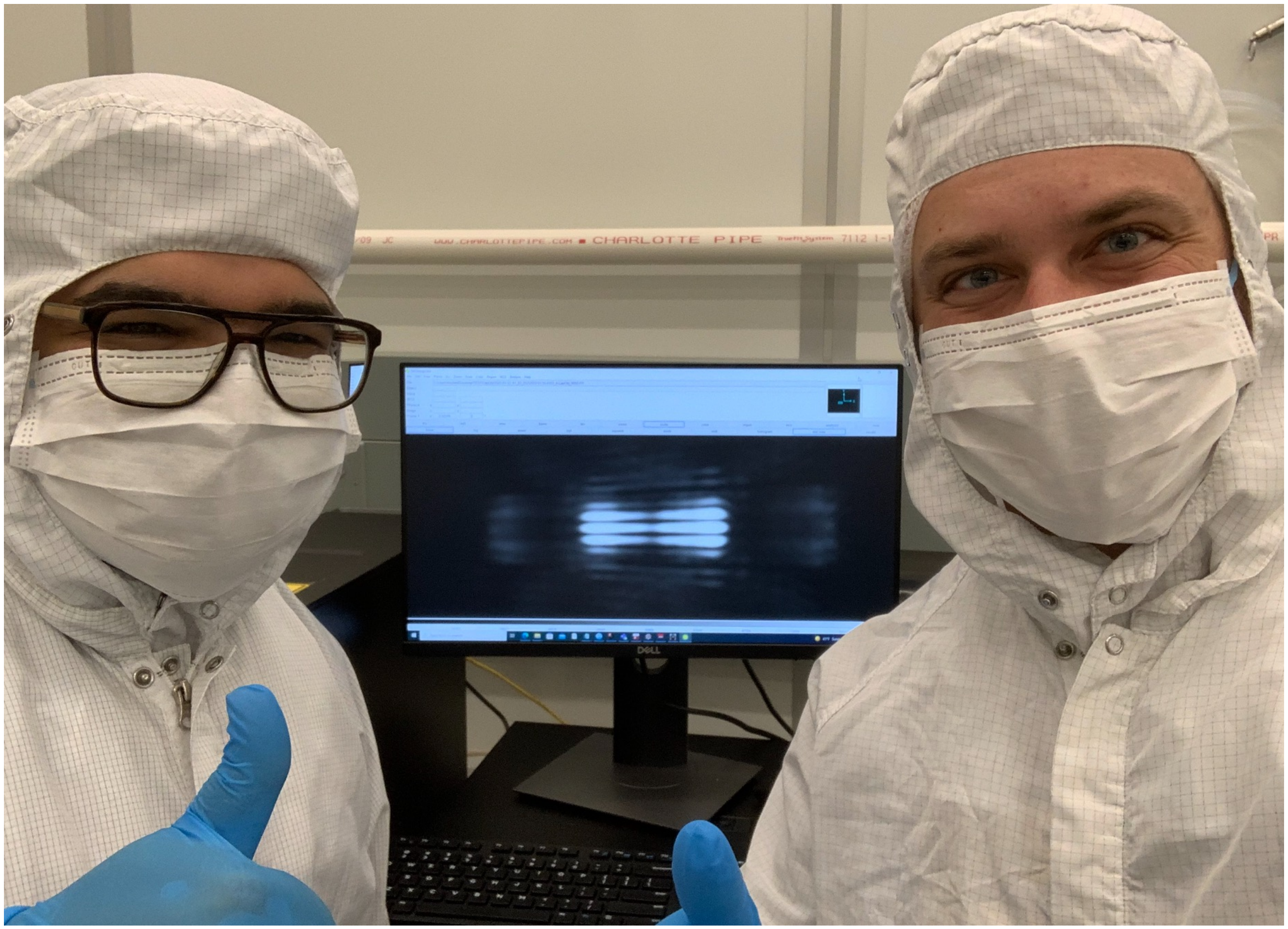


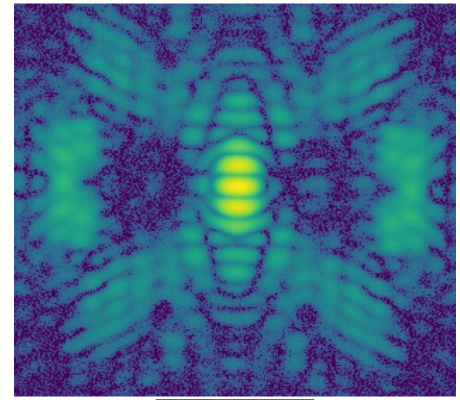
DNG 1012831
REQ: L4 OPT DESIGN - Spectral Resolution

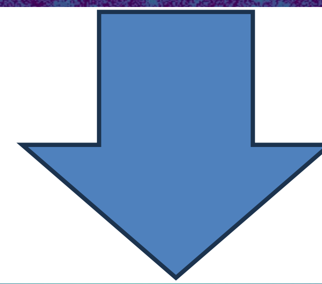
- Current best estimate of spectral resolution (R) based on Linespread Function (LSF) of the **slitless** PSF and the dispersion curve (previous chart).
  - R = wavelength / (FWHM of LSF))
  - Note CGI slits don't significantly impact the LSF
- **L4 Requirement**: Spectral resolution of R=50 at 730nm ± 10 nm in Band 3
  - Measured Resolution: 724.4 ± 0.5nm
  - Similar results for Band 2 prism

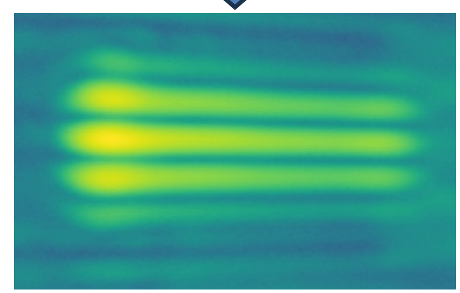


Thanks









BACKUP

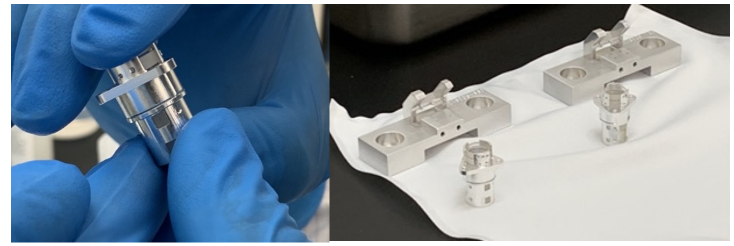
TV-40b "Wavelength Accuracy and Spectral Resolution" Test Summary

Test	Priority	Status	Results
Filter 3D scan	Tier 1	Completed	Transmission curve consistent w/ L4 req't
Filter 2C scan	Tier 1	Completed	Transmission curve consistent w/ L4 req't
Band 3 sub-band filter scans	Tier 2	Completed	Transmission filter profiles
Band 3 Prism scan	Tier 1	Completed	Dispersion curve plot consistent with L7 req't (verified before at component level)
Band 2 Prism scan	Tier 2	Completed	Dispersion curve for Band 2
Prism + Slit spectral resolution w/ LLTF	Tier 2	1 of 2 slits (R1C2)	Slit misaligned with PSF
Prism + Slit spectral resolution w/ SELECT	Tier 3	Not attempted	-
Band 2 sub-band filter scans	Tier 3	Not attempted	-

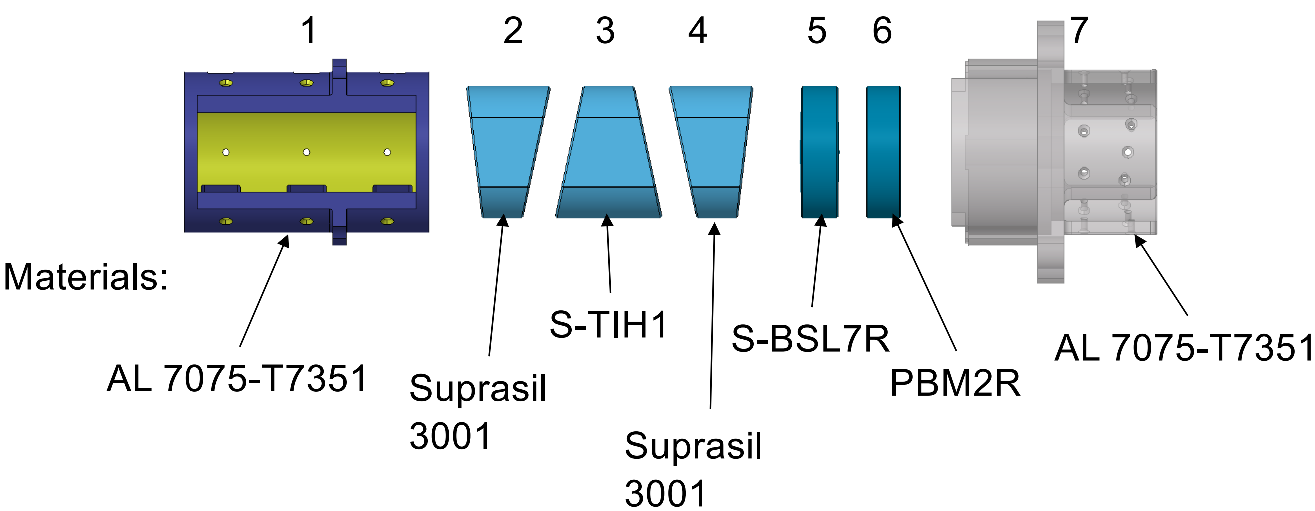
ZOD Assembly Optomechanical Design

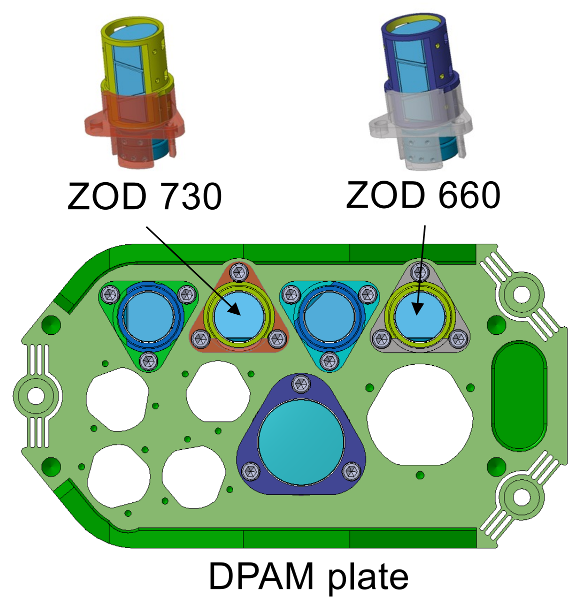
Overview:

- There are two variants – ZOD 660 and ZOD 730
- Lenses and prisms have just 10 mm diameter
- Design is composed of an prism tube (1), three prisms (2,3,4), two lenses (5,6), and a lens tube (7)



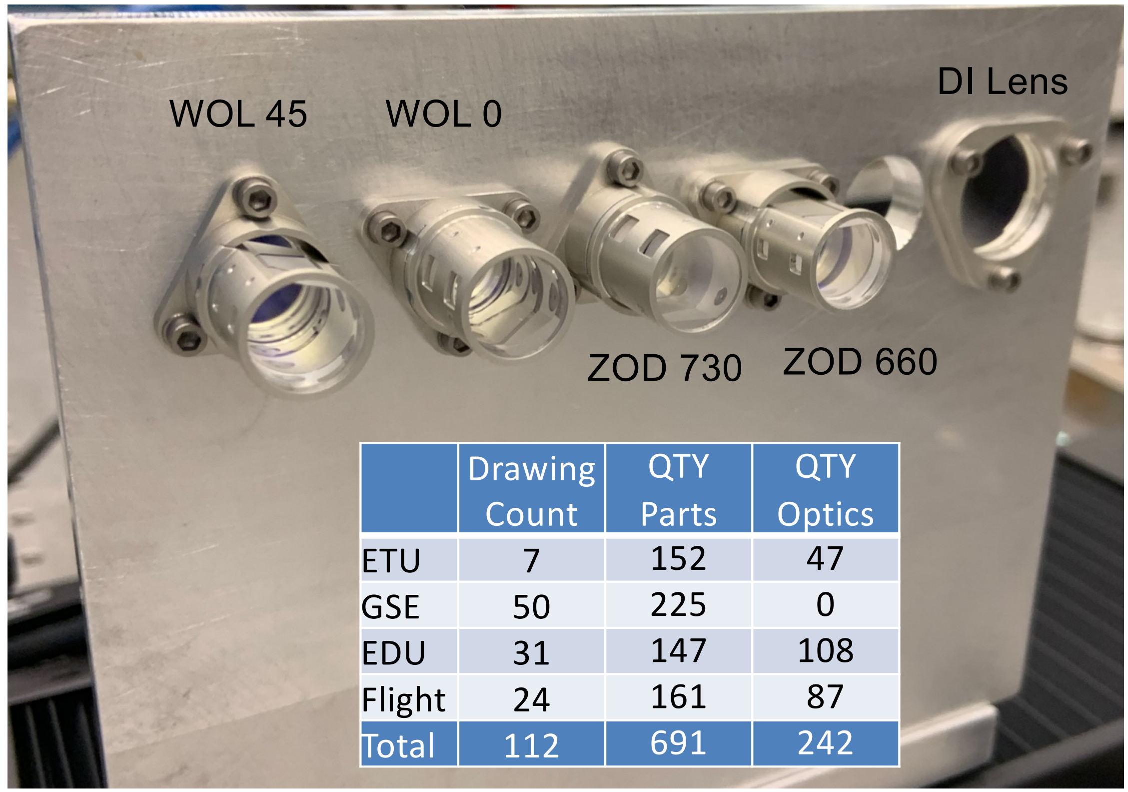
ZOD 660/730 EDU's fully assembled





Testing and Verification at GSFC

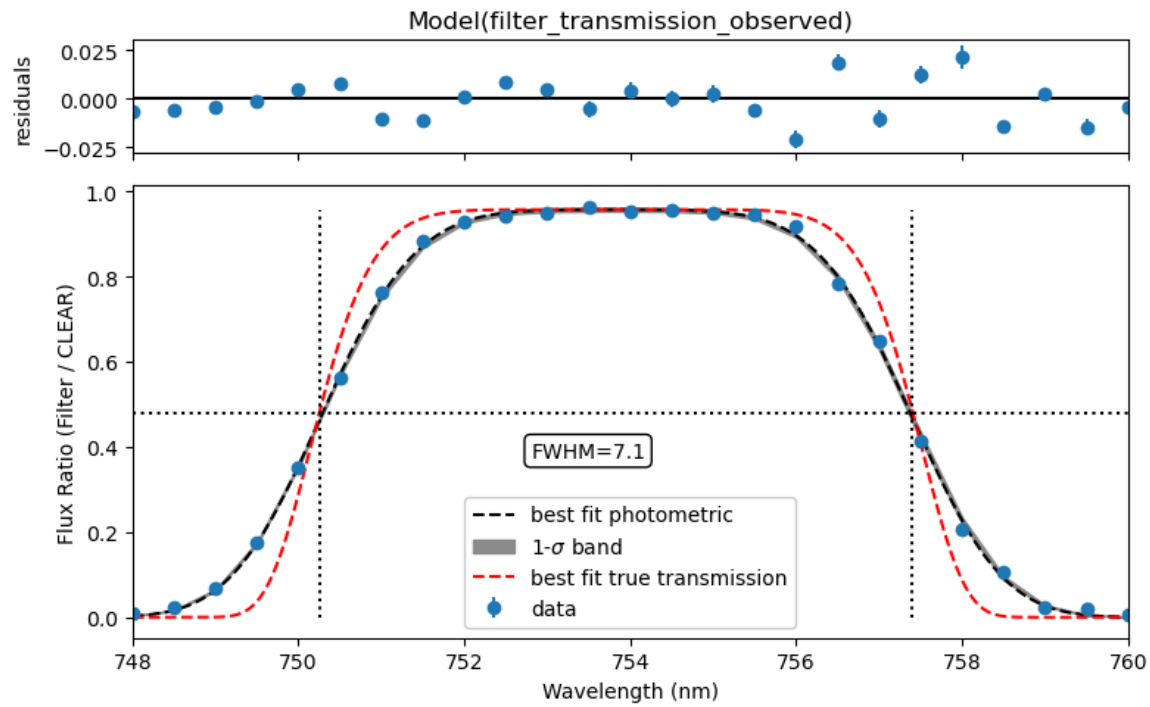
- **DI Lens**
  - 7 key and driving requirements
    - 1 verified by analysis
  - 24 total requirements
    - 2 verified by analysis
  - No non-compliance
- **Spectroscopy modes**
  - 12 key and driving requirements
    - 1 verified by analysis
  - 25 total requirements
    - 3 Number verified by analysis
  - No non-compliance
- **Wollaston modes**
  - 12 key and driving requirements
    - 1 verified by analysis
  - 28 total requirements
    - 3 verified by analysis
  - No non-compliance



	Drawing Count	QTY Parts	QTY Optics
ETU	7	152	47
GSE	50	225	0
EDU	31	147	108
Flight	24	161	87
Total	112	691	242

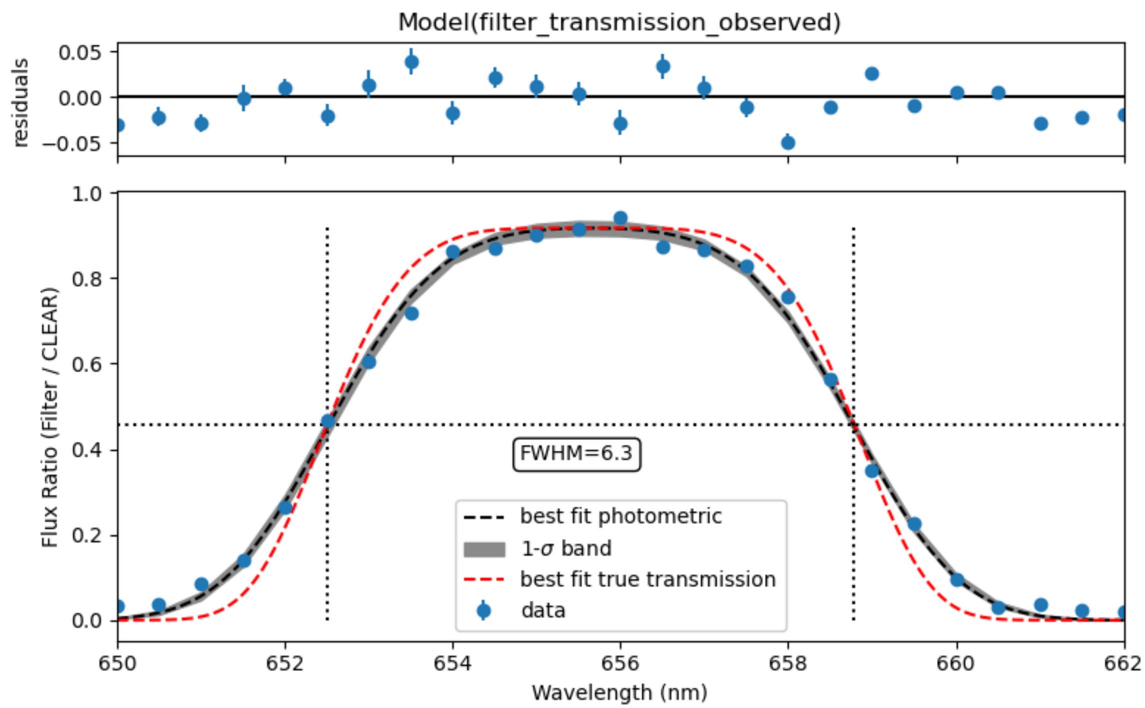
DNG 1012834
REQ: L4 OPT DESIGN - Narrow-band Filters for Spectroscopy

- Narrowband Filter 3D (Center: 754nm)
- Wavelengths measured: 25
  - 748-760nm
- Filter Center: 753.8 nm ± 0.5 nm
- Filter Width: 7.1 nm ± 0.2 nm
- Requirement: Filter center must be 754 ± 2 nm
  - **Satisfied**



DNG 1012834
REQ: L4 OPT DESIGN - Narrow-band Filters for Spectroscopy

- Narrowband Filter 2C
- Wavelengths measured: 25
  - 650-662 nm
- Filter Center: 655.7 nm ± 0.5 nm
- Filter Width: 6.3 ± 0.2 nm
- Requirement: Filter center must be 656.3 +/- 1.5 nm
  - **Satisfied**



DNG 1012831
REQ: L4 OPT DESIGN - Spectral Resolution

- Example comparisons of TVAC images (left column) and model images (right column) of the prism-dispersed PSF, through different sub-band filters.
- Measured PSF FWHM values are 1-3% higher, this may explain part of the offset between predicted and measured spectral resolution.