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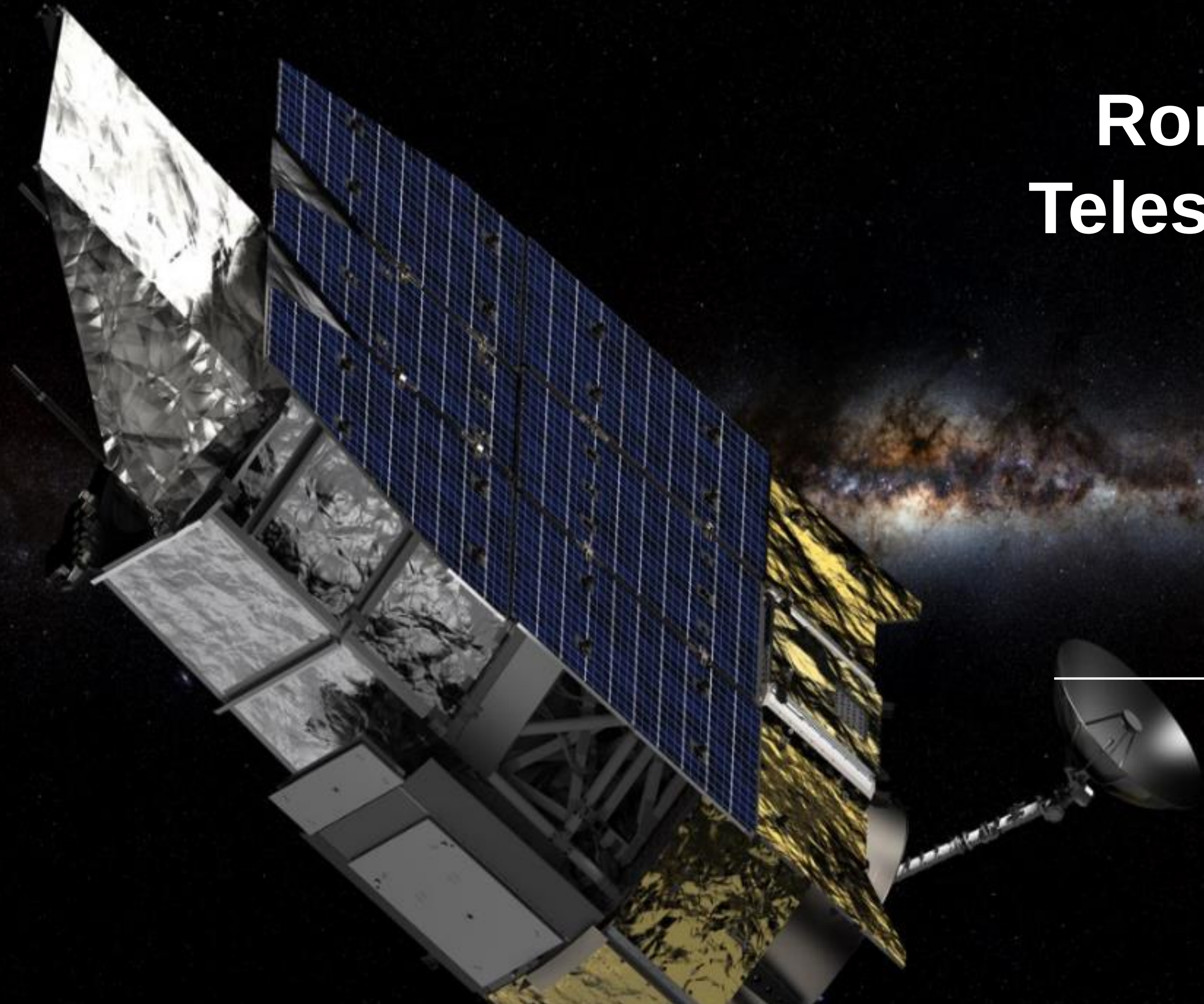
Roman Nancy Space Telescope Spectroscopy

June 4, 2023



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Spectroscopy of Nancy Grace Roman Space Telescope (RST): Grism and Prism Assemblies

Qian Gong, Evan Bray, Victor J. Chambers, Bente Eegholm, Margaret Dominguez, Guangjun Gao, John Lehan, Cathy Marx, Joshua Schlieder, and Laurie Seide

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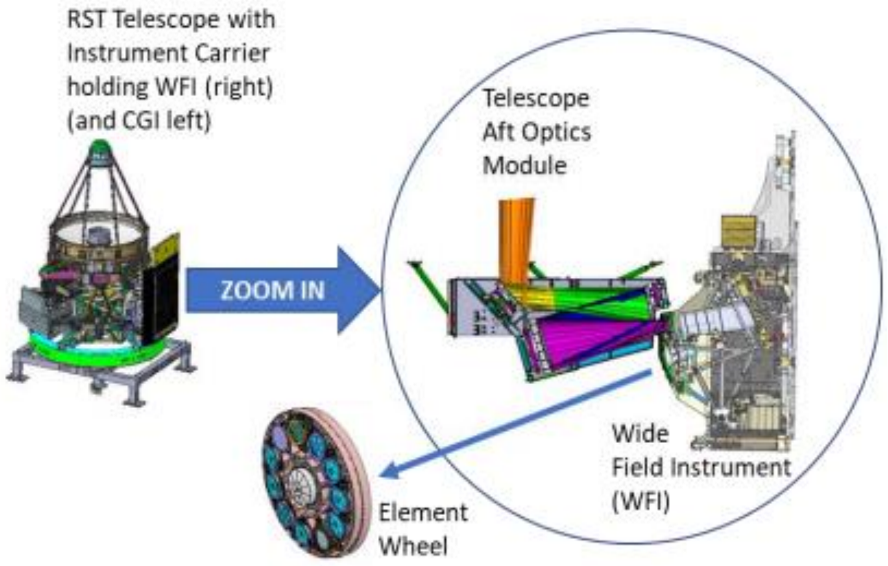
Introduction

- This talk presents an overview of RST slitless spectrometers: high resolution grism and low resolution prism assemblies.
- Combined with selected bandpass filters, grism and prism will perform the high latitude wide area and time domain surveys to understand the mystery of dark energy. The details are covered in the presentation : "Science Drivers of the Nancy Grace Roman Space Telescope Grism and Prism" by Joshua Schlieder.



- The following slides start from the formulation of optical concept design based on the grism and prism requirements driven by the science goals. It emphasizes the challenges that the design and development encountered and the solutions to overcome the challenges.

Top level requirements for Grism and prism

Spectral requirement

	Throughput	Dispersion scale	Dispersion solution	Ghost intensity
Grism **1.0µm < λ < 1.95 µm**	Mean 55% Min. 35%	1.0 nm/pix – 1.2 nm/pix	0.1 nm RMS	0.3%
Prism **0.75 µm < λ < 1.8 µm**	Mean 73% Min. 35%	2.0 nm/pix – 9.5 nm/pix	0.5 nm RMS	0.3%

Wavefront error requirement

Grism	**Wavefront error ≤ 140 nm RMS at 1550 nm over 95% Field of View**
Prism	**Wavefront error ≤ 137.5 nm RMS at 1200 nm over 90% Field of View**

Overall Challenges

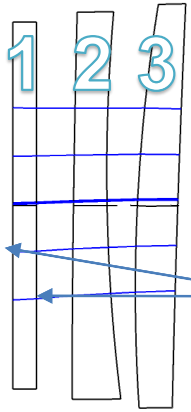
- The main challenge for both grism and prism is to meet the image quality and wavefront error due to:
  - Wide Field Of View: more than 100 x larger than the wide field camera of Hubble Space Telescope (HST).
  - Wider spectral range from 750 nm to 1800 nm.
  - Located in a non-collimated f/8 space.
  - To fit into a tightly allocated space as two elements of the filter wheel.
- The paper describes the three major development and implementation phases:
  - Optical Design
  - Fabrication and alignment
  - Calibration and characterization.
- The challenges and solutions of each phase are briefly addressed. The accomplishment of each step is summarized.

Optical design: Grism assembly

- **It was determined at a very early stage that Grism is the RST's slitless spectrometer with a compound multi-element assembly. So it has gone through three develop phases: Prototype, EDU and ETU, and finally flight assemblies.**
- **Challenges:**
  - **To provide required spectral resolution implies that the grism needs to provide a diffraction limited optical design.**
  - **The geometric aberration introduced by a grating in non-collimated space is proportional to wavelength. It is impossible to be compensated with the shape and refractive index of the powered prism.**
- **Solution:**
  - **Introduce second diffractive surface to compensate the chromatic aberration from the grating.**
  - **Final grism design is consist of 3 elements: a parallel plate with diffractive surfaces on both sides plus 2 powered prisms.**

Optical design: Grism assembly

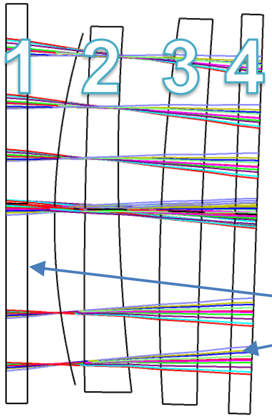
Flight Design



Three element design with 2 diffractive surfaces on 2 sides of Element #1.

Diffractive surfaces

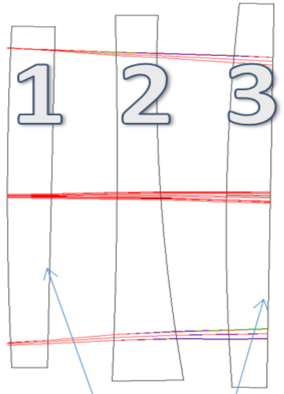
EDU Design



Four element design with 2 diffractive surfaces on Elements #1 and #4.

Diffractive surfaces

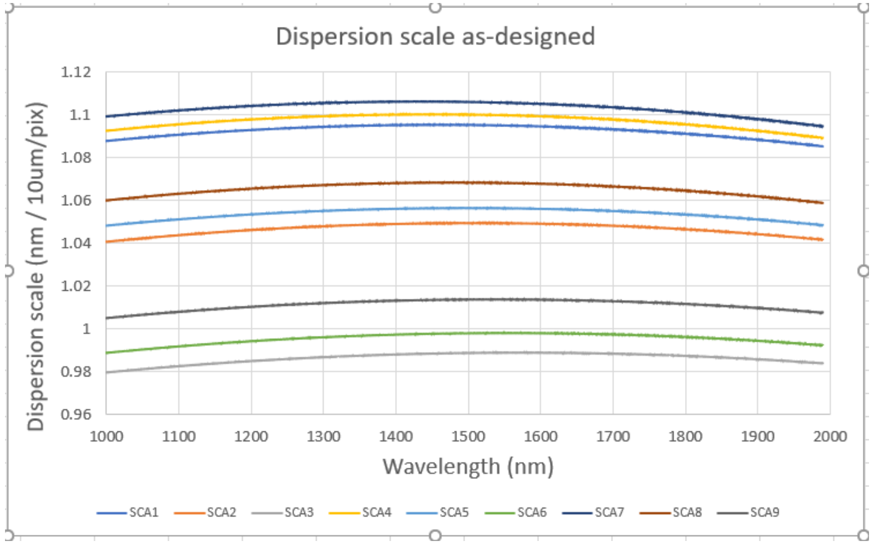
Prototype Design



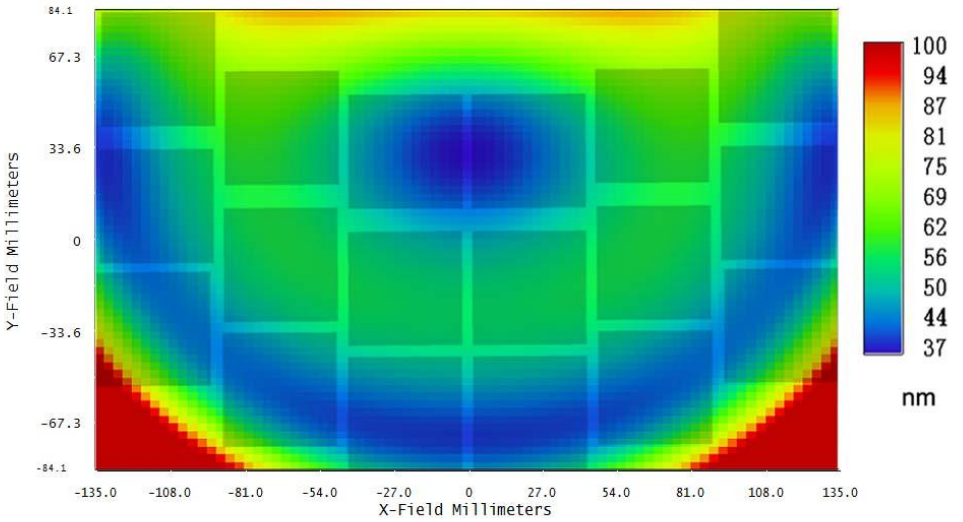
Three element design with 2 diffractive surfaces on the flat side of Elements #1 and #4.

Diffractive surfaces

All elements are made of Fused silica.



Wavefront map at 1550 nm



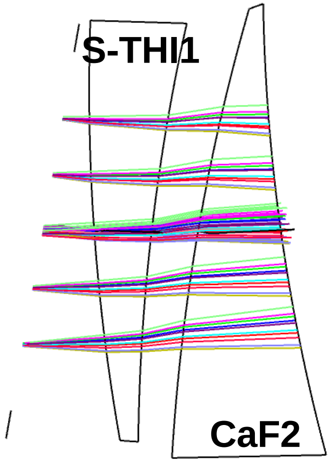
The grism design closely meets both dispersion and wavefront requirements.

Optical Design: Prism assembly

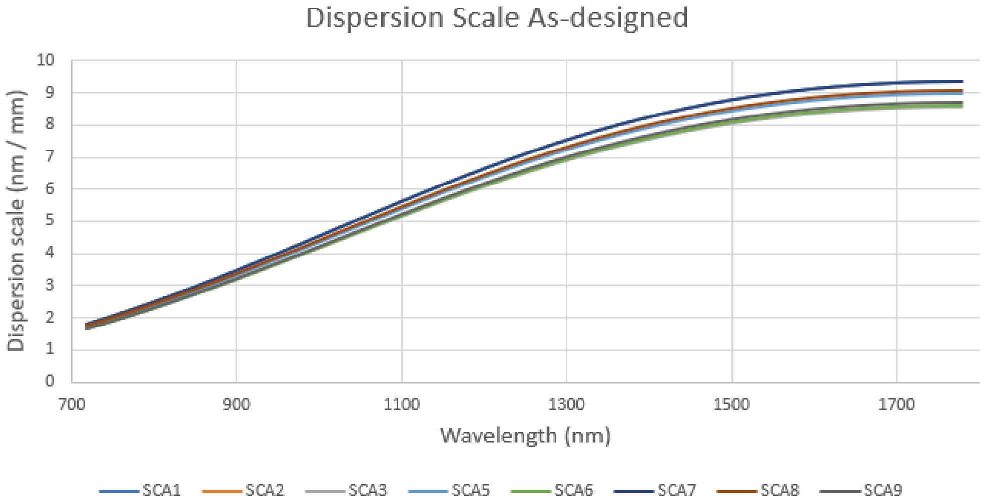
- **The prism assembly was added to WFI much later. So it only went through ETU and flight phases. Both use the same optical design.**
- **Challenge:**
  - **The large FOV and the wide wavelength range still pose a great challenge for the design for aberration control. Furthermore, the output beam from prism assembly is required to be zero deviation at the desired wavelength.**
  - **A rarely seen phenomenon had appeared during the initial design: in the middle of the spectrum, the dispersion direction is reversed, which means a part of the spectrum was overlapped.**
- **Solution**
  - **The refractive index and dispersion (Abbe number) selection of the two materials is critical for a successful design. The high index material mainly provides the required dispersion, and the low index material provides the zero deviation.   The final material selection is S-THI1 and CaF2. This combination ensured a monotonic spectrum and the required spectral resolution.**

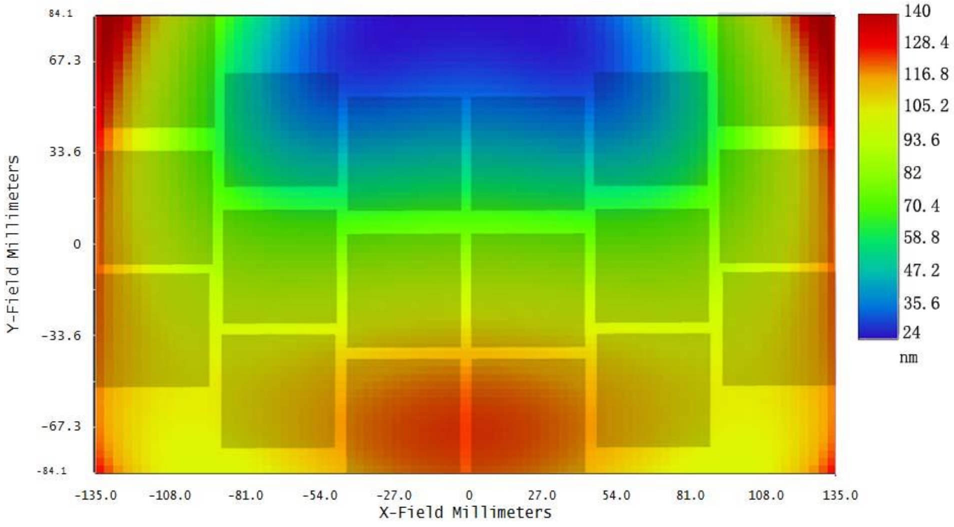
Optical design: Prism assembly

Flight prism



Two element design with all spherical surfaces.
One is made of S-THI1 glass to provide the desired spectral dispersion, the other one is made of CaF2 to make the beam zero deviation at the selected wavelength.

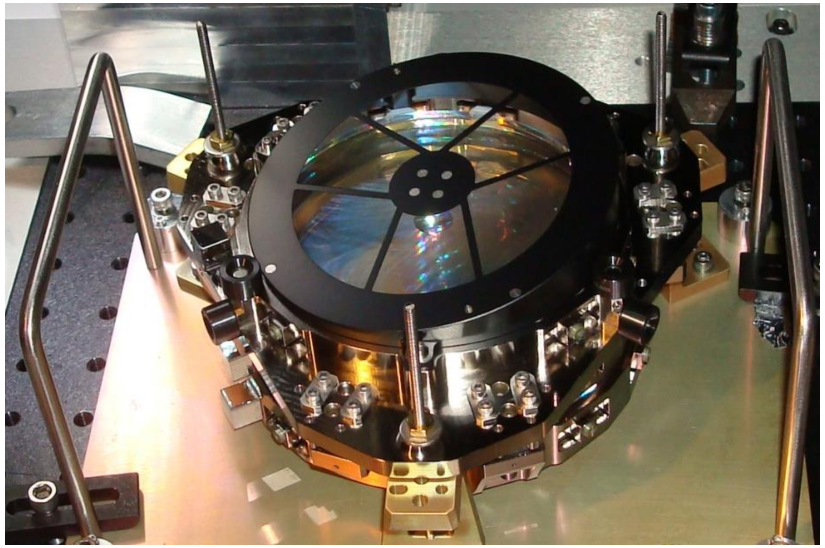




The prism design meets both dispersion and wavefront requirements

Details of Grism and prism optical design are covered in presentation: "Nancy Grace Roman Space Telescope (RST) Grism and Prism: Optical Design" by Guangjun Gao, present by Catherine Marx

Fabrication and Alignment: Grism



- **Challenge:**
  - Grism includes two diffractive surfaces, which indicates that high diffraction efficiency is needed.
  - Element inspections and assembly alignment posed a big challenge for the three elements: a flat with double sided diffractive surfaces and two powered prisms.
- **Solution:**
  - Using multistep plasma etching technology to make high efficiency and wide band diffractive surfaces.
  - Use Computer Generated Hologram (CGH) with specially designed fiducials on it for each element. On the other hand, fiducials and references were also carefully added to element itself.
  - Precision metrology were performed on each element.
  - Using the grism optical model and recorded fiducial data on each element to align the whole grism assembly. The precision metrology tools and creative methods are applied.

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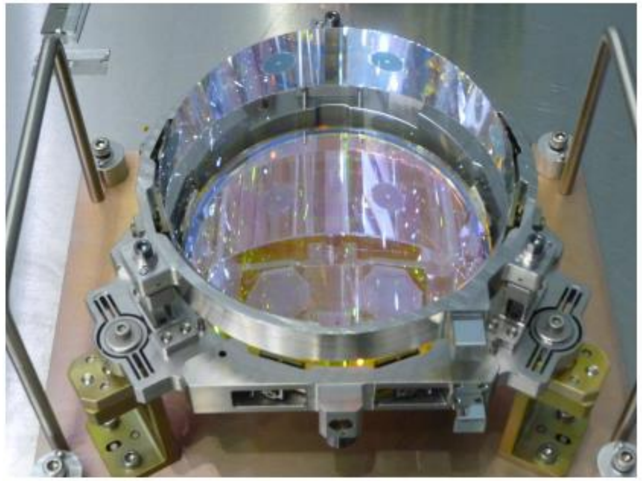
Fabrication and alignment: Prism

- **Challenge**
  - A lot of the prism's challenges are similar to grism's that needs CGH and precision metrology.
  - An unique challenge posed to prism is the refractive index uncertainty of S-THI1 that has significant impact on image and dispersion scale.
  - The other prism is CaF2, which is not only difficult to fabricate, but also has a much higher CTE than other optical materials.



- **Solution**
  - A lot of the prism's challenges are similar to grism's that needs CGH and precision metrology.
  - An unique challenge posed to prism is the refractive index uncertainty of S-THI1 that has significant impact on image quality and dispersion scale.
  - The other prism is CaF2, which is not only difficult to fabricate, but also has a much higher CTE than other optical materials.

Details of Grism and prism fabrication and alignment are covered in presentation: "Alignment and wavefront testing results of the Nancy Grace Roman Space Telescope Grism and Prism assemblies" by Margaret Dominguez

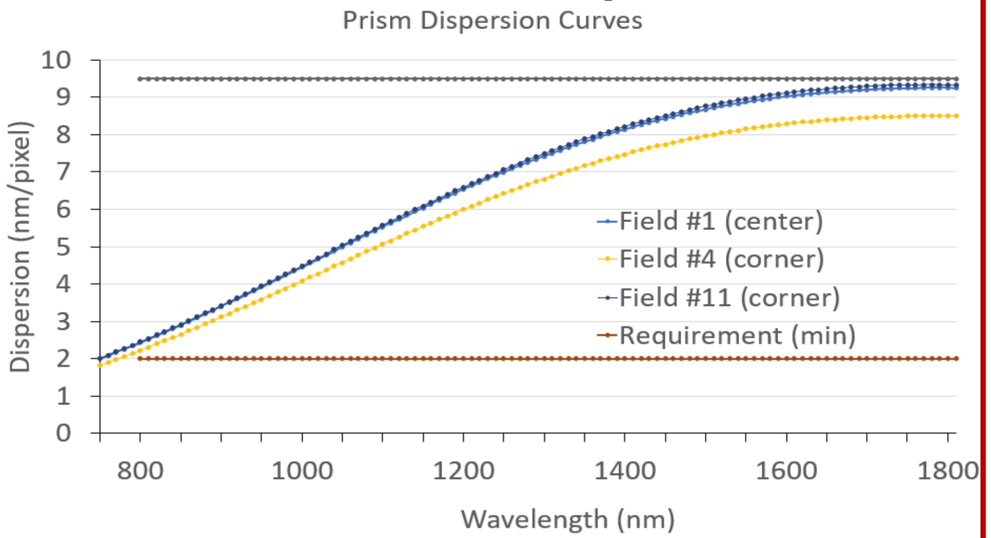
Calibration and Characterization

- **Main tasks: diffraction efficiency and throughput, encircled energy, radiometric calibration, bandpass filter edge measurement, and dispersion scale.**
- **Challenge:**
  - Even though all tests have challenges, the spectral accuracy and wavelength knowledge is the most challenging test. This is because the slitless spectrometers strongly rely on the edge sharpness of the wide bandpass filter and the dispersion scale to determine the absolute wavelength. In effect the slope of the edge is not steep enough to provide a decisive wavelength, plus it is field and polarization-dependent.
- **Solution**
  - Calibration testbed has been carefully designed and aligned to provide better than diffraction limited beam for Grism/prism assemblies.
  - White light laser, Super continuum source from NKT, was used to provide point source with continuum spectral coverage in our wavelength range (700 – 2000 nm).
  - Comb filters were designed to provide a series spectral lines with the desired spacing and bandwidth.
  - FFT based Optical Spectral Analyzers (OSA) were used to calibrate source wavelengths. The OSAs were calibrated by an Argon calibration source.
  - Innovative data collection and analysis methods were used to get the final edge measurements and dispersion scale.

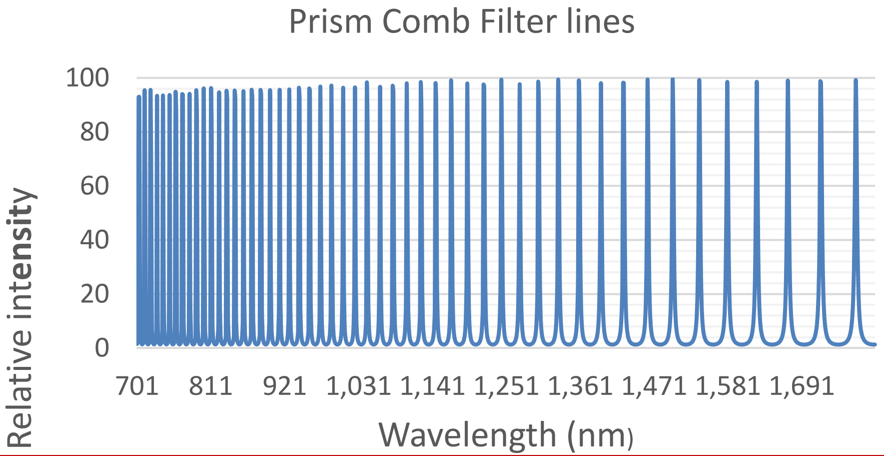
Details of Grism and prism calibration are covered in presentation: "Spectral Characterization of the RST Grism and Prism Spectrometers" by Evan Bray

Calibration and Characterization

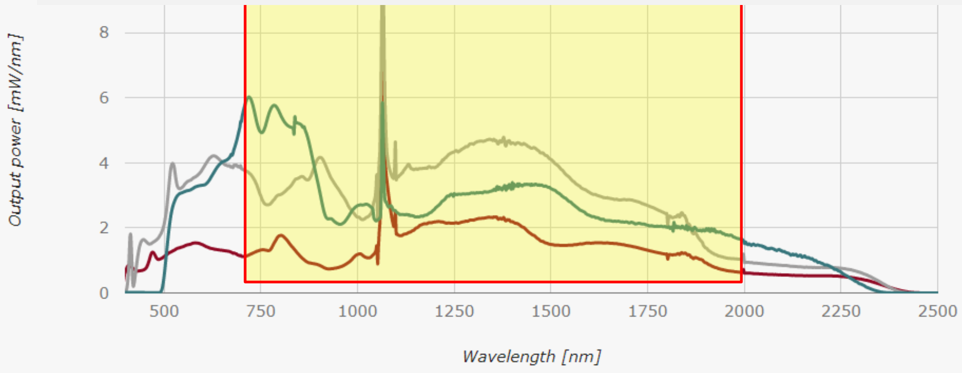
- **Here are some examples from our calibration equipment and devices.**



Designed Comb filter line spacing closely matches prism’s dispersion scale.



White light laser spectrum covers grism/prism wavelength range in 700 – 2000 nm.



General Specifications[a]		
Item #	**OSA20xC**	**OSA305**
Spectral Resolution[b]	7.5 GHz (0.25 cm^{-1}) See *Resolution in Spectrometer Mode* Graph Below	1.9 GHz (0.063 cm^{-1}) See *Resolution in Spectrometer Mode* Graph Below
Spectral Accuracy[c]	±2 ppm[d]	±0.2 ppm[d]
Spectral Precision[e]	1 ppm[d]	0.2 ppm[d]
Wavelength Meter Resolution	0.1 ppm[d]	
Wavelength Meter Display Resolution[f]	9 Decimals	
Wavelength Meter Accuracy[d]	±1 ppm[d]	±0.5 ppm[d]
Wavelength Meter Precision[g]	0.2 ppm[d]	
Input Power (Max)	10 mW (10 dBm)	
Input Damage Threshold[h]	20 mW (13 dBm)	
Power Level Accuracy[i]	±1 dB	±0.4 dB
Optical Rejection Ratio[j]	30 dB	40 dB
Polarization Dependence	±1 dB	±0.1 dB

Summary

Calibration and characterization results show that Grism and prism assemblies closely meet both spectral and wavefront requirements!

RST grism/prism related topics to be presented next

1. **Margaret Zoila Dominguez, "Alignment and Wavefront Testing Results of the Nancy Grace Roman Space Telescope Grism and Prism Assemblies"**
2. **Evan Phillip Bray, "Measured Spectral Properties of the Grism and Prism Spectrometers for the Nancy Grace Roman Space Telescope - Deviations From Model Expectations"**
3. **Guangjun Gao, "Nancy Grace Roman Space Telescope (RST) Grism and Prism: Optical Design"**
4. **John P Lehan, "In-Situ Index Determination for the Nancy Grace Roman Space Telescope (NGRST) Wide-field, Slitless, Imaging Prism Spectrometer"**
5. **Joshua Edward Schlieder, "Science Drivers of the Nancy Grace Roman Space Telescope Grism and Prism"**
6. **Guangjun Gao, "Nancy Grace Roman Space Telescope Grism and Prism: Flight as-built Models"**