Nancy Grace Roman Space Telescope (RST) Grism and Prism: Flight as-built Models

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Abstract: Grism and Prism are two important spectroscopic instruments on the RST. We present the modeling process for the as-built flight Grism and Prism hardware, and on-orbit Monte Carlo simulations to predict their end-of-life (EOL) performance.

1. Introduction

The RST, a flag-ship project of NASA Goddard Space Flight Center, is an observatory designed to provide fundamental and revolutionizing discoveries of dark energy, exoplanets, and infrared astrophysics. The RST optical payload includes three main modules: the Optical Telescope Assembly, Wide Field Instrument (WFI), and Coronagraph Instrument. There are two spectroscopic imaging devices in the WFI, Grism and Prism, which are placed in an Element Wheel Assembly (EWA) along with eight filters and rotated into place when needed. This levies significant optical imaging design constraints to produce a non-deviating, zero power system that is parfocal with all the other instruments and the telescope itself (i.e., with no instruments inserted into the beam), as shown in Fig.1.

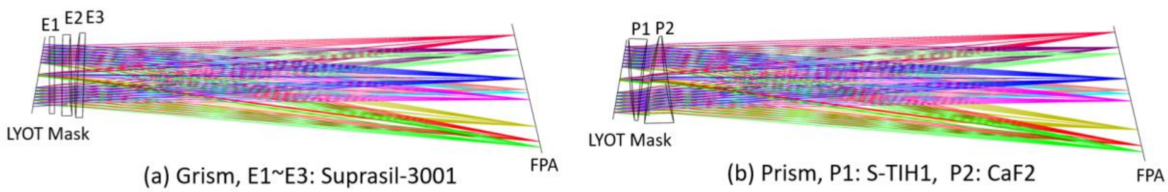


Fig.1 Layout of the Grism and Prism Assemblies. Light from telescope enters the assemblies from the left in the figures above, is dispersed and forms spectra on the FPA surface. For the Grism the spectral spread length is about 8.6mm, and Prism about 1.7mm.

2. As-built Models of Grism and Prism

2.1 As-built Model of the Grism

The as-built model is tied tightly to the optical measurements at the assembly level. For Grism, element E3 was used as compensator in alignment. The field dependance of the aberrations, astigmatism especially, determines the five DoF's of the E3 adjustment (x, y, z, Rx, Ry). The axial adjustment (z) is determined by the parfocality shift as a function of field. This is a simplified picture. There is coupling between some of the DoF's and, especially, the parfocality (z) shift. The field variation of the aberrations and parfocality adequately constrain E3's adjustment. This alignment determines the first order and Seidel behavior. The terms of low-to-mid spatial frequency are a function of several different effects (coating distortion, fabrication imperfections, glass inhomogeneity, stress-optic effects, coating run-off, etc.). The cumulative effects are modeled as surface deformations and placed on the first surface of E2. It should be noted that there are two as-built models: one appliable near room temperature (293K+/-10K), and another for cryogenic temperatures (175+/-20K) used for on-orbit observatory modeling. There is no significant performance change from ambient to cold due to the low CTE of the Grism's materials. Table 1 lists the comparison of RMS WFE (Root-Mean-Square Wavefront Error) of the Grism as-built cold model and test results [1].

2.2 As-built Model of the Prism

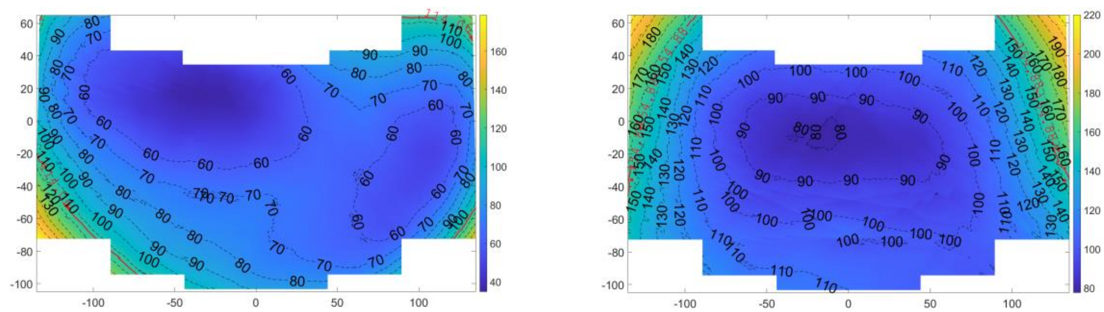
For the Prism, element P2 is used as the compensator and P2-to-P1 alignment can be determined by the field dependent aberrations and parfocality shift. Prism's P1 element has significant mid-spatial frequency residual errors resultant from figure correction which was modeled employing an interferogram file applied to each of its surfaces. The Prism has ambient-to-cold performance change larger than the Grism because of its materials. The linkage between the cold and warm models was constrained by physical predictions for the optical materials (radii, thicknesses, average indices, etc.) but optical measurements drove determination of the movement of the mount. Additionally, higher-order effects (beyond Seidel performance) are also measurement driven as discussed above. Also, as with the Grism, there are unique warm and cold models. Comparison of the as-built cold Prism model and interferometric test results are shown in Tbl.1. Making the as-built model work properly spectrally proved more difficult than expected but was successfully accomplished. This is outlined in the paper by Lehan, et al in these proceedings [2-3].

Table 1. RMS WFE comparison between as-built cold models and interferometry test results of Grism and Prism. The test assembly models are used to mimic beams from an aberration-free telescope pass through the as-built models. Grism and Prism have different test fields [1].

	Field of View									
RMS WFE (nm)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Grism Model	27.1	26.5	36.3	120.5	79.9	49.6	19.6	66.0	26.4	--
Grism Test	31.3	28.6	40.6	121.2	80.9	51.8	24.4	70.2	28.6	--
Prism Model	36.2	38.1	200.4	168.7	162.0	81.5	77.8	88.9	142.4	68.4
Prism Test	39.0	39.3	198.4	171.9	158.6	81.0	77.8	91.4	144.1	70.0

3. Integration to Telescope and EOL on-orbit performance prediction

With the cold as-built Grism/Prism models, we can install and adjust the position of those as-built models in the EWA of the as-built telescope model to optimize image quality. Since the as-built telescope is currently not finalized, telescope models from telescope Monte Carlo simulations were used in this analysis. The on-orbit perturbations included are those from cool-down, thermal gradients, dry-out process, gravity release, invar growth, etc. We applied those perturbations to the observatory model and performed on-orbit focus adjustments. We can obtain EOL on-orbit models and estimate the performance. Fig. 2. (a) and (b) show the 2D RMS WFE distribution of Grism and Prism over the focal plane. Tbl.2 shows the EOL predicted performance and requirements, both Grism and Prism on-orbit performance meet the requirements with margin.



(a) Grism (b) Prism

Fig.2. EOL flight Observatory Grism and Prism RMS WFE (unit:nm), red solid lines are 95% field line for Grism and 90% field line for Prism

Table 2. End-of-life on-orbit predicted performance

RMS WFE (nm)	Predicted	Requirement
Grism 95% field	114.06	<165
Prism 90% field	154.88	<160

[1] Margaret Dominguez, etc. “Alignment and wavefront testing results of the Grism and Prism slitless Spectrometers for the Nancy Grace Roman Space Telescope”, to be published in Optical Design and Fabrication 2023 (IODC, OFT), Optica Technical Digest (Optica, 2023).

[2] John Lehan, et al. “In-situ Index Determination for the Nancy Grace Roman Space Telescope Wide-field, slitless, Imaging Prism Spectrometer”, to be published in Optical Design and Fabrication 2023 (IODC, OFT), Optica Technical Digest (Optica, 2023).

[3] Evan Bray, et al. “Measured Spectral Properties of the Grism and Prism Spectrometers for the Nancy Grace Roman Space Telescope-Deviations from Model Expectations”, to be published in Optical Design and Fabrication 2023 (IODC, OFT), Optica Technical Digest (Optica, 2023).