On the alignment and focusing of the Marshall Grazing Incidence X-ray Spectrometer (MaGIXS)

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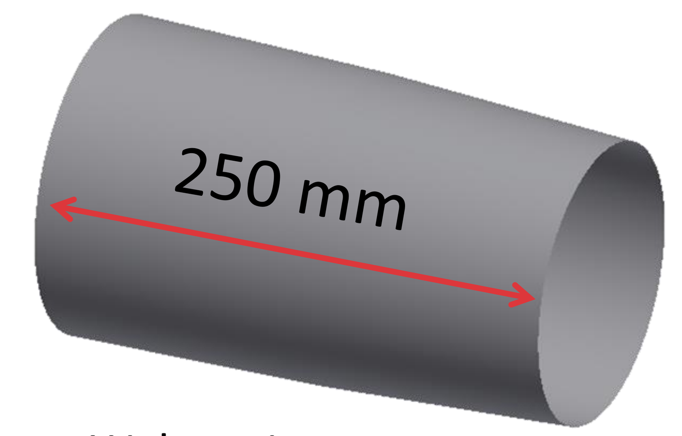
Experiment Background

The Marshall Grazing Incidence X-ray Spectrometer (MaGIXS) is a NASA sounding rocket instrument designed to observe soft X-ray emissions from 24 – 6 Å (0.5 - 2.0 keV energies) in the solar atmosphere. For the first time, high-temperature, low-emission plasma will be observed directly with 5 arcsecond spatial and 22 mÅ (7.5 – 0.47 eV) spectral resolution. The unique optical design consists of a Wolter-I telescope and a 3-optic grazing-incidence spectrograph. Mandrel fabrication and nickel replication will be performed at MSFC. Mounting and sub-system alignment of the flight optics will be performed at the Smithsonian Astrophysical Observatory (SAO). End-to-end testing of the instrument will be performed at the Stray Light Facility (SLF) at MSFC

Performance Specs.

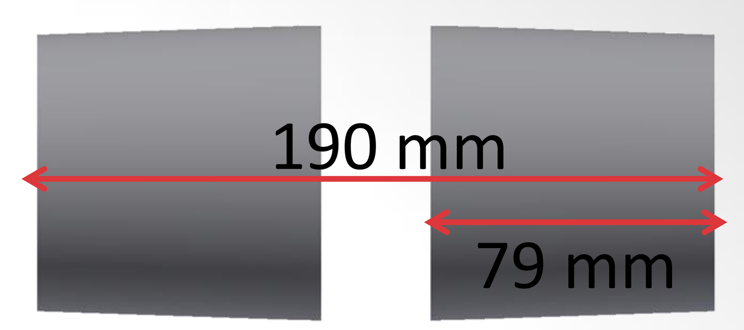
- Passband: 6.0 – 24.0 Å (2.0 – 0.5 keV)
- Spectral resolution: 22 mÅ (7.5 – 0.47 eV)
- Spectral plate scale: 11 mÅ/pixel (3.8 – 0.25 eV/pixel)
- Spatial resolution: 5’’
- Spatial plate scale: 2.8’’/pixel
- Good off-axis geometric aberration: half –field angle RMS spot radius < 5 µm

Telescope Mirror



- Wolter - I
- Nickel replicated mirror shell
- Iridium coated
- Focal length = 1090 mm
- Graze angle = 0.957°
- r_{max} = 75.12 mm
- r_{min} = 66.75 mm
- A_{geo} (34° sector) = 87 mm^2
- 0.5 nm surface roughness

Spectrometer Mirrors

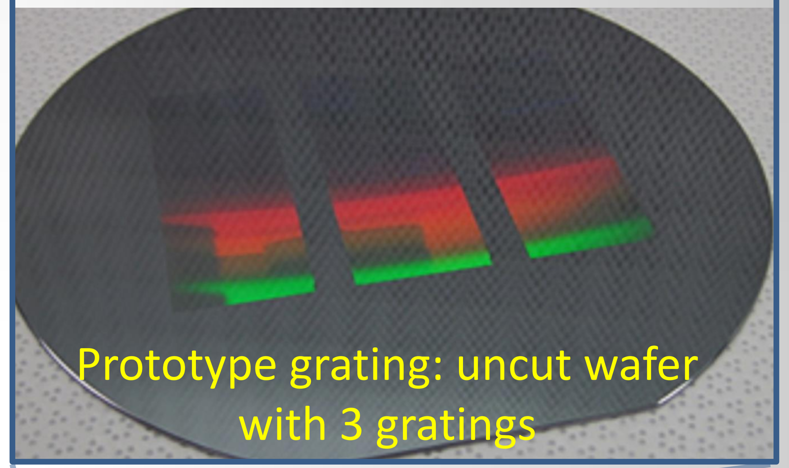


- Finite conjugate paraboloid pair
- Nickel replicated mirror shells
- Iridium coated
- Focal length = 597 mm
- r_{max} = 41.91 mm
- r_{min} = 39.21 mm
- Segment length = 79 mm

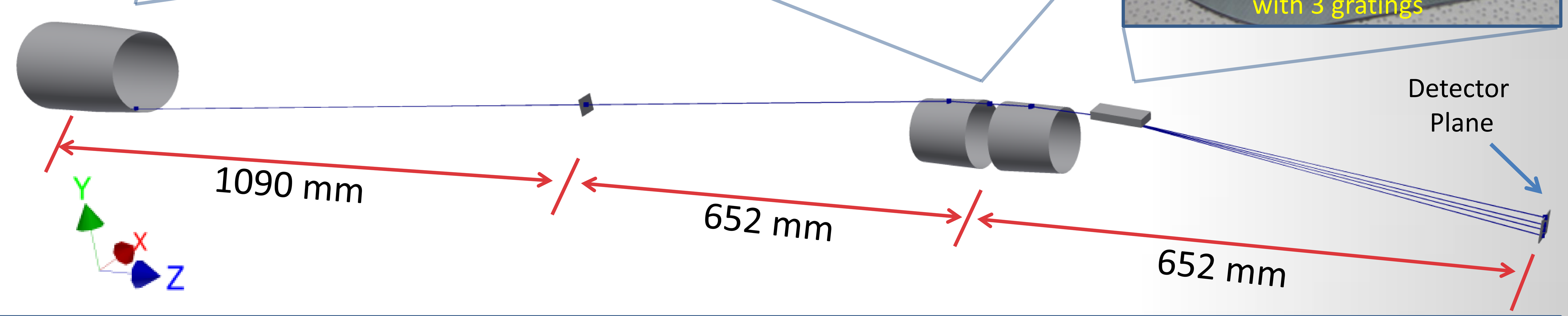
Grating

- Blazed planar varied line space
- Silicon substrate
- Gold coated
- Size: 64 x 25 mm
- Blaze angle: 1.6°
- Ruling: 2146-2709 lines/mm

The gratings will be fabricated by MIT and Izentis LLC using direct E-beam lithography and anisotropic etching techniques.



Prototype grating: uncut wafer with 3 gratings



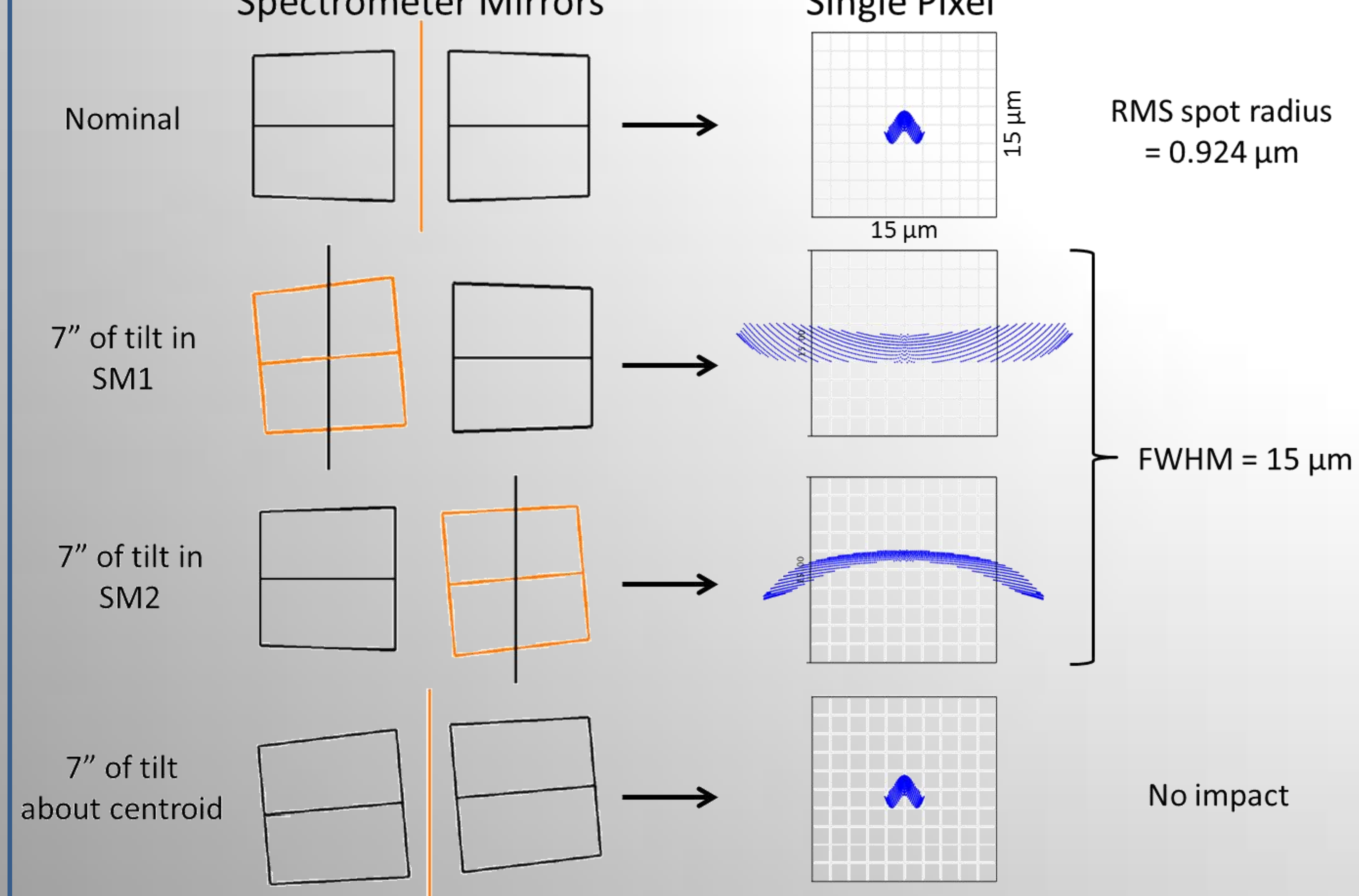
Alignment Sensitivity Analysis

Using the Zemax model of the system, an analysis was performed to determine the maximum alignment error for each component and optical sub-assembly (e.g. integrated spectrometer mirror pair). The spectrometer mirrors and grating were determined to be the most sensitive to alignment error. The performance metrics for determining maximum error are:

- RMS Spot Size → Spatial Resolution
- Spectral Error → Spectral Resolution
- Vignetting → Field of view and contrast

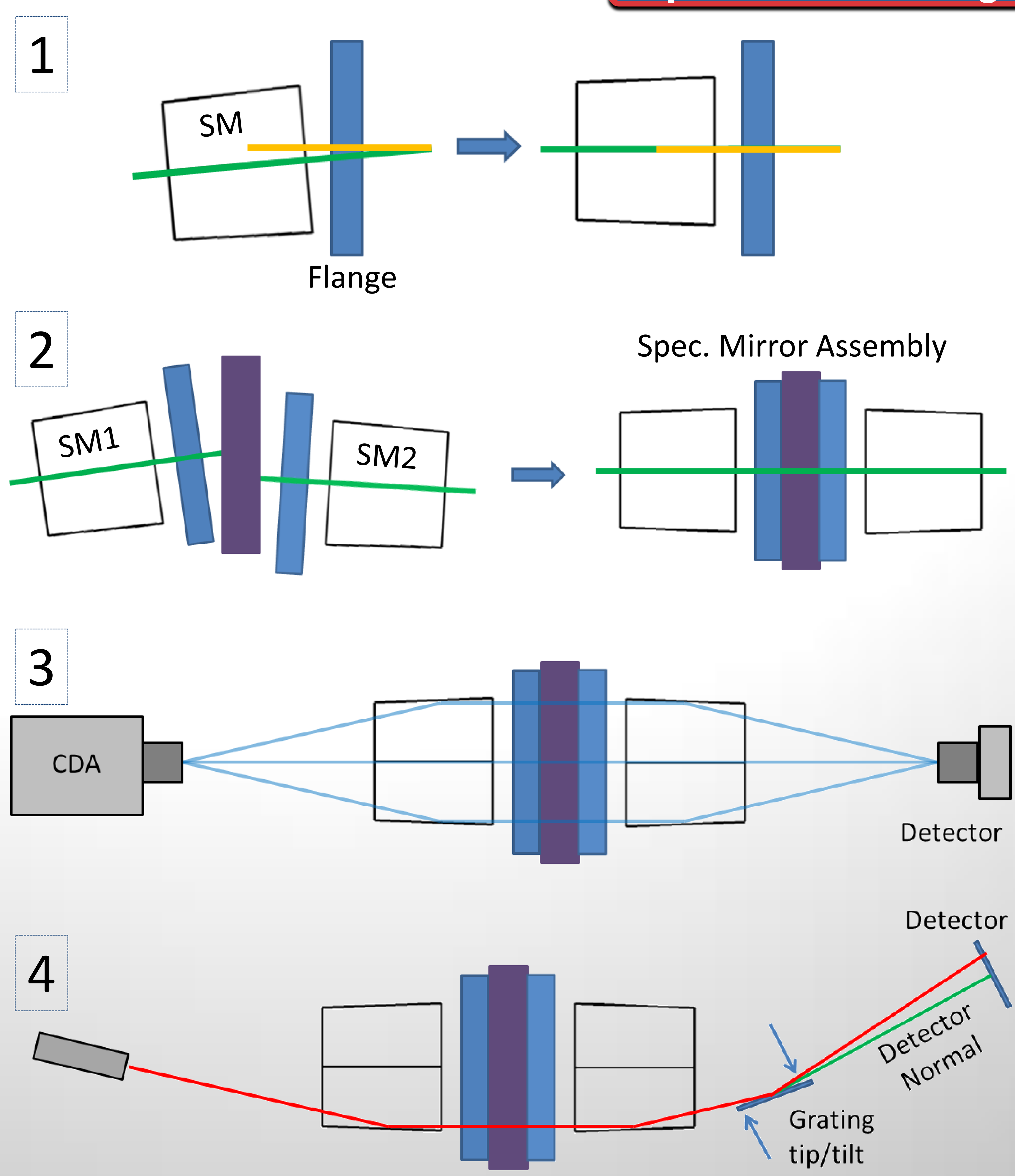
Table: Alignment Error for Spec. Mirror 1

Error Type	Unit Motion (µm) or (arcsec)	RMS Spot Size (µm)	Spectral Error (mÅ) [eV]	Vignetting (%)
Nominal	--	0.924	--	--
Decenter +X, -X	600.0, 600.0	4.36, 4.36	5.1 [1.75], 5.1 [1.75]	0.2, 0.2
Decenter +Y, -Y	600.0, 600.0	0.927, 0.916	35.3 [12.02], -35.3 [-12.12]	0.4, -0.4
Despace +Z, -Z	50.0, 50.0	0.739, 1.373	1.2 [0.41], -1.2 [-0.41]	0.0, 0.0
Tilt +X, -X	7.0, 7.5	7.64, 7.02	-13.9 [4.78], 14.9 [4.78]	0.2, 0.2
Tilt +Y, -Y	12.0, 12.0	7.39, 7.39	0.0, 0.0	0.0, 0.0



- 7” of tilt between SM1 & SM2 pushes FWHM out of spec
- 7” of tilt for SM1 & SM2 sub-assembly has no impact on performance

Spectrometer Alignment



1. Align mirror axis to mounting flange axis using a theodolite, reference flat bonded to the flange and the centroid detector assembly: axes must be concentric and parallel. Bond mirror in place. This step is performed for both SM1 and SM2.
2. Align both SM1 and SM2 to each other using theodolite and reference mirrors. The goal is to get both mirror axes concentric and parallel.
3. Integrate CDA and a detector for fine alignment of SM1 to SM2. Shim mirror mounts to remove tip/tilt, lock configuration.
4. Integrate grating with spectrometer mirror assembly. Adjust tip/tilt of grating until visible laser beam pierces the center of the detector, in the detector plane. Tilt grating at an angle equal to the angular separation between the 0th and 1st order as predicted by the grating equation.
5. End-to-end (Wolter - I & spectrometer) test in the Stray Light Facility at MSFC. Through focus scan in X-ray beam line to determine best finite source focus. Use finite source focus to compute infinite source focus. Machine shims for infinite source focus.