Characterization of Single Bounce Ghost Rays in MaGIXS-2 Ground Calibration using Ray-Tracing Simulation

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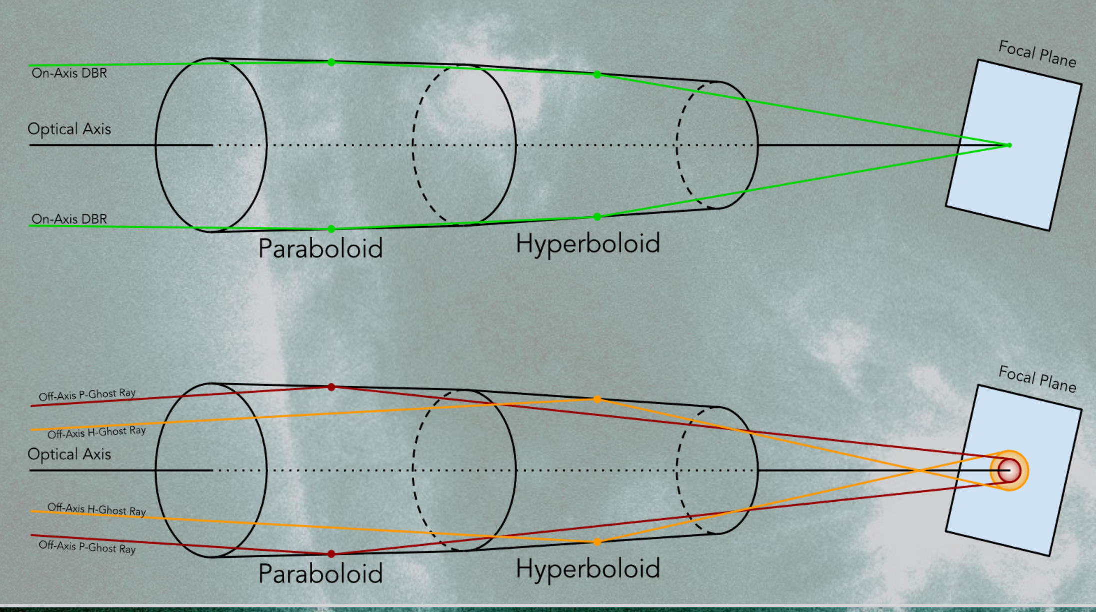
Abstract

The second launch of the Marshall Grazing Incidence X-ray Spectrometer (MaGIXS-2) sounding rocket experiment had a successful flight on 16th July 2024. MaGIXS-2 is a slitless-imaging spectrometer, designed to observe dispersed images of the solar coronal structures in soft X-ray using grazing incidence X-ray mirrors. The optical design includes a Wolter-I type X-ray mirror, a reflective variable line space grating and a focal plane low noise CCD to observe the X-rays in 6 to 30 Å wavelength range. The end-to-end ground calibration tests are performed using the 100m X-ray beam-line at the Stray Light Test Facility at NASA Marshall Space Flight Center (MSFC). Understanding the performance of the instrument as a function of wavelength, position of the source at several on and off-axes values are included in the calibration tests, which are critical to better interpret the flight data. Analysis of calibration data shows evidence of singly reflected 'ghost' rays from the Wolter-1 X-ray mirror reaching the focal plane science camera, which can mimic on-axis photons.

In this work, we employ an existing ray-tracing simulation (developed for the FOXSI sounding rocket experiment) and adapt it for MaGIXS optical design. We simulate MaGIXS-2 instrument calibration test conditions to understand the spatial distribution and relative contribution of single bounce rays in the MaGIXS-2 ground calibration data and assess the implication for the flight data.

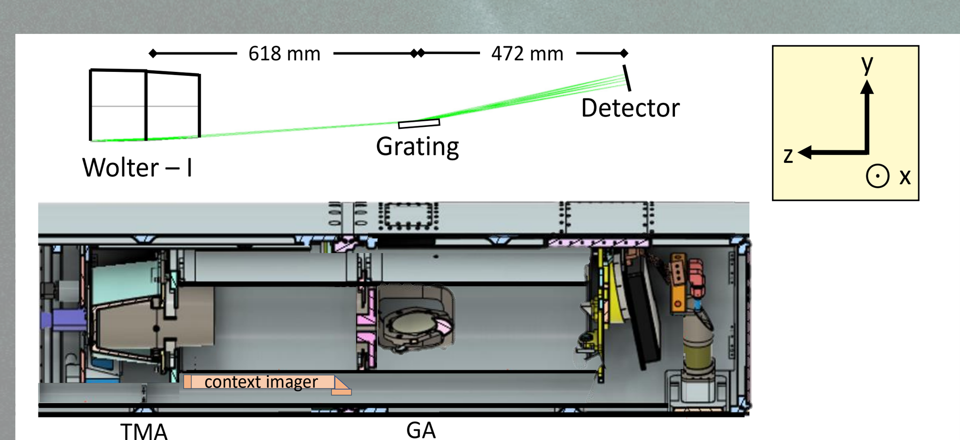
Principles of Optics

During the MaGIXS-2 instrument calibration, we observed single bounce "ghost" rays coming from different off axis grazing angles that interfered with our detector's image. Since our detector is placed away from the optical axis, as shown in the image above, it is particularly vulnerable to this kind of interference caused by unfocused singly reflected photons. After these results were found, we wanted a way to characterize the effects of ghost ray interference.



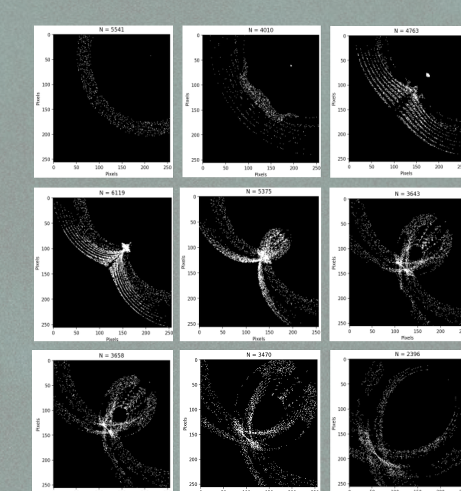
The MaGIXS-2 Experiment

The Marshall Grazing Incidence X-ray Spectrometer 2 (MaGIXS-2) is the second flight of a NASA sounding rocket instrument designed as a slitless soft X-ray imaging spectrometer used to observe the frequency of heating in solar active regions.[1][2] The MaGIXS-2 instrument is the first of its kind to provide spatially resolved soft X-ray spectra from plasma across a wide field of view.

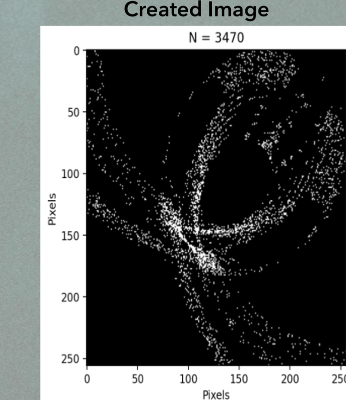


Grazing-Incidence Optics Simulation Tool

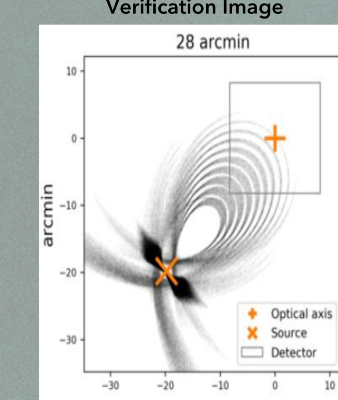
The preliminary training was done by running the raytracing simulation using the Foxsi sounding rocket experiment's optical design. Once I had become acclimatized with the software and had an ample understanding of its features, I then moved to verifying the program remained functional when MaGIXS-2 optical designs were implemented.



Simulated ghost ray images at different off-axis grazing angles [0-32, x4] using the Foxsi optics parameters



Simulated ghost rays created at a 28 arcmin grazing angle

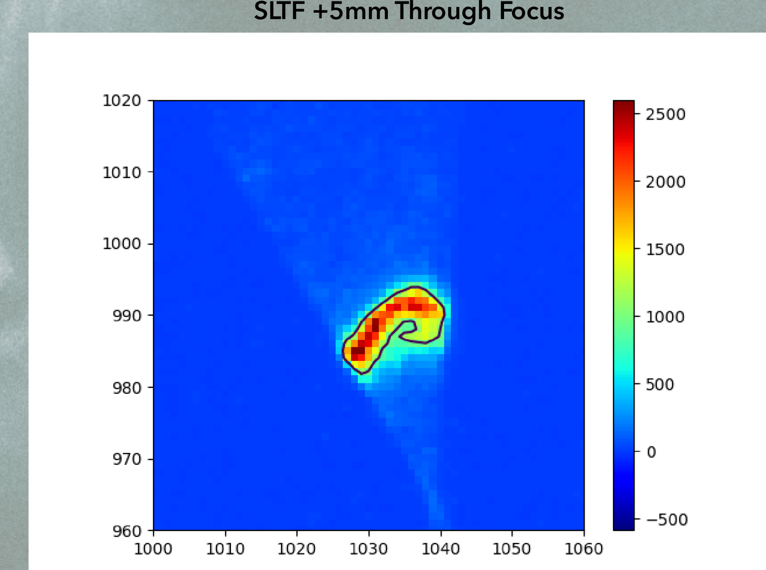


From Buitrago-Casas 2020[3], using 10-Shell Optics

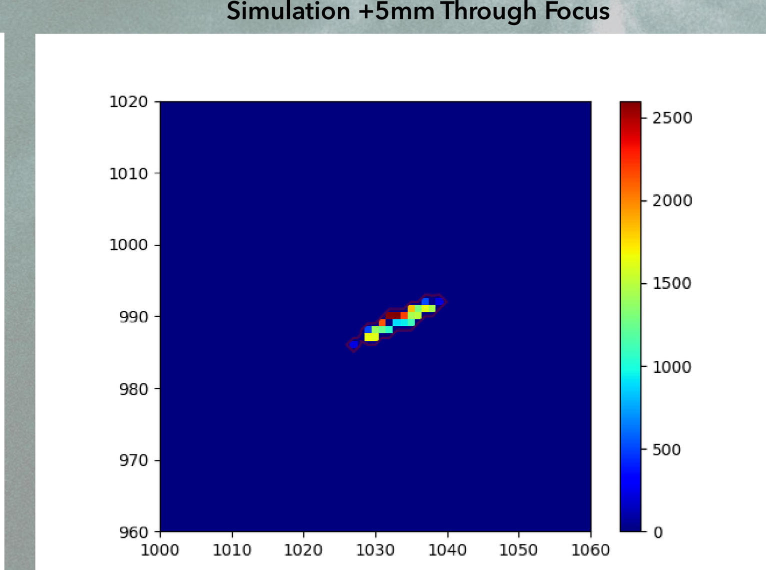
Ground Calibration Comparison

Through focus testing describes aligning the detector along the optical axis, then acquiring images through a gradual change of distance from the optics so that an optimum image focus can be obtained. Given the direct alignment, this means that we can exactly recreate this test using our ray tracing simulation.

SLTF +5mm Through Focus



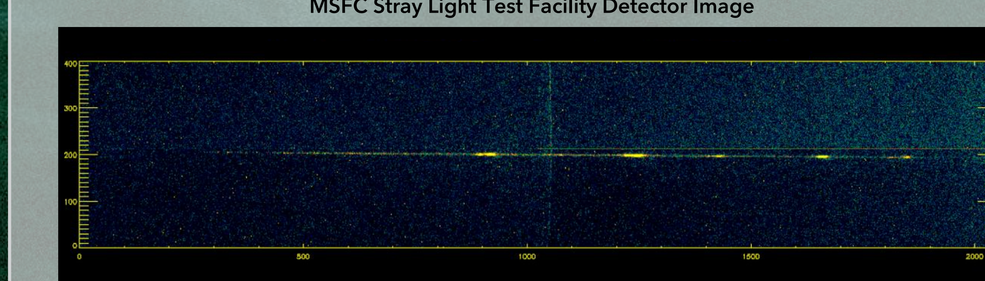
Simulation +5mm Through Focus



Preliminary Results

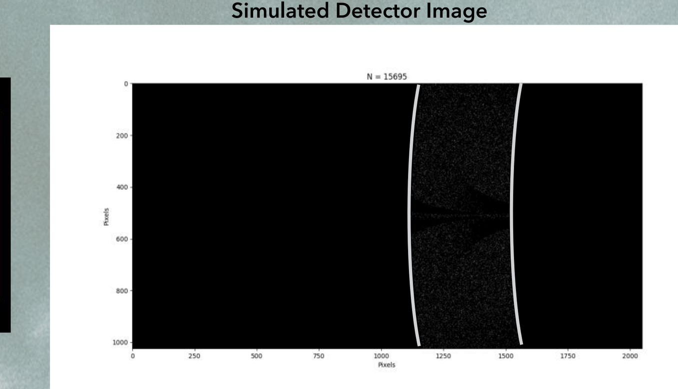
To recreate the detector images found at the Stray Light Testing Facility as MSFC, I used the available optical layout's estimated measurements to roughly determine the detector's position with respect to the central optical axis. Then after only allowing the light from 34% of the mirror's circumference, to mimic the rays used by the MaGIXS-2 optics, I placed the source -2 arcminutes off-axis.

MSFC Stray Light Test Facility Detector Image



Ghost Ray interference pattern present at -2' off-axis

Simulated Detector Image



Ghost Ray Interference Pattern (Detector Mirrored)

Conclusions and Future Work

Conclusions:

The outcome of this research so far is very promising after I was able to accurately recreate the exact through focus testing setup and results. In addition to the promising preliminary results obtaining a visible single bounce photon band similar to the off-axis testing results despite the lack of exact optical layout measurements.

Future Work:

- Recreating the off-axis simulation testing with the exact optical geometry
- Quantifying ghost ray throughput as a function of grazing angle

References and Acknowledgements

1. Athiray, P.S., et al. 2019, ApJ
2. Champey, P.R. et al. 2022, JAI
3. J.C. Buitrago-Casas, et al. 2020, JINST 15 P11032