Stray light analysis for the Solar Corona Imager of the ASO-S mission

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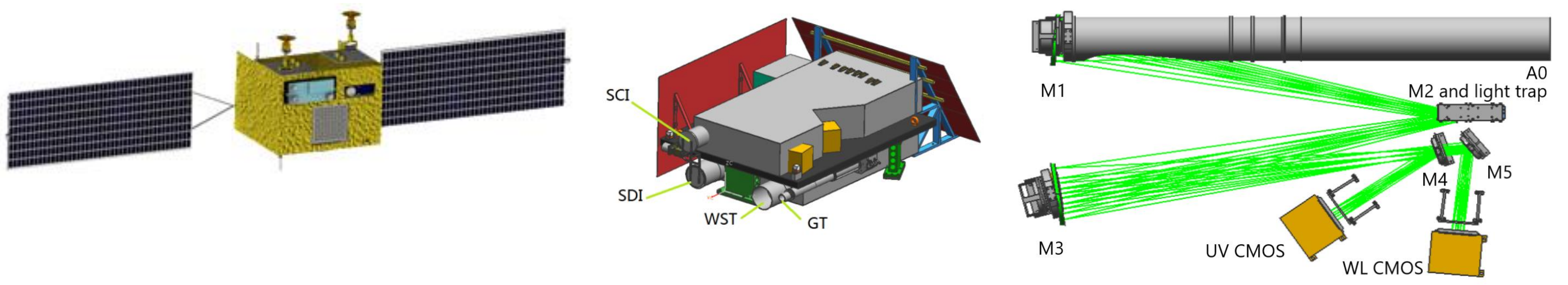

Figure 1. Advanced Space-based Solar Observatory (ASO-S) satellite, Lyman-alpha Solar Telescope (LST) payload and Solar Corona Imager (SCI) coronagraph respectively.

Abstract: The Advanced Space-based Solar Observatory (ASO-S) is the first Chinese satellite for solar physics study. Lyman-alpha Solar Telescope (LST)/Solar Corona Imager (SCI) is an internally occulted reflective coronagraph, which images the inner corona in both HI Lyα and white-light waveband. In this work, the stray light simulations are performed on the white light channel of the SCI lab model. The primary contributor to stray light is due to scattering off the micro-roughness surface of primary mirror M1. The choice of the inner field-of-view (FoV) is also considered on the amount of stray light.

The ASO-S mission and SCI: The ASO-S mission was proposed by the Chinese solar community in 2011, and formally approved by the Chinese Academy of Sciences (CAS) under the Strategic Priority Research Program on Space Science in June 2017. The ASO-S aims at the study of solar magnetic field, solar flares, coronal mass ejections (CMEs) and the relationship among them. ASO-S payload consists of three instruments: the Full-disk solar vector MagnetoGraph (FMG), the Lyman-alpha Solar Telescope (LST), and the solar Hard X-ray Imager (HXI). Their features are shown in table 1. The ASO-S is scheduled to be launched in early 2022, with a nominal mission life of 4 years.

FMG	Aperture	140 mm
	Detector	CMOS 4k by 4k, 16 fps
	Wavelength	Fe I 532.4 nm
	Sensitivities	5 G for longitudinal component
		150 G for transverse component
LST/SDI	FoV	0 – 1.2 $R_\odot$
	Waveband	121.6 ± 7.5 nm
	Pixel resolution	0.56´´
LST/WST	FoV	0 – 1.2 $R_\odot$
	Waveband	360 ± 2.0 nm
	Pixel resolution	0.56´´
LST/SCI	FoV	1.1 – 2.5 $R_\odot$
	Waveband	121.6 ± 10 nm, 700 ± 40 nm
	Detector	CMOS 2k by 2k
HXI	Energy range	30 – 200 keV
	Cadence	0.5 s
	Effective area	200 cm^2

Table 1. The ASO-S payloads specifications.

SCI is a Lyot-type coronagraph. Its optical design is shown in Figure 1. Both coronal and solar disk radiation enter the system through the entrance aperture (A0) and are imaged by M1 onto M2 plane. Solar disk radiation leaves the optical path through the cone-shaped hole in the center of M2 and is absorbed by the light trap. Coronal radiation is split into two beams after M4, and detected in the UV and VL image planes, respectively. Lyot stop (A1) is placed in the conjugate plane of A0 imaged by M1, M2 and M3, to block the light diffracted by A0 edge.

The SCI lab model and stray light simulations: In order to compare with the laboratory result, the stray light simulations are performed using the SCI lab model design in the non-sequential modality of Zemax OpticStudio. The SCI lab model has a smaller aperture of diameter 40 mm (the aperture of SCI is 60 mm), and the surfaces of M1 and M3 are spherical and not ellipsoidal. Its layout, including the reference system, and object parameters are shown in figure 2 and table 2 respectively. Only white light channel is simulated.

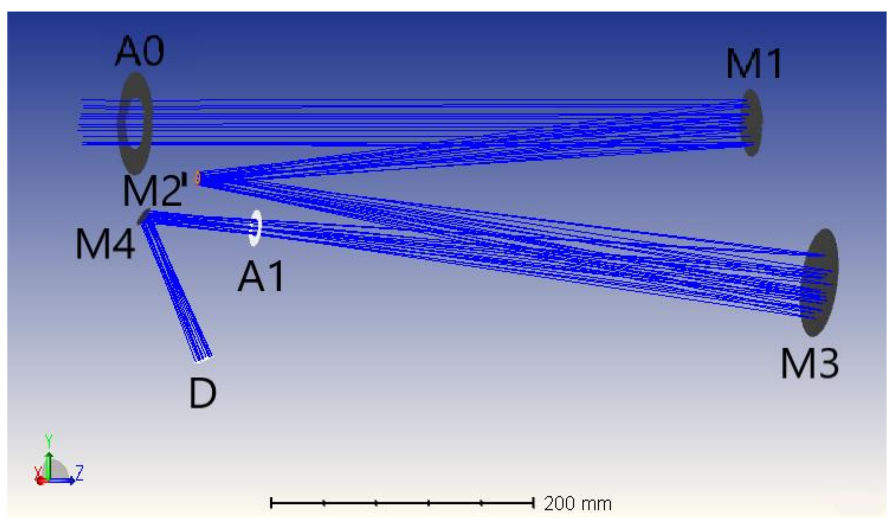

Figure 2. The layout of the SCI lab model. Reference system and ruler are also plotted.

Objects	Radius	Curvature radius
A0	20 mm	Infinite
M1	25.9 mm	-900 mm
M2	2.4 – 5.42 mm	-500 mm
M3	41.58 mm	-580 mm
A1	6.79 mm	Infinite
M4	8.11 mm	Infinite
D	7.11 mm	Infinite

Table 2. Parameters used in Zemax for simulations.

Sun is modeled with the "source two angle", which produces a uniform source. It's placed 40 mm out of A0, with circular shape, angular extension of ±0.266° and a normalized power equal to 1 W.
The surface scattering due to the optical surfaces micro-roughness is simulated by the widely used analytical ABg model. The bidirectional scattering distribution function (BSDF) of a surface with a roughness RMS σ is:

$$BSDF^{RMS}(\theta) = \frac{A}{B + (\sin\theta)^g}$$

with parameters given by

$$A = \frac{\pi}{2}\frac{\Delta n^2 \sigma^2}{\lambda^2}, B = \left(\frac{\lambda}{2\pi L}\right)^2, g = 2,$$

where Δn = 2 is the refractive index change and L is the autocorrelation length.

Results of simulations: To simplify the stray light estimate and analyze the influence of M1 surface micro-roughness, the light scattered by other mirrors and diffracted by A0 and A1 are ignored. Both Sun irradiance (the light trap is removed) and stray light are detected in the focal plane. Stray light levels along the FoV for different RMS σ and autocorrelation length of M1 are shown in figure 3, compared with the K-corona signal.
By ray tracing the disk light, source of stray light, distributed on M1 surface, is shown in figure 4.
The influence of inner FoV is shown in figure 5. In this case, the surface scattering of other mirrors is also included.

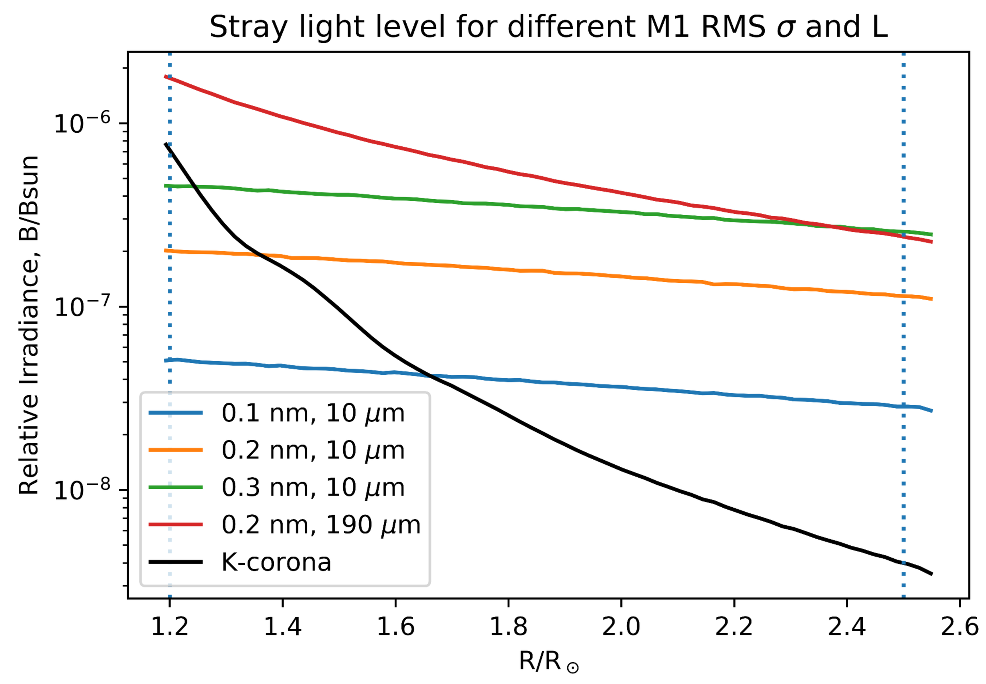

Figure 3. Stray light levels as the function of FoV with different M1 surface RMS σ and autocorrelation length.

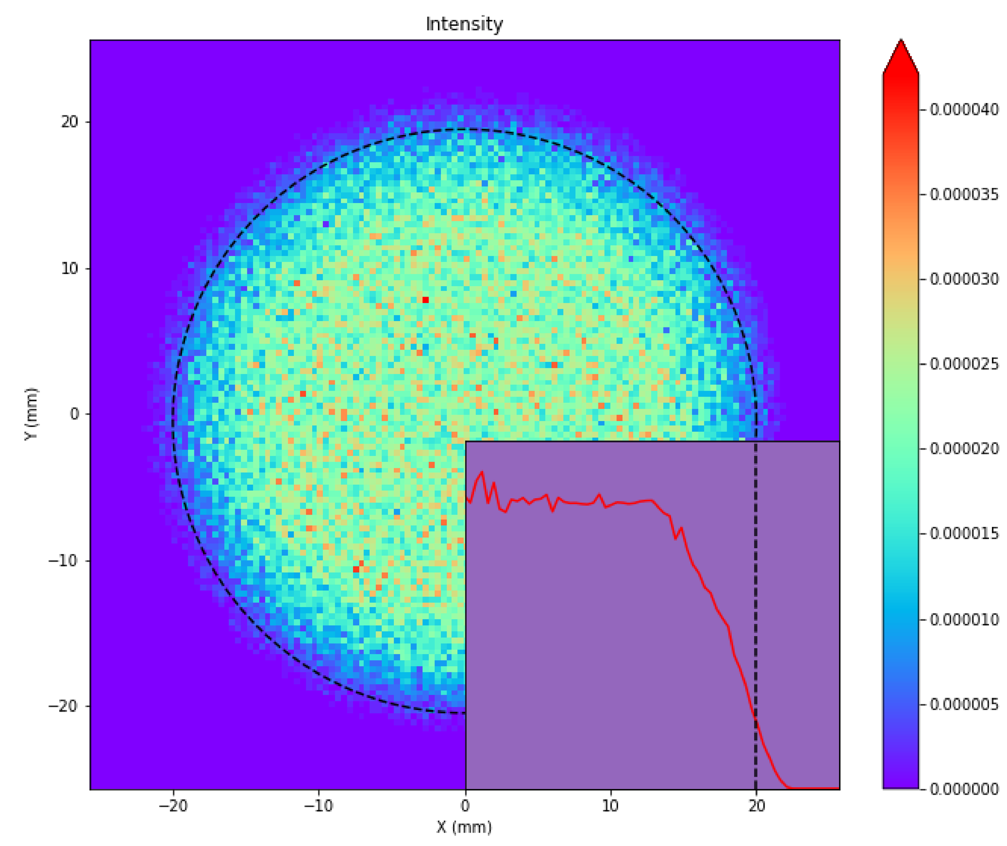

Figure 4. Source of stray light distributed on the M1 surface. The dashed circle represents the A0 edge.

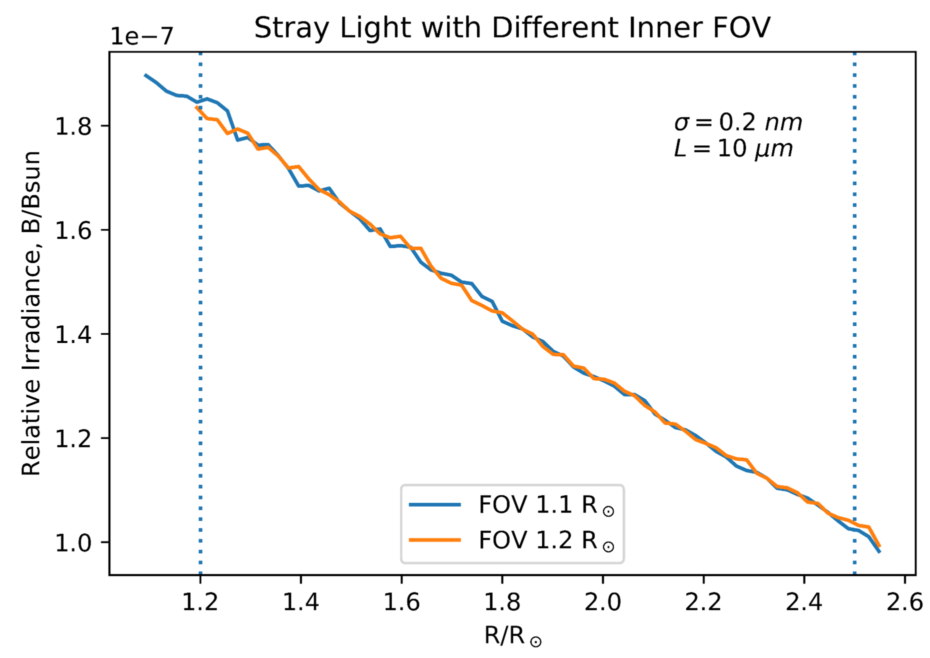

Figure 5. Stray light level with different inner FoV.

Conclusions: The average B_{stray}/B_{Sun} detected in lab is over 10^5, much larger than the simulation results. The cause should be from the SCI model properties, laboratory condition, and simplification of analysis, casual parameters. Even for the simulation results, stray light does not fulfill the requirements for a FoV upto 2.5 $R_\odot$. We also conclude that the central part of M1 contributes the most stray light, changing the FoV doesn't have significant effect on the amount of stray light.
Effort is still being made to improve the SCI performance, lab condition, and measure the objects parameters. We will analyze the stray light due to A0 diffraction and compare the results with that of lab in detail in the next work. SCI will also be analyzed.