STRAY LIGHT TESTING OF WISPR BAFFLE DEVELOPMENT MODEL

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I. INTRODUCTION

Solar Probe Plus (SPP) is a NASA mission developed to visit and study the sun closer than ever before. SPP is designed to orbit as close as 7 million km (9.86 solar radii) from Sun center. One of its instruments: WISPR (Wide-Field Imager for Solar Probe Plus) will be the first 'local' imager to provide the relation between the large-scale corona and the in-situ measurements. The stray light rejection is critical for the imaging instrument.

The Centre Spatial de Liège in Belgium (CSL) owns a stray light test facility for In Field and Out of Field of View stray light measurements. This facility is updated to realize a stray light test on the WISPR Development Model (DM).

The design of the WISPR is based on a series of baffles used to reduce the scattered light from the solar disk and reflections from the spacecraft to levels below the scene brightness. Average predicted stray light: <2x10-9 B/Bs @ 9.86Rs and <2x10-12 B/Bs @ 0.25AU, well below the K+F corona [2].

The theoretical performances of the baffling systems have been experimentally verified at CSL during the instrument development phase of WISPR.

Two main requests have been checked:

- The stray light due to the reflection and scattering of structures surrounding WISPR.
- The correlation between the numerical model of WISPR and observed stray light measurements

II. WIDE-FIELD IMAGER FOR SOLAR PROBE PLUS DEVELOPMENT MODEL

WISPR is designed, developed and will be operated by the Solar & Heliospheric Physics Branch at the Naval Research Laboratory (NRL).

The WISPR instrument concept is based on the SECCHI/HI and SoloHI design. It consists of two-telescope, the inner telescope extending from 13.5° to 53° and the outer telescope extending from 50° to 108°. The two-telescope implementation is necessary because FIELDS antennas are located in front of WISPR (just behind the heat shield) and with a single telescope, two of the antennas would intrude into the unobstructed FOV of the lens leading to unacceptable stray light levels (**Fig.1**).

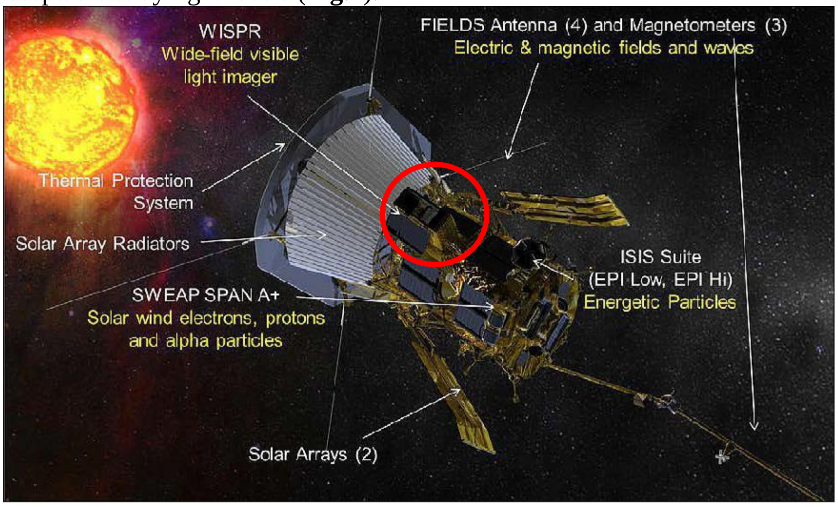

Fig.1. Artist's view of the SPP spacecraft

WISPR uses the Thermal Protection System (heat shield) as the first occulter (**Fig.1**). The mechanical design incorporates three baffle systems (forward, interior, and peripheral). A set of forward baffles (F1-F3) are located on a ledge to reduce the diffraction from the heat shield. An internal baffle assembly (I1-I7) reduces this stray light component further as well as stray light diffracted from the Fields antennas and other spacecraft structures. The peripheral baffles limit stray light from surrounding spacecraft surfaces entering the interior baffle cavity and reaching the detectors (**Fig.2**). The Development Model (DM) of WISPR is realized to verify experimentally the stray light model. The baffles are representative of the instrument (**Fig.3**).

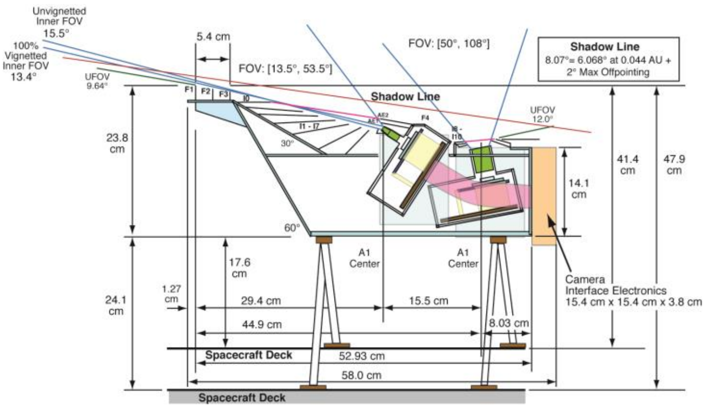

Fig.2. Side view of the WISPR instrument

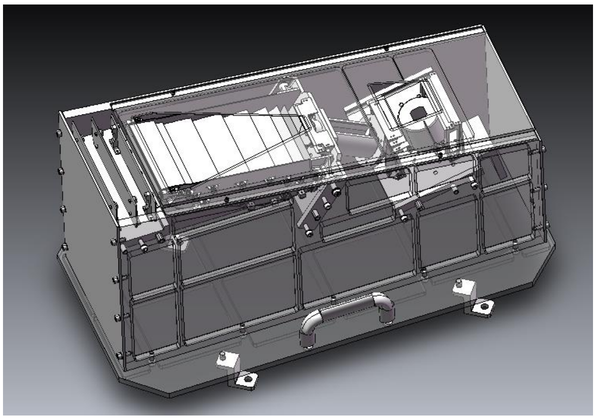

Fig.3. WISPR DM

III. STRAY LIGHT FACILITY DESCRIPTION

The facility is in a clean room (class 100) to eliminate undesired air particles scatter light sources. The chamber was closed but at atmospheric pressure. Inside the chamber dedicated baffles are implemented to eliminate undesired light generated by the set up itself e.g retroreflected light away from the instrument under test. The WISPR DM is set in the vacuum chamber inside a black tent.

A general overview is given in **Fig.4**. The facility consists in the following items:

- the vacuum chamber
- the collimator
- the source pack with its monitoring
- the MGSE: hexapod, rotating table and goniometer to access all the required FOV
- the baffles design at all the level from the facility to the focal plane units

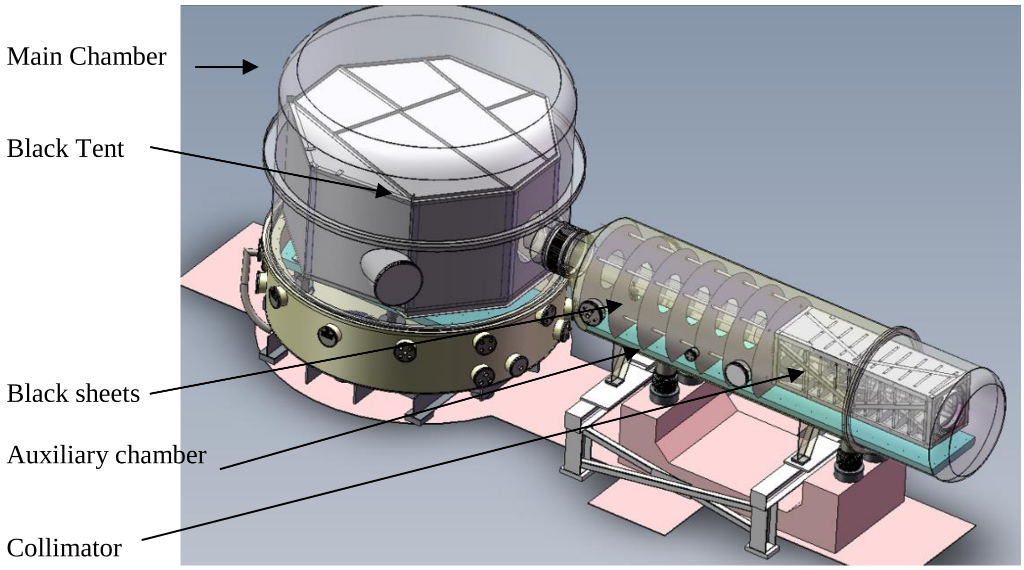

Fig.4. Test set-up

A. The vacuum chamber

The setup is implemented in a facility consisting of a main chamber (diameter 3m, height 2.8m, vertical axis) and an auxiliary chamber (diameter 1.2m, length 5m, horizontal axis).

B. The collimator

The collimator is set into the auxiliary chamber and has a 400mm off axis parabola (OAP). The off axis design suppresses the problem of stray light generated by the internal obstruction.

The goal of the truss is to support the primary mirror (OAP), the fold mirror and the Focal Plane assembly (FPA) (**Fig. 5**). The truss is in stainless steel and is black painted with MAP PU1.

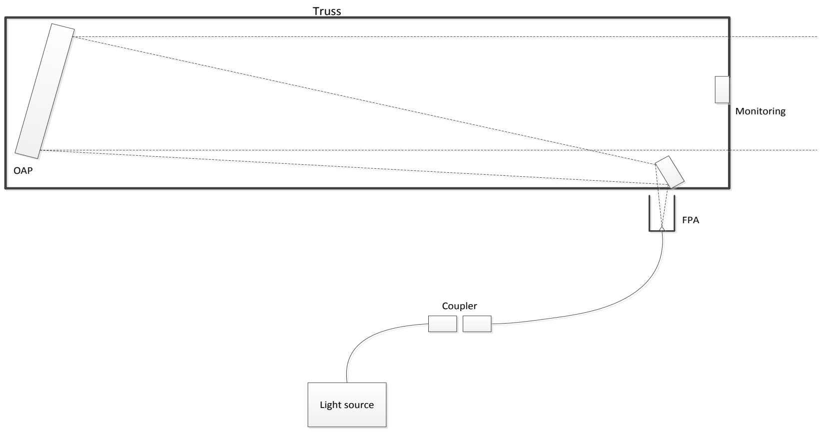

Fig. 5. Collimator schematic view

C. The source pack with its monitoring

The light source is either a Laser-Driven white Light Source (LDLS) or a 20W laser diode (λc = 805 nm) equipped with an optical fiber.

The source baffling has 2 main objectives (**Fig.6**):

- to avoid any stray light coming from reflection of parts around the point source or backscattered to the source;
- to limit the output beam Fnumber such as only optical surface are directly illuminated.

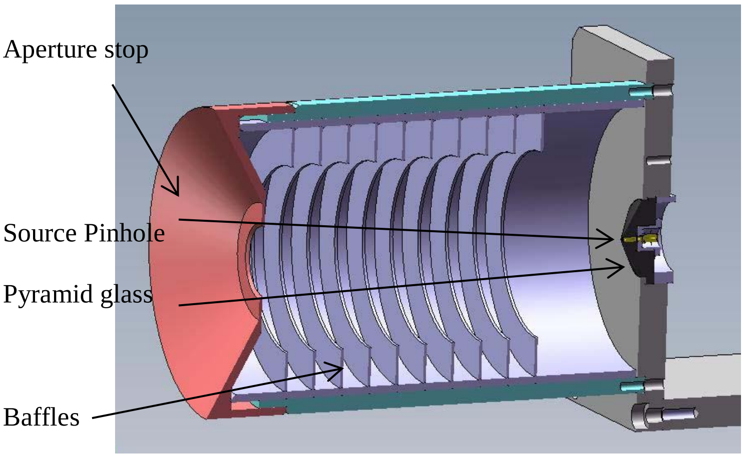

Fig. 6. Source pack

For the remaining backscattered light if any, a pyramid in black glass is placed around the source pinhole. The top of the pyramid has a hole of 400 µm. The pyramid shape is designed to reflect the ~4% specular reflected beam in the cylinder light trap. The cylinder around the pyramid is designed as a light trap such that no stray light is coming out the baffle. Black coating from Acktar is used for baffles and internal aperture stop.

The aperture stop limits the collimator Fnumber (Φ 300 mm) such as no black surface in directly viewed by the instrument is illuminated (mirror cell, vanes…)

An additional reflective fiber to fiber coupler allows to insert optical density for decreasing light flux or filters for selecting the wavelength.

The monitoring is placed into the collimated beam. It consists into a fold mirror, a collecting lens and a photodiode.

D. The Mechanical Ground Support Equipment (MGSE)

The purpose of the MGSE is to locate the instrument in correct orientation with respect to the collimated beam. The MGSE orients the instrument in the range ± 180° in azimuth and -5°/+85° in elevation.

The WISPR DM is mounted onto a stack of stages (**Fig.** 7):

- A goniometric stage
- A rotation stage
- A hexapod for vertical adjustments and/or additional tip/tilt

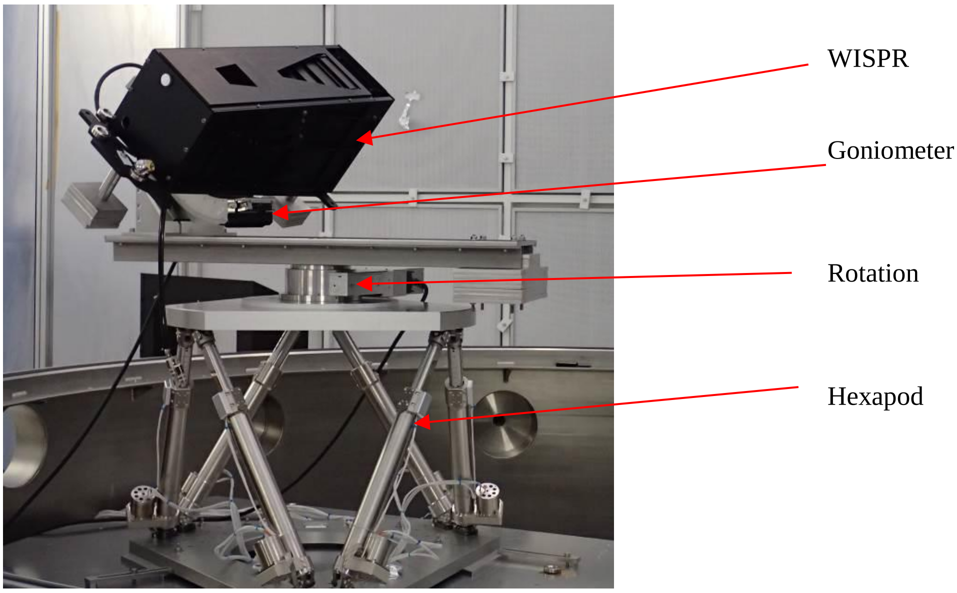

Fig 7. WISPR on MGSE

E. The baffles design

One of the most critical parts in the design of the stray light facility is to get rid of all internal stray light coming from reflection of the chamber wall or retro reflection from the tested item.

To limit this stray light, it is proposed to place the WISPR DM in a black tent. Additionally a DM baffle around of the entrance aperture is set to avoid back reflection to the focal plane (**Fig. 8**). Velblack is added in critical part.

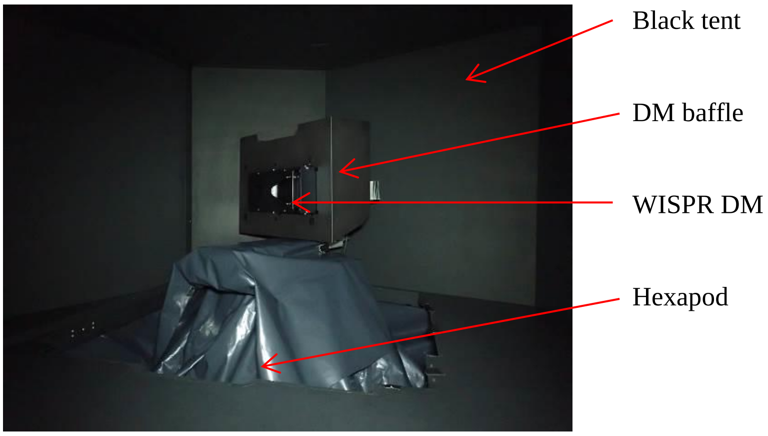

Fig 8. WISPR DM on the MGSE inside the black tent

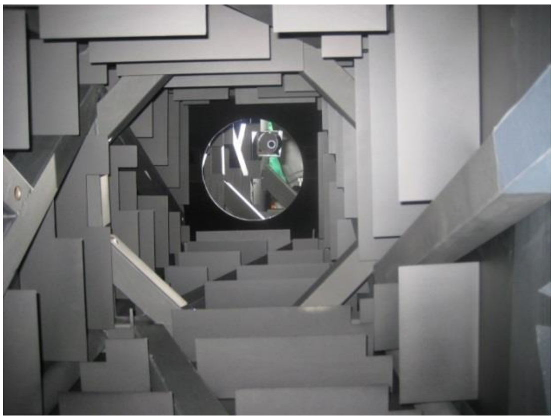

Fig 9.Vanes inside the truss

The collimator baffling is divided in two parts:

- A first baffling on the trust: black painted aluminum sheets to close the sides of the truss and vanes inside the trust to avoid grazing reflection (**Fig 9**.).
- A second baffling in the auxiliary chamber: set of black (MAP PU1 paint) Aluminium sheets with an aperture of 440 mm (**Fig 4**.).

F. Occulter

Occulter is used to mask the DM optical entrance during stray light measurement into the optics field of view. This occulter is removed for calibration measurement and out of the optics field of view.

IV. TEST DESCRIPTION

A. Principle of the test

The principle of this test is to illuminate the WISPR DM with collimated light from directions of stray-light sources. The residual light entering the telescope aperture is recorded with a GSE camera.

The recorded image is then compared to a simulated image obtained from ray-tracing analysis.

Because there are two telescopes, the same test is repeated on both telescopes with the same GSE camera.
The stray-light sources have been determined by the NRL and come from the surrounding structures (FIELDS antenna …), diffracted light due to the solar illumination and scene background (F corona, stars and planets).

B. Requirements to be verified

Two mains questions must be verified:

- Will the stray light due to the reflection/scattering of structures surrounding WISPR be below maximum required level?
- Does the numerical model of WISPR do a good job predicting the observed laboratory measured stray-light?

C. Test sequence overview

The test sequence is represented **Fig. 10**. The outer telescope aperture is larger than the GSE camera aperture. The mating holes for the GSE camera are oblong to allow shifting the aperture on the edges and the corners of the entrance aperture; two positions of the camera have been tested.

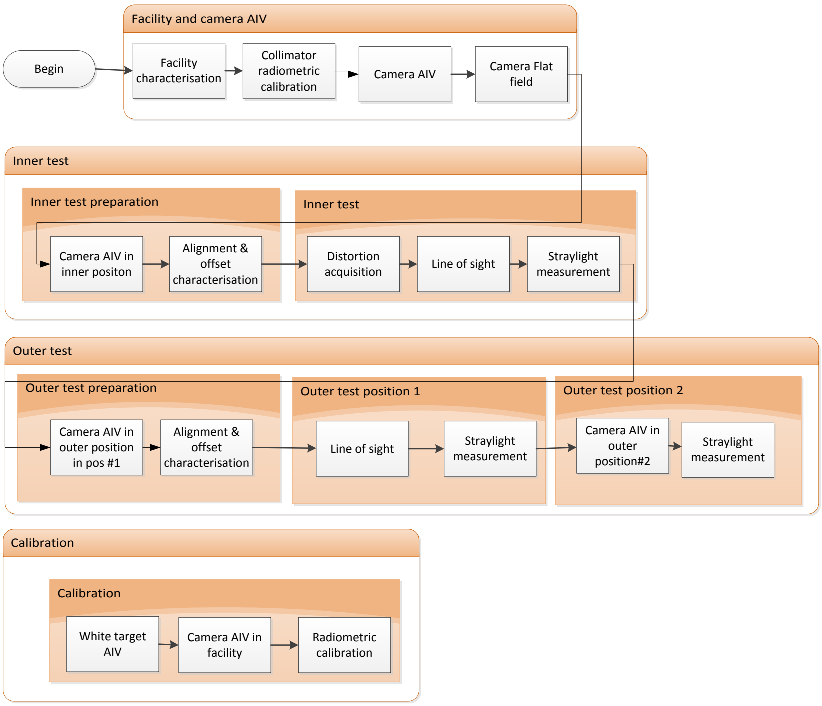

Fig 10. Test sequence overview

V. RESULTS

A. Facility and camera AIV

All GSE are positioned and aligned with a laser tracker and theodolite.
The optical performances of the collimator are characterized. That concerns:

- Spatial uniformity;
- Absolute radiance and monitoring calibration with both light sources.

The collimator radiometric calibration is performed with a calibrated photodiode.

The flat field of the optics (including camera, objective and relay optic) is measured with a spectralon integrating sphere. The integrating sphere is illuminated by the LDLS or by the laser diode through an optical fiber. The **Fig 11** shows a typical acquisition for the camera before and after flat field correction.

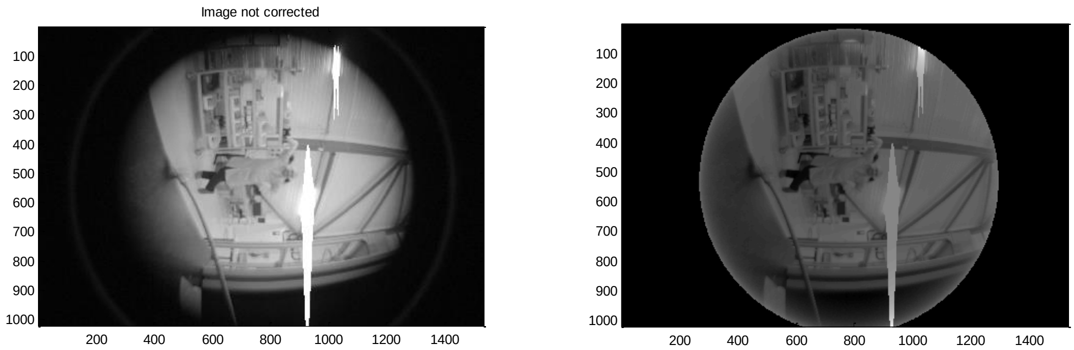

Fig 11. Typical acquisition scene without and with flat field correction.

B. Calibration

The radiometric calibration objective is to calibrate the collimated flux with the camera response. A Spectralon plate is set into the collimated beam and the camera is looking to the Spectralon (**Fig. 12**).

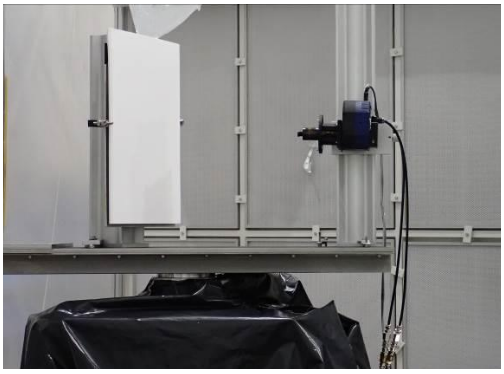

Fig.12. Photometric calibration setup.

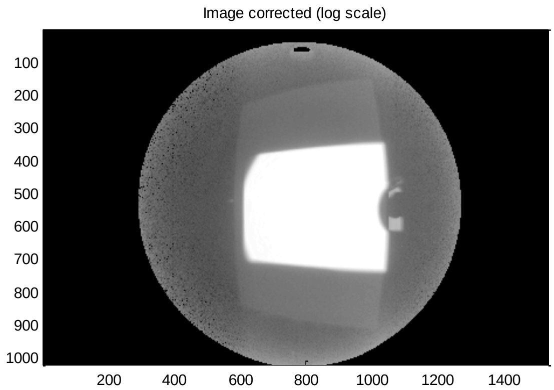

Fig.13. White target acquisition with LDLS.

The picture presented in **Fig.13** is realized with the LDLS. The same measurement has been realized with the laser diode light source. The results are presented in **Table 1**.

Table 1. Photometric calibration results

	LDLS	Laser diode light source
Measured signal:	575 ADU/s	800 ADU/s
Input signal:	1.27 10-6 nW	709 10-6 nW
Photometric calibration:	452.755 106 ADU/s/nW	1.12 106 ADU/s/nW
Radiance calibration:	11.51 (ADU/s)/(nW/cm²sr)	33.5 (ADU/s)/(µW/cm²sr)

C. Optical measurement

Distortion:

The camera distortion is tested at system level during stray light test by scanning the camera FOV along azimuth without occulter. **Fig. 14** shows typical collimator spots during the scanning of the FOV.

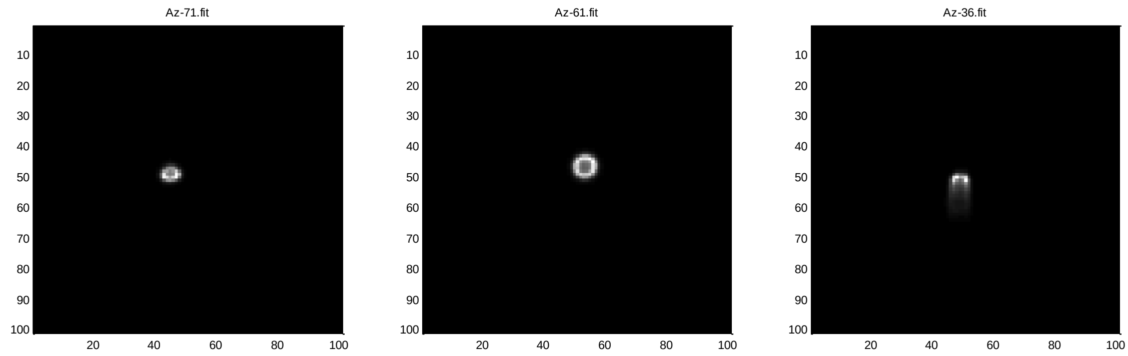

Fig 14. Typical collimator spot along azimuth

The variation of the spot centroid with respect to the centre of the FOV is plotted in **Fig 15**. The distortion is lower than ±0.6 px along a 40° field of view.

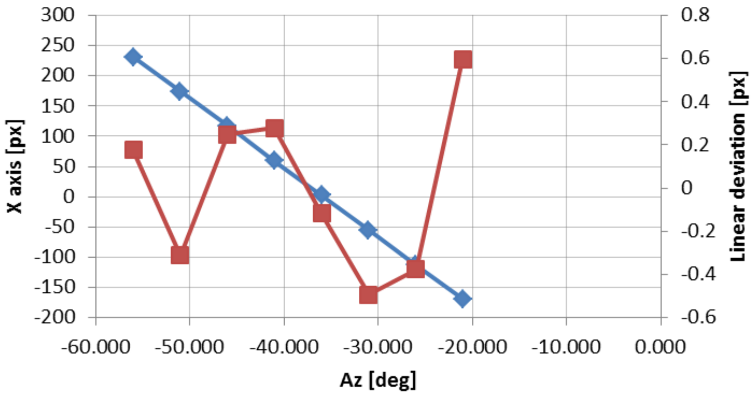

Fig 15. Distortion analysis (blue curve) and deviation from linear fitting (red curve).

Line of Sight

The distortion FOV scan allows to determine the angular deviation of the central pixel in azimuth. An optimization with elevation angle allows centering the PSF on the central pixel in order to know the exact optical axis deviation with respect to the WISPR reference.

Stray Light measurements

A large number of angles haven been measured to verify the stray light due to the reflection and scattering of structures surrounding WISPR. All illumination angles are determined by the NRL.

A short analysis is realised at CSL in order to verify the facility background level but the data processing has been made by NRL to realize the correlation between the numerical model of WISPR and observed stray light measurements.

Two configurations are shown in this document. The **Fig 16** and **Table 2** summarize the D1 configuration acquisition in inner telescope configuration. The “D” configuration corresponds of orientation for diffraction analysis. Four angles have been checked concerning the diffraction analysis, D1 is the first one. The **Fig 17** and **Table 3** summarize the HS5 configuration acquisition with the outer telescope. The “HS” configuration corresponds of the Heat Shield verification. Four angles have been checked concerning the Heat Shield verification. HS5 is the last one.

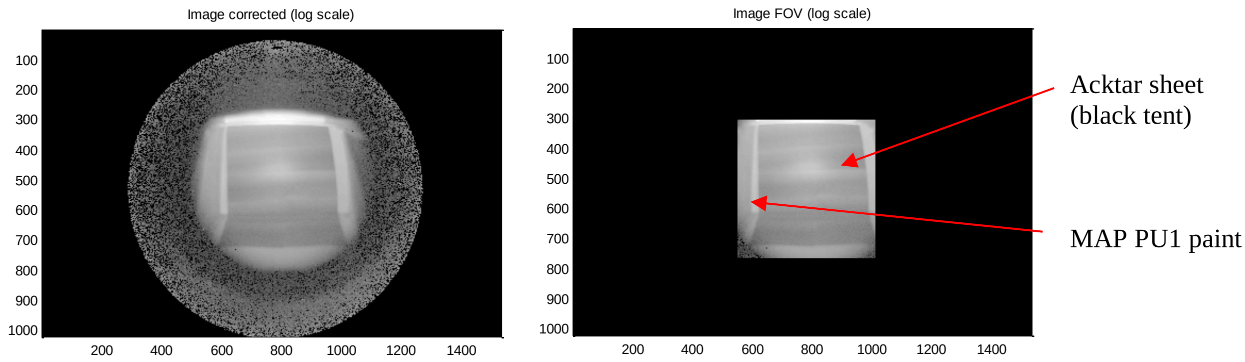

Fig 16. Distortion: Inner D1 configuration.

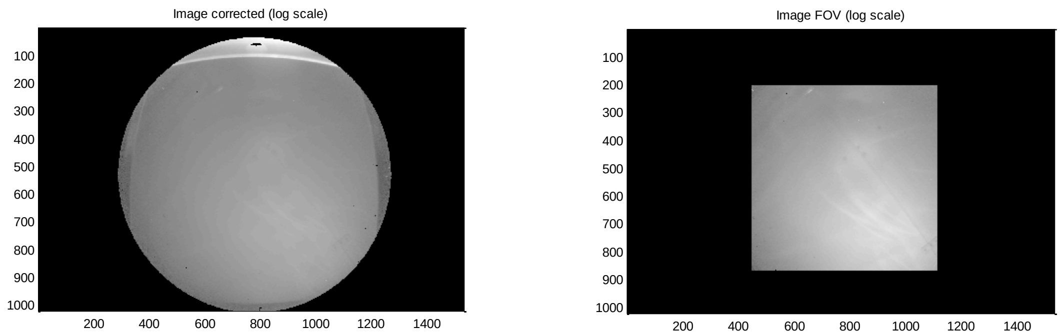

Fig 17. Outer #1 HS5 configuration.

Table 2. D1 in inner configuration

Filename:	D1_1_light
Light source:	Laser diode
Integration time:	400s
Monitoring:	6.135 V (low gain)
Collimator irradiance:	69.3 µW/cm²
Collimator radiance:	985.13 W/cm² sr
Background level:	0.7 ADU/s
Background radiance:	0.021 µW/cm² sr
Facility stray light:	2.1 10-11

Table 3. HS5 in outer configuration

Filename:	HS5_1_light
Light source:	Laser diode
Integration time:	2000s
Monitoring:	5.658 V (low gain)
Collimator irradiance:	63.9 µW/cm²
Collimator radiance:	908.035 W/cm² sr
Background level:	1.5 ADU/s
Background radiance:	0.044 µW/cm² sr
Facility stray light:	4.8 10-11

VI. CONCLUSIONS

The control of stray light due to spacecraft accommodations has been the major focus of the WISPR team during the preliminary design phase of the project. The verification of baffles design has been realized at CSL on the Development Model (WISPR DM). The CSL facility has been able to realize stray light test for in-field and out-field of view. During the test, the facility stray light is lower than 10^{-10}.

The correlation between the numerical model of WISPR and observed stray light measurements has been realized by the NRL. The numerical model is consistent with the experimental results.

VII. ACKNOWLEDGMENTS

This development would not have been possible without the help of the Belgian Science Policy Office (BELSPO).

VIII. REFERENCE

[1] E. Mazy, Y. Stockman, M.L. Hellin, “Design and modelisation of a stray light facility for space optical instrument,” *SPIE Optical Systems Design 2012*, vol. 8550, December 2012

[2] A. Vourlidas et al, “The Wide-Field Imager for Solar Probe Plus (WISPR),” Space Science Reviews, 2015