STRAYLIGHT TESTS FOR THE HELIOSPHERIC IMAGERS OF STEREO

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ABSTRACT

The design of the Heliospheric Imager (HI) of the NASA - Solar TErrestrial Relations Observatory (STEREO) is based on an optical baffle system. It will reject the solar disk light with attenuation of the order of 10^{-13} and 10^{-15}, and let two separate camera systems (HI-1 and HI-2) measure the extremely faint solar coronal mass ejections. A multi-vane diffractive system has been optimized to achieve the lower requirement (10^{-13} for HI-1) and is combined with a secondary baffling system to reach the 10^{-15} rejection performance in the second camera system (HI-2).

The theoretical performances of the baffling systems will be experimentally verified during the instrument development phase. A specific straylight test facility is being studied at CSL and preliminary tests have been conducted to prepare the HI instrument testing. The test set-up requirements and design considerations are discussed in this paper. The very high rejection performance requires to perform those tests under vacuum to avoid ambient air perturbations. Several light trapping systems have been developed for this application. A first breadboard has been built and tested. Preliminary results of those tests are presented.

1. INTRODUCTION

The STEREO program is a NASA mission dedicated to solar observations. Two spacecrafts will orbit around the sun with sufficient separation to provide remote sensing instruments with a stereoscopic view. Each spacecraft will include a Heliospheric Imager (HI) to view the heliosphere in the interval from 12 to 215 solar radii, which includes the Earth, as shown on Fig. 1

The HI experiment will obtain the first stereographic images of coronal mass ejections (CME) in interplanetary space. The key element of this instrument is the baffling system facing the sun, protecting the telescopes from solar disk, whose light is much brighter than the CME.

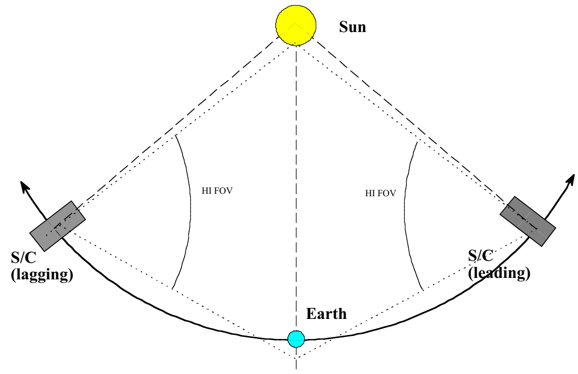

Fig. 1 STEREO mission orbit geometry

2. INSTRUMENT CONCEPT

Due to its very large field of view (more than 90 arcdeg), the HI field of view is shared into two camera systems (HI-1 and HI-2), with overlapping field of view. Both cameras will be active at very low light level.

Consequently, the key point in the HI instrument design is a baffle system that reduces straylight to a very low level, in particular for the solar disk brightness [2], [3], and [4]. The HI design is shown on Fig. 2. It consists on two optical systems. Two sets of baffle system allow the instrument to reach its baffling requirement: the forward baffle to keep the optical systems in the shadow of the solar brightness and the internal baffle to reject Earth and galactic straylight from HI 2.

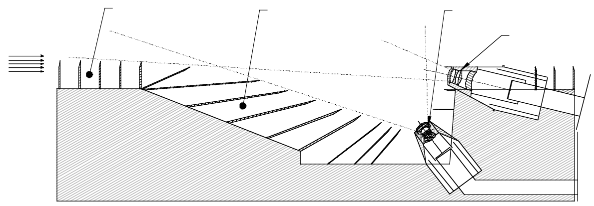

Fig. 2 HI Design

The function of the forward baffle is to reject the solar disk light and, to a lower extent, the inner corona light from both the open interior.

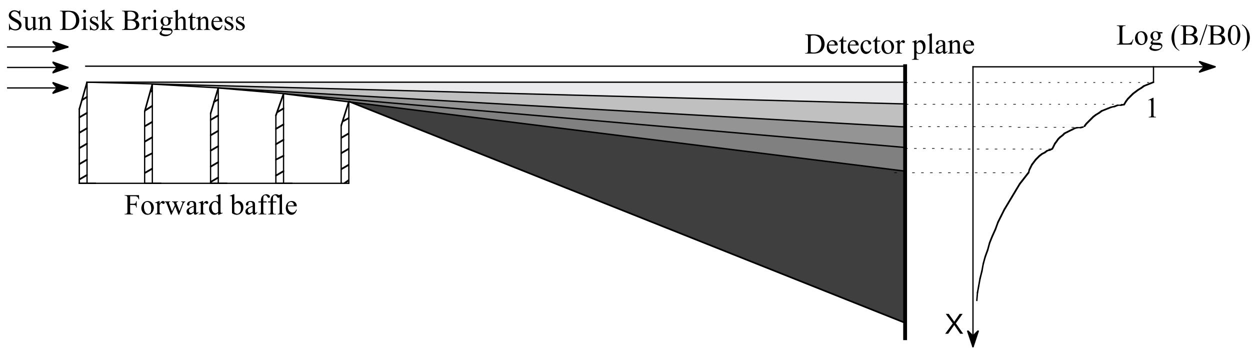

Fig. 3 Diffractive multi-vanes systems

To reach the required rejection level, a diffractive multi-vane baffle system was proposed. The vane edges are arranged in an arc such that the n^{th} intermediate vane blocks the bright linear diffracting edge of the $n-1^{th}$ vane from the view of the $n+1^{th}$ vane edge, as shown on Fig. 3.

This multi-vane design is based on both laboratories tested baffle system for a similar heliospheric imaging experiment [5] and theoretical computation. The degree of solar disk rejection afforded by the forward baffle was computed using Fresnel's second order approximation to the Fresnel-Kirchhoff diffraction integral for a semi-infinite half-screen [6].

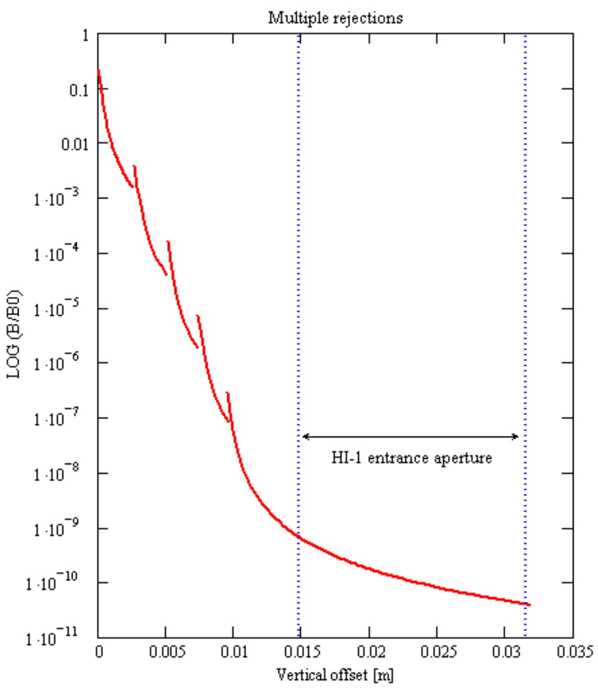

Fig.4 Forward baffle rejection curve

The resulting cascading rejection curve for the optimised forward baffle is shown on Fig. 4. The rejection level is 10^{-9} B/B_0 at the top entrance of the camera. As the last vane edge of the forward baffle is out of the HI 1 field of view, a supplementary 10^{-4} rejection factor from entrance aperture allows the global rejection level lower than the required 3.10^{-13} B/B_0.

The main function of the internal baffle is to reject residual Sun light, Earthshine and galactic straylight from HI-2.

3. STRAYLIGHT FACILITY

Straylight rejection is the key element to achieve good science with the instrument. Light from the solar disk must absolutely be suppressed. Therefore, it is of crucial importance to evaluate as much as possible the performance of straylight rejection.

The diffraction performance of multi-vane systems has not been tested before below about 10^{-8} mainly because of air particle diffusion [5]. In the case of the HI, the 5-vane system should produce rejection of 10^{-10}. Consequently, a vacuum straylight facility is studied and prepared at the Centre Spatial de Liège (CSL) to measure the HI vane rejection level and validate the cascading application of Fresnel theory.

The major requirements for the vacuum facility are high cleanliness level and good mechanical stability. In order to fulfil the straylight requirement, the diffusion by particles onto the instrument environment has to be as small as possible: a class 100 clean room is required. In order to fulfil the alignment constrains during vacuum tests, the optical bench has to be vibration isolated during the test. The FOCAL 2 facility (2 m diameter, 1.35 m x 5 m optical bench) at CSL, shown on Fig.5, fulfils all these requirements.

The straylight test will be composed of two conceptual configurations. In the first case, a small optical system with a highly sensitive detector (i.e. a photomultiplier) will point toward the last vane edge and measure the rejection level at various angles in order to verify the theoretical analysis. In the second case, the optical system will be adapted to match with HI-1 field of view and then simulate incoming straylight in HI-1.

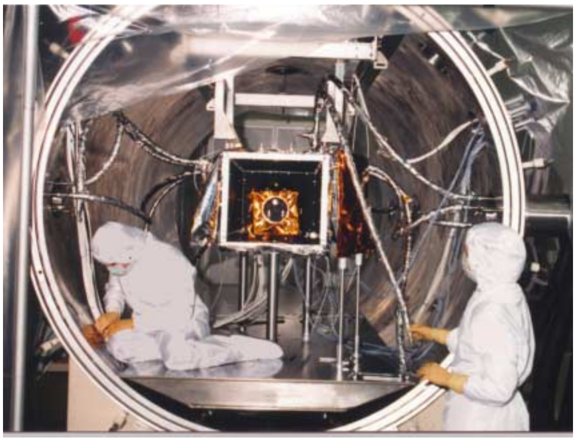

Fig. 5 FOCAL 2 facility at CSL

The vacuum test set-up of the optical bench is composed of five components as shown in Fig. 6: the mock-up, the detector, the light traps, the collimator and the black box.

To achieve an efficient straylight detection (10^{-10} level), the vanes are illuminated with an intense collimated pencil beam produced by a 20 W continuous laser diode. For that purpose, a collimator is used to send the beam onto the mock-up constituted by the vanes of the forward baffle system. One fraction of this beam is diffracted by the vanes towards the detector area while the remaining part is transmitted above the vanes or reflected by the first vane. These parts are absorbed by two specific light traps.

All these equipments in FOCAL 2 facility are surrounded by a black box in order to trap unwanted light and ensure a perfect black environment around the detector.

4. COMPONENTS OF THE TEST SET-UP

4.1 Collimator

The Sun brightness is simulated by a 100-mm focal length collimator located in front of the five vanes mock-up.

The source of the collimator is a powerful 20 CW laser diode at λ = 808 nm with a 600 µm core optic fiber. To simplify the laser diode manipulation and cooling, the source is external to the vacuum chamber. An optic fiber feedthrough with a 1m internal fiber transmit the light to the collimator focal plane.

The collimator design is mainly driven by two straylight requirements:

- First, the light flux out of the useful collimated beam, should be limited to avoid unwanted light flux into the vacuum chamber.
- Second, the aperture stop should not be seen directly by the detector and should not introduce diffracted straylight (by the forwards baffle) higher than the diffracted light to measure. A trade-off has been performed between the size and location of the output pupil and the ratio useful beam flux / injected flux in the focal plane.

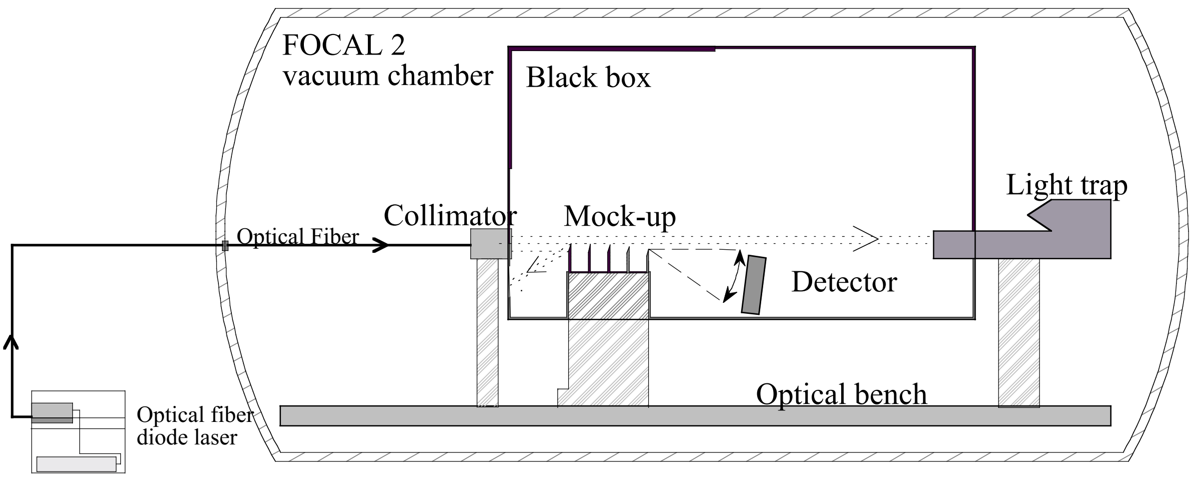

Fig. 6 Straylight test facility

The collimator design is presented in Fig. 7. It is based on a 100-mm focal length commercially available achromat doublet and a 2-stage baffle system. The 5.7 x 2.4 mm_ aperture stop is located before the optics in order to reject the output pupil far away from the mock-up.

The first stage of the baffle consists into a pyramidal "black" mirror, which reflects all useless light (outside the aperture stop) towards the collimator sides where it is diffuse. The shield prevents from a direct view between the collimator side and the focal plane area in front of the aperture stop. In all cases, the straylight need 5 specular or diffuse reflections before going through the aperture stop. The secondary baffle limits the useless beam that goes through the aperture stop.

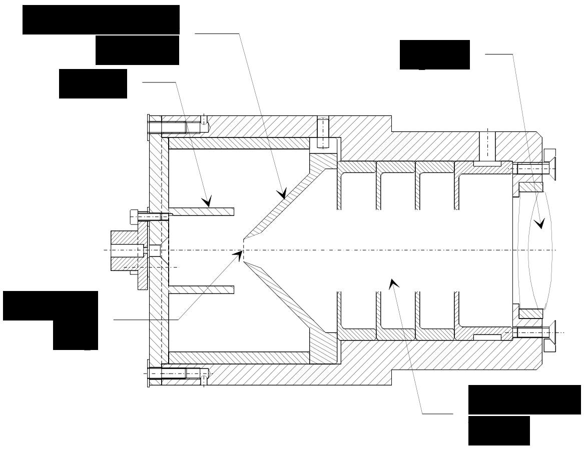

Fig. 7: Collimator design

The ratio of useful beam flux / injected flux is not more than 11 % but the straylight induced by the collimator out of the collimated beam is mainly diffuse and lower than 5 10^{-6} times the useful beam flux.

4.2 Light trap

In order to reach the required signal to noise ratio, straylight has to be absorbed in the facility with dedicated light traps. Three types of light trap are necessary: one to cover the detector field of view, one to absorb the collimated beam reflected onto the first vane of the forward baffle and the last one to absorb the collimated beam transmitted above the forward baffle.

The two first light traps are manufactured by simple panels covered with ultra-black velvet applique [7]. A specific light trap is designed to absorb the part of the collimated useful beam that goes through above the forward baffle system. This high power collimated beam has not to induced straylight onto the detector, which can limit drastically the test performances.

The light trap design, shown on Fig. 8, is optimized for a nearly collimated beam coming from a particular orientation. Its rejection is defined by the ratio:

$$R(\theta) = \frac{\text{Total incident light flux } \textit{along direction } \theta}{\text{Total light flux coming from the light trap entrance } (\textit{in all direction})}$$

The light trap rejection for an input collimated beam in the normal incidence shall be better than 10^9 or $R(\theta = 0) > 10^9$. The light trap rejection for light flux coming from any other direction ($\theta \neq 0$) shall be better than 10^5 or $\forall \theta \neq 0: \quad R(\theta) > 10^5$.

The light trap is designed in order to keep as deep as possible the characteristic of the input beam: to avoid diffuse light. The optical design is based on a 800-mm length tube with vanes at the end from which is located successively a set of 2 density filters and a classical conical light trap. The input collimated beam interacts sequentially with a first density filter, which absorbs a part of the light and reflects the residual towards the second filter. At the end, the collimated beam is absorbed by a conical light trap coated with a glossy black paint. The back-scattered light, coming from the conical light trap and from the filters (mainly due to the micro-roughness scattering) is still limited by the entrance tube and its vanes, all coated with quasi-lambertian black paint.

The major contribution to the total rejection comes from the back-scattered light due to the first filter micro-roughness. As the surface micro-roughness is limited to 0.3 nm RMS for manufacturing limitations, the useful micro-roughness is still decreased by shadowing effect due to the high incidence angle (> 60 arcdeg). In such case, the rejection for input collimated beam in the normal incidence is better than 0.5 10^9 mainly due to the micro-roughness scattering of filters.

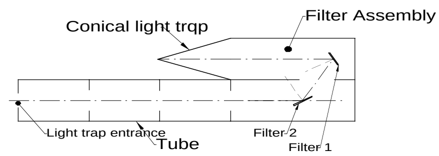

Fig. 8: Light trap design

4.3 Black box

For limiting the environmental straylight onto the vacuum chamber bright wall, all OGSE's are surrounded by Copper panel with quasi-lambertian black paint. The black box consist in a 1.1x1.7x0.8 m_ rectangular base box. All corners and apertures are closed with black kapton.

4.4 Detector

The detector consists on a Hamamatsu photomultiplier tube with a GaAs(Cu) photocathode having 12 % quantum efficiency at 808 nm. The photomultiplier is used in photon counting mode in order to detect very faint signal. To decrease the internal dark signal lower than 20 cps/s, the photomultiplier is cooled down to -20°C.

To limit the detected signal to interesting light only, a simple optical system reduces the field of view as shown in Fig. 9. The size of the detector is the driven parameter for its design: in order to measure small diffraction angle without inducing large straylight in the vacuum chamber, the top edge of the detector has not to be directly illuminated by the collimated beam from the source. The design of the optics and mechanics takes into account this requirement: the entrance pupil is close of the top edge of mechanics.

The detector is supported by a rotating frame around the last vane edge of the forward baffle in order to scan the various diffraction angles. All parts of the frame and the detector are either black anodized or black painted or covered with black kapton.

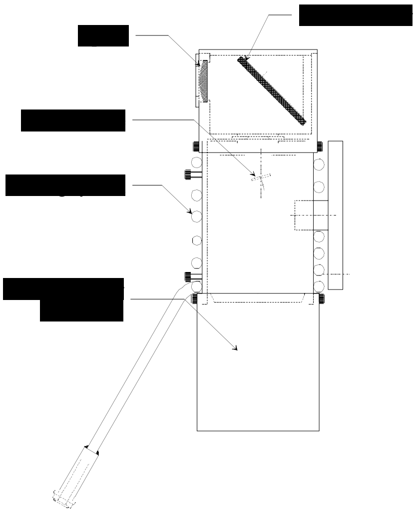

Fig. 9: Detector design

4.5 The mock-up

To support the detector rotating mechanism and the forward vanes, a mock-up structure will be used. This structure is either black anodized or black painted or covered with black kapton. Fig. 10 shows this mock-up mechanism with detector (in rotated position) and collimator elements.

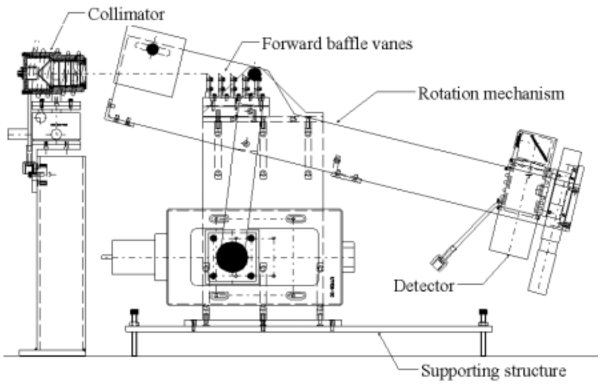

Fig. 10: Mock-up design

The structure is mounted on a tri-points screwing table to ensure horizontal positioning. A 100-mm step engine is used to reach a 15° rotation of the detector structure via 200 steps. Top of mock-up supports the five aluminium vanes whose separations and heights may be changed. The front face of the first vane is polished to ensure perfect reflection of non-diffracted and non-transmitted flux into light trap in front of it.

5. PRELIMINARY RESULTS

5.1 Non-vacuum test

At first, the optical fibers components of the set-up were tested, and their attenuation (in dB) was measured. Table 1 shows the measured characteristics of these components.

Optical component	Attenuation (dB / km)
5m external FO	4.3
1m internal FO	0.843
FO feedthrough	2.4

Table 1 Optical fiber components characteristic

Next, the one vane rejection was measured for the four tips of vane shown on Fig. 11 to determine the most efficient one [8], [9]. The A and B types are sharp edges with a 45° angle, while C and D tips are composed of a circular part of radius 1.41 and a straight part.

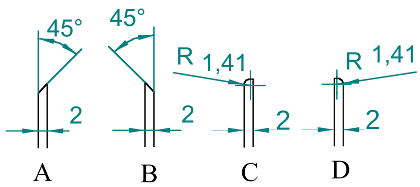

Fig. 11 Vane tips

These measurements were realized in a black room with both a 633-nm HeNe laser and the 808-nm diode laser in a simple diffraction set-up, as shown on Fig.12.

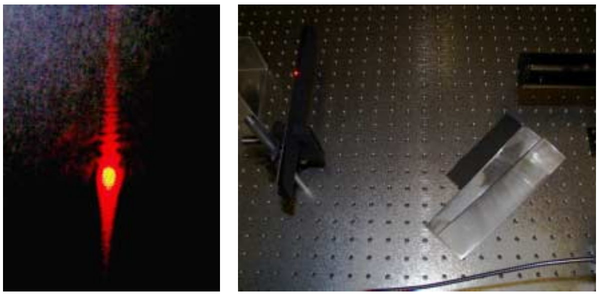

Fig.12 Non-vacuum test set-up and diffraction pattern

The rejection level for the four vane tips of Fig.11 (distance between vane and detector of 100-mm and vertical offset of 10-mm) are of the same order of magnitude (10^{-3}). Consequently, it is not possible to conclude that one vane tip is more efficient than the others. The type A will therefore be considered in next measurements and in future straylight tests.

Fig. 13 shows the results of one vane rejection level (y-axis) in function of the detector vertical offset (x-axis, in mm). The dot line shows the measurements, and the solid line the Fresnel theoretical rejection curve.

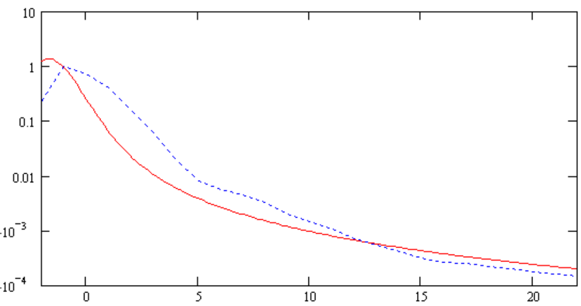

Fig. 13 Rejection of one vane in black room

5.2 Limits of results

The presented result shows the limit of black room testing facility and necessity to improve testing in a vacuum chamber.

Furthermore these results …

5.3 Test plan

In the prepared vacuum chamber, a first set of measurements will be realised to compare one vane rejection level with theoretical Fresnel calculations.

A second set of measurement will then be realised to measure rejection level of five vanes, inter-vane distance and vane heights being adaptable.

The complete set-up will later be re-used for the qualification model of HI to characterise the rejection level of the instrument forward baffle.

ACKNOWLEDGEMENTS

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