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INTERNAL CHECKUP ILLUMINATION SOURCES FOR METIS CORONAGRAPH ON SOLAR ORBITER

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I. INTRODUCTION

METIS is one of the remote sensing instrument on the Solar Orbiter mission [1]. It will acquire coronal images from distances from the Sun as close as 0.28 AU. The mission innovations rely not only in the spacecraft orbit [2]; METIS introduces many technical breakthroughs in the optical layout and in many other areas, mainly the inverted external occulter and the visible light (VL) polarimeter[3,4].

In order to check the proper functioning of each optical subsystem, an “internal checkup system” has been conceived and proposed. It is based on the acquisition of the visible light emitted from three LEDs positioned inside the telescope tube that illuminate the rear part of the entrance door of the instrument. The door itself acts as a diffuser that illuminates the optics and finally the detector. The monitoring of the intensity variations on the acquired images gives a simple and reliable operating feedback on the uniformity response of the whole optical chain as a function of time.

The optical geometry of the system is presented. In particular, a ray-tracing model for the estimation of the signal at the focal plane has been developed. The results of the simulations are presented.

The main requirements for the LED have been identified. A commercially available space-qualified LED model, suitable for the requests, has been identified. The power budget – the signal at the focal plane compared to the electrical power – is detailed. Furthermore, functionality tests on the identified LED have been started. The quantities that have been monitored are the optical power curve, the emitted spectrum, the emission angular distribution, the efficiency. All the parameters have been monitored at different temperatures, in the range, 20-80 ˚C. The results of this characterization are presented.

II. OPTICAL GEOMETRY

The architecture of the on flight checkup system for the visible light path of the METIS instrument is here described. Despite to be implemented on the visible light path of METIS, this system can provide feedbacks on the whole instrument.

The conceptual design is presented in Fig. 1. The photons emitted from the LEDs are back scattered by the rear surface of the external door [5]. These photons can, directly or after subsequent scattering processes, be redirected on to the visible light detector. Differently these photons can be absorbed by the surfaces of the different mechanical parts inside the telescope [6]. To estimate the signal at the visible light focal plane, it has been realized a functional STL Zemax model, Fig. 2, accounting for the main mechanical parts of interest in the optical ray-tracing of the calibration sources. The model accounts for: a) a simplified tube structure with entrance aperture; b) the support of the LED sources; c) the *Lyot stop* and its support; d) the *internal occulter* and its support.

Three LED sources have been simulated as point-like sources that are positioned at the end of the three support pylons inside the telescope tube. Each source emits 10^5 rays in a cone of ±2 deg.

The internal surface of the external door is modelled as a Lambertian scattering surface with zero absorbance, i.e. all the rays that are hitting the surface are scattered. Being the scattering process modelled as Lambertian (i.e., the process is independent from the direction of the incidence rays), the particular illumination footprint at the door not affect (in first approximation) on the illumination pattern at the detector plane. The telescope tube has been modelled having 98% absorption. The illumination at the VLP detector is shown in Fig 3 a), only a circular portion of the detector is illuminated. The radial profile of this illumination pattern is shown in Fig. 3 b). The maximum signal is localized in the radial interval 200 – 600 pixels, corresponding to an area of about 1.0×10^6 pixels. It has been performed a simulation starting from 5×10^6 rays. The attenuation between the illuminating power and that reaching the VL detector is roughly 3×10^{-4}. The photon transfer chain is modeled as shown in Fig. 4. The transfer efficiencies of each block involved in the process are shown in red.

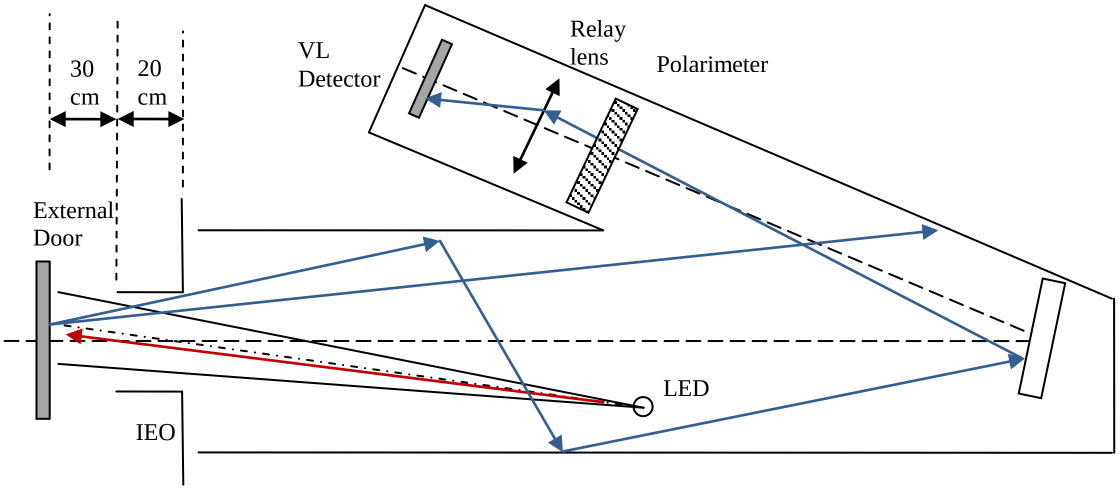

Fig. 1. Working principle of the "checkup system" for METIS. The photons emitted from the LED (red arrow) are back scattered from the rear part of the external door. After some scattering processes (blue rays), they can be redirected to the detector plane. IEO *Inverted External Occulter*, VL *Visible Light*. The mirror inside the telescope and all the internal *stops* are not indicated.

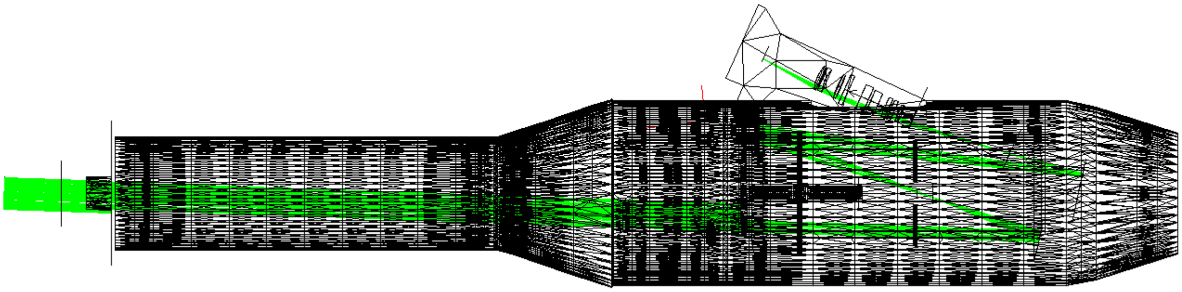

Fig. 2. Integration of the optical model with the telescope mechanical envelope. In green the ray from the Sun, and used as test for checking the proper "alignment" between the optical and the mechanical model.

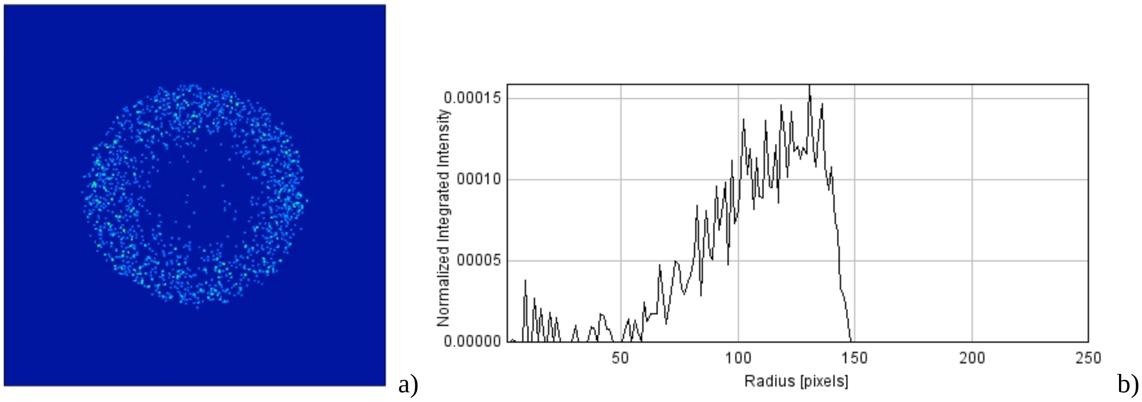

Fig. 3. Illumination on the VL detector: a) image; b) radial profile (pixels binned by a factor four), the signal is concentrated in the region 200 – 600 pixels.

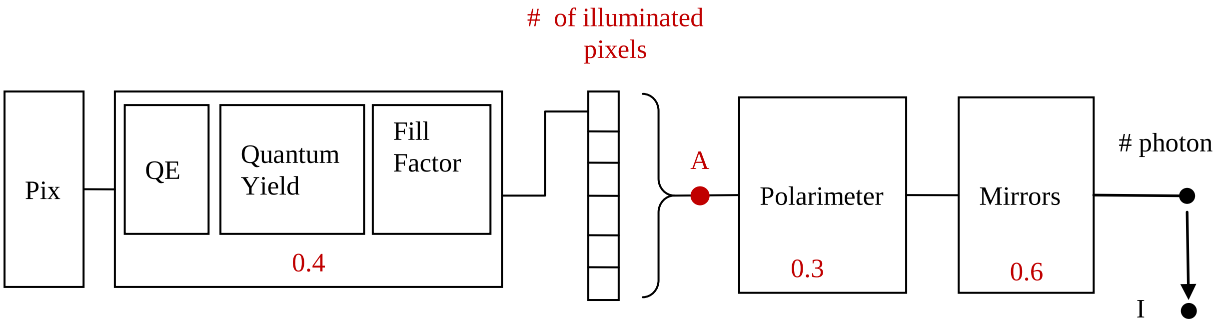

Fig. 4. Photon transfer chain (starting from right to left).

The flux calculation is shown in Tab. 1. Three LED sources have been supposed, each of them emitting 1 mW of optical power within the wavelength bandwidth of the VLP (2 eV mean photon energy).

Table 1. Flux calculation. Three LEDs, each of them emitting 1 mW of optical power on ±2°, mean photon energy 2 eV.

Sources (W)	Scattering factor of the internal surface of the door	Attenuation	Photon transport	Illuminated pixel	Power /pixel (W/pixel)	Interacting e-/px/s (2 eV photons)
3.0E-03	1.0	3.0E-04	0.072	1.0E+06	6.4E-14	2.0E+05

The interacting electrons are of the order of 2×10^5 e-/px/s. The actual counts have to be rescaled for the effective scattering factor of the internal surface of the door, here supposed to be unity. It is worth to be noted that even in the case of a scattering much lower than unity, the signal on the detector is definitely beyond the detection capabilities.

The main requirements for the LED are here itemized:

a) Spectral emission has to include the band 580 nm – 640 nm (coincident with the working spectral region of the VL path).
b) Within this spectral band**,** the optical emission has to be in the range 0.1-1.5 mW per LED inside 0.0038 steradiants, i.e., a cone with 4 deg angular aperture. For this purpose, a condensing optical element is planned to be placed in front of each LED.
c) The power consumption of the whole *"calibration subsystem"*, to operate the three LEDs sources, has to be less than 1 W.
d) The LED sources have to survive in the environmental conditions [7].

III. LED IDENTIFICATION ON MARKET

LED sources have been space-qualified for their use onboard the Bepi Colombo mission to Mercury. NICHIA NJSW036BLT LED passed the qualification, acceptance and radiation tests to be used onboard of Bepi Colombo. Details are given in [8]. The LED is emitting on a wide spectral region, from 400 to 760 nm, therefore most of the optical power is lost outside the spectral range accepted by the visible channel of METIS. The emission spectrum is presented in section IV; approximately only 15% of the emitted power is available within the spectral range 580-640 nm. The LED directionality, also discussed in section IV, assure that the 50% of the luminous power is emitted in a cone of +/-33 deg. This luminous intensity can be projected through the IEO aperture using an opportune lens in front of the LED.

Operating the LED with 2.8 V and 100 mA the dissipated power (280 mW) is compatible with the power consumption requirement c) in section II (assuming three LED the total absorbed power is less than 1 W). With a forward current of 100 mA, the relative intensity is about 0.3. In this regime the luminous flux emitted from a single LED is 20 lm, corresponding to about 14 cd per LED, that are emitted within 1 sr FWHM in the 400-750 spectral interval. Using an appropriate lens, we suppose to redirect through the IEO, within an angle of ±2 deg, the photons that originate from the LED source. In this case, the optical power reaching the internal surface of the door from the three LEDs is 4.6 mW, calculated as the FWHM optical power in an angle of ±2 deg and in the 580-640 nm spectral interval. This optical power even exceeds what has been calculated with the simulations reported in Tab. 1. It can be concluded that the white LED here considered may give the optical flux as required for the calibration sources.

IV. PRELIMINARILY TESTS ON THE IDENTIFIED LED MODEL

In order to confirm the working parameters of the LEDs sources, and verify their variations as a function of the environmental temperature, we have tested three NJSW036BLT samples of at 20 – 40 – 60 – 80 °C. The considered parameters have been the optical power as a function of the current and the corresponding spectra. The results are presented in Fig. 5 and Fig. 6 respectively. In both figures the effect of the temperature is evident, and should be considered for a proper implementation of this paradigm.

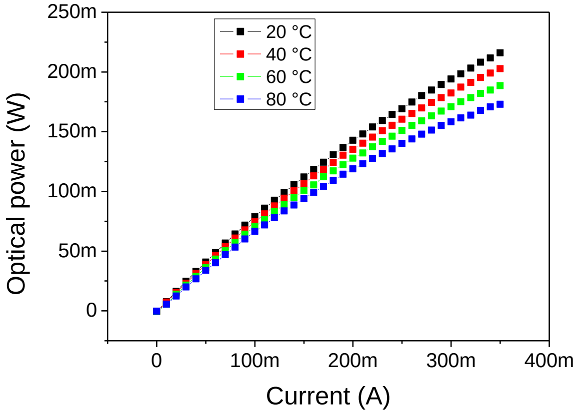

Fig. 5. Optical power as a function of the current. Four working temperatures have been considered: 20 – 40 – 60 – 80 °C.

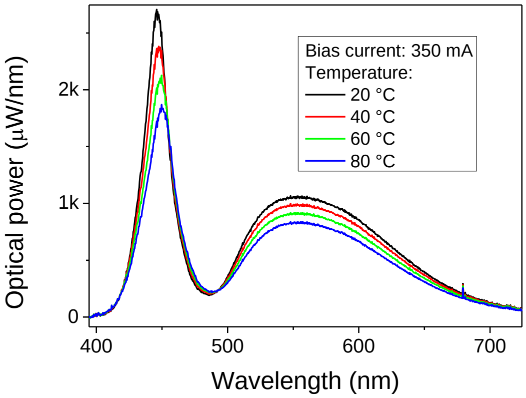

Fig. 6. Emission spectra of the considered LED model. Four working temperatures have been considered: 20 – 40 – 60 – 80 °C.

The possibility of "transmit" effectively the light emitted from the LED to the door surface, and the amount of projected power, depend on the angular emissivity of the source. This parameter has been investigated and some results are presented in Fig. 7 and Fig. 8. As expected the angular distribution is well compatible with the specifications. A future step will be the design of the "collimation" lens for the LEDs. We are at the moment proposing a lens, or a doublet if necessary, made in fused silica. The properties of homogeneity at the door are at the moment under investigation.

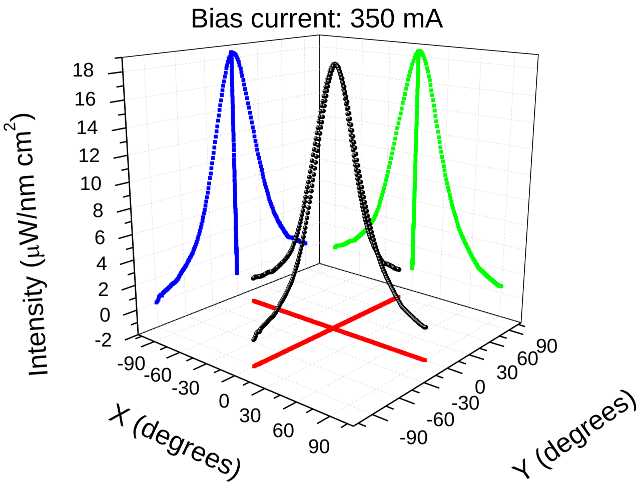

Fig. 7. Emission angular distribution on two orthogonal directions. The intensity is provided in absolute units.

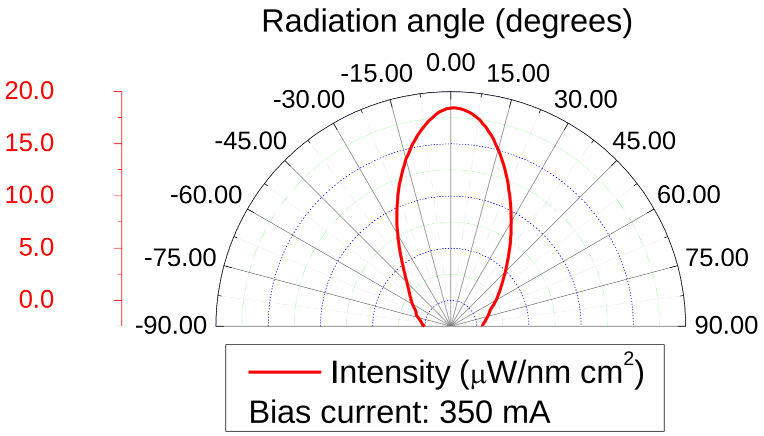

Fig. 8. Directionality of the LED emission: polar plot. The bias current is 350 mA. The intensity is provided in absolute units.

V CONCLUSIONS

In this work we have evaluate the use of LED sources, installed inside the tube of the METIS coronagraph, as an internal checkup system for the instrument after the launch. The simulations confirm that the requirements on the sources, in order to acquire a suitable signal, are compatible with the use of commercially available and space qualified LED emitters. The interference of this subsystem with the telescope is quite limited, in particular the *power budget* is less than 1 W.

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