Publication Year	2016
Acceptance in OA@INAF	2020-05-27T12:34:08Z
Title	Radiation, Thermal Gradient and Weight: a threefold dilemma for PLATO
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DOI	10.1117/12.2232579
Handle	http://hdl.handle.net/20.500.12386/25226
Series	PROCEEDINGS OF SPIE
Number	9904

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Event: SPIE Astronomical Telescopes + Instrumentation, 2016, Edinburgh, United Kingdom

Radiation, Thermal Gradient and Weight: a threefold dilemma for PLATO

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ABSTRACT

The project PLAnetary Transits and Oscillations of stars (PLATO) is one of the selected medium class (M class) missions in the framework of the ESA Cosmic Vision 2015-2025 program. The mean scientific goal of PLATO is the discovery and study of extrasolar planetary systems by means of planetary transits detection. The opto mechanical subsystem of the payload is made of 32 normal telescope optical units (N-TOUs) and 2 fast telescope optical units (F-TOUs). The optical configuration of each TOU is an all refractive design based on six properly optimized lenses. In the current baseline, in front of each TOU a Suprasil window is foreseen. The main purposes of the entrance window are to shield the following lenses from possible damaging high energy radiation and to mitigate the thermal gradient that the first optical element will experience during the launch from ground to space environment. In contrast, the presence of the window increases the overall mass by a non-negligible quantity. We describe here the radiation and thermal analysis and their impact on the quality and risks assessment, summarizing the trade-off process with pro and cons on having or dropping the entrance window in the optical train.

Keywords: Space telescope, wide field camera, radiation, thermal gradient, extra-solar planetary system, asteroseismology.

1. INTRODUCTION

The project PLAnetary Transits and Oscillations of stars (PLATO) is the medium size mission (M3) selected by the European Space Agency (ESA) in the framework of the Cosmic Vision 2015-2025 program. The main scientific goal [1] of PLATO is to discover and characterize a large number of extrasolar planetary systems, providing the first catalogue of potentially habitable planets with known mean densities and ages. The exoplanet mean densities will be retrieved by coupling the information of the planet radius provided by PLATO via photometric transit method with the information of the planet mass obtained through radial velocity measurements of dedicated ground-based telescopes follow-up. Stellar masses, radii and ages are derived by asteroseismic analyses of the photometric light curves.

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Space Telescopes and Instrumentation 2016: Optical, Infrared, and Millimeter Wave, edited by
Howard A. MacEwen, Giovanni G. Fazio, Makenzie Lystrup, Proc. of SPIE Vol. 9904,
990430 · © 2016 SPIE · CCC code: 0277-786X/16/$18 · doi: 10.1117/12.2232579

The scientific payload [2], accordingly to the baseline presented to the ESA System Requirement Review (SRR), consists of 34 cameras mounted on a common optical bench (see Figure 1). Two cameras, namely fast cameras, are dedicated to improve the pointing stability performance of the spacecraft on-board star-tracking system and will be specialized in two different photometric bands (blue 500-675 nm, red 675-1000 nm) for science purposes. The remaining 32 cameras, namely normal cameras, will observe in panchromatic mode between 500 and 1000 nm. A detailed mission overview is given in [3].

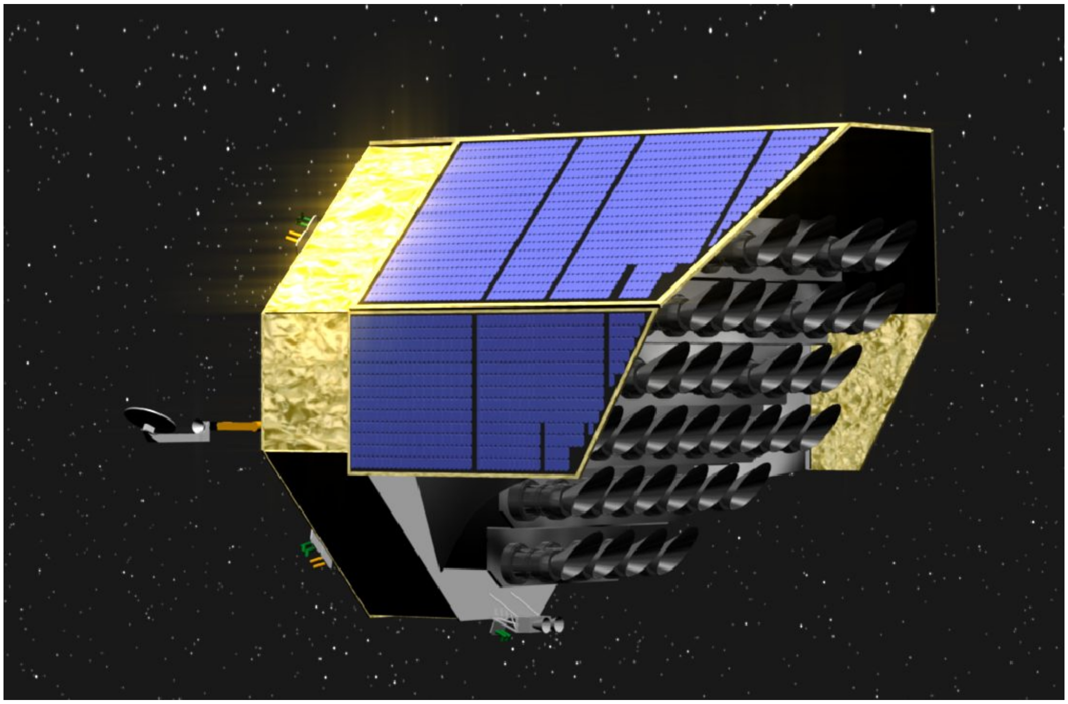

Figure 1. One of the possible arrangements of the 34 cameras onboard PLATO.

Each camera is basically composed of a telescope optical unit (TOU), i.e. the optical components and the mechanical structure, a focal plane module (FPM), a front-end electronic (FEE) and camera support structure (CSS). All the TOUs, 32 N-TOUs and 2 F-TOUs, have the same optical design but for the filter selecting the proper wavelength band. The TOU optical configuration consists of a window, placed at the entrance of the telescope, six lenses, and a physical aperture representing the stop of the optical system. The TOU focuses incoming collimated beams onto a focal plane, on which the FPA is positioned. Layouts of the optical configuration and of the mechanical structure are shown in Figure 2. A more detailed description of the current TOU optical configuration is given in [4].

The optical system has been optimized in order to deliver over the full field of view an optical quality defined as the 90% geometrical polychromatic enclosed energy contained in 2×2 pixels^2 with a depth of focus of ±20 µm. For the class of selected optical configuration, this result is obtained by introducing an even aspherical surface on the first lens (L1) and by taking advantage of a glass with low dispersion (large Abbe number). In the current baseline the selected material for L1 is the S-FPL51 produced by OHARA (Abbe number = 81.55).

Unfortunately, S-FPL51 is not a radiation hardened glass; its resistance to the potentially damaging particles is somehow moderate [5]. The radiation shielding has then been obtained by implementing a front window to the optical system. The window material is currently foreseen to be Suprasil (produced by HERAEUS) whose radiation resistance properties are excellent [6]. On the other side, the introduction of such window implies a mass increase of about 586 g, corresponding to an overall optics mass increment of about 11%.

In the following, we will discuss and justify the presence of the window, summarizing the trade-off process with pro and cons on having or dropping the entrance window in the optical train.

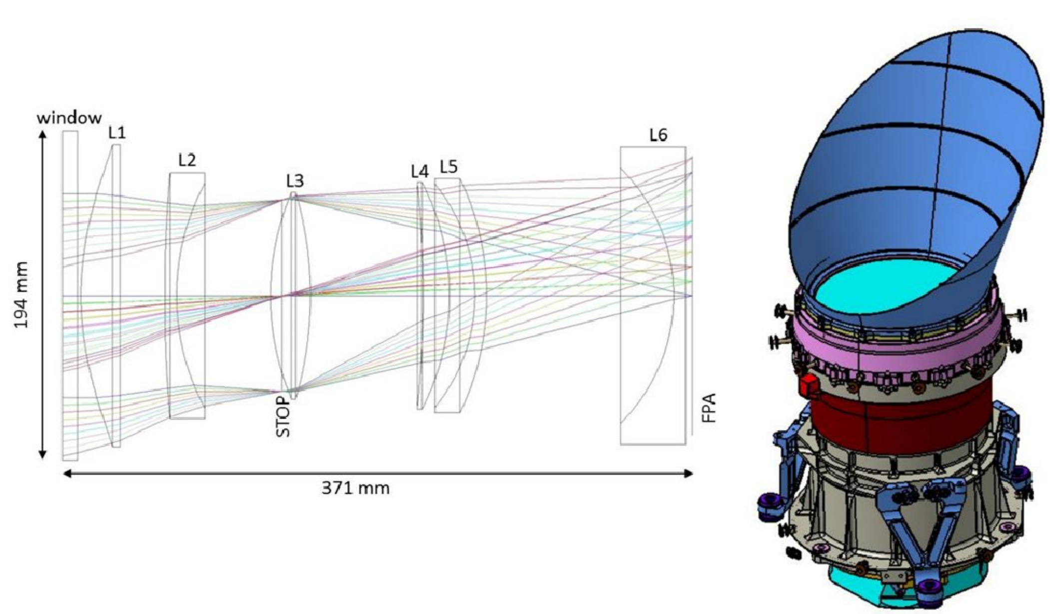

Figure 2. TOU optical layout (left) and TOU structure (right).

2. RADIATION

The PLATO spacecraft will be launched with Soyuz via a transfer orbit to travel to the Lagrange point L2 behind the Moon. This is a benign radiation environment only threated by solar flare events if these are directed towards Earth and Moon. The L2 radiation environment is bland climate hence compare with a GEO orbit. Nevertheless, optics, detectors and electronic components will be exposed to potentially damaging radiation, mainly solar protons, both during travelling to and at L2 point.

Table 1. Estimated surface doses for PLATO optical elements.

	Surface Dose (8 years) [KRad]
Window	**160.0**
L1	**8.5**
L2	**5.1**
L3	**2.6**
L4	**2.5**
L5	**0.5**
L6	**50.0**

The surface doses for each optical element of the current baseline have been estimated assuming an overall mission life time of 8 years. Results are reported in Table 1. The analysis has been performed using a sectoring analysis SW tool called FASTRAD. Being the spacecraft configuration not yet selected, the model assumes for the bus a structure similar to those already flying for Plank and Herschel mission with the same shielding capability. The telescopes are then disposed on a common optical bench surrounded by the spacecraft sunshield protecting the instruments from one side. A scheme of the model is shown in Figure 3.

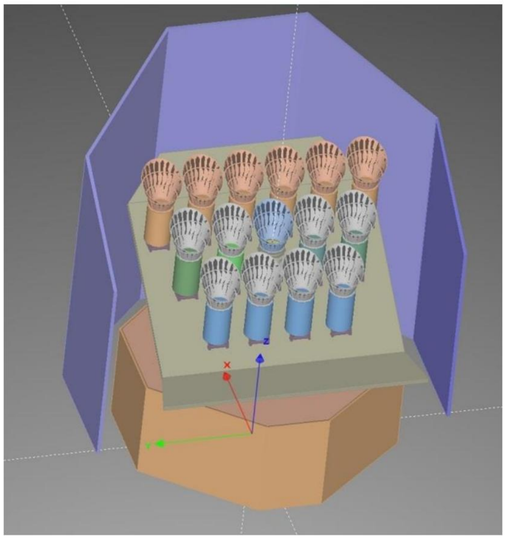

Figure 3. Envelopes of PLATO Platform and Telescopes implemented in the radiation analysis model.

Surface doses have been set as input parameters for the computation of the lenses transmissivity loss. In Figure 4, it is shown the estimated transmissivity of L1 at the beginning of life, at the end of life with Suprasil entrance window (current baseline) and at the end of life without the entrance window. For the current baseline scenario, the L1 transmissivity loss is expected to be less than 1% over the whole spectral range, thanks to the radiation shielding provided by the Suprasil entrance window, whose transmissivity is practically unaffected by the radiation. Removing the entrance window would translate into a severe L1 transmissivity loss (about 20% in the worst case), that has been considered unacceptable due to the corresponding science return loss.

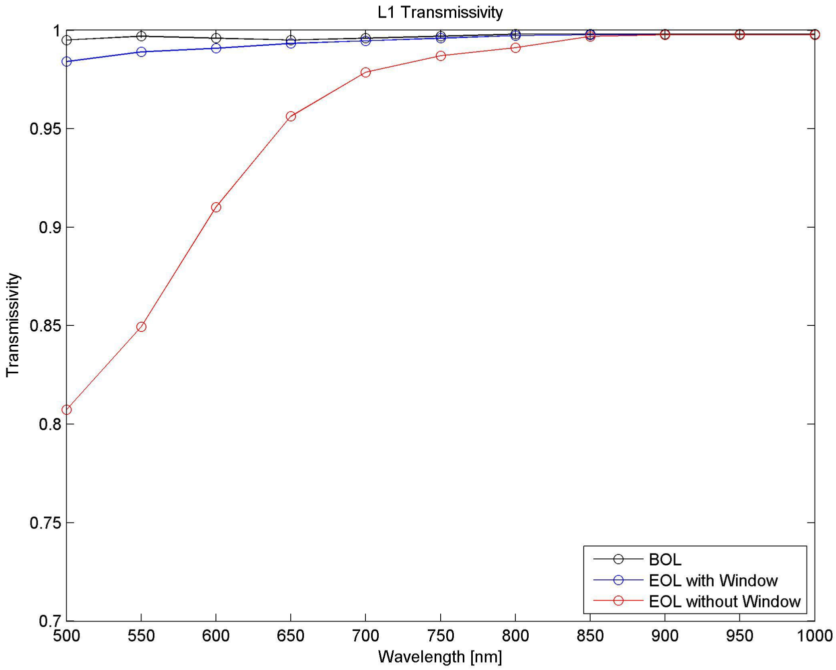

Figure 4. Estimated transmissivity of L1 at the beginning of life (black curve), at the end of life with entrance window (blue curve) and at the end of life without the entrance window (red curve).

A straightforward solution to avoid the transmissivity loss and, at the same time, to avoid the mass increase due to the introduction of the entrance window is the substitution of the L1 glass with a radiation hardened one. For the selected class of optical solutions, the required optical quality can be nominally achieved by having an L1 glass with low dispersion. Among the glasses presenting both these qualities, we have individuated just the Calcium Fluoride (already selected for the L3 glass). Calcium Fluoride has an Abbe number equal to 95.23 and it is naturally radiation hardened [7]. Moreover, it has been verified that the aspherical surface is manufacturable onto Calcium Fluoride substrate via magnetorheological finishing technique.

3. THERMAL GRADIENT

The PLATO spacecraft will be launched with Soyuz via a transfer orbit to travel to the Lagrange point L2. During the first part of the foreseen trajectory the cameras will experience a thermal gradient that could be potentially destructive for the optics. In particular, for the current foreseen orbit there will be a direct exposure of the first optical element to the Sun illumination lasting for about 1000 s with an angle of incidence of about 50 degrees with respect to the cameras optical axis.

The thermal gradient of the L1, with and without the entrance window, has been estimated using a PLATO model implemented in SYSTEMA/THERMICA software. Results are shown in Figure 5. After 1000 s Sun exposure, the maximum spatial thermal gradient on L1 has been estimated to be about 7°C with entrance window and about 12°C without entrance window. A similar analysis has been carried out for the entrance window and the result is shown in Figure 6. After 1000 s Sun exposure, the maximum spatial thermal gradient on the entrance window has been estimated to be about 23°C. The presence of the window will attenuate the maximum thermal gradient on L1 by about a factor 2.

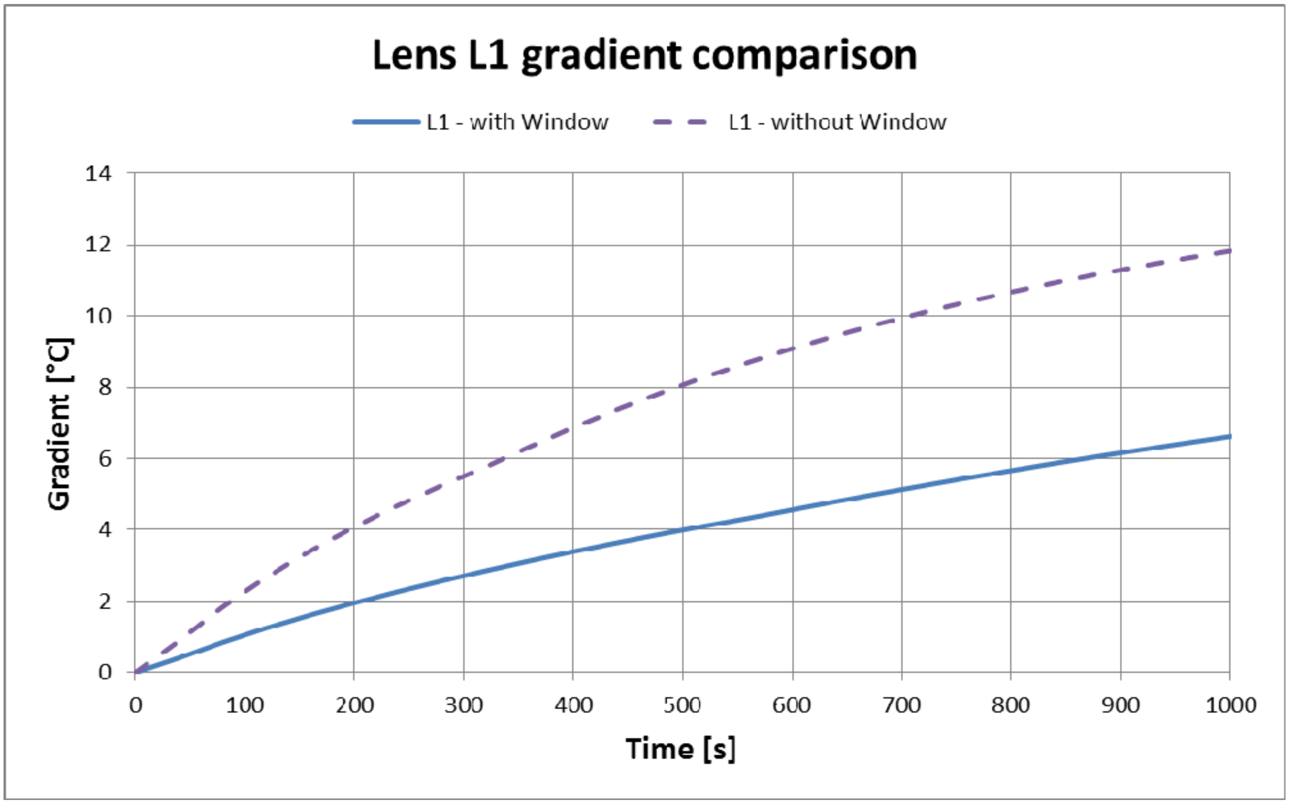

Figure 5. Estimated thermal gradient experienced by L1 with and without entrance window for direct sun illumination lasting for 1000s.

A thermal gradient will translate into thermoelastic stresses on the optics an on the mounting interface. The material properties driving the thermos-elastic stresses are CTE and Young's modulus. In the baseline configuration, the entrance window is made of Suprasil (synthetic fused silica) which has a very low CTE (0.5 ppm/K), moderate stiffness (71.7

GPa) and good strength properties, making it the most suitable choice for this application. Fused silica is, in fact, very well known as being thermo-shock resistant. L1 is made of S-FPL51: the higher CTE (13.6 ppm/K) and stiffness (72.7 GPa) make the glass more sensitive to thermal gradients, but the presence of the window, which limits the thermal gradients, and the good mechanical properties of the material are sufficient to guarantee a safe design.

Assuming to remove the entrance window, L1 material should change from S-FPL51 to Calcium Fluoride in order to match the optical quality requirement. Calcium Fluoride has rather large CTE (18.4 ppm/K), high Young's modulus (89.9 GPa / 146.1 GPa, depending on the crystal direction), and thermal conductivity of only 9.71 W/m/K, which contributes increasing the thermal gradients. Furthermore it is a fragile material. The use of calcium fluoride for L1 would significantly increase the risks of catastrophic H/W failures and is therefore considered a not viable design.

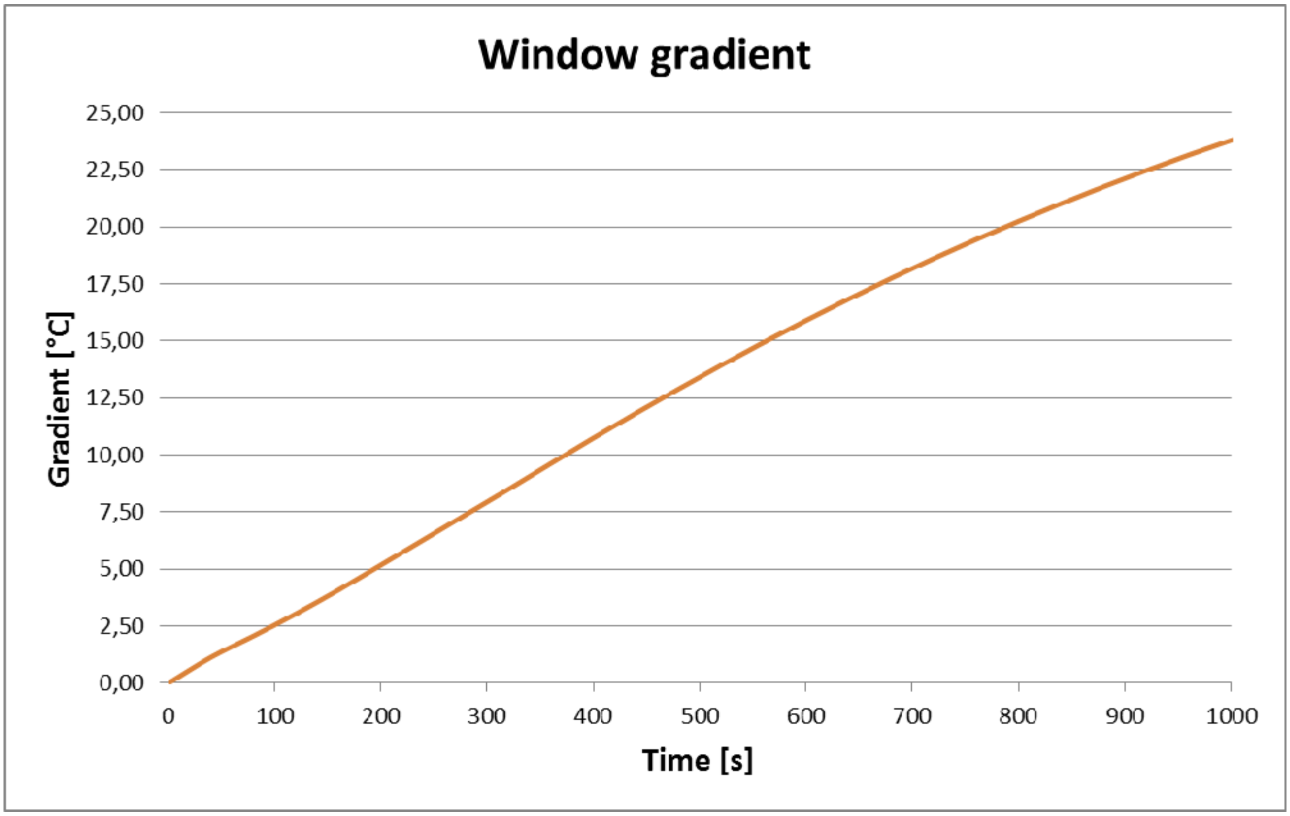

Figure 6. Estimated thermal gradient experienced by the entrance window for direct sun illumination lasting for 1000s.

4. WEIGHT

The current optical configuration implements an entrance window made in Suprasil (density 2.2 g/cm^3). The physical aperture diameter is about 194 mm. Actually, the window thickness has been set to 9 mm, implying a window mass of about 586 g, i.e. 11.2% of the overall mass (the overall optics mass, including the window, has been estimated to be about 5218g). The entrance window mass can be in principle reduced by decreasing the aperture diameter, but this will entail an increase of the mechanical vignetting introduced into the optical system, lowering the stellar fluxes mainly at the FoV edge. A trade-off on the acceptable mechanical vignetting is currently ongoing. On the other hand, the entrance window mass can be reduced by decreasing the thickness. The nominal thickness value has been set tacking into account of the manufacturing constraint to guarantee the required optical quality and the entrance window survivability during the launch phase. Further studies to optimize the window thickness are ongoing.

Removing the entrance window and substituting the L1 material S-FPL51 (density 3.6 g/cm^3) with Calcium Fluoride (density 3.2 g/cm^3) implies a mass saving of about 729 g (about 14% of the overall optics mass). Given that in the current baseline the number of cameras is 34, the overall mass saving will be about 24.8 Kg.

5. CONCLUSIONS

We have briefly described the analyses and the considerations justifying the presence of the entrance window in the PLATO baseline optical configuration. Basically, the main purposes of the entrance window are to shield the following lens L1 from possible damaging high energy radiation and to mitigate the thermal gradient that the first optical element will experience during the launch from ground to space environment. In contrast, the presence of the window increases the overall mass by a non-negligible quantity. Removing the entrance window would improve the mass budget, but at the same time, it increases the risks of catastrophic H/W failures.

6. ACKNOWLEDGMENTS

This study was supported by the Italian Space Agency (ASI) – Contract number 2015-019-R0.

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