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PLATO: a multiple telescope spacecraft for exo-planets hunting

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ABSTRACT

PLATO stands for PLAnetary Transits and Oscillation of stars and is a Medium sized mission selected as M3 by the European Space Agency as part of the Cosmic Vision program. The strategy behind is to scrutinize a large fraction of the sky collecting lightcurves of a large number of stars and detecting transits of exo-planets whose apparent orbit allow for the transit to be visible from the Earth. Furthermore, as the transit is basically able to provide the ratio of the size of the transiting planet to the host star, the latter is being characterized by asteroseismology, allowing to provide accurate masses, radii and hence density of a large sample of extra solar bodies. In order to be able to then follow up from the ground via spectroscopy radial velocity measurements these candidates the search must be confined to rather bright stars. To comply with the statistical rate of the occurrence of such transits around these kind of stars one needs a telescope with a moderate aperture of the order of one meter but with a Field of View that is of the order of 50 degrees in diameter. This is achieved by splitting the optical aperture into a few dozens identical telescopes with partially overlapping Field of View to build up a mixed ensemble of differently covered area of the sky to comply with various classes of magnitude stars. The single telescopes are refractive optical systems with an internally located pupil defined by a CaF2 lens, and comprising an aspheric front lens and a strong field flattener optical element close to the detectors mosaic. In order to continuously monitor for a few years with the aim to detect planetary transits similar to an hypothetical twin of the Earth, with the same revolution period, the spacecraft is going to be operated while orbiting around the L2 Lagrangian point of the Earth-Sun system so that the Earth disk is no longer a constraints potentially interfering with such a wide field continuous uninterrupted survey.

Keywords: Space telescope, extra-solar planetary system.

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1. INTRODUCTION

Exo-planetary science entered the realm of actual discovered planets among normal stars by about a couple of decades [1] in a way –on the other hand this is the way science progress- that was not predicted or planned by the vast majority of the community. The first exo-planet around a normal star, in fact, has been discovered using at the time state of the art radial velocity techniques with a relatively modest aperture telescope size and detecting a planet (later becoming the first example of a class named hot-Jupiters) that has no commonalities with the only other known planetary system at the time. While one can trace back to some visionary prediction [2] in such a sense, this should be an indication that prediction, in any young branch of science, and especially in this one, could be dangerous and, on the positive side, would likely lead to a number of interesting surprises. Discussing techniques to discover novel extra solar planetary system in such a pre-discovery period authoritative panelists, most likely resonating the common feeling of the community predicted [3] that among the various techniques for planet hunting the one using transits on the solar disk would be "*unsuitable to statistical studies due to the exceedingly low detection rate*" that is the exact contrary of the today situation where, after the precursory work of COROT [3], the KEPLER [4] mission secured the most valuable statistical analysis of the exo-planets population.

However, selection effects by the various techniques often do not overlap, especially when choosing the most detectable planets on the various technological sides. While, for instance, astrometric detection of an exoplanetary system, as correctly depicted in [3] would be able to collect such alien worlds for basically any mutual orientation of the exoplanets orbit with respect to the observer's view point, the current technological development is still lacking to find a suitable large number of such exoworlds. In spite of the request of numerous and tedious observations from the ground in case of the radial velocity, and of a continuous almost uninterrupted search in case of transit (a feature that favour the space based observations, even without considering the deleterious effects of the atmospheric scintillation), these two techniques led to the larger number of detected exoplanets. Still, while the current figures (a few thousands, the exact number facing the same lifetime of one terrestrial day) sounds large in absolute number, this is still below the number o fstars by the naked eye, making its comparison with respect to our knowledge of stars (objects, on the other hands, to some extent much simpler and prone to variabilities than exoplanets) basically appearing as an extremely tiny fraction.

In particular, current statistical analysis lack of a detailed information on the density of the planets, a basic parameters to start to characterize them on a physical basys and to at least try to forumlate some initial considerations on the likelyness and kind of atmospheres. In this context further transit missions aimed to bright stars are considered extremely valuable. TESS [6] is likely to become a precursor in such an area, while the concept of PLATO [7] is aiming –with all the caution to be exerted because of the danger associated with any kind of prediction in the field- to assess an extremely detailed picture of a vast fraction of the bright stars ospiting planets to periods as large as one terrestrial year.

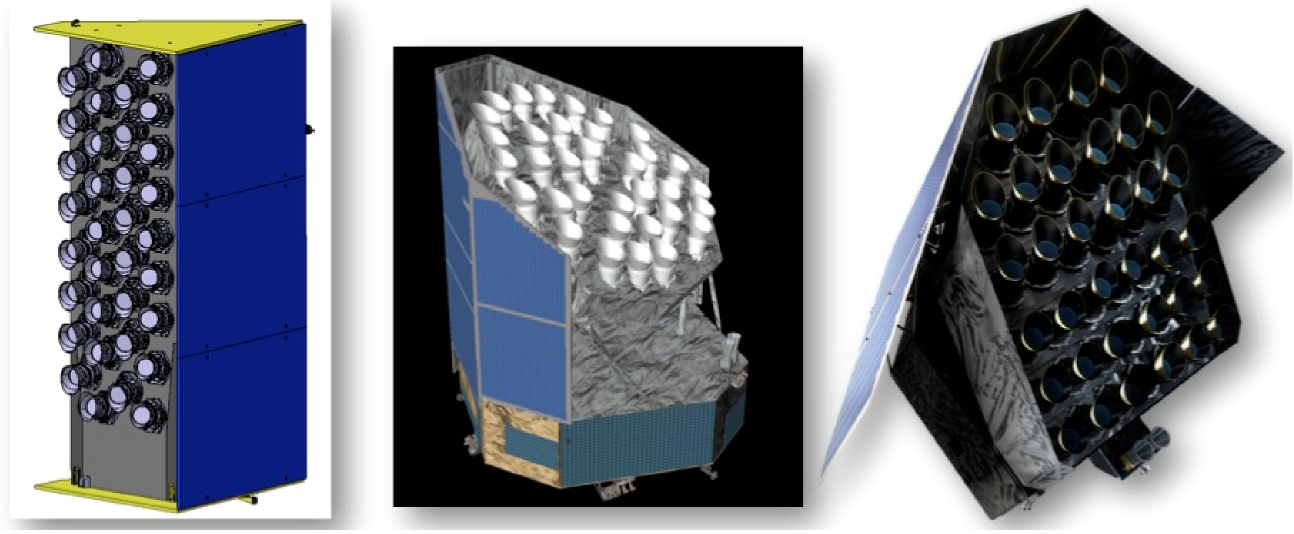

Figure 1. Three different configurations studied for the PLATO spacecraft concept. From left to right the ones provided by Astrium, Thales-Alenia and OHB industries. Although the disposition of the TOUs and the aspect ratios of the overall configurations are different they all retain the main concept of a sunshield that is ecnompassed by solar panels and by placing all the edges of the latter and of the TOUs baffle in a single common plane.

PLATO, in fact, is conceived to hunt for exoplanetary systems through transit with very high precison and with ininterrupted observations for a few years because such systems could be easily measurable with radial velocity tecniques from the ground, so securing all the relevant physical paprmeters, would lead, through asteroseismology, to assess the host star characteristics with high accuracy and would allow for a possible detection by direct imaging at the largest elongations of the exoplanets with longest period. Ultimately –although this is reported here as a visionary remark- could lead to the identification of possible targets of futuristic interstellar missions [8].

2. MISSION OVERVIEW

Given the requirement sketched above, PLATO would requires, basically, a one meter sized class telescope to have uninterrupted acccess to a large portion of the sky, large enough to contain a number of relatively bright stars to allow, once statistical down-selection because of the probability of finding an exoplanetary system whose orbital plane is sufficiently close to the one that allows for a transit detection, their actual discovery.

Furthermore, the precision required in the photometric accuracy (of the order of a few tens of ppm) would requires a relatively large number of pixel, given the full well of nowadays CCDs. This is an issue usually attached by spreading the PSF onto several pixels. In PLATO, however, instead of using a single large telescope with a relatively large plate scale the choice have been to split the aperture in a number of identical small telescopes. In this way the same target is imaged through several telescopes and corresponding CCDs. A PSF that is basically spreading the light onto 2x2 pixel in a configuration with N telescopes, is equivalent to spread the light onto 4N pixels with a related augmented capacity of the detector. The use of several small telescopes is also a choice of minimizing the risk spreading the reliability onto several telescopes. These are named, within the PLATO framework, as Telescope Optical Units, or TOU [9].

Initially conceived as off-axis catadioptric optical systems these evolved into purely refractive units in which, after a long and detailed assessment, the design evolved in a modified Gauss-like design in which the pupil encompass a lens with low Abbe number, specifically CaF2, a front lens that encompass high order off-axis correction through an aspheric surface, and a low curvature negative lens is located close to the focal plane in order to flatten the focal surface. Given the very large FoV employed by the TOU the choice of the pupil in the mid-point of the optical train is the one that allow for the smaller mass of the optics for the whole system.

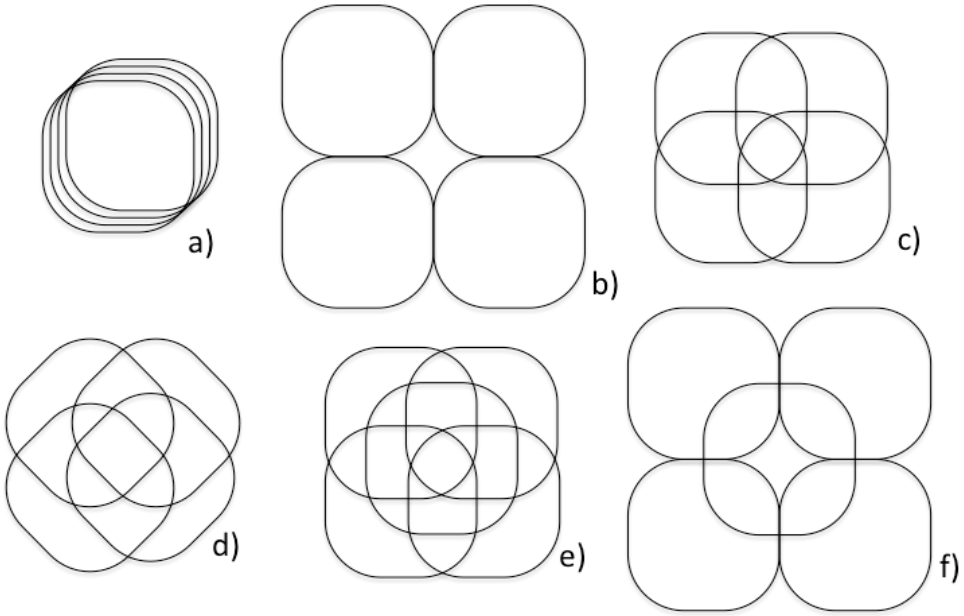

Figure 2. Various possible arrangement for the various individual FoV of the TOUs inside PLATO. The individual patch in the sky imaged from a single TOU is a square array rouneded up by the vignetting edge of the centered optics. In a) simply the all TOUS are pled un onto the others (in the drawing they are slightly displaced for pictorial purposes), in b) they have no overlap and smack each other maxiimising the covered FoV while in c) they holds a partial overlap allowing for fainter targets in the common areas. In d) the alignment between the CCDs and the rounding is rotated by 45deg while in e) and f) hibrid versions of the second and third one are shown with an added central FoV leaving 90deg fold simmetry.

In order to have an unobstructed view of a FoV as large as 40x40 degrees for a timescale in excess of one year, any low or intermediate altitude orbits are not compliant. In fact PLATO is intended to reach the lagrangian point L2 from where the only disturbance is represented by the Sun. The long pointing targets, essential to discover real twins -also in terms of revolution periods- of the Earth, so must lies away from the ecliptic plane, and moderately close to the galactic plane. A position too close, in fact, will leads to a strong confusion issues, while a much more distant one run the risk to cover a relatively small number of bright targets.

Because of the follow-up two of such long pointing runs are foreseen, one for a location in the North hemisphere, and one in the Southern one. Further to this, in an order that is still to be arranged in detail, a certain number of step and stare surveys of the order of a few months are foreseen. Depending upon the details of the complete program an area of the sky as large as half the whole celestial sphere, could be investigated, although for the vat majority, only for a limited time interval.

The cadence of observations is retained of the order of one exposure every about 20seconds, while a couple of dedicated TOUs, identical in optomechanical terms to the others but with two frame transfer CCDs are scanning the sky with a much faster cadence of 2seconds, allowing for the detection of transients and transits for a limited number of extremely bright stars.

While PLATO orbits around the Sun in L2, the spacecraft will most of the time be three-axis stabilized toward one of the two long pointing regions. In order to avoid to have rotating devices for the solar panels assuring power to the spacecraft, and to keep at a reasonable level the surface of the latter, these are confined to one side of the spacecraft, that is rotated by 90 degrees every three months. This required that, in order to maintain uniformity in the coverage of the survey, the focal plane format would be essentially symmetric for 90degrees rotation around a certain line of sight. Of course this is accomplished by a centered optical system whose focal plane is arranged in a symmetrical squared manner. However, it has been recognized that, in order to augment the probability to find transit in rather bright stars it is effective to split some or all of the telescopes into four groups, and to displace their optical axis in a four-fold symmetry around the line of sight of the spacecraft.

This led to the initial nominal baseline of four groups of 9 TOUS and two additional fast TOUs leading to a total of 34 small telescopes. These figures are now being optimized at the moment of writing to be fully compliant with the mass requirements that, in the meantime, become more and more mature.

In fact any number of telescope is selectable, although some are divided in groups of four and the remaining are centered over the line of sight, regardless they are the fast ones or the normal one contributing in the latter case, to the augmentation of the equivalent aperture only in the central region of the observed sky.

3. THE TELESCOPE OPTICAL UNIT

Details of the TOUs are presented elsewhere through this conference [10..15] but, further to the overall philosophy some additional comments are required in this context.

With the solely exception of the high gain antenna link, there are no mechanism with moving parts in PLATO and the TOU has not exceptions. In fact the focusing of the optical train is maintained through thermal control. Some heaters along the AlBeMet tube would allow for such a task using as a feedback both housekeeping thermal sensor and the images on the focal planes directly. While usually the algorithm to extract star's fluxes is uploaded and just the mere flux and centroid information is carried back, during repointing and for housekeeping purposes several imagettes can be downloaded in order to assess the image performance and to take actions. The baffle, in this respect, acts further than to suppress straylight, also as thermal radiator.

The ensemble of the TOUs, pointing into five different directions, holds baffles that are slightly different, although their optomechanical part is completely identical and interchangeable, such that the end portion of the baffles defines a common plane, with a given tolerances, where the edges of the so-called sun-shield (holding, in some configurations, the terminal side of the solar panels) is also located.

As in any fully refractive optical design, the use of special glasses, especially to control chromatic aberration is very attractive. In our case the only unconventional element (namely in CaF2) has been place well deeply inside the optical train hence being a the highest degree of protection from thermal shocks, while attempt to use naturally radiation hardened glasses (like fused silica) for the two extremes of the optical tube led to slightly less performing optical quality. After having examined all the various configurations we decided nevertheless to introduce a frontal window with the double scope to protect from radiation darkening the front lens and to control better the thermal control of the same lens, where the only aspheric surface is contained.

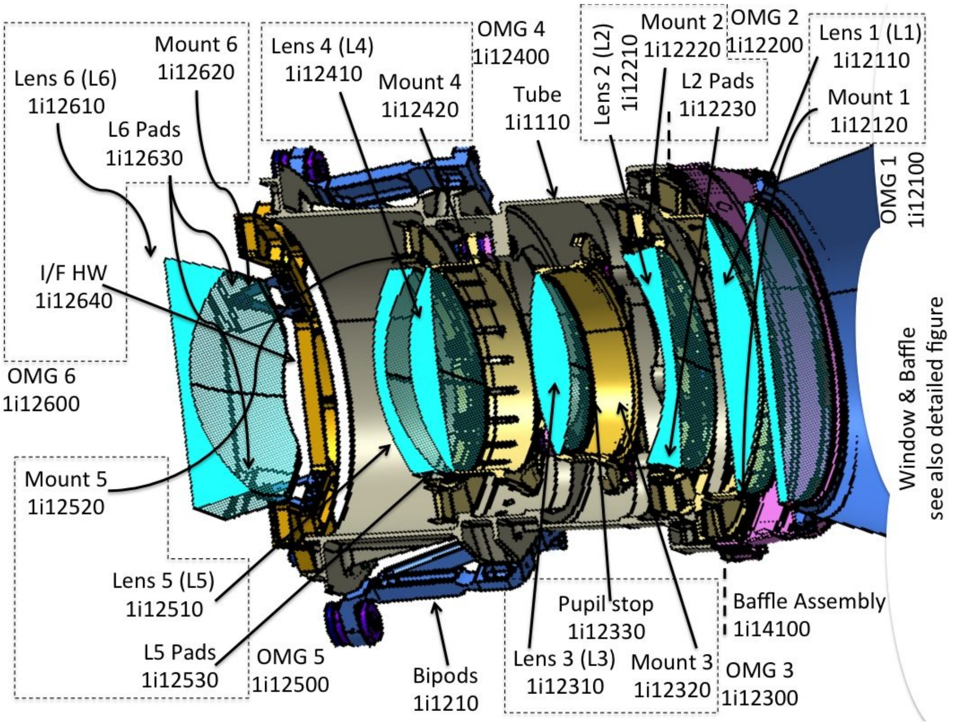

Figure 3. A cros section of the PLATOs TOU with description and coded number for several optical elements and their support. Light is getting from the right to the left and the entrance baffle is only partially shown. After a plane-parallel flat window to isolte thermically and shield from radiation the first lens, L1, proviuded with aspheric power, the entrance beam is defined by a physical pupil stop close to a CaF2 lens (L3) and the beam is then converging toward the rear part of the optical train where the last element, L6, acts as a powerful field flattener onto an array of four 2500x2500 CCDs.

As this mission employ a relatively large number of identical TOUs, a lot of care has been spent to assess the system is able to attain nominal performances with an alignment activity that can be performed at ambient temperature, and just double checked at the operation conditions. A breadboard has been manufactured and aligned using several approaches and then checked in thermovacuum and we are currently building a prototype to further refine this approach. The breadboard is characteristic of the full behavior of the TOU for a full aperture beam on-axis while the prototype would encompass the final full field of view performances. While alignment is performed by taking advantage of the spurious reflections of the various glass-vacuum interfaces the overall optical quality is performed on the full aperture beam.

Despace errors, in this respect, are measured, every time a new optical components is introduced in the optical train, by analyzing the optical behavior of the incomplete system and checking it through on-axis interferometry or measurement of the basic optical properties. A down-selection using a tree of combinations has been carried out in order to establish the order for which the various optical elements are to be assembled, so that, for instance, the partial system always exhibits a positive optical power with a reasonable focal length such that laboratory measurements can be carried out without the introduction of any null lens and hence minimizing the possibility to introduce errors propagated by possible mis-manufacturing of auxiliary alignment optical elements.

Mass optimization is ongoing in order to ensure the exact number of TOUs. In this respect a deep analysis has been performed in order to establish the mass saving for a number of reduction of performance of the single unit. These would encompass a reduction in the Field of View, in the clear on-axis aperture and in the amount of vignetting at the edges, each performed in a perturbative fashion with respect to the nominal design. Once a direction is going to be selected an assessment study is to be performed in order to define precisely the advanced optomechanical concept.

Finally it is interesting to compare the whole ensemble of PLATO TOUs with other optical systems. In fact the best analogy can be made with the human eye. The full Field of View is in fact comparable to the central vision and it is interesting that the area of the detector is comparable to the one of the front lens, and in fact larger than the area of the pupil stop. Depending upon the configuration and the number of TOUs, the whole PLATO optomehcnaical assembly reminds of an eye with a corneal lens and a retina of one meter squared size.

4. CONCLUSIONS

PLATO is an ensemble of small telescopes, named TOUs that will hunt for exoplanets by looking simultaneously and uninterruptly toward a direction of the sky with single Field of View partially overlapping. This concept has been granted selection by ESA as a Medium sized mission and is going to be soon adopted for a launch currently foreseen in 2025. At that time, after three decades of discovering the kind of planets that are the most diverse from the ones known in our Solar System (hot Jupiters, sub-Mercury revolution period planets, super-Earths) it promises to produce a catalog of accurate radii, masses and densities plunging us into the post-Galileian phase of the discovery of this realm of alien worlds, dragging the field into what happen to the knowledge in the stellar field in the past centuries. The variety of conditions to which the same physical kind of planets can be exposed, will surely makes the zoo much more diversified and prone of surprises. It is maybe the only credible prediction the one that PLATO will offer much more surprises than expectations.

5. ACKNOWLEDGMENTS

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