A one meter class eye for the PLAnetary Transit and Oscillation spacecraft

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Abstract

PLATO stands for PLAnetary Transits and Oscillations and it is the forthcoming third Medium sized mission of ESA, planned to be launched in 2024. Its optical payload is an ensembe of 34 small telescopes that mimic a single one meter class aperture with a huge Field of View of more than 50 degrees in size. Aiming to find exoplanets around bright neabry stars it is designed to discover a significant number of relatively nearby Earth-like worlds. A description of the optomechanical adopted solution and a speculative scenario to further explore such alien worlds is briefly given.

Keywords: universe, exoplanet, interstellar flight

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1. Introduction

The quest for exploring new worlds is within the mankind aspiration from ever. After the exploration of our own Solar System a new challenge is going to face the human being in the next future: exploring exo-worlds, planets revolving around stars other than the Sun, commonly noted in the astronomical realm as exo-planets. Since a couple of decades the existence of these alien worlds escaped from the field of theory and speculation and entered the realm of direct and (in the vast majority of cases) indirect observations[1]. While accurate and temporally properly sampled measurements of the radial velocity through high precision spectroscopy figured out to be one of the best technique to estimate the mass of these bodies, transits -occourring when by chance the observer is close enough to the orbital plane of the exoplanet- proved to be one of the most prolific technique. The latter offers a good estimate of the size of the planet but almost no clue on its mass. Because of the statistical nature of such kind of observations a massive number of stars are to be continuously sampled in order to gain a significant number of exoplanets transits. This can be achieved by a deeper view onto a large number of relatively faint stars, or by employing a huge Field of View (FoV hereafter), allowing to spot transiting planets on a significant number of much brighter (and nearby) stars. A relatively bright star discovered using the transit method can be further spectroscopically investigated and -with the caveat that the orbital plane is known to be almost coincident with the observer- a mass and hence a mean density can be estimated. To date several space missions and several dedicated efforts from the ground have pursued such a target. Namely Corot[2] and especially Kepler[3, 4] find out about two thousands exoplanets, and there are indications that further analysis of the lightcurves and further observations from the ground will allow to assess even more. While this is a massive number with respect to our knowledge of a couple of decades ago, this is still lower than the number of stars visible with the naked eye in both hemispheres in clear nights.

It is interesting to note that today only a handful of exoplanets are known from both transit and radial velocity method, and none of these is known to have an Earth-like mass. Furthermore, the search encompassed a tiny fraction of the visible sky and mostly on relativel faint and far away stars.

We still lack to know with precision the nature of the exoplanets around the closest stars, to find genuine twins of our own planet, and to be able to count with precision more exoplanets than naked eye stars.

In few words, in spite of the excitment and of the massive flow of information coming from the previous missions, we still stand in an analog of pre-Galileian era, at least in terms of comparable number of known exoplanets and on their detailed nature.

While any transit mission will be unable to find out all of the exoplanets in the neighboroud of our Solar System, the European Space Agency selected a Medium size mission for its M3 slot, PLATO[5, 6, 7, 8, 9] to achieve an unprecedent charting of exoplanets around bright and relatively close stars, allowing them to be further measured using radial velocity and leading to a first, although still fragmentary, picture of the physics (because of the estimated density) of alien worlds in our own vicinity, maybe one of the first step for a further -although today very futuristic- direct exploration.

2. The big eye(s) of PLATO

Achieving a very large FoV in common with a lrelatively arge aperture lead to fast focal ratio optics. How fast depends upon the available detector format. With a pixel size of the order of ten micrometers, as nowadays state of the art scientific grade -space qualified- CCDs are available[10], this translates into extremely short focal length in order to covere a few ten of degrees of FoV on a reasonable detector surface encompassing order of magnitude of one hundred million of pixels. As this would leads to an impossibly short focal ratio (much lower than unity) the only solution would be to segment the optics in some manner. Segmentation is a well known approach that can be used at several levels (for istance in the FoV or in the pupil plane). In PLATO the natural choice is to segment the telescope into several small telescopes with the same large FoV, mimicing a larger aperture by the numerical coaddition of the collected frames. This approach has also other advantages, namely:

- the equivalent full well, and hence the dynamic response of the ensemble of the CCDs, is proportionally augmented to the number of individual telescopes;
- the inherent multiplexing allows for a much robust payload, as the failure of one detector or of one telescope only lower the overall performances;
- an additional degree of freedom can be introduced, namely the pointing of the telescopes, individually or as groups, into slightly different regions with some partial overlap in order to encompass -as an ensemble- a larger FoV, although at the expense of an equivalent smaller telescope aperture, leading to a larger chance to detect transits around particularly bright and nearby stars.

In the case of PLATO the choice of Earth-Sun lagrangian point allows for the Earth and the Moon to become relatively small in the sky (any low Earth orbit will inhibit a really wide FoV uninterrupted coverage); mass saving solution with solar panels -the solely source of power for such a kind of mission- covering only a limited range of angles with respect to the spacecraft, requires a rotation of the whole spacecraft in one Earth's revolution year. A fourfold simmetry in the optical choice allow for a rotation of 90deg of the spacecraft every three months, leading to an acceptance angle for the solar panel that will never exceed 45deg. Because commercially available focal planes pixels are naturally arranged in a bidimensional manner this is the solution that introduce minimum calibration errors, as any star will hit a different portion of the detector at any 90deg rotation, but with the same behaviour with respect to the orientation of the pixels boundaries.

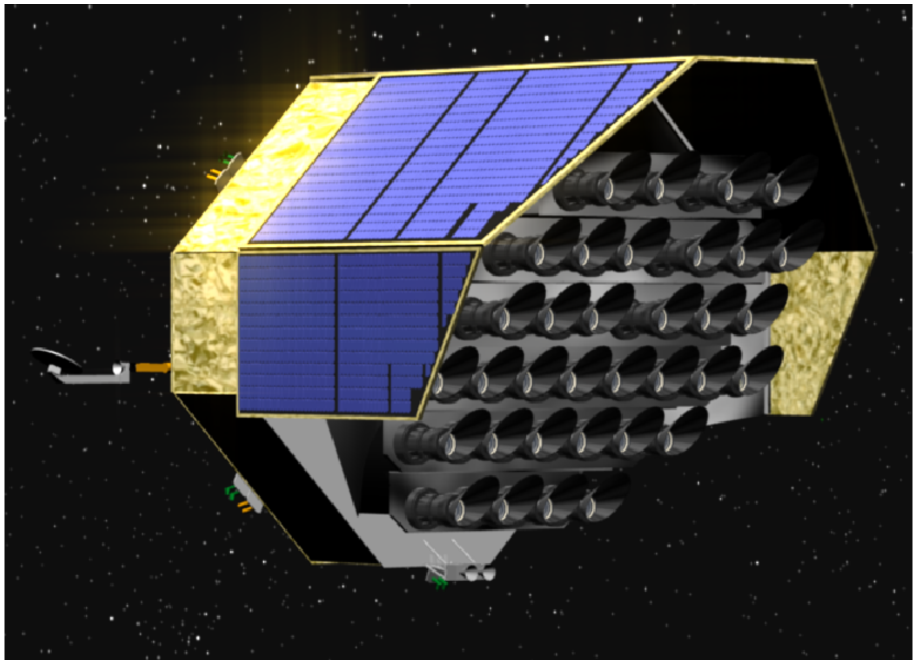

Figure 1: One of the possible arrangement of the 34 small telescopes onboard PLATO.

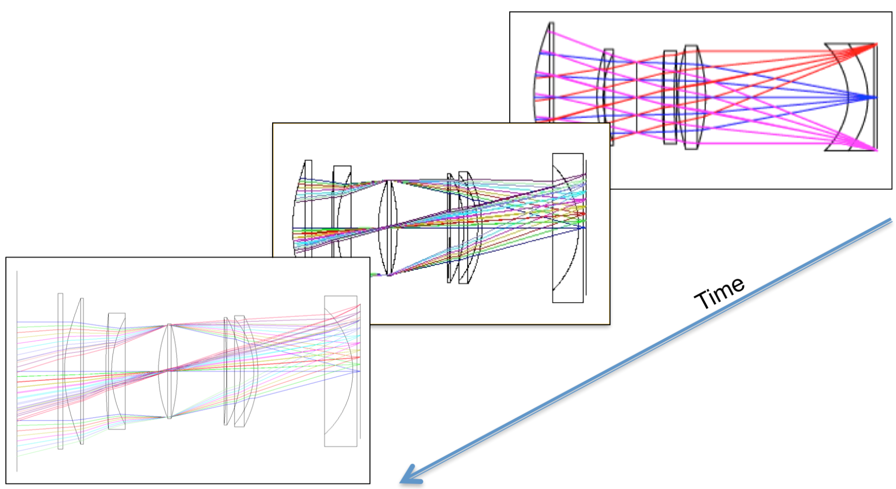

Figure 2: During the development of the project the optical design evolved toward a more compact, efficient, and with larger aperture and Field of View, solution.

An off-axis, all reflective solution, although initially investigated by ESA through industrial contractors, would exhibits a number of drawbacks for this kind of optics:

- The design would requires relatively large sizes of reflective elements;
- rejection of direct straylight soon become the major limitation in the covered FoV;
- sensitivity to displacements of the starlike images impose strong limitations to the optomechanics.

While none of these drawbacks affects a fully dioptric solutions, the adoption of a catadioptric (i.e. a mix of lenses and mirrors) will takes the worst from the two kind of possible solutions, further to the ones mentioned above, the chromatism (or -better- the additional need to control it) and the potentially limiting selection of usable glasses to avoid deterioration of performances within the mission timescale because of irradiation by high energy particles.

The effects of jitter deserves a special discussion.. Because of the high quality photometry required a jitter of a fraction of a pixel size is required to be mantained over long survey times. A reflective solution introduce, because of the large sensitivity of the image motion to the tilt of the employed mirrors, an additional term into the jitter budget, while, generally speaking, refractive elements are -at first order- inherently immune to such an issue.

Because of the described reasons we opted immediately for an all refractive solution[11], evolving the design within the project to larger pupil size and FoV with respect to the initial baseline reference design. Special attention has also been paid to the selection and machineability of the lenses and an initially choosen lens in BaF_2 has been dropped in favour of a much simpler CaF_2 lens. Furthermore we produced three prototypes of this special glass lens and subjected to a number of thermal cycling and vibration stress tests, combined in different ways, in order to eventually understand proper risk mitigating actions. These encompassed the initially designed support and none of these failed, prov-

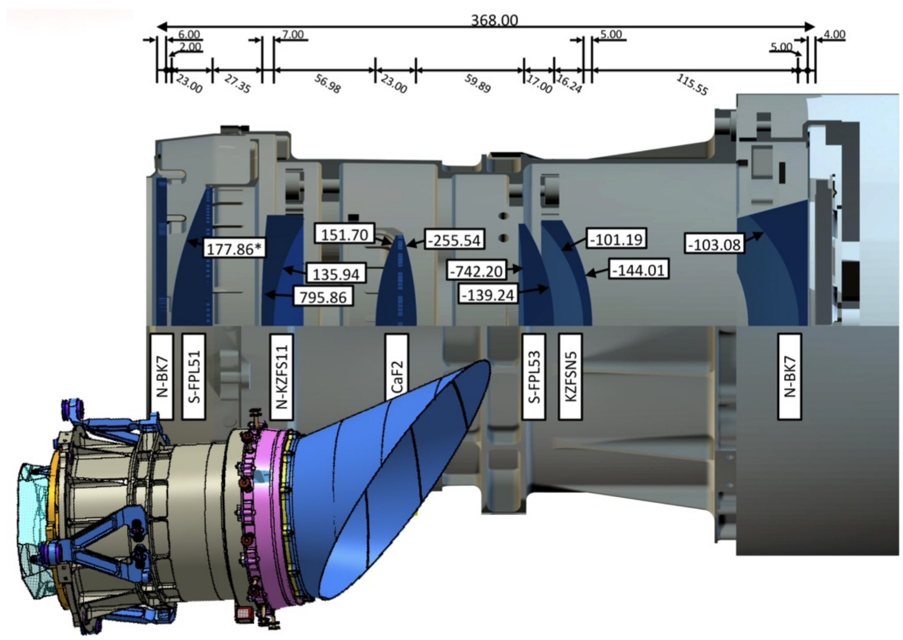

Figure 3: The cross-section of the current baseline for the optical design of a single telescope, along with a general view. All dimensions are in mm.

ing the goodness of the adopted choice.

Special care has also to be given to the relatively large mass production of optomechanical components required in this mission. We are, in fact, speaking of about 34 optomechanical units, each with 7 refracting components amounting to almost 240 optical elements, just for the Flight model. To assess the doability of this production, further to an industry based manufacturability study encompassing industries over Italy, France, Switzerland and Germany, we focussed our attention to alignment of the optomechanics. The choice of a centered optical system with all refractive elements favoured a solution based on Newton's ring spurious reflection as a tool to assess the misalignment of single elements. While we demonstrated that the alignment is doable within a couple of days[12] it is noticeable that the operation temperature and of course the pressure environment, much different from the ones where the alignment is being achieved, as in the vacuum it is foresee that PLATO will operate with the telescopes at temperatures around -100C.

With this goal in mind the alignement is done with respect to a target slightly different than the nominal one, such that thermoelastic properties of the telescope optical unit, once embedded in its final operational environment, will be close enough to the desired optical performances. This has been demonstrated by placing a breadboard mimicing the thermoelastic variations of the final tube and lenses almost identical to the flight final ones (mostly other than radiation hardening) and testing the optical quality with a combination of an interferomegram and a Hartmann test. These tests hold the special feature, in both cases, that most of the optical elements were located in warm and most controllable environment rather than in the vaccum where only a dedicated detector is placed, and the kind of measurement being chosen to be independent from its displacement due to some unpredictable thermoelastic behaviour of its support (not being part of the final flying unit) allowing for a very robust measurment scheme.

Finally a few words to describe the intended arrangement of the whole ensemble of telescopes. The 34 telescope optical units are actually arranged in four

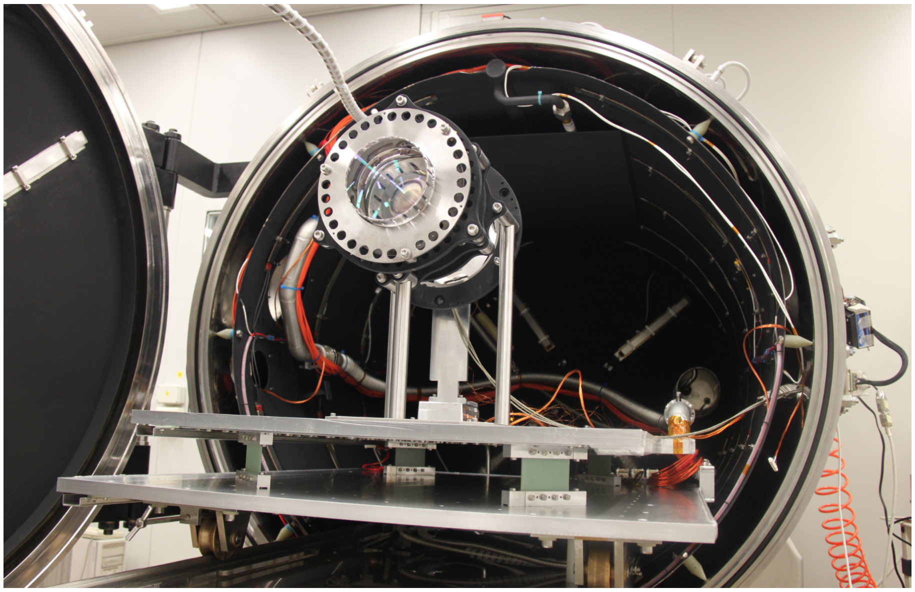

Figure 4: The prototype while being inserted in the cryovacuum chamber for testing its optical quality in the final environment of operations.

identical groups of 8 each, plus two specially coated units, named "fast" as they are intended to sample the very brightest stars to a ten times faster sampling than the other ones. These two units also cover different spectral wavelength regions (namely a "red" and a "blue" one) for asteroseismology purposes. This will greatly enhance the ability to figure out among the others, the age of the stars where exoplanets will be found transiting around. The four groups of "normal" units are displaced each other by a fraction of their FoV. The choice is to have this to be about one half of the nominal FoV diameter, such that the overall covered FoV is greatly augmented, although at the expenses of being only partially covered by the various individual telescopes.

3. What is next?

In the vicinity of our Solar System, the typical distance between stars (or physically coupled groups of stars, like a binary or triple systems) is of the order

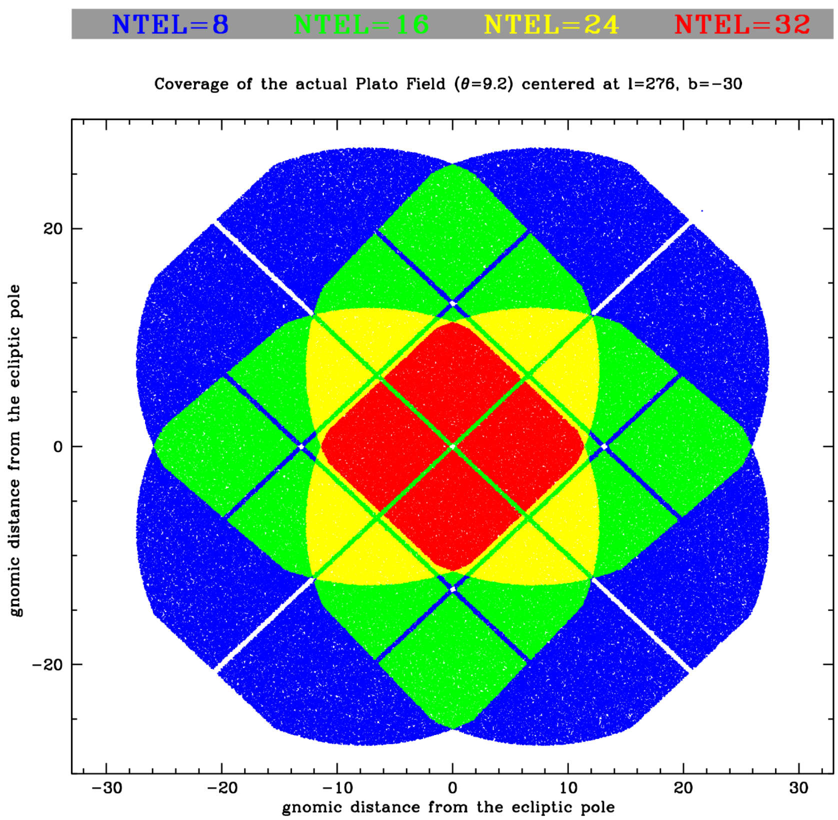

Figure 5: The Field of View of the various telescopes assmeble themselves over the sky in order to give different coverages for different directions.

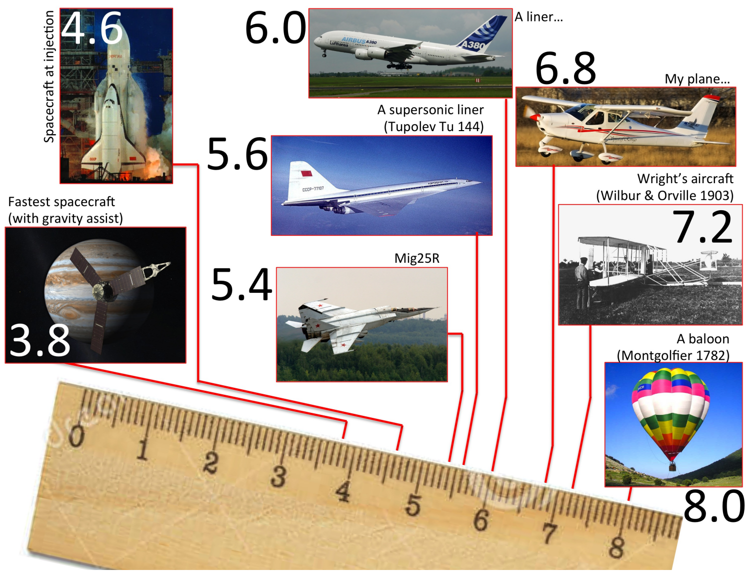

Figure 6: In a century of flight the speed achieved by human made objects evolved by four orders of magnitude. The same amount is needed to reach the ultimate speed of light.

of one parsec (or about 3.26 light years). This means that, assuming PLATO in its 7..8 years planned mission will observe a couple of about 3 years runs at the northerh and southern emispheres, and several ”step and stare” shorter run, will be able to find just a fraction of exoplanets with revolution times comparable to the Earth (and almost none with revolutions times much longer). Furthermore the yeld will be limited in a statistical sense, as -for istance- a twin of the Sun-Earth will exhibits about 1 out of one hundred chance of a direct transit. While this scenario is slightly pessimistic (through perturbations on short revolution period planets will be possible to detect some of longer ones) the scenario is that, although PLATO will suddenly makes the number of exoworlds known to jump to the realm of several thousands (finally passing the number of naked eye stars, making a sort of post-Galileian era in the exoplanet science) still the knowledge of the world in the -say- 10 light years around us, will be limited.

For very close stars, however, eXtreme Adaptive Optics, nowadays possible, coupled to the next generation of Extremely Large Telescopes, planned to have first light more or less at the same time PLATO will open its eye(s) toward the heaven, will probably allow for further discoveries.

And, while the next step of exoplanet explorations will likely rely on spectroscopic investigation of their atmosphere, another key ingredient to get a sharper view of the nature of these alien worlds, the mapping of the nearest exoplanets in view of a futuristic direct robotic exploration will become -it is an easy speculation- more and more appealing[13].

Human powered flight is doable by slightly more than a century, and one can define a speed parameter q as:

$$q = \log_{10} \frac{v}{c} \tag{1}$$

where c being the speed of light. it is worth noting that the evolution of powered flight made in the last century enough advancement that a similar further leap will lead us in the formidable realm of considering as doable a robotic mission, although of a duration of several decades (by a small factor larger than several missions achieved on outer planets or on comets), to directly explore alien worlds. While it is highly speculative which kind of technology will allow for such a goal, there is no doubt that a definitive mapping of the worlds outside our one in the vcinity of our Sun will be an unavoidable step toward interstellar direct exploration, placing maybe the initial steps for a further human one.

4. Conclusions

Charting the nearby alien worlds, also in the possible perspective of future in-situ exploration, is a formidable accomplishment that PLATO will just start, although its contribution is expected to be a significant one. The adoption of a relatively large subdivision of the optical monitoring task to about three dozens of dioptric telescopes has several advantages that has been briefly outlined here. The ensemble of the optomechanical system will mimic a telescope whose optical characteristics in terms of speed (focal ratio), aperture and Field of View would be impossible otherwise. Further characterization of the atmosphere of these alien worlds or a more complete survey (for instance using extremely high precision astrometry instead of transits) will requires missions of similar or larger size aiming specifically to such novel tasks, and possibly exploiting technologies that are today just in their developing stages. In-situ exploration will need a boost of new technological development similar to the one occoured in the last century; which one is of course just speculative at this time.

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