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Event: SPIE Astronomical Telescopes + Instrumentation, 2018, Austin, Texas, United States

PLATO: the ESA mission for exo-planets discovery

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ABSTRACT

PLATO (PLAnetary Transits and Oscillation of stars) is the ESA Medium size dedicated to exo-planets discovery, adopted in the framework of the Cosmic Vision program. The PLATO launch is planned in 2026 and the mission will last at least 4 years in the Lagrangian point L2. The primary scientific goal of PLATO is to discover and characterize a large amount of exo-planets hosted by bright nearby stars, constraining with unprecedented precision their radii by mean of transits technique and the age of the stars through by asteroseismology. By coupling the radius information with the mass knowledge, provided by a dedicated ground-based spectroscopy radial velocity measurements campaign, it would be possible to determine the planet density. Ultimately, PLATO will deliver the largest samples ever of well characterized exo-planets, discriminating among their 'zoology'. The large amount of required bright stars can be achieved by a relatively small aperture telescope (about 1 meter class) with a wide Field of View (about 1000 square degrees). The PLATO strategy is to split the collecting area into 24 identical 120 mm aperture diameter fully refractive cameras with partially overlapped Field of View delivering an overall instantaneous sky covered area of about 2232 square degrees. The opto-mechanical sub-system of each camera, namely Telescope Optical Unit, is basically composed by a 6 lenses fully refractive optical system, presenting one aspheric surface on the front lens, and by a mechanical structure made in AlBeMet.

Keywords: PLATO, Exoplanets, transits, ESA medium class mission, asteroseismology, refractive design

Space Telescopes and Instrumentation 2018: Optical, Infrared, and Millimeter Wave, edited by Makenzie Lystrup, Howard A. MacEwen, Giovanni G. Fazio, Proc. of SPIE Vol. 10698, 106984X

1. INTRODUCTION

The quest for exoplanets (so are called planetary-mass bodies orbiting stars other than the Sun) started in the '90s, with the discovery of the first exoplanetary system [1], soon followed by the first exoplanet orbiting a solar-type star [2]. More than two decades has passed since then, with many rapid improvements on both the technological side and on the scientific analysis and interpretation of the data. Nowadays, one of the most cited database (the Nasa Exoplanet Archive; https://exoplanetarchive.ipac.caltech.edu/) lists ~3,700 confirmed exoplanets, many of them hosted by ~600 known multi-planetary systems. Still, despite these impressive numbers, a coherent and convincing picture of how planetary systems form and evolve is missing [3].

The transit method to discover new planets exploits the lucky geometrical configuration where the orbital plane of the planet is close to be aligned with the line of sight. In these cases, the planet itself, which is essentially dark with respect to its host star, occults a fraction of the stellar disk at regular intervals, producing small dips in the light curve which, even in the most favorable case of close-by giant planets, last a few hours and are only 1% deep. In the case of an Earth twin hosted by a Sun analog, the transit depth (which is approximately proportional to the squared ratio between the planetary and the stellar radii) is about 80 parts per million (p.p.m.), a quantity which is extremely challenging to measure even with the existing space-based facilities. Despite this, transit-finding satellites such as CoRoT [4] and especially Kepler [5] and its continuation K2 [6] have been the most fruitful in terms of number of discoveries (see Figure 1).

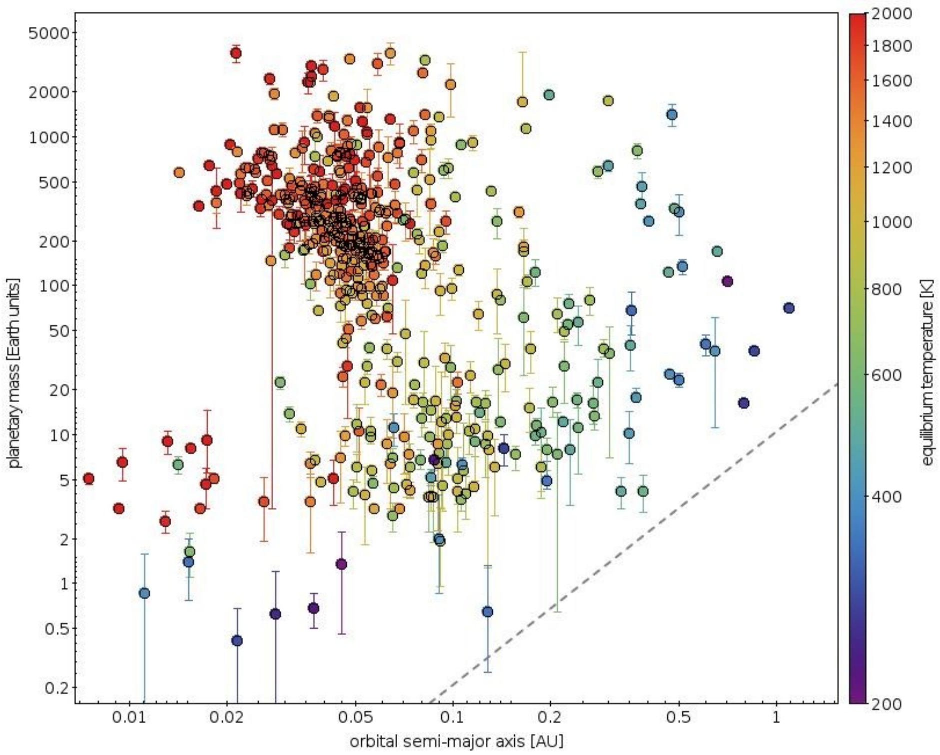

Figure 1. All the 590 exoplanets confirmed so far for which both radius and masses is reliably known, on the plane semi-major axis vs. planetary mass. The equilibrium temperature of the planets, calculated from reasonable assumptions, is color-coded from 200 to 2000 K. The dashed line marks the empty region where habitable terrestrial planets should lie. This is a region that PLATO will fill.

Transits are also crucial in the characterization of exoplanets, being our only opportunity to measure their radii in a geometrical, direct way. Once the planetary mass is known from the radial velocity technique (RV) or from other dynamical methods such as the Transit Time Variations (TTV), we can infer their bulk density, a fundamental quantity to get a first guess on what a planet is made of (e.g., rocky, icy, gaseous or something in between) [7]. Going even further, transits enable the so called transmission and emission spectroscopy, where the analysis of the stellar light filtering through the planetary limb (in the former case) or the light emitted by the planet itself (in the latter case) allow us to detect the exoplanetary atmosphere and, in the most favorable cases, to measure its chemical composition and physical state [8]. In this context, transiting systems are currently thought to be the "royal road" to more deeply characterize specific classes of exoplanets and to put them in an evolutionary frame. In particular, discovering and characterizing the so-called «habitable planets», i.e. rocky planets orbiting at the right distance from their stars to allow liquid water to condense on their surfaces [9], is currently seen by most astronomers as the holy grail of planetary science.

The original Kepler mission, responsible for the discovery of most planets known so far [10], yielded an impressive statistical census of them by continuously monitoring a 105-deg² area of the sky in the northern hemisphere with a single Schmidt telescope. The scientific return of the Kepler targets has been immense, including the well-known result that small planets are strikingly common around solar-type stars. Nevertheless, while Kepler has been a powerful machine for detecting transits, most of the planets it delivered are challenging to be confirmed, followed-up and studied more in detail. The main reason is that its survey area was negligible when compared with the full sky (~105 vs. 41,000 deg²). The correspondingly small solid angle probed implies that more distant stars needed to be measured to reach a significant sample size, and that on average most planets discovered by Kepler are faint. Because both RV measurements and atmospheric studies are photon-starving techniques, they rather need very bright targets to be effective. In other words, many Kepler candidate planets do not have any measured mass, and though a few habitable candidates have been published, their confirmation (not to mention their characterization) appears not feasible in the near future.

TESS [11], launched in 2018, is going to change the census of characterized planets by scanning most of the sky during its two-year nominal mission with four wide-field cameras. TESS is expected to discover a similar number of planets with respect to Kepler, but around stars ~5 magnitudes brighter, on average [12]. Those planets would be invaluable not only because of the bright-star opportunity mentioned above, but also because of the perfect synergy with JWST for the atmospheric characterization [13], and with CHEOPS for a wide range of science cases [14]. Unfortunately, the TESS scanning law makes its detection efficiency to be biased toward short-period planets, rendering the chase to planets in the HZ effective only for low-mass stars (M dwarfs), where the habitable zone lies much closer to the parent star. The fact that only a very small fraction of the sky is covered for a full 1-year baseline, combined with the small diameter of the telescope, makes TESS uneffective in detecting long-period, small-size planets, such as the long-awaited Earth twins, i.e. rocky planets in the HZ of G-type dwarfs. More in general, a large fraction of the parameter space will be unexplored.

PLATO [15] will fill the gaps left by Kepler/K2 and TESS. By combining a photometric precision even better than that of Kepler, plus a sky coverage comparable to TESS, PLATO will finally carry out an unprecedented census of planets hosted by bright and nearby stars, including Earth twins amenable to RV confirmation and atmospheric characterization with the next-generation instruments such as the ELT ones. We will also overcome a known limitation of the transit technique we are approaching right now: as the photometric precision increases, the uncertainty on the planetary parameters are becoming more and more dominated not by the measurement error, but rather on the assumed stellar parameters. PLATO will be able to perform an asteroseismological analysis on its primary targets, delivering accurate masses and radii of the host stars, and stellar ages as well. The latter are crucial to put the discovered planetary systems in an evolutionary perspective, allowing us for the first time to probe how the dynamical architecture of the system and the physical/chemical properties of individual planets change with time. Every aspect of PLATO is of course optimized to maximize its planet yield, especially on the regions of the parameter space where both long-period planets and bright stellar hosts lie. This includes a mixed observing strategy contemplating up to two "long-duration" fields, where a given sky region at high ecliptic latitude is stared for up to three years, and many shorter "step & stare" fields tiling most of the remaining sky with a shorter baseline.

2. THE MISSION OVERVIEW

PLATO (PLAnetary Transits and Oscillation of stars) mission has been selected in 2014, and adopted in 2017, by ESA as medium class mission M3 devoted to exo-planets discovery in the framework of the Cosmic Vision 2015-2025 program with a launch opportunity in 2026. The launcher (Soyuz 2-1b or Ariane 6) will bring the satellite in orbit around the Earth-Sun Lagrangian point L2.

The current observation strategy foresees up to two long pointing fields lasting 2-3 years (one in the southern and one in the northern hemisphere), required for the detection of long period planets (up to one year orbital period). A second step-and-stares phase includes several short pointing fields of 2-5 months. The definition of the fields is currently under investigation. A scheme of a possible mission profile is shown in Figure 2, where the hypothetical fields covered during the mission are compared with ones covered by Kepler, K2 and CoRoT.

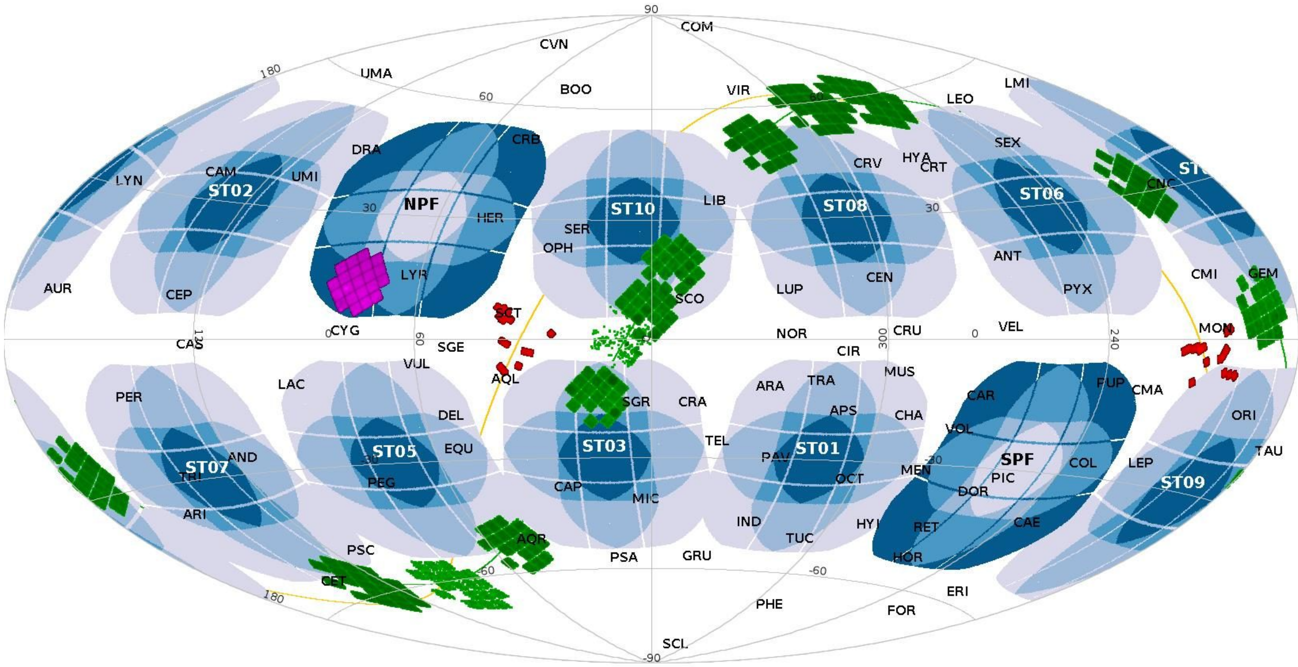

Figure 2. Aitoff projection of the whole sky in Galactic coordinates, showing the footprints of the most successful planet-finding missions (magenta: Kepler, green: K2, red: CoRoT) and an hypothetical PLATO mission profile (shades of blue). All these fields are centered at |b|=30°, and the different shades of blue correspond to a different number of co-pointing PLATO cameras (6, 12, 18, 24). The two long-duration fields NPF and SPF are shown here with an inverted color scale. The choice of the observation strategy will remain flexible till close to the lunch in order to take into account all information available from other experiments at the time PLATO is ready to fly.

The scientific payload [16, 17] consists of 26 cameras mounted on a common optical bench: 24 cameras, named normal cameras, are completely dedicated to scientific observations, while 2 cameras, named fast cameras, will be dedicated to very bright stars and will support and improve the pointing stability performance of the spacecraft on-board star-tracking system. Each camera consists of a telescope optical unit (TOU), i.e. the opto-mechanical system, a focal plane module (FPA), a front-end electronic (FEE), a FEE support structure, and related thermal equipment. The 2 fast cameras are specialized in two different photometric bands (blue 505-700 nm, red 665-1050 nm) for science purposes and are read-out every 2.5 seconds. The 24 normal cameras will observe in broad band “white light” (500-1050 nm) with a read-out cadence of 25 seconds. A scheme of the PLATO spacecraft and of the camera is shown in Figure 3.

Each camera will collect the scientific signal with an aperture diameter of 120 mm over a Field of View area of 1037 deg^2. In order to maximize the sample of observed near-by bright stars, the instantaneous Field of View has been increased by dividing the normal cameras in four groups of 6 cameras each. Each camera of a group will share the same line of sight, while the four groups point towards a sky direction which is displaced by about 9.2 degrees from the center of the overall field of view. This configuration allows the increasing of the overall instantaneous coverage to about 2232 $degrees^2$, with overlapping portions of sky covered by multiple groups. The 2 fast cameras pointing direction coincides with the line of sight of the overall Field of View. A scheme of the overlapping line of sight is shown in Figure 4.

The equivalent aperture diameter of the in the 24 overlapping normal camera Field of View is about 600 mm. The choice to split the collecting area over several cameras instead of single one with equivalent aperture (despite the possibility to increase the instantaneous overall Field of View) is dictated by required photometric accuracy and achievable optical configuration. The photometric accuracy required by PLATO (~30-40 p.p.m.) imposed to spread the PSF over a relatively large number of pixels with the nowadays CCDs full well capacity. From this point of view, spreading the PSF over 2×2 pixels on the 24 cameras is equivalent to spreading the PSF into 2×2×24 pixels on a single camera with equivalent aperture. PLATO requires a relatively large plate scale (~833 arcsec/mm), obtained as result of a trade-off between the size of the Field of View and the acceptable scientific sources crowding. Assuming a single equivalent aperture camera, this implies that the optical configuration should deliver an F/# of about 0.4-0.5, i.e. extremely difficult, if not impossible, to realize. At last, splitting the collecting area over several camera has also been conceived as risk mitigation strategy.

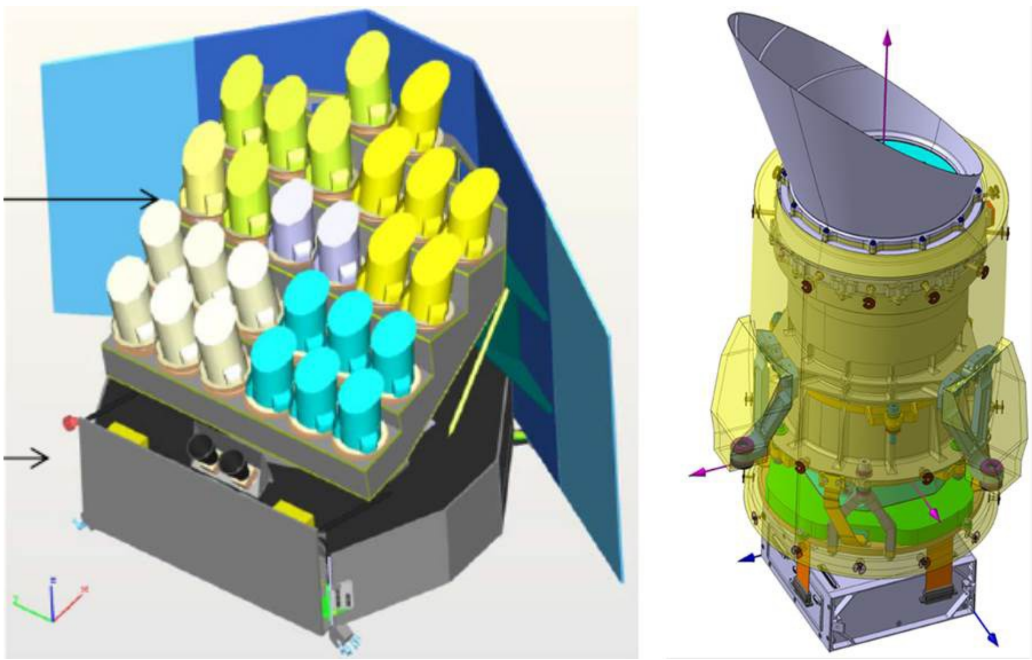

Figure 3. Scheme of PLATO spacecraft (left) and of a PLATO camera (right).

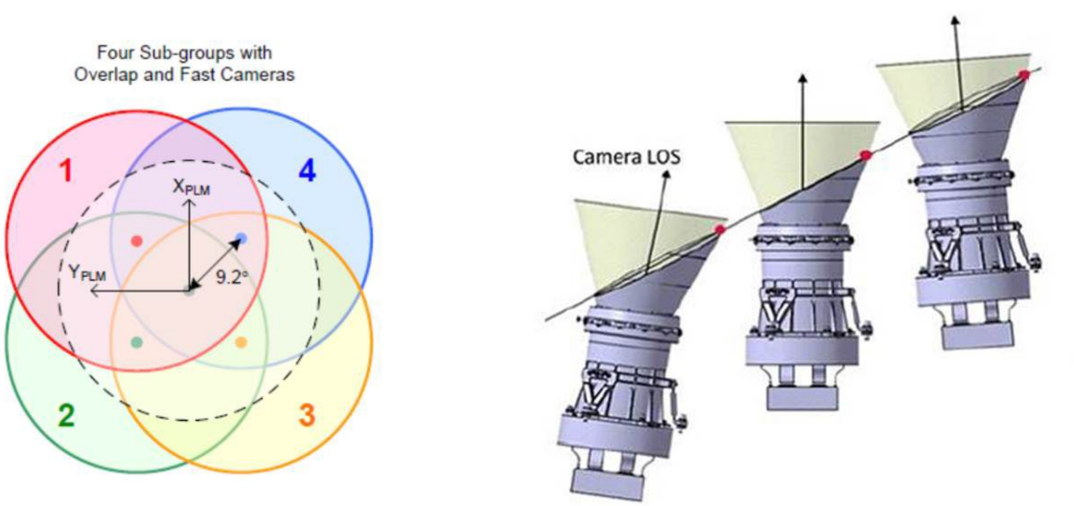

Figure 4. Scheme of the overlapping line of sight.

All the cameras have a focal plane array [18] composed by 4 large format type CCD 270 by Teledyne e2v. The CCD 270 has a format of 4510×4510 pixels^2 with pixel size 18 μm. For the normal cameras, the focal plane array is in full-frame mode while for the fast cameras it is in frame-transfer mode. The only difference between the two is the presence of the metallization store shield on the frame-transfer device. The CCD will be passively cooled to the operational working temperature of -70°C.

3. THE TELESCOPE OPTICAL UNIT

The TOU optical configuration changed several times during the evolution of the project. Initially it was conceived as an off-axis catadioptric system but soon the configuration moves to a fully refractive design based on double-gauss like class of solutions [19, 20].

All the TOUs, 24 Normal-TOUs and 2 Fast-TOUs, have the same optical design but for the filter deposited on the frontal window 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 Focal Plane Array is positioned. The TOU optical Layout is shown in Figure 5.

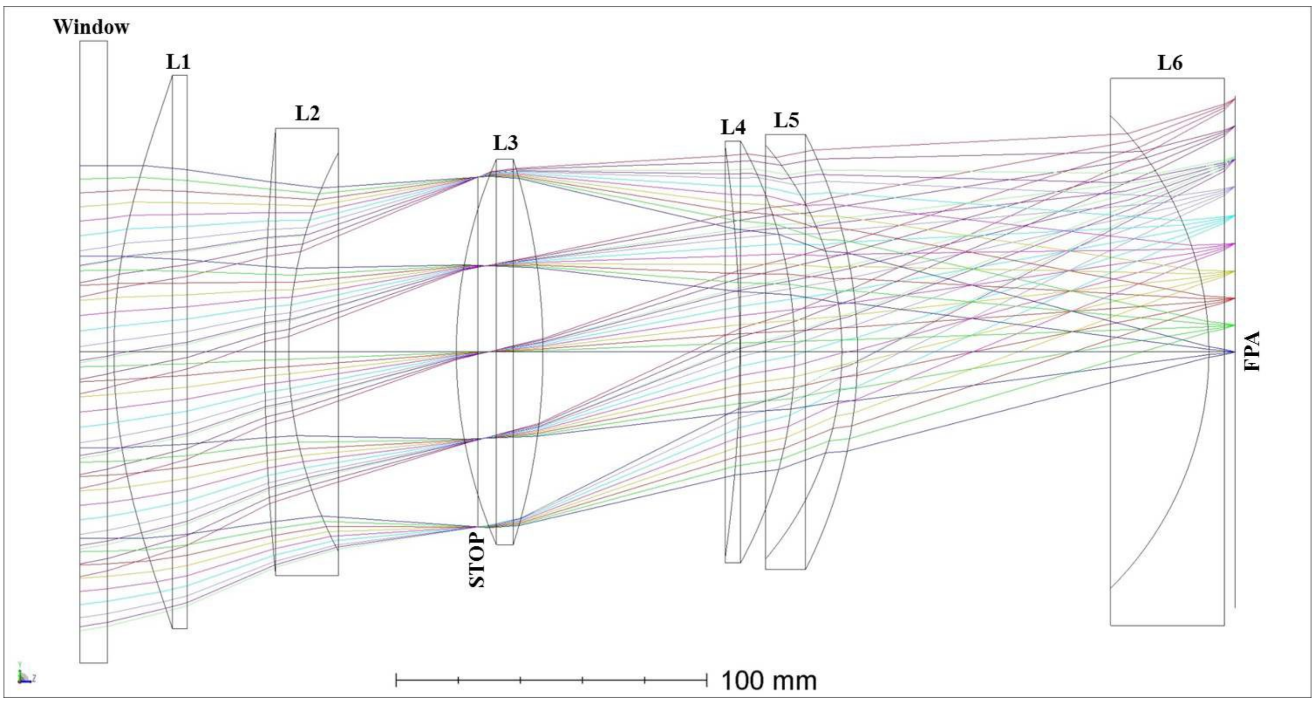

Figure 5. Optical layout of a TOU.

The presence of the window allows mitigating the thermal shock on the first lens during the launch and shields the first lens from potentially damaging high energy radiation (mainly solar protons). In the internal surface of the window it is deposited the wavelength band filter: for the Normal-TOUs it is a high-pass filter with cutoff wavelength at 500 nm able to define the blue edge of the wavelength spectral range, being the red edge determined by the detector quantum efficiency; for the Fast-TOUs it is pass-band filter 505-700 nm for the blue, 665-1050 nm for the red, with the red edge determined by the detector quantum efficiency).

Given the large required Field of View (~37.8 degrees), in the first surface of the front lens we have introduced an even aspheric surface able to recover the image quality within the specifications. Placing the pupil stop at the center of the optical system helps to minimize the overall mass of the optical train. The pupil stop size has been dimensioned in order to guarantee the 120 mm of the entrance pupil diameter. The last lens it is placed very close to the focal plane and, basically, acts as field flattener. Being the latter partially exposed to the external environment, the chosen glass is the radiation hardened version of N-BK7 (grade 18).

The nominal optical system is able to deliver 90% polychromatic geometrical enclosed energy in 2×2 pixels[2] with respect to centroid at the nominal working temperature of -80°C with a depth of focus of ± 20 μm.

The lenses mountings has been designed and dimensioned to guarantee the survivability of the optical components during the launch (vibrations and thermal stress) and are based on an elastic self-re-centering concept to maintain the on-ground alignment. The external tube is made in AlBeMet, guarantying the opto-mechanical stiffness with small impact on the mass budget. A scheme of the opto-mechanical layout is shown in Figure 6.

The TOUs are thermally stabilized at about -80°C. The thermal stabilization is achieved through heaters placed along the AlBeMet tube and thermal sensors giving the feedback for the control loop. Moreover, the TOUs (and the cameras) do not implement any movable parts. The on-orbit best focal plane position will be achieved properly driving the thermal control system, having as feedback the image performance of several stars distributed over the whole Field of View. Each TOU will mount a baffle for straylight rejection purposes, which will also act as thermal radiator.

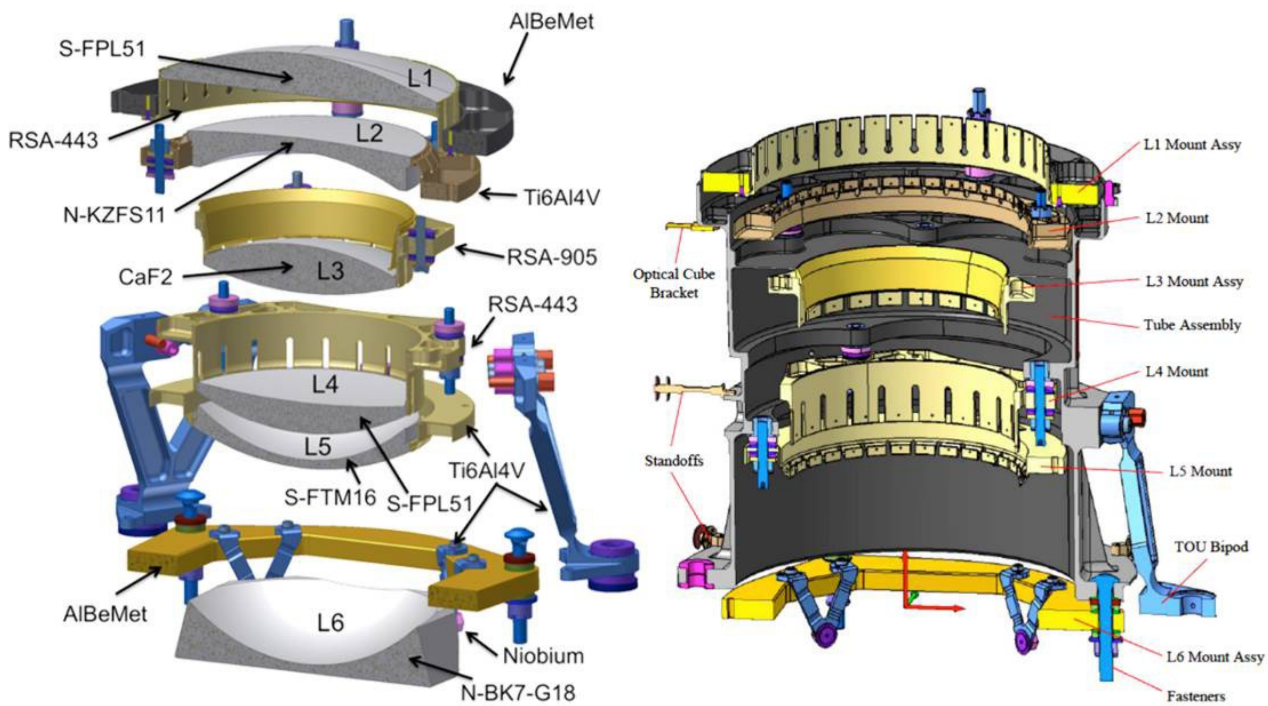

Figure 6. Opto-mechanical layout of the TOU.

4. CONCLUSIONS

PLATO is the unique mission among the planned ones designed to discover and characterize exo-planets orbiting on time scale up to years. Its core program focuses on the detection and characterization of extraterrestrial planets in the habitable zones of solar-like host stars, and potentially Earth twins. PLATO will deliver the largest statistical sample ever of well characterized exo-planets (masses, radii, densities and ages), discriminating among their 'zoology' and contextualizing them in the surrounding environment.

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