ABSTRACT

The CHaracterizing ExOPlanet Satellite (CHEOPS) is an ESA Small Mission whose launch is planned for the end of 2017. It is a Ritchey-Chretien telescope with a 320 mm aperture providing a FoV of 0.32 degrees, which will target nearby bright stars already known to host planets, and measure, through ultrahigh precision photometry, the radius of exo-planets, allowing to determine their composition.

This paper will present the details of the AIV plan for a demonstration model of the CHEOPS Telescope with equivalent structure but different CTEs. Alignment procedures, needed GSEs and devised verification tests will be described and a path for the AIV of the flight model, which will take place at industries premises, will be sketched.

Keywords: CHEOPS, Exo-planets, Transits, ESA, Small Mission, Telescope, AIV

1. INTRODUCTION

The CHaracterizing ExOPlanet Satellite (CHEOPS) [1][2] is an ESA S-class Mission whose adoption by SPC took place in February 2014 and whose launch is planned for the end of 2017. It is a dedicated mission to search for transits by means of ultrahigh precision photometry of nearby bright (V<12, goal: 13) stars already known to host planets. It will be sent into a sun-synchronous Low Earth orbit (620-800 km) that optimizes uninterrupted observations and minimizes thermal variations of the S/C and stray light on the satellite. It will have the capability to point almost any location on the sky, reaching sub-millimag photometric precision on planets already discovered by existing Radial Velocity surveys, such as HARPS-S [3] & N [4] or planned ground and space missions based on transits detection (i.e. NGTS [5] and TESS [6]). It will provide precise radii measurements of super-Earths and Neptune-size planets. During the scheduled 3.5 year mission, hundreds of targets are planned to be observed with ultra-high precision photometry, providing valuable data for constraining the mass-radius relation of exoplanets, especially in the 1-6 R\textsubscript{Earth} regime, allowing to determine their structure and composition and hence gain knowledge on planets formation and evolution.

The major requirement on the CHEOPS instrument is photometric stability, therefore the detector gain has to be extremely stable and Earth stray light must be suppressed to a very high degree. The payload is a single instrument: an F/8 Ritchey-Chretien two mirrors on-axis telescope with an aperture of 320 mm, followed by a Back End Optics (BEO) module whose main purpose is to re-image the telescope focal plane on the detector, in order to provide an intermediate pupil where a mask can be placed for the straylight rejection, and to reshape a defocused PSF accordingly to specifications. It will provide a FoV with a diameter of 0.32 degrees.

Under the responsibility of the Italian team is the Assembly, Integration and Verification (AIV) of a Demonstration Model (DM) of the CHEOPS Telescope. This aims validating an alignment and testing procedure within the given requirements at ambient temperature conditions (to be used for the flight model integration) and tests that will be done...
by an industrial contractor under INAF responsibility. The optics will be flight representative (but not radiation hardened) and the mechanical structure will be equivalent but with different CTE.

This paper will present the details of the AIV plan, concerning alignment procedure, needed GSEs and devised verification tests.

2. CHEOPS OPTICAL DESIGN

CHEOPS is composed of two subsystems: a compact Ritchey-Chretien telescope (TEL) and Back-End Optics (BEO), a re-imaging system whose purpose is to reshape the PSF accordingly to specifications. BEO is composed of two spaced achromatic doublets: the first one forming a 10 mm pupil, while the second one focusing onto CHEOPS Detector.

Straylight reduction is obtained through the use of baffles with internal vanes and two properly dimensioned masks located at intermediate focus and pupil locations. The main parameters of the optical design can be found in Table 1, while the optical layout of TEL and BEO in Figure 1.

The Focal Plane Array (FPA) will be located at a Defocused Focal Plane (DFP) in order to obtain a defocused PSF, spread over a quite large amount of pixels, in order to reach extremely precise photometry. Further details can be found in [3].
Table 1. Main parameters of the optical configuration.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spectral range</td>
<td>400 – 1100 nm</td>
</tr>
<tr>
<td>Entrance pupil diameter</td>
<td>320 mm</td>
</tr>
<tr>
<td>Central obstruction diameter</td>
<td>68 mm</td>
</tr>
<tr>
<td>Working F/#</td>
<td>8.38 @ 750 nm</td>
</tr>
<tr>
<td>Field of View (diameter)</td>
<td>0.32 degrees</td>
</tr>
<tr>
<td>Effective focal length</td>
<td>2681 mm @ 750 nm</td>
</tr>
<tr>
<td>Pixel size</td>
<td>13 micron</td>
</tr>
<tr>
<td>Plate scale</td>
<td>1 arcsec/pixel</td>
</tr>
<tr>
<td>Detector format</td>
<td>1024×1024 pixel²</td>
</tr>
</tbody>
</table>

3. CHEOPS INSTRUMENT SYSTEM

CHEOPS Instrument System main parts, visible in Figure 2, are the baffle and cover assembly, the optical telescope assembly, the focal plane module, back-end electronics and radiators.

In particular, for the purpose of this writing, TEL (Figure 3) is the subsystem made by the assembly of:

- an opto-mechanical tube, consisting of a mechanical structure mounting the primary (M1) and secondary (M2) mirrors
- a carbon fiber Optical Bench (OB)
- the BEO, consisting of a mechanical part mounting a set of small optics, D1, M3 and D2.

The collective name “Optical Train” is used for the mere optical elements and the mounts directly connected to them (M1G+M2G+D1G+M3G+D2G).
4. MODEL PHILOSOPHY

Different models have been foreseen to thoroughly test the system in the tight schedule of CHEOPS before its launch (end of 2017), and are presented in Table 2. In particular, a Demonstration Model (DM) will be realized with an identical structure made with different material, therefore thermally not equivalent. The TEL DM will be used at INAF Padova laboratories in order to verify all interfaces, define possible GSEs, test at ambient temperature TEL integration, alignment and verification procedures and prove the feasibility of the alignment within the requirements. Afterwards it will undergo test integration and alignment procedures with respect to the Focal Plane Module at the University of Bern. The TEL Proto-Flight Model (PFM) will be assembled, aligned and verified by an industrial contractor selected by ASI and supervised by INAF.

Table 2 CHEOPS TEL and its sub-system model philosophy

<table>
<thead>
<tr>
<th>Model</th>
<th>Name</th>
<th>Purpose</th>
<th>Top Level Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>STM</td>
<td>Structural Thermal Model</td>
<td>Mechanical verification of design and interface verification</td>
<td>Flight-representative mechanical interfaces, mass, volume, and power</td>
</tr>
<tr>
<td>EQM</td>
<td>Engineering Qualification Model (BEO)</td>
<td>Qualification of design and interface verification of the BEO</td>
<td>Flight-representative mechanical interfaces and optics (no radhard)</td>
</tr>
<tr>
<td>DM</td>
<td>Demonstration Model (TEL)</td>
<td>Test TEL integration, alignment and verification (no cryo-vacuum) procedures</td>
<td>Flight-representative mechanical interfaces and optics (no light-weighted, no radhard)</td>
</tr>
<tr>
<td>PFM</td>
<td>Proto-Flight Model</td>
<td>Flight</td>
<td>Flight</td>
</tr>
</tbody>
</table>

5. ALIGNMENT TOLERANCES & DEGREES OF FREEDOM

Alignment tolerances have been defined based on scientific and technical constraints. However, while the tolerances related to TEL optics wrt OB are the final ones, those related to internal alignment are still preliminary, needing
Concerning the detector, as previously explained in Section 2, it will be moved wrt to the focal plane and furthermore it will be used as compensator (shall be able to translate ± 260 μm from best-defocused position), so tolerances are indicative of a geometrical increase of the PSF of a quarter of pixel.

5.1.1 **Optical train degrees of freedom**

Optical train elements are provided with the following Degrees of Freedom (DoF):

- **M1**: tilt, centering
- **M2**: tilt, centering, focusing
- **BEO Housing**: tilt, centering, focusing
- **D1 & D2**: tilt, centering, focusing
- **M3**: tilt, focusing

6. **TEL DM AIV PROCEDURE**

An AIV procedure has been devised in order to integrate and align a TEL DM in ambient conditions (about 20° C), operations to be carried out at INAF-Padova laboratories, to demonstrate the feasibility of an alignment inside the given requirements and verify the opto-mechanical interfaces and alignment tools.

The optical design allows the telescope mirrors relative alignment to be optimized separately from the BEO (which can also be internally aligned separately, except for D2). The current TEL DM alignment procedure foresees the definition of the optical axis by means of a mechanical bearing. Its accuracy, at the moment estimated to be +/- 50 μrad in wobble, sets the limits of the achievable performance. The alignment of the optical train is accomplished via reflections or refractions on the involved optical surfaces and opto-mechanically linked to the mentioned bearing. Mainly HeNe sources (632.8 nm) will be used during the alignment phase including HeNe laser and a Zygo interferometer equipped with a 300 mm beam-expander delivering a high quality (WFE<λ/10 PtV) collimated beam. These will allow co-aligning the various optical axes of the several elements within tolerances. A large flat mirror positioned on the M2 side and equipped with tilt adjustments will allow to explore the full FoV.

In order to better evaluate all interfaces and develop the best mounting and supporting strategy and alignment tools, we took advantage of a TEL 3D model realized in house with a 3D printer [8].

6.1 **Bearing rotation axis alignment to OB**

The first phase consists in the alignment of the bearing rotation axis to the OB reference plane (M1 side), defining the alignment reference for the whole TEL alignment. CHEOPS OB is held with a proper handling at a certain height from a laboratory optical bench, such that the telescope tube, a 500 mm flat mirror (tilted of 45°) on a tip-tilt mount and a

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**Table 3 Alignment tolerances**

<table>
<thead>
<tr>
<th>Optics</th>
<th>Center</th>
<th>Tilt</th>
<th>Focus</th>
</tr>
</thead>
<tbody>
<tr>
<td>TEL-OB</td>
<td>± 250 μm</td>
<td>± 200 μrad</td>
<td></td>
</tr>
<tr>
<td>M1-M2</td>
<td>± 10 μm</td>
<td>± 100 μrad</td>
<td>± 10 μm</td>
</tr>
<tr>
<td>Intermediate FP</td>
<td></td>
<td>± 10 μm</td>
<td></td>
</tr>
<tr>
<td>D1</td>
<td>± 20 μm</td>
<td>± 190 μrad</td>
<td>± 20 μm</td>
</tr>
<tr>
<td>M3</td>
<td>± 100 μm</td>
<td>± 190 μrad</td>
<td>± 100 μm</td>
</tr>
<tr>
<td>D2</td>
<td>± 20 μm</td>
<td>± 190 μrad</td>
<td>± 50 μm</td>
</tr>
<tr>
<td>Detector</td>
<td>±1.88 mrad</td>
<td>± 25 μm</td>
<td></td>
</tr>
</tbody>
</table>
bearing can fit under it. OB is connected to the handling by means of 3 contact points in order to avoid surface deformation. A bearing, with wobble < +/-50 μrad, is positioned on the optical bench and equipped with centering and tilt capabilities. A small optical bench, hereafter called platform, is connected to the rotating part of the bearing.

The bearing is adjusted in tilt and centering until a dial gauge fixed to the platform measures the same value for a complete rotation. At this point bearing axis becomes our reference for the alignment and it will be monitored to verify that ambient effects do not introduce misalignments. Setup for this phase is shown in Figure 4.

Figure 4: Schematic representation of setup for the alignment of bearing rotation axis wrt to OB through a dial gauge.

6.2 Internal tube alignment

6.2.1 M1 mirror assembly

M1 is the primary mirror in Zerodur material, with a diameter of 320 mm and a central hole with diameter of 68 mm. In PFM model it will be light-weighted with mass of approximately 4.5Kg, while for DM it will have a mass > 10 kg. M1 is mounted on an Invar ring (M1 mount), whose current conceptual design includes multiple radially flexible “blades”, to compensate difference in thermal expansion between Invar and glass (Figure 7). This multi-flexural system spreads the loads and distributes the bonding area on several fingers, avoiding load concentration due to thermal mismatch between the glue and the mirror. M1 Group is fixed to M1 interfaces barrels, which have positioning pins to hold them in place avoid transmitting shear forces and torques when the screws are tightened. Using a specific manipulator (allowing M1 tilt and centering) which connects to the hollow part of M1 mount, the assembly M1G+M1 interface is positioned inside the bipods’ holes (M1 support) and M1 is installed. M1 support is fixed to the OB on one side and to the Internal Tube on the other side (see Figure 6).

6.2.2 M1 alignment

To perform M1 alignment with respect to the bearing optical axis (and therefore OB reference plane), a small setup is installed onto the platform (see Figure 5). A laser, eventually equipped with a focusing lens or a beam expander and an iris, shines in the direction of a beam-splitter (BS). Half of the light is sent toward the edge of M1, while the other half proceeds toward a small flat mirror (FM#1) equipped with tip-tilt mount, which sends the beam toward an area on M1 closer to the vertex. Two test cameras (CCD#1 and CCD#2) are placed to intercept both axis. Iteratively, M1 centering and tilt are adjusted until spots on both cameras are minimized for a full bearing rotation.

6.2.3 M1 gluing

After alignment wrt OB is achieved, glue is injected at the three interface points in the gap between M1 interface barrels and the holes of M1 support. After curing manipulator is removed.
Figure 5: Schematic representation of setup to align M1 to the bearing rotation axis

Figure 6: Drawing showing connection points between M1 Assembly to Internal Tube and OB and between M2 Assembly and Internal tube.
Figure 7: Exploded view of M1 Assembly (left) and M2 assembly (right). Zerodur M1 mirror (light blue) is held by an Invar ring with pads (M1 Mount, red). The two parts are glued. The grey barrels are M1 interfaces between M1 mount and bipods (M1 Support, blue). Zerodur M2 mirror (light blue) is glued to M2 Mount (red). M2 interfaces connect M2 Group to M2 Support (blue).

6.2.4 On-axis source definition

A small flat mirror (FM#2) is fixed onto a dedicated tip-tilt mount, “above” OB and is aligned in order to have its surface perpendicular to the bearing rotation axis (Figure 8). This is achieved minimizing the movement of the spot projected from a laser head fixed to the rotating platform and reflected from FM#2.

Figure 8: Schematic representation of the on-axis source setup. A small flat mirror (FM#2) was previously aligned to be perpendicular wrt bearing rotation axis

At this point FM#3, a large flat mirror (clear aperture 460 mm, \(\lambda/40\) RMS), equipped with tip-tilt adjustment is installed on a plate over bearing. A Zygo interferometer, equipped with a 300 mm beam-expander sends a beam toward FM#3,
which is tilted in order to co-align the beam to the bearing rotation axis to produce the “on-axis beam” (Figure 8). This is achieved minimizing the tip-tilt term measured by Zygo interferometer. Just as a note, the best solution would obviously be to achieve an expansion of the beam up to 320 mm (M1 diameter), but due to cost and delivery time issues a 300 mm beam-expander is currently being considered.

Afterwards a test camera (without housing) is positioned on the intermediate focal plane nominal position (CCD# FP) through a structure connected with BEO. Focus adjustment for this camera is foreseen. A laser head, installed on the platform, shines onto the CCD. Laser tip-tit is adjusted until the movement of the spot onto the CCD is minimized for a complete bearing rotation. In this way the TEL FP intersection with the bearing axis is defined and recorded.

6.2.5  M2 mirror mount

M2 is made of Zerodur and has a diameter of 68 mm and a mass of approx. 0.1Kg. After being glued to its mount, using a manipulator M2G is placed inside M2 support hole through M2 interface and M2 support (spider) is fixed to the Internal tube. M2 support is connected to the Internal Tube with 2 screws for each of the 3 attaching point (see Figure 6). Internal Tube has to be connected to OB as shown in Figure 6.

6.2.6  Ritchey-Chrétien internal alignment

The previously obtained wide collimated on-axis beam enters from M2 side and M2 is iteratively adjusted in tip-tilt, centering and focusing until having a focused image with symmetric quality along the FoV (see Figure 9). The center of the field is defined by the previously recorded position and the off–axis images are obtained tilting FM#3. Once the camera is removed, FP mask should be placed in its location. It’s oversized by 1 mm, therefore mechanical accuracy should be good enough for centering, while a fast lens, aligned in focus prior to CCD removal, could be used for focusing purposes.

At this stage, as simulation for intermediate settling vibrations, misalignments comparable with expected values will be deliberately introduced for DM, to verify performance variations, while for PFM a real vibration test could be performed.

6.2.7  M2 gluing

After alignment of M2 wrt to M1 is achieved, glue is injected through M2 interface to M2 support.

Figure 9: Conceptual scheme of the Ritchey-Chretien internal alignment. M2 is iteratively adjusted in tip-tilt, centering and focusing until having a focused image with symmetric quality along the FoV. The center of the field was previously defined. To explore the FoV, the entrance beam is tilted by means of FM#3.
6.3 BEO internal alignment

BEO optics consist into two pre-assembled doublets D1 and D2 and a flat mirror, M3. M3 should be mechanically repositionable (pinning) with a high precision (0.01 mm), because it will have to be inserted and removed in the different alignment phases.

BEO internal alignment is performed as much as possible independently from the rest of TEL. Current plan is to consider D1 as reference for the alignment, since it will not be accessible after BEO integration to OB. D1 barrel has to be machined in order to allow mechanically for a centering inside tolerances. To align D1 and D2, both transmitted and back reflected beams are considered. For the latter we will make Airy rings (and if visible Newton’s rings, produced by lens surfaces interference) concentric. Small setups including lasers (or eventually interferometer in order to have a highly collimated beam), test CCDs to image beams at entrance and exit of the BEO, BSs and flat mirrors will be use throughout this alignment.

As first thing the reference axis is defined in a mechanical way, aligning a laser to the center of pupil mask and focal plane mask (Figure 10 left). Afterwards, iteratively, laser is centered wrt to D1, avoiding to tilt it (Figure 10 center). Then, D1 is aligned in tilt looking at back-reflections and laser is centered. Once laser and D1 are aligned one to the other inside tolerances, center of the beam is marked on CCD#1 (Figure 10 right).

Figure 10: Concept for BEO reference axis definition and D1 tilt alignment

To assure a 90° deviation angle inside the housing, and define optical axis centered with BEO mechanics, a pentaprism will be used in place of M3 and aligned in tilt and along the optical axis in order to make the laser beam exiting through the reference mask’s center (Figure 11 left). Then, M3 replaces the pentaprism and is aligned in tilt and focus. And the position of the beam is marked on CCD#2 (Figure 11 right).

Figure 11: Left: a pentaprism replaces M3, to assure a 90° deviation angle and a reference mask is inserted to align the pentaprism to the mechanical housing. Right: M3 is re-installed and aligned.
To focus D1 wrt pupil and focal plane, where pupil masks are positioned, D1 is illuminated from both sides and small flat mirrors can be positioned in order to have their reflective surface onto the pupil/focal plane (a slot on the BEO mechanics/pupil mask has to be considered to allow this operation), see Figure 12. D1 position is adjusted in focus until having a focused spot onto CCD. It is verified to be inside tolerances illuminating it also from the other side and performing the same operations again. As last step D2 is aligned in tip-tilt and centering using transmitted beam seen on CCD#1 and back-reflected beam on CCD#2 (Figure 13).

![Figure 12: Concept for a setup to focus D1, illuminating it from both sides.](image1)

![Figure 13: Concept for a setup to align D2 in tilt and centering](image2)

### 6.4 BEO to TEL alignment

Final phase consists in the integration and alignment of BEO wrt OB and the opto-mechanical tube, as shown in Figure 3. M3 is removed and a Zygo interferometer and a beam-expander, through FM#3, illuminate Opto-mechanical Tube and BEO, as in Figure 8. BEO is held with a manipulator and is adjusted in focus until the beam coming out from D1 is roughly collimated. A flat mirror is inserted above OB, similarly to Figure 8 and is adjusted in tip-tilt in order to be perpendicular to the optical axis, allowing to analyze optical quality with Zygo in double-pass. Afterwards, BEO is iteratively adjusted in order to reduce aberrations on Zygo: defocus is minimized adjusting the BEO housing, coma is minimized centering the BEO and astigmatism is minimized tilting the BEO. Since we work with HeNe monochromatic light, after alignment the BEO should be shifted along the optical quantity by a known quantity. Shims have to be realized and inserted between BEO tripod and OB in order to fix it in this aligned configuration.

Then, M3 is re-installed and a test CCD is positioned on the nominal focal plane position (thanks to mechanical reference). At this point D2 is adjusted in focus until minimizing spot size onto CCD (Figure 14). Focal plane position has to be recorded by optical and mechanical means for FPM alignment in Bern. It will be verified also that field stop is not vignetting.
Finally, to verify optical quality of the fully aligned DM, FM#3, reflecting the Zygo beam into the TEL, is tip-tilted to explore the TEL FoV. All other verifications of test to be performed are reported in Section 7.

7. AIV TEST PLAN

In this section are outlined the main tests to be performed in order to verify CHEOPS TEL requirements are met. A few of them will be verified both on DM and PFM, while all tests concerning cryo-vacuum or vibration tests will be performed only on the PFM, due to the DM mechanical structure, which will be produced in aluminum and not in carbon fiber, and to the fact that masses will not be representative of the final ones.

- **Bandpass on DM + PFM**
  The TEL bandpass should be verified by means of a proper light source to include wavelengths between 400 and 1100 nm.

- **Throughput on DM + PFM**
  Throughput of the optical system has to be assessed over the wavelength range 400-1100 nm, and should be larger than 85% (detector is not considered). AR coating of the single lenses and mirrors must be measured and shown to be consistent with nominal values within 10% each or 30% of the whole BEO (whichever is more stringent). The total throughput will be measured with the help of a photodiode.

- **Effective F-Ratio on DM + PFM**
  Effective focal length should be measured at a single wavelength in the center of the FoV. Measuring also the aperture, the F-ratio can be retrieved. The value should be consistent with the nominal one by 1%.

- **TEL optical quality over FoV on DM + PFM**
  Optical quality has to be verified in at least three wavelength (or in white light with a known spectral distribution) to assess the Encircled Energy (EE) in the best focal plane position, which should be as good as 80% in a diameter < 3.7 pixels over the whole FoV. The measurement should be performed in at least five positions, encompassing the whole range explored with the nominal detector. Suggestion is to use (0,0), (0, 0.16), (0, - 0.16), (0.16, 0), (-0.16, 0) degrees. It should also be verified that for a FoV <0.12 degrees, 80% of the EE is inside a diameter < 2.7 pixels.
• **Optical quality on DM+PF**

Interferometric measurement will be used to assess the wavefront deformation of the whole system on-axis at one wavelength in the range of specification; the resulting WF should be as close to the nominal one as allowed: 40nm over 90% of the useful surface and less than 100 nm over the whole one. This verification test can be performed in double pass using a Zygo interferometer with a spherical element of appropriate focal length, as depicted in Figure 15.

![ZYGO Interferometer + spherical element](image)

Figure 15: Schematic representation of an interferometric test in double pass. A Zygo interferometer with a proper spherical element is considered.

• **PSF size on DM + PFM**

Optical quality should be verified also in the *defocused focal plane* nominal position, located at 3.672 mm from focused focal plane, at ambient temperature. At the FoV center, 90% EE should be contained in a spot diameter consistent with the nominal one (31.2 pixels) within 10 % (TBC with IIC). Defocused PSF should be recorded in white light. The same setup shown in Figure 9 could be used.

• **PSF Acceptance Function on DM + PFM**

Defocused PSF profiles should be verified over the whole FoV to be compliant with the given requirements and should be applied to CHEOPSim, a simulator to verify CHEOPS performances, for further testing.

• **Performance over pressure and temperature on PFM**

PSF tests should be repeated in a thermo-vacuum chamber, replicating in-flight conditions (T=-10 °C, P=0 atm) to verify performance over pressure and temperature at the nominal instrument operating conditions. Temperature test will be repeated also in a range of ± 5K with respect to nominal value (263 K).

• **Settling stability on PFM**

Mechanical interfaces will settle due to vibrations during launch, as well to the on-orbit moisture release. PSF should therefore be verified to be compliant with simulations after a test where launch loads effects, gravity and moisture releases are applied.

• **Mass on PFM**

Overall PFM TEL mass should be measured with a dynamometer. Optical train weight should not exceed 6 kg.
• **Contamination on PFM**

Cleanliness should be demonstrated to be of class 100 – ISO 5 or superior for at least seven points spread through the subsystem. Four can be coincident with optical surfaces (of which two must be M1 and M2 surfaces) and at least two must be co-located in the area of the internal baffle.

• **Definition of focal plane position on DM+PFM**

TEL focal plane shall be verified to lean in its nominal position and orientation wrt its reference plane with a precision of:

- Tilt: ± 1.88 mrad
- Defocus: ± 25 μm

To verify this requirement, the first step is the realization of a large collimated beam (at least 300 mm), obtained either through the means of a white light source and an Off-Axis Parabola (OAP) or through the use of an interferometer (Zygo) and a beam-expander. Of course in the latter case the multi-wavelength and monochromatic focal position difference will be computed and applied as a shift to the detector retrieved position.

A Hartmann mask, positioned at the entrance of TEL, will be used to define the position of the Focal Plane. Distance between two Hartmann’s mask holes (at least in two directions (i.e. x and y axes of Figure 16)) will be measured for different positions of the CCD along the optical axis. See Figure 16 for a possible setup.

![Hartmann test diagram](image-url)

**Figure 16:** Schematic representation of a Hartmann test. A Hartmann mask will be inserted at TEL entrance and the distance between 2 holes in the mask will be measured for different positions of the CCD along the optical axis to define the FP position. The two closest holes are representative of a possible trick to be used to understand if we are looking at an intra or extra-focal image.
8. CONCLUSIONS

AIV of the CHEOPS TEL Demonstration Model will take place at the INAF-Padova laboratories in warm conditions, starting in fall 2014. It has the aim to verify all interfaces, define GSEs and alignment tools and prove the feasibility of alignment inside the given requirements. The results of this study will provide guidelines and procedures to the industrial contractor responsible for the TEL PFM AIV.

REFERENCES


