International Conference on Space Optics—ICSO 2018

Chania, Greece

9–12 October 2018

Edited by Zoran Sodnik, Nikos Karafolas, and Bruno Cugny

Opto-mechanical alignment results of the Euclid near infrared spectro-photometer optical assembly NI-OA

H. Thiele

A. Mottaghibonab

M. Dubowy

A. Mecsaci

et al.

International Conference on Space Optics — ICSO 2018, edited by Zoran Sodnik, Nikos Karafolas, Bruno Cugny, Proc. of SPIE Vol. 11180, 111802V · © 2018 ESA and CNES · CCC code: 0277-786X/18/$18 · doi: 10.1117/12.2536022

Opto-mechanical Alignment Results of the Euclid Near Infrared Spectro-Photometer Optical Assembly NI-OA

H. Thiele[1*], A. Mottaghibonab[1], M. Dubowy[1], A. Mecsaci[1], E. Gubbini[1], K.Gawlik[1], F. Grupp[2], D. Penka[2], J. Kaminski[2]

[1]*OHB System AG, Manfred-Fuchs-Straße 1, 82234 Weßling, Germany.*

[2]*Max-Planck-Institute for Extraterrestrial Physics, Giessenbachstr, 85748 Garching, Germany*

Hans.Thiele@ohb.de, phone: +49 8153 4002 280

ABSTRACT

The Euclid payload features two instruments that are observing the sky simultaneously. The visual light high spatial resolution imager (VIS) and the Near Infrared Spectrometer and Photometer (NISP).

A Korsch type telescope with 1,2m diameter feeds both instruments via a dichroic beamsplitter. The NISP instrument reduces the incoming f/#20 beam of the telescope to an f/# 10 beam. The instruments optical system, the NISP Optical Assembly (NI-OA) contains 4 lenses, one single lens in front of a Grism and Filter wheel which is called collimator lens assembly (CoLA), and a lens triplet between these Grism and Filter wheel and the instruments focal plane, which is called camera lens assembly (CaLA). The focal plane consists of 16 Hawaii 2RG detectors.

The required alignment accuracy of the lens triplet and of the singlet relative to the triplet is very demanding and needs to be achieved and verified at the operational temperature of 134K. As an introduction the design, the integration and alignment concept are briefly summarized, as well as the measurement concept to verify the cold alignment within the cryostat. Alignment results for the integration of CaLA EQM and FM at room temperature are presented, the alignment stability after vibrational loads and thermal vacuum cycling is high, only minor changes of a few µm and arcsecs can be detected. The accuracy of the measured cryogenic alignment is demonstrated to be just a few µm and arcsec off the ideal predicted opto-mechanical alignment.

Keywords: Euclid, NISP, NI-OA, lens assembly, cryogenic alignment, alignment stability, glued lenses

1. INTRODUCTION

The Euclid Near Infrared Spectro-Photometer (NISP) optical system consists of a large Filter and GRISM wheel, 4 aspherical lenses with a large diameter of up to 168mm and an Infrared detector array. The opto-mechanical structure, which holds and keeps these units aligned is made from Silicon Carbite (SIC) (see **Figure 1-1**). The four lenses and their mounts are called **N**ear **I**nfrared Spectro-Photometer **O**ptical **A**ssembly (NI-OA). NI-OA is divided in 2 subunits, a lens triplet between filter wheel and detector which is named **Ca**mera **L**ens **A**ssembly (CaLA) and a single lens in front of the filter wheel, which is called **Co**rrector **L**ens **A**ssembly (CoLA). The whole NISP instrument operates at cryogenic temperature, with the Infrared detector at 90K and the NI-OA lenses at 134K.

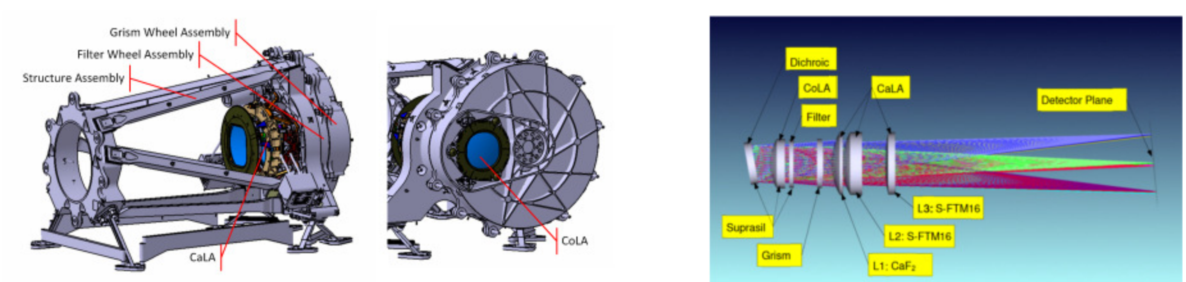

Figure **1-1** Near Infrared Spectro-Photometer (NI-SP) opto-mechanical design (left) and optical layout (right)

OHB is responsible for the opto-mechanical design of these two NI-OA units. The manufacturing, assembly and integration of the units is done by OHB while the alignment at room temperature is a joint task between OHB and Max-Planck-Institute for Extraterrestrial Physics (MPE). The verification of the opto-mechanical alignment of the NI-OA units at cryogenic conditions is again under responsibility of OHB. The final end to end optical performance test of the combined two units of NI-OA is MPE responsibility.

This paper is structured in the following sections: Section 2 briefly summarizes the opto-mechanical layout of NI-OA. The concept to mount and align CaLA at room temperature is explained in section 3. Section 4 briefly describes the measurement concept to verify that all lenses achieve precisely the desired aligned position at cryogenic temperature. A more detailed description of section 2-4 was presented in the previous conference [1]. Section 5 focusses on the alignment results and is structures in 4 subsections,

- the initial alignment accuracy during integration at room temperature,
- the stability of the alignment after thermal vacuum test
- the alignment accuracy at operational temperature and
- the stability of the alignment after vibrational tests.

Finally, section 6 concludes with a summary of the achievements and gives a brief outlook on the next activities.

2. NI-OA CALA OPTO-MECHANICAL DESIGN

The NI-OA opto-mechanical design is shown in Figure **2-1** All four lenses are mounted in their dedicated adaption ring. The CaF2 lens L1 of CaLA has a stainless steel adaption ring to match the CTE of CaF2. Both S-FTM16 lenses of CaLA, L2 and L3 are mounted in Titanium adaption rings. The separate Suprasil lens of CoLA requires an adaption ring made from INVAR M93 to minimize the CTE mismatch. The three lenses of CaLA are mounted on one central ring, the so-called lens-barrel, which is made from Titanium as well. For both Titanium adaption rings of L2 and L3 no CTE mismatch is present and they can be bolted to the lens-barrel directly. For the stainless steel adaption ring three Titanium bipods serve as interface and decouple the CTE mismatch between adaption ring and lens-barrel.

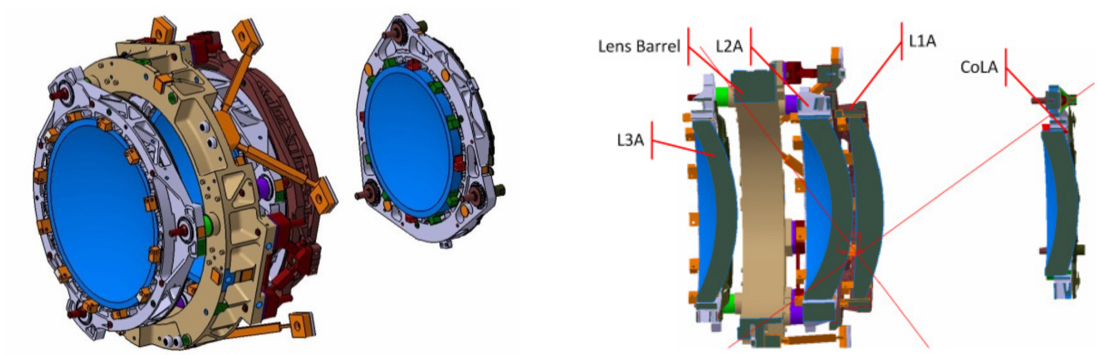

Figure **2-1** 3D CAD view of the Near Infrared Spectro-Photometer Optical Assembly (NI-OA) consisting of the CaLA triplet and CoLA (left), cross–section with nomenclature of lens-assemblies (right)

To mount the individual lenses to their adaption rings, an innovative gluing concept is applied. An extensive glue qualification campaign has been completed successfully, where all glass-to-metal and metal-to-metal glue interface combinations of NI-OA were tested under mission representative environmental conditions, especially the deep operational temperature [2]. The selected, low outgassing glue successfully passed this qualification program.

As the CTE match between lens material and mount material is not fully sufficient to avoid remaining stresses in the glass during cool down, additional flexure blades are part of each adaption ring design. Twelve flexure blades at the gluing interfaces provide additional flexibility and reduce the stresses in the glass to a tolerable minimum. The impact of the adaption ring design including the gluing interfaces on the optical performance of the lenses was extensively analyzed and tested for individual lenses [3]. The design with CTE matched adaption ring material, flexure blades at the glass to metal interfaces and a carefully designed glue interface decouple the lenses effectively from the mechanical structure and allow to achieve the specified SFE for all leases under operational temperature.

3. MOUNTING AND ALIGNMENT CONCEPT

The cryogenic operational temperature of 134K does not allow to perform any fine alignment of the unit while it is within the cryostat. The opto-mechanical alignment at room temperature needs to be precise enough and the alignment changes due to temperature have to be pre-compensated with such a high precision, that the optical performance at operational temperature is perfectly met. To achieve this, opto-mechanical alignment tolerances are derived for the individual lenses. The vertex position of each lens must be within +/-10µm laterally and +/-15µm along the axis, while the lenses might be tilted relative to their optical axis by maximum of 10 arcseconds. These values apply at operational temperature! The goal of the mounting and alignment concept now is to precisely predict the warm geometry of the unit (warm lens dimensions, warm dimensions of all structural components) and to integrate and align the lenses to achieve this warm geometry. If the alignment then fulfils the specified positional accuracy at operational temperature is verified with a opto-mechanical test under cryogenic conditions (see section 4) and ultimately by an end to end optical performance test.

For the integration at room temperature, the axial and tip/tilt alignment of the lenses is achieved by precision shimming. The correct shim thickness is derived from CMM measurements of the adaption ring interfaces, the lens barrel interfaces. The precise position of the lens within its adaption ring (vertex position and tip/tilt) is known by CMM measurement of adaption ring interfaces and the planar lens chamfer. The fabrication protocol of the lenses states the distance between lens vertex and a planar chamfer with µm precision. With these measured values and the warm geometry of CaLA, which is calculated with the structural model and all measured material CTEs, a precise shim geometry can be derived, with brings the vertex to its desired warm position and minimizes the tip/tilt of the lenses.

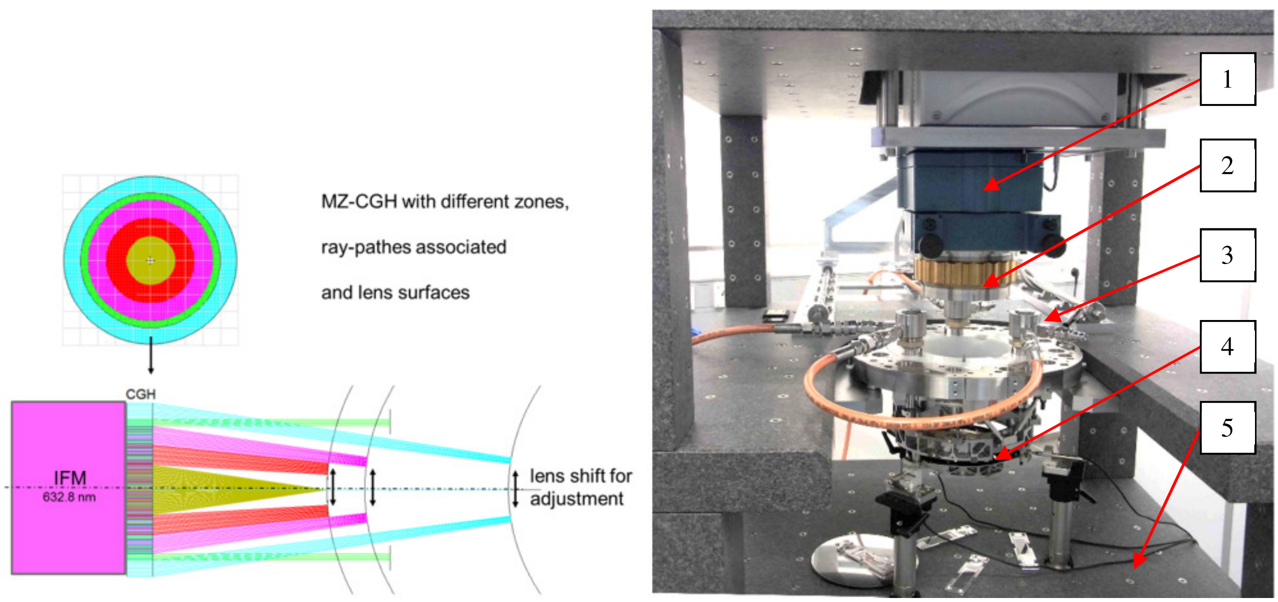

Figure 3-1 Alignment concept with Multi-Zonal-CGH (left); right: Interferometric alignment tower: 1: Zygo Interferometer, 2: multi-zone CGH, 3: Hydraulic bolt tensioner for tightening all three fixation bolts of a lens assembly simultaneously in the aligned position, 4: CaLA Structure with L3 and L2, 5: highly stable granite alignment tower

For the lateral alignment, some optical reference is needed to center the lenses relative to each other. For the Euclid NI-OA alignment a complex multi-zone computer generated hologram (CGH) was developed by MPE, which allows to center the tree lenses with µm accuracy during assembly of the unit. Figure 3-1 illustrates the multi-zone CGH concept. This alignment CGH contains a number of ring zones. Each of these ring zones has a focus length which is tailored to one of the three spherical lens surfaces. An additional fourth CGH ring delivers a parallel beam, which is intended to measure a planar reference to set up the optical axis at the beginning of the mounting and alignment sequence and to be able to control the setup stability between the individual steps of the procedure. The lens radii and distances, which are used for definition of this CGH are of course the radii at room temperature and the axial distances at room temperature. The CGH therefore also contains the pre-compensation information, which is also used to define the axial shims. Interferometer, CGH and the NI-OA opto-mechanics have to be mounted in a highly stable alignment tower, as shown in Figure 3-1 on the right. A detailed sequence of the integration steps with this setup is given in [1].

4. CRYOGENIC ALIGNMENT VERIFICATION CONCEPT

To verify the correct alignment of the CaLA optical subsystem at the operational temperature of 134K, an innovative measurement approach was realized. The cryogenic geometry of the system can be derived by subtraction of the cool down movements from the warm geometry, which is known precisely by CMM measurements at room temperature. This positional measurement, which has to achieve the same accuracy as a 3D measurement with a CMM, has to take place within the cryostat during cool down and at operational temperature. OHB selected an interferometric, fiberoptic distance sensor system, which was developed for cryogenic applications [4] and can detect movements of a flat reflective metal or glass surface in a distance range between a few cm up to more than 15cm with a sub-µm resolution. For each of the individual lens assemblies, the lens barrel and the interface plate, a set of these interferometric sensors monitors the axial and radial movement. All sensors are mounted on a highly stable Zerodur sensor mount, which is placed around the CaLA unit within the cryostat. (see Figure 4-1).

Figure 4-1 CaLA cryogenic alignment test. The ZERODUR structure holds all interferometric fiber optic distance sensors, which monitor the movement of each lens assembly in lateral and axial direction during the thermal cycling

As the resolution of the interferometric sensors is quite high (sub-µm) and as the required positional accuracy of the test is in the same order than the positional accuracy of a CMM, a dedicated calibration of this GSE was done, using a solid titanium dummy instead of CaLA. With the homogenous shrinkage of this Titanium dummy it was feasible to characterize the setup inside the cryostat. These values are later on used to correct the measured data of the actual CaLA triplet. A more detailed description of the setup and its calibration can be found in [1].

The environmental conditions for the thermal cycling and the measurement of the cryogenic alignment are as follows:

- RT: 295K, $p < 1 \times 10^{-5}$ hPa
- Non OPS min Accept&Qual: 105K, $p < 1 \times 10^{-5}$ hPa
- Non OPS max Accept&Qual: 323K, $p < 1 \times 10^{-5}$ hPa
- OPS min Accept&Qual: 128K, $p < 1 \times 10^{-5}$ hPa

At these temperatures, the temperature sensor stability criterion of ≤1K/h and the distance sensor stability of ≤200nm/h were reached within a stability time of 2h and distance measurements performed.

5. ALIGNMENT RESULTS

To show the precision, reproducibility and stability of the alignment at room temperature, the alignment results after integration and after environmental testing are presented. To demonstrate the reproducibility of the concept, measured values for both EQM and FM are presented in comparison for

- the initial integration alignment at room temperature
- the alignment stability after the cryogenic cycling
- the alignment accuracy at operational temperature
- the alignment stability after vibrational testing

5.1 Opto-mechanical alignment results at initial integration

The mounting and alignment concept, based on the multi-zone CGH and the solid granite alignment tower turned out to be sufficiently stable and accurate to achieve the desired alignment accuracy in the first integration run. No iteration was required. The axial and tip/tilt alignment could be achieved with pre-manufactured planar shims. Their axial dimension was derived from precise CMM results for lens assemblies and lens barrel to minimize any tip/tilt of the lenses and to position their vertices correctly along the optical axis.

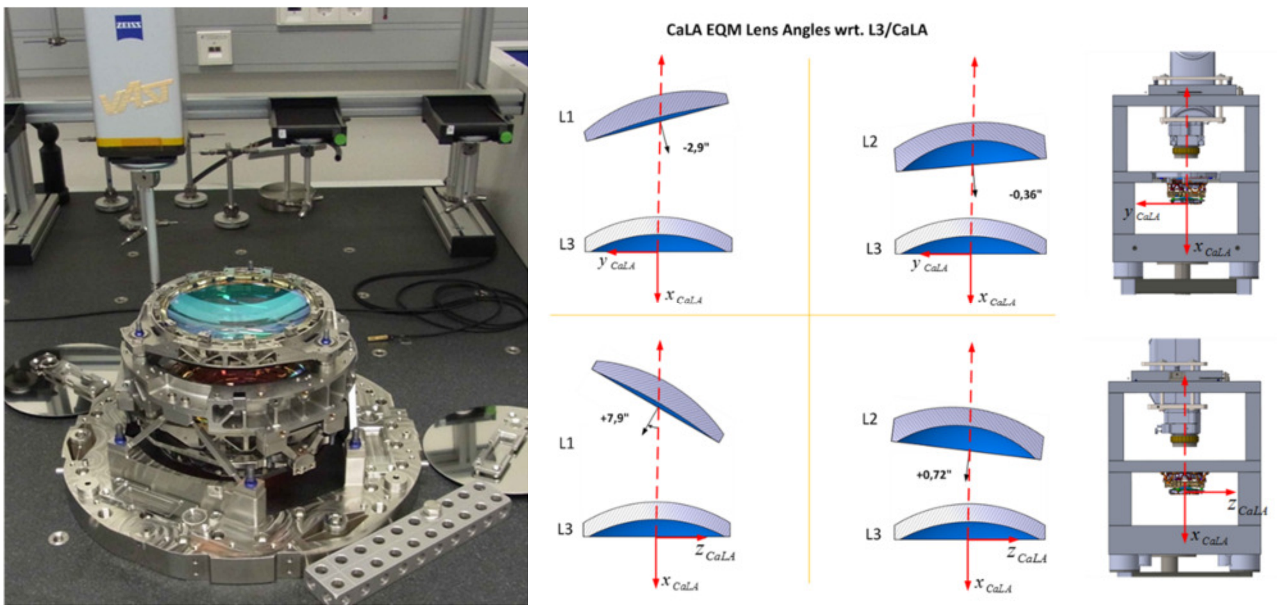

Figure 5-1 left: Coordinate Measurement Machine in ISO 4 environment to characterize the opto-mechanical alignment of CaLA before and after the environmental tests; Right: EQM measurement results, evaluated for tip/tilt angles between the individual lenses

The tip/tilt values and the axial displacement, which are shown in Figure 5-1 and Table 1, Table 2, Table 3 are based on precision CMM measurements. The lateral offset values of the lenses relative to each other as shown in Figure 5-2 on the right are based on interferometric measurements with the alignment CGH.

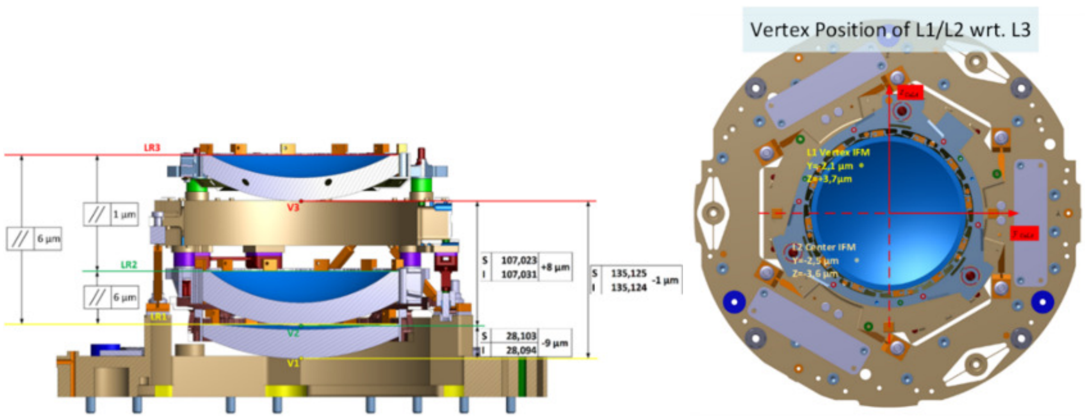

Figure 5-2 left: cross-section of CaLA showing the vertex positions of all three lenses and the relative tilt (parallelism)
right: top view to view of CaLA, showing lateral displacement of the L1 and L2 Vertices relative to the L3 Vertex

Table 1 CaLA EQM / ***FM*** Alignment Accuracy after integration at room temperature.

CaLA Alignment after integration	L1	L2	L3
Tip / Tilt	-2,9" / +7,9" ***-0,9" / -1,0"***	-0,4" / + 0,7" ***-4,4" / -1,2"***	0" / 0" (reference)
Relative axial vertex offset	-1µm ***+ 1µm***	+8µm ***+3µm***	0µm (reference)
Relative lateral vertex position	Y: -2.1µm / Z: +3,7µm ***Y: -3,4µm / Z: +4,0µm***	Y: -2,5µm / Z: -3,6µm ***Y: -0,8µm / Z: +2,2µm***	Y: 0µm Z: 0µm (reference)

5.2 Alignment stability after cryogenic cycling

The thermal cycling down to the cryogenic operational temperature has two different goals:

- Measurement of the movement during various cycles of cool-down and warm-up is targeted at the stability of the alignment and shows minor drift or slippage due to the glue at the glass to metal interfaces or micro slippage movements due to minor CTE differences at the mechanical interfaces within the CaLA structure or settling effects at the bolted interfaces.
- Verify that the opto-mechanical alignment at operational temperature is met within the required tolerances.

Table 2 CaLA EQM / ***FM*** Alignment Accuracy after thermal cycling at room temperature

CaLA alignment after thermal cycling	L1	L2	L3
Tip / Tilt	-3,2" / +7,6" ***-1,4" / -0,8"***	-1,4" / + 0,4" ***-4,4" / -1,3"***	0" / 0" (reference)
Relative axial vertex offset	-4µm ***-2µm***	+6µm ***+2µm***	0µm (reference)
Relative lateral vertex position	Y: -1,6µm / Z: +7,4µm ***Y: +1,8µm / Z: +6,0µm***	Y: -1,8µm / Z: -2,4µm ***Y: +1,2µm / Z: +2,2µm***	Y: 0µm Z: 0µm (reference)

5.3 Alignment accuracy at operational temperature

To determine the cold vertex positions of the lenses at OPS min Temperature (with ΔT = 158,15K) the raw data of the four axial distance sensors for each lens had to be corrected by the theoretical CTE-influence on the double pads and the lens.

The actual vertex position changes between the lenses at minimum operational temperature for EQM / ***FM*** are

Vertex 2-1: 102,09 µm / ***102,83 µm***

Vertex 3-1: 243,11 µm / ***243,26 µm***

The theoretical vertex position changes between the lenses calculated with NASTRAN and based on measured CTE values are:

Vertex 2-1: 103,77 µm / ***103,77 µm***

Vertex 3-1: 239,09 µm / ***239,09 µm***

The resulting difference between the theoretical and measured cold vertex positions of the lenses is:

Δ Vertex 2-1: -1,68 µm / ***-0,94 µm***

Δ Vertex 3-1: +4,02 µm / ***+4,17 µm***

The prediction of the delta between warm and cold geometry is very close to the actual measurement and therefore only these small deltas have to be added to the alignment tolerances at room temperature. This means that the vertex positions are clearly with the specified +/- 15µm at operational temperature.

In due consideration of the test setup movement, following translations and displacements (tip-tilt) of the lenses, LB and NI-SA of the x-, y- and z-axis can be derived. Figure 5-3 illustrates the translation and tip-tilt results of the lenses, LB of the CaLA EQM lenses and NI-SA during the thermal vacuum cycling (second cycle) after compensation of the test setup movements. Figure 5-4 shows the same evaluated data on translation and tip/tilt for the CaLA FM.

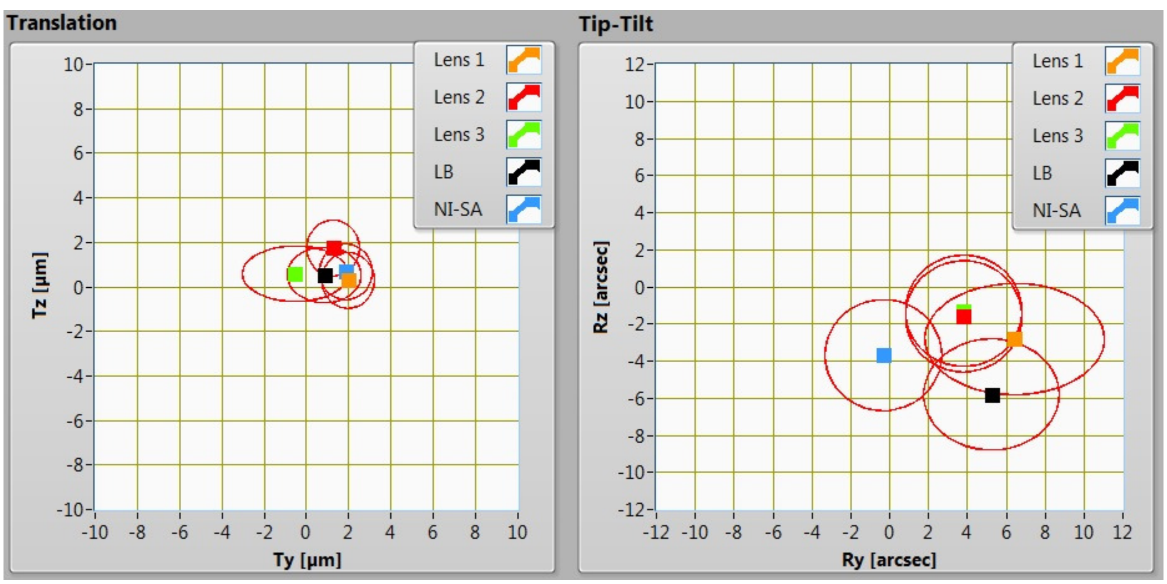

Figure 5-3: CaLA EQM translation and displacement (Tip-Tilt) of Lens 1-3, LB and NI-SA in z- and y-direction with correction values for the setup and error circles.

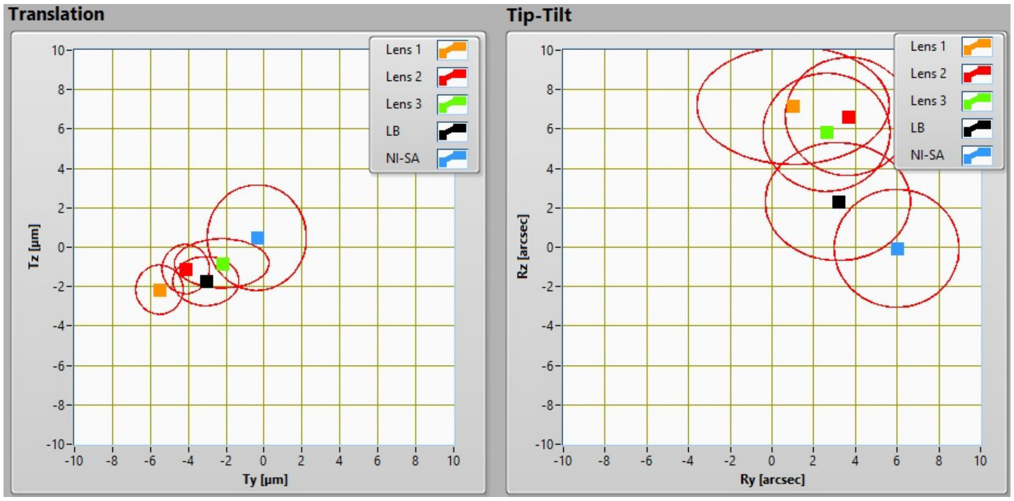

Figure 5-4 CaLA FM Translation and displacement (Tip-Tilt) of Lens 1-3, LB and NI-SA
in z- and y-direction with correction values and error circles

These extremely small differences for axial, lateral and tip/tilt displacements between model prediction and actual measurement are very impressive. The initial concept for alignment and cryogenic alignment verification did foresee an iteration in case the shrinkage during cool down would have been too large for the alignment budget. For such a scenario, a set of new shims would have to be derived and integrated to pre-compensate any unpredicted cool down movements. With these very small measured displacements, which stay clearly within the alignment budget, such an iteration with dedicated cold shims became obsolete. Even when these small offsets are added to the minor misalignment tolerances at room temperature (see Table 1) the lateral alignment budget at operational temperature of +/-10µm lateral displacement for the lens vertices and a tip/tilt tolerance below 10 arcsec are met.

5.4 Alignment stability after vibration testing

For each axis, the following vibration tests were performed:

- First resonance search; Input: 0.1g; 5-2000 Hz; 2 oct/min
- Sinus Load Run; Input: 25g; 5-100 Hz; 2 Oct/min
- Second resonance search; Input 0.1g; 5-2000 Hz; 2 oct/min
- Low Level Random Run
- Full Level Random (Notched Spectrum) Run (first 30s -6dB for checking), 0dB for 120s
    - Input X (Out Of Plane): 4.63 gRMS; Output (1σ): 12 gRMS
    - Input Y: 4.76 gRMS; Output (1σ): 9.5 gRMS
    - Input Z: 4.76 gRMS; Output (1σ): 8.5 gRMS
- Third resonance search; Input 0.1g; 5-2000 Hz; 2 oct/min

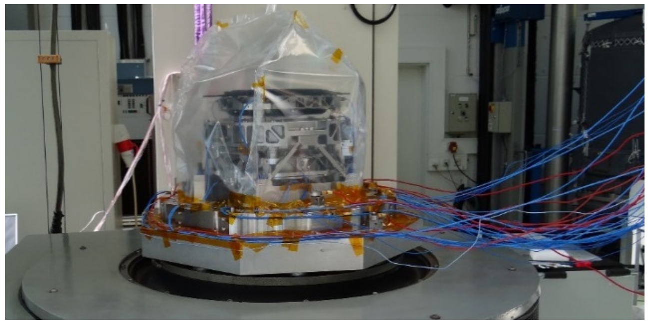

Figure 5-5 CaLA EQM mounted on the shaker at MPE (incl. protection cover for cleanliness)

Without going into detail about the actual loads, confirmed eigenfrequencies and required notching during the test, the main success criteria of the vibrational test are the structural integrity and the alignment stability. Table 3 shows the corresponding values after the vibration test campaign (compare to Table 2 for the values before that test campaign).

Table 3 CaLA EQM / ***FM*** Alignment Accuracy after vibration testing at room temperature

CaLA Alignment after vibration testing	L1	L2	L3
Tip / Tilt	-4,0" / +6,8" ***-1,6" / -0,3"***	-0,7" / + 2,5" ***-4,7" / +1,1"***	0" / 0" (reference)
Relative axial vertex offset	-5µm ***+1µm***	+6µm ***+4µm***	0µm (reference)
Relative lateral vertex position	Y: -6,9µm / Z: +5,7µm ***Y: -1,0µm / Z: +4,0µm***	Y: -7,0µm / Z: -2,9µm ***Y: -1,6µm / Z: -0,1µm***	Y: 0µm Z: 0µm (reference)

5.5 Assembly and alignment of CoLA relative to CaLA

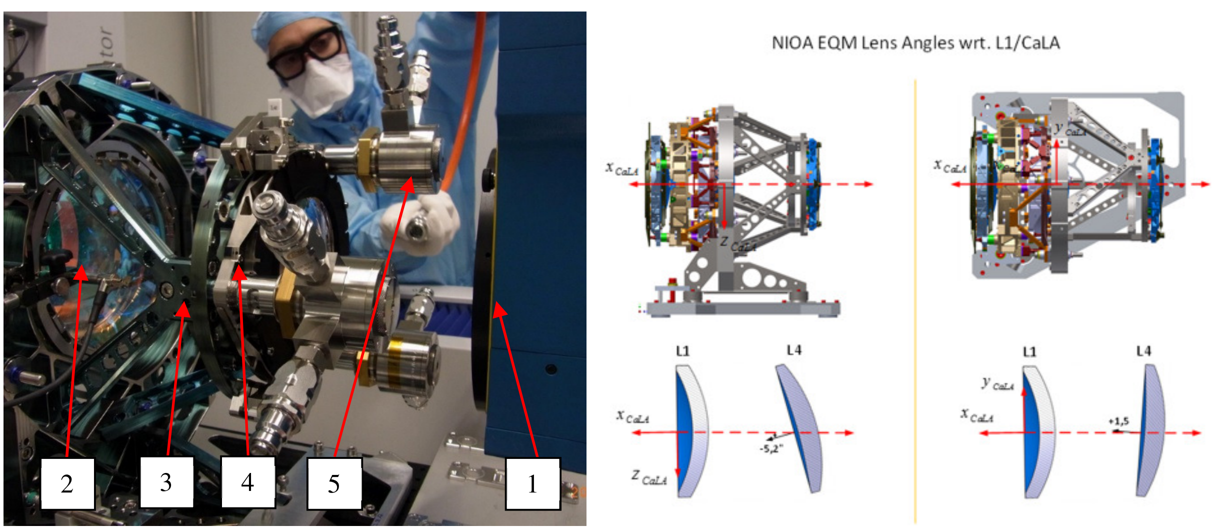

Figure 5-6 left: Assembly and alignment of CoLA lens relative to the CaLA Lens assembly: 1: Interferometer / alignment CGH; 2: L1 of CaLA; 3:Interface dummy between CaLA and CoLA, 4: CoLA Lens assembly; 5: Hydraulic bolt tensioner; right: achieved positional accuracy (tip/tilt) of CoLA relative to the L1 reference surface on CaLA, measured with a CMM.

For the end to end optical performance test at MPE both CaLA and Cola have to be mounted and aligned with respect to each other. The alignment concept is the same as for integration and alignment of CaLA: Interferometric observation with a multi-zone CGH and precision shimming to eliminate tip/tilt while achieving the correct axial distance. The setup for lateral alignment to center CoLA relative to CaLA is shown in Figure 5-6. As the SIC structure of the instrument is not available at MPE, a complex interface dummy made from INVAR simulates the mechanical interfaces and the CTE behavior at low temperatures. The CGH in front of the interferometer is aligned relative to the first lens surface of CaLA, visible on the very left. Thus the optical axis for the assembly is established. The CoLA lens assembly is mounted with three axial shims (minimizing tip/tilt and adjusting the correct axial position) and centered to the CGH. A dedicated hydraulic bolt tensioner is used to tighten the mounting bolts of CoLA in this position without introducing any torque, which would introduce stresses and decrease the final alignment accuracy. The aligned assembly is characterized with the CMM, remaining Tip/tilt angles are 1,5” and 5,2” relative to the optical axis. The positional accuracy along the optical axis is met with an accuracy of 5µm. The lateral displacement relative to L1 of CaLA is within +/- 5µm. These Tolerances are very small an far below the specified positional tolerance of CoLA relative to CaLA. which apply when both units are mounted on the actual SIC structure of the instrument.

6. CONCLUSION & OUTLOOK

6.1 Conclusion

The NIOA optical subsystems CaLA and CoLA have been successfully assembled, aligned and successfully passed their environmental test campaign for qualification and acceptance loads. They are ready for the optical end to end performance testing and integration into the NISP instrument.

- The highly accurate opto-mechanical alignment, which was achieved with a complex multi-zone CGH and precision shimming achieved the desired accuracy in the first integration and alignment run. No iteration and correction of shims was required for both EQM and FM. The stability of the alignment GSE and bolt tightening with the dedicated hydraulic bolt tensioner provided the required high precision.
- The aligned CaLA unit also fulfills the demanding opto-mechanical alignment requirements under thermal and vibrational loads and shows a very good stability in the order of only a few µm and arcsec positional changes. Tolerances for EQM and FM are comparable and demonstrate the reproducibility of the concept.
- The predicted cold geometry of the aligned CaLA system could be verified under cryogenic conditions with a highly stable and precise measurement setup within the cryostat. Thanks to the detailed structural prediction (Nastran model including measured CTEs for all glasses, adhesive and structural metals) and the precise characterization of the measurement setup the cryogenic alignment positions @ 134K could be verified with high precision and met the ideal theoretical alignment positions with just a few µm and arcsec offset.
- The gluing concept of the large lenses of NI-OA shows no degradation or drift during all environmental test activities. Even during the thermal cycling test and repeated measurement of the cryogenic alignment the glued assemblies remain very stable and fulfil the stringent positional requirement.

It has been successfully demonstrated that a lens assembly with large lenses up to 170mm diameter and various glasses and for an application at temperatures as low as 130K can be build and aligned and that the desired alignment accuracy below +/-10µm laterally and +/-15µm along the optical axis and below 10” in tip/tilt can be achieved using low outgassing glue for the mounting of the lenses.

6.2 Outlook

The CaLA and CoLA EQM and FM have been delivered to MPE for final optical performance testing at operational temperature at MPE facilities in Garching. Initial results of these NI-OA optical performance tests show an extremely good wavefront error and a PSF quality at operational temperature. Detailed results on the achieved optical performance will be published separately.

CaLA has been delivered to LAM and was successfully mounted on the actual SIC structure of the instrument. The integration of CoLA is pending and currently waits for integration of the Filter & Grism Wheels with their cryogenic actuator and closure of Panel 2 of the SIC structure.

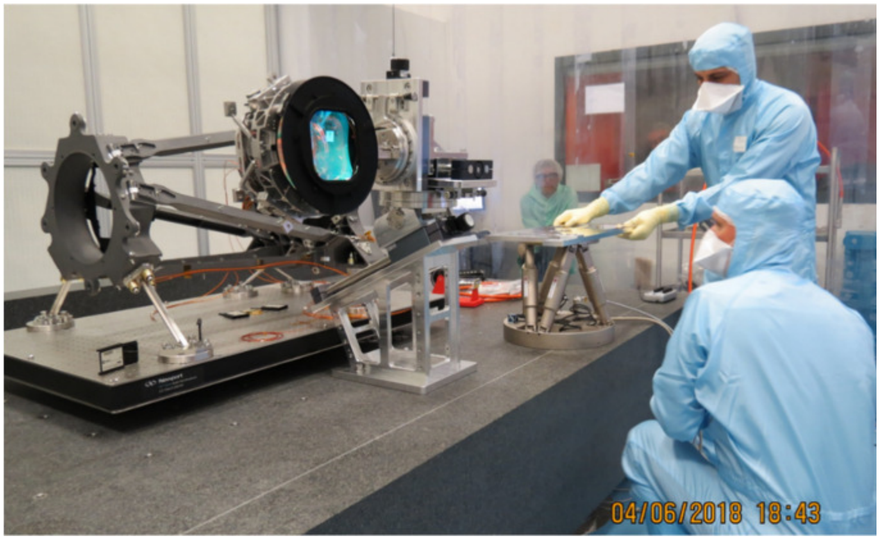

Figure 6-1 CaLA EQM integration to the NISP SIC structure at LAM

ACKNOWLEDGEMENTS

The development of the NISP optical assembly is performed under a contract from MPE, Garching. The MPE EUCLID participation is supported by DLR grant 50 OO 1101. The authors would like to acknowledge Max-Planck-Institute for Extraterrestrial Physics (Garching) for their co-operation.

REFERENCES

[1] H.Thiele et al., "Mounting, Metrology and Verification of Euclid Near Infrared Spectro-Photometer Optical Assembly NIOA", Proc. 119 ICSO 2016

[2] A. Mottaghibonab, et al., "Gluing Interface Qualification and Gluing Process Development of the EUCLID Near Infrared Spectro-Photometer Optical assembly", *Proc. SPIE 9912-42*, (2016)

[3] C. Gal, et al. ,"Optical Performance Analysis and Test Results of the EUCLID Near-Infrared Spectro-Photometer", Proc. SPIE 9912-42, (2016)

[4] K. Thurner, et al., " Fabry-Pérot interferometry for long range displacement sensing", REVIEW OF SCIENTIFIC INSTRUMENTS 84, 095005 (2013)