

WOB lenses verification at LAM – 10/11/2022

Measurement report

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Approval request

| Approved by | Function | Date | Signature |
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| Summary | This document deals with the verification of the main characteristics of the WOB |
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| | lenses. |
| Annexes | |

| Keywords | WOB, Fizeau interferometry, inspection, acceptance |
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| Distribution | |
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| Applicable Documents (AD) | | | | |
|---------------------------|------------------------|-----------|---------|--|
| AD | Title | Reference | Version | |
| AD1 | L5-rework | | | |
| AD2 | passport L6 (18983.2) | | | |
| AD3 | L7-rework | | | |
| AD4 | passport L9 (18983.4) | | | |
| AD5 | passport L10 (18983.5) | | | |
| AD6 | passport L11 (18983.6) | | | |

| Reference Documents (RD) | | | | |
|--------------------------|---------------------------------------|-----------|---------|--|
| RD | Title | Reference | Version | |
| RD1 | COLIBRÍ Optical Design v8.1 | | 8.1 | |
| RD2 | DDRAGO and WOB Mechanical Design v3.2 | | 3.2 | |
| RD3 | New_Specs_CAGIRE_lenses_Oct_2021 | | | |

| List of Abbreviations | | | | |
|-----------------------|----------------------------------|--|--|--|
| WOB | Warm Optical Bench | | | |
| UNAM | Univervidad Nacional Autonoma de | | | |
| | Mexico | | | |
| LAM | Laboratoire d'Astrophysique de | | | |
| | Marseille | | | |
| RoC | Radius Of Curvature | | | |
| CC | Concave | | | |



| СХ | Convex | |
|-----|------------------|--|
| SFE | Surface Error | |
| PTV | Peak-To-Valley | |
| RMS | Root Mean Square | |
| CA | Clear Aperture | |



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1. INTRODUCTION

The warm optical bench (WOB) is the optomechanical assembly that provides the optical beam coming from the COLIBRI telescope to the CAGIRE channel.

The design and the delivery of the WOB is under UNAM responsibility. The optical design of the WOB is described in details in RD1 and its optomechanical design is detailed in RD2. More specifically, the WOB is an assembly of 7 lenses, 3 fold mirrors.

The 3 fold mirrors are provided by UNAM and are not a part of this report.

Six of the lenses have been manufactured by Trioptics in Europe and have been delivered to LAM, where they are currently verified. Each lens has a measurement report from the manufacturer (from AD1 to AD6).

The seventh lens is being manufactured by Trioptics.

The current document reports on the verification of the 6 already-delivered lenses. The UNAM prescription for the lenses are given in RD3.

2. THE LENSES

The 6 lenses are spherical lenses and are labelled as: L5, L6, L7, L9, L10, L11. L8 is an aspherical lens and will be tested when delivered at LAM.

3. TEST PLAN

UNAM and LAM agreed on the test plan indicated in Table 1.

| Characteristic | Method | Tool | |
|----------------------|---|----------------------------|--|
| | Visual inspection | Unaided eye | |
| | | Comparison with etalon (if | |
| Cosmetics | | needed) | |
| | | Digital microscope or | |
| | | binocular (if needed) | |
| Diameter | Mechanical metrology by | Digital caliper | |
| Diameter | contact | Digital camper | |
| Central thickness | Mechanical metrology by | Contac sensor (comparator) | |
| Central thickness | contact | Thickness etalons | |
| Surface error | Interferometry | Fizeau interferometer | |
| Padius of our voture | Interferometry and mechanical | Fizeau interferometer with | |
| Radius of culvature | displacement | optical ruler | |
| | Table 1 · Test plan for each lens surface | | |

We do not verify the surface centrations, the lens wedges, the spectral response of the coatings, the roughness and the geometry of the bevels and chamfers.

4. **RESULTS**



Table 2 recapitulates the results obtained for diameters, central thicknesses and RoCs. The compliance with the prescription and the comparison with the manufacturer measurements are indicated.

<u>Remark on RoC measurement</u>: It is important to note that the measurement method from the manufacturer and that from LAM are certainly very different. It is believed that the manufacturer performs RoC measurements on uncoated lenses, during polishing, and with mechanical tools as spherometers (the diameter of the spherometer is unknown). LAM performs RoC measurements on coated lens by measuring the distance (with an optical ruler) between the 2 nulling positions of the lens in front of a Fizeau interferometry (the used diameter of one of the nulling position depends on the f-number of the reference sphere on the interferometer).

| Lens | Source | Diameter | Central | RoC of | RoC of | |
|------|--------------|---------------|--------------------------------|-------------|-------------|--|
| | | | thickness | surface 1 | surface 2 | |
| | Prescription | 90mm +0 -0.5 | 10 mm ± 0.1 mm | 90.000mm ± | 125.993mm ± | |
| 15 | | | | 0.1mm (CC) | 0.1mm (CX) | |
| LJ | Manufacturer | 89.90mm | 10.098mm | 90.053mm | 125.893mm | |
| | LAM | 89.88mm | 10.00mm | 90.06mm | 125.84mm | |
| | | | | | | |
| | Prescription | 128mm +0 -0.5 | $22\text{mm} \pm 0.1\text{mm}$ | 500.438mm ± | 117.025mm ± | |
| LC | 1 | | | 0.15mm (CC) | 0.1mm (CX) | |
| Lo | Manufacturer | 127.89mm | 21.883mm | 500.382mm | 117.115mm | |
| | LAM | 127.87mm | 21.82mm | 500.27mm | 117.10mm | |
| | | | | | | |
| | Prescription | 119mm +0 -0.5 | $12\text{mm} \pm 0.1\text{mm}$ | 147.517mm ± | 104.613mm ± | |
| L7 | - | | | 0.1mm (CX) | 0.1mm (CC) | |
| | Manufacturer | 118.86mm | 12.057mm | 147.562mm | 104.557mm | |
| | LAM | 118.87mm | 11.98mm | 147.56mm | 104.54mm | |
| | | | | | | |
| | Prescription | 154mm +0 -0.5 | $15\text{mm} \pm 0.1\text{mm}$ | 177.067mm ± | 293.682mm ± | |
| LO | - | | | 0.1mm (CC) | 0.1mm (CX) | |
| L9 | Manufacturer | 153.86mm | 14.950mm | 177.119mm | 293.782mm | |
| | LAM | 153.84mm | 14.95mm | 177.10mm | 293.70mm | |
| | | | | | | |
| | Prescription | 145mm +0 -0.5 | 15mm ± 0.1mm | 275.673mm ± | 156.215mm ± | |
| | 1 | | | 0.1mm (CX) | 0.1mm (CC) | |
| L10 | Manufacturer | 144.85mm | 15.018mm | 275.715mm | 156.274mm | |
| | LAM | 144.84mm | 15.02mm | 275.59mm | 156.29mm | |
| | | | | | | |
| | Prescription | 145mm +0 -0.5 | $30\text{mm} \pm 0.1\text{mm}$ | 195.182mm ± | 643.859mm ± | |
| T 11 | * | | | 0.1mm (CX) | 0.3mm (CX) | |
| LII | Manufacturer | 144.86mm | 30.015mm | 195.212mm | 643.959mm | |
| | LAM | 144.87mm | 29.98mm | 195.01mm | 643.82mm | |

 Table 2 : Diameters, central thicknesses and RoCs of the WOB lenses. A green (orange) cell indicates that the value is compliant (non-compliant) with the prescription.



Table 3 gives the results obtained for surface errors. Note that the SFE measurements of the manufacturer are on zones that are largely less than the clear aperture (which is surprising; maybe a bad conversion factor in the configuration of the software ?).

| Lens | Source | SFE of surface 1 | SFE of surface 2 |
|------|---------------|-------------------|-------------------------------|
| | Prescription | < 317nm PTV | < 317nm PTV |
| | CA=68mm | | |
| | Manufacturer* | 71nm PTV | 151nm PTV |
| L5 | On 14/12mm** | 13nm RMS | 30nm RMS |
| | LAM | 332nm PTV | 82nm PTV |
| | | 70nm RMS | 15nm RMS |
| | | On 60mm area*** | On 42mm area*** |
| | | | |
| | CA = 108mm | < 317nm PTV | < 317nm PTV |
| | Manufacturer* | 46nm PTV | 156nm PTV |
| L6 | On 13.6mm** | 8.5nm RMS | 26nm RMS |
| | LAM | 90nm PTV | 100nm PTV |
| | | 17nm RMS | 13.5nm RMS |
| | | On 167mm area*** | On 97mm area*** |
| | | | |
| | Prescription | < 317nm PTV | < 317nm PTV |
| | CA = 102mm | | |
| | Manufacturer* | 82nm PTV | 75nm PTV |
| L7 | On 14mm** | 15nm RMS | 16nm RMS |
| | LAM | 92nm PTV | 72nm PTV**** |
| | | 16nm RMS | 12nm RMS |
| | | On 49mm area*** | On 70mm area*** |
| | | | |
| | CA = 132mm | < 31/nm PTV | < 317nm PTV |
| | Manufacturer* | 70nm PTV | 229nm PTV |
| L9 | On 14mm** | 8.5nm RMS | 41nm RMS |
| | LAM | 168nm PTV | 50nm PTV |
| | | 24.5nm RMS | 10nm RMS |
| | | On 147/mm area*** | On 98mm area*** |
| | D 1 1 | | |
| | Prescription | < 31 / nm PTV | < 31 / nm PTV |
| | CA = 126mm | | |
| I 10 | Manufacturer* | 150nm PTV | 194nm PTV |
| LIU | ON 13mm** | 23nm RMS | 35nm KMIS |
| | LAM | SUNM PTV | 134nm PTV |
| | | onm KIVIS | 20nm KNIS On 120mm croc*** |
| | | On 92mm area*** | On 150mm area*** |
| | Dressription | < 317nm DTV | < 217nm DTV |
| L11 | Prescription | < 31/IIII F I V | |
| | CA = 118mm | | |



| Manufacturer* On 13mm** | 143nm PTV 27nm RMS | 157nm PTV 28nm RMS |
|----------------------------|-----------------------|-----------------------|
| LAM | 66nm PTV | 204nm PTV |
| | 13nm RMS | 28nm RMS |
| | On 65mm area*** | On 65mm area*** |

Table 3 : SFE values and cosmetics comments of each surface of the WOB lenses. A green (orange) cell indicates that the value is compliant (non-compliant) with the prescription. *The SFE values from the manufacturer are averaged values calculated from the PTV and RMS values coming from the manufacturer reports (sometimes, several values are given by the manufacturer because their measurements seem to not be very stable). **The measurement apertures indicated by the manufacturer are surprising (we suppose that the values given are on the CA). ***We indicate the diameters of the measurement circular areas on each surface; it is fixed by the reference spheres used. ****- This surface is out of specification in terms of cosmetics (big defect).

Sections 5 and 6 gives more details on surface errors (SFE) and cosmetics. The non-compliances are discussed in these sections. In Table 3, they only indicate non-compliances with respect to the PTV surface error specification as given to the manufacturer in RD3.

5. SURFACE ERROR MAPS

The surface error (SFE) maps are given below (from Figure 1 to Figure 12).



5.1. Surface error of the concave surface of L5

| Statistics Aberrat Histogram Inform | tions F lation | Fiducials | History Report | |
|--|--|--------------|-------------------|--------------------|
| Standard | | Customize Re | fresh | |
| | _ | | | |
| lliWave Report Sun | nr | | <u>_</u> | |
| Parameter | Value | Units | QC | |
| PV | 332.3568 | nm | | |
| RMS | 70.0125 | nm | | |
| | | | | |
| 4) Focus (norm) | 1.0529 | nm | | |
| 5) X Astig (norm) | 4.2859 | nm | | |
| 6) Y Astig (norm) | -62.4803 | nm | | |
| 7) X Coma (norm) | 3.6150 | nm | | |
| 8) Y Coma (norm) | -10.0532 | nm | | |
| 9) Spherical (norm) | -27.5030 | nm | | |
| | | | | |
| | | | | |
| Date(measured): Tur | e Sep 20 11 | 47:30 2022 | | |
| | | | | |
| Removed: X Tilt (norm). | Y Tilt (norm). | Focus (norm | | |
| Process: [5B.M.TM | DI | | | |
| | - | | - | |
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| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| Statistics Aberratio | ons Fi | ducials | History | |
| Histogram Informa | ition F | Regions | report | |
| Standard | - C | ustomize Ref | resh | |
| | | | | |
| liWave Report Sum | r | | | |
| Parameter | Value | Units | QC | |
| PV | 163.0733 | nm | | |
| RMS | 4.1432 | nm | | |
| | | | | |
| 4) Focus (norm) | 0.0090 | nm | | |
| 5) X Astig (norm) | -0.0008 | nm | | |
| G) X Astig (norm) | 0.0008 | | | |
| b) T Astig (norm) | -0.0005 | nm | | |
| 7) X Coma (norm) | 0.0017 | nm | | |
| 8) Y Coma (norm) | 0.0003 | nm | | |
| 9) Spherical (norm) | -0.0099 | nm | | |
| | | | | |
| | | | | |
| Date(measured): Tue | Sep 20 11: | 47:30 2022 | | |
| | | | | |
| Removed: All | | | | |
| Process: ISD M THE | () () () () () () () () () () () () () (| | | |
| CONTRACTOR IN THE | 1 | | | |
| Tocess. [58,W, IML | [נ | | | |
| Frocess. [ob,ivi, fML | [נ | | - | |
| Tocess. [ob,im, IML | ני | | | |
| TOCESS. [0B,W, IML | ני | | | |
| riocess. [08,ivi, IML | ני | | | and a start of the |
| -100835. [08,1W, 1ML |] | | | |
| 100835. [0B,IW, IML | J | | | |
| nocess. [OB,M, IML | J | | | Contraction of the |
| 100055. [0B,IW, IML | J | | | |

Figure 1 : SFE of the concave surface of L5. Measurement zone: 60mm with a f/1.5 reference sphere. Top: Low spatial-frequency map: bottom: medium and high spatial-frequency map (residuals surface error beyond the 36 first Zernike polynomials).

- ✓ The dominant mode is astigmatism.
- ✓ We note the presence of some spherical aberration.
- ✓ A big central bump exists (filtered here for convenience); it should not have impact on image quality because of the central obscuration of the telescope.
- ✓ Typical robotic polishing pattern are observed.
- ✓ Some random linear marks are observed.
- ✓ The SFE is slightly out of specification in terms of PTV value (but it includes the central bump which has no impact in image quality because of the central obscuration of the telescope). We propose to accept the lens since the RMS value is near λ /9 RMS at 633nm.



5.2. Surface error of the convex surface of L5

| InWave Report Sum Parameter Valu PV 82.339 RMS 04.712 4) Focus (norm) -0.023 5) X Astig (norm) -0.023 5) X Astig (norm) -0.023 6) Y Astig (norm) -0.023 6) Y Astig (norm) -0.023 6) Y Coma (norm) -0.023 5) Spherical (norm) -0.023 5) Spherical (norm) -0.023 5) Spherical (norm) -0.023 5) Spherical (norm) -0.023 Date(measured): Wed Oct 05 Removed X Tat (norm) -0.023 Removed X Tat | e Units OC 0 nm 6 nm 25 nm 25 nm 1 nm 1 nm 15.49-37 2022 m); Focus (norm) |
|--|--|
| PV 2010 PV 82.333 RMS 14.712 4) Focus (norm) -0.023 9) X Antig (norm) -11.64 6) Y Antig (norm) -4.014 7) X Coma (norm) -4.014 7) X Coma (norm) -4.014 8) Y Coma (norm) -4.012 9) Spherical (norm) -2.884 Date(measured): Wed Oct 05 Removed: X Till (norm) -2.884 Date(measured): Wed Oct 05 Removed: X Till (norm) -7.181 (norm Process: (58, M, TMD) | e Units GC 0 mm 0 mm 5 mm 5 mm 1 mm 1 mm 1 5:45-37 2022 mg, Frees perm) |
| PV 82.333 RMS 14.712 4) Focus (norm) -0.023 5) X Abig (norm) -0.11.65 6) Y Abig (norm) -0.024 6) Y Abig (norm) -0.024 8) Y Coma (norm) -0.022 9) Spherical (norm) -0.228 Date(measured): Wed Oct 05 Removed X TB (norm), Y TB (norm) Process: [58,M, TMO] | 0 nm 0 nm 5 nm 2 nm 1 nm 1 nm 15.49-37 2022 n), Fecus (norm) |
| 4) Focus (norm) - 10.023 5) X Antig (norm) - 11.68 6) Y Antig (norm) - 11.68 6) Y Antig (norm) - 1.072 9) Spherical (norm) - 2.865 Dato(measured): Wed Oct 05 nemoved: X 101 (norm) Y Till (nor Process: (58, M, TMD) | o anti 6 anti 5 anti 2 anti 1 anti 3 anti 15.45-37 2022 ni), focas (sent) |
| 4) Focus (norm) -0.023 5) X Asig (norm) -11.68 6) Y Asig (norm) -6.014 7) X Coma (norm) -6.014 1) Y Coma (norm) -1.072 9) Spherical (norm) -2.856 Date(measured): Wed Oct 05 Intervet 8 170 (norm) Y Till (norm) Process: (58, M, TMC) | 6 nm 26 nm 2 nm 3 nm 15.45.37 2822 n), Fecas (serm) |
| S) X Astig (norm) -11.62 G) Y Astig (norm) -11.62 G) Y Astig (norm) -1.162 G) Y Acoma (norm) -1.072 G) Spherical (norm) -2.856 hato(measured): Wed Oct 05 temored: X Till (norm), Y Till (norm) Yrocess: (50.M.TMD) | 26 mm 5 mm 2 mm 1 mm 3 mm 15.49-37 2022 m); Fecas (norm) |
| 6) Y Astig (serm) 4.014 7) X Cena (norm) 4.014 8) Y Coma (norm) 4.072 9) Spherical (norm) 2.856 Date(measured): Wed Oct 05 hemoved X Tri (norm), Y Tel (norm Process: (SB,M, TMO) | 5 mm 2 mm 3 mm 15-45-37 2022 nj, Foreas (somm) |
| 1) X Come (norm) - 3.325 By Come (norm) - 1.072 9) Spherical (norm) - 2.856 Date(measured): Wed Oct 05 Removed X TRI (norm), Y TRI (nor Process: [58, M, TMO] | 2 nm 3 nm 3 nm 15-43-37 2022 m), Forces (morm) |
| B) Y Come (norm) -1.072 S) Spherical (norm) -2.858 Date(measured): Wed Oct 05 Removed: X Till (norm), Y Till (nor Process: (\$8,M,TMO) | 1 nm 3 nm 15.49-37 2022 nj, focas (nem) |
| 9) Spherical (norm) -2.866 Date(measured): Wed Oct 05 Process: (58, M, TMC) | 3 nm 15.49-37 2022 m), Fecus (norm) |
| Date(measured): Wed Oct 05 tensored: A Trill (norm): Y Till (nor Process: (58, M, TMO) | 15.49.37 2022 nj, focas (norm) |
| Removed X Till (norm), Y Till (nor Process: (SB, M, TMO) | n), Focas (norm) |
| nemonia z tin (norm), y tin (nor Process: (50, M, TMO) | ng, recus (Bonn) |
| Autotora Abamatora | |
| dogram Information | Fiduciale History Regions Report • Customize Refresh |
| Nave Report Sumr | |
| Parameter Va | lue Units QC |
| V 37.24 | 154 nm |
| MS 2.67 | 59 nm |
| | |
| Focus (norm) -0.01 | 08 nm |
| X Astig (norm) -0.00 | 69 nm |
| Y Astig (norm) 0.000 | 19 nm |
| X Come (norm) 0.000 | 44 000 |
| X Coma (norm) -0.00 | 1 |
| (Feberlael (norm) 0.010 | |
| (spherical (norm) 0.010 | nm |
| ste(measured): Wed Oct 0 | 5 15:49:37 2022 |
| emoved: All | |
| COCESS: (SB M TMD) | |
| | - |

Figure 2 : SFE of the convex surface of L5. Measurement zone: 42mm with a f/3 reference sphere. Top: Low spatial-frequency map: bottom: medium and high spatial-frequency map (residuals surface error beyond the 36 first Zernike polynomials).

- \checkmark The dominant mode is astigmatism.
- \checkmark Typical robotic polishing pattern are observed.
- ✓ Some random linear marks are observed. Some local defects and/or dusts exist.
- ✓ Even by taking into account the scale factor for astigmatism ($CA^2/area^2 = 2.6$ here), *the SFE is compliant with the specification.*



5.3. Surface error of the concave surface of L6

| Standard | | Customize Re | efresh |
|---|--|---|-----------------|
| liWave Report Sur | mr | | 1 |
| Parameter | Value | Units | QC |
| PV | 88.9215 | nm | |
| RMS | 16.8030 | nm | |
| | | | |
| 4) Focus (norm) | -0.0615 | nm | |
| 5) X Astig (norm) | -8.0695 | nm | |
| 6) Y Astig (norm) | -10 4265 | om | |
| 7) X Coma (norm) | -0.5662 | nm | |
| 8) Y Coma (norm) | -1.5686 | nm | |
| 9) Soberical (norm) | -6.9510 | nm | |
| of opnenical (norm) | | | |
| Date(measured): Tu | ie Sep 20 14 | :04:06 2022 | |
| Removed: X Till (core) | Y Till (norm) | Focus Incom | |
| Process: ISB M Th | ID1 | , seas morn | |
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| Travas | | | |
| Wave Report Sum | | | |
| iWave Report Sum Parameter | ے بے Value | Units | QC |
| iWave Report Sum Parameter | r Value 139.2032 | Units | QC |
| iWave Report Sum Parameter V MS | Value 139.2032 5.4154 | Units | QC |
| iWave Report Sum Parameter W MS | Value 139.2032 5.4154 | Units nm nm | 8 |
| iWave Report Sum Parameter 2V RMS 4) Focus (norm) | Value 139.2032 5.4154 -0.0079 | Units nm nm nm | S |
| iWave Report Sum Parameter V MS 4) Focus (norm) 5) X Astig (norm) | Value 139.2032 5.4154 -0.0079 -0.0018 | Units nm nm nm nm | QC |
| IWave Report Sum Parameter V MS 4) Focus (norm) 5) X Astig (norm) 5) Y Astig (norm) | Value 139.2032 5.4154 -0.0079 -0.0018 -0.0002 | Units nm nm nm nm nm | QC |
| IWave Report Sum Parameter VX MS 4) Focus (norm) 5) X Astig (norm) 6) Y Astig (norm) 7) X Coma (norm) | Value 139.2032 5.4154 -0.0079 -0.0018 -0.0002 0.0033 | Units nm nm nm nm nm nm | 8 |
| IVave Report Sum Parameter V MS 4) Focus (norm) 5) Y Astig (norm) 5) Y Coma (norm) 5) Y Coma (norm) | Value 139.2032 5.4154 -0.0079 -0.0018 -0.0002 0.0033 -0.0014 | Units nm nm nm nm nm nm nm nm | QC |
| IVave Report Sum Parameter V MS 4) Focus (norm) 5) X Astig (norm) 5) X Astig (norm) 7) X Coma (norm) 8) Y Coma (norm) 9) Spherical (norm) | Value 139.2032 5.4154 -0.0079 -0.0018 -0.0002 0.0033 -0.0014 0.0070 | Units nm nm nm nm nm nm nm nm | QC |
| IWave Report Sum Parameter V MS 4) Focus (norm) 5) X Astig (norm) 5) X Astig (norm) 7) X Coma (norm) 9) Y Coma (norm) 9) Spherical (norm) ate(measured): Ture | Value 139.2032 5.4154 -0.0079 -0.0018 -0.0002 0.0033 -0.0014 0.0070 | Units nm nm nm nm nm nm nm nm nm | 30 00 |
| IWave Report Sum Parameter V MS 5 4) Focus (norm) 5) X Astig (norm) 5) X Astig (norm) 7) X Coma (norm) 9) Y Coma (norm) 9) Spherical (norm) 9) Spherical (norm) | y Value 139.2032 5.4154 -0.0079 -0.0018 -0.0002 0.0003 -0.0014 0.0070 Sep 20 14:0 | Units nm nm nm nm nm nm nm nm nm nm nm nm | 90 () |
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Figure 3 : SFE of the concave surface of L6. Measurement zone: 167mm with a f/3 reference sphere. Top: Low spatial-frequency map: bottom: medium and high spatial-frequency map (residuals surface error beyond the 36 first Zernike polynomials).

- ✓ The dominant modes are astigmatism and spherical aberration.
- ✓ Typical robotic polishing pattern are observed.
- ✓ Some random linear marks are observed. Some local defects and/or dusts exist.
- ✓ The SFE is compliant with the specification since the measurement zone is larger than the CA.



5.4. Surface error of the convex surface of L6

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Figure 4 : SFE of the convex surface of L6. Measurement zone: 97mm with a f/1.2 reference sphere. Top: Low spatial-frequency map: bottom: medium and high spatial-frequency map (residuals surface error beyond the 36 first Zernike polynomials).

- ✓ No dominant mode is observed.
- ✓ Some parasitic fringes are observed (their source is not clear). It does not impact the SFE lowfrequency pattern measurement.
- ✓ No clear robotic polishing pattern are observed, probably because of the parasitic fringes.
- ✓ Some local defects and/or dusts exist.
- ✓ Even by taking into account the diameter scale factor for astigmatism (CA²/area² = 1.2 here), *the SFE is compliant with the specification.*



5.5. Surface error of the convex surface of L7



Figure 5 : SFE of the convex surface of L7. Measurement zone: 49mm with a f/3 reference sphere. Top: Low spatial-frequency map: bottom: medium and high spatial-frequency map (residuals surface error beyond the 36 first Zernike polynomials).

- ✓ The dominant mode is astigmatism.
- ✓ A central bump is present.
- ✓ We observe clear robotic polishing pattern.
- ✓ Some local defects and/or dusts exist.
- ✓ By taking into account the diameter scale factor for astigmatism ($CA^2/area^2 = 4.3$ here), the SFE is maybe slightly non-compliant with the specification in terms of PTV value (but it probably includes dust or defects). We propose to accept the lens since the RMS value is near $\lambda/40$ RMS at 633nm.



5.6. Surface error of the concave surface of L7



Figure 6 : SFE of the concave surface of L7. Measurement zone: 70mm with a f/1.5 reference sphere. Top: Low spatial-frequency map: bottom: medium and high spatial-frequency map (residuals surface error beyond the 36 first Zernike polynomials).

- ✓ No dominant mode is present.
- ✓ A big defect is observed. It is unclear for the moment if it is a scratch due to optical paper contact or cleaning residuals (under the coating ?).
- ✓ We observe clear robotic polishing pattern. Some local defects and/or dusts exist.
- ✓ By taking into account the diameter scale factor for astigmatism ($CA^2/area^2 = 2.1$ here) and spherical aberration ($CA^4/area^4 = 4.5$ here), the SFE is maybe slightly non-compliant with the specification in terms of PTV values (but it probably includes dust or defects). We propose to accept the lens since the RMS value is near $\lambda/57$ RMS.
- ✓ The acceptance of this lens is an open question due to the presence of the big defect.



5.7. Surface error of the concave surface of L9



Figure 7 :SFE of the concave surface of L9. Measurement zone: 147mm with a f/1.2 reference sphere. Top: Low spatial-frequency map: bottom: medium and high spatial-frequency map (residuals surface error beyond the 36 first Zernike polynomials).

- ✓ The dominant modes are astigmatism and spherical aberration.
- \checkmark A central bump is present.
- ✓ We do not observe clear robotic polishing pattern (maybe nipples).
- ✓ Some local defects and/or dusts exist.
- ✓ Some parasitic fringes exist.
- ✓ The SFE is compliant with the specification since the measurement zone is larger than the CA.



5.8. Surface error of the convex surface of L9



Figure 8 : SFE of the convex surface of L9. Measurement zone: 98mm with a f/3 reference sphere. Top: Low spatial-frequency map: bottom: medium and high spatial-frequency map (residuals surface error beyond the 36 first Zernike polynomials). A low-pass filter has been applied to eliminate parasitic fringes.

- ✓ The dominant mode is astigmatism.
- ✓ A central bump is present.
- ✓ We observe clear robotic polishing pattern.
- ✓ Some local defects and/or dusts exist.
- ✓ Some parasitic fringes exist (which are filtered here by a low-pass filter).
- ✓ Even by taking into account the diameter scale factor for astigmatism ($CA^2/area^2 = 1.8$ here), *the SFE is compliant with the specification.*



5.9. Surface error of the convex surface of L10



Figure 9 : SFE of the convex surface of L10. Measurement zone: 92mm with a f/3 reference sphere. Top: Low spatial-frequency map: bottom: medium and high spatial-frequency map (residuals surface error beyond the 36 first Zernike polynomials). A low-pass filter has been applied to eliminate parasitic fringes.

- ✓ The dominant mode is spherical aberration.
- ✓ A central bump is present.
- ✓ We observe clear robotic polishing pattern.
- ✓ Some parasitic fringes exist (which are filtered here by a low-pass filter).
- ✓ Even by taking into account the diameter scale factor for spherical aberration (CA⁴/area⁴ = 3.5 here), *the SFE is compliant with the specification*.



5.10. Surface error of the concave surface of L10



Figure 10 : SFE of the concave surface of L10. Measurement zone: 130mm with a f/1.2 reference sphere. Top: Low spatial-frequency map: bottom: medium and high spatial-frequency map (residuals surface error beyond the 36 first Zernike polynomials).

- ✓ The dominant mode is astigmatism.
- ✓ A central bump is present.
- ✓ We do not observe robotic polishing pattern (mainly nipples).
- ✓ Some parasitic fringes exist.
- ✓ The SFE is compliant with the specification since the measurement zone is slightly larger than the CA.



5.11. Surface error of the short-radius convex surface of L11



Figure 11 : SFE of the short-radius convex surface of L11. Measurement zone: 65mm with a f/3 reference sphere. Top: Low spatial-frequency map: bottom: medium and high spatial-frequency map (residuals surface error beyond the 36 first Zernike polynomials). A low-pass filter has been applied to eliminate parasitic fringes.

- ✓ The dominant modes are astigmatism and coma (but their amplitude are small).
- ✓ A central bump is present.
- ✓ We observe robotic polishing pattern.
- ✓ Some local defects/dusts are observed.
- ✓ Some parasitic fringes exist (which are filtered here by a low-pass filter).
- ✓ By taking into account the diameter scale factor for astigmatism (CA²/area² = 3.3 here) and for coma (CA³/area³ = 6.0 here), the SFE is maybe slightly non-compliant with the specification in terms PTV value (but it includes the central bump which has no impact in image quality because of the central obscuration of the telescope). We propose to accept the lens since the RMS value is near λ/48 RMS at 633nm.



5.12. Surface error of the long-radius convex surface of L11



Figure 12 : SFE of the long-radius convex surface of L11. Measurement zone: 65mm with a f/10 reference sphere. Top: Low spatial-frequency map: bottom: medium and high spatial-frequency map (residuals surface error beyond the 36 first Zernike polynomials).

- \checkmark The dominant mode is spherical aberration.
- ✓ A central hole is present.
- ✓ We do not observe robotic polishing pattern (maybe nipples).
- ✓ Some local defects/dusts, a long mark and linear marks are observed
- ✓ By taking into account the diameter scale factor for spherical aberration (CA⁴/area⁴ = 10.8 here), the SFE is maybe slightly non-compliant with the specification in terms of PTV value (but it includes the central hole which has no impact on image quality because of the central obscuration of the telescope). We propose to accept the lens since the RMS value is near $\lambda/22$ RMS at 633nm.



6. VISUAL INSPECTION OF EACH SURFACE (COSMETICS)

We performed visual inspection of each surface. Globally speaking, we do not agree with the inspection done by the manufacturer and documented in their metrology reports (AD1 to AD6). We agree only for the lenses L9 and L10.

Generally, we observe that each convex surface has some scratches at their center (with loose coating material); we think that it is the effect of contact with the very low-quality optical paper they are packaged into.

We also note the presence of dust. For the inspection, we have flush the surfaces with dry air. The main dust were removed.

We have changed this paper for a smoother one.

The scratches we observe are generally a few mm long. Their width is really small (<<1mm).

There are some digs on all surfaces ($<50\mu$ m), some of which are on the glass and replicated by the coating, others seem to be evaporate projection due to non-control of the evaporation/sputtering process. This is maybe not critical and could be accepted.

The most critical defects are the blemished/cloudy zones on coatings (a few mm in diameter or quite large zones on some lenses; cf below) and the fracture coatings on the edge that can evolve in a bad way with time. There are non-adhesive coating in these areas.

6.1. Inspection of L5



Figure 13 : Visual inspection of L5

We propose to NOT accept L5.



6.2. Inspection of L6



Figure 14 : Visual inspection of L6

We propose to NOT accept L6.



6.3. Inspection of L7



Figure 15 : Visual inspection of L7





Figure 16 : Picture of the L7 defect (cloudy marks / blemish







Figure 17 : Digital micoscope pictures of the L7 defect (cloudy marks / blemish). Top: no defect zone (x100); middle: defect (x100); bottom: defect (x600

The coating is fractured with loose coating material. We think that it is due to strong contact with the optical paper.

We propose to NOR accept L7. We will discuss with Trioptics about the corrective solutions: coating removal (mechanical grinding, chemical removal), its impact on form and roughness, the risks for the other surface and the re-coating process (with L8?).



6.4. Inspection of L9



L9 could be accepted except for the presence of some local blemishes that could be interpreted as non-adhesive coating. Moreover, one can relate to the section 6.7 for some important remark concerning the impact of L9 coatings on the integration of the L8/L9 doublet.

6.5. Inspection of L10







6.6. Inspection of L11



Figure 20 : Visual inspection of L11

We propose to NOT accept L11.

6.7. Conclusions

As a conclusion, we cannot accept the lenses in terms of optical aspect. The more critical point is the presence of local non-adhesive zones (a few mm in diameter) and sometime of larger zones of fractured coating with the presence of loose material (see L5, L6, L7, L11). The ageing of these defects is a major risk.

Comments on L9:

During the integration of L8/L9 doublet, both lenses shall be glued with a transparent optical glue. For this, L9 should have not been coated on one of its surface. L9 does not show big defects but local blemishes are also present. We have to find a way to de-coat L9; a way is to not accept this lens because of the blemishes.

L8 is currently manufactured. The coating of its spherical surface has been frozen until our GO (but it should not be coated for gluing).