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A. Caillat

A. Costille

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EUCLID/NISP GRISM QUALIFICATION MODEL AIT/AIV CAMPAIGN: OPTICAL, MECHANICAL, THERMAL AND VIBRATION TESTS

A. Caillat¹, A. Costille¹, S. Pascal¹, C. Rossin¹, S. Vives¹, B. Foulon¹, P. Sanchez¹

¹Aix Marseille Université CNRS, LAM (Laboratoire d'Astrophysique de Marseille) UMR 7326, 13388, Marseille, France

ABSTRACT

Dark matter and dark energy mysteries will be explored by the Euclid ESA M-class space mission which will be launched in 2020. Millions of galaxies will be surveyed through visible imagery and NIR imagery and spectroscopy in order to map in three dimensions the Universe at different evolution stages over the past 10 billion years. The massive NIR spectroscopic survey will be done efficiently by the NISP instrument thanks to the use of gratings (for “Grating pRISMs”) developed under the responsibility of the LAM. In this paper, we present the verification philosophy applied to test and validate each grism before the delivery to the project. The test sequence covers a large set of verifications: optical tests to validate efficiency and WFE of the component, mechanical tests to validate the robustness to vibration, thermal tests to validate its behavior in cryogenic environment and a complete metrology of the assembled component. We show the test results obtained on the first grism Engineering and Qualification Model (EQM) which will be delivered to the NISP project in fall 2016.

I. INTRODUCTION

The Dark Universe is one of the most challenging questions in Astrophysics that will be investigated thanks to the ESA space mission Euclid which will be launched in 2020. Millions of visible and NIR galaxies images and spectra will be collected in order to reconstruct the 4-dimensionnal space-time map of our Universe. For this huge galaxies NIR survey, the Near Infrared Spectro-Photometer (NISP (1)) instrument shown on Figure 1 works with both photometric and spectroscopic modes by switching between broadband filters and gratings mounted on two rotated wheels.

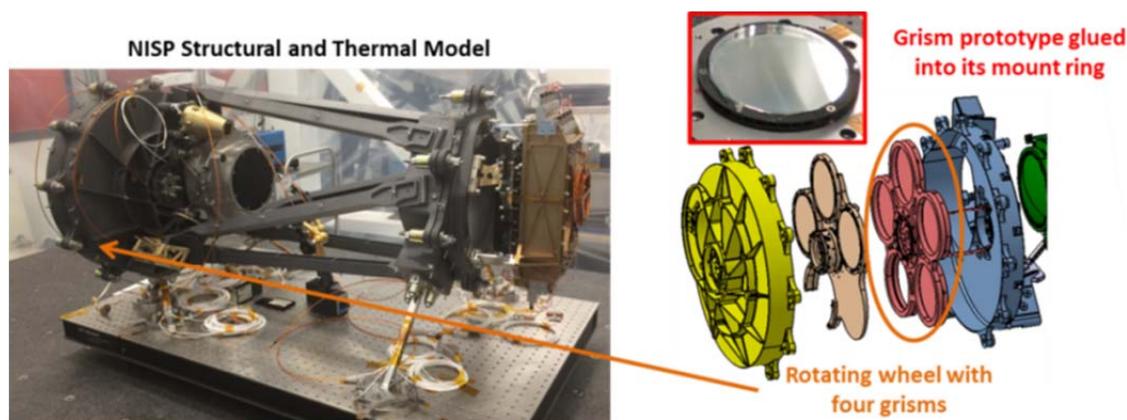


Figure 1: The NISP Structural and Thermal Model picture, its rotated wheels CAD model with filters and gratings respectively for imaging and spectroscopic modes and one grism prototype picture.

A grism (2) is a dispersive optical component composed of a blazed transmission grating and a prism. Used in an instrument, it allows combining image and spectroscopy of the same field of view with the same optical system and detector, thus simplifying instrument optical concept with respect to slit spectroscopy (3).

Four different gratings are used in NISP: 3 to cover the 1.2-1.8 μ m bandpass with 3 different orientations, and 1 to cover the 0.92-1.3 μ m bandpass. Each grism is glued into an invar ring which is screwed on the wheel. The Laboratoire d'Astrophysique de Marseille (LAM (4)) is responsible for the optical, mechanical and thermal design, manufacturing and validation of these gratings since a lot of experience has been acquired for many years in the development of such optical components (5), (6), (7), (8).

The development of NISP is in the phase C and the realization of the first grism EQM is finished since the optical part has been glued onto the ring in August 2016. All the optical performances have been verified and

the final tests, in particular the qualification campaign in cryogenic and vibration environments as well as the metrology of the complete component will be done before the delivery to the Euclid/NISP project at the end of September 2016. LAM will deliver the four flight models in April 2017 and their manufacturing is already on-going.

In this paper, we describe first the Euclid/NISP grisms opto-mechanical design and point out its particularities. Second, we explain the manufacturing process and the test plan implemented to validate each component. Finally, we present the qualification test results obtained until now on the grism EQM.

II. EUCLID/NISP GRISMS DESCRIPTION

Figure 1 presents the Euclid/NISP grisms architecture through a general CAD view of its opto-mechanical design and the associated product tree.

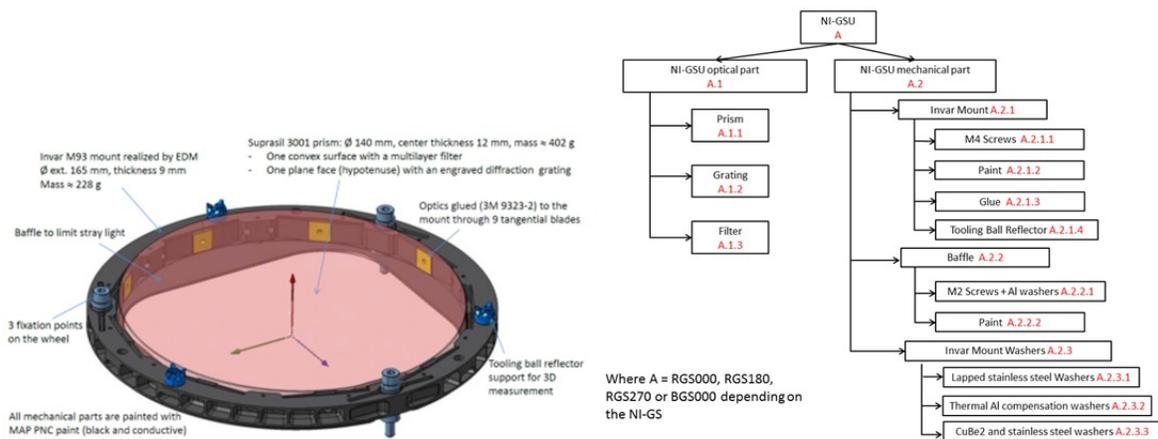


Figure 2: Euclid/NISP grisms architecture: CAD model design (left) and associated product tree (right).

Figure 3 is a cut off layout of the NISP grisms optical part showing the complexity of these optical components which include four different optical functions:

- Dispersion without deviation of the beam at one chosen wavelength thanks to the grating engraved on a prism,
- Spectral filtering with a wide and deep spectral rejection band thanks to a multilayer filter,
- Focus thanks to the 10m curvature radius of the first surface of the prism where the filter is deposited,
- Spectral wavefront correction thanks to the non-straight neither parallel grooves of the grating.

Consequently, the manufacturing of such optical components is very challenging and requires four industrial partners working on a single optical component. At each manufacturing step, optical verification tests are done, particularly for the transmitted efficiency and the wavefront error specifications, to allow the pursuit of the manufacturing process.

The optical specifications for the four NISP grisms are given in (9). Two of them are identical thus selected for the EQM optical specifications detailed in (10) and the main characteristics are recalled in Table 1.

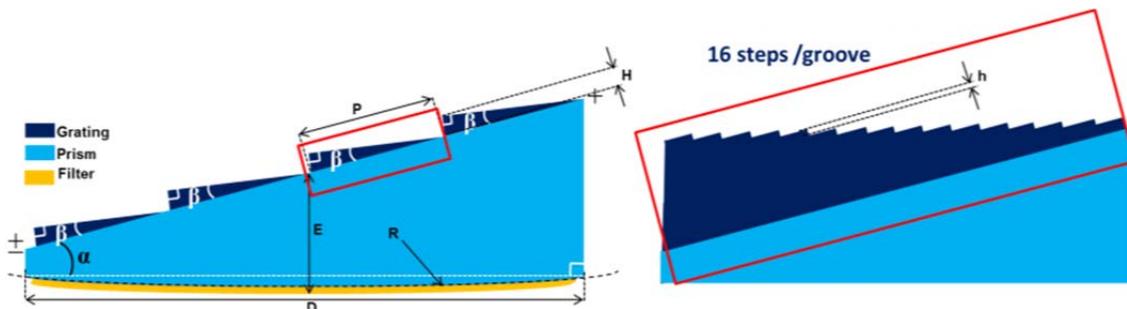


Figure 3: Cut off layout of a NISP grism and detail of one groove structure.

Table 1: Main optical specifications of the grism EQM.

Parameter	Specification
Shape	Prismatic with the grating on the hypotenuse and the other face (filter) curved and convex
Full diameter	140 +/- 0.05 mm
Clear aperture diameter	136 mm
Thickness at the center	12 mm +/- 0.02 mm
Angle between the two faces	2.145 +/- 0.032° (+/- 2 arcmin)
Spectral band pass range	1250-1850nm
Mean transmitted efficiency on band pass	>65 % in order 1 and > 1% in order 0
Incident beam angle	+/- 7°
Out of band bloking range and levels	< 5.10-4 in [400-550] nm < 2.10-2 in [550-920] nm < 5.10-4 in [920-2500] nm
Mean pitch P	72.6±1 μm
Groove Height H	3.16 +/- 0.08 μm
Height of the intermediate steps h	211 ± 40 nm
Line shape	Curve defined by "binary 1" surface in Zemax
Curvature radius of the filter face	-9631.06 mm CX +/- 0.25 fringes at 633 nm
SFE of the filter face on Zernike 5-15	RMSi < 10 nm

The optical part of the grisms is glued in a mechanical Invar M93 ring which maintains the grism integrity during the spacecraft launch (design limit load: 60g and first global resonance >400Hz) and in cryogenic environment (operational temperature: 130K). The total area glued, the number and the length of the flexible blades compensating the small CTE difference between Suprasil 3001 and Invar have been determined by the quasi-static accelerations to be undergone by the system.

In addition, a baffle is mounted on the ring to limit scattered light in the NISP instrument. The complete grism is fixed on the Invar wheel thanks to three M4 screws on three blades enabling to minimize stresses in the optical element due to thermal differences and to interface defaults that deform the component at the wheel interface. More details on the analysis of the grism mechanical part can be found in (11).

III. NISP GRISMS AIT/V PHILOSOPHY

A. Manufacturing process

The manufacturing of the grism is quite a long and complex operation that takes about ten months per component including all the test phases at Laboratoire d'Astrophysique de Marseille (LAM). The optical and the mechanical parts are manufactured in parallel, and then glued together. Eight companies are involved in the development of the component:

- The optical part is manufactured thanks to a consortium of three companies:
 - SILIOS TECHNOLOGIES (12) is the grating manufacturer. The resin-free grating (suitable for space environment without qualification tests needed) is directly engraved into a Suprasil 3001 parallel plate supplied by TRIOPTICS (13) using a cumulative etching technology based on successive masking photolithography and reactive ion etching steps. More details on this technology can be found in [6];
 - WINLIGHT OPTICS (14) is the prism manufacturer. The cut, the grounding and the polishing of the prism and the curved/convex surface is done after the grating manufacturing. A special care is taken to protect the grating from any damage during all this phase;
 - OPTICS BALZERS JENA (15) is the filter manufacturer. The multilayer (~100) filter deposited on the curved face of the prism opposite to the grating.
- The mechanical mount is manufactured by three companies:
 - ALSYOM (16) is the Invar ring manufacturer with Electro Discharged Machining;
 - CLAPPAZ (17) is the Invar baffle manufacturer;
 - MAP (18) does the PNC painting of the Invar ring and the baffle allowing to protect the Invar from corrosion and to avoid any stray light due to reflections on the mount.
- WINLIGHT SYSTEM (19) does the gluing which has been qualified during the phase B of the Euclid project through tests on samples submitted to thermal cycling and damp-heat aging environments.

B. Assembly, Integration and Test plan

Figure 4 presents the Assembly, Integration, Tests and Verification (AIT/V) process applied to validate each grism.

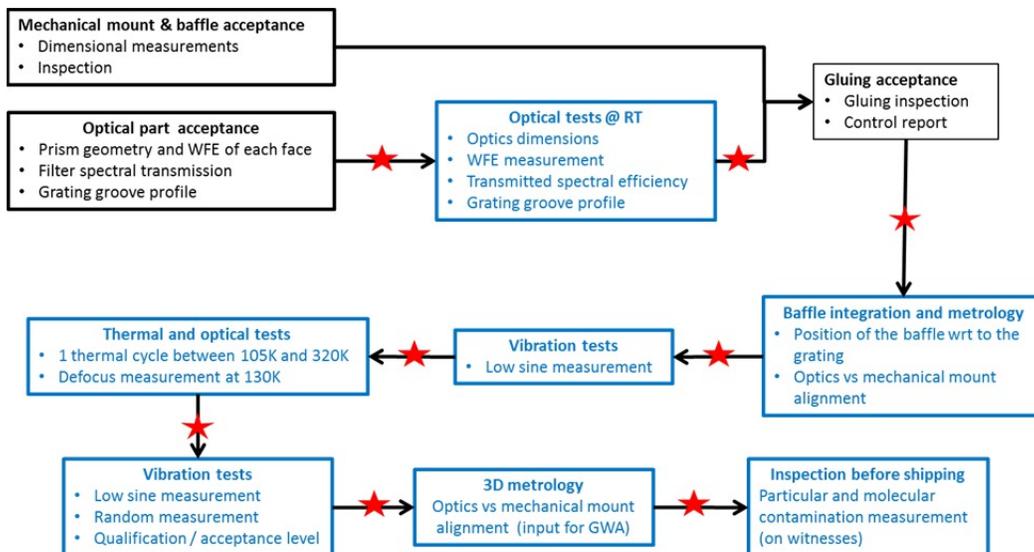


Figure 4: AIT/V flow chart of the grism. The tasks performed at LAM are indicated in blue. The tasks done by the suppliers are indicated in black. The red stars correspond to the visual inspections done on the optics.

The acceptance of each part of the component is done at the supplier level after manufacturing and includes a set of key measurements listed in black in Figure 4. The main verification tests and performance validations are done at LAM and indicated in blue in Figure 4. Some tests are done twice: first at the supplier level, then at LAM so as to cross-check the performances measured.

The main optical characteristics are validated at LAM on the optical component alone before the assembly of the optics and the mechanics. The transmitted efficiency and the transmitted wavefront error (TWFE) budgets are split between the different parts of the component so they are verified several times along the manufacturing process.

After gluing of the optics onto the mechanics, the mechanical validation of the component is done. In particular the grism is tested in cryogenic and vibration environments in order to qualify the component for space environment. At the end, the complete 3D metrology of the component is done, as required for the alignment on the wheel.

Visual inspections of the component, specifically the optical surfaces, are done before and after each manufacturing step and verification test. In addition, the particular and molecular contamination of the component is followed throughout all the AIT phases thanks to witness samples and particle counters.

IV. PERFORMANCE QUALIFICATION SETUPS

A. Optical test setups

Three main optical setups are used to control the optical performances of the grisms. Figure 5 shows the optical bench specially designed and implemented at LAM to measure the NISP grisms transmitted efficiency on 90mm clear aperture in the transmitted orders zero and one. This setup and the associated measurement method are fully described in (10). This measurement is done twice: after the grating manufacturing and after the filter deposition. The transmitted efficiency is closely linked to the groove profile dimensions of the grating which are measured thanks to an interferential microscope Wyko NT9100 on several locations on the clear aperture in order to validate its uniformity.

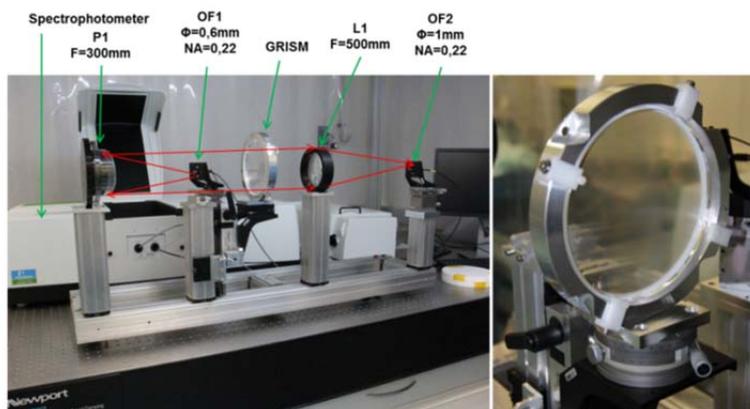


Figure 5: Transmitted efficiency measurement setup and detail of the grism mount allowing its translation and its rotation.

Figure 6 presents the optical setup used to measure the grating Surface Form Error (SFE) at each step of the grism manufacturing process, ie four times. After the manufacturing of the grating, we measure several reflected orders having a sufficient contrast at 633nm by rotating the grating around an axis parallel to its lines direction. The SFE in each order is projected onto the Zernike orthogonal basis and each aberration coefficient evolves linearly with the order number. We plot each aberration coefficient versus the diffracted order and the linear fit of each gives the grating contribution in order 1 (linear coefficient) and the substrate contribution (offset) which is common to all orders.

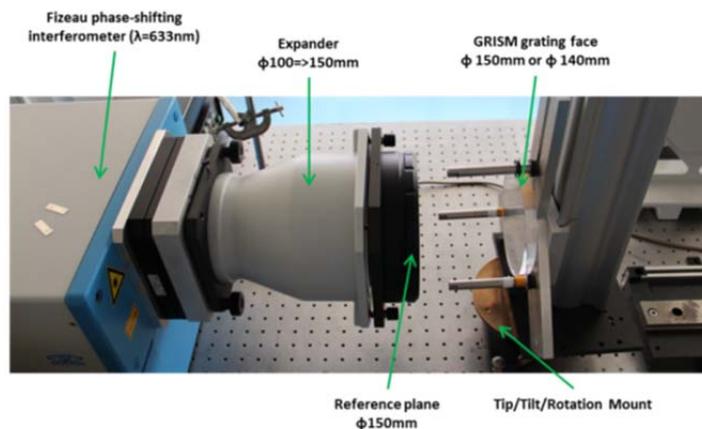


Figure 6: SFE measurement of the grating face at each manufacturing step.

Figure 7 shows the measurement setup used to measure the evolution of the convex filter face before and after filter manufacturing. This measurement is done after the manufacturing of each optical part to estimate the effect of the filter deposition and the gluing in the mount introducing mainly bending and affecting the associated TWFE.

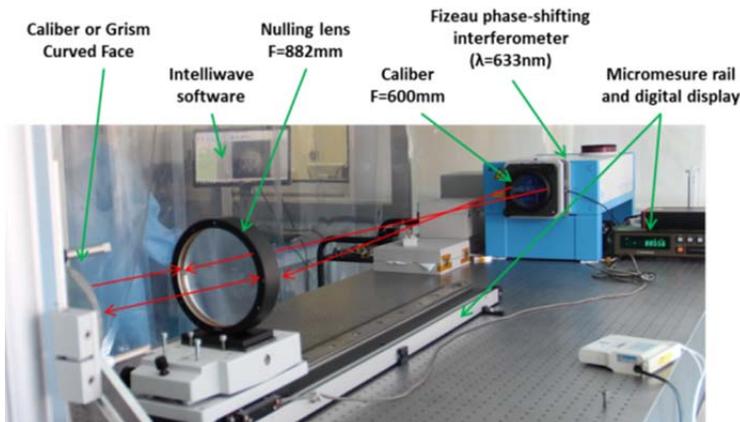


Figure 7: Measurement setup used to measure the total SFE of the filter face with 10m curvature radius.

B. Thermo-mechanical qualification tests setups

The thermo-mechanical qualification tests of the grisms are done at LAM thanks to two facilities shown on Figure 8: a shaker injecting until 37 kN in sine mode and a 0.8m³ cryostat.

The mechanical qualification of the grism is done thanks to the following vibration tests:

- 35g sine at 35 to 100 Hz along the three directions,
- 55g quasi-static sine at 50 to 55 Hz along the optical axis which is the most critical
- 15g RMS random at 20 to 2000 Hz along the three directions with notches at the grism resonant frequencies.

The grism thermal qualification is done through 8 thermal cycles from 300 to 100K.

A low level sine vibration test is done before and after mechanical and thermal qualification tests in order to check the integrity of the grism.

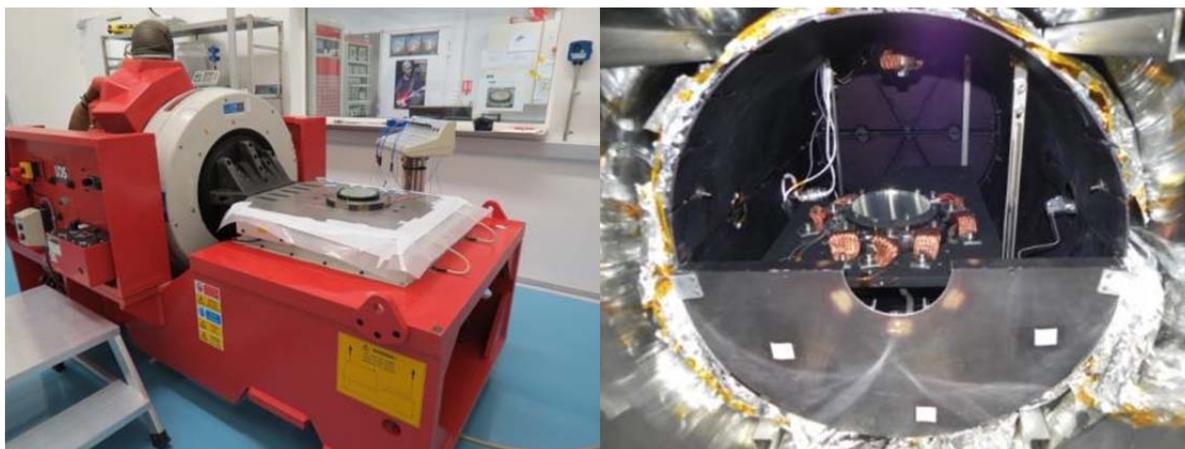


Figure 8: Picture of a grism prototype set on the shaker for vibration qualification tests (left) and inside the cryostat for thermal cycling and optical tests at operational temperature (130K).

IV. OPTICAL PERFORMANCES OF THE GRISM EQM

We present in this part the results of the optical tests done on the grism EQM except the results of the filter face SFE since their analysis is not finished. The thermo-mechanical tests will be done after the paper submission.

A. Transmitted efficiency

Figure 9 (left) presents the efficiency measured in the transmitted orders 0 and 1 of the grism EQM at the end of the manufacturing process, ie including the grating and the filter contributions. In order to check the performance on the whole 136mm diameter clear aperture of the grism, the spectral transmission in order 1 is measured on three 90mm diameter pupils. The transmitted efficiency is perfectly into the specification and very uniform over the clear aperture of the grism: 1,6% averaged on the spectral band 1250-1850nm in order 0 (>1% required) and 84,2% averaged in order 1 with the minimum at 71.4% (>65% required).

Figure 9 (right) shows a verification of the grating groove profile specified on five locations of the clear aperture since this parameter drives directly the centering of the spectral band. The groove height measured is $3.2 \pm 0.03 \mu\text{m}$ for $3.16 \pm 0.08 \mu\text{m}$ specified, which confirms the good efficiency performance measured.

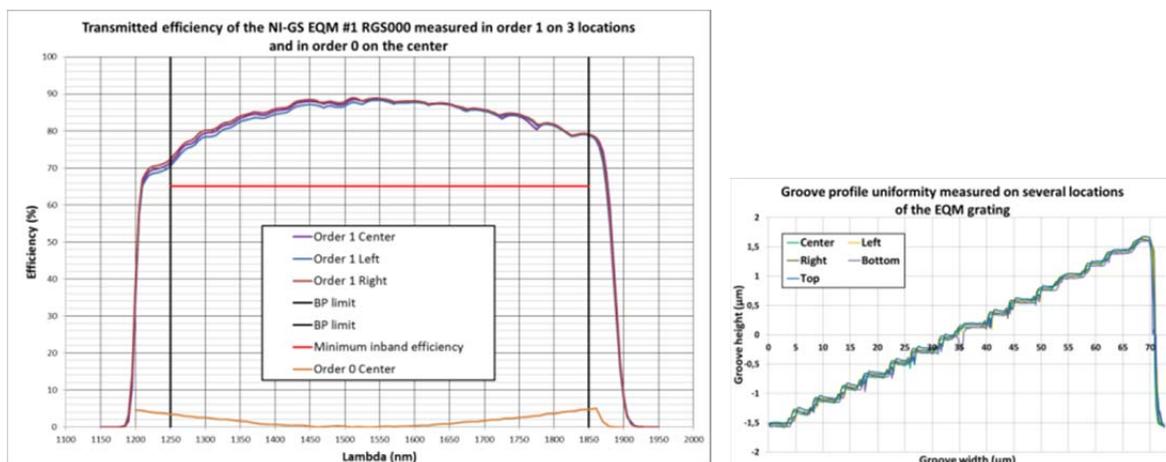


Figure 9: Transmitted efficiency of the grism EQM measured in orders 0 and 1 on its spectral band pass (left) and groove profile measured on the center and the edges of the grating.

B. Surface Form Error of the grating

Figure 10 shows an example of one measurement of the grating SFE in the sixth reflected order which is one of the most contrasted at 633nm. We average ten identical measurements for each order in order to optimize the accuracy. We can see that the rear face of the parallel plate forms also a fringe pattern less contrasted superimposed on the interferogram from the grating face (right image) thus introduces uncertainty. The averaging also compensates for the low fringe contrast of some other orders in the visible.

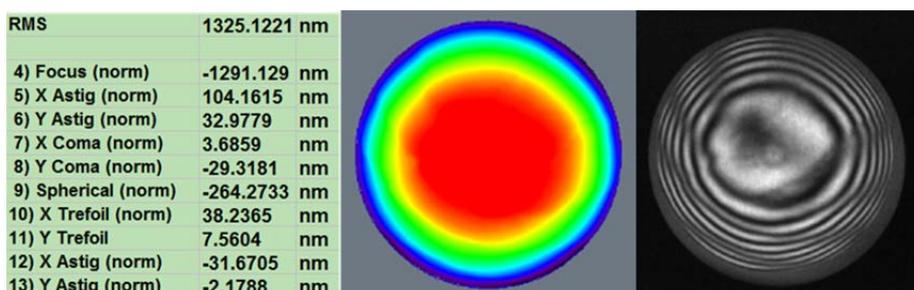


Figure 10: Example of one measurement of the grating SFE in the sixth reflected order.

Figure 11 shows the evolution of six Zernike coefficients (Focus, Astigmatism and coma along two orthogonal axis and spherical aberrations) measured on the reflected orders from 0 to 9 of the grating. Each point corresponds to the average of ten measurements like shown on Figure 10. The linear regression of each coefficient gives separately the grating and the substrate contributions to the SFE.

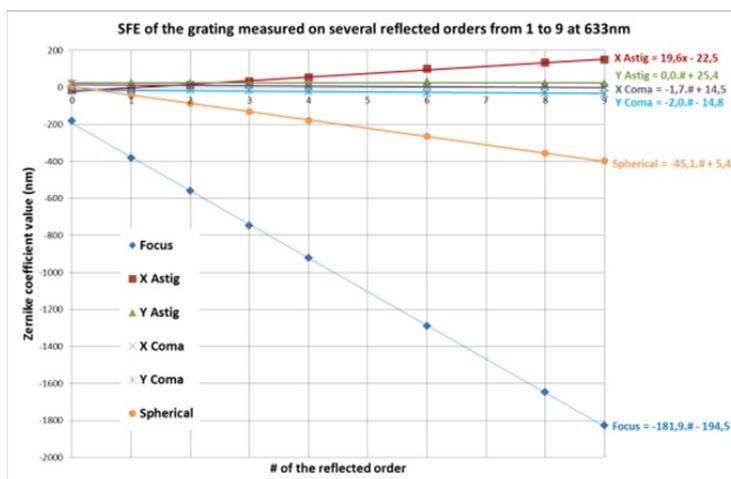


Figure 11: Evolution of the six main Zernike coefficients measured on the reflected orders from 0 to 9.
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Table 2 is the comparison between our measurements and the theoretical grating Zernike coefficients calculated in each order thanks to Zemax corresponding to the WFE introduced by the curvature of the grating lines defined by a binary 1 surface in the NISP Zemax model. The RMSi of the deltas (focus excluded) is only 6,1nm on the Zernike terms 5 to 15 which is largely within the 30nm RMSi SFE allowed for the grating and keep margin for the next manufacturing steps if needed. The focus difference of 1,6nm RMS is to be added to the substrate contribution.

Table 2: SFE measurement of the grating contribution compared to Zemax theoretical values.

	Measurement	Theory	Delta
Focus	-181,9	-183,5	1,6
X astig	19,6	22,6	3,0
Y astig	0,0	-0,5	0,5
X Coma	-1,7	0,7	2,4
Y Coma	-2,0	0,0	2,0
Spherical	-45,1	-45,4	0,3
X Trefoil	4,8	5,3	0,5
Y Trefoil,	1,4	1,9	0,5
X Astig	-6,7	-6,4	0,3
Y Astig	1,0	-1,5	2,5
X Coma	-4,4	-7,7	3,3
Y Coma	1,4	1,2	0,2
RMS	188,7	190,7	6,3
RMSi	50,2	52,0	6,1

V. CONCLUSION

In this paper, we presented the design of the grisms used for the NIR spectroscopy mode in the Euclid/NISP space instrument. We demonstrate the feasibility of these complex optical components which regroup four different optical and spectral functions: dispersion, filtering, wavefront correction and focus. We described the manufacturing process involving eight industrial partners: four for the optics manufacturing and four for the mechanics manufacturing and assembly by gluing.

Several specific setups and associated test procedure and data processing have been developed at LAM to measure the optical performances of the grisms, specifically transmitted efficiency and wavefront error that are really stringent. The validation of these setups has been done during the EQM test campaign which results demonstrate the compliance with the specifications: 71.4% minimum transmitted efficiency in order 1 for 65% required and only 6 nm RMS on the grating SFE for 30nm specified.

The grism is glued into a mechanical mount which should maintain without deformation and insure the integrity of the component during the launch with high vibration level and at operational cryogenic temperature of 130K. These thermo-mechanical tests are done with a shaker and a cryostat available at LAM demonstrating the qualification of the complete grism EQM for space environment.

The next step of the project is now to finish the qualification phase with the thermo-mechanical tests of the complete grism EQM which will be delivered in October 2016. The manufacturing of the four flight models for NISP is already on-going and they will be delivered in April 2017.

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