International Conference on Space Optics—ICSO 2018

Chania, Greece

9–12 October 2018

Edited by Zoran Sodnik, Nikos Karafolas, and Bruno Cugny

Optical performance of NISP grisms flight models for EUCLID mission

Anne Costille

A. Caillat

C. Rossin

S. Pascal

et al.

International Conference on Space Optics — ICSO 2018, edited by Zoran Sodnik, Nikos Karafolas, Bruno Cugny, Proc. of SPIE Vol. 11180, 1118013 · © 2018 ESA and CNES · CCC code: 0277-786X/18/$18 · doi: 10.1117/12.2535958

Optical performance of NISP grisms flight models for EUCLID mission

Anne Costille[*,a], A. Caillat[a], C. Rossin[b], S. Pascal[a], P. Sanchez[a], B. Foulon[a], C. Pariès[a], S. Tisserand[c], Y.Salaun[d], T. Weber[e]

[a]Aix Marseille Univ, CNRS, CNES, LAM UMR 7326, 13388, Marseille, France, [b]Observatoire de Physique du Globe de Clermont-Ferrand, Campus Universitaire des Cézeaux, 4 Avenue Blaise Pascal, TSA 60026 - CS 60026, 63178 Aubière Cedex, [c]Silios Technology, Peynier, France, [d]Winlight Optics, Pertuis, France, [e]Jena Optics Balzers, Jena, Deutschland

ABSTRACT

The launch of ESA EUCLID mission is foreseen in 36020. The goal of the mission is to understand the nature of the dark energy and to map the geometry of the dark matter. The EUCLID telescope will be equipped with two instruments working in the visible range (VIS) and in the IR range (NISP) to investigate the distance-redshift relationship and the evolution of cosmic structures. The NISP (Near Infrared Spectro-Photometer) will operate in the near-IR spectral range (0.9-2μm) with two observing modes: the photometric mode for the acquisition of images with broadband filters, and the spectroscopic mode for the acquisition of slitless dispersed images on the detectors. NISP is then using four low resolution grisms to acquire spectroscopic image in different orientations to better distinguish the spectra observed and to cover two spectral ranges: 1250-1850nm range, and 920-1300nm range. Since 2010, Laboratoire d'Astrophysique de Marseille is working on the development and the test of the NISP grisms, that are complex optical components. The grism combines four main optical functions: a grism function done by the grating on the prism hypotenuse, a spectral filter done by a multilayer filter deposited on the first face of the prism, a focus function done by the curved filter face of the prism and a spectral wavefront correction done by the grating which grooves paths are nor parallel, neither straight. The NISP instrument is now entering in the integration phase of the proto flight model of the instrument. Therefore, the NISP grism flight models have been manufactured and delivered to the grism wheel assembly for integration by end of 2017. In this paper, we present the optical performance and characteristics of the four EUCLID NISP grisms flight models that have been developed and manufactured by four different industrial partners then integrated and tested by LAM. We focus on the performance obtained on the optical performance of the component; wavefront error of the components, the spectral transmission and groove profiles. The test results analysis show that the grisms flight models for NISP are well within specifications with an efficiency better than 70% on the spectral bandpass and a wavefront error on surfaces better than 30nm RMS. The results on the component show a good control of the manufacturing and integration process despite the difficulties at the beginning of the project to manufacture these components.

Keywords: NISP, grism, flight model, grating, multilayer filter, spectroscopic mode, wavefront error, vibration qualification

1. INTRODUCTION

EUCLID mission[1] has been selected by ESA in 2012 in the context of the Cosmic Vision program to study the nature of dark energy and dark matter. The launch of the mission is foreseen in 2021. The mission is designed to map the geometry of the dark Universe by investigating the distance-redshift relationship and the evolution of cosmic structures thanks to two scientific instruments: the Near Infrared Spectroscopic Photometer (NISP)[2] and the Visible instrument (VIS)[3]. The NISP channel of Euclid is dedicated to measure the redshift of millions of galaxies and to analyze their spatial distribution in the Universe. NISP works with both photometric and spectroscopic modes by switching between broadband filters and grisms, mounted on two rotating wheels, to acquire data of the same field. The spectroscopic mode acquires dispersed images on the detector without a slit by using four different grisms mounted on a wheel.

*anne.costille@lam.fr; phone +33491055978; fax; +33491621190, www.lam.fr

The NISP project is now entering its final phase as the integration of the complete NISP instrument is started at Laboratoire d'Astrophysique de Marseille (LAM). The grisms designed for NISP are complex optical and mechanical components that have been studied deeply during phase A and B of NISP project[4] through the development of several prototypes done by LAM. One Engineering and Qualification Model (EQM) and four Flight Models (FM) grisms have been manufactured and successfully delivered to the project NISP by end of 2017 and the FM components are now integrated and tested on the wheel since Spring 2018. We present in this paper the results of the optical performance measurements of the grisms FM characterized at LAM, which will be used in NISP instrument: wavefront error, spectral transmission and grating groove profiles. We present finally the result of the alignment of the optical part on the mechanical part measured with a coordinate measurement machine.

2. EUCLID GRISM DESCRIPTION

2.1 Euclid NISP grisms overview

The Euclid NISP grisms are critical parts of the NISP instrument as they are complex optical and mechanical components. In NISP, there are four grisms mounted on a wheel:

- The grism NI-GSU-FM-RGS000: a "red grism" with a 2.145° prism angle transmitting in spectral band [1.25-1.85µm] and oriented at 0° to obtain a spectrum vertical on NISP detector,
- The grism NI-GSU-FM-RGS180: a "red grism" with a 2.145° prism angle transmitting in spectral band [1.25-1.85µm] and oriented at 180° to obtain a spectrum vertical on NISP detector but with the opposite direction compared to the 0° orientation,
- The grism NI-GSU-FM-RGS270: a "red grism" with a 2.145° prism angle transmitting in spectral band [1.25-1.85µm] and oriented at 270° to obtain a spectrum horizontal on NISP detector,
- The grism NI-GSU-FM-BGS000: a "blue grism" with a 1.77° prism angle transmitting in spectral band [0.92-1.3 µm] and oriented at 0° to obtain a spectrum vertical on NISP detector.

Each grism is made of two parts, as shown in Figure 1:

- The optical element i.e. the grism itself,
- The mechanical mount, which maintains the grism integrity in cryogenic environment on the wheel (130K) and during the spacecraft launch. In addition, a baffle is fixed on the mount to limit scattered light in NISP instrument due to the component or any stray light coming from the telescope. Details of the mechanical design and the mechanical analysis of its behavior are presented in [5].

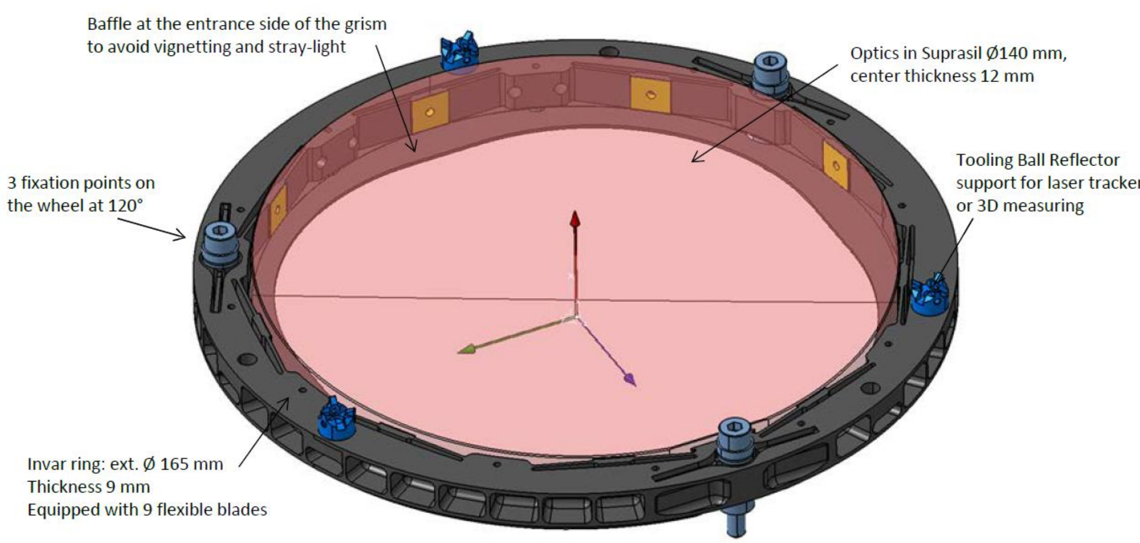

Figure 1. CAD representation of EUCLID NISP RGS000. The yellow squares indicate the gluing areas.

2.2 Euclid NISP grism optical part description

The optical part of NISP grism i.e. the grism itself, combines four optical functions in one component, which are represented in Figure 2:

- A grism in Suprasil 3001 made of a grating engraved on the prism hypotenuse to make the light undeviated at a chosen wavelength. In addition, a spectral wavefront correction is done by the curvature of the grating grooves. The grating being specific (low groove density and small groove angle) has made us develop a R&D program funded by CNES to manufacture the grating. Results of the R&D are presented in [4]. This R&D program has allowed to identify SILIOS Technologies Company as the manufacturer of the grating flight models,
- A spectral filter done by a multilayer filter deposited on the first surface of the prism,
- A focus function done by the curvature of the first surface of the prism.

The main optical specifications are recalled in the following table.

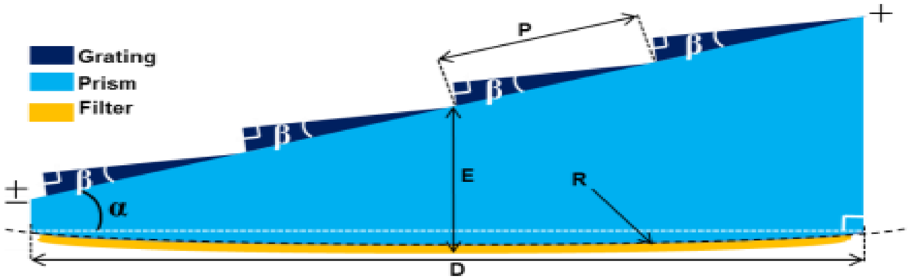

Figure 2: Scheme of the optical part.

Table 1. Optical specifications of the grisms for NISP instrument.

Parameter	**Red grisms** RGS000-RGS180	RGS270	**Blue grisms** BGS000
Spectral band-pass range	[1250-1850nm]		[920-1300nm]
Inband Transmission	>65 % in order 1 > 3% in order 0		>65 % in order 1 > 3% in order 0
Out of band blocking	< 5.10^{-4} in [400-550] nm < 2.10^{-2} in [550-920] nm < 5.10^{-4} in [920-2500] nm		< 5.10^{-4} in [400-550] nm < 2.10^{-2} in [550-920] nm < 5.10^{-4} in [920-2500] nm
Incident beam angle	+/- 7°		+/- 7°
Prism angle	2.145°+/-30’’		1.77° +/- 30’’
Curvature of the filter face	9631.06 mm +/- 0.5fr	-9272.898 mm +/-0.5fr	-9906.874 mm +/- 0.5fr
Filter Surface wavefront error quality	< 10nm rms on Zernike 5-15		< 10nm rms on Zernike 5-15
Grating Surface wavefront error quality	< 15 nm rms on Zernike 5-15		< 15 nm rms on Zernike 5-15
Mean pitch of the groove Mean groove frequency	72.55 µm 13.75 grooves/mm	72.96 µm 13.7 grooves/mm	66.22 µm 15.1 grooves/mm

Lines shape	Curved, defined by mathematical equations Binary 1 surface in ZEMAX 13EE	Curved, defined by mathematical equations Binary 1 surface in ZEMAX 13EE
Central thickness	12mm +/-20µm	12mm +/-20µm
Clear aperture	136mm	136mm
Nominal functional environment	T=130K, P=10-6mbars	T=130K, P=10-6mbars

2.3 EUCLID NISP grism manufacturing and test strategy

The complete manufacturing process and test sequence done on the NISP FM grisms is fully described in [6]. We recall in this section the main important points concerning the manufacturing of the grisms that were established thanks to the development of prototypes and the Engineering and Qualification Model (EQM) developed at the beginning of phase D of the project. The manufacturing process of the optical part is quite complex as several manufacturers operate on the optical component one after the other. The complete manufacturing process follows the sequence below:

1. Manufacturing of a parallel plate of 150mm delivered by TRIOPTICS [7];
2. Manufacturing of the grating on one side of the parallel plate by SILIOS Technologies [8];
3. Manufacturing of the prism with the convex filter face opposite to the grating by WINLIGHT Optics [9];
4. Manufacturing of the filter done by Optics BALZERS Jena [10];
5. In parallel, manufacturing of the mechanical mount done by Alsyom;
6. Alignment and gluing of the optical part in the mechanical mount done by WINLIGHT System.

The manufacturing of the four grisms FM has been started in early 2016 as the manufacturing time for one component is quite long. The manufacturing of a full component (optical part, mechanical part, gluing and test) lasts 9 months per component. The four FM for NISP have been delivered to the project at the end of 2017. These components are now fully assembled and aligned onto the grism wheel. Figure 3 presents a picture of each FM delivered to NISP project after the final inspection of the component. We can see on these pictures that the “red” grisms are very similar. The name identification of each component is engraved onto the mechanical mount to distinguish the components.

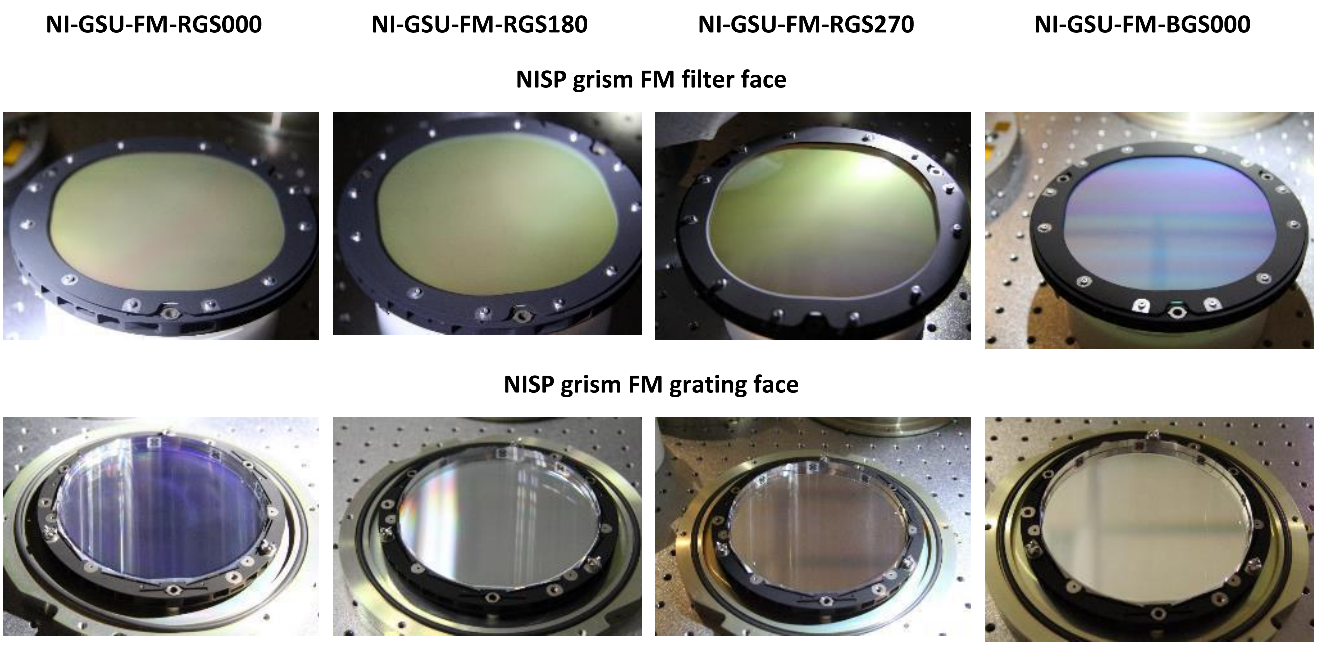

Figure 3. The NISP grism flight models before delivery to NISP project. For each component, the filter and the grating surfaces are shown.

3. OPTICAL PERFORMANCE OF NISP GRISMS FLIGHT MODELS

We present in this section the optical performance measured on each FM for NISP. The measurement of the optical performance is done with the test setups described in [6] according to the test plan of the grism components elaborated at the beginning of the project.

3.1 Groove profile measurement

The first validation of the performance done on the grism is the verification of the groove profile with respect to the specification. We measure the groove profile of the grating with an interferential microscope Wyko NT9100. In particular, we check the groove height of each grating and the groove width. Figure 4 presents the grating groove profile measured on the four grisms FM. The measurements done on the three red gratings demonstrate the very good repeatability of the manufacturing process concerning the groove dimensions: period and height. The profile of the blue grating is provided for information but its period and height is different from the red gratings. We can see also the discretization of the groove slopes in 16 small steps due to the manufacturing process proposed by SILIOS Technologies[11], which uses several photolithographic masks and etching phases. The little peaks observed at certain steps are due to mis-alignment errors between the masks but have a very few impact on the overall performance of the grating. Same profile have been obtained on the flight spares (FS) components showing a very good control of the grating manufacturing process.

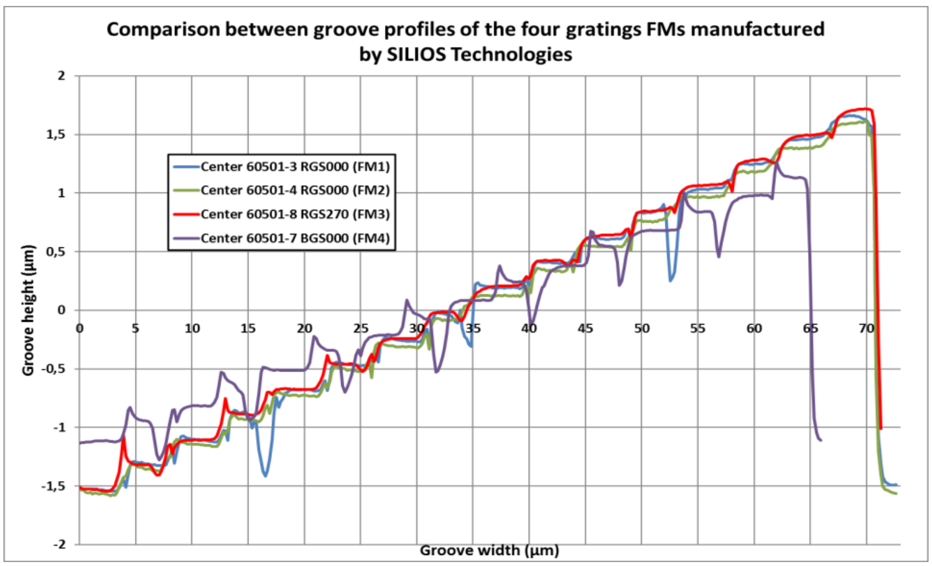

Figure 4: Grating groove profile measured on the four FM grisms.

3.2 Transmission measurement

The transmission of the grism into the bandpass is measured with a spectrophotometer specially adapted to measure the grism on 90mm aperture[6]. The measurement is done at the end of the manufacturing on the final components at LAM in order 0 and 1 onto the bandpass. All components are within specifications in the bandpass as all transmission is better than 65% for each FM. In average on the four FM measurements, the mean efficiency of the FM is about 75% with a maximum transmission of 90%. This is a very good result for components that combine a grating and a filter function. This is due to the high quality of the filter but also the high transmission done by the grating itself. In order 0, the average transmission is better than 1.4% for each model, which is also fine with respect to the calibration needs for NISP requiring more than 1%. Figure 5 presents the transmission curve of the NISP FM onto the bandpass done on the final components with filter and grating manufactured. We can remark that the transmission curves are very similar for the three red grisms, which demonstrate a very good reproducibility of the filter and the grating manufacturing process. One must note that the ripples that are seen on the curves are not due to the components but to the measurement set-up. More details on the transmission measurement can be found in [12].

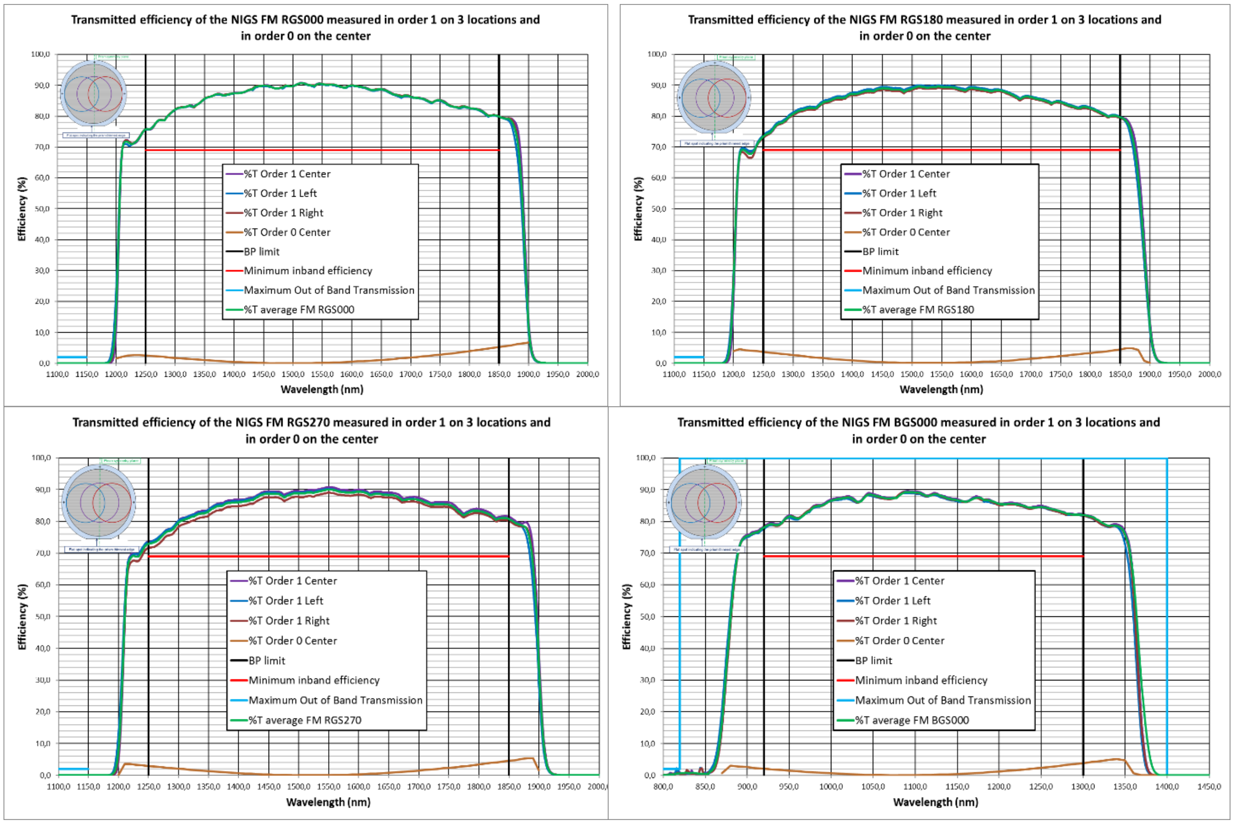

Figure 5. Transmission curve of each NISP FM components onto the bandpass (1250-1850nm for "red" grisms, 950-1250nm for "blue" grism).

3.3 SFE performance

The other main characteristics to be validated for the grism FMs are the Surface Form Error (SFE) performance, obviously linked to the transmitted Wave Front Error (WFE) performance of the component. We measure the SFE of the filter and grating surfaces thanks to a phase-shifting Fizeau interferometer working at 633nm[6]. The SFE and focus budgets have been distributed on each surface of the grism and also along the manufacturing process phases. The complete strategy for the SFE measurement of the grisms is fully described in [6,12]. The performance and compliance of the FM with the WFE specifications are provided in Table 2. We can see that all "red" grisms reach the specifications defined by the project concerning the SFE and focus term after manufacturing. Only the BGS000 grism shows some non-compliances with the specification that has been accepted by the project as the optical performance of the blue channel will not be affected too much. One can note also that the curvature introduced by the filter deposition and the gluing is larger than expected for the FM RGS000 and FM RGS180. After discussion with the project, and analysis that this deformation has a small impact on the transmitted WFE, it has been agreed to accept the components with this non-compliance. Table 2 also indicates the type of verification used to validate the specification. Only the compliance of the transmitted WFE is obtained thanks to analysis on Zemax software taking into account the measured SFE.

The validation of the SFE performance of the grisms has shown that the grating manufacturing was very good and that the equation of the grating was properly engraved by the grating manufacturer. The specification of the grating surfaces takes into account both the manufacturing of the surface itself and the grating manufacturing error i.e. the difference with a perfect grating. The error due to the grating manufacturing for each FM is lower than 15 nm RMS. Figure 6 presents an example of the theoretical interferogram of the grating function of the RGS270 component compared with the measured interferogram on the FM component in order 5. We can see a very good similarity between both interferograms. After analysis, the difference between manufacturing and theory is lower than 15 nm RMS, focus error included. This is a very good result.

Table 2. Summary of the WFE specifications and measurements obtained for all the grisms FM.

Specification Description	**Verification type**	**NI-GSU-FM-RGS000**	**NI-GSU-FM-RGS180**	**NI-GSU-FM-RGS270**	**NI-GSU-FM-BGS000**
Transmitted WFE < 20nm RMS @ 633mm (filter, gluing, mounting contribution)	Test & analysis	Compliant 12 nm RMS	Compliant 10 nm RMS	Compliant 12 nm RMS	Compliant 10 nm RMS
Focus error of the filter face of NIGSU shall be lower than +/- 0.5fringes from the nominal value	Test	Compliant 9633,23mm	Compliant 9631,06mm	Compliant 9272,43mm	Compliant 9908,27mm
Grating surface defocus < +/-0,5fr in order 1	Test	Compliant 0,34fr	Compliant 0,05fr	Compliant 0,06fr	Non Compliant 0,61fr
Grating surface RMSi < 30nm RMS in order 1	Test	Compliant 25,5nm RMS	Compliant 27 nm RMS	Compliant 27 nm RMS	Non Compliant 37,4nm RMS
Filter surface RMSi < 15 nm RMS	Test	Compliant 8,54 nm RMS	Compliant 10,5 nm RMS	Compliant 7 nm RMS	Compliant 3 nm RMS
Curvature of surfaces after gluing and filter deposition should not differ more than 5fr from the nominal value	Test	Non Compliant 5,52fr for grating 5,23fr for filter	Non Compliant 8,27fr for grating 8,4fr for filter	Compliant 4,63fr for grating 4,24fr for filter	Compliant 4,18fr for grating 4,42fr for filter

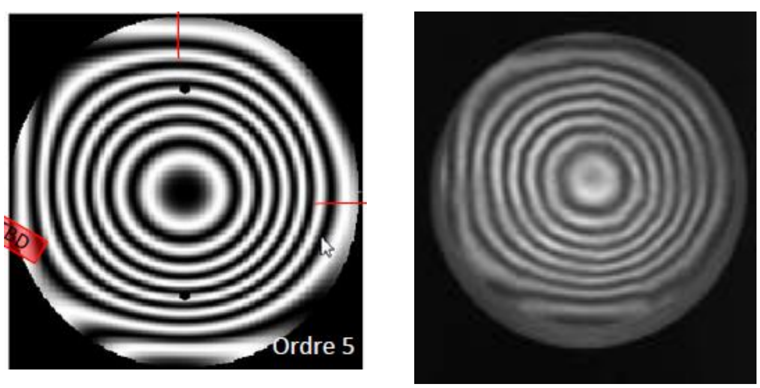

Figure 6. Theoritical interferogram for the grating of RGS270 in order 5 (left) compared to the measured interferogram of the FM RGS270 (right).

4. METROLOGY OF THE COMPONENT

In addition to the mechanical and optical characterization of the component, we have done a complete metrology of each grism to measure accurately the position of the optical reference (the center of the grating, indicated by 3 crosses engraved onto the grating surface) and the mechanical structure. The goal of this measurement is to verify that the component is correctly glued onto the mechanical structure. It is important to be in the budget allocated by the grism wheel assembly to ensure a good alignment of the grisms on the wheel. The measurement of each grism is done at LAM with an accura II Coordinate Measurement Machine (CMM) equipped with a RDS XXX head from ZEISS. This head can be equipped with a mechanical contact sensor and an optical sensor (VIS camera). A picture of the measurement set-up is provided in Figure 7. Results of the measurement of the three red grisms is provided in Table 3. Measurement uncertainties are estimated of +/- 15µm in Tx direction, +/-30µm in Ty and Tz, and 40’’ for all rotations. The metrology of the FM shows a very good accuracy of the gluing and alignment of the optical part inside the mechanical part. In particular, we have a good reproducibility of this process that allows us to provide components within specifications.

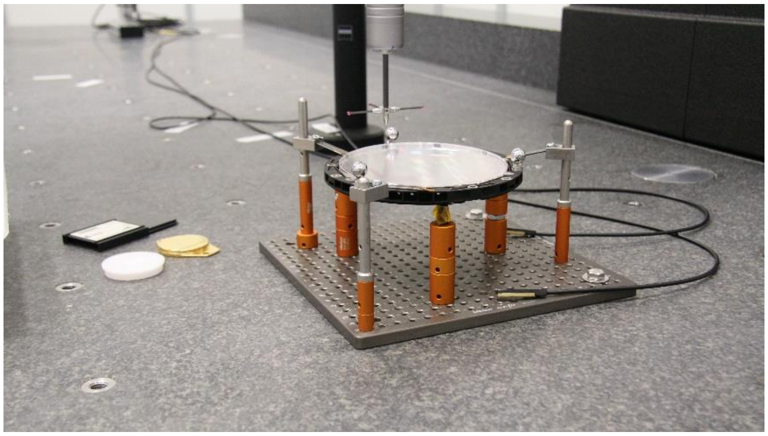

Figure 7. Picture of the FM RGS000 during its measurement on the CMM.

Table 3. Position of the optical center of the grism with respect to the mechanical structure for the 3 red FM grisms.

			RGS000			RGS180			RGS270	
Mechanical / optical alignment	**Spec RGS000**	**Tolerance**	**Value**	**difference wrt spec (µm/arcsec)**	**Spec RGS180**	**Value**	**difference wrt spec (µm/arcsec)**	**Spec RGS270**	**Value**	**difference wrt spec (µm/arcsec)**
X Pos	12,058	+/-80	12,123	65,429	12,058	12,054	-3,630	12,058	12,106	47,975
Y pos	0	+/-160	-0,067	-67,072	0,000	0,047	47,009	0,000	0,031	31,181
Z Pos	0	+/-160	-0,117	-117,100	0,000	0,152	151,516	0,000	0,002	2,424
Rot X (clock)	0	+/-8'	-0,043	-2,606	0,000	-0,022	-1,300	0,000	0,013	0,761
Rot Y (tip)	2,145	+/-65"	2,160	53,620	-2,145	-2,160	-52,340	0,000	0,003	10,860
Rot Z (tilt)	0	+/-65"	0,004	12,838	0,000	-0,002	-6,167	-2,145	-2,144	3,081

5. CONCLUSION

We have presented in this paper the overall performance of the NISP flight models for EUCLID mission. A more complete and detailed presentation can be found in [12]. The grisms manufactured, integrated and tested under the LAM responsibility have shown a very well compliance with the specifications of the project. The analyses of the tests results have shown that the grisms flight models for NISP are within specifications with an efficiency better than 70% on the spectral bandpass and a wavefront error on surfaces better than 30nm RMS. The components have also passed successfully the acceptance level vibrations and a thermal cycling at 130K. The EUCLID grisms flight models have been delivered to the NISP grism wheel in November 2017 and are now fully integrated onto the wheel. They will be installed in NISP instrument in October 2018. The grism FM will be tested and validated in NISP in early 2019 during NISP thermal test to demonstrate the full performance of the spectroscopic mode of NISP.

REFERENCES

[1] G. Racca; R. Laureijs; L. Stagnaro; J.-C. Salvignol, et al, "The Euclid mission design," *Proc. SPIE* 9904, Space Telescopes and Instrumentation 2016: Optical, Infrared, and Millimeter Wave, 99040-23 (2016)

[2] T. Maciaszek; et al., "Euclid near infrared spectrophotometer instrument concept and first test results at the end of phase C," *Proc. SPIE* 9904, Space Telescopes and Instrumentation 2016: Optical, Infrared, and Millimeter Wave, 99040-18 (2016)

[3] M. Cropper; S. Pottinger; S. Niemi; J. Denniston; et al., "VIS: the visible imager for Euclid," *Proc. SPIE* 9904, Space Telescopes and Instrumentation 2016: Optical, Infrared, and Millimeter Wave, 99040-16 (2016)

[4] A. Costille; A. Caillat; C. Rossin; S. Pascal; B. Foulon; P. Sanchez; S. Vives, "Final design and choice for EUCLID NISP grism," *Proc. SPIE* 9912, Advances in Optical and Mechanical Technologies for Telescopes and. Instrumentation II 2016, 99122C (2016)

[5] C. Rossin; A. Costille, A. Caillat, S. Pascal, P. Sanchez, et Al. “Final design of the Grism cryogenic mount for the Euclid-NISP mission”, *Proc. SPIE* 9912, Advances in Optical and Mechanical Technologies for Telescopes and. Instrumentation II 2016, paper 991261 (2016)

[6] A. Caillat; A. Costille; S. Pascal; S. Vives; C. Rossin; P. Sanchez; B. Foulon, " Optical verification tests of the NISP/Euclid grism qualification model," *Proc. SPIE* 9904, Space telescopes and Instrumentation 2016: Optical, Infrared, and Millimeter Wave, 99040R (2016)

[7] TRIOPTICS, http://www.trioptics.com/

[8] SILIOS Technologies, http://www.silios.com/

[9] WINLIGHT Optics, http://www.winlight-system.com/

[10] Optics Balzers Jena, http://www.opticsbalzers.com/

[11] A. Caillat; S. Pascal; S. Tisserand; K. Dohlen; R. Grange, et al., " Bulk silica transmission grating made by reactive ion etching for NIR space instruments ", *Proc. SPIE* 9151, Advances in Optical and Mechanical Technologies for Telescopes and Instrumentation, 91511F (2014)

[12] A. Costille; A. Caillat; C. Rossin; S. Pascal; B. Foulon; P. Sanchez; S. Vives, "The EUCLID NISP grisms flight models performance" *Proc. SPIE* 10698, Space Telescopes and Instrumentation 2018: Optical, Infrared, and Millimeter Wave 2018, 106982B (2018)