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ABSTRACT

The challenging constraints imposed on the Euclid telescope imaging performances have driven the design, manufacturing and characterisation of the multi-layers coatings of the dichroic. Indeed it was found that the coatings layers thickness inhomogeneity will introduce a wavelength dependent phase-shift resulting in degradation of the image quality of the telescope. Such changes must be characterized and/or simulated since they could be non-negligible contributors to the scientific performance accuracy. Several papers on this topic can be found in litterature, however the results can not be applied directly to Euclid's dichroic coatings. In particular an applicable model of the phase-shift variation with the wavelength could not be found and was developped. The results achieved with the mathematical model are compared to experimental results of tests performed on a development prototype of the Euclid's dichroic.

Keywords: imaging, Euclid, performance, dichroic, coating

1. INTRODUCTION

The Euclid's payload module comprised a 1.2 meter Korsch-type telescope feeding two instruments spectrally and spatially separated by a dichroic plate (see Figure 1). The light reflected by the front face of the dichroic is directed towards an instrument (VIS) working in the visible spectral range. The light transmitted in the spectral range [920nm;2000nm] is directed towards the Near Infrared Spectrometer and Photometer (NISP).

The dichroic has two complex multi-layers di-electric coatings, one on each face, which functions are : high spectral reflectance in the VIS instrument spectral band and high transmittance in the NISP spectral band, low ghost level for both instruments and low reflected/transmitted wavefront error (WFE) at operational temperatures (about 120K)[2]. However it is well-known[3] that di-electric multi-layers coatings introduce a wavelength (λ) dependent phase-shift in reflection and in transmission. This phase-shift will vary spatially over the coating area depending on the local deviation of the as-manufactured coating from the as-designed coating. The deviations are mainly due to the layers thickness variations.

The VIS instrument is dedicated to the gravitational weak-lensing probe[1] thus requiring an exquisite knowledge and characterization of the telescope's image quality. The phase-shift effect may thus have a significant impact on the scientific performance for the VIS instrument. Furthermore since the phase-shift also depends on λ two point objects in the sky with different spectra will have different polychromatic Point Spread Functions (PSF) thus rendering the in-flight calibration of the telescope even more complex.

The characterization of the phase-shift impact on the image quality was performed on a flight representative demonstrator dichroic model (DM) during the phase B2 of the Euclid project development. The purpose was to assess beforehand if the phase-shift introduced is acceptable or not performance-wise.

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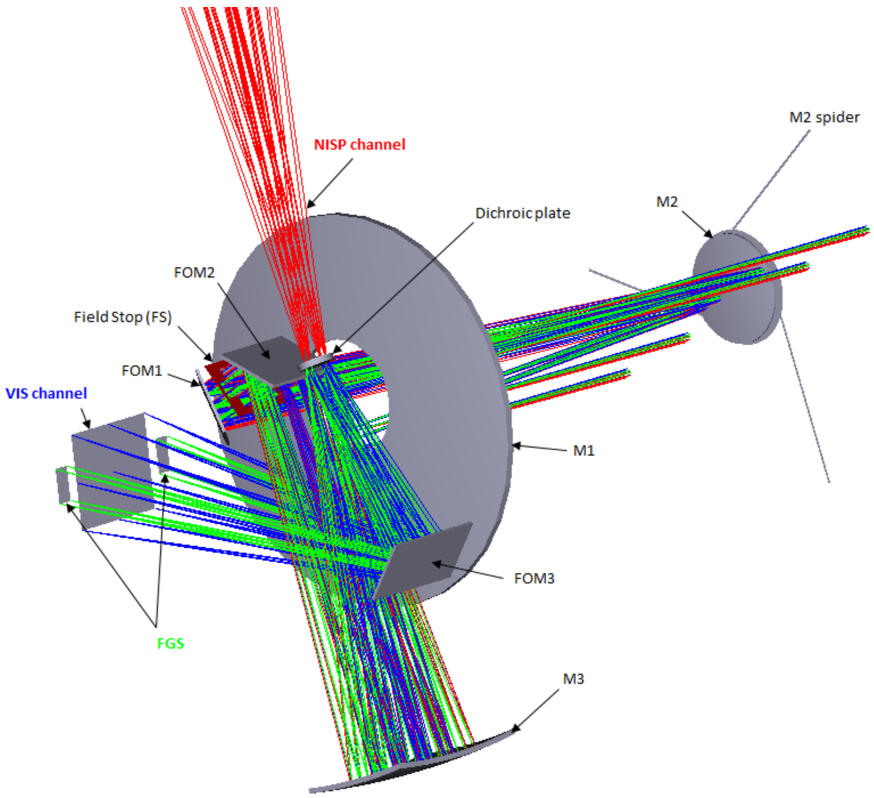

Figure 1. Euclid telescope optical lay-out.

2. EXPERIMENTAL RESULTS

The Wave front error (WFE) in reflection of the as-manufactured dichroic DM coatings was measured in Sodern (France) facilities at ambient temperature for the wavelengths λ=850nm and λ=625nm. A Shack-Hartmann wavefront sensor (SHWS) was used and specifically calibrated to that purpose. The budgeted accuracy on the WFE maps measured with the SHWS is 4 nm RMS.

The measured WFE maps shown in Figure 2 demonstrate clear differences. These discrepancies are further shown with the usual WFE metrics, Root-Mean-Square (RMS) and Peak to Valley (PtV) values, reported in Table 1.

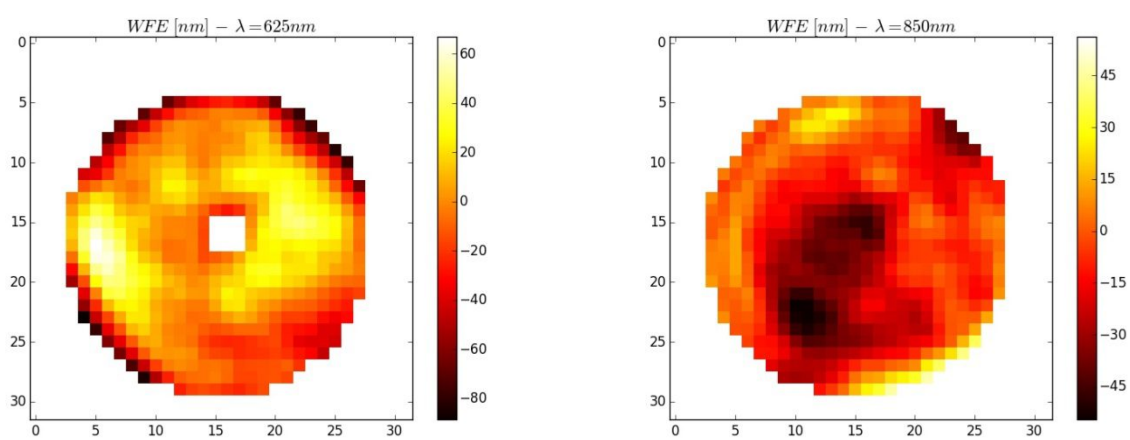

Figure 2. (Left) Measured WFE for λ=625nm; (Right) Measured WFE for λ=850nm. The colorbar units is in nanometer.

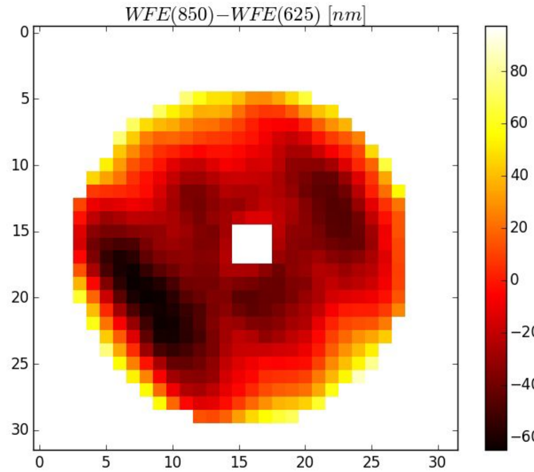

Figure 3. Difference of measured WFE maps.

The WFE maps difference is not negligible (Table 1) when considering that the WFE budget is driven by the diffraction limit at λ =800nm, i.e. 60nm RMS. Furthermore it is clear that the difference of the WFE maps have visible structures (see Figure 3). To confirm that those structures are due only to the coating a spatially resolved measurement of the spectral reflectance over the dichroic DM coated surface has been performed. The spectral shift for R=50% is determined by $\frac{\Delta\lambda}{\lambda_{design}} = \frac{\lambda_{measured} - \lambda_{design}}{\lambda_{design}}$ with λ_{design} (resp. $\lambda_{measured}$) the wavelength for which the coating reflectance as designed (resp. as measured) is 50%.

It is clear from Figure 4 that similar structures can be found both in the reflectance uniformity map and in WFE difference map. However the location of the smallest spectral shift in Figure 4 does not seem to correspond to the location of the smallest WFE difference in Figure 3.

Table 1. WFE maps statistics.

WFE map	**RMS [nm]**	**PtV [nm]**
WFE(850)	18.03	110.76
WFE(625)	26.19	155.24
WFE(850) - WFE(625)	32	162.3

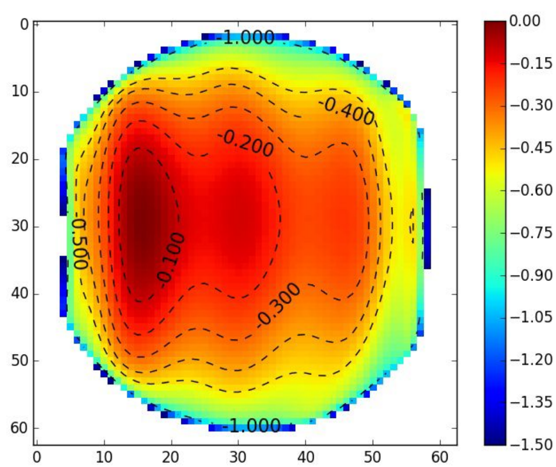

Figure 4. Spectral reflectance shift homogeneity in percentage of $\boldsymbol{\lambda_{design}}$ for R=50%.

3. IMAGE QUALITY SPECTRAL DEPENDENCE

A mathematical model has been developed based on the measured WFE maps to calculate the dichroic DM reflected WFE map for an arbitrary wavelength. The reconstructed maps are then use by the Euclid scientific consortium to derive the polychromatic PSFs in the telescope focal plane. The details of the model will be presented in a future publication and will not be discussed here; only the results obtained with the model are presented.

To validate the model we will compare the RMS and PtV of the reconstructed maps to the values obtained for the measured maps and also the RMS and PtV of the residuals WFE map defined as $WFE_{residual} = WFE_{reconstructed} - WFE_{measured}$.

The WFE maps reconstructed with the model are compared with the measured maps for λ=625nm and λ =850nm. The RMS and PtV of the reconstructed maps fit closely the RMS and PtV values of the measured maps (Table 2). For λ=625nm the reconstructed map is almost a perfect match to the measured one since the residual RMS is close to 1nm. However for λ=850nm the residuals are much higher. Such discrepancy can be explained by the choice of the wavelengths which do not fulfill the strict condition defined in the mathematical model which would ensure that the residuals can be neglected for all wavelengths. The RMS of the reconstructed maps are coherent with the RMS of the measured maps thus ensuring the validity of the model for the RMS and PtV values of the reconstructed maps.

Table 2. Statistics of reconstructed WFE maps.

WFE map	**λ = 850 nm**		**λ = 625 nm**	
	RMS [nm]	**PtV [nm]**	**RMS [nm]**	**PtV [nm]**
Measured	18.03	110.8	26.2	155.4
Reconstructed	18.04	113.02	24.9	147.5
Residuals	21.3	107.3	1.4	7.9

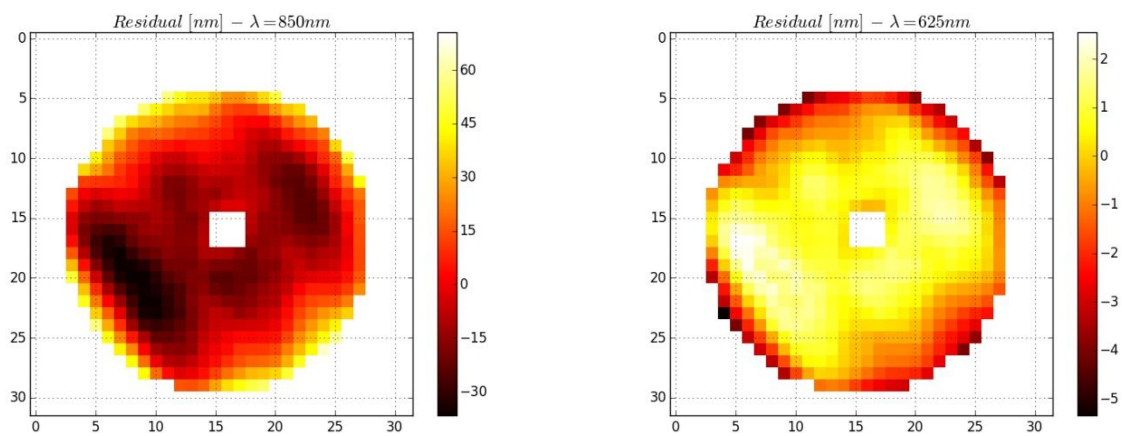

Figure 5. (Left) WFE residuals map for λ=850nm. (Right) WFE residuals map for λ=625nm.

The RMS of the WFE maps for λ ∈ [550nm;935nm] are calculated and shown in Figure 6.

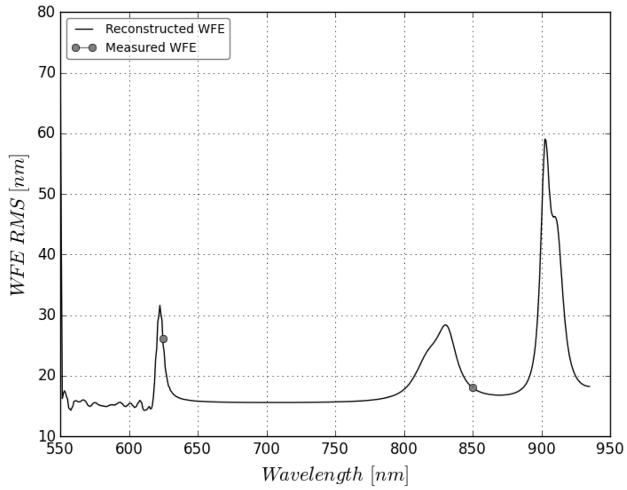

Figure 6. RMS of reconstructed WFE maps vs wavelength.

The Strehl ratio variation $\Delta S/S_{allocation}$ is used as a metric of the telescope image quality degradation due to the dichroic DM phase-shift. The term $S_{allocation}$ is the Strehl ratio achieved by the telescope assuming that the specified WFE budget for the telescope is met for all wavelengths. The term ΔS is defined as $\Delta S = S_{DM} - S_{allocation}$ with S_{DM} the telescope Strehl ratio expected with the reconstructed WFE of the dichroic DM.

From the results shown in Figure 7 we conclude that the degradation in Strehl ratio is limited over the VIS spectral range except around λ=900nm where the degradation can reach about 14%. A significant change in the weak-lensing probe metrics[2] used to characterize the PSF in-flight may then occur, potentially adding a non-compensated/non-calibrated bias to the Euclid mission's end products.

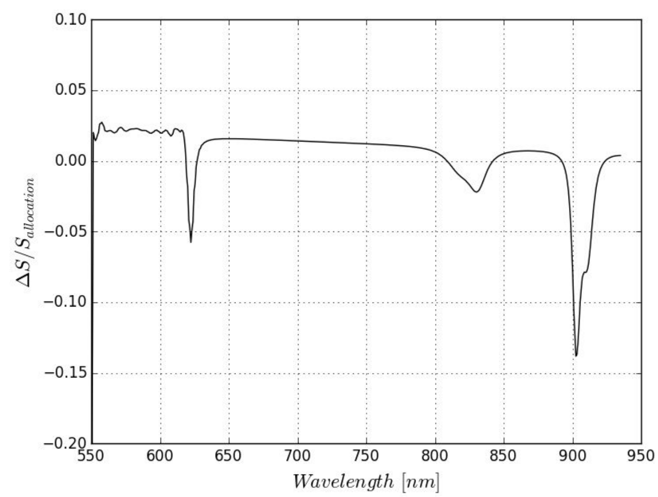

Figure 7. Strehl ratio degradation with wavelength.

4. CURRENT AND FUTURE ACTIVITIES

The root causes for the image quality variation with λ are:

1. The wavelength dependent group delay of the coating design
2. The non-uniformities in the layers thickness during the coating deposition process

Thus to minimize the image quality degradation it is necessary to both redesign the coating stack taking into account the group delay[4] introduced by the theoretical design and also to optimize the coating deposition process including fine tuning the layers deposition parameters like the deposition rate, the deposition mask in the coating chamber etc… . Both activities were performed under the lead of the dichroic manufacturer Optics Balzers Jena (OBJ). The amplitude of the group delay peaks was successfully reduced while retaining the same spectral performance in reflection. In addition a significant improvement in the coating layers uniformity was achieved. The spectral reflectance shift uniformity (Figure 8) is an indicator of the improvement.

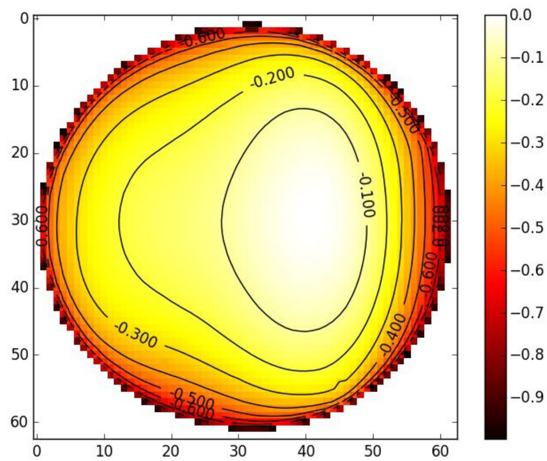

Figure 8. Spectral reflectance shift homogeneity over the dichroic coating diameter in percentage of $\boldsymbol{\lambda_{design}}$ for R=50% after improvement of the dichroic coating design.

A new flight-representative breadboard for the dichroic with the optimized coating design has been manufactured and is currently undergoing experimental characterization. The experimental activities include the measurement of the WFE in reflection at 4 different wavelengths in ambient conditions. From those measurements a definitive validation of the mathematical model mentioned in §3 will be performed. The WFE maps for the wavelengths in the VIS instrument spectral range will be calculated and used to determine the wavelength dependence of the PSFs in the VIS focal plane.

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REFERENCES

[1] Laureijs, R., Racca G., Stagnaro, L., Salvignol, J.-C., Lorenzo Alvarez, J., Saavedra Criado, G., Gaspar Venancio, L.M., Short, A., Strada P., Colombo , Buenadicha G., Hoar, J., Kohley, R., Vavrek, R., Mellier, Y., Berthe, M., Amiaux, J., Cropper, M., Niemi, S., Pottinger, S., Ealet, A., Jahnke, K., Maciaszek, T., Pasian, F., Sauvage, M., Wachter, S., Israelsson, U., Holmes, W., Seiffert, M., Cazaubiel, V., Anselmi, A., Musi, P., “Euclid mission status”, Proc. SPIE 9143, Space Telescopes and Instrumentation 2014: Optical, Infrared, and Millimeter Wave, 91430H (August 2, 2014).

[2] Gaspar Venancio, Luis M., Laureijs, René , Lorenzo, Jose , Salvignol, J.-C. , Short, Alex , Strada, Paolo , Vavrek, Roland , Vaillon, Ludovic , Gennaro, Corrado , Amiaux, Jerome , Prieto, Éric, “Euclid payload module: telescope characteristics and technical challenges”, Proc. SPIE 9143, Space Telescopes and Instrumentation 2014: Optical, Infrared, and Millimeter Wave, 91430I (2014).

[3] Baumeister, P. W., Jenkins, F. A. & Jeppesen, M. A., “Characteristics of the Phase-Dispersion Interference Filter”, Journal of the Optical Society of America 49**,** 1188 (1959).

[4] Lappschies, M., Weber, T. , Venancio, L., Jakobs, S., “Advanced dielectric coatings for the Euclid mission telescope manufactured by the PARMS process”, Proc. Optical Interference Coatings, *to be published* (2016).