OSIRIS

Optical, Spectroscopic, and Infrared Remote Imaging System

NAC and WAC Optical Band-pass Filter Transmissions

RO-RIS-MPAE-TN-091

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D / -	01-08-2018	G. Kovacs	All	First draft
D/a	20/8/2018	C. Tubiana		Corrected references in Table 1, Table 2, Table 3 Added ID of spare filters used for transmission curve measurements in Table 1, Table 2, Table 3 Added RD7 and RD8.
1/-	29/8/2018	C. Tubiana		Corrected typo
1/a	28/9/2018	C. Tubiana	Sec. 2.1, 2.3 3.2, A.2	Updated reference for filter transmission curve of WAC UV325 (added RD9). Figure 29 and Figure 31: displayed in the Rosetta standard orientation.

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1 General aspects

1.1 Scope

The OSIRIS cameras are equipped with a dual filter wheel mechanism. The WAC contains 14 band-pass filters while the NAC is equipped with 11 band-pass filters, one neutral density, and 4 focus adjustment optical components. This technical note discusses the transmission of these optical components (filters) including the variation across the image field of view. The objective is to provide a basis for a more accurate radiometric image analysis especially for the gas line filters.

1.2 Introduction

The OSIRIS filters accommodated by the filter wheels utilize dichroic band pass and anti-reflection coatings to select the required wavelength range. The selectin is achieved by multiple reflections and interferences inside the thin film layers. This method provides accurate wavelength selection and/or low reflectivity for imaging. However, the transmission characteristics are dependent on the incident angle of the optical beam.

1.3 Reference Documents

no.	document name	document number, Iss./Rev.
RD1	Filter Configuration Document	RO-RIS-MPAE-TN-059, D/e
RD2	Filter Retest Plan	RO-RIS-MPAE-PL-008, D/-
RD3	Filter Data Review	RO-RIS-MPAE-TN-063, D/- (including .7z and .zip files)
RD4	Filter Retest and Central Wavelength Estimate	RO-RIS-MPAE-TN-072, D/a
RD5	Reflection measurement of NAC and WAC filters (2)	R0-RIS-LAS-RP-45, 1/1
RD6	Reflection measurement of NAC filters (4)	R0-RIS-LAS-RP-048, 1/-
RD7	Filter accommodation on FWM, for NAC FLIGHT model	R0-RIS-LAS-TN-026, 2/-
RD8	FM-WAC FWM Optical Test Report	RO-RIS-INTA-RP-020, 1/-
RD9	Spectrogon characterization of WAC UV325	RO-RIS-MPAE-TN-092, 1/-

1.4 Abbreviations and acronyms

Name	Meaning	Units
ADP	Acceptance Data Package	
BME	Budapest University of Technology and Economics	
FWHM	Full width at half maximum, the measure of the filter band width	nm
CWL	Central wavelength	nm
PFM	Proto Flight Model	

TMAX	Maximum transmittance in band	
FOV	Field of view	deg or rad
BB	Broad band (filter)	
GRM	Ground Reference Model of the OSIRIS cameras	

2 Camera filter transmissions

2.1 Filter wheel population

The NAC and WAC filter wheel assemblies are mechanically identical. The wheels are numbered in the direction of the light propagation along the optical axis: wheel #1 is closer to the mirrors and wheel #2 is closer to the detector assembly. Each wheel can carry eight filters; however, in case of the WAC position 1 is left empty on both wheels.

The NAC filter wheels include 11 band-pass filters, 1 neutral density (ND) filter, and 4 focus adjusting plates:

Position	Name	ID[RD7]	CWL	FWHM	TMAX	Substrate	Measurement
1	FFP-UV	3 (1)	-		99.0	Suprasil	LAM[RD6]*
2	FFP-Vis	195 (194)	-		95.0	Suprasil	LAM[RD6]*
3	NFP-Vis	1 (3)	-		98.0	Suprasil	LAM[RD6]*
4	Near-IR	492	882.1	65.9	78.4	OG550	Spectrogon[RD3]
5	Ortho	296	805.3	40.5	69.8	OG550	Spectrogon[RD3]
6	Fe2O3	514	931.9	34.9	81.6	OG550	Spectrogon[RD3]
7	IR	332	989.3	38.2	78.1	OG550	Spectrogon[RD3]
8	ND	C (A)	-		5.0	NG5	LAM[RD5]*

Table 1 NAC Filter wheel 1 components (*measurement data of flight spare. The ID of the flight spare filter used for the transmission measurement is provided in brackets.)

Position	Name	ID[RD7]	CWL	FWHM	TMAX	Substrate	Measurement
1	FFP-IR	3 (2)	BB		99.0	Suprasil	LAM[RD6]*
2	Orange	444	649.2	84.5	92.4	OG550	Spectrogon[RD3]
3	Green	705	535.7	62.4	75.8	KG3	Spectrogon[RD3]
4	Blue	703	480.7	74.9	74.6	KG3	Spectrogon[RD3]
5	Far-UV	56	269.3	53.6	37.8	Suprasil	Spectrogon[RD3]
6	Near-UV	673	360.0	51.1	78.2	KG3	Spectrogon[RD3]
7	Hydra	530	701.2	22.1	87.4	OG550	Spectrogon[RD3]
8	Red	312	743.7	64.1	96.0	OG550	Spectrogon[RD3]

Table 2 NAC Filter wheel 2 (*measurement data of flight spare. The ID of the flight spare filter used for the transmission measurement is provided in brackets.)

The WAC filter wheels carry 14 band-pass filters, and two empty slots, so in imaging operations each filter is selected individually:

Position	Name	ID [RD8]	CWL	FWHM	TMAX	Substrate	Measurement
1	Empty					none	
2	Green	551	537.2	63.2	76.8	KG3	Spectrogon[RD3]

3	UV245	8	246.2	14.1	31.8	Suprasil	Spectrogon[RD3]
4	CS	32	259.0	5.6	29.8	Suprasil	Spectrogon[RD3]
5	UV295	255	295.9	10.9	30.4	Suprasil	Spectrogon[RD3]
6	OH	246	309.7	4.1	26	Suprasil	Spectrogon[RD3]
7	UV325	346	325.8	10.7	31.6	Suprasil	BME[RD9]
8	NH	136	335.9	4.1	23.6	Suprasil	Spectrogon[RD3]

Table 3 WAC Filter wheel 1 (*measurement data of flight spare. The ID of the flight spare filter used for the transmission measurement is provided in brackets.)

Position	Name	ID[RD8]	CWL	FWHM	TMAX	Substrate	Measurement
1	Empty					none	
2	Red	403	629.8	156.8	95.7	OG515	Spectrogon[RD3]
3	UV375	6	375.6	9.8	57.3	KG3	Spectrogon[RD3]
4	CN	27	388.4	5.2	37.4	KG3	Spectrogon[RD3]
5	NH2	575	572.1	11.5	60.9	KG3	Spectrogon[RD3]
6	Na	655	590.7	4.7	59.0	KG3	Spectrogon[RD3]
7	OI	302	631.6	4.0	52.4	OG550	Spectrogon[RD3]
8	Vis610	733	612.6	9.8	83.4	OG550	Spectrogon[RD3]

Table 4 WAC Filter wheel 2

2.2 NAC filter transmissions at the center of the field of view

The transmission data plotted below have been measured at the assembled position of the components, corresponding to the center region of the camera field. The files are listed in section 4. Data files marked (*) are measured on a flight lot component, in the same manufacturing batch:

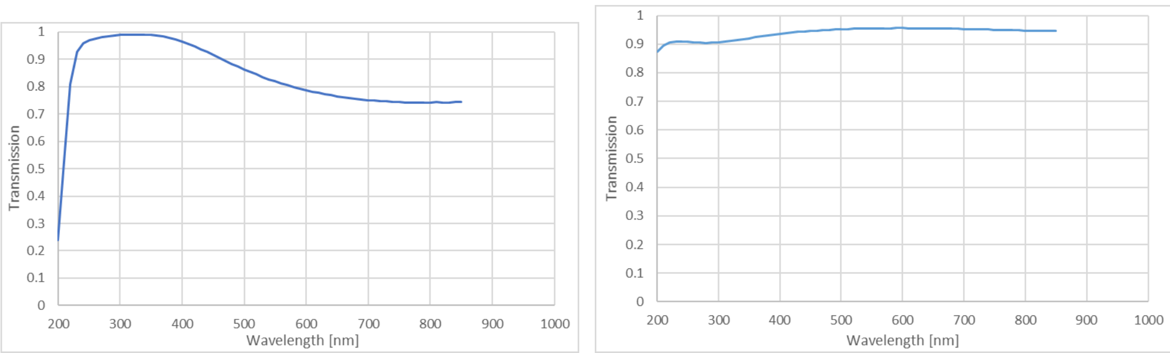


Figure 1 NAC FFP-UV* and FFP-VIS* transmission

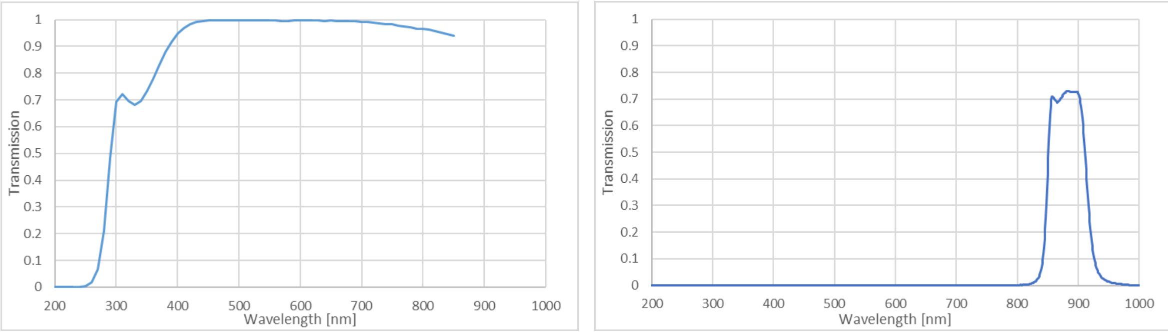


Figure 2 NAC NFP-Vis* and Near-IR transmission

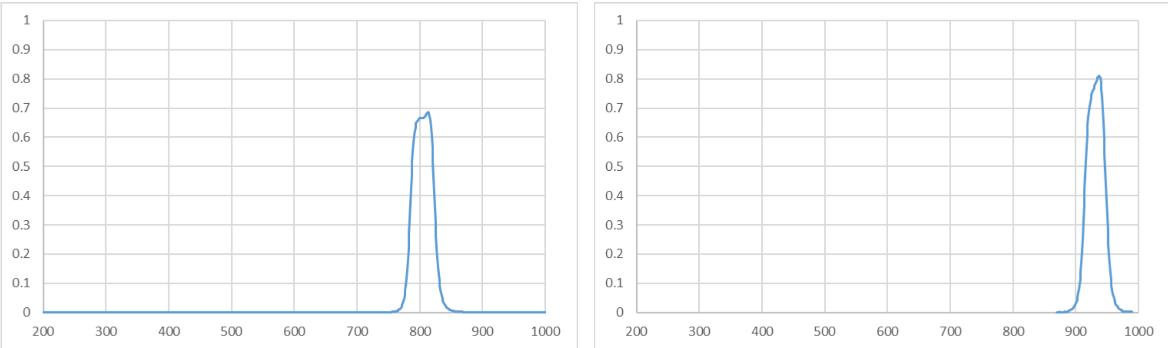


Figure 3 NAC Ortho and Fe2O3 transmission

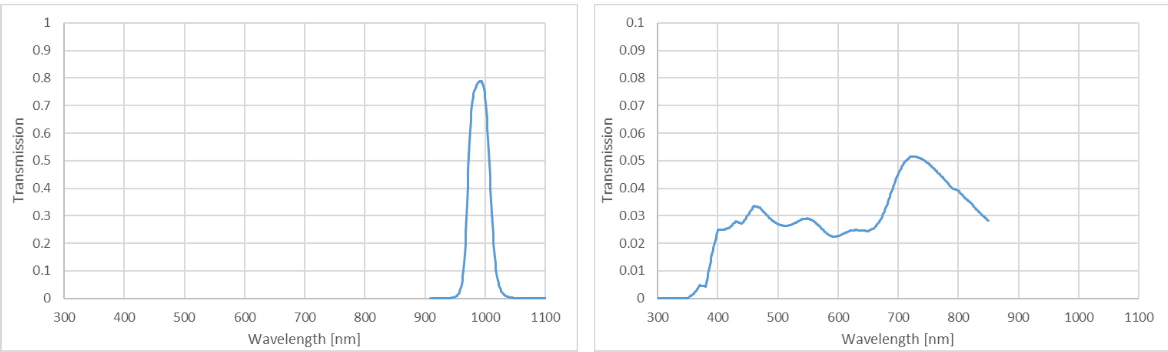


Figure 4 NAC IR and Neutral Density* filter transmission

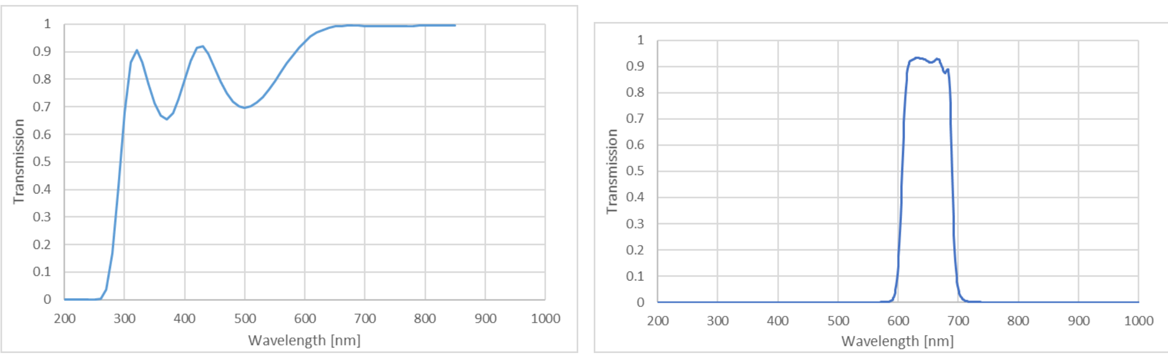


Figure 5 NAC FFP-IR and Orange filter transmission

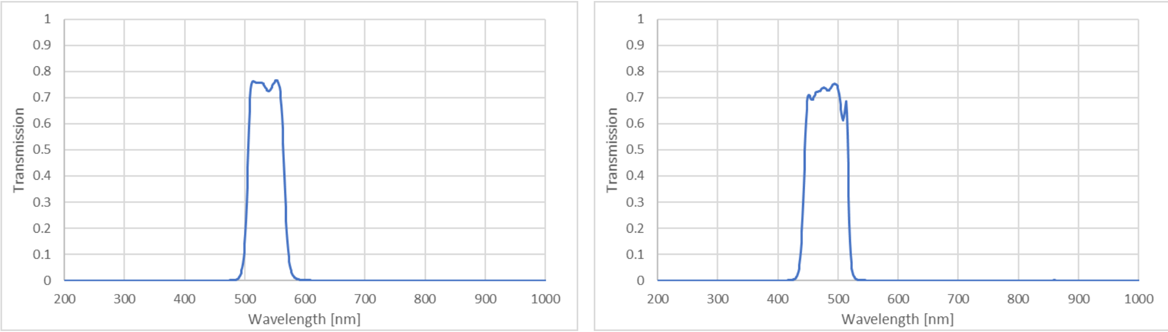


Figure 6 NAC Green and Blue transmission

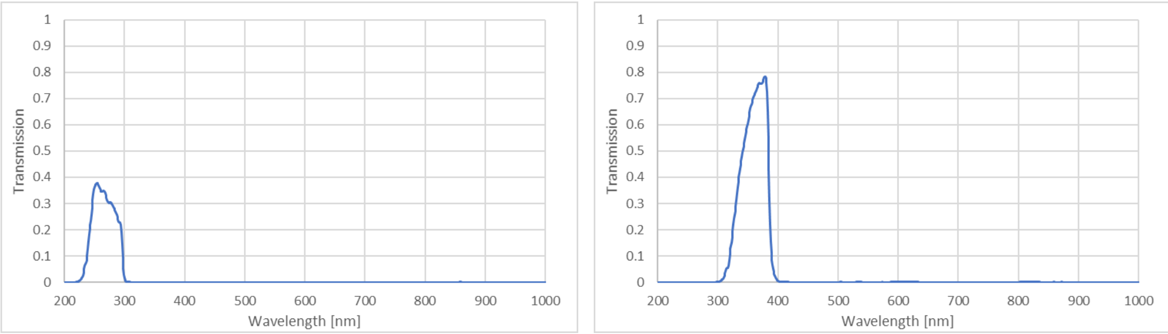


Figure 7 NAC Far-UV and Nar-UV filter transmission

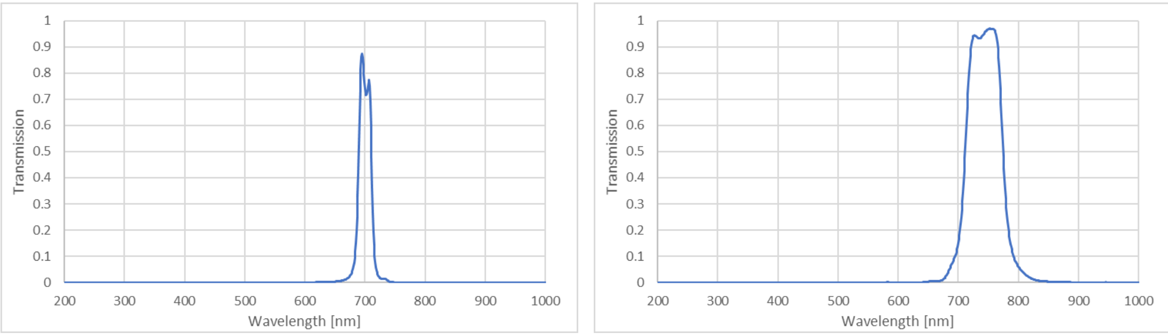


Figure 8 NAC Hydra and Red filter transmission

2.3 WAC filter transmissions at the center of the field of view

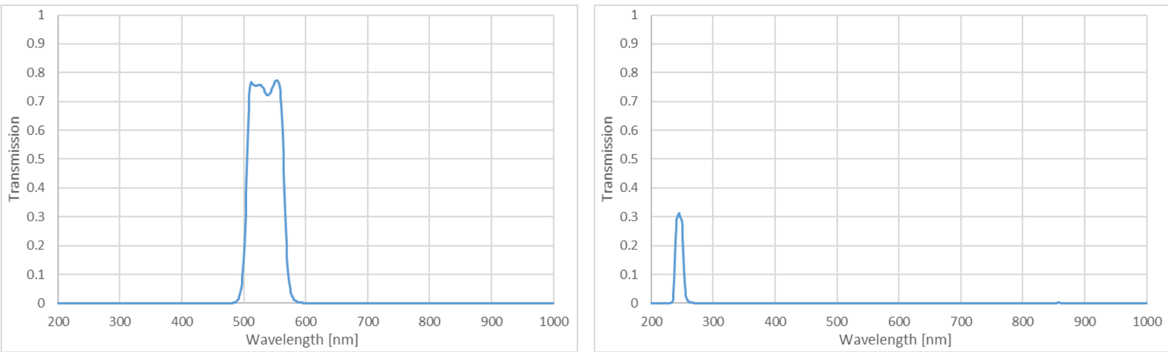


Figure 9 WAC Green and UV245 filter transmission

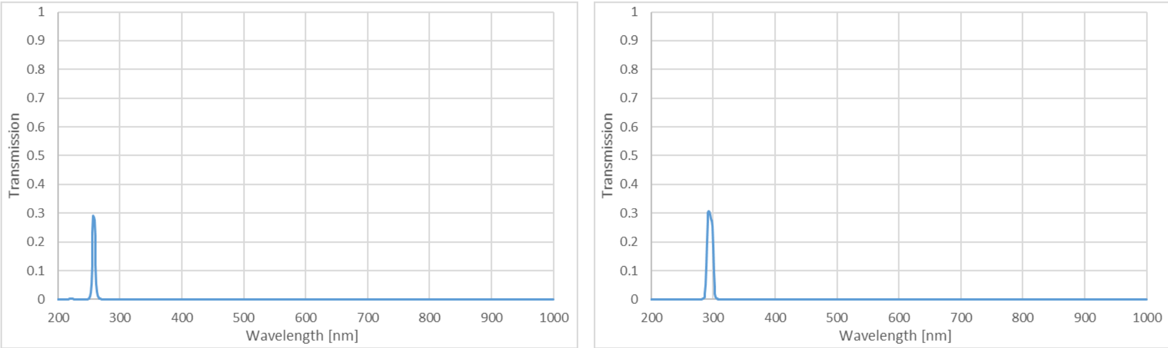


Figure 10 WAC CS and UV295 filter transmissions

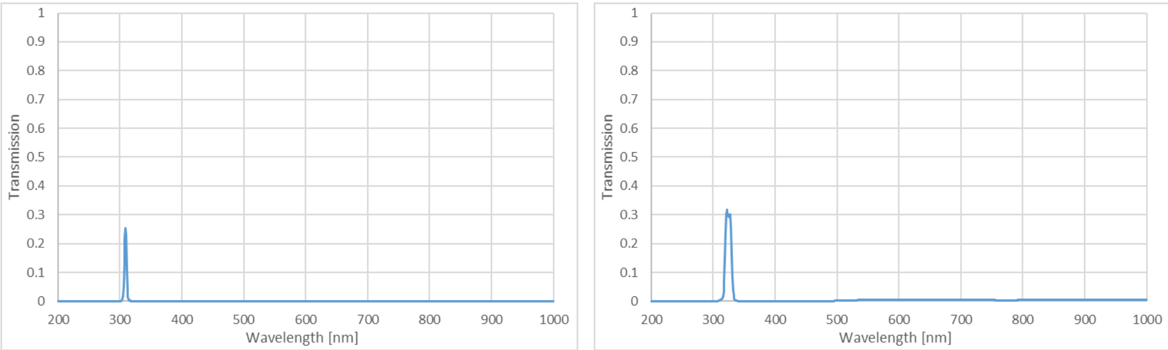


Figure 11 WAC OH and UV325 filter transmissions

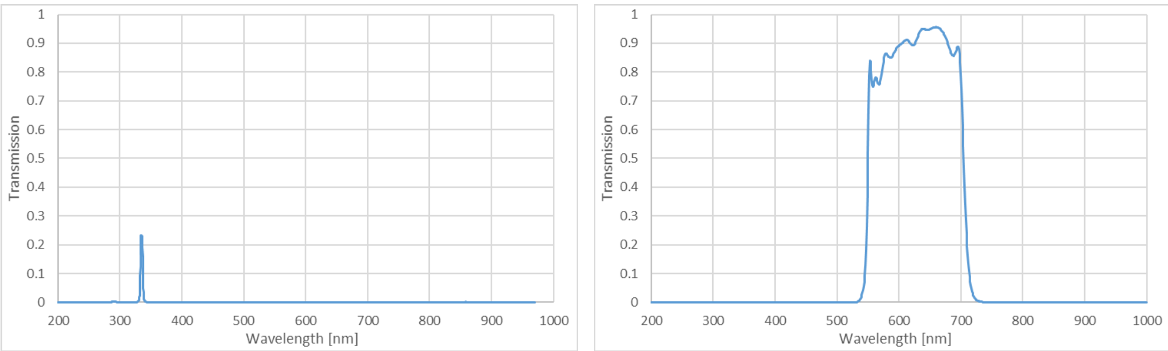


Figure 12 WAC NH and WAC Red filter transmissions

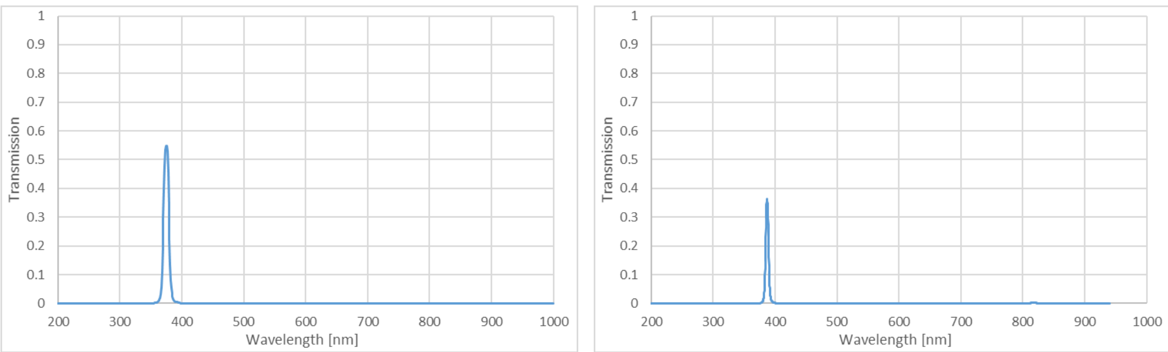


Figure 13 WAC UV375 and CN filter transmissions

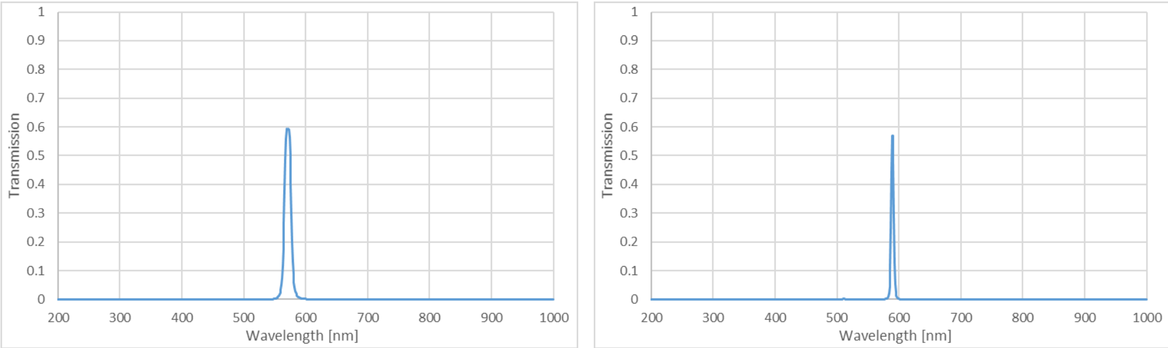


Figure 14 WAC NH2 and Na filter transmission

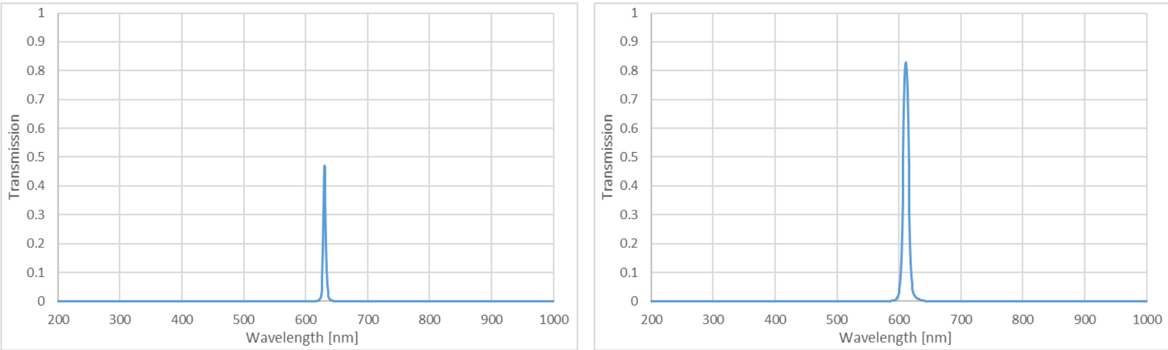


Figure 15 WAC OI and Vis610 filter transmission

3 Transmission variation vs. the FOV for the WAC narrow band filters

The OSIRIS camera designs are off-axis anastigmats. This design has an increasing incident angle of the principal ray across the field of view. This results in a varying optical transmission across the FOV. In case of narrow band filters and spectral line sources (gas emission detection), the camera response can be strongly dependent on the pixel position. However, for continuum sources (dust or surface reflection) the response variation is less significant. The effect was demonstrated in laboratory for the WAC Na line filter (Fig. 16). The current document extends the manufacturer supplied transmission data (valid only at the center of the image) with transmission data measured at several different incident angle. The transmission was characterized on the flight spare filters in 2012 at the Budapest University of Technology and Economics (BME) and the data files are listed in section 4.

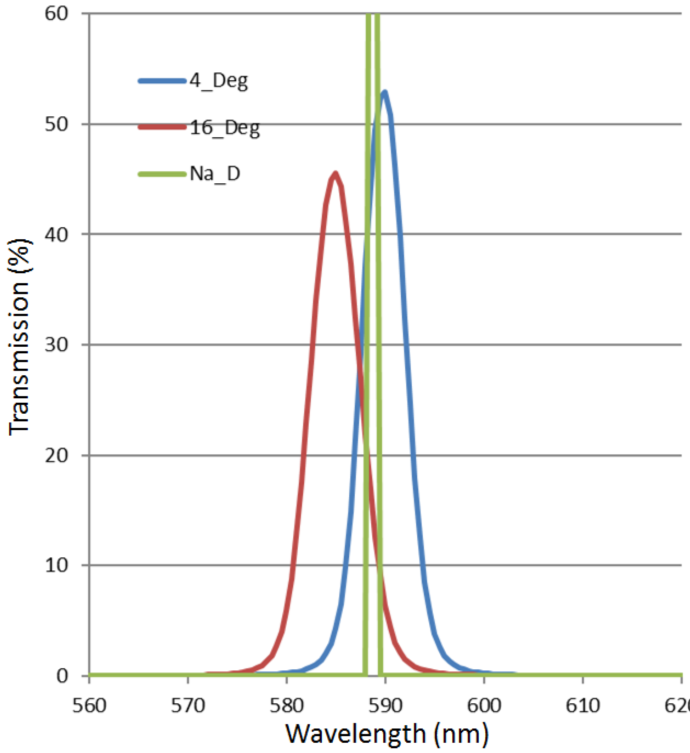
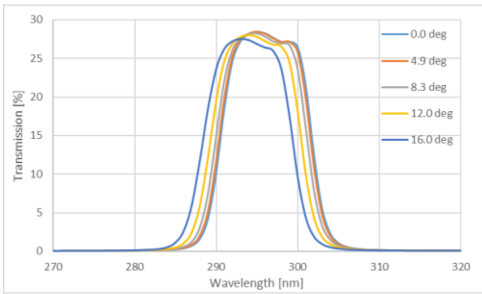


Figure 16 Na filter transmission at 4° and 15° beam angle in comparison to the Na D line pair vs. wavelength

3.1 Flight spare filter results

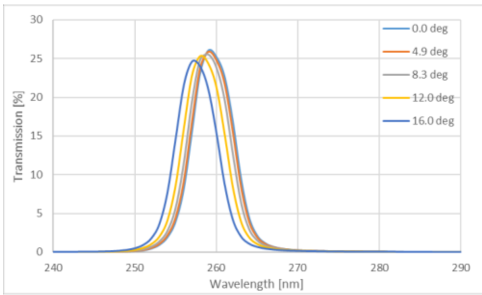
The 2012 filter campaign included also a specific measurement for the incident angle dependency of the transmission. The filter transmissions were recorded at several incident angles covering the cameras operational range (0-20°).

The **TMAX** value is the measured maximum transmission of the filter. The **FWHM** is bandwidth of the filter where the transmission is greater than 50% the **TMAX**. The wavelength range is determined by linear interpolation of the measurement points. **CWL** is the midpoint between the **FWHM** wavelengths (where transmittance is 50% of **TMAX**). Angles are measured in degrees.



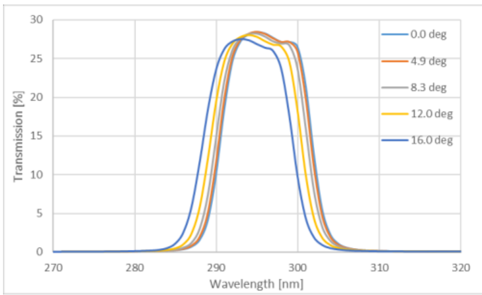
Angle	TMAX	FWHM	CWL
0	0.303	14.16	246.44
4.9	0.301	14.15	246.31
8.3	0.299	14.10	246.01
12	0.296	14.03	245.53
16	0.290	13.87	244.83

Figure 17 Measured transmissions (left) and fit to data (right) of WAC UV245 filter



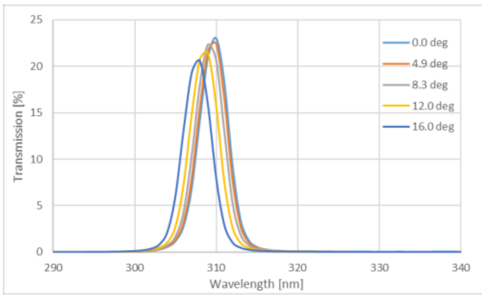
Angle	TMAX	FWHM	CWL
0	0.244	5.95	259.62
4.9	0.242	5.95	259.43
8.3	0.238	5.92	259.06
12	0.236	5.89	258.39
16	0.230	5.85	257.48

Figure 18 Measured transmissions (left) and fit to data (right) of WAC CS filter



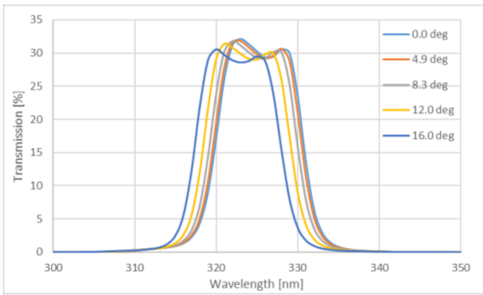
Angle	TMAX	FWHM	CWL
0	0.285	11.33	296.16
4.9	0.284	11.32	295.98
8.3	0.283	11.32	295.58
12	0.280	11.25	294.89
16	0.275	11.18	293.90

Figure 19 Measured transmissions (left) and fit to data (right) of WAC UV295 filter



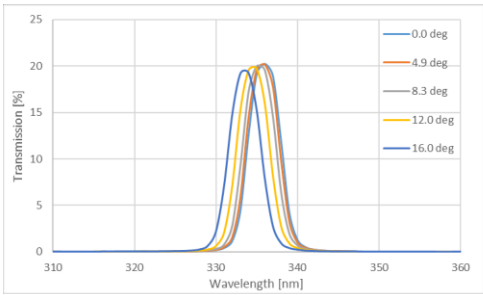
Angle	TMAX	FWHM	CWL
0	0.230	4.13	309.69
4.9	0.224	4.18	309.52
8.3	0.223	4.13	309.17
12	0.214	4.16	308.53
16	0.206	4.10	307.65

Figure 20 Measured transmissions (left) and fit to data (right) of WAC OH filter



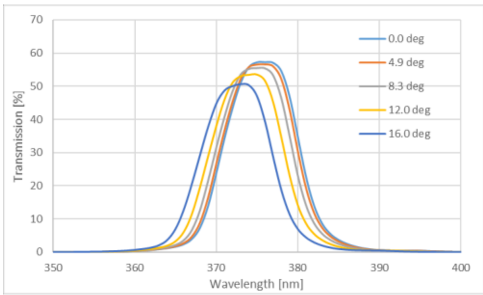
Angle	TMAX	FWHM	CWL
0	0.321	10.91	325.31
4.9	0.318	10.94	325.06
8.3	0.318	10.85	324.58
12	0.313	10.84	323.79
16	0.306	10.74	322.66

Figure 21 Measured transmissions (left) and fit to data (right) of WAC UV325 filter



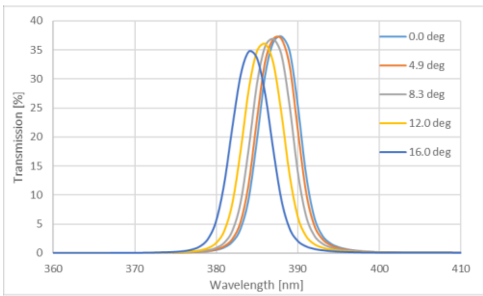
Angle	TMAX	FWHM	CWL
0	0.203	4.53	335.96
4.9	0.202	4.47	335.72
8.3	0.200	4.46	335.32
12	0.197	4.44	334.55
16	0.192	4.43	333.54

Figure 22 Measured transmissions (left) and fit to data (right) of WAC NH filter



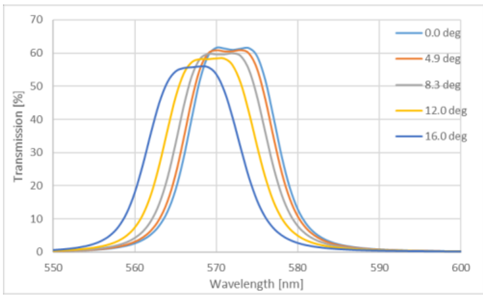
Angle	TMAX	FWHM	CWL
0	0.573	10.06	375.50
4.9	0.566	10.03	375.19
8.3	0.554	9.98	374.62
12	0.535	9.90	373.72
16	0.507	9.77	372.44

Figure 23 Measured transmissions (left) and fit to data (right) of WAC UV375 filter



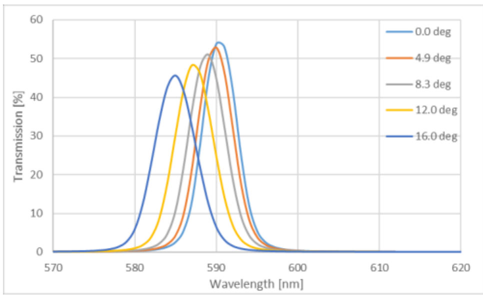
Angle	TMAX	FWHM	CWL
0	0.374	5.67	387.74
4.9	0.369	5.69	387.42
8.3	0.369	5.58	386.81
12	0.361	5.54	385.79
16	0.347	5.51	384.28

Figure 24 Measured transmissions (left) and fit to data (right) of WAC CN filter



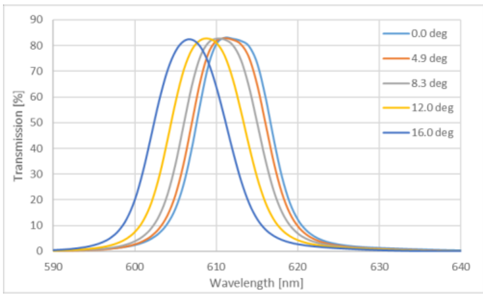
Angle	TMAX	FWHM	CWL
0	0.615	11.66	572.02
4.9	0.609	11.76	571.53
8.3	0.599	11.85	570.67
12	0.583	12.01	569.29
16	0.560	12.22	567.27

Figure 25 Measured transmissions (left) and fit to data (right) of WAC NH2 filter



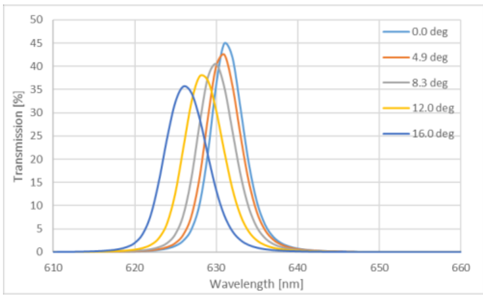
Angle	TMAX	FWHM	CWL
0	0.538	4.96	590.42
4.9	0.529	5.09	589.86
8.3	0.511	5.26	588.86
12	0.484	5.55	587.27
16	0.456	5.91	584.94

Figure 26 Measured transmissions (left) and fit to data (right) of WAC Na filter



Angle	TMAX	FWHM	CWL
0	0.831	10.10	612.10
4.9	0.828	10.04	611.50
8.3	0.827	10.14	610.50
12	0.826	10.10	608.90
16	0.824	10.10	606.80

Figure 27 Measured transmissions (left) and fit to data (right) of WAC Vis610 filter



Angle	TMAX	FWHM	CWL
0	0.449	4.65	631.40
4.9	0.425	4.99	630.89
8.3	0.406	5.27	629.98
12	0.379	5.72	628.49
16	0.357	6.14	626.33

Figure 28 Measured transmissions (left) and fit to data (right) of WAC OI filter

3.2 Correction data for WAC filters

The off-axis mirror anastigmat design results in a non-symmetric incident angle distribution across the image plane. This variation of the incident angle causes significant variation of the filter transmission, especially at the narrow band filters. To provide an aid for the accurate gas intensity calculations, correction data objects were created for each narrow band filter. The PDS data files contain four 'IMAGE' objects of 2048 x2048 pixels size.

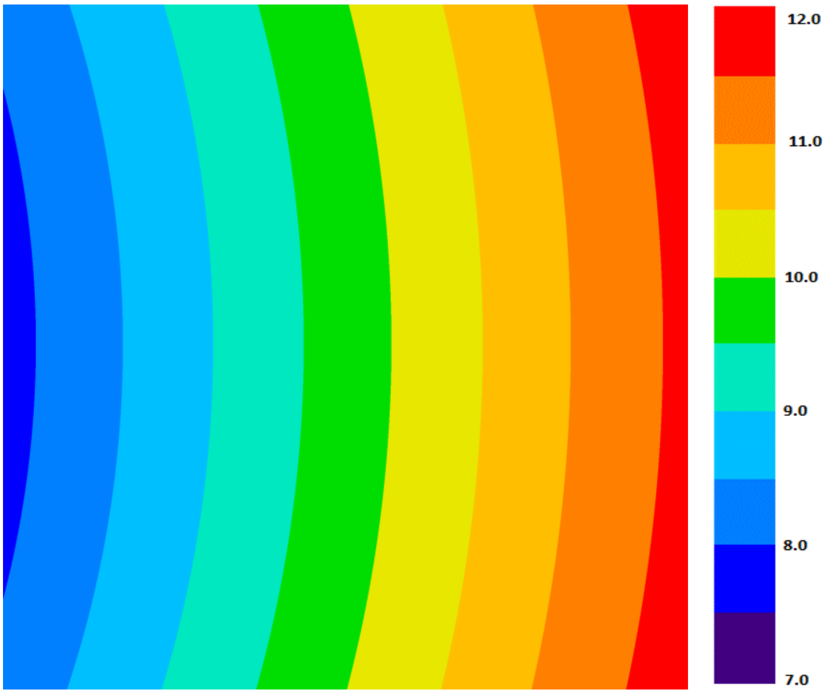


Figure 29 WAC principal ray incident angle vs. pixel position. The image is displayed in the Rosetta standard orientation.

To calculate the accurate transmission at a given pixel, the correction image provides four data planes at each pixel position:

- The first image plane (ANGLE_IMAGE) shows the incident angle of the principal ray (see Figure 29).
- The next three planes describe the main characteristics of the transmission band: the central wavelength (CWL_IMAGE), the bandwidth (FWHM_IMAGE), and the maximum transmission (MAXTR_IMAGE).

For a more detailed calculation, transmission curves are provided at several incident angles.

4 Calibration data files

4.1 NAC and WAC transmission data files

The data files contain the manufacturer supplied transmission data valid at the center region of the field of view are:

- NAC_FM_FLT_FFP_UV_V01.TXT
- NAC_FM_FLT_FFP_VIS_V01.TXT
- NAC_FM_FLT_NFP_VIS_V01.TXT
- NAC_FM_FLT_NEAR_IR_V01.TXT
- NAC_FM_FLT_ORTHO_V01.TXT
- NAC_FM_FLT_FE2O3_V01.TXT
- NAC_FM_FLT_IR_V01.TXT
- NAC_FM_FLT_ND_V01.TXT
- NAC_FM_FLT_FFP_IR_V01.TXT
- NAC_FM_FLT_ORANGE_V01.TXT
- NAC_FM_FLT_GREEN_V01.TXT
- NAC_FM_FLT_BLUE_V01.TXT
- NAC_FM_FLT_FAR_UV_V01.TXT
- NAC_FM_FLT_NEAR_UV_V01.TXT
- NAC_FM_FLT_HYDRA_V01.TXT
- NAC_FM_FLT_RED_V01.TXT
- WAC_FM_FLT_GREEN_V01.TXT
- WAC_FM_FLT_UV245_V01.TXT
- WAC_FM_FLT_CS_V01.TXT
- WAC_FM_FLT_UV295_V01.TXT
- WAC_FM_FLT_OH_V01.TXT
- WAC_FM_FLT_UV325_V01.TXT
- WAC_FM_FLT_NH_V01.TXT
- WAC_FM_FLT_RED_V01.TXT
- WAC_FM_FLT_UV375_V01.TXT
- WAC_FM_FLT_CN_V01.TXT
- WAC_FM_FLT_NH2_V01.TXT
- WAC_FM_FLT_NA_V01.TXT
- WAC_FM_FLT_OI_V01.TXT
- WAC_FM_FLT_VIS610_V01.TXT

4.2 WAC narrow band correction files

- WAC_FLT_BC_UV245_V01.IMG
- WAC_FLT_BC_CS_V01.IMG
- WAC_FLT_BC_UV295_V01.IMG
- WAC_FLT_BC_OH_V01.IMG
- WAC_FLT_BC_UV325_V01.IMG
- WAC_FLT_BC_NH_V01.IMG
- WAC_FLT_BC_UV375_V01.IMG
- WAC_FLT_BC_CN_V01.IMG
- WAC_FLT_BC_NH2_V01.IMG
- WAC_FLT_BC_NA_V01.IMG
- WAC_FLT_BC_OI_V01.IMG

- WAC_FLT_BC_VIS610_V01.IMG

4.3 WAC narrow band angular transmission files

- WAC_FLT_ANG_UV245_V01.TXT
- WAC_FLT_ANG_CS_V01.TXT
- WAC_FLT_ANG_UV295_V01.TXT
- WAC_FLT_ANG_OH_V01.TXT
- WAC_FLT_ANG_UV325_V01.TXT
- WAC_FLT_ANG_NH_V01.TXT
- WAC_FLT_ANG_UV375_V01.TXT
- WAC_FLT_ANG_CN_V01.TXT
- WAC_FLT_ANG_NH2_V01.TXT
- WAC_FLT_ANG_NA_V01.TXT
- WAC_FLT_ANG_OI_V01.TXT
- WAC_FLT_ANG_VIS610_V01.TXT

Appendix A Transmission variation laboratory measurement

A.1 Flat fielding with sodium (Na) line source

The laboratory measurement was carried out at MPS, Göttingen in 2016. The WAC GRM was operated in the calibration facility vacuum chamber. The large integrating sphere was modified to accommodate an OSRAM Na/10 spectral lamp. Test images were taken and evaluated with both sodium and halogen illumination, and with WAC Na, and Red filters.

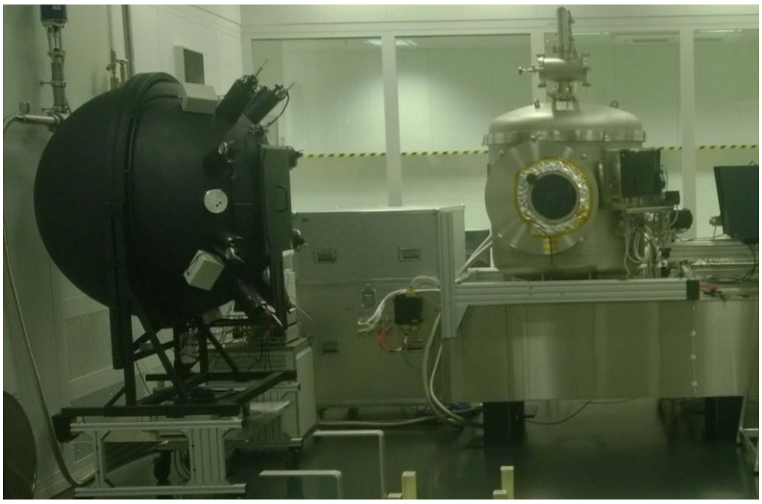


Figure 30 Test setup with integrating sphere

A.2 Test results

The WAC Na (narrow band sodium) images exhibited a significant intensity gradient in case of the sodium illumination, while the halogen illumination resulted in no effect. The WAC Red (broadband red) images did not show the gradient with either illumination source.

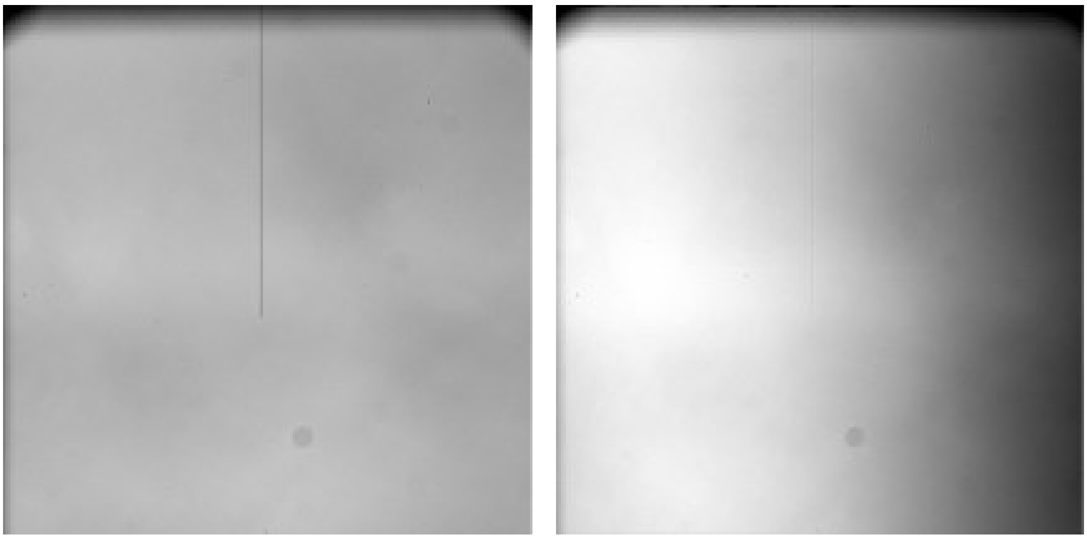


Figure 31 Na filter flat images with and halogen (left) and sodium (right) lamp illumination (0 – 10000 DNs). The images are displayed in the Rosetta standard orientation.

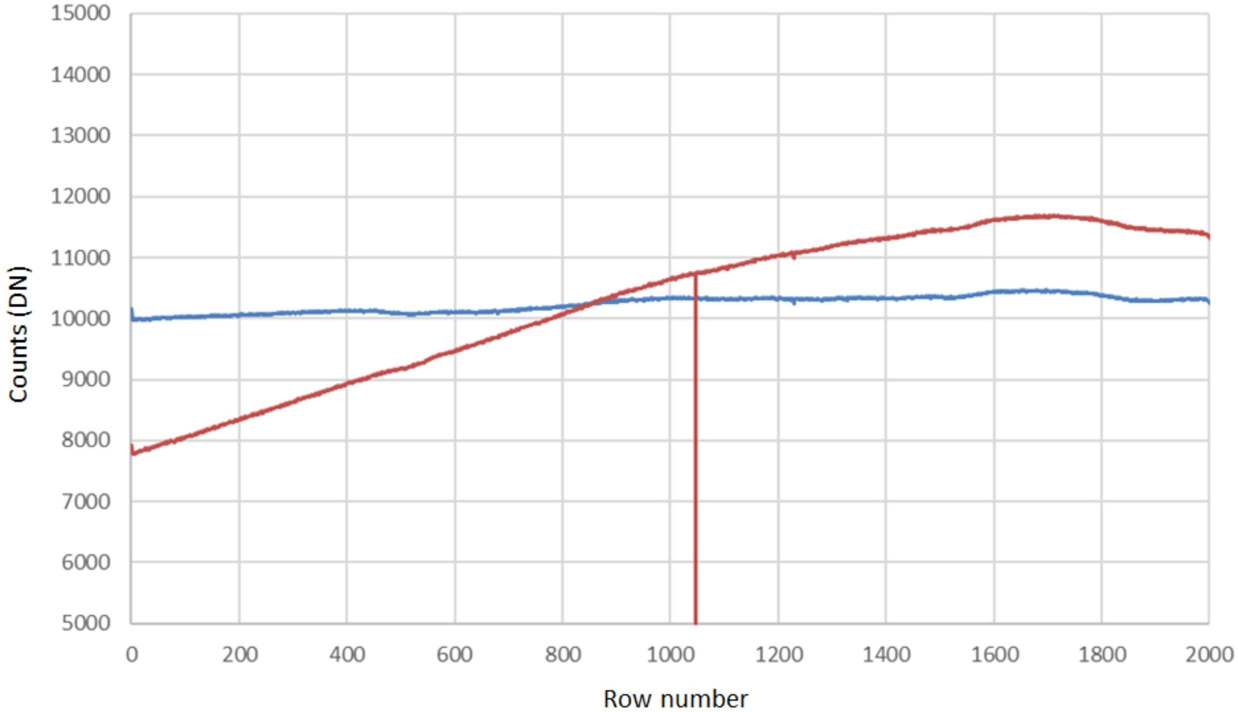


Figure 32 Average DNs of all rows of WAC Na (red line) and WAC Red (blue line) flat with sodium illumination (normalized)

The resulting intensity gradient across the FOV is due to the transmission variation caused by the incident angle of the optical beam and the narrow band illumination of the Na lamp. In case of broadband sources and broadband filters, the above effect is much smaller. For broadband sources the problem is essentially corrected by the flat fielding calibration step. The laboratory results were in line with the measured sodium filter characteristic at BME.