OSIRIS

Optical, Spectroscopic, and Infrared Remote Imaging System

Determination of the absolute calibration coefficients to radiometrically calibrate OSIRIS images

RO-RIS-MPAE-TN-074

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1/a	22/2/2017	C. Tubiana	Sec. 4	Added Section 4.
1/b	6/2/2018	C. Tubiana	Sec. 2 and 3.	Added Section 3. Clarified text and equation in Section 2.

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1 General aspects

1.1 Scope

This document describes how the absolute calibration coefficients to radiometrically calibrate OSIRIS images are determined.

1.2 Reference Documents

no.	document name	document number, Iss./Rev.
RD1	OSIRIS user manual	RO-RIS-MPAE-MA-004 D/s
RD2	Pre-calibration report CCD #242 (WAC FM)	RO-RIS-MPAE-RP-073 1/-
RD3	NAC CCD # 243 Acceptance Test Report	RO-RIS-MPAE-RP-355 1/-
RD4	measured_13_03_01.txt (V. Da Deppo, personal communication)	
RD5	Misura spettrofotometrica del trattamento ottico riflettate del 2° lotto di produzione M1-M2.	OS-GAL-TN-2001 2/0

2 Absolute Calibration Coefficients

Images of photometric standard stars (i.e. Vega) are used to determine the absolute calibration coefficients to radiometric calibrate OSIRIS images. For this, the raw level 1 images are bias subtracted, flat fielded and divided by the exposure time. After the center of the star is identified, the star flux is measured with the technique of aperture photometry (using the IDL routine aper.pro). The **measured star flux** (in DN/s) is $\boldsymbol{F}_{\mathbf{star,meas}}$, and it is the *integrated flux* in the filter bandpass.

The **tabulated star flux** ($\boldsymbol{F}_{\mathbf{star,c}}$) at the central wavelength of each filter (in W/ m^2 nm) is extracted from the star spectra. For Vega the spectrum from the HST catalogue is used (alpha_lyr_stis_005.ascii). For 16Cyg, since it is a solar type star, the solar spectrum from the HST catalogue (sun_reference_stis_001.ascii) scaled using the 16Cyg magnitude is used.

The absolute calibration coefficients are defined as:

$$C_{\text{solar-type}} = \frac{F_{\text{star,meas}} \times k}{F_{\text{star,c}}} \left[\frac{[\text{DN/s}] \times [\text{sr}]}{[\text{W/m}^2\text{nm}]}\right]$$

where k is the pixel scale of the camera in sr ($k_{\text{WAC}} = 9.91055 \times 10^{-9}$ sr, $k_{\text{NAC}} = 3.54744 \times 10^{-10}$ sr).

If the star used for the determination of the absolute calibration coefficients is not a solar-type star, as for example Vega, the absolute calibration coefficients must be scaled to solar colors.

$$C_{\text{non-solar-type}} = C_{\text{solar-type}} \times \frac{F_{\text{star,c}}}{F_{\text{Sun,c}}} \times \frac{\int F_{\text{Sun}}(\lambda)T(\lambda)\text{d}\lambda}{\int F_{\text{star}}(\lambda)T(\lambda)\text{d}\lambda}$$

$$= \frac{F_{\text{star,meas}} \times k}{F_{\text{star,c}}} \times \frac{F_{\text{star,c}}}{F_{\text{Sun,c}}} \times \frac{\int F_{\text{Sun}}(\lambda)T(\lambda)\text{d}\lambda}{\int F_{\text{star}}(\lambda)T(\lambda)\text{d}\lambda}$$

$$= k \times \frac{F_{\text{star,meas}}}{F_{\text{Sun,c}}} \times \frac{\int F_{\text{Sun}}(\lambda) T(\lambda) \mathrm{d}\lambda}{\int F_{\text{star}}(\lambda) T(\lambda) \mathrm{d}\lambda}$$

where:

- $F_{\text{star,c}}$ and $F_{\text{Sun,c}}$ are the flux of the star and of the Sun, respectively, at the central wavelength of the filter.
- $F_{\text{Sun}}(\lambda)$ and $F_{\text{star}}(\lambda)$ are the flux in the solar and stellar spectra, respectively. The solar and Vega spectra from the HST catalogue are used (Vega spectrum: alpha_lyr_stis_005.ascii, Solar spectrum: sun_reference_stis_001.ascii).
- $T(\lambda)$ is the throughput of the camera, including optics, filters, ARPs, and CCD. Details about the camera throughput can be found in Section 3.

To radiometric calibrate OSIRIS images acquired post-hibernation, Vega images – acquired during the delta calibration in May 2014 – have been used to determine the absolute calibration coefficients. For a few filter combinations (marked with asterisk in Table 1), no images were successfully acquitted in May 2014, thus for those filter combinations the absolute calibration coefficients determined pre-hibernation have been used.

The absolute calibration coefficients are summarized in Table 1.

Camera	Filter	λ_{cent} (nm)	$F_{\text{Sun,i}}$ (W/m^2)	$F_{\text{Sun,c}}$ (W/m^2 nm)	C ([DN/s]/[W m^{-2} sr^{-1} nm^{-1}])	Error (DN/s]/[W m^{-2} sr^{-1} nm^{-1}])
NAC	F22	649.20	71.9008	1.5650	121234824.000	327010.281
NAC	F23	535.70	56.5356	1.9650	64300000*	800000*
NAC	F24	480.70	64.3731	2.0300	61686400.000	955.361
NAC	F26	360.00	10.7657	1.0205	12493404.000	162338.125
NAC	F27	701.20	14.4538	1.4000	28615142.000	2093.743
NAC	F28	743.70	37.5997	1.2890	84561712.000	265704.188
NAC	F82	649.20	2.0161	1.5650	3278232.500	16708.744
NAC	F83	535.70	1.6328	1.9950	1760702.250	851.011
NAC	F84	480.70	2.0061	2.0600	1901347.375	7610.915
NAC	F86	360.00	0.0413	1.0305	53753.266	606.320
NAC	F87	701.20	0.6695	1.3950	1350260.500	1763.653
NAC	F88	743.70	1.9125	1.2890	4266544.000	26726.639
NAC	F15	269.30	0.5517	0.2481	1732428.000	9069.186
NAC	F16	360.00	11.4451	1.0305	13394721.000	53132.598
NAC	F81	600.00	11.7567	1.7790	14430000*	160000*
NAC	F21	600.00	384.5240	1.7790	506000000*	-
NAC	F31	600.00	394.9301	1.7790	522000000*	-
NAC	F41	882.10	11.8043	0.9230	40948524.000	3868.637
NAC	F51	805.30	11.4797	1.1180	32104672.000	184816.172
NAC	F58	790.50	0.8919	1.1610	2300684.000	19645.244

NAC	F61	931.90	3.9966	0.8480	14388393.000	4535.661
NAC	F71	989.30	1.7571	0.7363	5837449.500	38573.355
NAC	F32	649.20	74.9988	1.5620	127300000*	1500000*
NAC	F33	535.70	59.0598	1.9950	64222876.000	101183.891
NAC	F34	480.70	67.5977	2.0400	566800000*	-
NAC	F35	269.30	0.1375	0.2481	486429.594	11019.923
NAC	F36	360.00	9.3557	1.0305	10986951.000	597.698
NAC	F37	701.20	15.0607	1.3900	30541242.000	1506.911
NAC	F38	743.70	38.6864	1.2890	87498840.000	3473.541
WAC	F12	629.80	162.3346	1.7000	462665440.000	43079.898
WAC	F13	375.60	2.1484	1.1030	4794402.000	31081.021
WAC	F14	388.40	0.9468	1.0195	2498816.000	17774.492
WAC	F15	572.10	10.5525	1.8280	25524694.000	38454.344
WAC	F16	590.70	3.9602	1.8180	10110339.000	39456.324
WAC	F17	631.60	2.8359	1.6300	8595677.000	40090.859
WAC	F18	612.60	11.3855	1.7090	31450354.000	40769.199
WAC	F21	537.20	67.9369	1.8870	148923504.000	31496.266
WAC	F31	246.20	0.0445	0.0525	1460941.250	28717.393
WAC	F41	259.00	0.0317	0.1298	380327*	6461.48*
WAC	F51	295.90	0.2563	0.5712	779977.438	24728.229
WAC	F61	309.70	0.1109	0.5164	434188.312	32885.492
WAC	F71	325.80	0.6977	0.9099	1244928.625	30341.326
WAC	F81	335.90	0.1909	0.9776	425446.719	35902.289

Table 1 Absolute calibration coefficients used for the radiometric calibration of OSIRIS images. Most of coefficients have been determined from Vega observations done in May 2014 during the post-hibernation delta calibration. The coefficients marked with asterisk have been obtained pre-hibernation. Filter is the filter combination, λ_{cent} the central wavelength of the filter, $F_{Sun,i}$ and $F_{Sun,c}$ are the solar flux integrated over the bandpass and at the central wavelength of the filter, respectively. *C* is the absolute calibration coefficient and error the associated uncertainty.

3 Camera throughput

To calculate the throughput of the camera, the filter and ARP transmission curves, the mirror reflectivity, and the CCD quantum efficiency are used. Those files are stored in the OsiCalliope database.

The throughput of the camera is calculated using o_filter_integrate.pro and o_expected_signal.pro (Disrsoft routines). The throughput of the camera BUT filters, is calculated using o_optics.pro.

3.1 CCD quantum efficiency

3.1.1 By design quantum efficiency

OSIRIS NAC and WAC are equipped with (by design) identical CCDs, that are coated using "midband coating" (RD1). The quantum efficiency by design of the CCDs is shown in Figure 1.

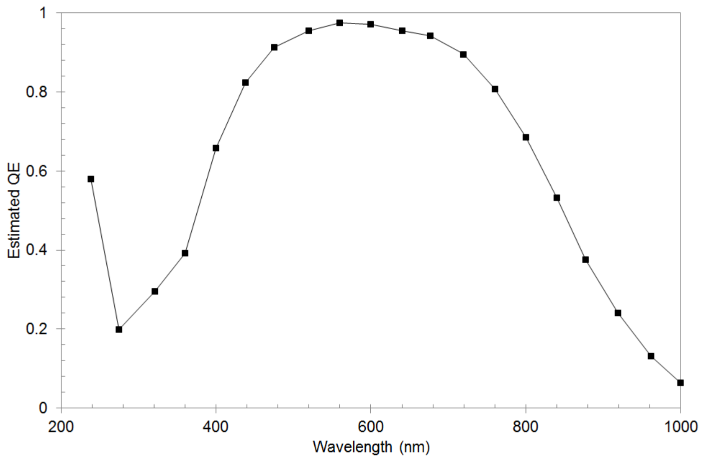

Figure 1 Quantum efficiency by design of the OSIRIS CCDs

3.1.2 Measured quantum efficiency of the flight CCDs

During the ground calibration, the quantum efficiency of the NAC (RD3) and WAC (RD2) CCDs (with $id_{NAC} = 243$ and $id_{WAC} = 242$, respectively) was measured on the flight models at room temperature (295 K) and close to operational temperature (180 K). The measured QEs are tabulated in Table 2 and shown in Figure 2.

	NAC CCD#243		WAC CCD#242	
Wavelength (nm)	**QE @ 295 K**	**QE @ 180 K**	**QE @ 295 K**	**QE @ 180 K**
260	0.342	0.289	0.343	0.443
280	0.247	0.205	0.237	0.291
300	0.311	0.268	0.289	0.314
320	0.367	0.308	0.33	0.333
340	0.415	0.353	0.363	0.35
360	0.463	0.388	0.409	0.358
380	0.585	0.551	0.5	0.472
399	0.759	0.742	0.658	0.629
400	0.754	0.762	0.668	0.658
449	0.873	0.891	0.764	0.743
450	0.868	0.894	0.779	0.751
500	0.913	0.969	0.822	0.815
550	0.928	0.988	0.829	0.836
600	0.917	0.974	0.813	0.821
650	0.89	0.934	0.785	0.801

700	0.846	0.862	0.745	0.743
750	0.779	0.757	0.694	0.659
800	0.69	0.634	0.618	0.56
850	0.574	0.49	0.5	0.424
900	0.437	0.335	0.399	0.308
950	0.285	0.188	0.252	0.176
1000	0.147	0.075	0.126	0.067

Table 2 Quantum efficiency of the NAC and of the WAC CCD, as measured on the flight models at room temperature (295 K) and close to operational temperature (180 K).

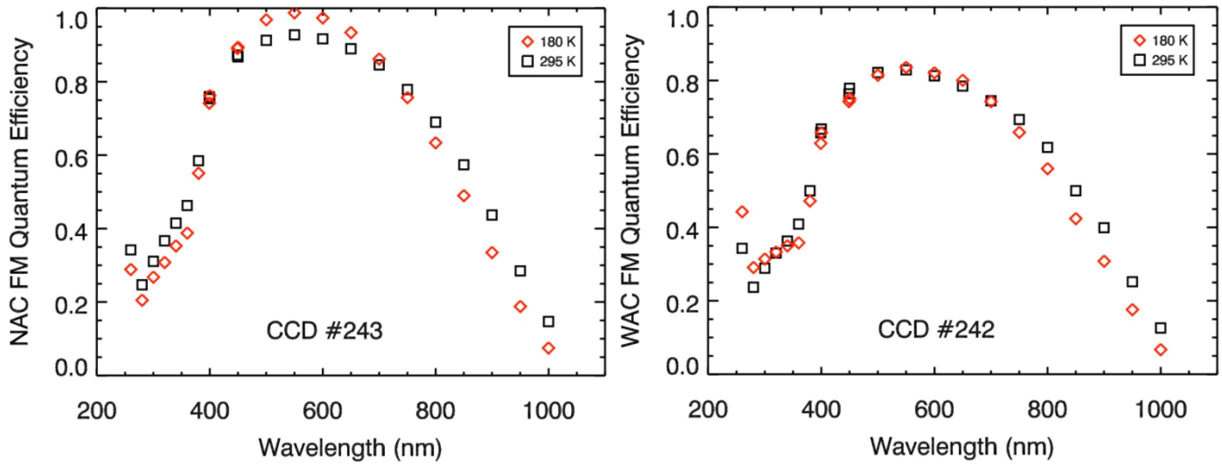

Figure 2 Quantum efficiency of the NAC (left) and of the WAC (right) CCD, as measured on the flight models at room temperature (295 K) and close to operational temperature (180 K).

For the determination of the absolute calibration coefficients, the QE of the NAC at 180 K (normalized at 650 nm) is used for both cameras (see Figure 3).

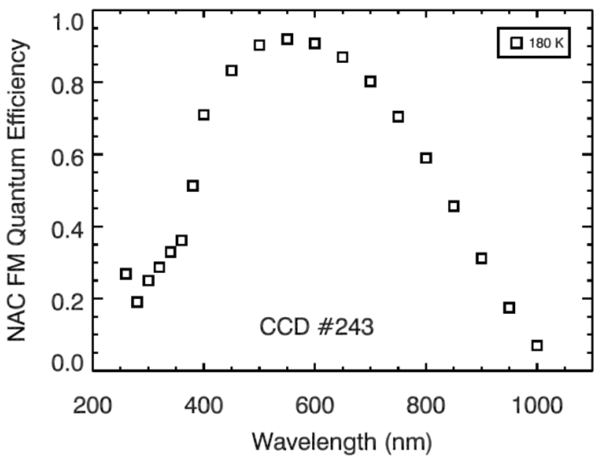

Figure 3 Normalized QE of the NAC at 180 K, used for the determination of the absolute calibration coefficients.

3.2 Filter transmission curves

Because of the characteristics of the interference filters, the filter transmission curves are CCD-position dependent. This effect is particularly significant for narrow-band filters and in case of gas line emissions. The determination of pixel-by-pixel transmission curves is undergoing.

The filter transmission curves specified by the manufacturer (and shown in Tubiana et al. 2015) are not valid for any physical pixel of the CCD.

3.3 Reflectivity of the mirrors and transmissivity of the Anti Radiation Plate (ARP)

NAC and WAC are a 3-mirrors and 2-mirrors off-axis system, respectively (RD1). The total reflectivity of the mirror system (R_{TOT}) is

$$R_{\mathrm{TOT}} = R^{\mathrm{N}}$$

where R is the reflectivity of one mirror and N the number of mirrors (i.e., N = 2 for WAC and N = 3 for NAC).

The measurement of the WAC mirror reflectivity is reported in RD5.

Both cameras are equipped with an Anti Radiation Plate (ARP), installed directly above the CCD, for radiation shielding (RD1). The measured transmissivity of the WAC APR is reported in RD4.

The total reflectivity of the mirrors and the transmissivity of the ARPs are shown in Figure 4.

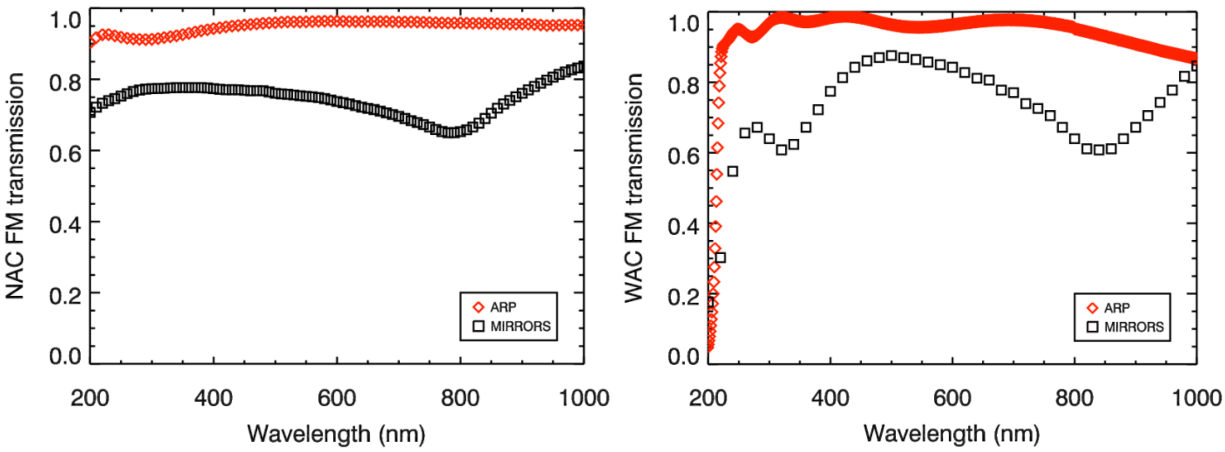

Figure 4 Measured total reflectivity of the mirrors and transmissivity of the ARPs for NAC (left) and WAC (right).

3.4 Data files

The data files used to determine the throughput of the cameras are:

- Quantum efficiency:
  - NAC_FM_QE_V01.TXT
  - WAC_FM_QE_V01.TXT
- Reflectivity of the mirrors:
  - NAC_FM_MIRROR_V01.TXT
  - WAC_FM_ MIRROR _V01.TXT
- Transmissivity of the ARPs:
  - NAC_FM_ARP_V01.TXT

  - WAC_FM_ ARP _V01.TXT

These files are stored in the OsiCalliope database in the folder THROUGHPUT.

4 Calibration files used by OsiCalliope

The calibration files used by OsiCalliope to calibrate OSIRIS images are:

- NAC_FM_ABSCAL_V01.TXT
- WAC_FM_ABSCAL_V01.TXT

Previous versions:

- NAC_FM_ABSCAL_FACTORS.LBL (obsolete, same values as NAC_FM_ABSCAL_V01.TXT)
- WAC_FM_ABSCAL_FACTORS.LBL (obsolete, same values as WAC_FM_ABSCAL_V01.TXT)