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OSIRIS/GTC Broad Band Imaging calibration

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Abstract

OSIRIS, the first light instrument at the 10.4 m GTC, provides broad band imaging capability via standard Sloan filters (u'g'r'i'z'). In the present work we describe the photometric calibration results, obtained during the first years of the instrument operation, from March 2010 to March 2014. Specifically, we present zeropoints and extinction curves. These can be used to calibrate data obtained with OSIRIS, either those observed during standard broad band imaging observations or, alternatively, the ones retrieved from the GTC data archive without a set of calibration files (for example, acquisition images for spectroscopic observations).

Introduction: OSIRIS Broad Band Imaging

OSIRIS (**O**ptical **S**ystem for **I**maging and low-Intermediate-**R**esolution **I**ntegrated **S**pectroscopy) is an imager and spectrograph for the optical wavelength range, located in the Nasmyth-B focus of 10.4 m Gran Telescopio Canarias (GTC). In addition to narrow band imaging via Tunable Filters, OSIRIS provides standard broad band imaging with Sloan filters and spectroscopic capabilities, as single long-slit as multi-object mode (Cepa et al. 2005, 2010) in an effective FOV of 7.8 x 7.8' (7.5' x 6' for MOS mode).

During the nightly operation of the instrument, a photometric standard is observed to estimate the photometric quality of the night. By using data collected during the first years of the instrument operation, a series of calibration results have been obtained. In the present work we describe in detail those results, which can be easily handled to calibrate data obtained with OSIRIS in the Broad Band Imaging mode of the instrument. It is also possible to extend this procedure when analyzing data retrieved from the GTC image archive, even with the aim to make scientific use of acquisition images for spectroscopic observations, generally obtained using one of the available Sloan filters.

Section 1: OSIRIS Broad Band Imaging

As part of the standard nightly calibrations during the GTC operation, at the beginning of the night a photometric standard star, from the list of Smith et al. (2002), is observed in the complete OSIRIS Sloan filter set. This measurement is used to derive the overall photometric quality of the night, and it's included as a standard calibration for all the observations performed in the Broad Band Imaging mode of the instrument that night. From this set of observations, the photometric zeropoints (Z) in each of the Sloan filters is routinely derived. Instrumental magnitudes can be obtained directly from the measured flux of a star by using the following formula:

$$m = Z - 2.5\ log_{10}\ [Flux\ (ADU/s)] - k\ X \quad (1)$$

where X is the airmass, and k is the extinction coefficient for the corresponding filter.

Note that Eq. (1) follows the standards for IRAF reduction packages, and the definition can be slightly different from the one usually presented in the bibliography for other telescopes (that give the zeropoints at an airmass equal to 1). To retrieve the full set of values for each night, there is a frequently updated version of the daily zeropoints table that can be found at: www.gtc.iac.es/instruments/osiris/media/zeropoints.html.

Several standard stars were observed during commissioning nights under good transparency conditions to derive the corresponding extinction's laws (see Figure 1), from which the extinction coefficients can be obtained. The average values for OSIRIS Sloan filter set are shown in Table 1, and are in agreement with the standard extinction values commonly assumed for the ORM (RGO/La Palma Technical Note nº 31).

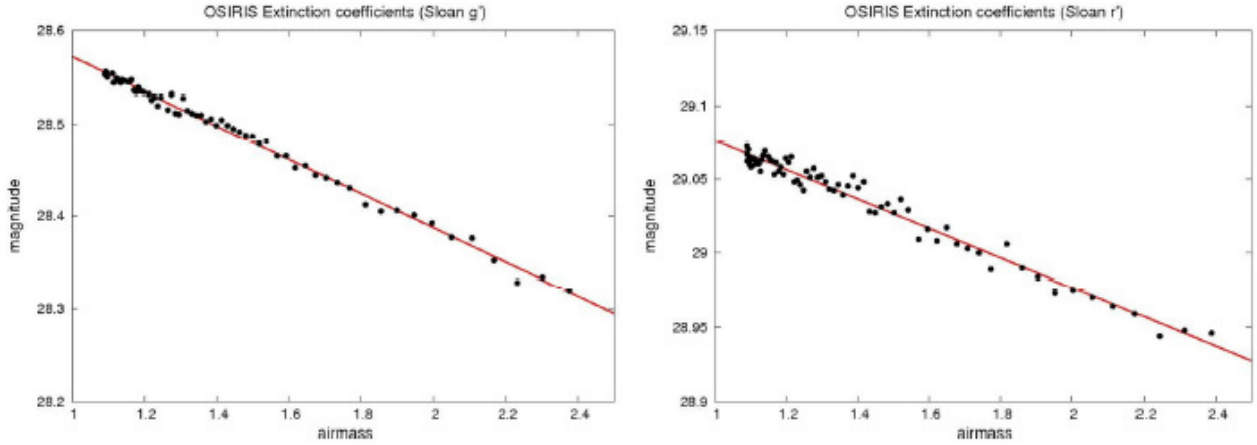

Fig. 1: .Extinction curves for OSIRIS Sloan filters g' (left) and r' (right) obtained during a commissioning night of the instrument. Error bars in the individual measurements are 0.02 mag and 0.01 mag, respectively.

Filter	***k (mag / airmass)***
Sloan u'	0.45 ± 0.02
Sloan g'	0.15 ± 0.02
Sloan r'	0.07 ± 0.01
Sloan i'	0.04 ± 0.01
Sloan z'	0.03 ± 0.02

Table 1: Mean extinction coefficients for OSIRIS Sloan filters.

It is also possible to include a second order correction by using the following colour terms that have also been obtained during the instrument commissioning. With these, it's possible to correct the calibrated magnitudes from the instrumental colours of the observed star (u'_0,g'_0,r'_0,i'_0,z'_0).

$$
\begin{aligned}
u' - u'_0 &= -25.807(\pm 0.053) - 0.071\ (\pm 0.023)\ (u'_0 - g'_0) \\
g' - g'_0 &= -28.823\ (\pm 0.040) - 0.078\ (\pm 0.013)\ (g'_0 - r'_0) \\
r' - r'_0 &= -29.291\ (\pm 0.017) - 0.114\ (\pm 0.028)\ (r'_0 - i'_0) \\
i' - i'_0 &= -28.857\ (\pm 0.015) - 0.079\ (\pm 0.041)\ (i'_0 - z'_0) \\
z' - z'_0 &= -28.231(\pm 0.031) - 0.072\ (\pm 0.052)\ (i'_0 - z'_0)
\end{aligned}
\qquad (2)
$$

Photometric zeropoints were obtained by doing aperture photometry in the standards, using a large aperture of 20 arcsec (corresponding with more than 20 times the average seeing value at the ORM) in order to enclose all the flux from the photometric standard. When other different apertures are considered, there is necessary to include an aperture correction, which is shown in Fig. 2 and Table 2, respectively. As it can be noted, only for apertures smaller than 3 arcsec the correction is really significant. Besides, there are no differences when other filter than Sloan r' is used.

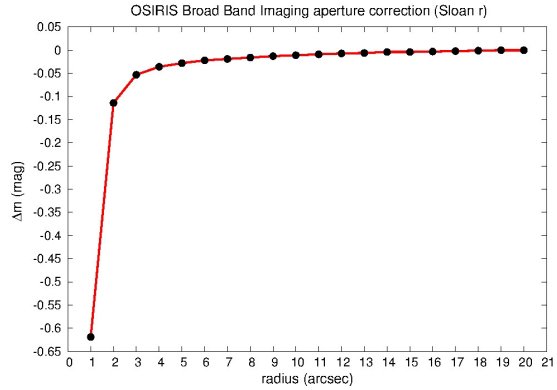

Fig. 2: Aperture correction curve for OSIRIS Sloan r filter.

r (")	**Δm**	**r (")**	**Δm**	**r (")**	**Δm**
1.0"	-0.619	8.0"	-0.016	15.0"	-0.004
2.0"	-0.114	9.0"	-0.013	16.0"	-0.003
3.0"	-0.053	10.0"	-0.011	17.0"	-0.002
4.0"	-0.036	11.0"	-0.009	18.0"	-0.001
5.0"	-0.028	12.0"	-0.007	19.0"	0.000
6.0"	-0.022	13.0"	-0.006	20.0"	0.000
7.0"	-0.019	14.0"	-0.004		

Table 2: Aperture correction values for OSIRIS Sloan r filter.

Finally, all the photometric calibrations made with OSIRIS are obtained at the standard pointing position of the instrument in Broad Band Imaging mode, corresponding with the pixel (256, 1024) in CCD2. Photometric accuracy of the zeropoints within CCD2 is better than 0.01 mag, hence there are no differences when analyzing targets observed at a different location in CCD2. However, zeropoint values in CCD1 are on average 0.12 mag smaller than the ones in CCD2 (that are the ones presented along this work). Therefore, this must be taken into account when translating the photometric calibration for targets placed in CCD1.

Summing up, it is then possible to obtain photometric calibrated magnitudes from the measured flux (ADUs/s) of a target by using all the calibration information presented along this section. Firstly, Eq. (1) can be applied by using the zeropoints obtained for that night (available at OSIRIS/GTC web page) and the extinction coefficients presented in Table 1. If colour information is available from the instrumental magnitudes (that is, observations were done in two filters), then colour terms shown in Eqs. (2) can be applied, and finally, the aperture correction shown in Table 2 has to be included depending on the aperture value used in the flux measurement (if this is lower than 20 arcsec). Secondly, if target is placed in CCD1, a 0.12 mag correction is needed to transform the calibrations to CCD1. The possibility of neglecting some of the last steps in the calibration will depend on the photometric accuracy required. In general, these calculations are more than enough for a photometric accuracy of 0.1 mag.

Section 2: Time evolution of the OSIRIS photometric zeropoints

As the instrumental zeropoints are obtained on a daily basis, it is possible to calculate average values by combining all the data retrieved since the beginning of the GTC telescope operation (approximately 450 nights with available photometric standard observations from March 1st 2010 to March 1st 2014). These results, grouped according to the night quality definition are shown in Table 3. As it can be seen, there are no differences between the nights classified as 'clear' or 'photometric', as expected because this latter is 'a posteriori' definition based on the extinction values derived and the photometric stability during the night. Also, there is no an objective measurement currently available at the telescope to classify a night as 'photometric' apart from the subjective decision of the night astronomer (GTC staff is working on that line via exploitation of a cloud sensor external to the telescope, but this work is still undergoing), diluting the differences between 'clear' and 'photometric' nights. In the case of having cirrus over the observatory ('spectroscopic' conditions) the zeropoint values decrease 0.4-0.5 mag on average, a reasonable number that does not heavily affect to the photon detection efficiency of the instrument. This behavior must be taken into account by OSIRIS users when calculating the expected S/N under 'spectroscopic' conditions, and it is well advised to add up to 0.5 mags to the target magnitude when obtaining S/N estimates with OSIRIS ETC (see Section 8.1 in the OSIRIS user manual available at OSIRIS/GTC web page). Finally, there are some nights affected by dust on the atmosphere, mainly during Summer time. In this case, the instrumental zeropoints are also decreased, in a less severe way than in the case of cirrus, but in any case showing the excellent sensitivity of the instrument even in bad observing conditions.

Filter \ Night type	Photometric	Clear	Clear (dusty)	Spectroscopic
Sloan u'	25.81 ± 0.09	25.76 ± 0.11	25.55 ± 0.19	25.38 ± 0.37
Sloan g'	28.83 ± 0.06	28.80 ± 0.07	28.61 ± 0.16	28.45 ± 0.26
Sloan r'	29.30 ± 0.05	29.27 ± 0.06	29.08 ± 0.14	28.92 ± 0.28
Sloan i'	28.86 ± 0.05	28.85 ± 0.05	28.64 ± 0.15	28.53 ± 0.23
Sloan z'	28.23 ± 0.06	28.22 ± 0.07	28.01 ± 0.17	27.91 ± 0.21

Table 3. Mean zeropoints values for OSIRIS Sloan filters in different night conditions.

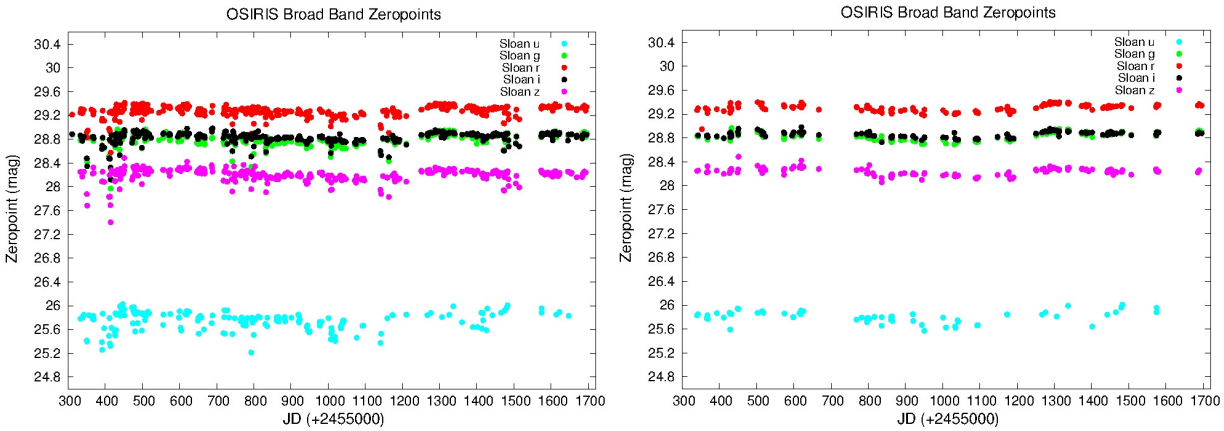

Fig. 3: Time evolution of OSIRIS zeropoints, in clear/photometric nights (left) or including only photometric nights (right).

Section 3: Zeropoints evolution with the GTC optical quality

In order to maintain the best optical quality at GTC, there is a routinary work at the telescope that consists of replacing 2-3 segments per month. The ones to be replaced are selected by reflectivity and scattering (R&S) measurements together with a visual inspection to evaluate the segment optical quality. Theoretically, reflectivity threshold to remove a single segment from the telescope is 86% at 650 nm. Once finished the R&S measurements and to set a priority in the election of the mirrors, the values of reflectivity are ordered from smallest to largest in ascending order and two or three segments with the lower reflectivity are chosen to be removed. This procedure has been routinely used in the last 2 years of the telescope operation, being less frequently during the first years. OSIRIS zeropoints values presented in this contribution have been used to evaluate the impact of this procedure on the final optical quality of OSIRIS@GTC. Figure 4 shows the time evolution of OSIRIS zeropoints for Sloan r filter by considering only those nights classified as 'photometric'. In the plot, red triangles show the date when a segment replacement was done. The number of triangles depends on the number of segments replaced at that moment. Finally, the two major contributions to the zeropoints increase were the replacement of M2 and M3 mirrors in October 2012 and June 2012, respectively. M2 and M3 play an important role on the zeropoints improvement, as with minor effort in changing these two mirrors, zeropoints increase considerably as well as the total reflectivity of the telescope.

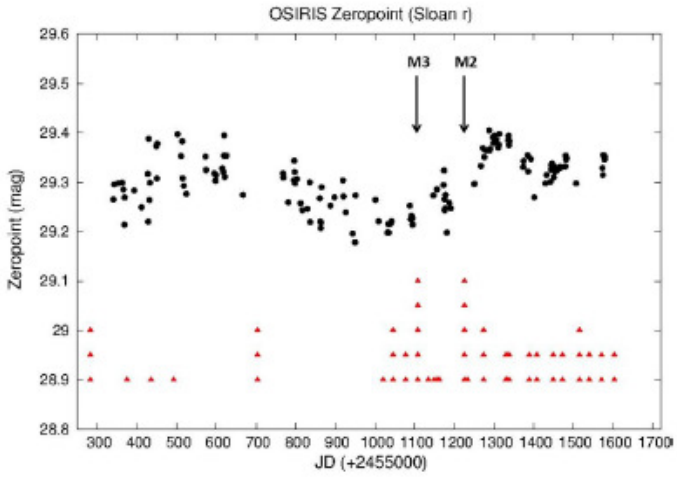

Fig. 4: Time evolution of OSIRIS zeropoint for Sloan r related to the aluminization of the main optical components of GTC.

As it can be seen, the current procedure of replacing segments every month allows to keep in a more stable way the overall optical quality, than it was previously done before. On the other hand, the loss of sensitivity was noticeable when this work was not done so frequently. Differences in any case are not so high, less than 0.1 mag at most, but this demonstrates the utility of the nightly monitorizing work of OSIRIS instrument as an alternative diagnosis of the GTC optical performance.

Conclusions

We have presented the broad band photometric calibration results obtained since the beginning of the OSIRIS@GTC operation. These calibrations can be used to correct data obtained with the instrument in broad band imaging mode. Additionally, data retrieved from the GTC data archive obtained without a proper calibration data set assigned, e.g, acquisition images for spectroscopy, can also be calibrated in order to be used for scientific purposes.

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