CANARIAN OBSERVATORIES UPDATES (CUps)

CUps nº1 - 2014

Flux calibration of OSIRIS/GTC Red Tunable Filter

A. Cabrera-Lavers[1,2,3] , A. Bongiovanni[2,3], J. Cepa[2,3] and R.G.M. Rutten[1]

e-mail: antonio.cabrera@gtc.iac.es

Affiliation

[1] GRANTECAN S.A., E-38712, Breña Baja, La Palma, Spain.

[2] Instituto de Astrofísica de Canarias, E-38205, La Laguna, Tenerife, Spain.

[3] Universidad de La Laguna, Departamento de Astrofísica, E-38206, La Laguna, Tenerife, Spain.

Abstract

One of the most interesting capabilities of OSIRIS, the first light instrument at the 10.4 m GTC, is the flexible narrow band imaging that is provided using Tunable Filters (both in the blue and red wavelength range). In the present contribution, we describe a method for flux calibration of the OSIRIS Red Tunable Filter data by using measurements obtained both during the instrument commissioning and in the first years of telescope operation. The method can also be extended to the medium band SHARDS filter set, available at the instrument for public use since 2012.

Introduction: OSIRIS Tunable Filters

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 10.4m Gran Telescopio Canarias (GTC). OSIRIS provides standard broad-band imaging with Sloan filters and spectroscopic capabilities both with a single long-slit and in multi-object mode (Cepa et al. 2005, 2010) in an effective FOV of 7.8 x 7.8' (7.5' x 6' in MOS mode). OSIRIS also includes an additional capability with the narrow-band imaging that is made possible through the use of Tunable Filters (TF). A TF is in essence a low resolution Fabry-Perot unit, where the filter is tuned by setting a specific separation between the optical Fabry-Perot plates, allowing the user to observe at any wavelength within the spectral range of the TF with a selected bandwidth.

OSIRIS has two different TFs: one for the blue range (Blue Tunable Filter, BTF) to be used in the wavelength interval λ = 4500 Å - 6710 Å (that will be upgraded down to 3600 Å in a near future) and another for the red range (Red Tunable Filter, RTF) to be used in the wavelength interval λ = 6510 Å - 9345 Å **.** They offer monochromatic imaging with an adjustable bandwidth (FWHM) between 4.5 Å and 20 Å (depending on the wavelength range), and with a tuning accuracy of 1 Å in the filter central wavelength.

OSIRIS TFs make possible to get low resolution spectral observations for all the targets within a wide field of view in combination with a telescope that provides large collecting area. The use of TFs may be more effective that the multi-object spectroscopy for a lot of different projects, but careful calibration is required. In this brief paper we explain how flux calibration of TF data can be obtained with reasonable accuracy, based on existing calibration data.

Section 1: Flux calibration of the OSIRIS Tunable Filters

As in any narrow-band interference filter, in order to calibrate the observations made with the RTF it is necessary to observe a spectrophotometric standard star with the same setup as the scientific observations, in order to obtain the transformation between the measured count rates and the flux in erg s^{-1} cm^{-2}.

The GTC's policy considers that TF calibrations are charged to the observer's program (unless secondary spectrophotometric standards measured spectroscopically by the user are in the FoV of the TF), hence it is necessary to define a specific Observing Block for this purpose, which translates in a noticeable overhead in the observing time. This is time consuming, and usually the awarded time at the telescope is not enough to account for this process, so an alternative way of calibrating the TF data would be very valuable. In the present work we describe an approximate flux calibration method based on existing calibration data of the TFs.

Section 2: OSIRIS Red Tunable Filter efficiency

During the commissioning of the OSIRIS instrument, and in particular of the TFs, the system efficiencies were one of the more relevant parameters to be obtained. With this prior knowledge it is possible to evaluate how the instrument+telescope system is fulfilling the expectations in terms of photon detection efficiency, something that is particularly relevant for the case of the TF as this element implies the use of very narrow band filters.

The total efficiency of the system (including telescope, detector and optics) is defined by the ratio between the measured and absolute fluxes of a standard star:

$$\varepsilon\,(\lambda) = \frac{F(\lambda)}{F_S\ (\lambda)} \qquad (1)$$

where the measured flux (in ADUs s^{-1}) must be transformed in real flux unities (erg s^{-1} cm^{-2} Å) through:

$$F\,(\lambda) = \frac{g\,K\,(\lambda)\,E_\gamma\,(\lambda)}{A_{tel}\ \delta\lambda_e}\,F\,(ADU\ s^{-1}) \qquad (2)$$

being:

- g : CCD gain (e-/ADU), that is 0.95 for the standard readout mode in OSIRIS.
- E_γ (λ): photon energy at a given wavelength (erg $Å^{-1}$) = 1.986485 x 10^{-8} λ^{-1}.
- A_{tel} : GTC primary mirror effective area = 7.34 x 10^5 cm^2.
- $\delta\lambda_e$: effective bandwidth of the filter (Å), that for OSIRIS Tunable Filters is equivalent to:

$$\delta\lambda_e = \frac{\pi}{2}\,\Delta\lambda \qquad (3)$$

where Δλ is the tuned bandwidth (FHWM) for the filter.

- K (λ): extinction correction:

$$K(\lambda) = 10^{0.4\,k(\lambda)\,X} \qquad (4)$$

where X is the airmass, and with k(λ) = 0.6185 – 0.0001347 λ + 7.453 x 10^{-9} λ^2, that is a second order polynomial fit to the standard extinction values for the ORM (RGO/La Palma Technical Note nº 31) valid for 5000 Å < λ < 9500 Å under good transparency conditions.

To calculate the RTF's efficiency, several spectrophotometric standard stars were observed along 2010-2012 period in photometric nights to ensure the best photometric conditions and sky transparency. Data for standards obtained during the scientific operation of OSIRIS were also included when optimal sky conditions were fulfilled in the corresponding program to increase the statistics. As there is no dependence with the tuned FWHM of the TF, all the data obtained in different configurations of central wavelengths and bandwidths can be combined together to obtain a global efficiency function.

With those, the efficiency curve shown in Figure 1 was obtained. There is a discrete distribution of points corresponding to the different observations that were compiled. However, a polynomial fit to the data (order 3) allows obtaining a function with a 1 Å sampling that can be handled more easily (red line).

Section 3: An alternative procedure for calibrating OSIRIS Red Tunable Filter data

From Equations (1) and (2), it is possible to flux-calibrate the data obtained during the scientific observations with the RTF once the system efficiency is known, by using the following expression:

$$F_S\ (\lambda) = \frac{g\,K\,(\lambda)\,E_\gamma\,(\lambda)}{\varepsilon\,(\lambda)\,A_{tel}\ \delta\lambda_e}\,F\ (ADU\ s^{-1}) \qquad (5)$$

that directly transforms the measured fluxes (in ADU s^{-1}) to calibrated fluxes (in erg s^{-1} cm^{-2} Å). Of course the transparency at the time of observation is not taken into account, and hence this method is only valid for situations of good sky transparency.

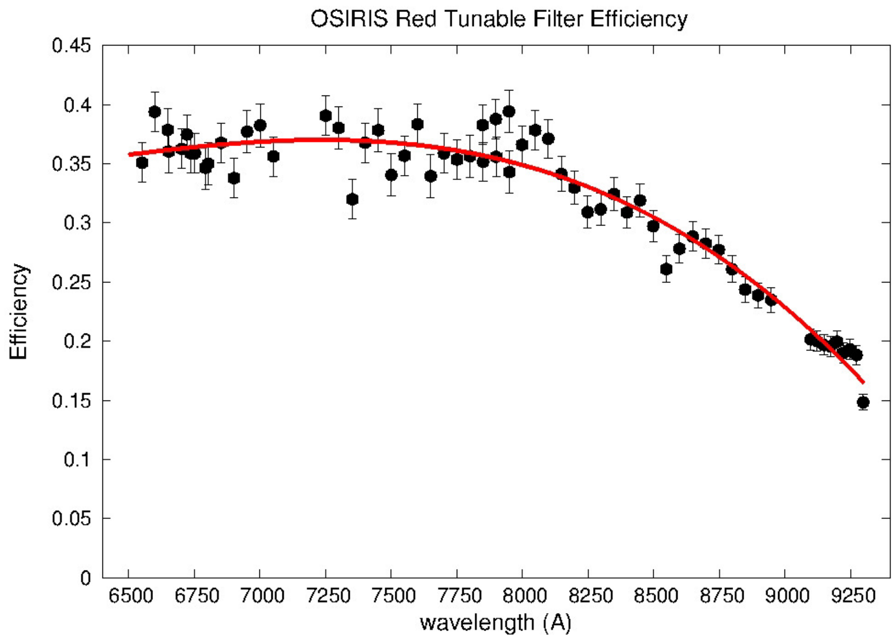

Fig. 1. RTF's efficiencies measured during OSIRIS commissioning (points). A polynomial fit to the data (red line) has been done to obtain a 1Å sampling. Error bars show the efficiency uncertainties derived from the standard star measurements.

This method has of course some uncertainties that arise from the combination of the intrinsic error of the standard measurements (to determine the system efficiency) as well as the use of the polynomial fit. Taking those into account we can assume a total accuracy of 7-10% in the fluxes. This value must be good enough for most of the scientific programs, and it is well in agreement with the accuracies that can be obtained by using specific standard star observations, as the normal standard's absolute fluxes have usually a larger sampling than the achievable with the TF.

In the case that higher accuracies are needed, the observing program strategies and/or calibration procedures must be defined accordingly (for example, for high accuracy spectrophotometric studies see the detailed description on the flux calibration presented in Mayya et al. (2012)).

Section 4: Extension to the calibration of the SHARDS filter set

The OSIRIS instrument also provides medium band imaging with a set of private filters for the SHARDS science program (for a detailed description both of the SHARDS survey and the peculiarities of this filter set, see Pérez-Gonzalez et al., 2013). This set consists of 25 filters spanning the wavelength range from 5000 Å to 9400 Å with bandwidths from 140 Å to 340 Å . Due to the design of the OSIRIS instrument those filters suffer from a notable central wavelength variation across the FOV, that from edge to edge of the OSIRIS FOV can be of the same order of the width of the filter itself. Hence, a SHARDS filter behaves as a very-low resolution Fabry-Perot, and the analysis of the data is similar to those of the TFs.

During the development of SHARDS observing program at GTC, a complete set of spectrophotometric standards were observed to determine the SHARDS filter's efficiencies in the same way as it was described in Section 2 for the TFs. The resulting efficiencies are shown in Figure 2 (points), again with a polynomial fit to the data (order 3) to get a function with a 1 Å sampling (red line).

We can therefore use the same approach as in the case of the OSIRIS RTF to calibrate the observations with SHARDS filters. In this case, we can apply Equation (5) with the efficiencies of SHARDS filters derived during the execution of the SHARDS program, and the rest of parameters shown in Section 2 (assuming in this case that $\delta\lambda_e$= FWHM, as corresponds with a top-hat filter). Of course, as in the case of the TFs, and since the central wavelength of the pass band varies over the OSIRIS field, the calibration wavelength to be used also varies over the field. We have estimated that the uncertainties in the flux calibration would be of the order of a 5-7%, for data obtained under good sky transparency, which should be good enough for most of the scientific programs.

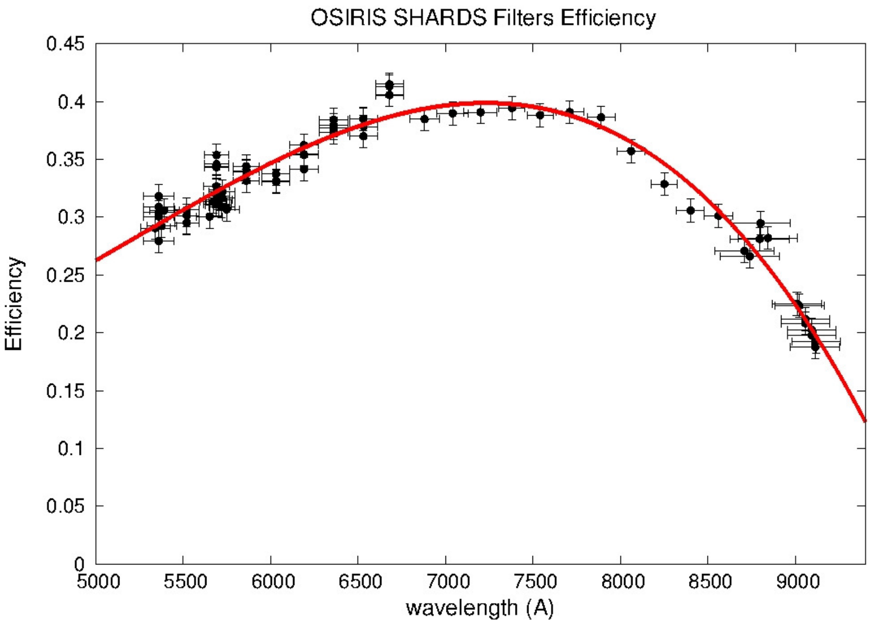

Fig. 2. SHARDS filters efficiencies measured during the development of SHARDs survey at the GTC (points). A polynomial fit to the data (red line) has been done to obtain a 1Å sampling. Error bars show both the efficiency uncertainties obtained from the standard star measurement and the filters' wavelength coverage (FWHM).

Conclusions

Here we present the complete set of efficiency values that can be used for calibrating the RTF observations with OSIRIS@GTC. Those values allow to obtain a flux calibration with approximately a 10% uncertainty, well in agreement with the accuracies achievable by the use of specific spectrophotometric standard observations, hence it can be used to decrease the overheads during the execution of an observing program at the GTC.

The full table can be retrieved from the GTC web pages (in the Tunable Filter's section):

www.gtc.iac.es/instruments/osiris/media/tables/RTF_efficiency_1Astep.txt

We also extend this approach to the observations made with the medium band SHARDS filters, using in this case the efficiencies corresponding to these derived in the same way as in the case of the RTF. The full table for the SHARDS filters can be also retrieved from the GTC web pages (SHARDS Filter's section):

www.gtc.iac.es/instruments/osiris/media/tables/SHARDS_efficiency_1Astep.txt

Acknowledgements

Based on observations made with the Gran Telescopio Canarias (GTC), installed at the Spanish Observatorio del Roque de los Muchachos of the Instituto de Astrofísica de Canarias, in the island of La Palma.

References

Cepa, J., Aguiar, M., Castañeda, H. O., et al. 2005, Revista Mexicana de Astronomia y Astrofisica Conference Series, 24, 1.
Cepa, J. 2010, Highlights of Spanish Astrophysics V, 15.
King, D.L., RGO/La Palma Technical Note nº 31:
www.ing.iac.es/Astronomy/observing/manuals/ps/tech_notes/tn031.pdf
Mayya Y. D., Rosa González, D., Vega, O, et al. 2012, 2012PASP, 124, 895.
Pérez-González, P. G., Cava, A., Barro, G.,et al. 2013, ApJ, 762, 46.

The Canarian Observatories Updates are published by the Instituto de Astrofísica de Canarias (IAC), c/Vía Láctea s/n, 38205 La Laguna, Tenerife, Spain.
The IAC is an internationalized Spanish research center that manages the Canarian Observatories that currently home to telescopes and other instruments belonging to 60 scientific institutions from 17 different countries.