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Testing the spectroscopic reconstruction for the Euclid experiment

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Summary. — *Euclid* will perform a slitless spectroscopic survey over one-third of the sky to extract the redshift of tens of millions of galaxies. To reach the required accuracy, the response of the instruments must be monitored over time with in-flight calibrations. In this paper, we present a framework to study the flux calibration in *Euclid* spectroscopic channel, which includes the pixel simulation, the extraction of the un-calibrated spectra, and the reconstruction of the illumination variation on the focal plane. This is a preliminary work aimed at building a framework that will allow a detailed quantification of the performance of the Self-Calibration.

1. – Introduction

Euclid is a space mission of the European Space Agency (ESA), scheduled for launch in 2023 and designed to investigate the nature of dark energy, gravity, and the absolute neutrino mass scale. The Near-Infrared Spectrometer and Photometer (NISP) instrument will allow us to obtain the spectra of the observed galaxies with a slitless configuration. The acquired spectra will be then processed, and the redshift z of tens of millions of galaxies will be evaluated with an accuracy of about $0.001(1+z)$ [1].

After launch, dust pitting, radiation damage, and material outgassing will degrade the transmission of the light through the instruments, leading to an attenuation of the measured flux, which depends both on the position on the focal plane and on the wavelength. To take into account and correct this effect, an in-flight calibration program has been developed [2].

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This paper presents a framework to study the in-flight flux calibration in the spectroscopic channel. We use the method proposed in [3] to reconstruct the response function of the instrument. The validation of the algorithm presented in [3] was based on an ideal synthetic calibration survey: each source was characterized by its position in the sky and the ideal count rate in the detector, while the measured counts were extracted from a Poisson distribution of the theoretical signals. In this work, we extend the method [3], to a slitless spectroscopic survey: we simulate spectra at the pixel level and reconstruct them to take into account different systematic effects such as detector non-idealities, background light, and the overlap of spectra from different sources.

2. – The in-flight flux calibration

In order to monitor the response of the instruments over time, *Euclid* will observe, on a monthly basis, the same area in the sky, called the Self-Calibration Field. This region consists of a $3.2\,\mathrm{deg}^2$ circular field located near the North Ecliptic Pole, which provides both a sufficient number of stars and a low background level from the Galactic disk.

In an ideal case, the measured signal of a source should be independent of the position on the focal plane. However, this instrument may introduce a dependence on both the position and the wavelength of the measured signal. The in-flight Self-Calibration aims to reconstruct this illumination variation through multiple observations of the same source at different positions on the focal plane.

3. – Simulation configuration

We use *Euclid* official simulator to produce the signal of two-dimensional spectra on the focal plane as illustrated in fig. 1. The following is a description of the main features of the simulations for the Self-Calibration.

- *Instrumental and environment features*: the simulator takes into account the read-out noise, bad pixels (*i.e.*, disconnected and saturated pixels), background light, and cosmic ray hits.
- *Pointing sequence*: in order to provide a complete and reliable reconstruction of the response of the instrument over the entire focal plane, it is necessary to use an

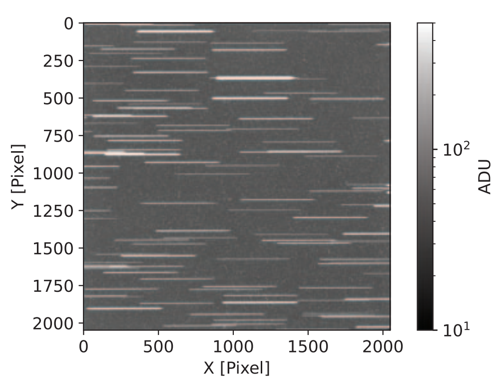

Fig. 1. – The Figure illustrates the signal recorded by a single detector in the spectroscopic channel. The signal is measured in Analog-to-Digital Units (ADU).

optimized pointing sequence. The Self-Calibration pointing sequence was derived (Risso I. *et al.*, in preparation) with a Monte Carlo approach and the leading idea is that all the spatial scales that will be observed during the survey should be observed in the calibration procedure. The resulting calibration sequence consists of 60 pointings from $10''$ to 0.7^{circ} dither scale.

- *Catalog of sources*: a crucial aspect to consider in simulations is the cross-contamination, *i.e.*, the overlapping of the signal from different sources. Cross-contamination strongly affects the spectra reconstruction, and thus the number of available sources for the calibration strategy. For this reason, we simulate the proper number and spectral type of sources that are expected to be observed by *Euclid* in the Self-Calibration Field based on theoretical models. Conservatively, we assume that no extended objects can be used for the calibration [4] and we include only stars in simulations.

- *Response function*: the response of the instrument is unknown and it will vary over time. Thus, it is necessary to simulate and reconstruct different response functions to validate that method [3].

4. – Data processing

We use *Euclid* official reconstruction algorithms to elaborate simulated images and extract the location and the signal of the spectra. The image defects are considered: bad pixels and cosmic ray hits are identified; non-linearity and dark current are corrected. The flat field is corrected, the locations of the sources are computed, the sky background is subtracted, and un-calibrated spectra are extracted.

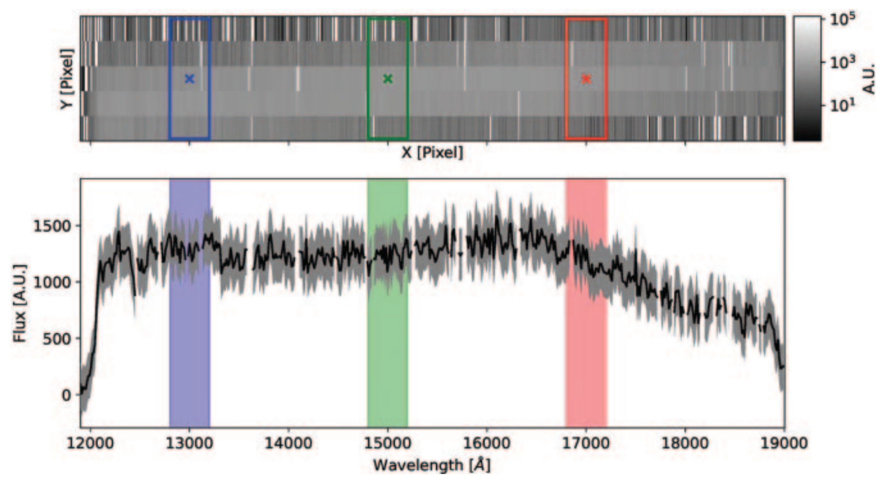

Fig. 2. – Location and extraction of the counts for a spectrum at three different wavelengths. Top panel: measured signal at the detector level in arbitrary units (A.U.). Cross marks represent the location mid-point of the first-order in the selected wavelength range. Bottom panel: one-dimensional un-calibrated spectrum from the image shown in the top panel with the associated uncertainty. The three shaded regions represent the wavelength ranges in which the spectrum is integrated.

The method presented in [3] allows the reconstruction of the response function in both photometry and spectroscopy. This method requires knowing the position and the counts of each source. In slitless spectroscopy, we select a specific wavelength range and integrate the signal over it as illustrated in fig. 2. We use the mid-point of the first-order spectrum in the selected wavelength range as the position coordinate [4]. The measured counts are compared to the expected ones, which are computed as the product of the theoretical rates, the exposure time, and the response function. Since both the theoretical rates and the absolute response function are unknown, there is an additional degree of freedom that must be set with the observation of a known source, *i.e.*, with the so-called *absolute calibration*.

5. – Conclusion

In this work, we extended the method described in [3] to the *Euclid* spectroscopic channel. In particular, we introduce systematic effects that are not present in photometry, such as overlap between spectra from different sources. *Euclid* official simulator allows us to study the relative flux calibration procedure starting from a simple case and gradually increasing the level of complexity. So far, we have simulated and reconstructed a uniform response function. We are now increasing precision in the extraction of the counts in order to reconstruct the non-uniform response of the instrument.

After completing validation, it will be possible to optimize the Self-Calibration procedure. In particular, we will optimize the value of the wavelength range for the integration of the signal and determine the minimum number of exposures that are required to calibrate each dispersing element.

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