The ESOReflex Workflow to reduce ESPRESSO data

Andrea Modigliani[1],Wolfram Freudling[1],Richard I. Anderson[1],
Christophe Lovis[2], Danuta Sosnowska[2], and Alex Segovia[2]

[1]*ESO, Garching, Germany;* `amodigli@eso.org`

[2]*Geneva Observatory, Geneva, Switzerland*

Abstract. ESPRESSO, the Echelle SPectrograph for Rocky Exoplanets and Stable Spectroscopic Observations installed at the incoherent combined Coudé facility of the VLT, started operations at the end of October 2018. The corresponding data can be processed by a dedicated pipeline developed by the ESPRESSO consortium and can be reduced at the user's desktop using an ESOReflex workflow. ESOReflex is an environment that provides an easy and flexible way to reduce VLT/VLTI science data using the ESO pipelines. This paper describes the challenges, the data reduction chain and the solutions adopted in the implemented workflow to support users reducing ESPRESSO data.

1. Introduction

ESPRESSO is a third-generation, fiber-fed, high-resolution, ultra-stable echelle spectrograph installed at the incoherent combined Coudé facility of the Very Large Telescope (VLT). It can be fed by the light of any of the VLT Unit Telescopes (UTs) as well as by the incoherently combined light of all four UT's together thus making ESPRESSO a spectrograph installed at the VLT the largest optical telescope in terms of collecting area in the world. The main scientific objectives are:

- finding and characterizing less massive exoplanets and their atmospheres;
- analysis of the variability of fundamental physical constants;
- determine star abundances in nearby galaxies.

2. Instrument features

A detailed description of the instrument can be found in Pepe (2010). We summarise the main features. ESPRESSO is a high resolution cross-dispersed spectrograph. To reach a precision of 10 cm/s in radial velocity, the spectrograph must be fiber fed, mounted on a very stiff structure, enclosed in a tank that is temperature (1mK) and pressure (1 μ bar) controlled. To optimise efficiency and increase spectral resolution, its wavelength range [380, 780nm] is split in two parts, [380, 550nm] and [550, 780nm], that feed respectively a BLUE and a RED camera. The spectrograph is wavelength calibrated using several sources, a ThAr lamp, a Fabry Perot (FP) etalon, and a Laser Fiber Comb

(LFC), that overall cover the full spectral range with high line density. The spectrograph is illuminated simultaneously by two fibres: fibre A dedicated to object observations, fiber B used for simultaneous calibrations (a wavelength calibration source, usually FP or LFC, or light from sky). The variability of the fundamental fine structure constant α and the proton to electron mass ratio μ can be assessed by observing very faint objects. This requires a large collecting area, obtained by combining light from up to four Unit Telescopes (UTs).

3. Data Reduction Pipeline and ESOReflex workflows

The ESPRESSO data reduction pipeline (Sosnowska et al. (2015)) can be efficiently run via the standard ESOReflex (Freudling et al. (2013)) Graphical User Interface (GUI).

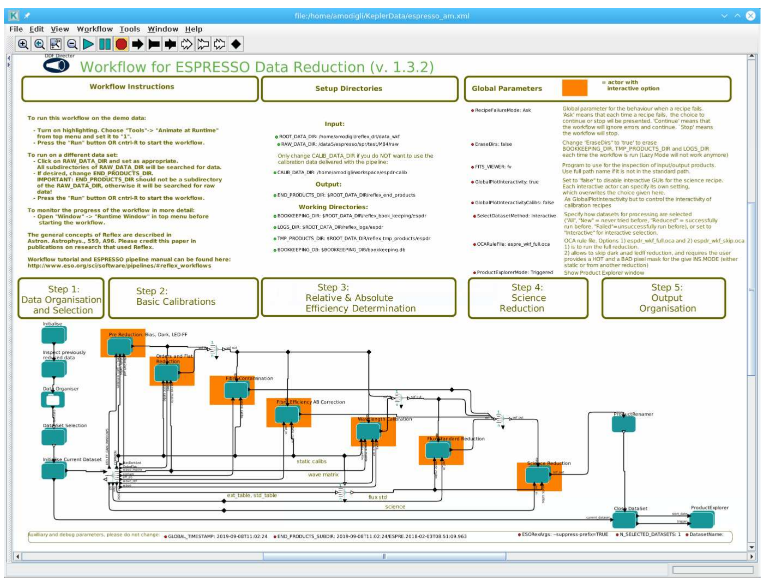

Figure 1. ESOReflex GUI for the ESPRESSO pipeline.

The data reduction pipeline is described in Sosnowska et al. (2015). The reduction chain involves the following sequence of data reduction steps. Bias frames are processed to create a master frame, monitor the read-out noise and generate a bias residuals frame. Dark frames are stacked to monitor the detector dark current level and generate an image of the hot pixels. Led flats are combined to obtain the conversion factor, measure the detector's pixel linearity and create a map of the non-linear pixels. Reducing two frames each with only one fibre illuminated by a flat lamp it is possible to determine the order and fibre slice traces. Acquiring ten flats with one fibre illuminated and the other off and another similar set with fibre illumination swapped, after stacking it is possible to determine a high SNR profile of the orders, their blaze and an image of the cross order profile at each order position, that is used during optimal extraction. Processing a frame with the fibre A dark and the other fibre illuminated by a FP (or LFC) it is possible to determine the contamination spectrum. Reducing a frame with both fibres illuminated by sky twilight, after extraction of each fibre spectrum and computation of their ratio it is possible to determine the relative fibre efficiency. Processing a frame where both fibres are illuminated by a FP the pipeline determines the position along the dispersion direction of the FP lines for each fibre and order. This solution is then combined with the one obtained from the reduction of two frames where one fibre is illuminated by a ThAr lamp and the other by a FP to obtain a very accurate wavelength position of each FP peak (based on a 6-peaks fit) using as zero point the ThAr based solution obtained on the other fibre which employs a very accurate line catalog without blends. By reducing the spectrum of a reference standard star the pipeline obtains the conversion factor from ADU to physical units. Finally the science spectra are processed as appropriate: for bright star observations it is critical to obtain a very precise wavelength calibration and eventually radial velocity measure, after correction of the night/day fibre drift and barycentric correction; for observations of faint sources it is instead important to have an accurate correction of the sky, which can be measured feeding the calibration fiber.

ESOReflex (`http://www.eso.org/reflex`) is an environment that provides an easy and flexible way to reduce VLT/VLTI science data. ESOReflex gives an overview of the data reduction sequence; it makes easy to inspect the intermediate and final data products, and repeat a given data reduction step to optimise data reduction quality; automatically organise, classify all raw data and associate master calibrations and static frames required to process a given science data set; users may plug-in their customised data reduction scripts; data reduction of steps for which the input data and reduction parameters have not changed is skept; it is the standard environment ESO offers to the user community to run ESO pipelines.

The ESRESSO workflow layout is shown on Figure 1. After pipeline installation the user may point the `RAW_DATA_DIR` to a directory where is located a complete set of ESPRESSO data, set the `END_PRODUCTS_DATA_DIR` to a convenient directory, and a few other workflow Global Parameters, for example the GlobalPlotInteractivity parameter to dis/activate the interactive actor for Science Reduction, then press the green arrow "play" button at the top of the ESOReflex GUI to have the data organised, classified and proper master and static calibrations associated in order to execute the full data reduction chain to enable science data processing.

To accommodate a wide spectral range of a high resolution cross dispersed spectrum it is also necessary to use large detector areas. ESPRESSO uses 9K×9K pixels detectors. Thus detector images contains around 100 million pixels, this challenging the corresponding data reduction performance. To speed-up bias, dark, led and flat frame processing we have used OpenMP to parallelise some data reduction bottlenecks.

The ESPRESSO spectrograph is mounted on a stiff structure within a temperature and pressure controlled thank. Thus it is expected that the spectral format is very stable, and that the map of hot and non-linear pixels will not change over time. To save time the user may skip the execution of the dark and led ff recipes, that generate these maps, once they have been obtained on a data set of the instrument mode the user is interested. It will be sufficient to copy the maps to the directory pointed by the global variable `CALIB_DATA_DIR` and change the value of the global parameter OCARuleFile as indicated on the ESOReflex top level layout to skip the reduction of dark and led data.

The ESPRESSO workflow offers interactivity on any data reduction step. ESOReflex GUIs present on the left hand side one or more panels to display relevant information as images, spectra or text. At the right hand side, near the top a subset of the recipe parameters and their values, is presented, organised in groups (tabs) according to their

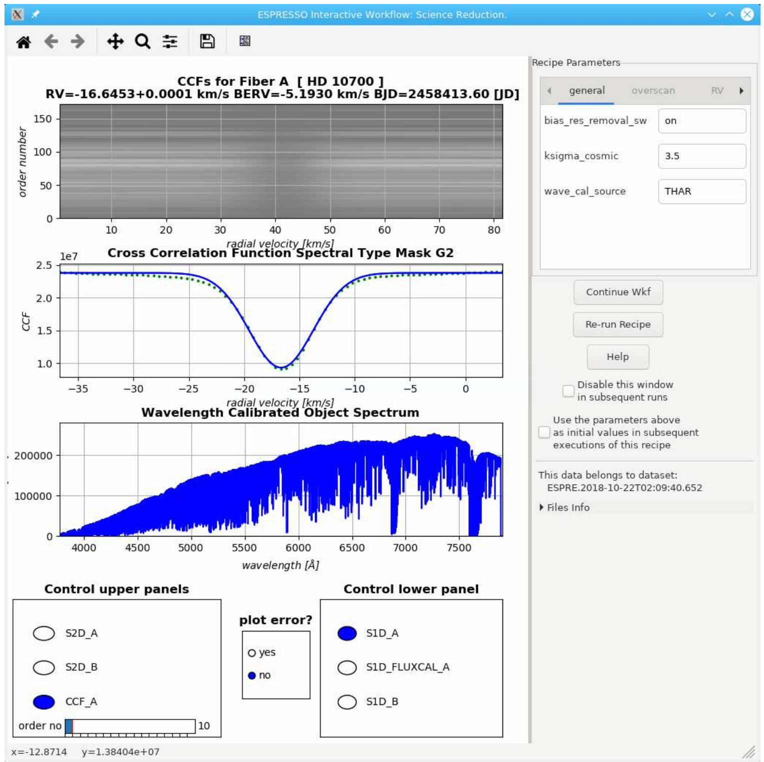

Figure 2. Science Reduction GUI.

purpose. Below, three buttons can be used to continue to the following data reduction step, to re-execute the recipe, or to provide help. Additional customisation can be done with two other check buttons. Information on the data set being processed and the input data is given below. Here we just describe the interactivity offered in the science data reduction. We decided to display at the top right hand side the S2D spectra, extracted spectra in dispersion-order space, and in the panel below the 1D spectrum corresponding to a given order trace; in case of science workflow either the Cross Correlation Function (CCF), the spectrum of the observed object or the spectrum of a calibrator at a given order. These options can be set by appropriate buttons or a slider to control the upper panels. A third panel displays other 1D spectra: the extracted merged object spectrum, the corresponding flux calibrated spectrum or the 1D merged spectrum of the calibration fibre. The user may also decide whether to display or not the error.

References

Freudling, W., Romaniello, M., Bramich, D. M., Ballester, P., Forchi, V., García-Dabló, C. E., Moehler, S., & Neeser, M. J. 2013, Astronomy and Astrophysics, 12, 127

Pepe, F. e. a. 2010, in SPIE 7735 (San Diego, California, United States: SPIE), vol. 77350F of Proceedings of the SPIE, Volume 7735, id. 77350F (2010)

Sosnowska, D., Lovis, C., Figueira, P., Modigliani, A., Marcantonio, P. D., Megevand, D., & Pepe, F. 2015, in ADASS XXIV, edited by A. R. Taylor, & E. Rosolowsky. (San Francisco: ASP), vol. 495 of ASP Conf. Ser., 285