ESO Phase 3 Data Release Description

Data Collection	ERIS/SPIFFIER
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Document Date	2024.07.17
Document Version	1.1

Abstract

This is the release of the reduced, reconstructed 3D cubes from the ERIS/SPIFFIER instrument from the beginning of operations on April 1, 2023 (P111).
The **E**nhanced **R**esolution **I**mager and **S**pectrograph (**ERIS**) is a general-use infrared integral field spectrograph (IFS) and imager (NIX) that utilises the adaptive optics on the VLT's Unit Telescope 4 (Yepun)[1]. The spectrograph is a medium-resolution IFS that operates in the near-infrared range of 1 – 2.5 µm (J, H, and K bands). SPIFFIER has twelve grating configurations. Three low-resolution (R~5,000) grating configurations span each of the J, H, and K bands. The nine high-resolution (R~10,000) configurations span each of these bands in sets of three, with each grating spanning approximately one half of the band (one covering the first half, one covering the second half, and one centred on the middle of the band). Three plate scales correspond to an on-sky field-of-view of 0.8" x 0.8", 3.2" x 3.2", and 8" x 8", with corresponding spaxel (spatial pixels) of sizes 12.5 x 25, 50 x 100, and 125 x 250 mas/spaxel, respectively[2]. SPIFFIER can be operated without adaptive optics (AO), with natural guide star AO, and/or with a single laser guide star.

The focus of this release is dedicated to the fully reduced data product cubes from the ERIS/SPIFFIER IFS. These data consist of science exposures that have been dark-corrected, flat-fielded, wavelength calibrated, sky background corrected and, if possible, photometrically calibrated. The reconstructed 3D combined cube constitutes the primary data product and is provided as a multi-extension file (MEF) consisting of the data, error and quality cubes. The fully processed, individual 3D cubes that make up each combined cube are also included, along with the mean collapsed combined cube (white light), the associated sky exposure cube, and the exposure map.

General information and ERIS/SPIFFIER processing

Overview of Observations

This data set contains all of the science observations done using the ERIS/SPIFFIER integral field spectrograph. These are not part of a single self-contained project or survey. Rather, they contain observations from many different projects and surveys, using various gratings and observing methods. The distribution of fields is obviously governed by the time of year in which the observations were taken.

[1] https://www.eso.org/sci/facilities/paranal/instruments/eris.html
[2] https://www.eso.org/sci/facilities/paranal/instruments/eris/inst.html

Release Content

This release contains all of the science observations done with ERIS/SPIFFIER since it began operations starting from April 2023 (period P111). New data products are being continuously created and are added at regular intervals.
This release also includes data processed from the ERIS/SPIFFIER Science Verification observations made from December 2 – 5, 2022 (https://www.eso.org/sci/activities/vltsv/erissv.html). Here, all proposals with "completed" or "partially completed" data status have been processed.

For science observations the following data products are available:

- Fully processed, reconstructed and combined 3D data cubes (primary product).
- Fully processed, individual reconstructed 3D data cubes that make up the combined cube.
- Associated sky exposure cube (if included in the observation template).
- Exposure map associated with the combined 3D data cube, to map the true exposure times over the mosaiced field.
- Mean-collapse of the combined 3D data cube (white light image).

All reduction has been done at the OB template level and no attempt has been made to combine data between multiple OB's.

The following observations have been omitted from this release:

- Observations done under any technical programme having an OBS.PROG.ID like "60" and "060" (including any standard star observations).

Release Notes

The data for this release was processed using the ERIS/SPIFFIER science pipeline developed by MPE Garching (Erich Wiezorrek, Yixian Cao, and Alex Agudo) and by ESO (Andrea Modigliani*)*. The main processing steps are described in the following section.

Data Reduction and Calibration

A detailed description of the data processing done for ERIS/SPIFFIER can be found in its pipeline manual[3]. A brief summary of all data reduction steps applied to the science observations is given below:

- Each SPIFFIER image is dark-corrected using a master dark frame of the correct DIT/NDIT combination. The dark frames are also used to detect hot pixels.
- Geometric detector distortions are corrected and the edges of each of the 32 pseudo slits are mapped.
- A dedicated set of gain and linearity frames are used to compute the detector gain and to detect non-linear pixels, that are flagged and mapped.
- Internal lamp flats are used to create a master flat to correct each frame for its pixel-to-pixel variations and large-scale features. These flats are also used to define cold pixels which, together with the hot and non-linear pixels define the bad pixel maps.
- An initial wavelength calibration is done using an internal arc lamp.
- If a photometric flux standard star of a given list (GD71, GD153, LTT3218, LTT7987, EG274, Feige110, EG21) is observed, a response and instrument efficiency computation is made.
- As ERIS is mounted at the UT4 Cassegrain focus, it is subject to instrument flexures that depend on the observation pointing. This can result in a spectral distortion that affects the wavelength calibration. Therefore, *in situ* [OH] sky lines are used to refine the wavelength solution. However, this requires that the science exposure is sufficiently long such that the [OH] lines are sufficiently bright and numerous. This is typically true for exposures of a few minutes or longer. An initial cube reconstruction is made for each science frame using the wavelength solution derived from the arc lamp. Then, any potential wavelength offset is computed by comparing the wavelengths of the detected [OH] lines to their expected wavelength values. This offset is folded back into the wavelength solution and the cube is reconstructed anew from the input raw data (the intial reconstruction is deleted). It is important to note that correcting the spectral flexure does not compromise the quality of the data as only the single, improved interpolation is applied.
- During the cube reconstruction, a correction is also made for the atmospheric refraction based on the ambient temperature, pressure, humidity, instrument rotation angle on the sky, the instrument parallactic angle, the observing wavelength, and the source position.
- If a dedicated sky frame has been observed, a sky background correction is made for each plane of the cube using the method described in Davies (2007)[4]. Briefly, the sky correction is done as follows:
    1. Sky spaxels are identified in each object cube
    2. The spectra in these spaxels are separately summed in both the object and sky cubes.
    3. A blackbody function is fit to the underlying continuum in the sky spectrum and subtracted from the object and sky cubes and extracted object and sky spectra.
    4. These corrected spectra are then compared to offsets in bright [OH] lines and the sky cube is shifted accordingly.
    5. The vibrational variations are then corrected using the same sky spaxels (step 1) by dividing the spectra into segments along the wavelength axis. For each segment the spectral vectors of bright [OH] lines are extracted.
    6. The sky spectrum is scaled to match the object spectrum in each wavelength segment.
    7. The scaling of each spectral segment is combined into a single scaling function which is applied to the sky spectrum.

[3] https://www.eso.org/sci/software/pipelines/
[4] https://ui.adsabs.harvard.edu/abs/2007MNRAS.375.1099D

8. Steps 5 to 7 are repeated of the rotations bands and the two scaling functions are combined.
9. This resulting scaling function is multiplied with the compensated sky cube and subtracted from the object cube.

- If a response curve based on a spectro-photometric standard star observation is associated with the science OB, then a flux calibration is applied.
- The cube resampling combines all input frames contained in the OB using the computed distortions and wavelength calibration. Only a single interpolation step is applied and the default method uses a *drizzle-like* weighting scheme.
- The spatial resolution quality keyword PSF_FWHM is computed using stellar sources in each image. If there are an insufficient number of stars in the field of view and AO is used, then the image PSF_FWHM is computed using the attached ASM_DATA table. The image quality is then measured from the Shack-Hartmann wavefront sensor. Otherwise, the Paranal seeing monitor (DIMM) is used by converting its value to the different telescope size, the different waveband, and an average over the duration of the exposure.

All image products are accompanied by a variance map that has been propagated through the most of the science data reduction process. However, due to the final cube resampling creating noise correlation effects, the error map for the science cube is compute using an empirical variance measure when three or more frames are combined. Each image product also includes a quality map (comprising the hot and cold bad pixels, non-linear pixels, and saturated pixels).

Data Quality

Master calibrations. All master calibrations used to process ERIS/SPIFFIER science exposures have been quality-reviewed and certified at the time of acquisition, as part of the closed QC loop with the Observatory which also includes trending. As part of the certification process for calibration data there is a scoring process to bring non-compliant behaviour of the calibrations to the attention of the QC scientist. All these cases have been handled as part of the certification procedure. Hence, there is reasonable evidence that the master calibrations catch all instrument properties, as relevant for the reduction, correctly and completely.

Wavelength Calibration

The initial wavelength calibration of SPIFFIER data is done with arc lamps. However, when the sky emission lines are sufficiently bright, this calibration is refined using [OH] lines in the science exposure. In very short, shallow exposure, this refinement may not be possible due to an insufficient number of adequately bright [OH] lines.
Measuring the variation and dispersion in a number of [OH] lines for 100 ERIS/SPIFFIER data cubes (see Figure 1), the overall precision is about +/- 4 km/s when calibrated with the internal arc lamps and refined with *in situ* [OH] lines.

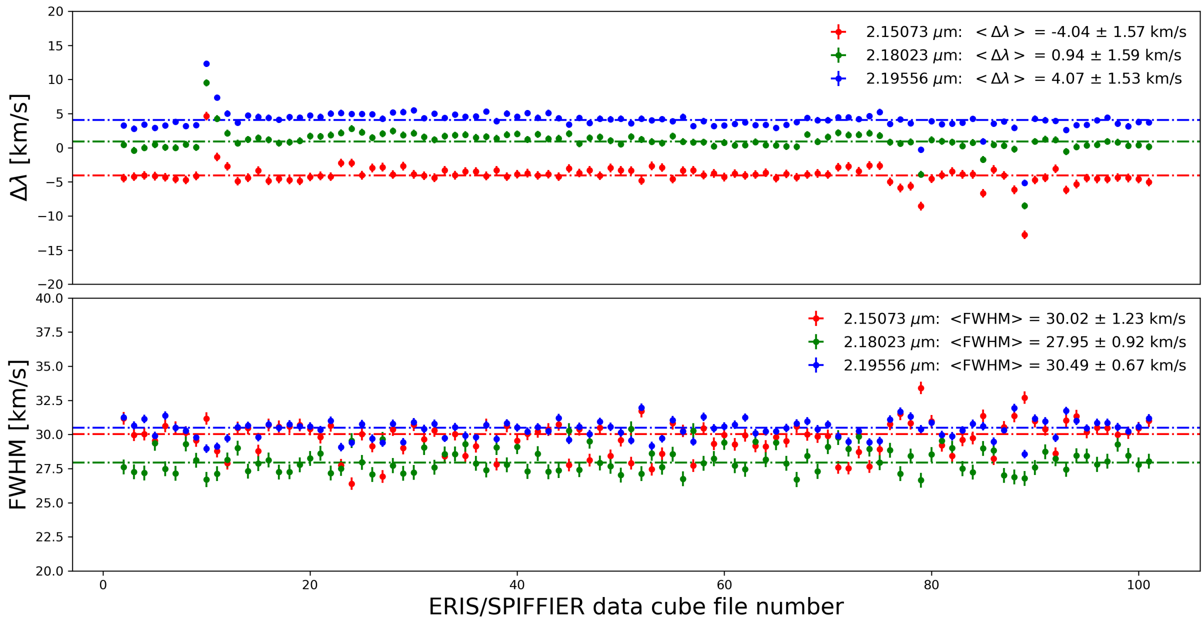

Figure 1: the wavelength shift (top panel) and FWHM (bottom panel) for three [OH] lines, as measured in a sample of 100 ERIS/SPIFFIER data cubes in K_middle/100mas. These observations were made in a wide variety of pointings (i.e. the full range of accessible altitudes and instrument rotator angles).

Astrometric Correction

The very small field-of-view inherent to an IFU (ranging from 0.8" x 0.8" to a maximum of 8" x 8" for SPIFFIER) precludes an *in situ* calibration based on astrometric field stars. Therefore, the SPIFFIER absolute world coordinate system (WCS) is set by the coordinates provided by the UT4 telescope. Generally, the absolute accuracy of this WCS is within 1 arcsec, but can sometimes be as large as 2 arcsec. If the science exposure is made using an offset from a PSF star (generally done for faint targets), the relative accuracy of this offset will be better than 0.5 arcsec.

Flux Calibration

The ERIS/SPIFFIER flux calibration is only done when a spectro-photometric standard has been explicitly requested by the science OB. Thus, not all data cubes can be flux calibrated.
To provide an estimate of the flux calibration precision, the fluctuation of the derived zero point flux was measured in 100 standard star observations spanning four months from August 2023 to November 2023. This was done in the K_middle grating and the 25 mas and 100 mas pixels scales. This data was obtained at the end of each observing night under varying photometric and seeing conditions, and using a variety of spectro-photometric standards. Based on this, we estimate a photometry precision of better than 15% (see Figure 2).

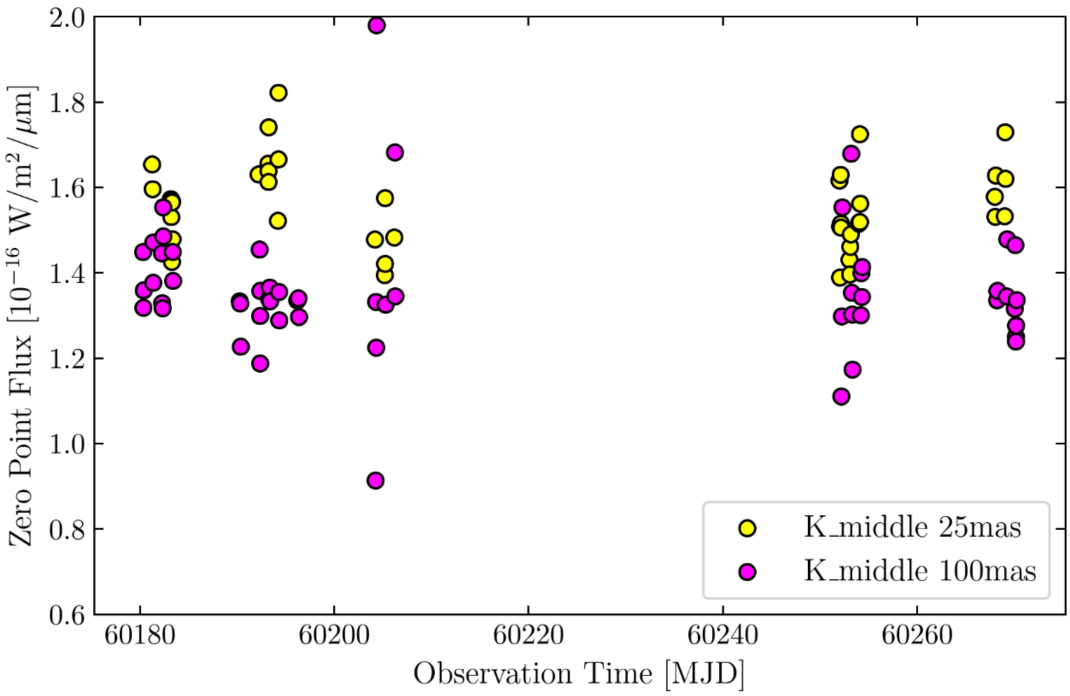

Figure 2: the variation of the zero point flux as derived from 100 standard stars taken between August and November 2023. The scatter is partly due to varying photometric and seeing conditions.

Known issues

Photometric calibration of ERIS/SPIFFIER observations are not automatically done, but must be requested by the user. In fact, many IFU observations are focussed on the kinematics and do not require a flux calibration or photometric conditions. For this reason, a number of ERIS/SPIFIFER data cubes will not be flux calibrated.

If IFU data is spatially under-sampled, ripples can appear in the extracted spectrum from the resampled cube. This is an unavoidable interpolation effect. A example of this is apparent in a standard star exposure taken in the 100mas scale with AO and in the K-middle passband (see figure 3). The standard star is spatially under- sampled and the majority of its flux falls in a single rectangular pixel. If the spectrum is extracted over a single pixel aperture the spectrum will have very apparent undulations. This is a known phenomenon[5] and if one integrates the flux over a reasonable aperture the wiggles go away, as the total flux is preserved.

[5] R.I.Davies, et al. . The Software Package for Astronomical Reductions with KMOS: SPARK, October 2013.

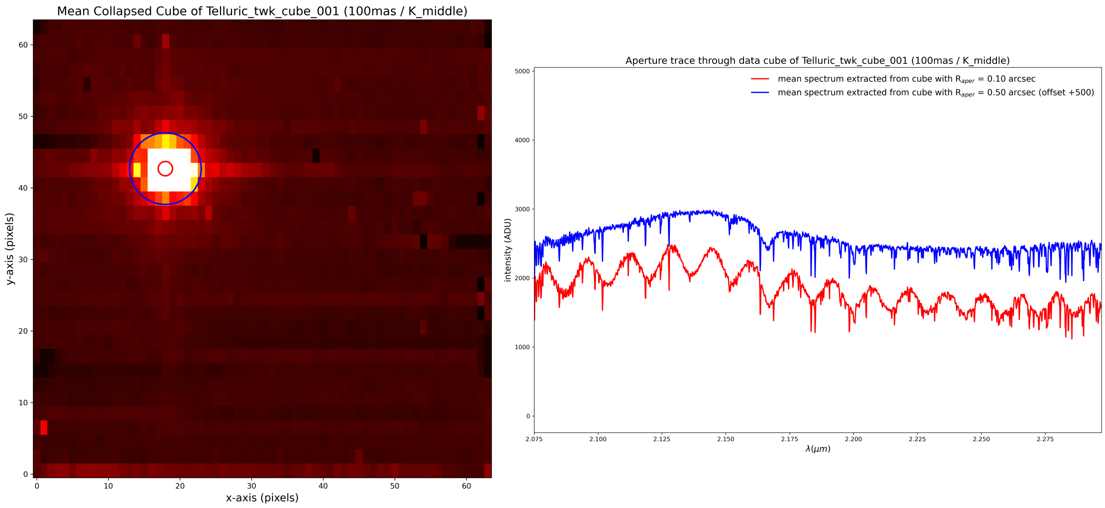

Figure 3: an example of extracted spectrum "wiggles" in an under-sampled ERIS/SPIFFIER standard star. Being under-sampled, the majority of the stand star's flux falls into a single rectangular spaxel. When extracting through the data cube over an aperture close to this single pixel (the red aperture in the collapsed cube shown on the left), the undulating spectrum becomes apparent (red trace: right-hand panel). When extracted over a reasonable aperture (blue aperture), the under-sampled wiggles average out (blue trace offset by 500 ADU).

Data Format

Files Types

The data set for each observation consists of one primary product file (the reconstructed 3D combined cube), several ancillary fits files (these are described in the table below) and one preview plot. The number of ancillary files depends on how many frames were taken on the target and on the sky during the observation. For some observations, there is no associated sky exposure.
Table 1 gives an overview of the provided files.

ORIGFILE begins with	**Type**	**Product category** HIERARCH.ESO.PRO.CATG and PRODCATG	**Number**	Primary or ancillary?	Description
ER_SCUF	fits	OBJECT_CUBE_COADD_FLUXCAL SCIENCE.CUBE.IFS	1	Primary	Processed/ reconstructed 3D combined cube
ER_SCUW	fits	OBJECT_CUBE_COADD_FLUXCAL_MEAN ANCILLARY.IMAGE.WHITELIGHT	1	Ancillary	White light image
ER_SCUI	fits	OBJECT_CUBE ANCILLARY.CUBE.IFS	n	Ancillary	Processed individual 3D cube
ER_SEXP	fits	EXPOSURE_MAP ANCILLARY.EXPM	1	Ancillary	Exposure map associated with the CO-ADD cube
ER_SCSI	fits	SKY_CUBE ANCILLARY.CUBE.IFS.SKY	m	Ancillary	Associated SKY exposure cube (if available)
	png		1	Ancillary	Preview plot

Table 1. Primary and ancillary products for a science observation

The ORIGFILE product names for the primary products (ER_SCUF) follow a naming convention which is:

ER_<TYPE>_<OBS_ID>_<DP_ID>_<ARM>_<TARGET>.fits

The ORIGFILE product name for the ancillary products (ER_SCUW and ER_SEXP) follows the same naming convention than the primary product.

The ORIGFILE product name for the individual exposures (ER_SCUI and ER_SCSI) follows also the convention of the primary product with the addition of <N> which is the exposure number in the template:

ER_<TYPE>_<OBS_ID>_<DP_ID>_<ARM>_<TARGET>_<N>.fits

Table 2 gives more details on the ORIGFILE naming convention.

In addition to the fits products, also a preview plots is delivered as ancillary file. It comes in the PNG image format and follow the naming convention:

r.ERIS.<DP_ID>_single.png

Component	Description
ER	ERIS product
<TYPE>	Product type. See Table 1.
<OBS_ID>	OB ID of the observation (header key HIERACH ESO OBS ID)
<DP_ID>	Time stamp in UT of the first exposure of the stack in the format <YEAR>-<MONTH>-<DAY>T<HOUR>:<MINUTE>:<SECOND>.<MILLISECOND>
<TARGET>	Coding of HIERARCH.ESO.OBS.TARG.NAME
<N>	HIERACH.ESO.TPL.EXPNO

Table 2. ORIGFILE naming convention

File structure and size

The primary ERIS/SPIFFIER product (**OBJECT_CUBE_COADD_FLUXCAL**) is a processed/recombined 3D fits file with 3D images as extensions (see Table 3). The size of the main product depends on the size of the recombined image and its wavelength resolution, and can vary from 150MB to 1GB.

The ancillary products (OBJECT_CUBE and SKY_CUBE) are both around 150MB, while the white light image (OBJECT_CUBE_COADD_FLUXCAL_MEAN) and the exposure map are less than 1MB.

Extension	Name	Description
0	Primary	
1	DATA	3D cube with 2 spatial dimensions and 1 wavelength axis
2	ERROR	Associated error
3	DQI	Data quality cube

Table 3: structure of the main science product with PRO.CATG **OBJECT_CUBE_COADD_FLUXCAL**

The additional (ancillary) products (OBJECT_CUBE and SKY_CUBE) follow the same structure (see Table 3).

The fits file EXPOSURE_MAP is a single 2D image containing the variation of the accumulated exposure time (in seconds) per spaxel of the combined cube.

Acknowledgement text

According to the ESO data access policy, all users of ESO data are required to acknowledge the source of the data with an appropriate citation in their publications.

Since processed data downloaded from the ESO Archive are assigned a Digital Object Identifier (DOI), the following statement must be included in any publications making use of them: Based on data obtained from the ESO Science Archive Facility with DOI(s) : https://doi.eso.org/10.18727/archive/91.

All users are kindly reminded to notify Mrs. Grothkopf (esodata at eso.org) upon acceptance or publication of a paper based on ESO data, including bibliographic references (title, authors, journal, volume, year, page numbers) and the observing programme ID(s) of the data used in the paper.