ESO Phase 3 Data Release Description

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Overview of important recent changes:

Version 1.0 *2025-05-01* *Document validated by SDQ.*

Abstract

This is the release of reduced 1D spectra from the upgraded CRIRES instrument, the CRIRES+[1] spectrograph. This is an open stream release, it includes CRIRES+ data archived so far and will be continuously expanded with new data in the future. The processing scheme is as homogeneous as possible.

The selected data covers the vast majority of the entire CRIRES+ data archive, from the beginning of operations in October 2021 until present. The overall data content grows with time as new data is being acquired and processed (approximately with monthly cadence and with a delay of 1 or 2 months). The L-band and M-band data are not included here because of the lack of arc lines for the wavelength calibration at these wavelengths. ASTROMETRY, POLARIMETRY and Generic offset (when the products are 2-Dimensional spectra) observations are also excluded since the related science recipes have not been scientifically validated. The data have been reduced with the CRIRES+ pipeline, version **`cr2re-1.6.9`** and higher. All data have their instrument signature removed: they have been de-biased, flat-fielded, wavelength-calibrated, extracted, sky-subtracted, co-added and 1-Dimensional (1D) spectra were extracted and wavelength calibrated, but not telluric corrected. All spectra have been reduced under the assumption of point-like sources. Error estimates and quality flags are provided. A list of the known data shortcomings is presented in section 'Known issues' of this document.

The processing performed by the ESO Science Data Quality Group is automated. It uses archived, closest-in-time, quality-controlled, and certified master calibrations. It is important to note that the reduction process itself was automatic, while the quality assessment and certification of the master calibrations was (and still is) human supervised.

The data format follows the ESO 1D spectroscopic standard[2] for Phase 3 data products. Each 1D spectrum is a multi-column binary FITS table. There is one product file for each set of input raw files. The set constitutes all raw files obtained with the same template for the NODDING and for STARE data. Note that only raw files taken with the same template are combined together, the IDP stream does not combine raw files taken with different templates or OBs.

Disclaimers:
(1) The data have been pipeline-processed automatically with the same set of pipeline parameters, set to deliver the best performance over the largest fraction of data, and with the best available calibration data. However, this universal reduction strategy is not necessarily optimal for all data sets or for the original scientific purpose of a given set of observations, or for the particular scientific goal of every archive user.
(2) The data are subject to some known issues (see Section Known issues and features).
It is the responsibility of the users to verify if the data is adequate to their scientific goals.

[1] http://www.eso.org/sci/facilities/paranal/instruments/crires.html
[2] http://www.eso.org/sci/observing/phase3/p3sdpstd.pdf

Release Content

The CRIRES+ release is a stream release, therefore, the overall data content is not fixed but grows with time as new data are acquired and processed. The data are tagged "CRIRESplus" on the ESO archive user interface[3]. The release does not include data from the old, pre-upgrade CRIRES (before 2021). Polarimetry, spectroastrometry and 2D observations are not included, as well as any L- and M-band observations.

The first CRIRES+ data was published in May 2025. They have been ingested since then into the archive in a chronological manner. Newly obtained data are being added at roughly monthly intervals and with a typical delay of 1 or 2 months, when all necessary master calibrations for the corresponding time interval become available.

In addition to the main products (the 1D spectra) this release contains other ancillary products that—from experience—are known to be useful for the typical high-resolution infrared spectroscopic science cases, including abundances, line profiles, and radial velocity studies. For spectral energy distribution analysis, when the continuum shape is relevant, the researchers should keep in mind that CRIRES+ is a multi-order high-resolution spectrograph, designed mainly for wavelength stability and efficiency. It is usually not operated to achieve high-precision spectrophotometry. Significant slit losses are to be expected—the instrument is not equipped with a wide slit.

Flux standards, telluric standards and radial velocity standards are observed regularly, typically on a weekly basis by the observatory as part of the calibration plan; user provided standard stars may be observed during visitor runs. Spectra in 1D format of all these standards are included in this release just like for any science target.

Products organization

The downloaded data come with their technical archive names. The first useful step to do is the organization of the data on the local disk. The easiest way to identify all files belonging together is the timestamp in their name, e.g. 2021-10-05T07:45:26.840, which is common to all file names of a data set.

The main product is the spectrum with PRODCATG=SCIENCE.SPECTRUM and there are other associated fits files packaged into a TAR file:

- for staring observations:
  - Order-by-order 1D extracted spectrum. This file is useful if individual orders must be treated separately like in case of applying the VIPER[4] (Velocity and IP EstimatoR) tool that improves the wavelength calibration with gas cell absorption features (see further).
  - Combined 2D calibrated spectrum. This file is useful if the users want to extract 1D spectra with tools different than the pipeline and/or if the object is (semi-)extended or binary.
  - Trace wave table with information about the position of the order, the wavelength calibration information and information about the slit curvature. This file is useful for users who want to carry out their own 1D spectrum extraction.
  - Spatial profiles of the target used in the optimal extraction of the 1D spectrum, carried out by the pipeline. This file is useful for verification of the optimal extraction, e.g. if the profile outside the target is close to zero, if it is well centered, etc.
- for nodding observations:
  - Order-by-order 1D extracted spectra in nodding position A, nodding position B, and for both together. Again, these files are useful for users who want to analyze the

[3] http://archive.eso.org/scienceportal/home?data_collection=CRIRESplus+
[4] https://mzechmeister.github.io/viper_RV_pipeline/

spectra on an order-by-order basis.

- Combined 2D calibrated spectra with the object in nodding position A and B, respectively. These files have the same usage as their analog for stare observations.
- Trace wave tables with information about the position of the order, the wavelength calibration information and information about the slit curvature. These files have the same usage as their analog for stare observations.
- Spatial profiles of the target used in the optimal extraction of the 1D, spectra carried out by the pipeline at positions A and B. Again, these are useful for verification of the optimal extraction.

The description of the file formats for all these products can be found in the Pipeline User Manual[5]. Finally, the ancillary products for both modes include two static plots to allow the users an easy visual inspection of the products – one showing all orders and another zoomed in only one order, number 5.
Summarizing, for each raw data set the user receives the primary science spectrum, the ancillary PNG plot for the order number 5, and a TAR file that contains all the other ancillary FITS files and another PNG plot showing all the orders.

Data Selection

Data selection is rule-based. It is organized along the following criteria:

- instrument: INSTRUME=CRIRES;
- observing technique: DPR.TECH=SPECTRUM,<obsmode>
  where obsmode is one of the following:
  - DIRECT,NODDING for stare mode
  - NODDING,JITTER for nodding mode
  - not NODDING,OTHER,
    not POLARIMETRY,
    not SPECTRUM, GENERIC,
    not NODDING,OTHER,ASTROMETRY and
    not DIRECT,OTHER,POLARIMETRY;
- category: DPR.CATG=SCIENCE for science observations or DPR.CATG=CALIB for the flux standard stars;
- type: DPR.TYPE=OBJECT for the science observations or DPR.CATG=STD for flux standard stars.

Data obtained in both visitor and service observing modes and with any combination of instrumental settings (central wavelength and slit width) are included in the release. Science data with the PROG.ID starting with 60 or 060 were excluded from the release, because they are test data, except for the standard stars that have (almost) always a PROG.ID 60.A-9051(A); the latter are always included in the processing.[6]

However, only those science and standard star data were processed for which certified master calibrations existed in the archive. Depending on their type, these master calibrations were obtained daily or less frequently, as described in the instrument Calibration plan (Table 4). They have been all processed by the Paranal Science Operations Data Quality Group (PSO) since May 2024. Data from the beginning of CRIRES+ operations (October 2021) until April 2024 have in addition been reprocessed with pipeline release cr2re-1.6.9 by the Science Data Quality Group (SDQ). All master calibrations that were used here were certified, meaning checked for quality and proper removal of the instrument effects. For CRIRES+, the selection pattern for master calibrations was complete from the beginning of the operations on.

There is no rejection based on the raw data quality. Likewise, we have not considered OB grades[7] for data selection: the observations might have any grade between A and D (if taken in SM), or X (in VM). The availability or unavailability of a particular file in this release does not imply any claim

[5] https://ftp.eso.org/pub/dfs/pipelines/instruments/crires/crire-pipeline-manual-2.3.17.pdf
[6] Users interested in searching only for CRIRES flux standards should use this PROG.ID on the interface.
[7] As given by the observatory staff to assess the match with user-defined constraints, for SM data.

about its data quality. There are sometimes data acquisition patterns for which the processing jobs is expected to fail (e.g. a NODDING data set with one raw file; a set with different numbers of NODDING A and NODDING B frames, a NODTHROW > 10). In some of those cases the raw data may still be processed with a fine-tuned strategy.

Note that for the observing modes NODDING and DIRECT (=STARE), all raw files taken in one template were combined to generate a single product. Importantly, multiple observations of the same OB, or observations across multiple OBs of the same object with identical instrument set ups *have not been co-added*. Observations acquired with grating settings covering complementary wavelength ranges selected to fill in the gaps between the orders *have also not been combined*, because such complementary observations were acquired with different templates. The automatic quality checks of the products flag out the rare cases when a template was aborted, and/or an additional quality issue(s) occurred (see section 'Data Quality').

Standard stars

Three types of CRIRES+ standard stars are regularly observed at the telescopes: for flux calibration, telluric correction and radial velocity. They are not marked in the headers as such but can be identified according to the instrumental setup documented in the FITS header keywords (see Table 1).

Table 1. Header keywords and their values, useful to identify different types of standard stars. Note that in visitor mode the values may differ.

Type of observatory provided standard, OBS.PROG.ID=60.A-9051(A)[8]	INS.SLIT1.NAME	INS1.OPTI1.NAME
spectrophotometric	w_0.4	FREE
telluric	w_0.2	FREE
radial velocity	w_0.2	GAS_SGC

Spectrophotometric or flux standards are used to restore the shape of the continuum only, not for absolute flux calibration, because the slits (widths 0.2 and 0.4 arcsec) that CRIRES+ uses, and the AO-assisted observations lead to variable slit losses and make the absolute calibration unreliable. These standards can be identified by checking the list of spectrophotometric standards that in the CRIRES+ User Manual and/or the list of spectrophotometric standards in the static calibration file that ESO supplies with the archive download tool CalSelector. The same list is also delivered as a static calibration with the ESO CRIRES+ pipeline.

Telluric standards help to remove the absorptions imprinted upon the science spectrum by various molecules (CO, H_2O, O_2, CH_4, etc.) in the Earth's atmosphere, so-called telluric features. Telluric stars should have as few intrinsic features as possible and should lack emission lines. Typically, telluric stars are late-B or early-A type, although some programs use solar analogs, because a telluric-free high-quality solar spectrum is available from the Sun. It is up to the archive user to identify standards appropriate for telluric correction.

Radial velocity standards are used to monitor the stability of the instrument or to serve as templates for measuring radial velocities of science targets. In the first case these are observed with the narrowest slit (0.2 arcsec) and are typically late-type stars that are rich of absorption features and are often giants, because their atmospheres are not subject to pressure broadening to the same extend as for the dwarf stars, and the absorption features are narrower. Again, it is up to the user to identify appropriate standards.

Some standard stars fulfill multiple roles—a spectrophotometric standard can serve as telluric

[8] Currently the different types of CRIRES+ standard stars cannot be distinguished by the raw frame header key DPR.TYPE=STD. From 2025-04-01 on (ESO observing period P115) CRIRES+ standard star raw fits frames can be also distinguished by their DPR.TYPE header key, which will be one of DPR.TYPE=STD,FLUX or STD,TELLURIC or STD,RV.

standard, if the science observations are performed with the wider slit; a Solar analog telluric standard can serve as a radial velocity template if the science target is also a Solar analog.

These standards are processed and archived in the same manner as the science targets. Generally, standard stars can be recognized by DPR.TYPE=STD, but some users may have observed standards as science targets (especially radial velocity ones) and in that case it is up to the archive user to identify them, e.g. from the name and coordinates. The standard stars are not used in the processing of the science data directly—in other words, the science data are not subject to flux calibration, telluric removal or radial velocity adjustment based on the standard star observations.

Gas cell radial velocity correction: for a fraction of the archival data, the users can improve the wavelength calibration in post-processing, if the targets are observed both with and without the gas cell. The tests indicate that this recalibration can improve the radial velocity precision down to 3 m/s (for sufficiently bright targets, rich of absorption features in the infrared). Data observed with the gas cell can be recognized by the INS1.OPTI1.NAME header keyword (available in the CRIRES specific search form[9]): GAS_SGC for spectra taken with the gas cell and FREE for spectra without it. Typically, observations in these two set ups are taken on the science targets back-to-back. A tool to recalibrate CRIRES+ gas cell data, called VIPER, is available to the community (Zechmeister et al. 2021: Astrophysics Source Code Library, record ascl:2108.006; Köhler et al. 2025). The files necessary to run VIPER (1D spectrum, in a FITS table, but with separated spectral orders) are delivered if the associated files are requested.

Release Notes

Depending on the observing mode, the data reduction uses the standard CRRES+ pipeline recipes `cr2res_obs_<mode>`, where `<mode>` is `staring` or `nodding`. The names of CRIRES+ recipes begin with `cr2res` to separate them from the recipes of the old pre-upgrade CRIRES pipeline (their names begin with `crires`). Descriptions of the science recipes are available in the Pipeline User Manual[10]. Find the pipeline version used for processing in the headers of the product files, under "PROCSOFT" or "HIERARCH ESO PRO REC1 PIPE ID". To generate Phase 3 compliant products, we set the recipe parameter idp=TRUE (default FALSE) and for a more robust 1D spectrum extraction we modified extract_swath_width=2048 (the fault was 500).

Pipeline Description

Information about the CRIRES+ pipeline (including downloads and manual) can be found at https://www.eso.org/sci/software/pipe_aem_table.html.

Data Reduction and Calibration

The main reduction steps of the CRIRES+ science and flux standard star data are the following:

- STARE observations:

- Load the input raw frames in an image list.
- Apply the dark and flat calibrations to the image list.
- Combine the images in the list.
- Load the input trace wave as a starting point for the wavelength calibration.
- Recompute a new trace wave with the specified slit fraction, defined with the --slit_frac parameter, if necessary.
- Extract the 1D spectra from the combined 2D spectra and generate:
    - combined 2D spectrum,
    - extracted 1D spectra, in order-by-order FITS ta multi-order merged IDP FITS,
    - spatial slit profile slit_func,
    - 2D model spectrum model_master.

[9] http://archive.eso.org/wdb/wdb/eso/crires/form

[10] See the CRIRES entry in the table at http://www.eso.org/sci/software/pipelines/. There you will also find the link to the latest version of the instrument-specific Reflex tutorial as 'CRIRES Reflex Tutorial'.

- Compute QC parameters.

- NODDING observations:

- Load the input raw frames in an image list.
- Apply the dark and flat calibrations to the image list.
- Split the full list into listA and listB image lists for the frames taken at nodding positions A and B, respectively.
- Compute differences diffA=listA-listB and diffB=listB-listA.
- Combine separately diffA and diffB into outputs:
    - combined[a|b] 2D spectrum where the targets are aligned for nodding positions A and B, respectively.
- Load the input trace wave.
- Compute the slit fractions for A and B by using the nodthrow information in the header and the assumption that A and B are at equal distances from the slit centre.
- Compute two new trace_wave files with these slit fractions from the previous step.
- Extract the spectra for A and for B and generate:
    - extracted[a|b] 1D spectra, order by order and merged IDP.
    - spatial slit profiles slit_func[a|b]
    - 2D model spectra model_master[a|b]
    - FITS tables with order tracing, slit shape parametrizations and wavelength calibrations trace_wave[a|b]
- Compute QC parameters.

In case of odd number of nodding mode input files, the pipeline rejects the last one and processes all others. Nodding with one input frame always fails.

Master Calibrations used for data reduction. Master calibrations used in this release are listed in Table 2. Their detailed description can be found in Sect. 7 of the Pipeline User Manual for the description of calibration data.

Wavelength scale. The CRIRES+ Echelle products have a topocentric wavelength scale; no corrections for barycentric or heliocentric motion have been applied, but the pipeline calculates and stores them in the header (HIERARCH.ESO.QC.VRAD.BARYCOR and ...HELICOR, in km/s). The wavelength scale refers to vacuum.

Table 2. Set of master calibrations used for data reduction.

Type* (pro.catg)	Name (first part)	Mandatory** or optional	Content
CAL_DETLIN_COEFFS	CR_PDCO	optional (but always provided)	detector non-linearity, based on darks and flats of different setups to cover the entire detector
CAL_DARK_BPM	CR_PBPD	mandatory	master dark, removes dark level and dark structure
CAL_FLAT_MASTER	CR_PFLT	mandatory	master spectroscopic flat
CAL_FLAT_EXTRACT_1D	CR_PFLE	mandatory	blaze function
CAL_WAVE_TW	CR_PDTW	mandatory	trace wave table with OBJECT=”WAVE,FPET”
PHOT_FLUX	CR_GPHF	mandatory	static response curve

** Mandatory means, that if the particular calibration is missing, the pipeline would always fail.

Master calibration names and recipe parameters used for reduction. The product header contains a list of all used master calibrations, look for keys “HIERARCH ESO PRO REC1 CAL<n> NAME” and “... CATG”, with the index n. The pipeline parameters and their values are listed as “HIERARCH ESO PRO REC1 PARAM<n> NAME” and “... VALUE”. Note that CRIRES+ master calibrations acquired and processed from early 2025 on will be archived with the different naming scheme than before.

Products. The CRIRES+ pipeline science recipes create several intermediate and final product files. The final product in the NODDING spectroscopic data format combines information from the following products: the final product with PRO.CATG=OBS_NODDING_EXTRACT**C**_IDP is the combined (by adding) spectrum of the two intermediate products with PRO.CATG=OBS_NODDING_EXTRACT**A**_IDP and OBS_NODDING_EXTRACT**B**_IDP corresponding to nodding positions A and B, respectively. In STARE mode, the final product with PRO.CATG is OBS_STARING_IDP. For a summary of some header parameters in the product files see Table 3.

Rejected or failed processing. Under the following conditions the pipeline processing always fails, and no data products exist[11]:

- NODDING data sets with only one input file.
- No master calibrations are available.
- No object spectrum is identified.
- The NODTHROW is larger than 10 arcsec.

The possible reasons for the creation of such data sets could be, respectively:

- Aborted templates (then the data are likely to be useless).
- Failure to execute the calibration plan (see Table 4 for a short summary), usually for operational reasons.
- Target drifting off the slit.
- User or operator error.

Note that only in very rare cases a product that was successfully created by the pipeline has been rejected. Even in case of heavy saturation we deliver the product to the ESO Science Archive, because the saturated pixels are marked in the QUAL column, and the unsaturated regions might still be useful. Also, products with large regions of negative flux have not been rejected, because for example isolated emission lines can still be seen in such spectra. Instead, the QCFLAGs have been set accordingly (see Section 'Data Quality').

Table *3*. Observation block (OB) related information in the product headers.

Parameter	Values	Meaning
OB related information:		
SM_VM	SM or VM	Data taken in Service Mode (SM) or Visitor Mode (VM); VM data are less constrained in terms of OB properties, have no user constraints defined and therefore no grades (formally they are always graded X meaning 'unknown').
OB_GRADE	A/B/C/D; X	Immediate grade given by the instrument operator, considering ambient conditions checked against user constraints.
OB_COMMENTS	Free text	Any optional comments added by the night astronomer, together with the *approximate* UT hh:mm (truncated after 200 characters). An OBs might have been executed several times during the night, with or without comments. In those cases, the user should carefully check that the listed comment applies to the spectrum with the closest *earlier* timestamp.
QC related information:		
QCFLAG	e.g. 01010	QC flag composed of 5 bits, see the Data Quality section below.
QC_COMMENT	Free text	Automatically added comment if a quality issue is discovered by the processing system (there are no human-provided comments).

[11] Such data could probably be processed interactively, e.g. with *Reflex*.

Table *4*. Changes of the CRIRES+ Calibration Plan.

Period	Notes:
2021-10-01 – 2022-01-01	The UNE and FPET wavelength calibration frames come from different templates (e,g, they have TPL.START).
2022-01-01 – 2022-03-31	The UNE and FPET wavelength calibration frames come from a common template (e,g, they have the same TPL.START).
2022-04-01 – present	New association rules for DARK master calibrations.

Data Quality

The data quality of various products is described in this section.

Master calibrations. All master calibrations have been quality-reviewed and certified at the time of acquisition, as part of the closed QC loop with the Paranal Observatory. This includes monitoring of the long-term trending[12]. The most important parameters for the quality of the data products are the signal-to-noise (hereafter, SNR) of the master flats, and the rms of the wavelength dispersion solutions. The former was always high enough to be dominated by the fixed-pattern (gain) noise, to avoid compromising the SNR of the science data.

SNR evaluation: per trace, take the median of the SPEC column, divide it by the median of the corresponding ERR column to obtain SNR for that trace; take the median of all valid values from all orders across all detectors to obtain an estimate for the entire spectrum.

QC.SIGNAL (STARE) and **QC.SIGNAL.AVG** (NODDING) evaluation: in STARE take the median flux of the 4th order 1st trace from the SPEC column of the extracted spectra; in NODDING mode do the same separately for A and B frames and then average the results.

Science products. There was some internal quality control on the pipeline processing of the science data, monitoring:

- the quality of the associations of calibration data (e.g., checking that the master calibrations were taken no more than a few days away from the science data);
- score flags for various properties of the products, e.g. the number of saturated pixels;
- on-demand QC reports and quick-look overviews for more in-depth assessment.

This information has largely been used to improve and fine-tune the reduction process. An individual one-by-one inspection of all products is not done.

Quality flags. Quality information on the product spectrum is provided in terms of the 5-bit quality control flag (set to '00000' if there are no problems):

- **Extraction flag:** evaluates if structural differences exist between the A and B spectra in nodding mode observations; it calculates fluxdiff = abs((fluxA - fluxB * medA/medB) / medC) and if it is >1000 for one or more orders could, it is flagged with '1';
- **SNR ratio flag:** if SNR in any order or detector is negative, it is flagged with '1';
- **Saturation flag**: in case the pipeline reports more than 400 saturated wavelength bins, it is flagged with '1';
- **ArB flag:** if in nodding mode the flux ratio between the 1D spectra at nodding A and the nodding B is less than 0.5 or more then 1/0.5 in any detector or order, it is flagged with '1'; in stare mode it is always '0';
- **Negative flag:** if the number of wavelength bins with negative flux exceeds 80 in any order or detector, it is flagged with '1'.
- These five flags are stored e.g. as **QCFLAG 00101** in the primary header of the primary product.

Previews. Two ancillary files with static plots, originally developed as quick-look quality control tools, are included, because they allow the archive user to preview the spectra (see Figs. 1-4).

[12] For more information check under the CRIRES+ link at http://www.eso.org/qc/ALL/daily_qc1.html.

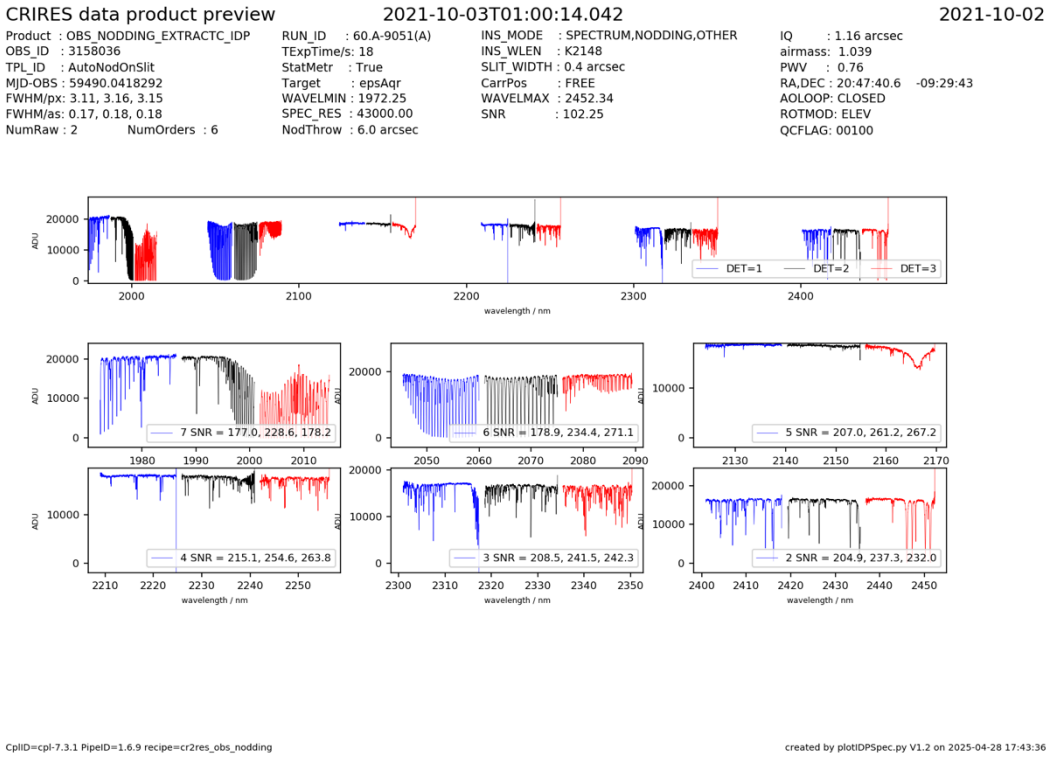

Figure 1. Ancillary preview plot. *On the top:* the left title column lists several header keyword values, the mean FWHM per detector in pixel and in arcsec, the number of raw input frames and the number of orders with signal. The second column shows among others the metrology status, the minimum wavelength in nm, the spectral resolution and the nod throw in case of nodding observations. The next column lists instrumental setup parameters, the maximum wavelength and the average SNR ratio. The right column shows ambient conditions and the five-bit long quality control flag. *Plot panels:* The upper plot box shows the entire final spectrum. The left detector (DET 1) is in blue; the middle detector (DET 2) is in black, and the right detector (DET 3) is in red. This K-band set up has large gaps between the orders; other setups may have overlaps instead (e.g., in Y-band, see Fig. 3). Note the small additional gaps between the detectors within the same order—they originate from the spatial gaps between the chips. The bottom two rows of panels zoom-in on each spectral order (labelled with the order number and SNR ratio per detector)—there are six orders in K-band and nine in Y-band, so in the latter case there will be a third row of panels (see Fig. 3 for an example).

Quality control of products. The quality of the reduction is monitored with quality control (QC) parameters calculated by the pipeline that are stored in header keywords of the science products. These parameters are extracted from the headers and are stored in a database that is publicly accessible through a browser[13] and includes a plotter[14] interface.

[13] http://archive.eso.org/qc1/qc1_cgi?action=qc1_browse_table&table=criresp_science_idp
[14] http://archive.eso.org/qc1/qc1_cgi?action=qc1_plot_table&table=criresp_science_idp

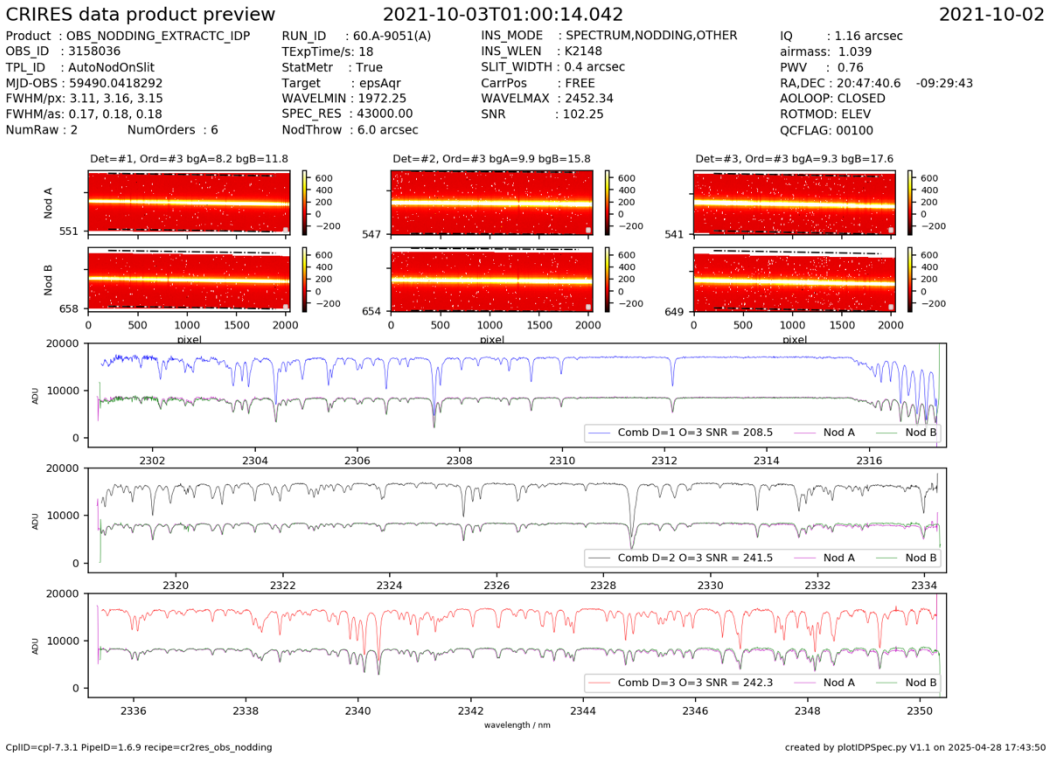

Figure 2. Ancillary preview plot for order only for #5 of the observation in Fig. 1. It follows similar structure, except the upper panels shows the nodding A and nodding B of the 2D spectra of this order for the three detectors (D=1..3); the colour bars indicate the count levels in ADUs. The lower panels show the extracted 1D spectra for a given order on the three detectors (D=1..3, top to bottom) for nodding A, nodding B and the combined final spectrum from the two noddings added together. The legend shows the pipeline reported SNR.

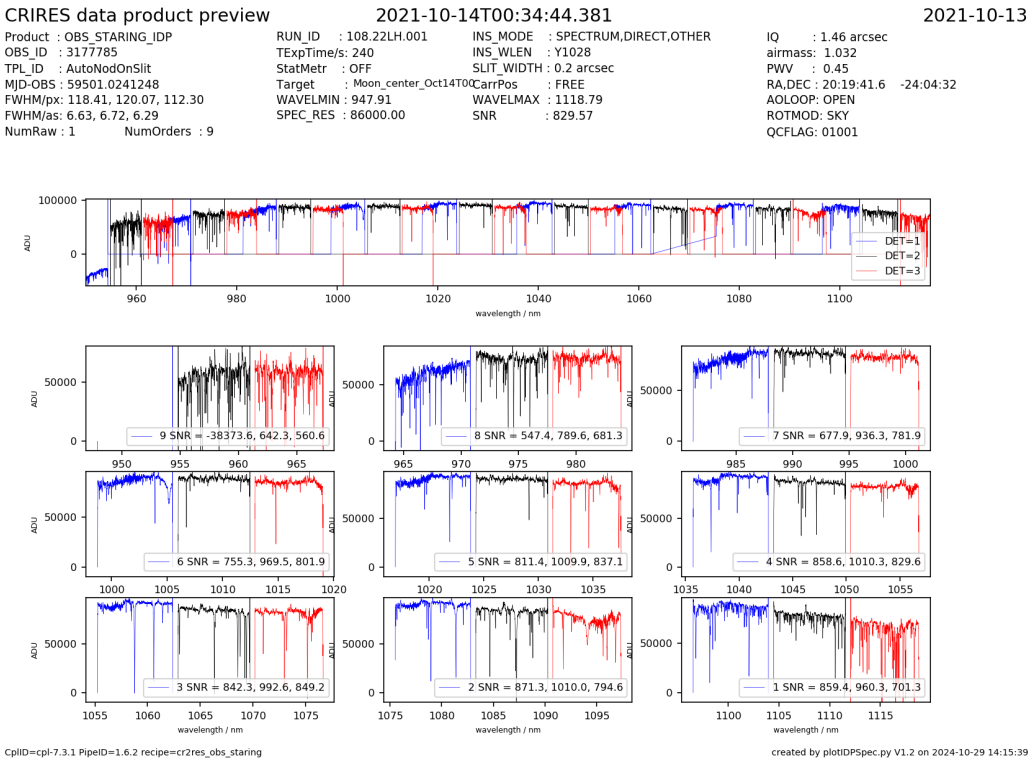

Figure 3. The same as Fig. 1 for a solar spectrum, acquired in STARE mode, pointing the telescope at the moon centre. The

set up is Y1028 grating and 0.2 arcsec slit. It features nine orders, hence the three rows of panels. Note the overlap between some orders on the topmost panel.

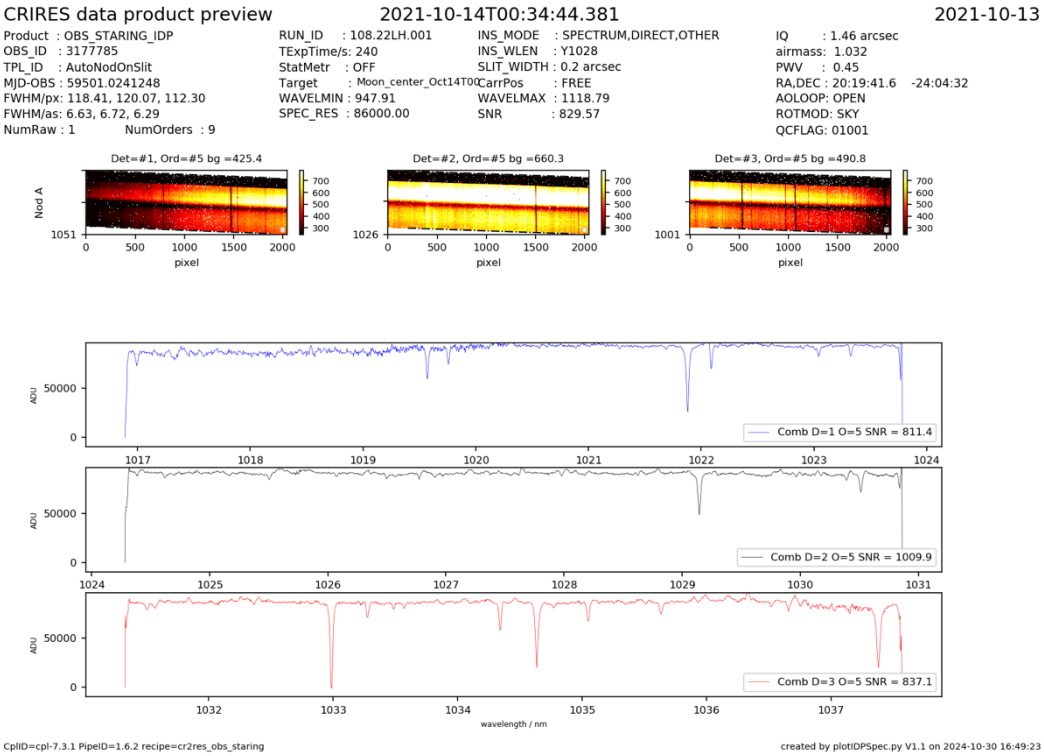

Figure 4. The same as Fig. 2, but for the STARE mode spectrum shown in Fig. 3.

Known issues and features

The list below will evolve with time. Please also check Sections 7 and 8 of the Pipeline User Manual and the CRIRES+ Reflex Tutorial[15]. Further information can be found in the data reduction FAQ page[16]. Finally, the CRIERS+ new page[17] contains the most up to date information about instrument changes.

Issues

Underestimation of the pipeline errors. Studies of the pipeline products indicated that the derived errors are probably underestimated by about a factor of two with respect to the actual measured noise. An empirically derived correction was applied only to the error columns of the IDP products (*EXTRACTA_IDP.fits, *EXTRACTB_IDP.fits *EXTRACTC_IDP.fits). Other products were not corrected, so the users could fall back to the original errors, if preferred. This correction is good to within 15-20% for median flux levels up to 25,000 ADU on an individual spectrum but it still yields optimistic results for larger fluxes (it is more realistic than using errors without correction). For more reliable results the users are advised to measure the noise in the vicinity of the features of their interest.

Partial saturation of some IDP spectra. The saturation level on all three CRIRES+ detectors is about 37000 ADU per pixel. For some raw data this level is exceeded, often during observations of blue standards (e.g. white dwarfs). Nevertheless, such data sets were included in the collection,

[15] https://www.eso.org/sci/software/pipe_aem_table.html (go to 'CRIRES+ Reflex Tutorial').

[16] Go to the CRIRES+ section of http://www.eso.org/sci/data-processing/faq.html.

[17] https://www.eso.org/sci/facilities/paranal/instruments/crires/news.html

because at least part of the spectra can be scientifically useful.

Classification of standard stars. Currently, the types of standard stars in this release cannot be unequivocally identified by DPR.TYPE keyword saved in their headers. Instead, a combination of INS.SLIT1.NAME and INS1.OPTI1.NAME must be considered. The archive users should also pay attention to the time of the observation and the airmass (for telluric standards).

Residuals from the blaze function correction. The data were processed with a master calibration with PRO.CATG=CAL_FLAT_EXTRACT_1D to remove the blaze function per order. Nevertheless, the product may still show jumps between neighboring pieces of spectra, especially near the edges of the wavelength coverage (e.g., the bluest piece in Fig.3).

Features

Gaps between spectral orders. Two settings—Y1028 and Y1029, due to their lower dispersion—produce a wider wavelength coverage, so the spectral orders overlap and can be merged into a single spectrum (except for the small gaps between adjacent detectors). This is obvious in the upper boxes in Figs. 1 and 3 are compared. In all other set-ups the users must observe their targets with two complementary set-ups to fill the inter-order gaps. The pipeline provides a recipe to do this (`cr2res_util_splice`; see the Pipeline User Manual for details).

File Types

The primary CRIRES+ echelle product is a 1D spectrum, in binary FITS table spectroscopic data format. The FITS file product naming scheme for primary and ancillary products is described in Table 5. The static inspection images are named with time stamps as follows: r.CRIRES.*yyy-mm-dd*T*hh:mm:ss.sss*_tpl_0000 _X10.png or r.CRIRES.*yyyy-mm-dd*T*hh:mm:ss.sss*_tpl_0000_X5.png – the former shows all orders and the latter only order number 5 (see for examples Figs. 1-4).

Table 5. Product naming scheme.

ORIGFILE names starting with	Product category HIERARCH.ESO.PRO.CATG	Description
Stare mode observations		
CR_SOSE	OBS_STARING_IDP	1D IDP spectrum
CR_PSED	OBS_STARING_EXTRACT	1D order-by-order spectrum
CR_SPCD	OBS_STARING_COMBINED	2D combined spectrum
CR_PDTW	CAL_WAVE_TW	trace wave table
CR_PSFD	OBS_STARING_SLITFUNC	pipeline slit function
Nodding mode observations		
CR_SONE	OBS_NODDING_EXTRACTC_IDP	1D IDP spectrum
CR_PSEA, CR_PSEB, CR_PSEC	OBS_NODDING_EXTRACTA, OBS_NODDING_EXTRACTB, OBS_NODDING_EXTRACT_COMB	1D order-by-order spectra for noddings A, B and both combined (by adding)
CR_PSCA, CR_PSCB	OBS_NODDING_COMBINEDA, OBS_NODDING_COMBINEDB	2D combined spectrum for noddings A and B
CR_PSTA, CR_PSTB	OBS_NODDING_TWA, OBS_NODDING_TWB	trace wave tables for noddings A and B
CR_PSFA, CR_PSFB	OBS_NODDING_SLITFUNCA, OBS_NODDING_SLITFUNCB	pipeline slit functions for noddings A and B

The components of the naming convention of the ORIGFILE product name: e.g. CR_SONE_3662348_2024-07-09T23:33:54.611_320_Y1029_02.fits (Table 6).
The same schema is also used for the standard star spectra. Their RUN_ID is 60.A-9051(A), if they are provided by the observatory as part of the regular calibration plan. User defined standard stars (e.g., observed in visitor mode) use the RUN_ID specific to the observing program in the header. Observatory provided standard stars can be identified via OBJECT=STD or PRO.SCIENCE=F (F=false, and T for true for science observations).
The user may want to read the ORIGFILE header key and rename the archive-delivered FITS files.

Table 6. Product naming scheme components.

ORIGFILE component	CR	SONE, SOSE	3662348	2024-07-09T23:33:54.611	320_Y1029_02
refers to …	CRIRES+	SONE=SCI_OBS_NOD_EXTRACT SOSE=SCI_OBS_STARE_EXTRACT	OB ID	timestamp of first raw sci. or std. file in the data set	setup string: DET.SEQ1.DIT+'_'+INS.WLEN.ID+'_'+INS.SLIT.ID

File structure

The primary CRIRES+ product CR_SONE for nodding and CR_SOSE for staring comes as binary FITS table with multi-column format. The columns' contents are explained in Table 7.

Table 7. Internal structure of the CRIRES+ spectrum.

column	label	content
#1	WAVE	wavelength in air [nm]
#2	FLUX	extracted, wavelength-calibrated, sky-subtracted, SCIENCE signal [ADU]
#3	ERR	error of FLUX [ADU]
#4	QUAL	quality flag per wavelength bin, pipeline propagated throughout the reduction.
#5	ORDER	[Nb Order] number of the spectral order
#6	TRACE	[Nb Trace] number of the trace
#7	DETEC	[Nb Detector] number of the detector, one of the three
#8	XPOS	position on the detector [pixels]

File Size

The (unbinned) CRIRES+ product (PRO.CATG=OBS_NODDING_EXTRACTC_IDP) has about 2.4 MB of size. Files are always uncompressed.

Acknowledgment text

According to the ESO data access policy, all users of ESO data are required toa cknowledge 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:

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