ESO Phase 3 NIRPS Data Release Description

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Abstract

This is the release of reduced spectra from the high-resolution near-infrared spectrograph NIRPS (Near Infra-Red Planet Searcher)[1] in operation at the ESO La Silla 3.6m telescope. The spectrograph offers a wavelength range from 970 to 1850 nm. The spectral resolution depends on the instrument mode. The median resolving power is 82000 in HA (High Accuracy) mode and 75000 in HE (High Efficiency) mode. The spectrograph is fed with two fibres. One fibre (fibre A) is placed on the object. The second fibre (fibre B) can be used to either measure the sky background or to simultaneously collect light from a reference calibration source. A Fabry-Perot (FP) cavity is the operationally used simultaneous reference which allows to measure the instrumental drift between the night-time observation and the daytime wavelength calibration. The reader is referred to the NIRPS user manual[2] for details about the instrument and the data acquisition strategy.

This release is an open stream release. It is complete from start of operations on 1st April 2023 to date. Data content is not fixed but grows with time as new data is acquired and processed. The release covers practically all NIRPS science data in both HA and HE modes. All data have been reduced automatically using the Data Reduction Software (DRS) pipeline version 3.2.6 or higher developed by the NIRPS Consortium and made publicly available to the community (see NIRPS pipeline User Manual - NIRPS-4500-GEN-DER-2113) as per ESO agreement.

The reduction includes extraction of the spectrum, flat fielding, wavelength calibration, flux calibration and telluric correction. In addition, sky subtraction is performed if fibre B is placed on sky. A cross correlation with a stellar reference mask is executed in order to calculate the radial velocity (RV) of the observed object. Please note that systematic shifts of the RV values can occur between different versions of the pipeline. It is highly recommended to use only products from the same pipeline version for RV studies. The NIRPS pipeline extracts a spectrum from each single exposure.

Release Content

The data frames are tagged "NIRPS" in the ESO archive user interface[4]. The release contains science data from all NIRPS instrument modes and set-ups since the beginning of the instrument operations in April 2023.

The only two aspects in which user can set up NIRPS to achieve a science objective are:

- selection of the instrument mode (HA or HE), defining simultaneously spectral resolution
- selection of the source to illuminate the reference fibre (Sky or simultaneous calibration sources)

[1] https://www.eso.org/sci/facilities/lasilla/instruments/nirps.html
[2] https://www.eso.org/sci/facilities/lasilla/instruments/NIRPS/doc/manuals/NIRPS-2000-GEN-UM-148-2.3_User_Manual.pdf
[3] https://www.eso.org/sci/software/pipelines/nirps
[4] https://archive.eso.org/scienceportal/home?data_collection=NIRPS

Data from all instrumental modes are processed. Processing of NIRPS science data is based on single exposures: every science exposure is pipeline-processed and results in an extracted, flux-calibrated spectrum and a number of additional products described later.

Data contained in this release are selected based on the following rules:

- Instrument (INSTRUME)= NIRPS
- Data product category (PRODCATG) = SCIENCE.SPECTRUM
- Technique for observation (OBSTECH) = ECHELLE
- Category of raw frame (PRO.REC1.RAW1.CATG) = OBJ_SKY or OBJ_FP.

Processing of the NIRPS science data has a success rate of nearly 100%, only very few input raw files are rejected. No selection is made on the basis of the observing mode (visitor or service).

Normally, the data is subject to the standard one-year proprietary policy. In the case of GTO data, the extracted barycentric (BERV) corrected 1-dimension spectra will be delivered after the one-year exclusivity period with a random radial velocity shift of up to 100 m/s (0.0004 nm @ 1.2 micron). The file name contains the string 'S1D_FINAL_TRUNCATED_WAVE_A.fits' and no additional associated files will be available. The extracted, BERV corrected and telluric-free 1-dimension spectra with precise wavelength (S1D_FINAL), together with the extracted 2-dimension spectra (S2D), the extracted telluric-free spectra (S2D_TELL_CORR), and the Cross-Correlation (CCF) FITS files including the precise radial velocity will be provided after the two-year exclusivity period. Considering that the source code of the NIRPS DRS is publicly available[5], the raw frames (pixels and fits headers) are also protected for an exclusivity period of 2 years in order to protect radial velocities. This also extends to the associated HARPS raw (pixel and fits headers) data.

HELIOS (HARPS Experiment for Light Integrated Over the Sun) data are not part of the NIRPS collection, but are offered via the dedicated HELIOS collection.

Release Notes

Simultaneous observations with HARPS

NIRPS can be used alone or simultaneously with HARPS. The FITS keyword TPL.ID (template signature ID) tells whether a HARPS file is associated with a NIRPS file (e.g. NIRPS_gen_obs_HARPS_HAM) and OBS.ID gives the same ID for both the NIRPS and the HARPS data files.

Data Reduction and Calibration

A detailed description of the NIRPS pipeline can be found in the pipeline user manual which is available from the ESO pipeline web pages. The initially released data set was processed with version 3.2.6 of the pipeline. The actual version used for processing can be found in the header of any product in the keyword "PROCSOFT".

Data reduction includes preprocessing, dark current subtraction, spectrum extraction, flat fielding, correction for the Echelle blaze function, wavelength calibration, drift correction if FP on fibre B, merging of Echelle orders, flux calibration and telluric correction. Below the individual reduction steps are described in detail.

Wavelength calibrations. Wavelength calibration is achieved in two steps. The Fabry-Perot (FP) light source provides a high number of evenly distributed lines for an accurate relative wavelength calibration. The absolute wavelengths are determined by an exposure with a Uranium-Neon (UNe) hollow-cathode

[5] https://www.eso.org/sci/software/pipelines/nirps/nirps-pipe-recipes.html

lamp. NIRPS is expected to be soon equipped with a laser frequency comb (LFC) which can be used alternatively to the UNe lamp together with FP. However, only UNe and FP exposures are taken for the wavelength calibration in this release. Wavelengths in the "WAVE" extension of the output products are expressed in vacuum.

Barycentric correction. The wavelengths in the science spectrum are corrected to the barycentre of the solar system. The Barycentric Earth Radial Velocity is computed using the target coordinates and proper motions from P2 and it is stored in the header in the header keyword QC BERV. Users must take care to enter the precise coordinates, epoch, equinox and proper motions of their targets (1 arcsec error can introduce 10 cm/s offset).

Correction for instrumental drift. The NIRPS spectrograph is fed with two fibres simultaneously. Fibre A is placed on the scientific object. Fibre B can be used to record the sky or the FP source during the science exposure. In the latter case the instrumental drift between the science observation and the daytime wavelength calibration is calculated and corrected for in the wavelength solution. When fibre B is on sky, the use of the FP is not advised, as the measured drift is less precise due to modal noise than the instrumental stability. In addition, having the SKY on fiber B allows the pipeline to correct for OH emission lines contamination.

Contamination induced by the FP. When fibre B is used to measure the FP light, the strong FP lines can contaminate the detector at the position of fibre A. This effect is measured with dedicated calibration frames and has been monitored since the start of operation. The monitoring indicates that the FP does not lead to a measurable contamination, correction of it is, therefore, not applied in the data reduction for this release.

Cleaning of cosmic ray hits. Cosmic ray hits are cleaned from the 2D science frame using histogram threshold.

Spectrum extraction. The spectra are extracted with an optimal extraction algorithm using cross-dispersion order profiles that are obtained from the spectral flat fields.

Flux calibration. Extracted spectra are always flux calibrated by the pipeline. According to the NIRPS calibration plan, spectroscopic flux standards are observed during technical nights. Exact measurements of the actual atmospheric conditions on a specific night are, therefore, not available. For this release, sets of standard stars have been identified that are representative for a given time period. All science observations from such a period have then been calibrated with the same set.

Telluric correction. The extracted spectra are telluric corrected on order-by-order basis with forward radiative transfer modeling assuming a singlepheric layer and a line list from the HITRAN database. A subset of selected telluric lines is used to robustly fit the spectrum through a Levenberg-Marquardt minimization algorithm. A detailed description of the technique is available in Allart et al. (2022, A&A, 26, 666). The results from the telluric correction are stored in the header in "HIERARCH ESO QC TELL XXX", where XXX stands in for a designation of a given molecule absorber. A pre-telluric correction spectrum is also available among the data products, so the users can apply alternative methods to carry out the telluric absorption removal.

Radial velocity calculation. The NIRPS science recipe computes the cross-correlation function (CCF) of the extracted spectrum in wavelength-order space with respect to a binary template of a given spectral type. The radial velocity (RV) is then obtained from a Gaussian fit to the CCF. Template masks for G-, K-, and M-type stars are available within the pipeline. The results are written into the "HIERARCH ESO QC CCF *" header keywords of the output products; the measured RV value can be found in "HIERARCH ESO QC CCF RV", the corresponding error in "HIERARCH ESO QC CCF RV ERROR", and the used mask in "HIERARCH ESO QC CCF MASK". This information is available only in the header of the downloaded data, and not available via header display services.

The value computed by the pipeline also depends on the accuracy of the parameters defined by the user who prepared the observations. In particular, the mask and the coordinates and proper motion. If in the archive there are two spectra of the same object by two different programs,

different PIs might have entered different parameters which might give a RV offset. Therefore, when working with RV time series, one has to be sure all data are obtained with the same assumptions.
All these parameters are recorded in the FITS header under the following keywords:

```
HIERARCH ESO OCS TARG SPTYPE
HIERARCH ESO TEL TARG PMA
HIERARCH ESO TEL TARG PMD
HIERARCH ESO TEL TARG RADVEL
HIERARCH ESO TEL TARG ALPHA
HIERARCH ESO TEL TARG COORDTYPE
HIERARCH ESO TEL TARG DELTA
HIERARCH ESO TEL TARG EPOCH
HIERARCH ESO TEL TARG EPOCHSYSTEM

HIERARCH ESO TEL TARG EQUINOX
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Calibrations used for data reduction. Table 1 lists the required calibration types that are needed for the reduction of science data. Please check the pipeline user manual for further details.

Table 1. NIRPS calibrations

Type	Purpose
DARK	Hot pixel map and Master Dark (Static product)
LED	Detector flat-field for Bad pixel map (Static product)
Order definition flat	Defines the position of the orders on the detector
(Spectral) flat field	Orders profile, spectral flat field and blaze
Wavelength calibration (UNe + FP)	Wavelength solution. Calibration with FP-FP, UNe-FP and FP-UNe are used for the product
Contamination	Measures the contamination from the FP source on fibre B. Not used for data reduction in this release
Sky-Sky flat	Give the relative efficiency of fibre B with respect to fibre A. Not used for data reduction in this release
Standard Photometric stars	Absolute flux calibration
Standard telluric stars	Used for static product and available for users

All calibrations used in this release have been processed with pipeline version 3.2.6 or higher. Calibration and science data for NIRPS are always processed with the same pipeline version.

The pipeline will always use the calibrations closest in time which passed the QC and acquired before the science spectra.

Data Quality

Static calibrations. All used static calibrations have been quality-reviewed and certified at the time of acquisition.

QC flag. Each pipeline product is quality checked and contains QC flag (e.g. QC.SCIRED.CHECK for science exposures) indicating good quality (1) or bad quality (0). Only the products with QC=1 should be used for reduction.

Known Features and Issues

Dependency of RV values on pipeline version. Changes of the algorithms in various parts of the pipeline can result in shifts of the calculated RV values from one pipeline version to another. It must be checked that all observations that are used have been reduced with the same pipeline version. All science products that are provided in this release have been processed with the same pipeline version as the master calibrations. This ensures internal consistency of the release. For future additions to this release, different pipeline versions than in the initial release may be used. The consistency between science products and master calibrations will, however, be kept. The user is advised to check the actual pipeline version, that is recorded in the "PRO.REC1.PIPE.ID" header keyword, before comparing RV values.

Data Format

File Types

The data set for each observation consists of one primary product file (S1D_FINAL) and several ancillary fits files. The number of ancillary files depends on the source for fibre B (FP or sky) and whether or not cross correlation was performed. The primary NIRPS science data product is a 1D spectrum with merged Echelle orders. The file has one FITS table extension. The table columns contain the wavelength array, the extracted flux, the error of the flux, and some additional quantities listed in Table 2.

Table 2. Table columns of primary product file S1D_FINAL

Column	Unit	Description
WAVE	Å	Wavelength (in vacuum)
FLUX	erg/cm²/s/Å	Extracted flux including all the corrections available
ERR	erg/cm²/s/Å	Corresponding error
QUAL	None	Quality. Values above 0 may indicate issues with the data, e.g. saturation
SNR	None	Signal-to-noise ratio of the extracted spectrum
WAVE_AIR	Å	Wavelength (in air)
FLUX_EL	Count	Extracted electrons per wavelength bin, not sky-subtracted
ERR_EL	Count	Corresponding error
QUAL_EL	None	Corresponding quality
FLUX_CAL	erg/cm²/s/Å	Extracted flux, not sky-subtracted
ERR_CAL	erg/cm²/s/Å	Corresponding error
QUAL_CAL	None	Corresponding quality
FLUX_CAL_SKYSUB	erg/cm²/s/Å	Extracted flux, sky-subtracted; only present if fibre B is on sky
ERR_CAL_SKYSUB	erg/cm²/s/Å	Corresponding error
QUAL_CAL_SKYSUB	None	Corresponding quality
FLUX_EL_SKYSUB	Count	Extracted electrons per wavelength bin, sky-subtracted; only present if fibre B is on sky
ERR_EL_SKYSUB	Count	Corresponding error
QUAL_EL_SKYSUB	None	Corresponding quality
FLUX_TELL_EL	Count	Extracted electrons per wavelength bin, telluric corrected, not sky-subtracted
ERR_TELL_EL	Count	Corresponding error
QUAL_TELL_EL	None	Corresponding quality
ATM_TRANSM	None	Atmospheric transmission spectrum normalized to unity

FLUX_TELL_CAL	erg/cm²/s/Å	Extracted flux, telluric corrected, not sky-subtracted
ERR_TELL_CAL	erg/cm²/s/Å	Corresponding error
QUAL_TELL_CAL	None	Corresponding quality
FLUX_TELL_EL_SKYSUB	Count	Extracted electrons per wavelength bin, telluric corrected, sky-subtracted; only present if fibre B is on sky
ERR_TELL_EL_SKYSUB	Count	Corresponding error
QUAL_TELL_EL_SKYSUB	None	Corresponding quality
FLUX_TELL_CAL_SKYSUB	erg/cm²/s/Å	Extracted flux, telluric corrected, sky-subtracted; only present if fibre B is on sky
ERR_TELL_CAL_SKYSUB	erg/cm²/s/Å	Corresponding error
QUAL_TELL_CAL_SKYSUB	None	Corresponding quality

There are several additional files which are associated to the primary product as described in the following table:

1) the extracted spectrum of fibre B (sky spectrum or FP);
2) the cross-correlation function of fibre A for the computation of the radial velocity;
3) The drift matrix, only in case fibre B is on FP
4) a TAR file with additional pipeline products: the telluric spectra derived from the telluric correction in S2D format.

Table 3: Primary, ancillary and associated products of NIRPS spectra.

Product category PRO.CATG	Number	Primary / Ancillary / Ass. tar	Description
S1D_FINAL_A	1	Primary	Flux-calibrated co-added 1-D spectrum of the target (fibre A)
S1D_FINAL_B	1	Ancillary	Extracted co-added 1-D spectrum of fibre B
CCF_TELL_CORR_A	1	Ancillary	Cross-correlation function of fibre A after telluric correction. If not available CCF_A is provided
DRIFT_MATRIX_B	0/1	Ancillary	Drift between science exposure and wavelength-calibration, only in case of OBJ_FP
S2D_A	1	Ass. tar	Extracted spectra for each order of fibreA, not flux-calibrated, deflatted, divided by blaze function
S2D_SKYSUB_A	1	Ass.tar	Extracted spectra for each order, sky-subtracted, not flux-calibrated, deflatted, divided by the blaze function
S2D_BLAZE_A	1	Ass. tar	Extracted spectra for each order of fibre A, not flux-calibrated, deflatted, not divided by blaze function
BLAZE_A	1	Ass.tar	Blaze function
S2D_TELL_CORR_A	1	Ass. tar	Extracted spectra for each order of fibre A, not flux-calibrated, divided by blaze function, telluric corrected and sky emission lines corrected if OBJ_SKY

Acknowledgements

Publications based on data obtained with the NIRPS instrument should quote the following reference paper: Bouchy, F., Doyon, R., Artigau, E. et al., 2017, The Messenger, 169, 21.

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

According to the Data Access Policy for ESO Data held in the ESO Science Archive Facility, all users 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/92.