NIRPS User Manual

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Change Record

Issue	§	Page	Date	Observations	RIX
1.0		all	2021.09.06	First complete version including RIXs answers	
2.0		all	2021.10.18	Updated after COMM3	
2.1		all	2022.08.16	Updated after COMM5 for call for proposal	
2.2		all	2022.08.17	Last corrections for CfP P111	
2.3		all	2023.02.22	Updated version for CfP P112	

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1. GENERAL ASPECTS

1.1 Scope of the document

The NIRPS User Manual is intended to give all necessary information to potential science users of the NIRPS instrument, to help them decide on the opportunity to use the instrument for their scientific applications, to be used as a reference when writing observing proposals during phase 1 (Call for proposals) and when preparing the observations during phase 2.

For this purpose, this document provides:

- A brief description of NIRPS science drivers;
- An overall description of the NIRPS technical characteristics, its performance and its observing modes;
- Practical information on the preparation and execution of observations;
- A brief description of the NIRPS data and the NIRPS pipeline data reduction.
- The following documents are closely related to this manual and should be consulted as well:
  - the P2 User Manual
  - the NIRPS Templates Reference Manual
  - The NIRPS Pipeline User Manual

The content presented here is based on material provided by the NIRPS Consortium. Comments and suggestions are welcome and should be addressed to the NIRPS Operations team:

lasilla@eso.org

1.2 On-going upgrade of NIRPS

- The present version of the NIRPS user manual is based on the NIRPS commissionings done in Nov 2022 and Jan 2023 and reflects the performances obtained at that time. Some upgrades of the instrument will be completed during the last commissioning in March as well as during P111 ;
- The thermal stabilization of the cryostat will be reinforced.
- A laser frequency comb will be installed.

1.3 Additional information on NIRPS

Users are invited to check the following NIRPS user webpage which may include the latest updated information:

https://www.eso.org/sci/facilities/lasilla/instruments/nirps.html

ESO Support contact: lasilla@eso.org

NIRPS Support contact : nirps_support@listes.umontreal.ca

1.4 Applicable Documents

no.	document name	document number, Iss./Rev.
AD1	ESO Science Data Products Standard	ESO-044286

1.5 Reference Documents

no.	document name	document number, Iss./Rev.
RD1	NIRPS Pipeline User Manual	NIRPS-4500-GEN-UM-211_2.4.16
RD2	NIRPS Templates Reference Manual	NIRPS-4500-GEN-UM-203_1.9

1.6 Acronyms

AO	Adaptive Optics
HA	High Accuracy
HE	High Efficiency
SNR	Signal-to-Noise Ratio

2. NIRPS SCIENCE DRIVERS

NIRPS (Near-InfraRed Planet Searcher) is an instrument designed for high-resolution high-fidelity spectroscopy and high-precision radial velocities (RV) in the near-infrared (*YJH* bands) on the 3.6m ESO-La Silla telescope. Aiming to achieve a long-term radial precision of 1 m/s on M dwarfs, NIRPS is designed to find rocky planets orbiting M dwarfs and operates together with HARPS (High Accuracy Radial velocity Planet Searcher).

NIRPS has been designed to explore the exciting prospects offered by the M dwarfs, focusing on three main science cases: 1) mass and density measurements of transiting exoplanets around M dwarfs; 2) blind radial velocity survey for exoplanets orbiting M dwarfs to find golden targets for direct imaging studies to be carried out with future extreme AO imagers on ELT, 3) atmospheric characterisation of exoplanets through high-resolution transmission spectroscopy.

While the detection of an Earth analogue around a Sun-like star requires a precision of better than 10 cm/s, M dwarfs offer a more accessible and attractive means. The amplitude of the RV signal scales with $M_S^{-2/3}$, where M_S is the stellar mass. In addition, thanks to their much lower luminosity, the habitable zone of M dwarfs is typically 10 times closer than in the case of Sun-like stars. These combined effects imply that for a star of spectral type mid-M with an Earth-mass planet within Habitable Zone the RV signal is on the order of 1 m/s.

While exoplanet detection and characterisation are the main science drivers of NIRPS, a number of other significant science niches are foreseen like 1) the dynamical studies of ultra-cool dwarfs in young moving groups; 2) stellar variability studies that attempt to measure minute variations in line profiles, such as Doppler imaging of ultracool stars and brown dwarfs.

Simultaneous observations with HARPS and NIRPS will allow a better calibration of stellar activity during RV monitoring of Sun-like stars thanks to the fact that radial velocities are less affected to stellar spot variations in the nIR than in the visible. Nearby G and K stars are bright enough to allow m/s precision measurements in either the optical or near-infrared.

3. INSTRUMENT DESCRIPTION

3.1 Instrument overview

NIRPS was built by the NIRPS consortium consisting of *Université de Montréal* (UdM), *Université de Genève* (UniGe), *Instituto de Astrofisica de Canarias* (IAC), *Université Grenoble Alpes* (UGA), *Instituto de astrofisica e ciencias do espaço* (IA), *Universidade Federal do Rio Grande do Norte* (UFRN) and with substantial contribution from ESO-LaSilla and ESO-Garching.

The design of NIRPS is based on experience acquired with HARPS, ESPRESSO and SPIRou. NIRPS is a fibre-fed, high-resolution cross-dispersed echelle spectrograph operating in the near-infrared in a cryogenic vacuum tank located in the Coudé floor of the 3.6-m telescope. NIRPS is an adaptive optics (AO) fibre-fed spectrograph. The AO system leads to an efficient coupling into a 0.4-arcsecond multi-mode fibre. A 0.9-arcsecond fibre is used for fainter targets and degraded seeing conditions.

NIRPS is composed of four different subsystems: The Front-End, the Calibration Unit, the Fibre Link, the spectrograph and the detector. These are represented in Fig.1 and described in the following sections.

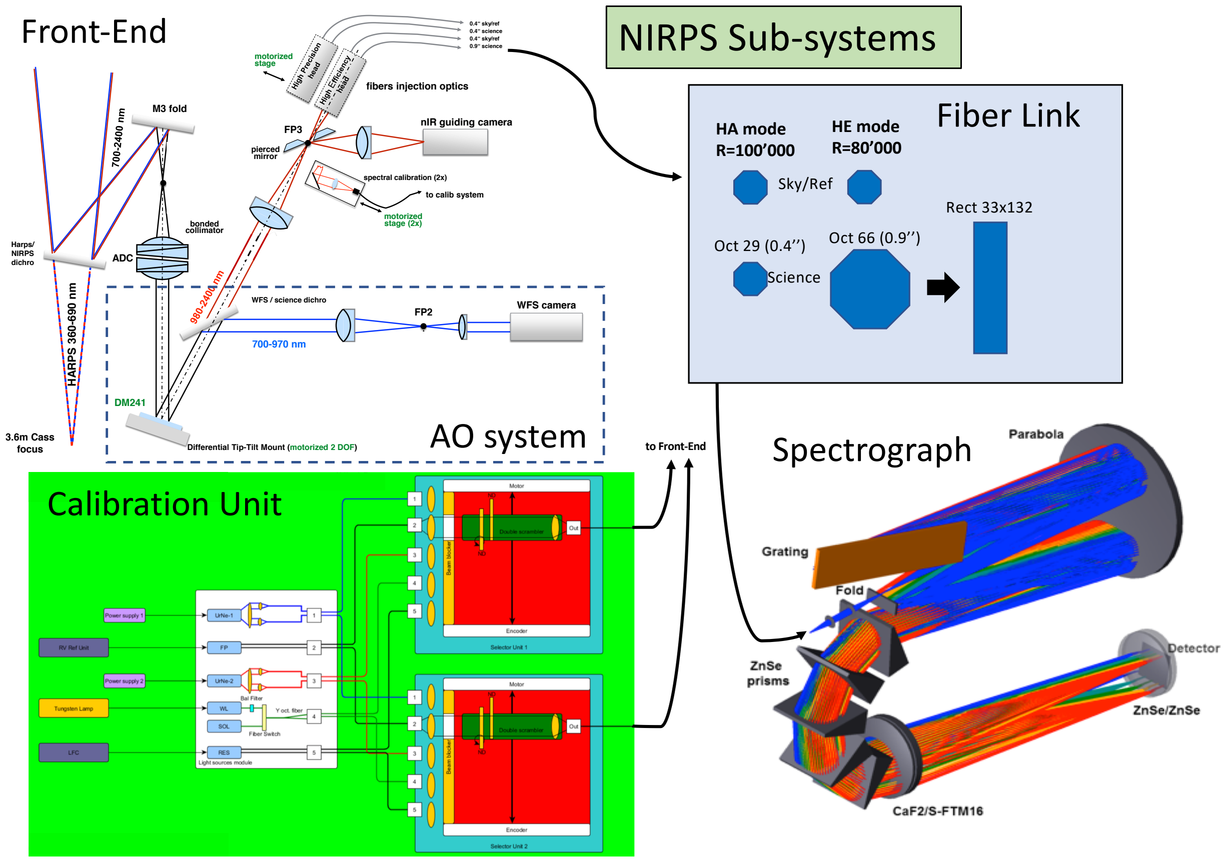

Figure 1 : NIRPS and its different subsystems: Front-End, Calibration Unit, Fiber Link and Spectrograph

Table 1 : Summary of NIRPS main properties

Subsystem	**Parameters**
HA mode	Spectral resolution $\lambda/\Delta\lambda$ = 84 000 0.4 arcsec object fibre, AO assisted feed 0.4 arcsec simultaneous reference fibre for sky or drift
HE mode	Spectral resolution $\lambda/\Delta\lambda$ = 72 000 0.9 arcsec double slicing in the pupil plane 0.4 arcsec simultaneous reference fibre for sky or drift
Environment	Vacuum : < 10^{-5} mbar Cryogenic: 80 K with 1 mK stability
Spectral domain	0.974 – 1.919 µm (*YJH* photometric bandpasses)
Calibration Sources	Uranium-Neon Hollow-Cathode lamp Stabilized etalon Fabry-Perot Laser Frequency Comb expected in 2023
Detector	Hawaii 4RG, 4k x 4k, 15 µm pixels
Limiting Magnitudes	Bright End: H = -0.5 for HE / H = 0.2 for HA Faint End: I = 14.5
Stability	< 2 m/s intrinsic stability over one night Wavelength Calibration < 0.8 m/s over 15 nights
Sampling	1.02 km/s per pixel, 3.5 pixels per FWHM in HA mode
Operation	Simultaneous operation with HARPS without degrading HARPS performance

3.2 *The Front-End*

The Front-End (FE) sub-system is composed of different sub-modules located in a base-plate bolted directly to the Cassegrain rotator of the 3.6-m telescope. The front-end uses a dichroic to extract the

700nm-2400nm band from the telescope beam, corrects for atmospheric dispersion and injects the *YJH* light into the fibre link. The visible light goes straight into the HARPS "bonnette" as it was going through the adapter before NIRPS. HARPS can be operated solo as it has been before. In that case the VIS-NIR dichroic is removed from the beam. HARPS can be also operated in parallel with NIRPS on the same target. The AO system is designed around a 14×14 Shack-Hartmann wavefront sensor (WFS) with a field stop of 6.5 arcsec on sky operating between 700 and 950 nm coupled to a 15×15 deformable mirror (DM) with a loop frequency of 250 to 1000 Hz. Two linear actuators activate the tip and tilt rotation axes of the mount on which the Deformable Mirror of the AO system is mounted. They allow for the correction of the differential tip-tilt between the HARPS optical path and NIRPS optical path. Two linear stages are used to insert the light from the spectral calibration sources in the science fibre and/or reference fibre. A linear stage allows to swap form the High Accuracy mode with 0.4" fibres to the High Efficiency mode with 0.9" fibres. A linear stage allows to change the magnification of the nIR guiding camera. The high magnification is the default mode used to guide the image on the fibre head and to perform diffraction limited imaging for the fine characterization of the AO PSF. The Front-end control cabinet is a 1400mm high liquid-cooled cabinet located on the side of the 3.6-m telescope cage.

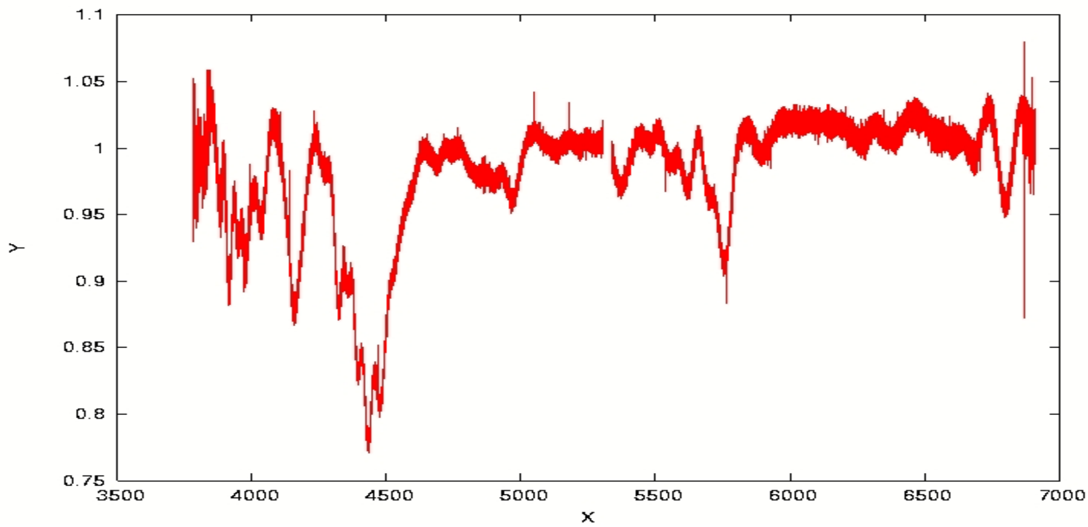

Figure 2 : Transmission of the VIS-NIRP dichroic as measured on sky on the star HR718 during COMM1

On average the transmission of the VIS-NIR dichroic is in the range 0.96 - 0.98 (specification > 0.95) and in agreement with measurement made in lab. The bluest part (including H & K Ca lines) presents a very good transmission. The most affected part if between 435 and 455 nm with a drop of about 20% of the throughput (10% in S/N). Observations which require the highest S/N in this domain must then consider to use the mode HARPS only. Furthermore, due to the non-smooth transmission of the dichroic around the Calcium H&K lines (390nm), a slightly offset of Ca H&K index could be found with the dichroic in position with respect to old adaptor.

The VIS-NIR dichroic does not affect the HARPS RV precision and does not introduce any RV offset above a level of 19 cm/s in HAM and 60 cm/s in EGGS.

The NIRPS nIR InGaAs guiding camera (FLI C-Red2) with the high magnification mode is covering a field-of-view of 18 x 22 $arcsec^2$ with a plate scale of 35 mas/pixel. The angle of North is 148.4+-3.4 degrees, with the angle measured in the TCCD from horizontal X axis to vertical Y axis counterclockwise. On figure 3, the zoom on the nIR guiding camera shows the green circle corresponding to the FoV of the WFS (± 2 arcsec), the blue circle to the size of the HA fibre (0.4 arcsec), the blue square to the area of guiding computation and the red cross to the effective guiding position. The guiding on the NIRPS fibre hole is done using the AO system. The offload of the AO tip-tilt is done at low frequency (~0.1 Hz) to the tip-tilt mount with a total excursion of ±40 arcsec. The telescope guiding is always done with the HARPS Technical Guiding camera (TCCD) covering a FoV of 77 x 77 arcsec.

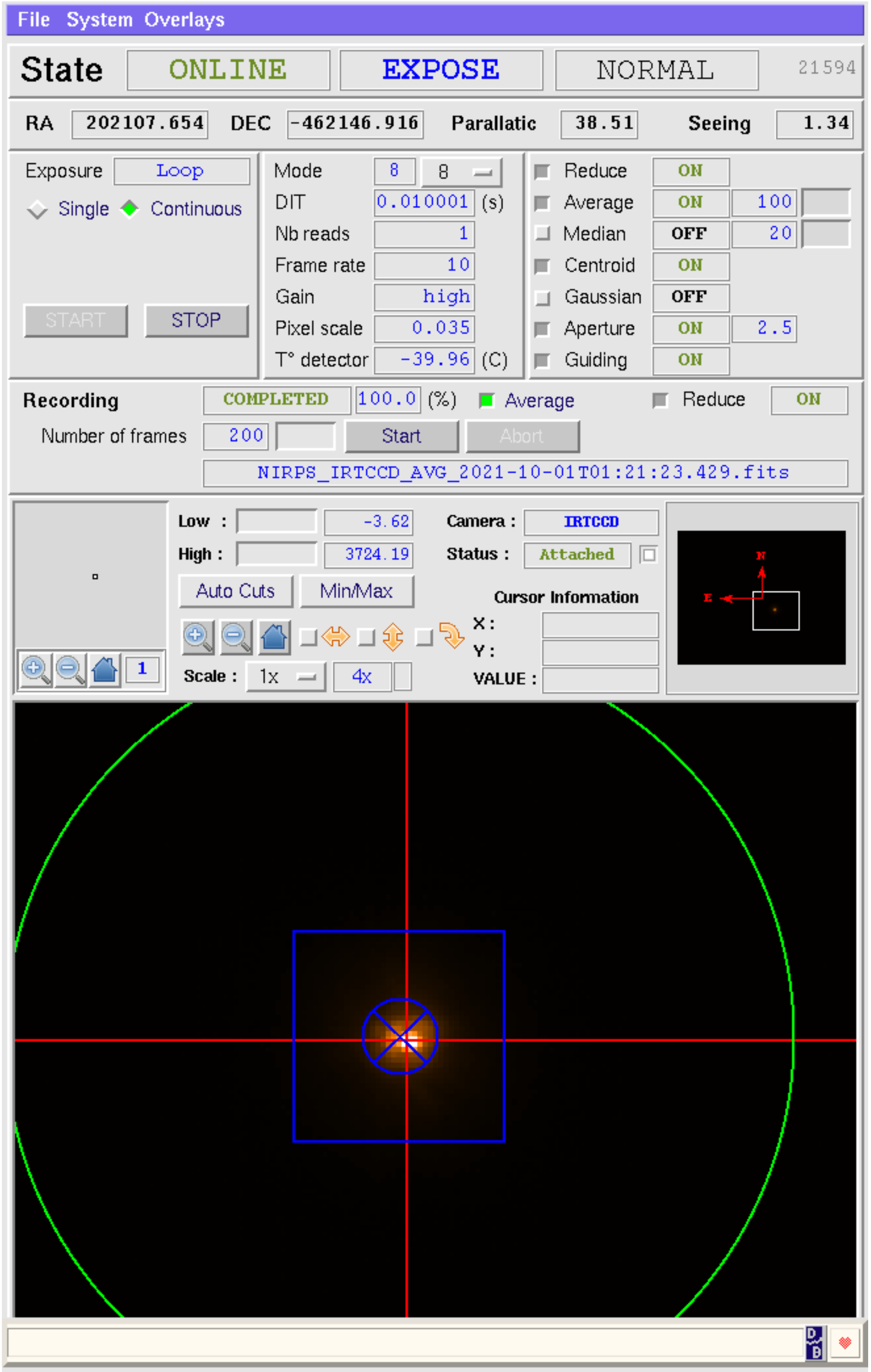

Figure 3 : Near-Infrared guiding camera window

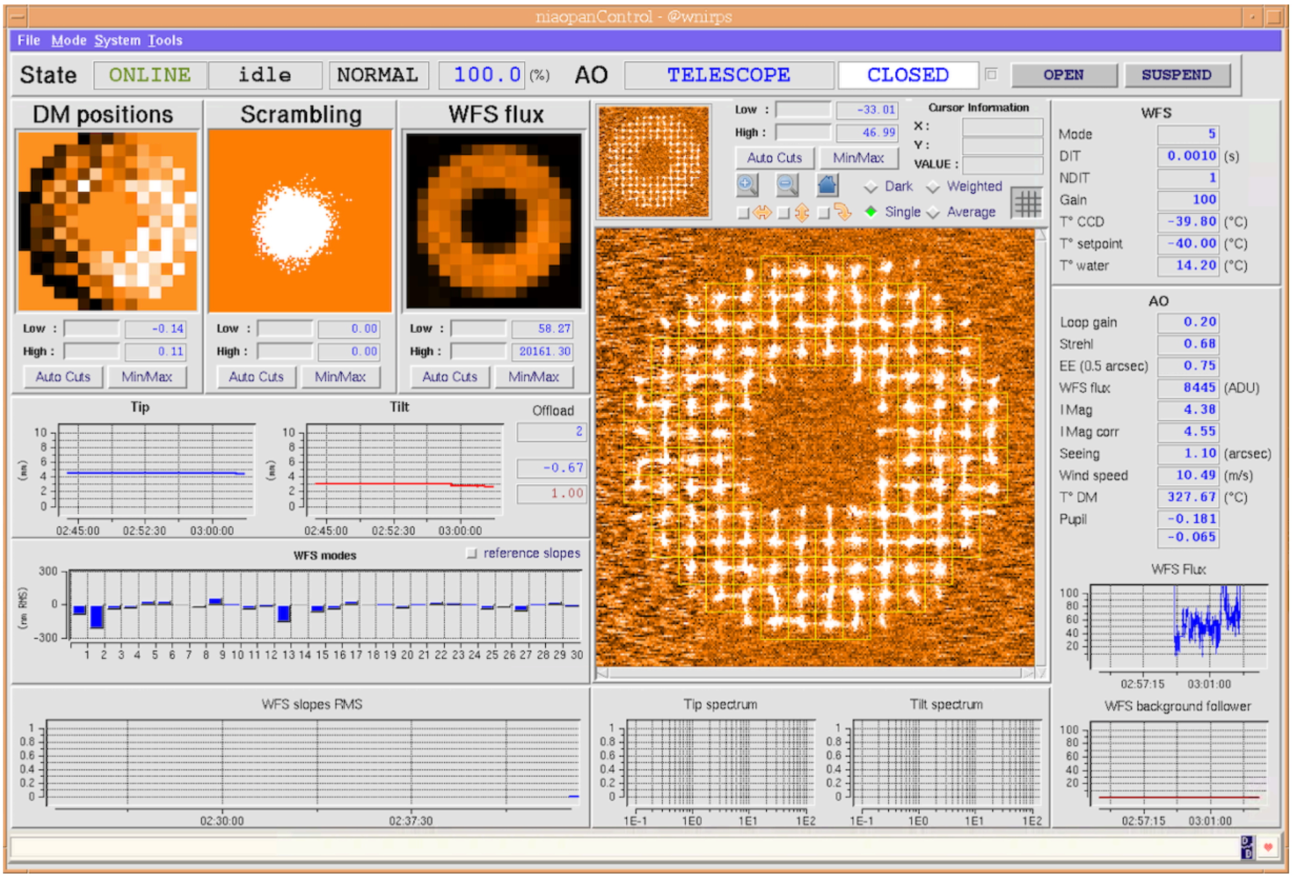

Figure 4 : NIRPS AO window

3.3 The Calibration Unit

The calibration unit includes a set of lamps and is connected to several calibration devices to properly calibrate the instrument. It contains all light sources, controllers and injection optics necessary to the NIRPS front end. The lamp/devices lights can be fed into any of the two fibres ('object' or 'reference'). This unit has its own control module for the various lamps and lasers power supplies. The whole calibration unit is composed of the following elements:

- Two selector units for each fibre.
- Two laser diodes for AO calibration.
- 2 Uranium-Neon Hollow-Cathode lamps for absolute wavelength calibration.
- 1 Tungsten lamp for order localization, profile definition, and spectral flat-field.
- 1 Fabry-Perot (FP) cavity illuminated in white light for simultaneous reference. This spectral lamp is also used in combination with the UrNe to extend and improve the wavelength calibration.
- 1 available slot for a future Laser-Frequency Comb (expected ~~early~~ 2023) to deliver the most accurate wavelength solution.

3.4 The Fibre link

The Fibre Link converts the F/10.9 beam, from the Front-End, in a F/4.2 beam and injects it into an optical fibre that is used to transport light to the spectrograph. The Fibre Link includes several provisions to scramble the light in addition to its obvious function of guiding the light from the telescope to the spectrograph through optical fibres. The purpose of the light scrambling is to stabilize the position of the photocenter of the light to a tiny fraction of the fibre diameter. The fibre head is bolted in place inside the Front-End. The fibre double-scramblers and the fibre slicer are located in a bell housing bolted to the Back-End vacuum vessel. The last leg of the fibre link from the scramblers to the spectrograph input object point is inside the vacuum vessel. The fibre stretcher for both HA and HE modes is a separate unit which mixes the modes and modulates the optical path seen by the propagation modes in order to uniformise the beam and to minimize the modal noise. The Fibre Link supports 2 observing modes: 1) The HA mode that enables to reach a spectral resolution of 84 000 with a 0.4 arcsec fibre; 2) The HE mode that uses a 0.9 arcsec fibre which is sliced in two halves at a pupil level feeding a rectangular fibre and allow to reach a spectral resolution of 72 000. Both observing modes HA and HE have a simultaneous reference fiber of 0.4 arcsec for sky or drift measurement.

3.5 The Spectrograph

The Back-End is a cross-dispersed echelle spectrograph of white-pupil type operating in quasi-Littrow conditions. It is enclosed in a cryostat, itself mounted in a vacuum vessel. The cryogenic enclosure is maintained at 80 K within 1 mK RMS thanks to two cryocoolers and maintained at a pressure < 10^{-6} mbar. No moving parts are located inside the cryogenic enclosure. All necessary moving parts are located in the NIRPS Front-End. The spectrograph vacuum vessel will be located in Coudé east room of the ESO 3.6 m Telescope. The fibre beam (29 microns/F4.2: 55 microns/F8.0) is collimated by the parabola and relayed to the echelle grating. The grating diffracts the collimated beam which is relayed back to the parabola. The parabola focuses the diffracted collimated beam to the flat mirror which folds it back to the parabola. The parabola collimates the diffracted beam to the cross disperser made of 5 refractive prisms which rotate the beam by 180 degrees. The refractive camera focuses the diffracted and cross-dispersed beam on the detector. Two fibres feed the spectrograph, one object fibre and one reference fibre. The spectra of the light from both fibres are formed by the spectrograph side by side on the detector.

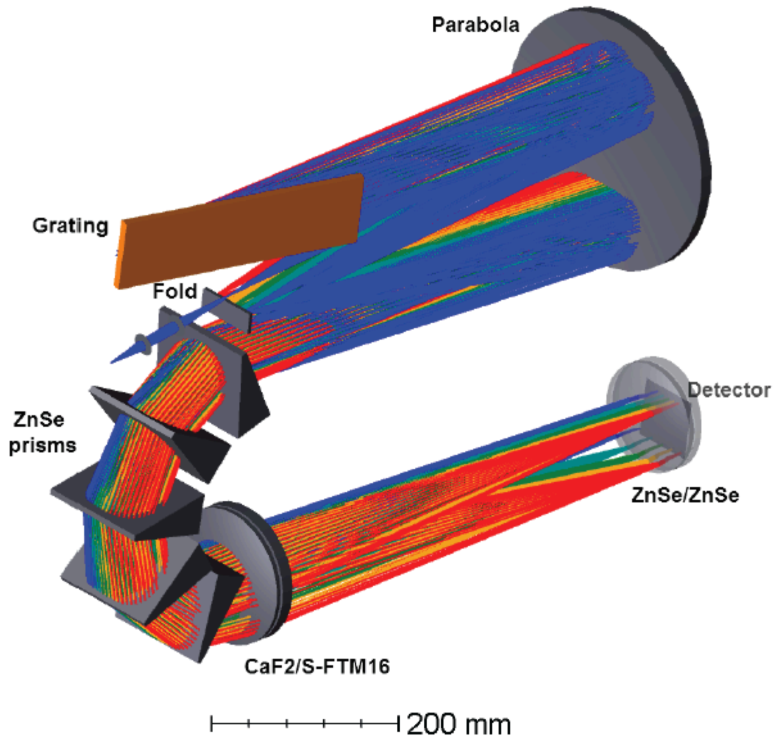

Figure 5 : optical light path of the spectrograph

3.6 The detector

The detector used in NIRPS is a high-performance infrared focal plane array (FPA) Hawaii-4RG (H4RG) built by Teledyne Scientific & Imaging (TSI). The H4RG is a 4096×4096 pixels hybrid technology CMOS detector. Individual reads of 5.5733 sec are used for the Exposure meter algorithm to measure the stellar flux and to accurately measure the mid-time of the exposure (flux weighted mean of the time).

NIRPS H4RG detector has a single readout mode. At the start of a science exposure, a detector reset is performed, and throughout the exposure the detector is read every ~5.5733s. The science exposure is as long as required and as such can be sampled by many tens of readouts. The final 2D science image is obtained by measuring the per-pixel slope of flux value as a function of time. This up-the-ramp sampling minimizes the effective readout noise and has additional benefits. While NIRPS integrations can be arbitrarily long, there is no reason to go beyond the timescale over which the dark current dominates over readout noise (RON); with typical values of 10 e- RON and 1.7 e-/min dark current, this corresponds to a practical limit on integration times of ~15 minutes. Longer total integrations can be obtained by taking multiple exposures interleaved by resets. The minimum integration for the H4RG is 5.5733s and there is a constant overhead of 11.14s for all of exposures.

The RON depends on the number of readouts with the following equation:

RON = sqrt(400/NDSAMPLES + 100) [e-]

The DARK current = 0.028 [e-/s] = 1.7 [e-/min] = 100 [e-/hour]

According to the exposure time provided by the user (DET_UIT), the Detector Control Software will automatically compute the number of non-destructive samples (individual reads of 5.5733 s) with the following scheme:

If DET_UIT < 5.5733 sec:
    DET_NDSAMPLES = 2
    DET_DIT = 5.5733

If DET_UIT > 5.5733s:
    DET_NDSAMPLES = around (DET_UIT / 5.5733) + 1
    DET_DIT = 5.5733 x (NDSAMPLES -1)

Exposure time greater than 1000 sec are not recommended since the DARK noise is no more neglectable compared to the RON and must be split into multiple exposures (NEXPO)

The conversion factor of the NIRPS's detector is 1.27 e-/ADU. The typical deviation from linearity is 3% @ 40'600 ADU and 5% at 48'300 ADU and is corrected-for at the detector control level. Ramp images provided to the users are linearized. Saturation level is fixed to 45'000 ADU / pixel on the data reduction pipeline.

The fractional flux remaining due to the detector persistence is close to 10^{-4} after 2 minutes and less than 10^{-5} after 20 minutes. The observation of a 2.5 mag (x10 times) fainter target 2 minutes after the previous one and with similar line-of-sight velocity (~5 km/s) could introduce at maximum a radial velocity error close to 2 m/s. The recommended strategy would be, if possible, to observe fainter target first when there is a 'collision' in line-of-sight velocity within one night. In the case above, observing the faint target first would lead to a persistence at the 10^{-5} level leading to a maximum radial velocity error at the level of 2 cm/s.

Figure 6 is showing the Detector Control Software window which includes the number of NDSAMPLES and the exposure meter value for both fibers.

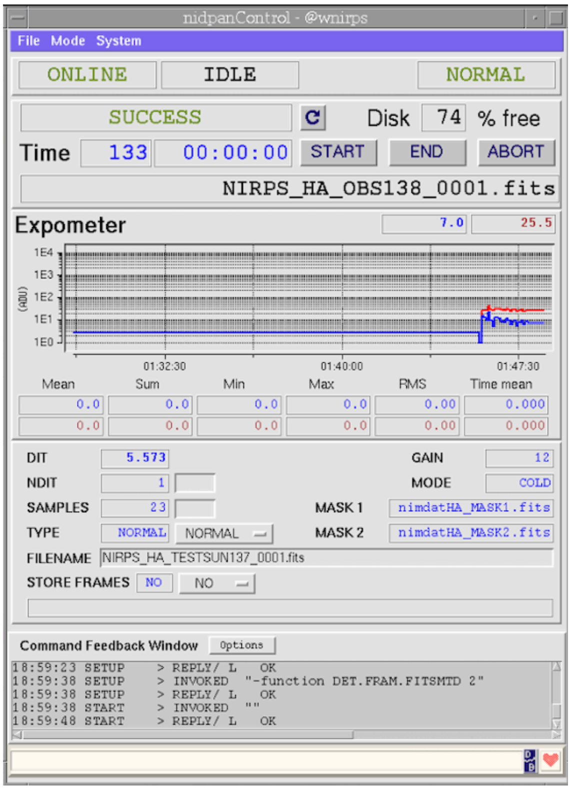

Figure 6 : Detector Software Control window

4. NIRPS CONFIGURATION MODES

4.1 Instrument modes

NIRPS was built for mechanical stability. By construction, the spectral format is fixed and the instrument configuration pre-defined. The only two aspects in which a user can configure NIRPS for a science objective are:

- selection of the instrument mode (HA or HE), defining simultaneously spectral resolution, angle sub-tended in the sky and numerical sampling;
- selection of the source to illuminate the reference fibre (Sky or simultaneous calibration sources – FP or LFC)

NIRPS can be used alone or simultaneously with HARPS.

4.2 Acquisition Modes

The reference fibre can receive either sky light or light from a calibration source for simultaneous instrumental drift measurement. In the first case, the reference fibre collects sky light from a second pinhole that points to a distance of 37 arcseconds away from the main scientific target and not visible in the nIR guiding camera.

Alternatively, the FP source can be used to illuminate the reference fibre at the same time we collect scientific data on the object fibre. This option is used to track instrumental drifts down to 1 m/s level. The mode is developed for high S/N scientific exposures, when calculating the RV uncertainty, the limiting factor is not the photon noise on the target but potential instrumental drifts inside the spectrograph.

At this time (Feb 2023), the spectrograph is more stable that the FP so the usage of simultaneous drift reference might not be helpful, even for high RV precision. Using the reference fibre to measure the sky spectra might be advisable. By doing so one can characterize accurately the sky background and the detector noise contribution to the error budget. When pointing the fibre B to the sky the user should make sure that no companion star falls on it during the course of observations by looking on the finding chart.

There are two acquisition templates for NIRPS alone mode:

- objAB: Object positioned in the first fiber and sky in the second.
- wavesimult: Object positioned in the first fiber and a calibration source positioned in the second fiber (default if FP) for drift measurement

There are four acquisition templates for NIRPS+HARPS mode:

- NIRPS_HA + HARPS_HAM,
- NIRPS_HA + HARPS_EGGS,
- NIRPS_HE + HARPS_HAM,
- NIRPS_HE + HARPS_EGGS.

The acquisition templates must include the specific target parameters:

- Magnitude in I and and in J band (for WFS and NIRCAM automatic preset)
- The target spectral type (for CCF mask selection)
- Target systemic radial velocity

And the acquisition mode for each instrument:

- ObjA, objAB, wavesimult or thosimult for HARPS
- ObjAB or wavesimult for NIRPS

5. INSTRUMENT PERFORMANCES

5.1 Spectroscopic performances

NIRPS spectrum wavelength coverage is 974nm to 1919nm, which is 71 orders in one single exposure. **Error! Reference source not found.** is showing the extracted spectrum for Proxima star.

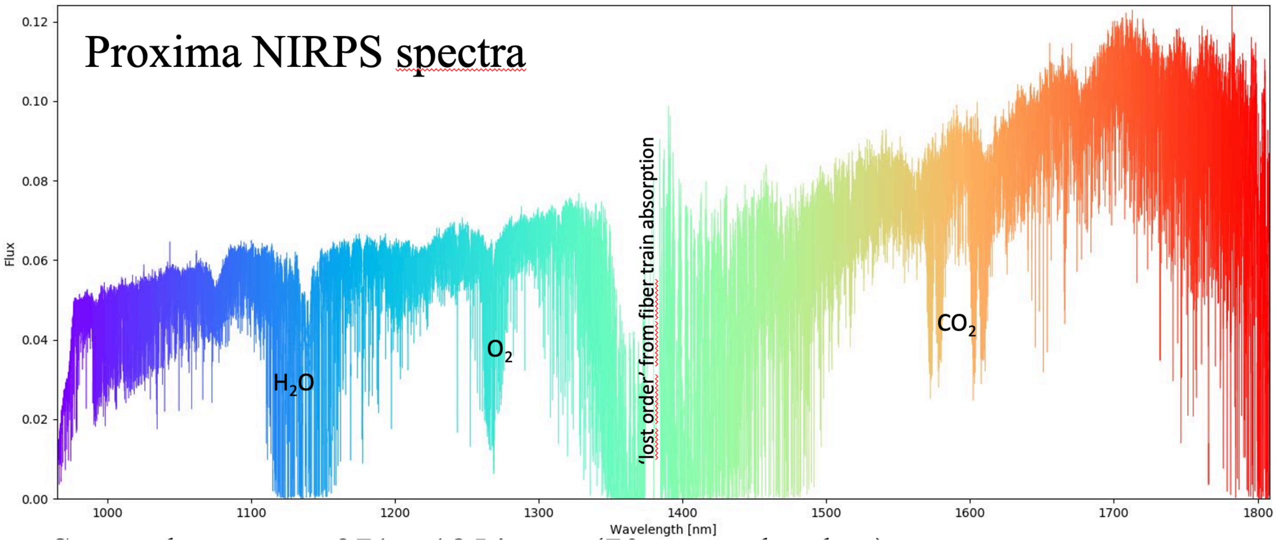

Figure 7 : NIRPS Proxima spectrum observed during COMM5 prior to telluric correction. Major telluric absorptions features are flagged. No useful signal is recovered around 1370 nm because of fibre train absorption; this domain would be useless even without this loss due to strong telluric water absorption.

For the HA mode, the Table 3 and Table 4 summarized the geometric format and wavelength format, respectively. For the HE Mode, the Table 5 and Table 6 summarized the geometric format and wavelength format, respectively.

Table 3 : High Accuracy Mode – Geometric Format

Order	**Echelle Order**	**Y position of center [pixel]**		**X position of blaze peak [pixel]**		**Width of order at >50% of blaze [pixel]**	
x	**x**	**A**	**B**	**A**	**B**	**A**	**B**
1	148	152.2	152.2	2077	2111	2103(1122-3225)	2094(1138-3232)
2	147	230.1	230.1	2096	2109	2149(1112-3261)	2141(1119-3260)
3	146	306.8	306.8	2155	2096	2149(1113-3262)	2135(1107-3242)
4	145	382.5	382.5	2097	2092	2156(1107-3263)	2160(1095-3255)
5	144	457.2	457.2	2094	2096	2186(1096-3282)	2175(1081-3256)

6	143	530.9	530.9	2154	2108	2151(1099-3250)	2159(1079-3238)
7	142	603.7	603.7	2115	2060	2153(1094-3247)	2141(1081-3222)
8	141	675.5	675.5	2114	2123	2169(1085-3254)	2167(1070-3237)
9	140	746.5	746.5	2115	2102	2204(1073-3277)	2195(1063-3258)
10	139	816.6	816.6	2159	2133	2216(1072-3288)	2210(1062-3272)
11	138	885.7	885.7	2098	2174	2199(1090-3289)	2232(1062-3294)
12	137	954.1	954.1	2141	2109	2223(1060-3283)	2224(1067-3291)
13	136	1021.7	1021.7	2143	2131	2268(1052-3320)	2283(1055-3338)
14	135	1088.5	1088.5	2167	2133	2290(1051-3341)	2286(1056-3342)
15	134	1154.5	1154.5	2127	2113	2281(1046-3327)	2285(1049-3334)
16	133	1219.7	1219.7	2130	2132	2287(1033-3320)	2282(1045-3327)
17	132	1284.2	1284.2	2112	2053	2299(1026-3325)	2303(1026-3329)
18	131	1347.9	1347.9	2071	2056	2320(1008-3328)	2306(1012-3318)
19	130	1411	1411	2095	2036	2340(993-3333)	2322(990-3312)
20	129	1473.3	1473.3	2086	2083	2354(975-3329)	2348(974-3322)
21	128	1535	1535	2069	2045	2375(964-3339)	2370(958-3328)
22	127	1596	1596	2093	2096	2386(965-3351)	2389(954-3343)
23	126	1656.3	1656.3	2093	2051	2405(961-3366)	2407(957-3364)
24	125	1715.9	1715.9	2074	2101	2442(943-3385)	2440(950-3390)
25	124	1775	1775	2124	2130	2462(940-3402)	2455(944-3399)
26	123	1833.4	1833.4	2109	2133	2471(930-3401)	2474(927-3401)
27	122	1891.2	1891.2	2109	2157	2504(913-3417)	2497(908-3405)
28	121	1948.4	1948.4	2113	2132	2537(898-3435)	2543(890-3433)
29	120	2005	2005	2093	2044	2588(867-3455)	2587(868-3455)
30	119	2061	2061	2141	2108	2608(849-3457)	2597(849-3446)
31	118	2116.5	2116.5	2002	2072	2564(828-3392)	2572(819-3391)
32	117	2171.3	2171.3	1977	1945	2644(744-3388)	2644(731-3375)
33	116	2225.7	2225.7	2156	2187	2711(839-3550)	2702(828-3530)
34	115	2279.5	2279.5	2150	2192	2631(892-3523)	2639(874-3513)
35	114	2332.7	2332.7	1998	2001	2619(862-3481)	2613(850-3463)
36	113	2385.4	2385.4	2004	1991	2647(830-3477)	2636(819-3455)

37	112	2437.6	2437.6	2060	1999	2667(815-3482)	2650(813-3463)
38	111	2489.3	2489.3	1986	1989	2680(805-3485)	2684(808-3492)
39	110	2540.5	2540.5	1962	2000	2704(771-3475)	2703(787-3490)
40	109	2591.1	2591.1	1992	1995	2716(723-3439)	2721(731-3452)
41	108	2641.3	2641.3	1966	1924	2810(644-3454)	2798(658-3456)
42	107	2690.9	2690.9	2053	2062	2795(624-3419)	2810(630-3440)
43	106	2740.1	2740.1	1653	1658	2098(448-2546)	2096(457-2553)
44	103	2884.9	2884.9	2769	2789	2628(1456-4084)	2659(1425-4084)
45	102	2932.2	2932.2	2406	2387	2975(980-3955)	2985(941-3926)
46	101	2979.1	2979.1	2268	2253	3025(793-3818)	3022(770-3792)
47	100	3025.5	3025.5	2332	2274	3071(711-3782)	3062(678-3740)
48	99	3071.4	3071.4	2270	2106	3074(663-3737)	3072(639-3711)
49	98	3116.9	3116.9	2039	2050	3101(646-3747)	3082(620-3702)
50	97	3162.1	3162.1	2043	1977	3109(622-3731)	3106(608-3714)
51	96	3206.7	3206.7	1989	2082	3129(600-3729)	3126(591-3717)
52	95	3250.9	3250.9	2082	2055	3133(598-3731)	3155(589-3744)
53	94	3294.8	3294.8	2053	2059	3175(579-3754)	3192(576-3768)
54	93	3338.2	3338.2	1999	1967	3240(543-3783)	3224(567-3791)
55	92	3381.3	3381.3	1998	1993	3300(509-3809)	3300(521-3821)
56	91	3423.8	3423.8	2131	2030	3342(476-3818)	3354(483-3837)
57	90	3466	3466	2006	2068	3400(439-3839)	3403(447-3850)
58	89	3507.8	3507.8	1933	1984	3477(376-3853)	3491(395-3886)
59	88	3549.2	3549.2	1962	2056	3558(325-3883)	3505(356-3861)
60	87	3590.3	3590.3	2051	1999	3660(252-3912)	3636(253-3889)
61	86	3630.9	3630.9	1996	2021	3621(226-3847)	3631(197-3828)
62	85	3671.2	3671.2	2040	2139	3728(232-3960)	3759(193-3952)
63	84	3711.1	3711.1	2137	2092	3764(220-3984)	3728(205-3933)
64	83	3750.6	3750.6	2193	1976	3870(214-4084)	3889(195-4084)
65	82	3789.8	3789.8	2067	2090	3843(241-4084)	3871(213-4084)
66	81	3828.7	3828.7	2168	2088	3895(188-4083)	3925(153-4078)
67	80	3867.2	3867.2	1967	1989	3928(156-4084)	3756(169-3925)

68	79	3905.3	3905.3	1860	1847	3875(159-4034)	3814(187-4001)
69	78	3943.1	3943.1	2007	1965	3503(354-3857)	3510(353-3863)
70	77	3980.5	3980.5	2047	1987	3372(312-3684)	3553(252-3805)
71	76	4017.6	4017.6	2083	2104	3785(110-3895)	3854(69-3923)

Table 4 : High Accuracy Mode – Wavelength Format

Order	**Echelle Order**	**Peak blaze wavelength [nm]**		**FSR* length (low - high) [nm]**		**TSR** length (low - high) [nm]**	
x	**x**	**A**	**B**	**A**	**B**	**A**	**B**
1	148	979.9	980	7.0(976.5-983.5)	6.9(976.6-983.5)	13.5(972.2-985.8)	13.5(972.2-985.8)
2	147	986.6	986.7	7.1(983.1-990.3)	7.1(983.2-990.3)	13.6(978.8-992.5)	13.6(978.8-992.5)
3	146	993.6	993.4	7.2(989.9-997.1)	7.2(989.8-997.0)	13.7(985.5-999.3)	13.7(985.5-999.3)
4	145	1000.2	1000.2	7.3(996.7-1003.9)	7.3(996.6-1003.9)	13.8(992.3-1006.2)	13.9(992.3-1006.2)
5	144	1007.2	1007.2	7.4(1003.5-1011.0)	7.4(1003.5-1010.9)	14.0(999.2-1013.2)	14.0(999.2-1013.2)
6	143	1014.4	1014.3	7.4(1010.6-1017.9)	7.4(1010.5-1017.9)	14.1(1006.2-1020.3)	14.1(1006.2-1020.3)
7	142	1021.4	1021.2	7.4(1017.7-1025.1)	7.4(1017.6-1025.0)	14.2(1013.3-1027.5)	14.2(1013.3-1027.5)
8	141	1028.7	1028.7	7.5(1024.9-1032.4)	7.6(1024.8-1032.4)	14.3(1020.5-1034.8)	14.3(1020.5-1034.8)
9	140	1036	1036	7.7(1032.1-1039.8)	7.7(1032.1-1039.8)	14.4(1027.8-1042.1)	14.4(1027.8-1042.2)
10	139	1043.6	1043.5	7.8(1039.6-1047.4)	7.8(1039.5-1047.3)	14.5(1035.2-1049.6)	14.5(1035.2-1049.7)
11	138	1051	1051.3	7.8(1047.2-1055.0)	7.9(1047.0-1055.0)	14.6(1042.7-1057.3)	14.6(1042.7-1057.3)
12	137	1058.8	1058.7	8.0(1054.7-1062.6)	8.0(1054.7-1062.7)	14.7(1050.3-1065.0)	14.7(1050.3-1065.0)
13	136	1066.6	1066.6	8.2(1062.4-1070.6)	8.2(1062.4-1070.6)	14.8(1058.0-1072.8)	14.8(1058.0-1072.8)
14	135	1074.6	1074.5	8.3(1070.3-1078.6)	8.3(1070.3-1078.6)	14.9(1065.8-1080.8)	14.9(1065.8-1080.8)

15	134	1082.5	1082.4	8.3(1078.2-1086.6)	8.3(1078.3-1086.6)	15.0(1073.8-1088.8)	15.0(1073.8-1088.8)
16	133	1090.6	1090.6	8.4(1086.3-1094.7)	8.4(1086.3-1094.7)	15.2(1081.9-1097.0)	15.2(1081.9-1097.0)
17	132	1098.8	1098.6	8.5(1094.5-1103.0)	8.6(1094.5-1103.0)	15.3(1090.1-1105.3)	15.3(1090.1-1105.3)
18	131	1107	1107	8.7(1102.8-1111.5)	8.6(1102.8-1111.4)	15.4(1098.4-1113.8)	15.4(1098.4-1113.8)
19	130	1115.6	1115.4	8.8(1111.2-1120.0)	8.8(1111.2-1120.0)	15.5(1106.8-1122.3)	15.5(1106.8-1122.3)
20	129	1124.3	1124.2	9.0(1119.7-1128.7)	8.9(1119.7-1128.7)	15.6(1115.4-1131.0)	15.6(1115.4-1131.0)
21	128	1133	1132.9	9.1(1128.4-1137.5)	9.1(1128.4-1137.5)	15.7(1124.1-1139.9)	15.7(1124.1-1139.9)
22	127	1142	1142	9.2(1137.3-1146.5)	9.2(1137.3-1146.5)	15.9(1133.0-1148.8)	15.9(1133.0-1148.8)
23	126	1151.1	1150.9	9.4(1146.3-1155.7)	9.4(1146.3-1155.7)	16.0(1142.0-1158.0)	16.0(1142.0-1158.0)
24	125	1160.2	1160.3	9.6(1155.4-1165.0)	9.6(1155.5-1165.0)	16.1(1151.1-1167.2)	16.1(1151.1-1167.2)
25	124	1169.7	1169.8	9.7(1164.7-1174.4)	9.7(1164.8-1174.4)	16.2(1160.4-1176.6)	16.2(1160.4-1176.6)
26	123	1179.2	1179.3	9.8(1174.2-1184.0)	9.8(1174.2-1184.0)	16.4(1169.8-1186.2)	16.4(1169.8-1186.2)
27	122	1188.9	1189.1	10.0(1183.7-1193.7)	10.0(1183.7-1193.7)	16.5(1179.4-1195.9)	16.5(1179.4-1195.9)
28	121	1198.7	1198.8	10.2(1193.4-1203.7)	10.3(1193.4-1203.7)	16.6(1189.2-1205.8)	16.6(1189.2-1205.8)
29	120	1208.6	1208.4	10.5(1203.2-1213.8)	10.5(1203.2-1213.8)	16.7(1199.1-1215.8)	16.7(1199.1-1215.8)
30	119	1219	1218.8	10.7(1213.3-1224.0)	10.7(1213.3-1223.9)	16.9(1209.2-1226.1)	16.9(1209.2-1226.1)
31	118	1228.7	1229	10.7(1223.4-1234.1)	10.7(1223.4-1234.1)	17.0(1219.4-1236.4)	17.0(1219.4-1236.4)
32	117	1239.1	1239	11.1(1233.5-1244.6)	11.2(1233.4-1244.6)	17.1(1229.9-1247.0)	17.1(1229.9-1247.0)
33	116	1250.5	1250.7	11.4(1244.6-1256.0)	11.3(1244.6-1255.9)	17.3(1240.5-1257.8)	17.3(1240.5-1257.8)
34	115	1261.4	1261.6	11.1(1255.7-1266.8)	11.1(1255.6-1266.7)	17.4(1251.3-1268.7)	17.4(1251.3-1268.7)

35	114	1271.8	1271.8	11.2(1266.6-1277.7)	11.2(1266.5-1277.7)	17.6(1262.2-1279.8)	17.6(1262.2-1279.8)
36	113	1283.1	1283	11.4(1277.6-1289.0)	11.4(1277.6-1288.9)	17.7(1273.4-1291.1)	17.7(1273.4-1291.1)
37	112	1294.8	1294.5	11.6(1288.9-1300.5)	11.5(1288.9-1300.5)	17.9(1284.8-1302.7)	17.9(1284.8-1302.7)
38	111	1306.1	1306.1	11.8(1300.5-1312.3)	11.8(1300.5-1312.3)	18.0(1296.4-1314.4)	18.0(1296.4-1314.4)
39	110	1317.9	1318.1	12.0(1312.2-1324.2)	12.0(1312.2-1324.2)	18.2(1308.2-1326.3)	18.2(1308.2-1326.3)
40	109	1330.1	1330.1	12.2(1324.0-1336.2)	12.2(1324.0-1336.2)	18.3(1320.2-1338.5)	18.3(1320.2-1338.5)
41	108	1342.3	1342.1	12.8(1335.8-1348.6)	12.7(1335.9-1348.6)	18.5(1332.4-1350.9)	18.5(1332.4-1350.9)
42	107	1355.2	1355.3	12.8(1348.2-1361.0)	12.9(1348.2-1361.1)	18.6(1344.9-1363.5)	18.6(1344.9-1363.5)
43	106	1366.1	1366.2	10.3(1360.0-1370.3)	10.2(1360.0-1370.3)	18.8(1357.6-1376.4)	18.8(1357.6-1376.4)
44	103	1411.2	1411.2	11.5(1404.9-1416.4)	11.6(1404.8-1416.4)	19.3(1397.1-1416.4)	19.3(1397.1-1416.4)
45	102	1423.3	1423.3	13.6(1416.2-1429.8)	13.7(1416.0-1429.7)	19.5(1410.8-1430.3)	19.5(1410.8-1430.3)
46	101	1436.8	1436.7	14.2(1429.3-1443.5)	14.2(1429.1-1443.4)	19.7(1424.8-1444.5)	19.7(1424.8-1444.5)
47	100	1451.5	1451.2	14.7(1443.1-1457.7)	14.7(1442.9-1457.6)	19.8(1439.1-1458.9)	19.8(1439.1-1458.9)
48	99	1465.8	1465	14.9(1457.4-1472.3)	14.9(1457.3-1472.2)	20.0(1453.6-1473.6)	20.0(1453.6-1473.6)
49	98	1479.6	1479.7	15.2(1472.2-1487.3)	15.1(1472.0-1487.2)	20.2(1468.5-1488.7)	20.2(1468.5-1488.7)
50	97	1494.9	1494.6	15.4(1487.2-1502.6)	15.4(1487.2-1502.5)	20.4(1483.6-1504.0)	20.4(1483.6-1504.0)
51	96	1510.2	1510.7	15.6(1502.6-1518.2)	15.6(1502.6-1518.2)	20.6(1499.1-1519.7)	20.6(1499.1-1519.7)
52	95	1526.6	1526.4	15.8(1518.4-1534.2)	15.9(1518.4-1534.3)	20.8(1514.9-1535.7)	20.8(1514.9-1535.6)
53	94	1542.7	1542.7	16.2(1534.5-1550.6)	16.2(1534.5-1550.7)	21.0(1531.0-1552.0)	21.0(1531.0-1552.0)
54	93	1559	1558.8	16.7(1550.8-1567.4)	16.5(1550.9-1567.5)	21.2(1547.5-1568.7)	21.2(1547.5-1568.7)

55	92	1575.9	1575.9	17.1(1567.4-1584.6)	17.1(1567.5-1584.6)	21.4(1564.3-1585.7)	21.4(1564.3-1585.7)
56	91	1593.9	1593.4	17.6(1584.4-1602.0)	17.6(1584.5-1602.1)	21.6(1581.5-1603.1)	21.6(1581.5-1603.1)
57	90	1611	1611.3	18.1(1601.8-1619.9)	18.0(1601.9-1619.9)	21.9(1599.1-1620.9)	21.8(1599.1-1620.9)
58	89	1628.7	1628.9	18.7(1619.4-1638.1)	18.7(1619.6-1638.3)	22.1(1617.0-1639.1)	22.1(1617.1-1639.1)
59	88	1647.3	1647.9	19.4(1637.5-1656.9)	19.1(1637.7-1656.8)	22.3(1635.4-1657.7)	22.3(1635.4-1657.7)
60	87	1666.8	1666.5	20.2(1655.9-1676.0)	20.0(1655.9-1675.9)	22.5(1654.2-1676.8)	22.5(1654.2-1676.8)
61	86	1685.8	1686	20.3(1675.0-1695.2)	20.4(1674.8-1695.1)	22.8(1673.5-1696.3)	22.8(1673.5-1696.3)
62	85	1705.9	1706.5	20.9(1694.7-1715.7)	21.2(1694.5-1715.6)	23.0(1693.2-1716.2)	23.0(1693.2-1716.2)
63	84	1726.8	1726.5	21.4(1714.8-1736.2)	21.2(1714.7-1736.0)	23.3(1713.4-1736.6)	23.3(1713.4-1736.6)
64	83	1747.9	1746.6	22.1(1735.5-1757.6)	22.2(1735.3-1757.6)	23.5(1734.0-1757.6)	23.5(1734.0-1757.6)
65	82	1768.5	1768.6	22.2(1756.8-1779.0)	22.3(1756.6-1779.0)	23.8(1755.2-1779.0)	23.8(1755.2-1779.0)
66	81	1790.9	1790.4	22.8(1778.2-1800.9)	23.0(1777.9-1800.9)	24.1(1776.9-1800.9)	24.1(1776.9-1800.9)
67	80	1812.1	1812.2	23.3(1800.2-1823.4)	22.4(1800.3-1822.7)	24.4(1799.1-1823.4)	24.3(1799.1-1823.4)
68	79	1834.4	1834.3	23.3(1823.0-1846.3)	22.9(1823.2-1846.1)	24.6(1821.9-1846.5)	24.6(1821.9-1846.5)
69	78	1858.8	1858.5	21.3(1847.8-1869.1)	21.3(1847.8-1869.1)	24.9(1845.2-1870.2)	24.9(1845.2-1870.2)
70	77	1883.2	1882.8	21.0(1871.5-1892.5)	22.0(1871.1-1893.1)	25.2(1869.2-1894.4)	25.2(1869.2-1894.4)
71	76	1908.2	1908.3	23.8(1894.6-1918.4)	24.2(1894.3-1918.6)	25.5(1893.8-1919.4)	25.5(1893.8-1919.4)

Table 5 : High Efficiency Mode – Geometric Format

Order	**Echelle Order**	**Y position of center [pixel]**	**X position of blaze peak**	**Width of order at >50% of blaze**

x	x	A	B	A	B	A	B
1	148	154	154	2072	2084	2100(1093-3193)	2106(1064-3170)
2	147	231.8	231.8	2089	2095	2144(1084-3228)	2149(1051-3200)
3	146	308.4	308.4	2077	2032	2142(1085-3227)	2133(1054-3187)
4	145	384.3	384.3	2086	2042	2164(1075-3239)	2167(1044-3211)
5	144	459	459	2095	2034	2173(1069-3242)	2166(1034-3200)
6	143	532.7	532.7	2074	2038	2156(1065-3221)	2163(1031-3194)
7	142	605.4	605.4	2075	2053	2148(1066-3214)	2151(1032-3183)
8	141	677.2	677.2	2069	2045	2172(1053-3225)	2174(1022-3196)
9	140	748.1	748.1	2112	2079	2200(1042-3242)	2200(1014-3214)
10	139	818.1	818.1	2178	2085	2219(1036-3255)	2204(1012-3216)
11	138	887.4	887.4	2101	2071	2199(1059-3258)	2223(1003-3226)
12	137	955.7	955.7	2107	2036	2220(1029-3249)	2229(1002-3231)
13	136	1023.3	1023.3	2092	2087	2267(1021-3288)	2273(991-3264)
14	135	1090.1	1090.1	2122	2071	2284(1015-3299)	2278(989-3267)
15	134	1156.1	1156.1	2103	2036	2277(1010-3287)	2276(982-3258)
16	133	1221.2	1221.2	2086	2021	2286(999-3285)	2284(975-3259)
17	132	1285.7	1285.7	2051	2053	2303(987-3290)	2300(961-3261)
18	131	1349.5	1349.5	2011	1991	2313(975-3288)	2308(948-3256)
19	130	1412.4	1412.4	2002	2002	2332(957-3289)	2326(931-3257)
20	129	1474.8	1474.8	2053	2033	2348(943-3291)	2344(917-3261)
21	128	1536.4	1536.4	2054	2043	2374(929-3303)	2363(905-3268)
22	127	1597.4	1597.4	2067	2080	2380(927-3307)	2382(900-3282)
23	126	1657.7	1657.7	2073	2024	2405(920-3325)	2394(898-3292)
24	125	1717.3	1717.3	2060	2054	2434(912-3346)	2431(889-3320)
25	124	1776.4	1776.4	2090	2089	2460(902-3362)	2453(877-3330)
26	123	1834.8	1834.8	2120	2118	2470(894-3364)	2473(862-3335)
27	122	1892.5	1892.5	2125	2058	2492(879-3371)	2495(845-3340)
28	121	1949.8	1949.8	2092	2043	2540(856-3396)	2531(829-3360)
29	120	2006.3	2006.3	2125	2052	2583(834-3417)	2573(808-3381)
30	119	2062.4	2062.4	2099	2107	2597(818-3415)	2597(787-3384)

31	118	2117.8	2117.8	2019	2020	2561(795-3356)	2553(764-3317)
32	117	2172.7	2172.7	1943	1957	2646(710-3356)	2645(671-3316)
33	116	2226.9	2226.9	2126	2134	2702(807-3509)	2690(783-3473)
34	115	2280.8	2280.8	2128	2041	2626(854-3480)	2625(827-3452)
35	114	2334.1	2334.1	1996	2006	2616(830-3446)	2607(799-3406)
36	113	2386.7	2386.7	2004	1990	2635(809-3444)	2635(770-3405)
37	112	2438.9	2438.9	1990	1990	2664(788-3452)	2643(764-3407)
38	111	2490.5	2490.5	1989	1989	2678(775-3453)	2669(746-3415)
39	110	2541.7	2541.7	1989	1966	2689(753-3442)	2684(724-3408)
40	109	2592.3	2592.3	1955	1881	2723(692-3415)	2717(658-3375)
41	108	2642.4	2642.4	1965	1872	2808(624-3432)	2793(592-3385)
42	107	2692.1	2692.1	2019	2003	2800(599-3399)	2786(565-3351)
43	106	2741.2	2741.2	1614	1593	2138(418-2556)	2090(392-2482)
44	103	2885.9	2885.9	2725	2717	2688(1396-4084)	2712(1372-4084)
45	102	2933.2	2933.2	2359	2312	2979(939-3918)	2972(907-3879)
46	101	2980.2	2980.2	2268	2256	3013(774-3787)	3031(732-3763)
47	100	3026.6	3026.6	2243	2278	3065(684-3749)	3062(651-3713)
48	99	3072.5	3072.5	2134	2054	3077(637-3714)	3080(607-3687)
49	98	3118.1	3118.1	2110	2093	3092(612-3704)	3091(585-3676)
50	97	3163.2	3163.2	2006	1970	3101(599-3700)	3103(572-3675)
51	96	3207.9	3207.9	2012	1983	3125(583-3708)	3118(552-3670)
52	95	3252	3252	2053	2065	3134(571-3705)	3140(538-3678)
53	94	3295.9	3295.9	1990	1963	3184(549-3733)	3160(530-3690)
54	93	3339.3	3339.3	2001	1913	3244(516-3760)	3224(500-3724)
55	92	3382.3	3382.3	2047	1941	3300(483-3783)	3298(463-3761)
56	91	3424.9	3424.9	2054	2035	3358(442-3800)	3344(423-3767)
57	90	3467	3467	2050	2002	3392(405-3797)	3397(379-3776)
58	89	3508.9	3508.9	1965	1938	3481(348-3829)	3465(331-3796)
59	88	3550.2	3550.2	1970	2126	3532(306-3838)	3529(283-3812)
60	87	3591.2	3591.2	2073	1989	3646(216-3862)	3640(196-3836)
61	86	3631.9	3631.9	2011	2025	3646(171-3817)	3630(152-3782)

62	85	3672.1	3672.1	2099	2016	3732(183-3915)	3719(151-3870)
63	84	3712	3712	2002	2020	3754(177-3931)	3711(151-3862)
64	83	3751.5	3751.5	2126	2030	3921(163-4084)	3946(138-4084)
65	82	3790.7	3790.7	2074	2035	3893(191-4084)	3953(131-4084)
66	81	3829.5	3829.5	2127	2054	3917(136-4053)	3906(1-3907)
67	80	3867.8	3867.8	2072	1897	3920(104-4024)	3771(6-3777)
68	79	3905.9	3905.9	1807	1742	3873(129-4002)	3746(84-3830)
69	78	3943.7	3943.7	1964	1888	3626(228-3854)	3760(1-3761)
70	77	3981.2	3981.2	2001	1969	3524(269-3793)	3576(39-3615)
71	76	4018.3	4018.3	2042	2018	3842(121-3963)	3747(1-3748)

Table 6 : High Efficiency Mode – Wavelength Format

Order	**Echelle Order**	**Peak blaze wavelength [nm]**		**FSR* length (low - high) [nm]**		**TSR** length (low - high) [nm]**	
x	**x**	**A**	**B**	**A**	**B**	**A**	**B**
1	148	980	980.1	7.0(976.5-983.5)	7.0(976.5-983.5)	13.5(972.4-985.9)	13.5(972.4-986.0)
2	147	986.7	986.8	7.2(983.1-990.3)	7.2(983.1-990.3)	13.6(979.0-992.6)	13.6(979.0-992.7)
3	146	993.4	993.4	7.2(989.9-997.1)	7.2(989.8-997.0)	13.7(985.7-999.4)	13.7(985.7-999.5)
4	145	1000.3	1000.2	7.3(996.7-1004.0)	7.4(996.6-1004.0)	13.9(992.5-1006.3)	13.9(992.5-1006.4)
5	144	1007.3	1007.2	7.4(1003.6-1011.0)	7.4(1003.5-1010.9)	14.0(999.4-1013.3)	14.0(999.4-1013.4)
6	143	1014.3	1014.2	7.4(1010.6-1018.0)	7.5(1010.5-1018.0)	14.1(1006.3-1020.4)	14.1(1006.4-1020.5)
7	142	1021.4	1021.4	7.4(1017.7-1025.1)	7.5(1017.6-1025.1)	14.2(1013.4-1027.6)	14.2(1013.5-1027.7)
8	141	1028.6	1028.6	7.6(1024.9-1032.4)	7.6(1024.8-1032.4)	14.3(1020.6-1034.9)	14.3(1020.7-1035.0)
9	140	1036.1	1036.1	7.7(1032.1-1039.9)	7.8(1032.1-1039.9)	14.4(1027.9-1042.3)	14.4(1028.0-1042.4)

10	139	1043.8	1043.6	7.9(1039.5-1047.4)	7.8(1039.5-1047.4)	14.5(1035.3-1049.8)	14.5(1035.4-1049.9)
11	138	1051.1	1051.1	7.8(1047.2-1055.0)	8.0(1047.0-1055.0)	14.6(1042.8-1057.4)	14.6(1042.9-1057.5)
12	137	1058.8	1058.6	8.0(1054.7-1062.7)	8.0(1054.7-1062.7)	14.7(1050.4-1065.1)	14.7(1050.5-1065.2)
13	136	1066.5	1066.6	8.2(1062.4-1070.6)	8.2(1062.4-1070.6)	14.8(1058.1-1072.9)	14.8(1058.2-1073.0)
14	135	1074.6	1074.5	8.3(1070.3-1078.6)	8.3(1070.2-1078.6)	14.9(1066.0-1080.9)	14.9(1066.0-1081.0)
15	134	1082.5	1082.3	8.4(1078.2-1086.6)	8.4(1078.2-1086.6)	15.0(1073.9-1089.0)	15.0(1074.0-1089.0)
16	133	1090.6	1090.4	8.5(1086.3-1094.7)	8.5(1086.3-1094.7)	15.2(1082.0-1097.1)	15.2(1082.1-1097.2)
17	132	1098.7	1098.8	8.6(1094.5-1103.1)	8.6(1094.4-1103.0)	15.3(1090.2-1105.5)	15.3(1090.3-1105.5)
18	131	1106.9	1107	8.7(1102.8-1111.5)	8.7(1102.7-1111.5)	15.4(1098.5-1113.9)	15.4(1098.6-1114.0)
19	130	1115.4	1115.5	8.8(1111.2-1120.0)	8.8(1111.2-1120.0)	15.5(1107.0-1122.5)	15.5(1107.1-1122.6)
20	129	1124.3	1124.3	9.0(1119.7-1128.7)	9.0(1119.7-1128.7)	15.6(1115.5-1131.2)	15.6(1115.6-1131.3)
21	128	1133.1	1133.1	9.1(1128.4-1137.6)	9.1(1128.4-1137.5)	15.7(1124.3-1140.0)	15.7(1124.4-1140.1)
22	127	1142	1142.2	9.2(1137.3-1146.5)	9.3(1137.3-1146.5)	15.9(1133.1-1149.0)	15.9(1133.2-1149.1)
23	126	1151.1	1151	9.4(1146.3-1155.7)	9.4(1146.3-1155.7)	16.0(1142.1-1158.1)	16.0(1142.2-1158.2)
24	125	1160.3	1160.3	9.6(1155.4-1165.0)	9.6(1155.4-1165.0)	16.1(1151.3-1167.4)	16.1(1151.4-1167.5)
25	124	1169.7	1169.8	9.7(1164.7-1174.5)	9.8(1164.7-1174.4)	16.2(1160.5-1176.8)	16.2(1160.6-1176.9)
26	123	1179.4	1179.5	9.9(1174.1-1184.0)	9.9(1174.1-1184.0)	16.4(1170.0-1186.3)	16.4(1170.1-1186.4)
27	122	1189.1	1188.9	10.0(1183.7-1193.7)	10.1(1183.6-1193.7)	16.5(1179.6-1196.1)	16.5(1179.7-1196.2)
28	121	1198.8	1198.7	10.3(1193.4-1203.7)	10.3(1193.4-1203.7)	16.6(1189.3-1205.9)	16.6(1189.4-1206.0)
29	120	1208.9	1208.7	10.6(1203.2-1213.8)	10.6(1203.2-1213.8)	16.7(1199.2-1216.0)	16.7(1199.3-1216.1)

30	119	1218.9	1219.1	10.7(1213.3-1224.0)	10.7(1213.2-1224.0)	16.9(1209.3-1226.2)	16.9(1209.4-1226.3)
31	118	1228.9	1229	10.7(1223.4-1234.1)	10.7(1223.4-1234.1)	17.0(1219.6-1236.6)	17.0(1219.7-1236.7)
32	117	1239.1	1239.3	11.2(1233.5-1244.7)	11.2(1233.4-1244.6)	17.1(1230.0-1247.2)	17.1(1230.1-1247.3)
33	116	1250.6	1250.7	11.4(1244.6-1256.0)	11.3(1244.6-1255.9)	17.3(1240.6-1257.9)	17.3(1240.7-1258.0)
34	115	1261.5	1261.2	11.1(1255.7-1266.8)	11.1(1255.6-1266.8)	17.4(1251.4-1268.8)	17.4(1251.5-1268.9)
35	114	1271.9	1272.1	11.2(1266.6-1277.8)	11.2(1266.5-1277.7)	17.6(1262.4-1280.0)	17.6(1262.5-1280.1)
36	113	1283.2	1283.3	11.4(1277.7-1289.1)	11.4(1277.6-1289.0)	17.7(1273.6-1291.3)	17.7(1273.7-1291.4)
37	112	1294.6	1294.7	11.6(1289.0-1300.6)	11.6(1289.0-1300.5)	17.9(1285.0-1302.8)	17.9(1285.1-1302.9)
38	111	1306.3	1306.4	11.8(1300.5-1312.3)	11.8(1300.5-1312.3)	18.0(1296.5-1314.5)	18.0(1296.6-1314.7)
39	110	1318.2	1318.2	12.0(1312.2-1324.2)	12.0(1312.2-1324.2)	18.2(1308.3-1326.5)	18.2(1308.4-1326.6)
40	109	1330.1	1329.9	12.3(1324.0-1336.2)	12.3(1323.9-1336.2)	18.3(1320.3-1338.7)	18.3(1320.4-1338.8)
41	108	1342.5	1342.1	12.8(1335.9-1348.7)	12.8(1335.8-1348.6)	18.5(1332.6-1351.0)	18.5(1332.7-1351.2)
42	107	1355.3	1355.3	12.9(1348.2-1361.1)	12.9(1348.2-1361.1)	18.6(1345.0-1363.7)	18.6(1345.1-1363.8)
43	106	1366.1	1366.1	10.5(1360.0-1370.5)	10.3(1360.0-1370.3)	18.8(1357.7-1376.5)	18.8(1357.8-1376.6)
44	103	1411.1	1411.2	11.8(1404.8-1416.6)	11.9(1404.8-1416.7)	19.3(1397.3-1416.6)	19.3(1397.4-1416.7)
45	102	1423.3	1423.2	13.7(1416.2-1429.9)	13.7(1416.1-1429.8)	19.5(1411.0-1430.5)	19.5(1411.1-1430.6)
46	101	1437	1437	14.2(1429.3-1443.5)	14.3(1429.2-1443.5)	19.7(1425.0-1444.6)	19.7(1425.1-1444.8)
47	100	1451.2	1451.5	14.7(1443.1-1457.8)	14.7(1443.1-1457.8)	19.8(1439.2-1459.1)	19.8(1439.4-1459.2)
48	99	1465.3	1465.1	14.9(1457.4-1472.4)	15.0(1457.4-1472.4)	20.0(1453.8-1473.8)	20.0(1453.9-1473.9)
49	98	1480.2	1480.2	15.2(1472.2-1487.3)	15.2(1472.1-1487.4)	20.2(1468.6-1488.8)	20.2(1468.8-1489.0)

50	97	1494.9	1494.8	15.4(1487.3-1502.7)	15.4(1487.3-1502.7)	20.4(1483.8-1504.2)	20.4(1483.9-1504.3)
51	96	1510.5	1510.5	15.6(1502.7-1518.3)	15.7(1502.6-1518.3)	20.6(1499.2-1519.8)	20.6(1499.4-1520.0)
52	95	1526.6	1526.8	15.9(1518.4-1534.3)	15.9(1518.4-1534.3)	20.8(1515.0-1535.8)	20.8(1515.2-1536.0)
53	94	1542.5	1542.5	16.3(1534.5-1550.7)	16.2(1534.5-1550.7)	21.0(1531.2-1552.2)	21.0(1531.3-1552.3)
54	93	1559.2	1558.8	16.7(1550.8-1567.5)	16.7(1550.8-1567.5)	21.2(1547.6-1568.8)	21.2(1547.8-1569.0)
55	92	1576.4	1575.9	17.2(1567.4-1584.6)	17.2(1567.5-1584.7)	21.4(1564.5-1585.9)	21.4(1564.6-1586.0)
56	91	1593.7	1593.7	17.7(1584.4-1602.1)	17.7(1584.4-1602.1)	21.6(1581.7-1603.3)	21.6(1581.8-1603.4)
57	90	1611.4	1611.3	18.1(1601.8-1619.9)	18.2(1601.8-1619.9)	21.9(1599.3-1621.1)	21.8(1599.4-1621.2)
58	89	1629	1629	18.8(1619.5-1638.2)	18.7(1619.5-1638.2)	22.1(1617.2-1639.3)	22.1(1617.4-1639.5)
59	88	1647.6	1648.6	19.3(1637.6-1656.9)	19.3(1637.6-1656.9)	22.3(1635.6-1657.9)	22.3(1635.8-1658.1)
60	87	1667.1	1666.8	20.2(1655.8-1676.0)	20.2(1655.9-1676.0)	22.5(1654.4-1677.0)	22.5(1654.6-1677.1)
61	86	1686.1	1686.3	20.5(1674.8-1695.3)	20.4(1674.8-1695.3)	22.8(1673.7-1696.5)	22.8(1673.8-1696.6)
62	85	1706.5	1706.1	21.1(1694.6-1715.7)	21.1(1694.5-1715.6)	23.0(1693.4-1716.4)	23.0(1693.5-1716.6)
63	84	1726.2	1726.5	21.4(1714.8-1736.2)	21.3(1714.7-1736.0)	23.3(1713.6-1736.8)	23.3(1713.7-1737.0)
64	83	1747.7	1747.3	22.4(1735.3-1757.8)	22.6(1735.3-1757.9)	23.5(1734.2-1757.8)	23.5(1734.4-1757.9)
65	82	1768.7	1768.6	22.5(1756.7-1779.2)	22.9(1756.4-1779.3)	23.8(1755.4-1779.2)	23.8(1755.5-1779.3)
66	81	1790.9	1790.6	23.0(1778.0-1801.0)	23.2(1777.2-1800.5)	24.1(1777.1-1801.1)	24.1(1777.2-1801.3)
67	80	1812.9	1812	23.3(1800.0-1823.4)	22.9(1799.5-1822.3)	24.4(1799.3-1823.6)	24.3(1799.4-1823.8)
68	79	1834.2	1834	23.3(1823.0-1846.3)	22.8(1822.8-1845.7)	24.6(1822.1-1846.7)	24.6(1822.2-1846.9)
69	78	1858.7	1858.4	22.2(1847.1-1869.3)	23.3(1845.6-1869.0)	24.9(1845.5-1870.4)	24.9(1845.6-1870.5)

70	77	1883.1	1883.1	21.8(1871.4-1893.2)	22.6(1869.9-1892.5)	25.2(1869.4-1894.7)	25.2(1869.6-1894.8)
71	76	1908.2	1908.2	24.1(1894.9-1919.0)	23.8(1894.2-1918.1)	25.5(1894.0-1919.6)	25.5(1894.2-1919.7)

5.2 Total efficiency

The following figure 9 corresponds to the expected and predicted overall throughput of the instrument including atmosphere, telescope, fiber coupling and spectrograph.

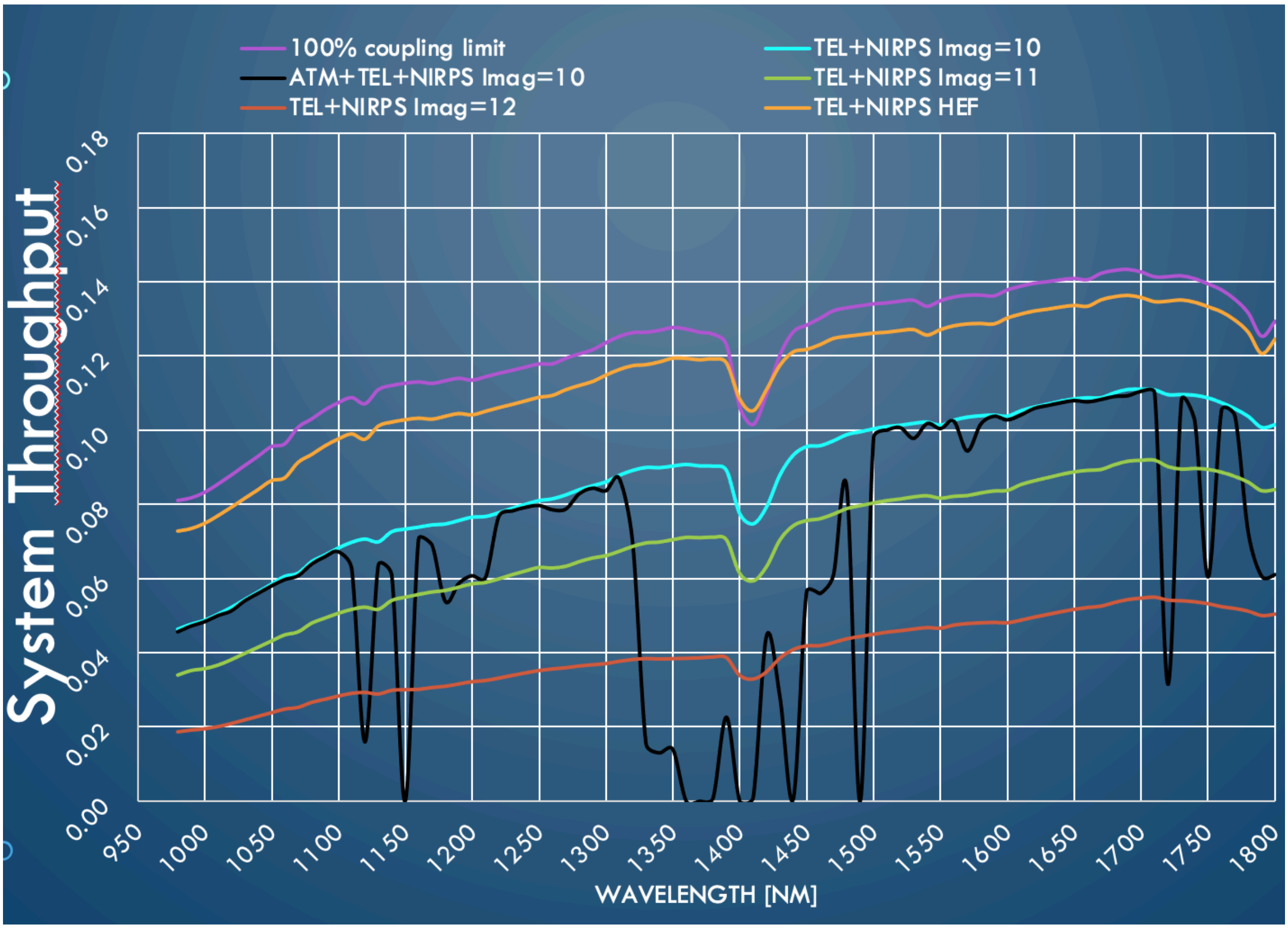

Figure 8 : Expected total system efficiency

SNR at 1619nm (H-band) was measured during the commissionings in both HA and HE modes and show a very good agreement with expectation as shown in Fig. 10.

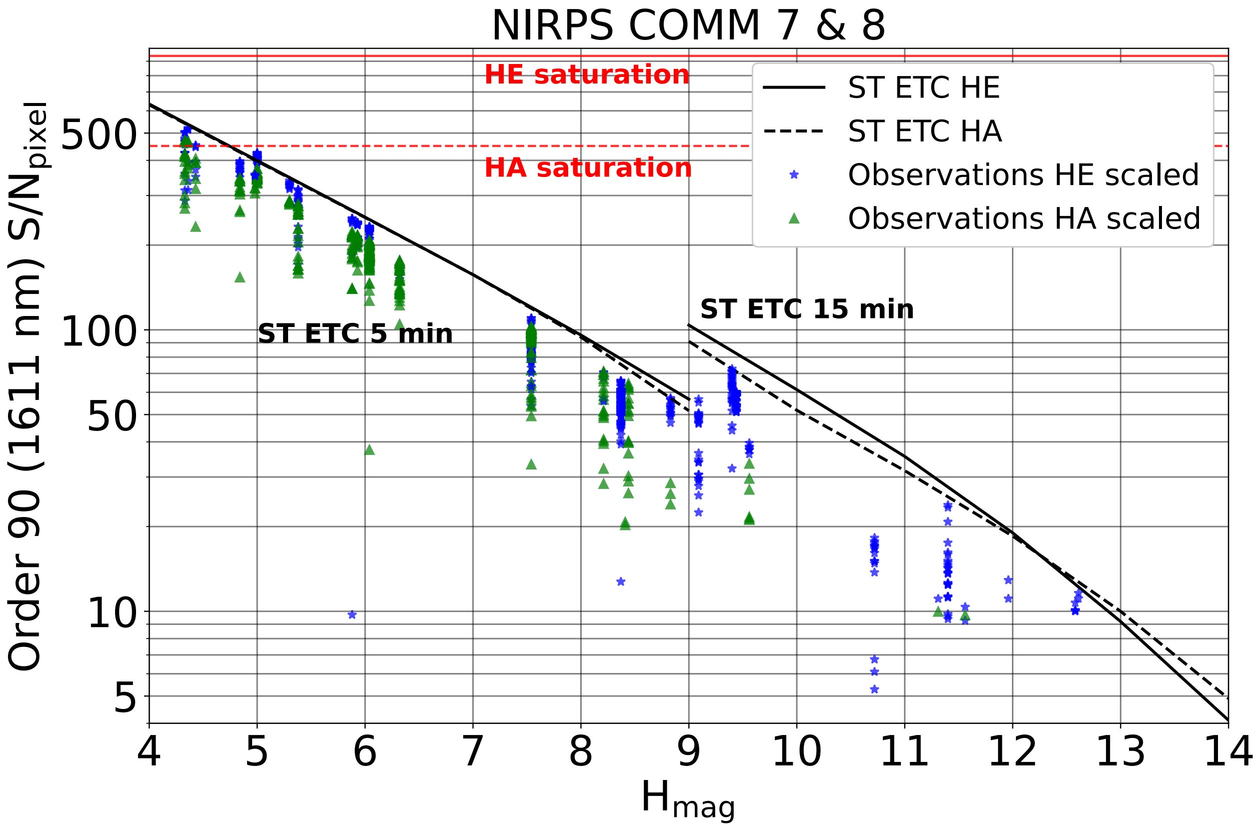

Figure 9 : SNR per pixel at 1619nm as function of H magnitude as observed during COMM7 (Nov 2022) and COMM8 (Jan 2022).

5.3 On-Sky RV precision

The RV accuracy of NIRPS is central to its science case, but it is important to note that at this stage (Feb 2023), it remains less constrained than other instrument properties. The user should keep this in mind when planning observations in the semester P112 (Oct 2023) and check for updates of this document and the NIRPS web page where we will report progress from upcoming commissioning in 2023.

The commissionings demonstrated that NIRPS can provide a <2-3 m/s RMS for bright targets such as Proxima over a timescale of two weeks and 1.5 m/s within a baseline of 4 hours. There are a number of caveats that should be kept in mind, and we most likely will see an improvement of performances in future commissioning, but this remains to be confirmed.

The data is affected by a statistic noise that is similar in structure to fiber modal noise at the ~0.5 % level. This noise imprints an additional RMS to the data and is fixed in velocity space (not following the line-of-sight RV change), worsening the RV performance.

Overall, prior to any further on-sky confirmation, it would be advisable, as of Feb 2023, not to propose a science program for which <2 m/s velocimetry precision is required, keeping in mind that this value is expected to be revised in the near-future.

Some investigations were led to try to identify if precision RV measurements should be acquired in HA or HE mode. At this time (Feb 2023), while HA has a slightly higher resolution than HE, the modal noise is intrinsically higher in HA than HE. The HE mode seems to have a slight edge over HA for pRV.

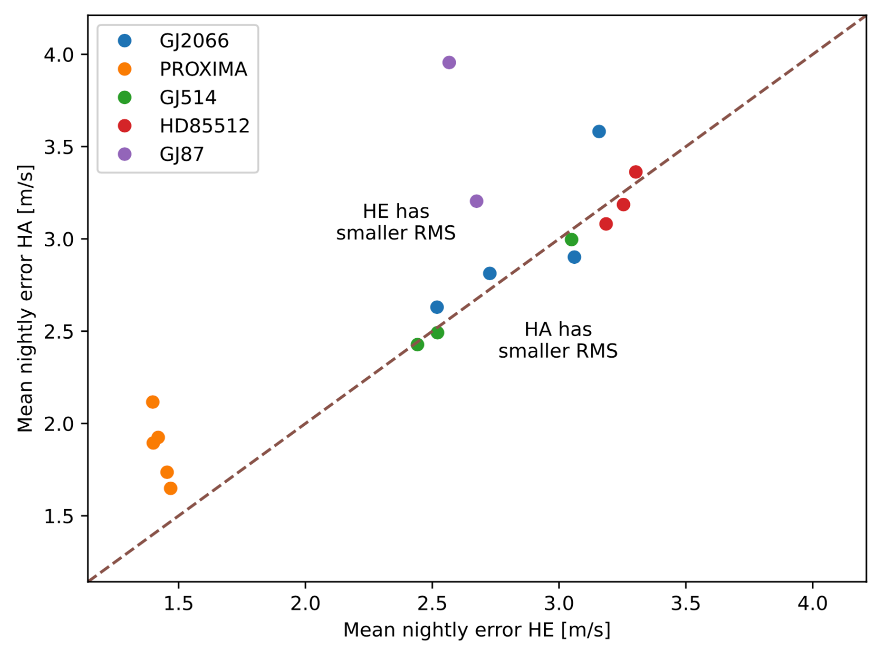

Figure 11: Mean night error in HA mode vs HE mode

5.4 Bad pixels, Dark current, Diffused light and Ghosts

The typical number of bad pixels of the H4RG detector is estimated to be close to 0.5% of the total number of pixels, but these pixels are strongly clustered, so the fraction of resolution elements affected by a bad pixel tends to be lower than a random spatial distribution would suggest. The dark current level was measured to be 1.7 e- / min. The background light was estimated to 1.2 e- / min. The echelle grating presents some Rowland ghosts (due to long-term grooves periodicities), Lyman ghosts (due to short-term grooves periodicities) and scattered / background light introducing structures at the level of 0.1 to 1% to the peak energy.

6. OBSERVING WITH NIRPS

From the operational point-of-view, NIRPS is a relatively simple instrument, with a fixed spectral format and two well-defined instrument configurations: High Accuracy (HA) or High Efficiency (HE).

Once the instrument configuration is defined, the only remaining set-up choice is the light source illuminating the reference Fibre B. The available options are FP for simultaneous drift measurement or the SKY for sky recording.

The following acquisition templates are offered Phase 1 of in P111:

NIRPS_HA_acq_objAB: NIRPS alone in High Accuracy mode with simultaneous SKy

NIRPS_HA_acq_wavesimult: NIRPS alone in High Accuracy Mode with simultaneous reference

NIRPS_HE_acq_objAB: NIRPS alone in High Efficiency mode with simultaneous SKy

NIRPS_HE_acq_wavesimult: NIRPS alone in High Efficiency Mode with simultaneous reference

NIRPS_HA_acq_HARPS_EGGS: NIRPS High Accuracy + HARPS High Efficiency

NIRPS_HA_acq_HARPS_HAM: NIRPS High Accuracy + HARPS High Accuracy

NIRPS_HE_acq_HARPS_EGGS: NIRPS High Efficiency + HARPS High Efficiency

NIRPS_HE_acq_HARPS_HAM: NIRPS High Efficiency + HARPS High Accuracy

Just like for other ESO instruments, the preparation of NIRPS observations is done with p2 and assisted by the Exposure Time Calculator (ETC).

https://www.eso.org/sci/observing/phase2/p2intro.html

https://etc.eso.org/observing/etc/nirps

NIRPS is offered in Visitor Mode (VM) and Delegated Visitor Mode (dVM) but not in Service Mode (SM) as for all instruments at La Silla.

6.1 Using the ETC to prepare observations

The HARPS/NIRPS Exposure Time Calculator is available on the following ESO website:

https://etc.eso.org/observing/etc/nirps

Several parameters need to be selected:

- Target Spectral type
- Magnitude
- Instrument setup

- Exposure time

6.2 Preparation of P1 and P2 material

The telescope time proposal preparation and submission will follow the standard ESO procedures. Proposals for observations at the ESO telescopes are invited twice a year. A Call for Proposals is issued twice a year, at the beginning of March (for observations to be carried out between October 1 of the current year and March 31 of the following year) and at the beginning of September (for observations to be carried out between April 1 and September 30 of the year following the release of the Call). Proposals must be submitted by the respective deadline (end of March and end of September) using the Web-based p1 interface accessible at www.eso.org/p1.

The observations with NIRPS and HARPS+NIRPS will be carried out in the standard ESO way, i.e. using the standard ESO tools: P2, vOT, BOB. Users are responsible to prepare and manage their observations using the web-based for ESO Phase 2 observing preparation tool for La Silla accessible at www.eso.org/p2ls.

6.3 Calibration Plan

The NIRPS Back-End calibrations are performed during the day to determine the dark and bad pixels map, location and geometry of spectral orders, the blaze profile, the spectral flat-field response and the wavelength calibration. The calibration sequence must be completed at least 2 hours before the start of the night to avoid any persistence on the NIR detector from strong HC source lines. A standard calibration OB containing the entire sequence is predefined for each instrumental configuration (HE and HA) to facilitate the daily calibration activities and it is available to the telescope Operators.

The total duration of the calibration sequence for both HA and HE is about 2 hours.

Table 2 : List of daily calibration exposures which are performed for both modes (HA and HE)

Exposure	**Science Fibre A**	**Reference Fibre B**	**DRS recipe name**	**Duration**
Dark	Dark	Dark	Cal_DARK	7 min
Localization A and B	White / Dark	Dark / White	Cal_ORDERDEF	7min
Flat-Field A and B	White / Dark	Dark / White	CAL_FLAT	37 min
Contam	Dark	FP	CAL_CONTAM	2 min
Wave_FP_FP	FP	FP	CAL_WAVE_FP	2 min
Wave_HC_FP	Hollow-Cathode	FP	CAL_WAVE_HC	20 min
Wave_FP_HC	FP	Hollow Cathode	CAL_WAVE_HC	20 min
Wave_HC_HC	Hollow-Cathode	Hollow-Cathode	CAL_WAVE_HC	20 min

6.4 HARPS+NIRPS observing templates

In order to define the science exposure for the simultaneous HARPS+NIRPS observation, the user must configure 5 parameters:

- HARPS_DET_UIT = [0 ….3600] (Exposure time in sec of one sub-exposure)
- HARPS_TPL_NEXP = [1 ….999] (Number of sub-exposures)
- NIRPS_DET_UIT = [5.57 …. 1000] (Exposure time in sec of one sub-exposure)
    - Exposure time cannot be shorter than 5.57s as this is the delay between two consecutive readouts. Exposure times longer than ~1000s are not recommended. As the detector is read continuously, integration times are always a multiple of the readout time (5.57s).
- NIRPS_TPL_NEXP = [1 … 999] (Number of sub-exposures)

HARPS_readMode = 416kHz,1,high / 104kHz,1,high

In order to optimize telescope time, integration times should be roughly matched to minimize overheads and the user must take care to adapt these 4 parameters in order to have:

HARPS_DET_UIT x HARPS_TPL_NEXP ≈ NIRPS_DET_UIT x NIRPS_TPL_NEXP

Furthermore, user should consider that NIRPS_DET_UIT > 1000s and HARPS_DET_UIT > 3600s are not recommended.

NIRPS_DET_DIT and DET_NDSAMPLES are computed automatically by the instrument control software with the following scheme:

If NIRPS_DET_UIT < 5.57 sec:

NIRPS_DET_NDSAMPLES = 2

NIRPS_DET_DIT = 5.57

If NIRPS_DET_UIT > 5.57 sec:

NIRPS_DET_NDSAMPLES = round (NIRPS_DET_UIT / 5.57) + 1

NIRPS_DET_DIT = 5.57 x (NIRPS_DET_NDSAMPLES -1)

6.5 NIRPS Acquisition

The preset of the telescope and target acquisition is first done with the telescope-HARPS TCCD. The target is selected by the TIO and the HARPS guiding (via a dedicated tip-tilt table) is launched on the TCCD. The TiO then selects and clicks and the target on the NIRPS guiding camera. It automatically centers the target in the WFS field of view, close the AO using the nominal parameter according to the I magnitude defined in the OB, and activates the guiding on the NIRPS fibre hole.

Pointing restrictions and weather limits are the usaul on applied on the 3.6m (see section 6.2.2 of HARPS User Manual)

The typical overhead for the NIRPS+HARPS acquisition is 5 min including telescope pointing and centering, target selection, HARPS TCCD guiding, instrument configuration, AO loop activated and NIRPS TCCD guiding.

Overhead can be found on the following link:

http://www.eso.org/sci/facilities/lasilla/cfp/cfp111/overheads.html

6.6 Night calibrations

A set of predefined spectrophotometric standards and telluric standards (fast rotating early type stars) are regularly observed during twilling. These observations are done by the TiO or under request.

7. SOFTWARE FOR AND END-TO-END OPERATION

The NIRPS instrument was designed along with a complete software suite. The final objective is to provide the observer with a complete science-graded dataset, increasing the efficiency and scientific output of the instrument. For this purpose, a software-cycle integrated view was adopted, from the preparation of the observations to the data reduction and analysis. The NIRPS Data Flow System (DFS) includes the following main components:

- ESO's p2 tool for Phase-2 preparation.
- Specific instrument control and observation templates: NIRPS is compliant with the usual VLT control software environment and concepts.
- The DRS (Data Reduction Software): a brief description is given below. The interested reader is referred to the corresponding reference documents for more detailed information.

7.1 *Data Reduction Software*

NIRPS is provided with a data-reduction software (DRS) pipeline to deliver high-quality science-grade reduced spectra. The final products of the DRS are extracted wavelength- calibrated spectra, along with the RV. If the fibre B is pointed to the sky, an additional data product provides sky-subtracted data; if fibre B is used for simultaneous RV monitoring, the drift is calculated and applied to the calculated RV. The extracted spectra can also be flux calibrated if associated to spectro-photometric standards.

See NIRPS Pipeline User Manual (NIRPS-4500-GEN-UM-211)

https://www.eso.org/sci/facilities/lasilla/instruments/nirps/doc.html

7.2 *NIRPS Data Flow*

The raw data are archived in the ESO archive and retrieved directly from there. The reduced data are archived in the ESO archive. NIR guiding camera pre-reduced images corresponding to the average of the guiding images taken during the NIRPS exposure are also archived as an HDU extension of the NIRPS raw image.

For NIRPS, the raw frame data rate is 32 Mb every 5.57 sec all the time during the entire night. Only the fitted ramps (raw data) are sent to the archive, which represents the data rate of 302.5 MB per exposure (including 4 fits extensions). Considering an exposure time of typically 5 minutes (+ 5 min overheads) and a maximum of 100 observations per night, the expected data rate is ~30 GB per night. To that, one needs to add the calibration files (45 files x 2 times per night), i.e. 90 files per night totalizing ~30 GB. The volume of data product (reduced data) for the 4 calibration sets is ~ 3 GB. The volume of data product (reduced data) for 1 science exposure is ~0.1 GB. The volume of data product (reduced data) for 1 typical night of science exposures is ~ 10 GB. The grand total of volume of data (raw data + reduced data) for NIRPS is then ~73 GB per night.