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	

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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:

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1.2 On-going upgrade of NIRPS

- The present version of the NIRPS user manual is based on the first NIRPS commissioning done in June 2022 and reflects the performances obtained at that time. Several upgrades of the instrument are on-going and will be completed by the start of P111 (April 2023):

- A new echelle grating already qualified and tested in lab was installed in July 2022. It presents a diffraction-limited image quality and an efficiency close to 70%. It will be tested on NIRPS in Sept-Oct 2022. We expect both a gain in spectral resolution and in throughput.
- The modal noise will be minimized by optimizing the scanning mode of the AO system at the fiber entrance.
- 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

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.

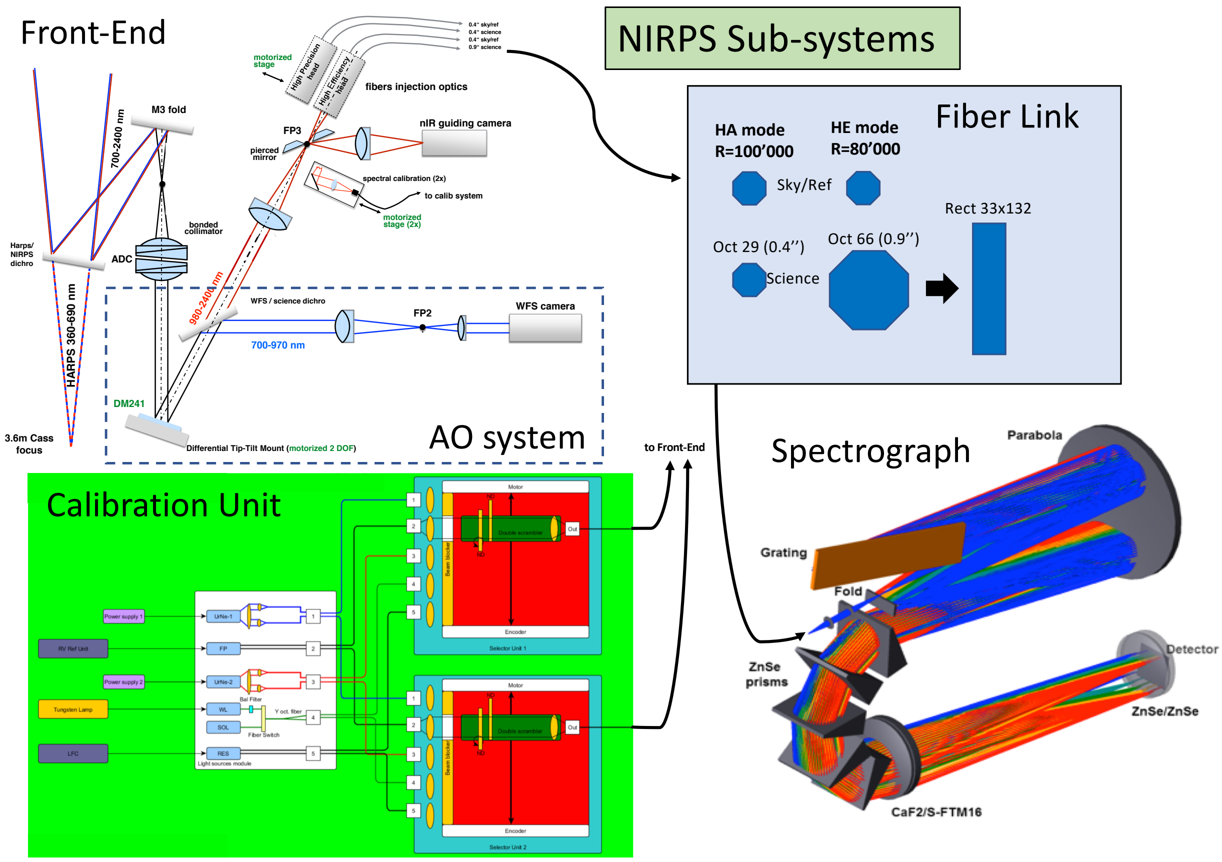

Figure 1 : NIRPS and its different subsystems: Front-End, Calibration Unit, Fiber Link and Spectrograph

Table 1 : Summary of NIRPS main properties

Subsystem	**Parameters**
HA mode	Spectral resolution $\lambda/\Delta\lambda$ = 82 000 (expected to be 100 000 with the upgraded grating) 0.4 arcsec object fibre, AO assisted feed 0.4 arcsec simultaneous reference fibre for sky or drift
HE mode	Spectral resolution $\lambda/\Delta\lambda$ = 75 000 (expected to be >80 000 with the upgraded grating) 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	0.971 – 1.854 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 0.75 m/s
Sampling	0.94 km/s per pixel, 3.9 pixels per FWHM
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.

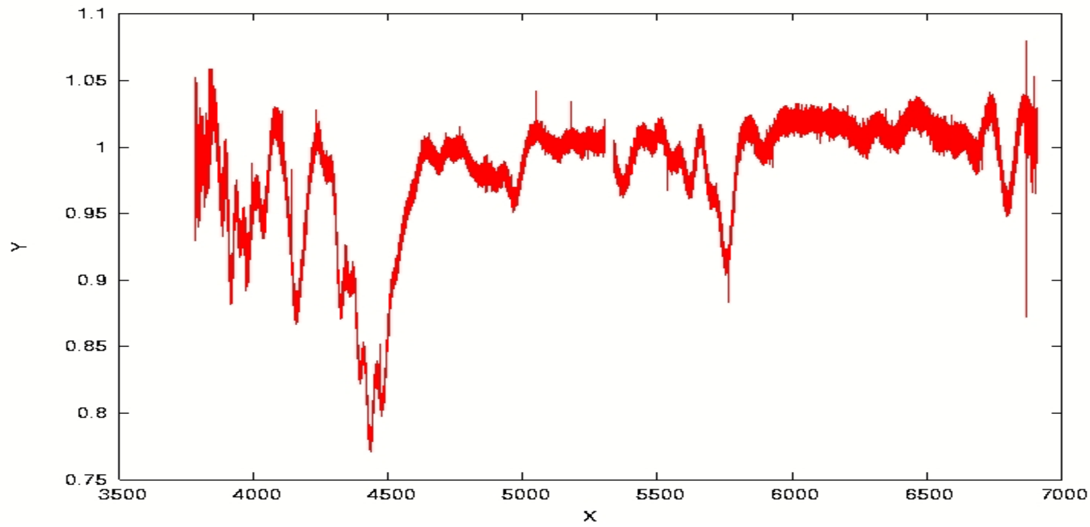

Figure 2 : Transmission of the VIS-NIRP dichroic as measured on sky on the star HR718 during COMM1

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. 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.

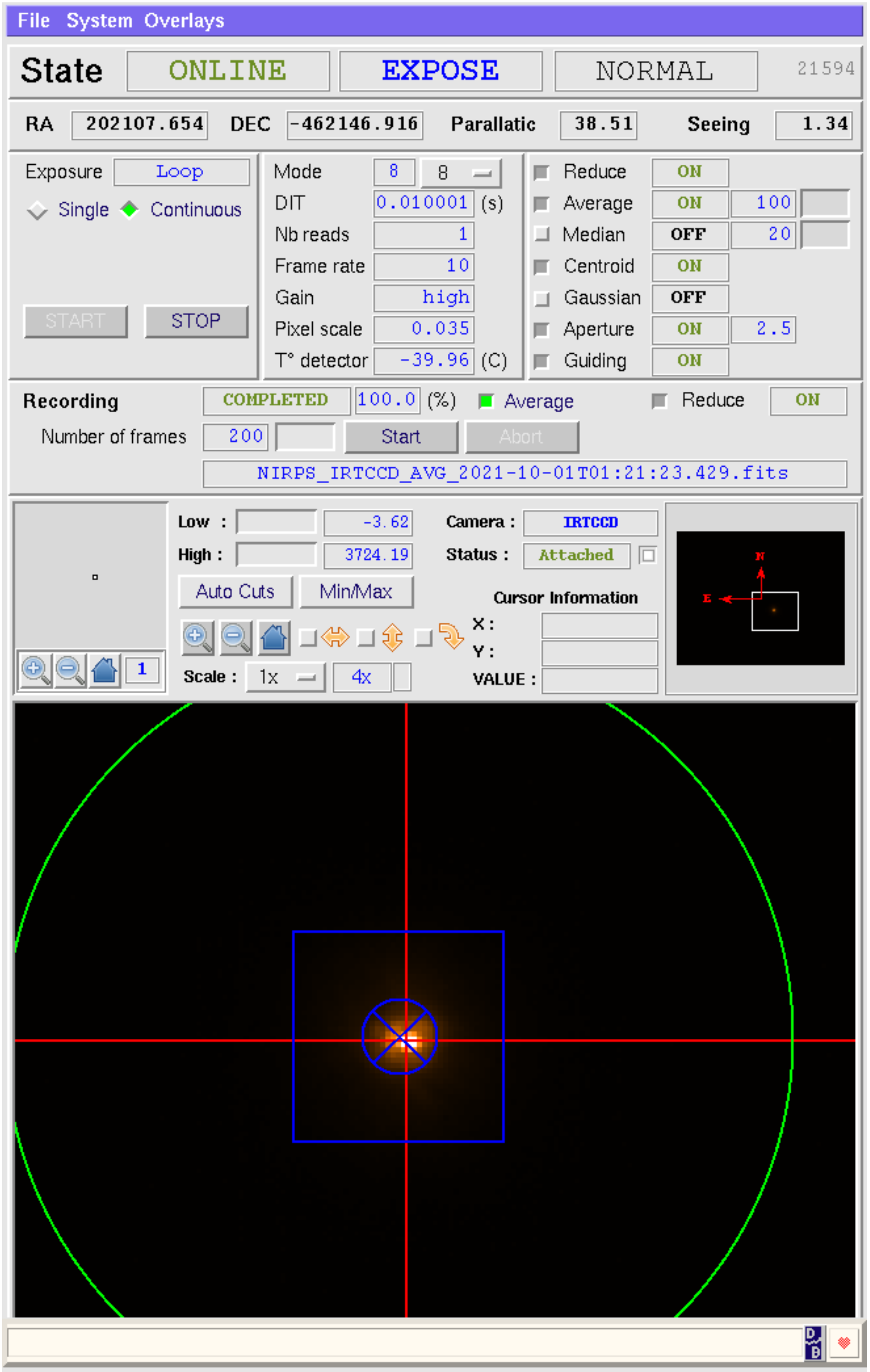

Figure 3 : Near-Infrared guiding camera window

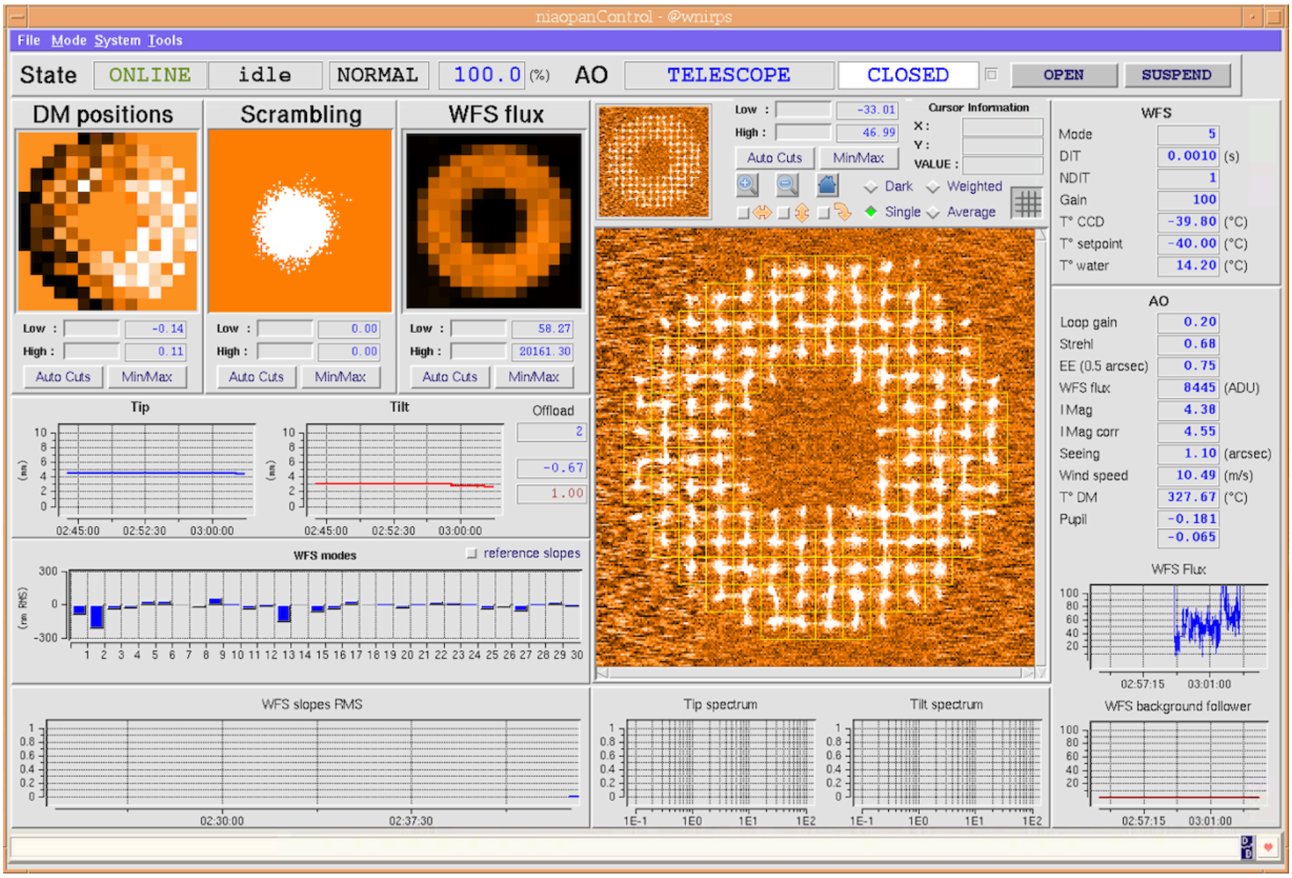

Figure 4 : NIRPS AO window

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 HA mode 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 82’000 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 75’000. 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.

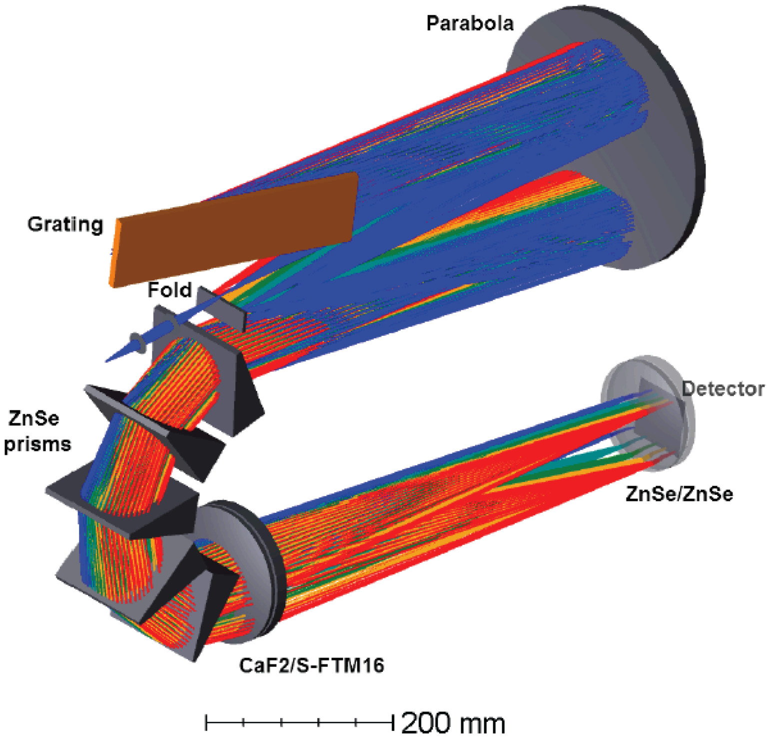

Figure 5 : optical light path of the spectrograph

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% @ 40600 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.

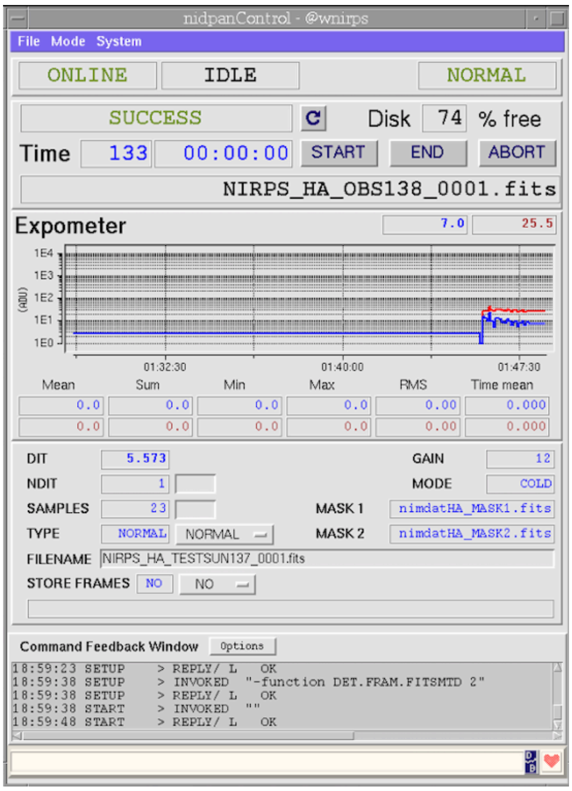

Figure 6 : Detector Software Control window

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.

For high RV precision, at the level of a few m/s, the usage of simultaneous drift reference is recommended. This is only necessary when the photon noise reached on the target is of the same level or smaller, otherwise photon noise on the target will be the limiting factor.

For RV targets with a photon noise larger than 3 m/s, targets for which no RV measurements are intended, or for sources for which a high spectral fidelity is preferable rather than tracking the instrument's internal drift, it is preferable to use the reference fibre to measure the sky spectra. 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 971nm to 1854nm, which is 70 orders in one single exposure. **Error! Reference source not found.** is showing the extracted spectrum for Proxima star.

Error! Reference source not found.

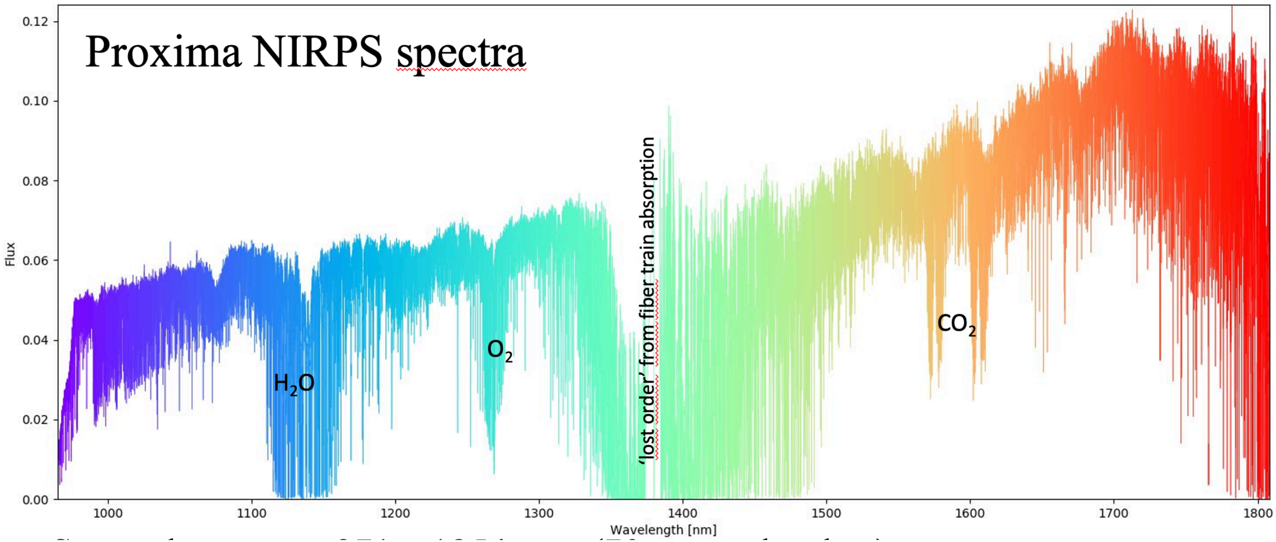

Figure 7 : NIRPS Proxima spectrum observed during COMM5 prior to telluric correction. Major telluric absorptions features are flagged. No useful signal is recovered around 1370 nm because of fibre train absorption; this domain would be useless even without this loss due to strong telluric water absorption.

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	149	254.1	254.1	2147	2167	2516(1012-3528)	2490(1017-3507)
2	148	331.1	331.1	2136	2109	2534(1016-3550)	2507(1010-3517)
3	147	407	407	2144	2136	2522(1011-3533)	2511(1000-3511)
4	146	482	482	2182	2172	2536(1000-3536)	2535(994-3529)
5	145	555.8	555.8	2169	2142	2544(1000-3544)	2542(990-3532)
6	144	628.8	628.8	2098	2133	2525(1004-3529)	2516(994-3510)

7	143	700.8	700.8	2175	2144	2540(988-3528)	2525(980-3505)
8	142	772	772	2139	2109	2562(973-3535)	2550(970-3520)
9	141	842.3	842.3	2100	2095	2588(962-3550)	2585(950-3535)
10	140	911.7	911.7	2163	2079	2618(943-3561)	2610(930-3540)
11	139	980.3	980.3	2058	2093	2637(928-3565)	2636(921-3557)
12	138	1048.1	1048.1	2137	2077	2653(912-3565)	2664(910-3574)
13	137	1115.2	1115.2	2148	2137	2684(907-3591)	2674(903-3577)
14	136	1181.4	1181.4	2120	2080	2704(896-3600)	2702(886-3588)
15	135	1246.9	1246.9	2155	2140	2706(886-3592)	2702(878-3580)
16	134	1311.6	1311.6	2123	2133	2717(877-3594)	2707(874-3581)
17	133	1375.7	1375.7	2089	2049	2711(878-3589)	2697(874-3571)
18	132	1439	1439	2129	2065	2718(866-3584)	2702(863-3565)
19	131	1501.6	1501.6	2072	2056	2736(856-3592)	2735(846-3581)
20	130	1563.5	1563.5	2038	2067	2753(844-3597)	2770(830-3600)
21	129	1624.8	1624.8	2102	2108	2792(822-3614)	2789(820-3609)
22	128	1685.4	1685.4	2046	2079	2815(813-3628)	2817(803-3620)
23	127	1745.4	1745.4	2120	2069	2857(796-3653)	2854(788-3642)
24	126	1804.7	1804.7	2094	2115	2876(784-3660)	2882(776-3658)
25	125	1863.5	1863.5	2146	2152	2901(763-3664)	2899(765-3664)
26	124	1921.6	1921.6	2171	2197	2923(747-3670)	2914(745-3659)
27	123	1979.1	1979.1	2188	2159	2943(728-3671)	2944(724-3668)
28	122	2036	2036	2155	2179	2965(723-3688)	2953(715-3668)
29	121	2092.4	2092.4	2145	2116	2967(718-3685)	2978(699-3677)
30	120	2148.1	2148.1	2135	2072	2994(704-3698)	2986(696-3682)
31	119	2203.4	2203.4	2045	2060	3002(680-3682)	3004(679-3683)
32	118	2258	2258	1879	1974	2980(591-3571)	3008(622-3630)
33	117	2312.2	2312.2	2044	1963	3212(580-3792)	3140(609-3749)
34	116	2365.8	2365.8	2091	2044	3153(709-3862)	3140(662-3802)
35	115	2418.9	2418.9	2110	2077	3165(665-3830)	3162(631-3793)
36	114	2471.4	2471.4	1983	1980	3209(603-3812)	3195(598-3793)
37	113	2523.4	2523.4	2041	2003	3240(570-3810)	3237(564-3801)
38	112	2574.9	2574.9	2093	2083	3233(557-3790)	3243(551-3794)
39	111	2626	2626	2010	2083	3218(538-3756)	3234(537-3771)
40	110	2676.6	2676.6	2037	2101	3214(506-3720)	3224(512-3736)
41	109	2726.6	2726.6	1983	2009	3236(430-3666)	3264(474-3738)
42	108	2776.3	2776.3	1991	1997	3326(391-3717)	3333(439-3772)
43	107	2825.3	2825.3	1893	1913	3029(334-3363)	3127(409-3536)

44	106	2873.9	2873.9	705	900	1514(1-1515)	1933(1-1934)
45	104	2969.8	2969.8	3177	2838	2408(1676-4084)	2916(1168-4084)
46	103	3017.2	3017.2	2640	2432	3068(1016-4084)	3345(739-4084)
47	102	3064	3064	2295	2249	3407(677-4084)	3571(513-4084)
48	101	3110.5	3110.5	2193	2217	3589(495-4084)	3657(427-4084)
49	100	3156.3	3156.3	2207	2246	3665(419-4084)	3717(367-4084)
50	99	3201.9	3201.9	2226	2099	3711(373-4084)	3740(344-4084)
51	98	3247	3247	2073	1973	3739(345-4084)	3781(303-4084)
52	97	3291.7	3291.7	2054	1918	3796(286-4082)	3791(293-4084)
53	96	3335.9	3335.9	2043	2195	3833(251-4084)	3835(249-4084)
54	95	3379.8	3379.8	2139	1978	3847(237-4084)	3851(233-4084)
55	94	3423.3	3423.3	1978	1994	3856(228-4084)	3865(219-4084)
56	93	3466.3	3466.3	1989	2004	3900(184-4084)	3906(178-4084)
57	92	3509	3509	1945	1946	3988(96-4084)	4009(75-4084)
58	91	3551.2	3551.2	2229	1967	4082(2-4084)	4077(7-4084)
59	90	3593.1	3593.1	2051	2061	4083(1-4084)	4083(1-4084)
60	89	3634.6	3634.6	2082	2129	4083(1-4084)	4083(1-4084)
61	88	3675.7	3675.7	2041	2158	4083(1-4084)	4083(1-4084)
62	87	3716.5	3716.5	2103	2119	4083(1-4084)	4083(1-4084)
63	86	3756.8	3756.8	1992	1951	4083(1-4084)	4083(1-4084)
64	85	3796.9	3796.9	1980	2088	4083(1-4084)	4083(1-4084)
65	84	3836.5	3836.5	2132	2063	4083(1-4084)	4083(1-4084)
66	83	3875.8	3875.8	1961	1946	4083(1-4084)	4083(1-4084)
67	82	3914.8	3914.8	1989	1961	4083(1-4084)	4083(1-4084)
68	81	3953.3	3953.3	1696	1686	4083(1-4084)	4083(1-4084)
69	80	3991.6	3991.6	1708	1741	4066(1-4067)	4062(1-4063)
70	79	4029.6	4029.6	1994	1919	4001(1-4002)	4005(1-4006)

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	149	978.2	978.3	7.6(974.5-982.1)	7.5(974.5-982.0)	12.5(970.9-983.4)	12.5(970.9-983.4)
2	148	984.8	984.7	7.6(981.1-988.8)	7.6(981.1-988.7)	12.6(977.5-990.0)	12.6(977.5-990.0)
3	147	991.5	991.5	7.7(987.8-995.4)	7.7(987.7-995.4)	12.7(984.1-996.8)	12.7(984.1-996.8)
4	146	998.4	998.4	7.8(994.5-1002.3)	7.8(994.5-1002.3)	12.8(990.8-1003.6)	12.8(990.8-1003.6)
5	145	1005.3	1005.2	7.9(1001.3-1009.2)	7.9(1001.3-1009.2)	12.9(997.7-1010.5)	12.9(997.7-1010.5)
6	144	1012	1012.1	7.9(1008.3-1016.2)	7.8(1008.3-1016.1)	13.0(1004.6-1017.5)	13.0(1004.6-1017.5)

7	143	1019.4	1019.3	8.0(1015.3-1023.3)	7.9(1015.3-1023.2)	13.0(1011.6-1024.7)	13.0(1011.6-1024.7)
8	142	1026.4	1026.3	8.1(1022.4-1030.5)	8.1(1022.4-1030.5)	13.1(1018.7-1031.9)	13.1(1018.7-1031.9)
9	141	1033.6	1033.6	8.2(1029.6-1037.9)	8.2(1029.6-1037.8)	13.2(1026.0-1039.2)	13.2(1026.0-1039.2)
10	140	1041.2	1040.9	8.4(1036.9-1045.3)	8.4(1036.9-1045.2)	13.3(1033.3-1046.6)	13.3(1033.3-1046.6)
11	139	1048.3	1048.4	8.5(1044.3-1052.8)	8.5(1044.3-1052.8)	13.4(1040.7-1054.2)	13.4(1040.7-1054.2)
12	138	1056.2	1056	8.7(1051.8-1060.5)	8.7(1051.8-1060.5)	13.5(1048.3-1061.8)	13.5(1048.3-1061.8)
13	137	1063.9	1063.9	8.8(1059.5-1068.3)	8.8(1059.5-1068.2)	13.6(1055.9-1069.6)	13.6(1055.9-1069.6)
14	136	1071.6	1071.5	8.9(1067.2-1076.2)	8.9(1067.2-1076.1)	13.7(1063.7-1077.4)	13.7(1063.7-1077.4)
15	135	1079.7	1079.6	9.0(1075.1-1084.1)	9.0(1075.1-1084.1)	13.8(1071.6-1085.4)	13.8(1071.6-1085.4)
16	134	1087.6	1087.7	9.1(1083.1-1092.2)	9.1(1083.1-1092.2)	13.9(1079.6-1093.5)	13.9(1079.6-1093.5)
17	133	1095.7	1095.6	9.2(1091.2-1100.4)	9.1(1091.2-1100.4)	14.0(1087.7-1101.7)	14.0(1087.7-1101.7)
18	132	1104.1	1103.9	9.3(1099.4-1108.7)	9.2(1099.4-1108.7)	14.2(1095.9-1110.1)	14.2(1095.9-1110.1)
19	131	1112.4	1112.3	9.4(1107.8-1117.2)	9.4(1107.8-1117.2)	14.3(1104.3-1118.5)	14.3(1104.3-1118.5)
20	130	1120.8	1120.9	9.5(1116.3-1125.8)	9.6(1116.2-1125.8)	14.4(1112.8-1127.1)	14.4(1112.8-1127.1)
21	129	1129.7	1129.7	9.7(1124.8-1134.6)	9.7(1124.8-1134.6)	14.5(1121.4-1135.9)	14.5(1121.4-1135.9)
22	128	1138.4	1138.5	9.9(1133.6-1143.5)	9.9(1133.6-1143.5)	14.6(1130.2-1144.8)	14.6(1130.2-1144.8)
23	127	1147.6	1147.4	10.1(1142.5-1152.6)	10.1(1142.4-1152.5)	14.7(1139.1-1153.8)	14.7(1139.1-1153.8)
24	126	1156.6	1156.7	10.3(1151.5-1161.7)	10.3(1151.4-1161.7)	14.8(1148.1-1162.9)	14.8(1148.1-1162.9)
25	125	1166	1166.1	10.4(1160.6-1171.0)	10.4(1160.6-1171.0)	14.9(1157.3-1172.2)	14.9(1157.3-1172.2)
26	124	1175.5	1175.6	10.6(1169.9-1180.5)	10.6(1169.9-1180.5)	15.0(1166.6-1181.7)	15.0(1166.6-1181.7)
27	123	1185.2	1185	10.8(1179.3-1190.1)	10.8(1179.3-1190.1)	15.1(1176.1-1191.3)	15.1(1176.1-1191.3)
28	122	1194.7	1194.8	10.9(1189.0-1199.9)	10.9(1188.9-1199.8)	15.3(1185.8-1201.0)	15.3(1185.8-1201.0)
29	121	1204.6	1204.5	11.0(1198.8-1209.8)	11.1(1198.7-1209.8)	15.4(1195.6-1211.0)	15.4(1195.6-1211.0)
30	120	1214.6	1214.3	11.2(1208.7-1219.9)	11.2(1208.7-1219.9)	15.5(1205.6-1221.1)	15.5(1205.6-1221.1)
31	119	1224.4	1224.5	11.4(1218.8-1230.1)	11.4(1218.8-1230.1)	15.6(1215.7-1231.3)	15.6(1215.7-1231.3)
32	118	1234.2	1234.5	11.5(1228.7-1240.2)	11.5(1228.8-1240.4)	15.8(1226.0-1241.7)	15.7(1226.0-1241.7)
33	117	1245.4	1245	12.3(1239.2-1251.5)	12.1(1239.3-1251.4)	15.9(1236.5-1252.4)	15.9(1236.5-1252.4)
34	116	1256.3	1256.1	12.1(1250.4-1262.5)	12.1(1250.2-1262.3)	16.0(1247.1-1263.2)	16.0(1247.1-1263.1)
35	115	1267.3	1267.2	12.3(1261.1-1273.4)	12.3(1261.0-1273.2)	16.1(1258.0-1274.1)	16.1(1258.0-1274.1)
36	114	1277.9	1277.9	12.6(1271.9-1284.5)	12.5(1271.9-1284.4)	16.3(1269.0-1285.3)	16.3(1269.0-1285.3)
37	113	1289.4	1289.3	12.8(1283.0-1295.8)	12.8(1283.0-1295.8)	16.4(1280.3-1296.7)	16.4(1280.3-1296.7)
38	112	1301.2	1301.1	12.9(1294.4-1307.3)	13.0(1294.4-1307.3)	16.5(1291.7-1308.2)	16.5(1291.7-1308.2)
39	111	1312.5	1312.8	13.0(1306.0-1319.0)	13.1(1306.0-1319.0)	16.7(1303.4-1320.0)	16.7(1303.4-1320.0)
40	110	1324.6	1324.8	13.2(1317.7-1330.9)	13.2(1317.7-1330.9)	16.8(1315.2-1332.0)	16.8(1315.2-1332.0)
41	109	1336.5	1336.6	13.5(1329.4-1342.9)	13.5(1329.6-1343.1)	17.0(1327.3-1344.2)	17.0(1327.3-1344.2)
42	108	1348.9	1348.9	14.0(1341.5-1355.5)	13.9(1341.8-1355.7)	17.1(1339.6-1356.7)	17.1(1339.6-1356.7)
43	107	1361.1	1361.2	13.1(1353.8-1366.9)	13.4(1354.2-1367.5)	17.2(1352.1-1369.4)	17.2(1352.1-1369.4)
44	106	1368.4	1369.4	7.4(1364.9-1372.3)	9.2(1364.9-1374.1)	17.5(1364.9-1382.4)	17.4(1364.9-1382.3)
45	104	1405.6	1404.3	9.5(1399.4-1408.8)	11.8(1397.0-1408.8)	17.7(1391.1-1408.8)	17.7(1391.1-1408.8)
46	103	1417.2	1416.3	12.7(1409.8-1422.5)	14.0(1408.5-1422.5)	17.9(1404.6-1422.5)	17.9(1404.7-1422.5)
47	102	1429.6	1429.4	14.5(1422.0-1436.4)	15.3(1421.1-1436.4)	18.0(1418.4-1436.4)	18.0(1418.4-1436.4)

48	101	1443.3	1443.4	15.6(1435.1-1450.7)	15.9(1434.7-1450.7)	18.2(1432.5-1450.7)	18.2(1432.5-1450.7)
49	100	1457.8	1458	16.1(1449.1-1465.2)	16.4(1448.8-1465.2)	18.4(1446.8-1465.2)	18.3(1446.8-1465.2)
50	99	1472.6	1472	16.5(1463.5-1480.0)	16.6(1463.3-1480.0)	18.5(1461.4-1480.0)	18.5(1461.4-1480.0)
51	98	1486.9	1486.5	16.8(1478.2-1495.1)	17.0(1478.0-1495.0)	18.7(1476.4-1495.1)	18.7(1476.4-1495.0)
52	97	1502.2	1501.5	17.3(1493.2-1510.4)	17.2(1493.2-1510.5)	18.9(1491.6-1510.5)	18.9(1491.6-1510.5)
53	96	1517.8	1518.5	17.6(1508.5-1526.2)	17.7(1508.5-1526.2)	19.0(1507.1-1526.2)	19.0(1507.1-1526.2)
54	95	1534.2	1533.4	17.9(1524.3-1542.2)	17.9(1524.3-1542.2)	19.2(1523.0-1542.2)	19.2(1523.0-1542.2)
55	94	1549.7	1549.8	18.1(1540.5-1558.6)	18.2(1540.5-1558.6)	19.4(1539.2-1558.6)	19.4(1539.2-1558.6)
56	93	1566.5	1566.5	18.6(1556.8-1575.4)	18.6(1556.8-1575.4)	19.6(1555.8-1575.4)	19.6(1555.8-1575.4)
57	92	1583.3	1583.3	19.2(1573.3-1592.5)	19.4(1573.1-1592.5)	19.8(1572.7-1592.5)	19.8(1572.7-1592.5)
58	91	1602.1	1600.8	20.0(1590.0-1610.0)	20.0(1590.0-1610.0)	20.0(1590.0-1610.0)	20.0(1590.0-1610.0)
59	90	1619	1619	20.2(1607.7-1627.9)	20.2(1607.7-1627.9)	20.2(1607.7-1627.9)	20.2(1607.7-1627.9)
60	89	1637.3	1637.6	20.4(1625.7-1646.2)	20.4(1625.8-1646.2)	20.4(1625.7-1646.2)	20.4(1625.8-1646.2)
61	88	1655.7	1656.3	20.6(1644.2-1664.9)	20.6(1644.2-1664.9)	20.6(1644.2-1664.9)	20.6(1644.2-1664.9)
62	87	1675.1	1675.1	20.8(1663.1-1684.0)	20.8(1663.1-1684.0)	20.8(1663.1-1684.0)	20.8(1663.1-1684.0)
63	86	1694	1693.7	21.1(1682.5-1703.6)	21.1(1682.5-1703.6)	21.1(1682.5-1703.6)	21.1(1682.5-1703.6)
64	85	1713.8	1714.4	21.3(1702.3-1723.6)	21.3(1702.3-1723.6)	21.3(1702.3-1723.6)	21.3(1702.3-1723.6)
65	84	1735	1734.7	21.5(1722.6-1744.1)	21.5(1722.6-1744.1)	21.5(1722.6-1744.1)	21.5(1722.6-1744.1)
66	83	1755	1754.9	21.8(1743.3-1765.1)	21.8(1743.3-1765.1)	21.8(1743.3-1765.1)	21.8(1743.3-1765.1)
67	82	1776.6	1776.4	22.0(1764.6-1786.6)	22.0(1764.6-1786.6)	22.0(1764.6-1786.6)	22.0(1764.6-1786.6)
68	81	1796.9	1796.8	22.3(1786.4-1808.7)	22.2(1786.4-1808.7)	22.3(1786.4-1808.7)	22.2(1786.4-1808.7)
69	80	1819.4	1819.6	22.4(1808.8-1831.2)	22.4(1808.8-1831.2)	22.5(1808.8-1831.3)	22.5(1808.8-1831.3)
70	79	1844.1	1843.6	22.4(1831.7-1854.1)	22.4(1831.7-1854.1)	22.8(1831.7-1854.4)	22.8(1831.7-1854.4)

Table 5 : High Efficiency 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	149	255.7	255.7	2145	2160	2518(983-3501)	2498(950-3448)
2	148	332.7	332.7	2136	2091	2529(987-3516)	2505(945-3450)
3	147	408.6	408.6	2133	2110	2512(979-3491)	2515(935-3450)
4	146	483.6	483.6	2167	2060	2535(972-3507)	2545(930-3475)
5	145	557.4	557.4	2125	2055	2544(972-3516)	2526(925-3451)
6	144	630.3	630.3	2100	2115	2519(970-3489)	2515(922-3437)
7	143	702.3	702.3	2132	2064	2534(956-3490)	2531(912-3443)
8	142	773.5	773.5	2137	2018	2557(944-3501)	2557(902-3459)

9	141	843.8	843.8	2102	2101	2591(928-3519)	2589(886-3475)
10	140	913.2	913.2	2080	2036	2606(918-3524)	2612(867-3479)
11	139	981.8	981.8	2055	2042	2642(892-3534)	2611(853-3464)
12	138	1049.6	1049.6	2085	2056	2659(878-3537)	2661(839-3500)
13	137	1116.5	1116.5	2103	2008	2683(872-3555)	2673(834-3507)
14	136	1182.8	1182.8	2075	2071	2700(857-3557)	2696(816-3512)
15	135	1248.3	1248.3	2049	2090	2709(844-3553)	2696(806-3502)
16	134	1313.1	1313.1	2061	2016	2707(838-3545)	2699(799-3498)
17	133	1377.1	1377.1	2016	2015	2692(842-3534)	2702(794-3496)
18	132	1440.3	1440.3	2027	2012	2712(828-3540)	2724(786-3510)
19	131	1503	1503	2070	2054	2739(814-3553)	2749(779-3528)
20	130	1564.8	1564.8	2038	2026	2765(805-3570)	2764(771-3535)
21	129	1626.2	1626.2	2057	2070	2788(791-3579)	2795(754-3549)
22	128	1686.7	1686.7	2070	2042	2811(777-3588)	2817(740-3557)
23	127	1746.7	1746.7	2063	2038	2853(755-3608)	2859(716-3575)
24	126	1806	1806	2053	2062	2892(738-3630)	2879(706-3585)
25	125	1864.7	1864.7	2129	2090	2911(722-3633)	2912(688-3600)
26	124	1922.8	1922.8	2096	2151	2931(705-3636)	2930(667-3597)
27	123	1980.3	1980.3	2158	2120	2949(688-3637)	2962(645-3607)
28	122	2037.2	2037.2	2155	2076	2960(685-3645)	2975(641-3616)
29	121	2093.6	2093.6	2130	2005	2987(675-3662)	2987(638-3625)
30	120	2149.4	2149.4	2043	2050	2996(670-3666)	2984(637-3621)
31	119	2204.6	2204.6	2016	1975	3009(651-3660)	3008(607-3615)
32	118	2259.2	2259.2	1995	1913	3031(587-3618)	3022(546-3568)
33	117	2313.4	2313.4	2000	1936	3157(578-3735)	3154(535-3689)
34	116	2366.9	2366.9	2013	1994	3144(638-3782)	3146(598-3744)
35	115	2420	2420	2074	2065	3162(609-3771)	3166(560-3726)
36	114	2472.6	2472.6	2006	1946	3210(566-3776)	3204(519-3723)
37	113	2524.6	2524.6	2039	2000	3252(535-3787)	3237(495-3732)
38	112	2576.1	2576.1	2075	2045	3243(524-3767)	3245(483-3728)
39	111	2627.1	2627.1	2069	1988	3227(523-3750)	3247(468-3715)
40	110	2677.7	2677.7	2024	2017	3236(496-3732)	3238(444-3682)
41	109	2727.7	2727.7	2015	1937	3265(452-3717)	3272(396-3668)
42	108	2777.3	2777.3	1978	1969	3328(417-3745)	3331(363-3694)

43	107	2826.3	2826.3	1968	1844	3150(374-3524)	3159(318-3477)
44	106	2874.6	2874.6	948	859	1981(1-1982)	1884(1-1885)
45	104	2971	2971	2620	2509	2948(1136-4084)	2981(1103-4084)
46	103	3018.3	3018.3	2123	2341	3391(693-4084)	3416(668-4084)
47	102	3065.1	3065.1	2231	2220	3590(494-4084)	3639(445-4084)
48	101	3111.3	3111.3	2179	2215	3687(397-4084)	3737(347-4084)
49	100	3157.3	3157.3	2235	2178	3740(344-4084)	3750(290-4040)
50	99	3202.9	3202.9	2178	2066	3776(308-4084)	3737(272-4009)
51	98	3247.9	3247.9	2127	1968	3796(288-4084)	3846(238-4084)
52	97	3292.7	3292.7	1999	1929	3836(247-4083)	3901(183-4084)
53	96	3336.9	3336.9	1989	1979	3869(215-4084)	3938(146-4084)
54	95	3380.8	3380.8	2014	1947	3889(195-4084)	3888(125-4013)
55	94	3424.2	3424.2	1990	1984	3905(179-4084)	3962(122-4084)
56	93	3467.2	3467.2	1978	1972	3947(137-4084)	4083(1-4084)
57	92	3509.9	3509.9	1947	1981	4057(27-4084)	4083(1-4084)
58	91	3552.1	3552.1	2218	2010	4083(1-4084)	4083(1-4084)
59	90	3594	3594	2037	2005	4083(1-4084)	4083(1-4084)
60	89	3635.5	3635.5	2113	2074	4083(1-4084)	4083(1-4084)
61	88	3676.6	3676.6	2046	2121	4083(1-4084)	4083(1-4084)
62	87	3717.3	3717.3	2076	2069	4083(1-4084)	4083(1-4084)
63	86	3757.6	3757.6	1996	1968	4083(1-4084)	4083(1-4084)
64	85	3797.6	3797.6	1946	2082	4083(1-4084)	4083(1-4084)
65	84	3837.3	3837.3	2046	1826	4083(1-4084)	4083(1-4084)
66	83	3876.5	3876.5	2065	2009	4083(1-4084)	4083(1-4084)
67	82	3915.4	3915.4	1997	1751	4083(1-4084)	4081(1-4082)
68	81	3954	3954	1733	1636	4083(1-4084)	4064(1-4065)
69	80	3992.2	3992.2	1683	1682	4083(1-4084)	4007(1-4008)
70	79	4030.2	4030.2	1729	1799	4051(1-4052)	3959(1-3960)

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	149	978.3	978.4	7.6(974.5-982.1)	7.6(974.5-982.0)	12.5(971.0-983.5)	12.5(971.1-983.6)
2	148	984.9	984.8	7.7(981.1-988.8)	7.6(981.0-988.7)	12.6(977.6-990.1)	12.6(977.6-990.2)
3	147	991.6	991.6	7.7(987.8-995.4)	7.7(987.7-995.4)	12.7(984.2-996.9)	12.7(984.3-997.0)
4	146	998.5	998.2	7.8(994.5-1002.3)	7.9(994.4-1002.3)	12.8(990.9-1003.7)	12.8(991.0-1003.8)
5	145	1005.2	1005.1	7.9(1001.4-1009.2)	7.9(1001.3-1009.2)	12.9(997.8-1010.6)	12.9(997.9-1010.7)
6	144	1012.1	1012.3	7.9(1008.3-1016.2)	7.9(1008.2-1016.1)	13.0(1004.7-1017.7)	13.0(1004.8-1017.7)
7	143	1019.3	1019.2	8.0(1015.3-1023.3)	8.0(1015.2-1023.3)	13.0(1011.7-1024.8)	13.1(1011.8-1024.9)
8	142	1026.5	1026.2	8.1(1022.4-1030.5)	8.2(1022.3-1030.5)	13.1(1018.9-1032.0)	13.1(1018.9-1032.1)
9	141	1033.7	1033.8	8.3(1029.6-1037.9)	8.3(1029.5-1037.9)	13.2(1026.1-1039.3)	13.2(1026.2-1039.4)
10	140	1041	1040.9	8.4(1036.9-1045.3)	8.5(1036.8-1045.3)	13.3(1033.4-1046.7)	13.3(1033.5-1046.8)
11	139	1048.4	1048.4	8.6(1044.3-1052.9)	8.5(1044.2-1052.8)	13.4(1040.8-1054.3)	13.4(1040.9-1054.4)
12	138	1056.1	1056.1	8.7(1051.8-1060.5)	8.8(1051.7-1060.5)	13.5(1048.4-1061.9)	13.5(1048.5-1062.0)
13	137	1063.9	1063.6	8.8(1059.5-1068.3)	8.9(1059.4-1068.2)	13.6(1056.0-1069.7)	13.6(1056.1-1069.8)
14	136	1071.6	1071.7	9.0(1067.2-1076.2)	9.0(1067.2-1076.2)	13.7(1063.8-1077.5)	13.7(1063.9-1077.7)
15	135	1079.5	1079.7	9.1(1075.0-1084.1)	9.1(1075.0-1084.1)	13.8(1071.7-1085.5)	13.8(1071.8-1085.6)
16	134	1087.6	1087.5	9.1(1083.0-1092.2)	9.2(1083.0-1092.1)	13.9(1079.7-1093.6)	13.9(1079.8-1093.7)
17	133	1095.6	1095.7	9.2(1091.2-1100.4)	9.2(1091.1-1100.3)	14.0(1087.8-1101.8)	14.0(1087.9-1101.9)
18	132	1103.9	1103.9	9.3(1099.4-1108.7)	9.4(1099.3-1108.7)	14.2(1096.0-1110.2)	14.2(1096.1-1110.3)
19	131	1112.5	1112.5	9.5(1107.8-1117.2)	9.5(1107.7-1117.2)	14.3(1104.4-1118.7)	14.3(1104.5-1118.8)
20	130	1120.9	1121	9.6(1116.2-1125.9)	9.7(1116.2-1125.8)	14.4(1112.9-1127.3)	14.4(1113.0-1127.4)
21	129	1129.7	1129.8	9.8(1124.8-1134.6)	9.8(1124.8-1134.6)	14.5(1121.5-1136.0)	14.5(1121.6-1136.1)
22	128	1138.6	1138.6	9.9(1133.6-1143.5)	10.0(1133.5-1143.5)	14.6(1130.3-1144.9)	14.6(1130.4-1145.0)
23	127	1147.5	1147.5	10.2(1142.4-1152.6)	10.2(1142.3-1152.6)	14.7(1139.2-1153.9)	14.7(1139.3-1154.0)
24	126	1156.6	1156.7	10.4(1151.4-1161.8)	10.4(1151.4-1161.7)	14.8(1148.3-1163.1)	14.8(1148.3-1163.1)
25	125	1166.1	1166.1	10.5(1160.6-1171.1)	10.6(1160.5-1171.1)	14.9(1157.4-1172.4)	14.9(1157.5-1172.4)
26	124	1175.4	1175.7	10.7(1169.8-1180.5)	10.7(1169.8-1180.5)	15.0(1166.8-1181.8)	15.0(1166.9-1181.9)
27	123	1185.2	1185.1	10.8(1179.3-1190.1)	10.9(1179.2-1190.1)	15.1(1176.3-1191.4)	15.1(1176.4-1191.5)
28	122	1194.9	1194.7	11.0(1188.9-1199.9)	11.1(1188.8-1199.9)	15.3(1185.9-1201.2)	15.3(1186.0-1201.3)
29	121	1204.7	1204.3	11.1(1198.7-1209.9)	11.2(1198.7-1209.8)	15.4(1195.7-1211.1)	15.4(1195.8-1211.2)
30	120	1214.4	1214.5	11.3(1208.7-1220.0)	11.3(1208.6-1219.9)	15.5(1205.7-1221.2)	15.5(1205.8-1221.3)
31	119	1224.5	1224.4	11.4(1218.8-1230.2)	11.5(1218.7-1230.1)	15.6(1215.8-1231.5)	15.6(1215.9-1231.5)
32	118	1234.8	1234.5	11.7(1228.8-1240.5)	11.7(1228.7-1240.4)	15.8(1226.1-1241.9)	15.7(1226.2-1242.0)
33	117	1245.3	1245.2	12.2(1239.3-1251.5)	12.2(1239.2-1251.4)	15.9(1236.6-1252.5)	15.9(1236.7-1252.6)
34	116	1256.1	1256.1	12.1(1250.2-1262.4)	12.2(1250.2-1262.4)	16.0(1247.3-1263.3)	16.0(1247.4-1263.4)
35	115	1267.3	1267.3	12.3(1261.0-1273.3)	12.4(1260.9-1273.3)	16.1(1258.1-1274.3)	16.1(1258.2-1274.4)
36	114	1278.1	1278	12.6(1271.9-1284.5)	12.7(1271.7-1284.4)	16.3(1269.2-1285.4)	16.3(1269.3-1285.5)
37	113	1289.6	1289.5	12.9(1283.0-1295.9)	12.9(1282.9-1295.8)	16.4(1280.4-1296.8)	16.4(1280.5-1296.9)

38	112	1301.2	1301.2	13.0(1294.4-1307.4)	13.1(1294.3-1307.4)	16.5(1291.9-1308.4)	16.5(1292.0-1308.5)
39	111	1312.9	1312.7	13.1(1306.0-1319.1)	13.2(1305.9-1319.1)	16.7(1303.5-1320.2)	16.7(1303.6-1320.3)
40	110	1324.7	1324.7	13.3(1317.8-1331.0)	13.3(1317.6-1331.0)	16.8(1315.4-1332.2)	16.8(1315.5-1332.3)
41	109	1336.8	1336.6	13.5(1329.7-1343.2)	13.6(1329.5-1343.1)	17.0(1327.4-1344.4)	17.0(1327.5-1344.5)
42	108	1349	1349.1	13.9(1341.8-1355.7)	14.0(1341.7-1355.7)	17.1(1339.7-1356.8)	17.1(1339.8-1356.9)
43	107	1361.6	1361.1	13.5(1354.1-1367.6)	13.6(1354.0-1367.6)	17.2(1352.3-1369.5)	17.2(1352.4-1369.6)
44	106	1369.8	1369.4	9.5(1365.0-1374.5)	9.0(1365.1-1374.2)	17.4(1365.0-1382.4)	17.4(1365.1-1382.5)
45	104	1403.6	1403.3	12.0(1397.0-1409.0)	12.1(1397.0-1409.1)	17.7(1391.3-1409.0)	17.7(1391.4-1409.1)
46	103	1415.1	1416.2	14.3(1408.4-1422.7)	14.4(1408.4-1422.8)	17.9(1404.8-1422.7)	17.9(1404.9-1422.8)
47	102	1429.5	1429.5	15.4(1421.2-1436.6)	15.7(1421.0-1436.7)	18.0(1418.6-1436.6)	18.0(1418.7-1436.7)
48	101	1443.4	1443.7	16.1(1434.7-1450.8)	16.3(1434.6-1450.9)	18.2(1432.6-1450.8)	18.2(1432.8-1450.9)
49	100	1458.1	1457.9	16.5(1448.8-1465.3)	16.6(1448.6-1465.3)	18.4(1447.0-1465.3)	18.3(1447.1-1465.4)
50	99	1472.5	1472.2	16.8(1463.3-1480.1)	16.8(1463.2-1480.0)	18.5(1461.6-1480.1)	18.5(1461.7-1480.2)
51	98	1487.3	1486.7	17.1(1478.1-1495.2)	17.4(1477.9-1495.3)	18.7(1476.5-1495.2)	18.7(1476.6-1495.3)
52	97	1502.1	1501.9	17.5(1493.1-1510.6)	17.8(1492.9-1510.7)	18.9(1491.8-1510.6)	18.9(1491.9-1510.7)
53	96	1517.7	1517.7	17.8(1508.5-1526.4)	18.2(1508.2-1526.5)	19.0(1507.3-1526.4)	19.0(1507.4-1526.5)
54	95	1533.8	1533.6	18.1(1524.3-1542.4)	18.3(1524.0-1542.3)	19.2(1523.2-1542.4)	19.2(1523.3-1542.5)
55	94	1550	1550.1	18.4(1540.4-1558.8)	18.7(1540.2-1558.9)	19.4(1539.4-1558.8)	19.4(1539.5-1558.9)
56	93	1566.6	1566.7	18.8(1556.7-1575.6)	19.6(1556.1-1575.7)	19.6(1556.0-1575.6)	19.6(1556.1-1575.7)
57	92	1583.5	1583.7	19.7(1573.0-1592.7)	19.8(1573.0-1592.8)	19.8(1572.9-1592.7)	19.8(1573.0-1592.8)
58	91	1602.2	1601.3	20.0(1590.2-1610.2)	20.0(1590.3-1610.3)	20.0(1590.2-1610.2)	20.0(1590.3-1610.3)
59	90	1619.1	1619	20.2(1607.9-1628.1)	20.2(1608.0-1628.2)	20.2(1607.9-1628.1)	20.2(1608.0-1628.2)
60	89	1637.7	1637.6	20.4(1625.9-1646.3)	20.4(1626.1-1646.5)	20.4(1625.9-1646.3)	20.4(1626.1-1646.5)
61	88	1655.9	1656.4	20.6(1644.4-1665.0)	20.6(1644.5-1665.2)	20.6(1644.4-1665.0)	20.6(1644.5-1665.2)
62	87	1675.1	1675.2	20.8(1663.3-1684.2)	20.8(1663.5-1684.3)	20.8(1663.3-1684.2)	20.8(1663.5-1684.3)
63	86	1694.2	1694.2	21.1(1682.7-1703.7)	21.1(1682.8-1703.9)	21.1(1682.7-1703.7)	21.1(1682.8-1703.9)
64	85	1713.8	1714.7	21.3(1702.5-1723.8)	21.3(1702.6-1723.9)	21.3(1702.5-1723.8)	21.3(1702.6-1723.9)
65	84	1734.8	1733.7	21.5(1722.8-1744.3)	21.5(1722.9-1744.4)	21.5(1722.8-1744.3)	21.5(1722.9-1744.4)
66	83	1755.8	1755.6	21.8(1743.5-1765.3)	21.8(1743.7-1765.4)	21.8(1743.5-1765.3)	21.8(1743.7-1765.4)
67	82	1776.8	1775.6	22.0(1764.8-1786.8)	22.0(1764.9-1786.9)	22.0(1764.8-1786.8)	22.0(1764.9-1786.9)
68	81	1797.3	1796.9	22.3(1786.6-1808.9)	22.2(1786.7-1808.9)	22.3(1786.6-1808.9)	22.2(1786.7-1809.0)
69	80	1819.5	1819.6	22.5(1809.0-1831.5)	22.2(1809.1-1831.3)	22.5(1809.0-1831.5)	22.5(1809.1-1831.6)
70	79	1842.7	1843.3	22.6(1831.9-1854.5)	22.2(1832.0-1854.2)	22.8(1831.9-1854.6)	22.8(1832.0-1854.8)

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.

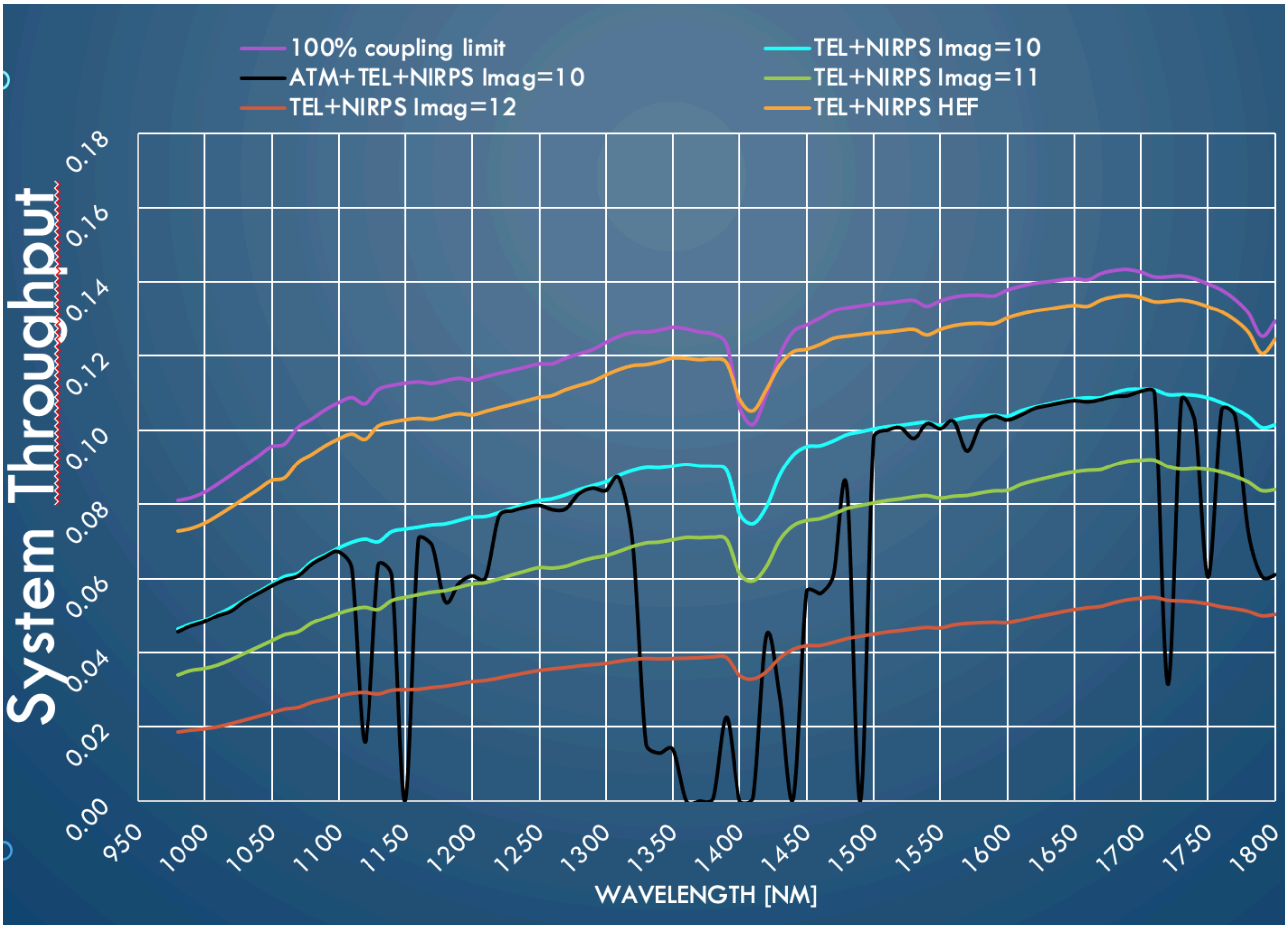

Figure 8 : Expected total system efficiency

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

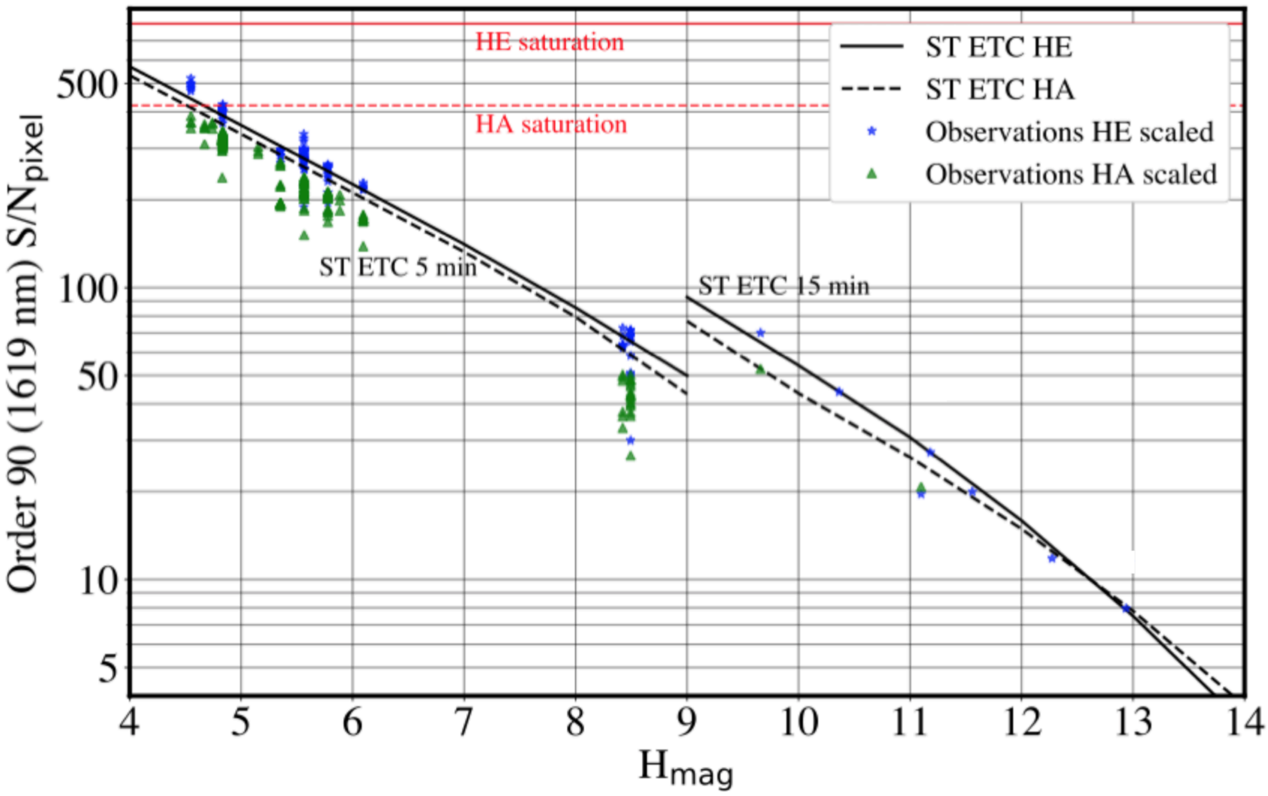

Figure 9 : SNR per pixel at 1619nm as function of H magnitude as observed during COMM5 (June 2022).

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 (July 2022), it remains less constrained than other instrument properties. The user should keep this in mind when planning observations in the first semester P111 (April 2023) and check for updates of this document and the NIRPS web page where we will report progress from upcoming commissionings in late-2022.

The June 2022 commissioning demonstrated that NIRPS is capable of providing a 3 m/s RMS for a bright target (Barnard's star) 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 ~1 % 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. Late in the June-2022 commissioning we found means of much reducing this 'noise' by tweaking the AO behavior, but no pRV timeseries has been obtained since. Furthermore, these values have been obtained with a echelle grating known be suboptimal with increased scattered light and degraded resolution. A new grating has been procured and is now in NIRPS, but we have yet to obtain on-sky data with it. This grating is expected to reduce the fixed noise and to increase both the throughput and the spectral resolution significantly.

Overall, prior to any further on-sky confirmation, it would be advisable not to propose a science program for which <3 m/s velocimetry precision is required, keeping in mind that this value is expected to be revised in the near-future.

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. 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.