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Near-InfraRed Planet Searcher to Join HARPS on the ESO 3.6-metre Telescope

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The Near-InfraRed Planet Searcher (NIRPS) is a new ultra-stable infrared (*YJH*) spectrograph that will be installed on ESO's 3.6-metre Telescope in La Silla, Chile. Aiming to achieve a precision of 1 m s^{-1}, NIRPS is designed to find rocky planets orbiting M dwarfs, and will operate together with the High Accuracy Radial velocity Planet Searcher (HARPS), also on the 3.6-metre Telescope. In this article we describe the NIRPS science cases and present its main technical characteristics.

In the past two decades, the study of exoplanets has matured from a largely speculative endeavour to the forefront of astronomy. It has moved from the discovery of a handful of massive, close-in giants, called hot Jupiters, to uncovering various populations of planets unlike anything known in our own Solar System (Mayor et al., 2014). Great strides have been made in our understanding of exoplanets, but one notable goal remains to be achieved: the characterisation of terrestrial planets in the temperate zone around a star. While the study of such planets around Sun-like stars is exceedingly challenging with existing facilities, the diminutive red dwarfs offer a significant observational shortcut; their smaller radii, lower temperatures, lower masses and the relatively short orbital periods of planets in their temperate zones make them much easier targets for this type of study.

In response to an ESO call for new instruments for the New Technology Telescope (NTT), the NIRPS consortium proposed a dedicated near-infrared spectrograph to undertake an ambitious survey of planetary systems around M dwarfs. This would nicely complement the surveys that have been running for a decade on HARPS by enlarging the sample of M dwarfs that can be observed, while providing better stellar activity filtering. After the selection of the SOXS[1] (Son Of X-Shooter) spectrograph for the NTT, it was clear that the exoplanet community in the Member States needed another facility to maintain the leadership built over the last decade thanks, to a large extent, to HARPS. Therefore in May 2015, ESO invited the NIRPS team to adapt the original NIRPS design to the Cassegrain focus of the ESO 3.6-metre Telescope in La Silla for simultaneous observation with the HARPS spectrograph.

In order to be in phase with future space missions such as the Transiting Exoplanet Survey Satellite (TESS), the CHaracterising ExOPlanets Satellite (CHEOPS), the James Webb Space Telescope (JWST) and the PLAnetary Transits and Oscillations of stars (PLATO), NIRPS is being developed on a fast track, its first light is scheduled for the last quarter of 2019. As of mid-2017 the design of the instrument has been finalised and construction has started.

La Silla Paranal Observatory: a hub for extrasolar planet research

Our knowledge of the frequency of planets, the architecture of planetary systems and their nature (mass, size, bulk composition, atmosphere) has been revolutionised in the last two decades thanks to various detection techniques providing complementary measurements. Observational efforts were undertaken with ground- and space-based facilities, notably radial velocity (RV) surveys using high-precision spectrographs and transit surveys from space satellites (Convection, Rotation et Transits planétaires, CoRoT, and Kepler) and from ground-based projects (for example, the Wide Angle Search for Planets, WASP, and the Hungarian Automated Telescope system, HAT). The forthcoming space armada, initiated by the launch of JWST, TESS and CHEOPS in 2018, and PLATO in 2026, will only spark a new revolution in the field of extrasolar planets if it is complemented by efficient ground-based facilities. The La Silla Paranal Observatory has a key role to play as it already hosts prime ground-based planet-finding facilities. These instruments predominantly approach exoplanet study through radial velocity measurements (using, for example, the High Accuracy Radial velocity Planet Searcher, HARPS, CORALIE and the forthcoming Echelle SPectrograph for Rocky Exoplanet and Stable Spectroscopic Observations, ESPRESSO), through detecting and monitoring transits (for example, the Next-Generation Transit Survey, NGTS), and through high-contrast imaging (using the Spectro-Polarimetric High-contrast Exoplanet REsearch instrument, SPHERE, and the planned Planetary Camera and Spectrograph on ESO's Extemely Large Telescope, ELT). NIRPS will enable complementary precise RV measurements in the near-infrared with a precision of 1 m s^{-1}, specifically targeting the detection of low-mass planets around the coolest stars. The NIRPS survey will provide an in-depth monitoring of all southern nearby M dwarfs, complementing large-scale surveys that probe > 1000 M dwarfs for giant planets and brown dwarf companions, such as the Apache Point Observatory Galaxy Evolution Experiment (APOGEE; Deshpande et al., 2013).

M dwarfs: a shortcut to habitability and life

The detection of life beyond Earth is arguably still a few decades away, and will require substantial further technical developments. Regardless of how distant the detection of signs of life might be, the roadmap leading to it has already been traced and consists of well-defined sequential steps:

- Finding transiting or directly imageable planets in the habitable zone of cool stars using ground- and space-based surveys and characterising their orbits, masses, density and bulk composition;
- Characterising planetary atmospheres from space (or from the ground in the most favourable cases);
- Seeking chemical imbalances as tracers of potential biosignatures.

While the detection of an Earth analogue around a Sun-like star requires a precision of better than 10 cm s^{-1}, M dwarfs offer a more accessible and attractive means of achieving the above goals. The amplitude of the RV signal scales with $m^{-2/3}$, where m 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 receiving an Earth-like insolation (i.e., the amount of energy per area per time at this orbital separation, amounting to about 1360 W m^{-2} for the Earth), this RV signal is on the order of 1 m s^{-1} and therefore detectable with state-of-the-art RV spectrographs. As M dwarfs are cool and emit most of their flux in the near-infrared, one ideally needs to obtain RV measurements in this domain to reach the highest possible precision. Furthermore, for a fixed planetary radius, the depth of a planetary transit scales with r^{-2} (where r is the stellar radius), making transit follow-ups of Earth-sized planets around low-mass stars significantly easier.

Although HARPS was optimised to obtain high precision radial velocity measurements for Sun-like G and K dwarfs, a large fraction of HARPS nights over the last decade were allocated to monitor M dwarfs. Following the discovery of a Neptune-like planet around the M3V star Gl581 (Bonfils et al., 2005) more than a decade ago, a large number of planets were uncovered around M dwarfs despite the fact that these stars are particularly faint at optical wavelengths (Astudillo-Defru et al., 2017). Significant discoveries include the first planets orbiting in an M dwarf habitable zone (Gl667Cc; Delfosset al., 2013) and an Earth-mass planet around our nearest celestial neighbour, Proxima Centauri (Anglada-Escudé et al., 2016). In combination with photometric surveys, HARPS played a key role in discovering and characterising transiting planets around M dwarfs, paving the way towards their atmospheric characterisation (Charbonneau et al, 2009; Almenara et al., 2015; Berta-Thompson et al., 2015; Ditmann et al., 2017).

Several studies produced initial estimates of the fraction of M dwarfs hosting Earth-like planets inside the habitable zone. Results based on transits (Dressing & Charbonneau, 2015) and radial velocity measurements from HARPS (Bonfils et al., 2013) all suggest that Earth-sized planets are abundant around M dwarfs, at least 40 % of these stars having such a planet in their habitable zone. Such a high rate is encouraging and provides a strong argument for shifting the attention of exoplanet searches to M dwarfs, which in turn requires a shift towards the near-infrared.

NIRPS main science cases

NIRPS has been designed to explore the exciting prospects offered by the M dwarfs, focusing on three main science cases.

Mass and density measurements of transiting Earths around M dwarfs

Thousands of planets transiting nearby M dwarfs are expected to be found in the coming years, with TESS (Ricket et al., 2014) and PLATO (Rauer et al., 2014), likely to be the main sources of transit candidates. Ground-based surveys such as ExTrA (Exoplanets in Transits and their Atmospheres), TRAPPIST (the TRAnsiting Planets and PlanetesImals Small Telescope), as well as NGTS and SPECULOOS (Search for habitable Planets EClipsing ULtra-cOOl Stars) at the La Silla Paranal Observatory, and MEarth in the USA (Berta et al., 2013) will provide a continuous supply of additional targets.

Given the high fraction of M dwarfs hosting Earth-like planets inside the habitable zone, it is expected that the yield of transiting habitable planets among the M dwarfs will be correspondingly high. Those planets will be the subject of intensive follow-up with RV and photometric observations, and will be the primary targets for atmospheric studies with the JWST. A robust interpretation of the JWST data will ultimately require a constraint on the bulk density of the planet. The planetary radius — from the transit depth — and a mass estimate are required, and these can only be obtained from near-infrared RV data or, in very specific cases, transit-timing variations (TTV). NIRPS is an ideal tool to target M dwarfs, being able to provide masses for a large number of transiting planets and therefore to disentangle transiting planets from diluted background eclipsing binaries. Figure 1 illustrates the parameter space allowed by NIRPS in comparison to state-of-the-art optical spectrographs; considering that most host stars will be M dwarfs, NIRPS will enable the measurement of a large number of masses of super-Earths in their habitable zones.

Preparing for the 2030's: an RV search for planets to image with the ELT

M dwarfs are the preferred targets for direct imaging studies to be carried out with future extreme adaptive optics imagers on the ELT-class telescopes (Snellen et al., 2015). NIRPS will monitor a sample of the closest ~ 100 southern M dwarfs with the goal of finding the closest habitable worlds to the Sun (Figures 2 and 3). As these planets are most likely members of multi-planetary systems, this survey requires a relatively large number of visits per star (100 to 200), as demonstrated by the HARPS experience. Although such a programme can be performed by NIRPS alone, simultaneous HARPS observations will increase the overall efficiency of the telescope, as that will improve the photon noise budget by 15–40 %, depending on the effective temperature of the host star.

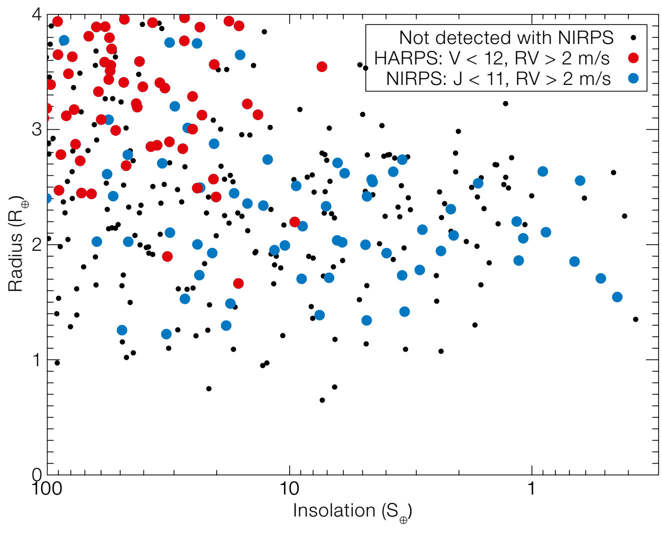

Figure 1. Simulated TESS sample of southern (declination < 20°) planets in an insolation versus radius diagram. Planets amenable to HARPS follow-up are shown in red while those, much more numerous, amenable to NIRPS follow-up are shown in blue. NIRPS will allow the follow-up of numerous planets that are only slightly larger than Earth (1–2.5 $R_\oplus$) and that receive a comparable insolation (0.3–10 $S_\oplus$). Radius, insolation and photometric values are drawn from the simulated set (Sullivan et al., 2015). These planets will be the prime targets for atmospheric characterisation studies with the JWST.

Moreover, the simultaneous use of NIRPS and HARPS will help to disentangle planetary signals from pure stellar jitter; stellar activity shows chromatic dependence whereas the planetary signal, due to the planet's gravitational pull, is known to be achromatic (Figueira et al., 2010). This will enhance the scientific output by filtering out false positives efficiently. Gaia astrometry and direct imaging will complement such studies by detecting planets on wide orbits (> 1000 days).

Atmospheric characterisation of exoplanets

Transiting planets offer a unique opportunity to gather information about the composition and temperature of their atmospheres, as well as the presence of molecular species, including biosignature gases or surface atmospheric features. High-resolution transmission spectroscopy allows the wavelength shift of individual narrow spectral features in the atmosphere to be tracked as the planet orbits the star. As an example, in HARPS observations of the hot Jupiter HD 189733 (Woolf & Wallerstein, 2005) the Na doublet was spectrally resolved, allowing its line contrasts to be measured and the temperature to be derived at two different altitudes.

Thanks to its large spectral coverage, several spectroscopic features are present within the wavelength range of NIRPS, such as CO, CO_2, CH_4, H_2O in the *H*-band, and also Na, H_2O in the visible domain. This plethora of molecules makes NIRPS very competitive in characterising the atmospheres of hot Jupiters and hot Neptunes. In addition, by measuring the spectroscopic transit, the projected spin-orbit alignment can be measured using the Rossiter-McLaughlin effect, providing an important parameter linked to the formation and dynamic evolution of the system. The spin-orbit alignment has never been measured for small planets orbiting M dwarfs and would provide new insights into the dynamical histories of these planets.

Other science cases covered by NIRPS

While exoplanet detection and characterisation will take the lion's share of NIRPS observing time, a number of other significant science niches are foreseen for the instrument. NIRPS is expected to

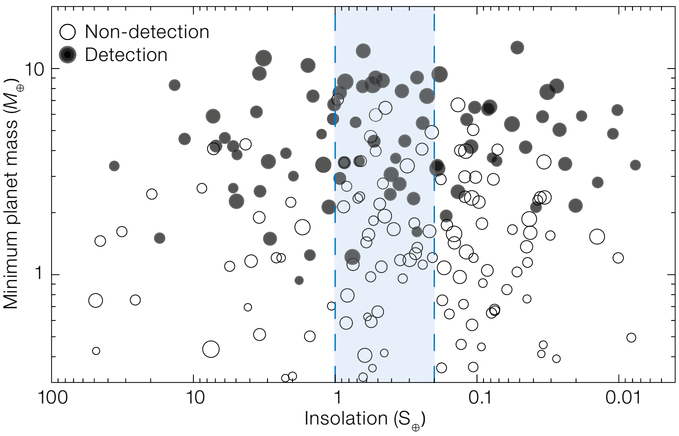

Figure 2. Simulated NIRPS planet survey results in the insolation/minimum planet mass plane. With the predicted NIRPS performances and realistic stellar properties we recovered 79 planets around 100 stars in 150 to 200 visits per star. The detection framework is described in Cloutier et al. (2017). The size of each marker is proportional to the planet's radius. The approximate "maximum greenhouse" and "water-loss" limits of the habitable zone are highlighted in blue ($0.2 \leq S/S_\oplus \leq 1$); (Kopparapu et al., 2013).

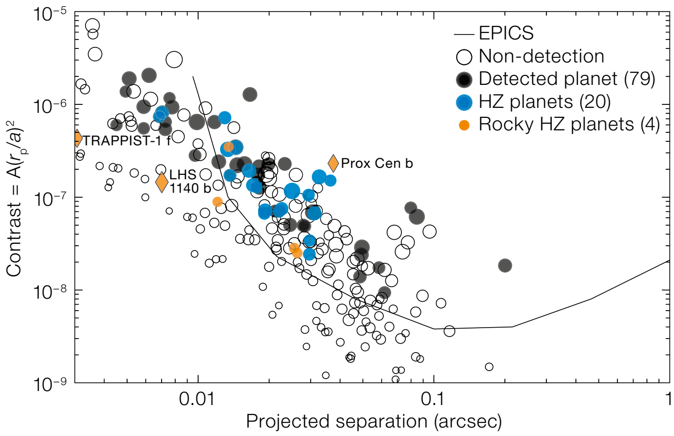

Figure 3. The same simulated NIRPS planet population as shown in Figure 2 in the projected separation/contrast plane. The contrast in reflected light depends on the planet radius (r_p), separation (a) and geometric albedo (A; we have assumed a value of A = 0.3 for all planets). Shaded circles represent planets that would be detected with NIRPS; detected habitable-zone planets are highlighted in blue and detected rocky ($r_p < 1.5\ R_\oplus$) habitable-zone planets are highlighted in red. The planet population is compared to the contrast curve expected to be achieved by the third generation of near-infrared imagers (using the ELT). Orange diamonds show the estimated location of nearby habitable-zone planets around M dwarfs (Anglada-Escudé et al., 2016; Gillon et al., 2016; Dittmann et al., 2017).

contribute to dynamical studies of ultra-cool dwarfs in young moving groups, enabling RV measurements well into the sub-stellar regime all the way to the deuterium-burning limit. These require kilometre per second accuracy at near-infrared wavelengths. The exquisite line spread function stability required for exoplanet detection will permit 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. Nearby G and K stars are bright enough to allow metre per second-precision measurements in either the optical or near-infrared.

Near-infrared wavelengths are best suited to observations of cool, red M dwarfs, not only because their spectral energy distribution makes them more than an order of magnitude brighter in the NIR than in the visible, but also because near-infrared stellar spectra are significantly less blended than their visible counterparts. This factor is critical in allowing for a more precise line-by-line analysis (Önehag et al., 2012; Wyttenbach et al., 2015) and motivates the expansion of spectroscopic analysis to the near-infrared. The derivation of precise stellar parameters will allow us to move one step further, and obtain precise chemical abundances for key elements (such as alpha and iron-peak elements) in M dwarfs, opening up new avenues for research, such as the chemical evolution of the Galaxy as monitored by its most populous inhabitants.

Specifications, overall design and expected performance

To achieve its science goals, NIRPS must meet a suite of top-level requirements. The spectrograph will operate in the *Y*-, *J*- and *H*-bands with continuous coverage from 0.98 to 1.8 mm. It will ensure high radial velocity precision and high spectral fidelity corresponding to 1 m s^{-1} in less than 30 min for an M3 star with $H = 9$. Its spectral resolution will be 100 000 to best exploit the spectral content. It will be operated simultaneously with HARPS without degrading the HARPS performance. First light is planned for 2019, considering the timeline for space missions such as JWST and TESS.

An adaptive optics fibre-fed spectrograph

NIRPS is part of a new generation of adaptive optics (AO) fibre-fed spectrographs. Its originality resides in the use of a multi-mode fibre that is much less affected by AO correction residuals than a single-mode fibre, while allowing comparatively higher coupling efficiency in degraded seeing and on fainter targets, with relaxed AO specifications.

NIRPS will mainly use a 0.4-arcsecond fibre, half that required for a seeing-limited instrument, allowing a spectrograph design that is half as big as that of HARPS, while meeting the requirements for high throughput and high spectral resolution.

The AO system is designed around a 14 × 14 Shack-Hartmann wavefront sensor (WFS) operating between 700 and 950 nanometres, coupled to a 15 × 15 deformable mirror with a loop frequency of 250 to 1000 Hz. The high density of actuators and the high speed are necessary to correct for high-order wavefront errors and to reach a high coupling efficiency. The AO will lead to a 50 % efficiency for targets as faint as $I = 12$ in median seeing conditions (Woolf & Wallerstein, 2005). A 0.9-arcsecond fibre will be used for fainter targets and degraded seeing conditions. Figure 4 shows the expected overall throughput of NIRPS in the two modes, the High Accu-

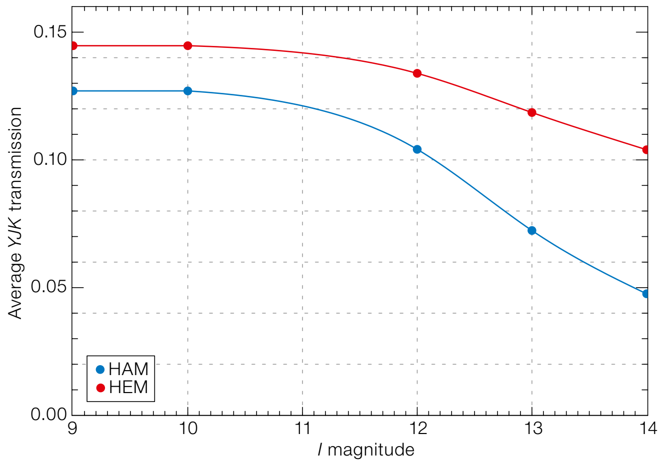

Figure 4. Expected overall throughputs of the NIRPS instrument, including atmosphere and telescope, with AO system as a function of *I*-band magnitude for a median seeing of 0.9 arcseconds for the HAM (0.4-arcsecond fibre) and HEM (0.9-arcsecond fibre) modes.

racy Mode (HAM) and the High Efficiency Mode (HEM).

While a smaller fibre increases modal noise, NIRPS will use the many degrees of freedom offered by its AO system to properly scramble the stellar flux at the fibre's entrance. This will be used in conjunction with three more scrambling methods: octagonal fibres; a fibre stretcher that modulates the phase between modes; and a double scrambler that exchanges the near and far fields.

A compact cryogenic echelle spectrograph

The entire optical design is oriented to maximise high spectral resolution, long-term spectral stability and overall throughput (Figure 5). Light exiting from both object and calibration fibre links is collimated by a parabolic mirror used in triple pass and is relayed to an R4 echelle grating. The diffracted collimated beam is focused by the parabola on a flat mirror that folds the beam back to the parabola. The cross dispersion is done with a series of five refractive ZnSe prisms that rotate the beam by 180°. A four-lens refractive camera focuses the beam on an a Hawaii 4RG 4096 × 4096 infrared detector. The instrument covers the 0.97 to 1.81 μm domain on 69 spectral orders with a 1 km s^{-1} pixel sampling at a resolution (λ/Δλ) of 100 000 (HAM) or 75 000 (HEM). The global throughput of the spectrograph alone is estimated to be 30 % at 0.97 μm and 45 % at 1.81 μm. The spectrograph is installed inside a cylindrical cryostat (1.12-metre diameter, 3.37 metres long) maintained at an operating temperature of 80 K with a stability of 1 mK and an operating pressure of 10^{-5} mbar (Figure 6). The instrument will be installed in the East Coudé Room of the 3.6-metre Telescope.

While some near-infrared radial-velocity instruments have opted to cover the *K*-band (2.0–2.38 μm), the decision was taken not to do so for NIRPS, favouring higher spectral resolution and simplicity. We nevertheless preserved the possibility of adding, at a later time, a *K*-band spectrograph in a separate cryostat. The common path of the NIRPS front-end, including the atmospheric dispersion corrector (ADC), covers the *K*-band.

Two main observing modes combined with HARPS

The HARPS and NIRPS spectrographs can be operated individually or jointly. The default operation mode will see both instruments operating simultaneously, except for high-fidelity polarimetric observations with HARPSpol. NIRPS and HARPS are fed by different fibre links permanently mounted at the Cassegrain focus; each instrument will have two different modes, HEM and HAM. For NIRPS, the HAM and the HEM use 0.4 and 0.9 arcsecond-fibres respectively, leading to spectral resolutions of R = 100 000 and 75 000. The HEM uses a pupil slicer inserted in the double scrambler. Users can switch between modes at any time during the night, and the mode used in one spectrograph does not constrain the mode used in the other spectrograph. Each mode is composed of two fibres, a science channel fed by the stellar beam and a simultaneous calibration channel fed by the background sky light or by a calibration lamp (Hollow-Cathode lamp, Fabry-Pérot, or Laser Frequency Comb). In principle, all the different configurations will be available and are technically possible for HARPS and NIRPS. The new front end shown in Figure 7 includes all the opto-mechanical devices:

1) The VIS/NIR dichroic movable beam splitter to enable HARPS-only and HARPSpol observations.
2) The ADC covering the 700–2400 nm domain.
3) The deformable mirror of the AO system mounted on the tip-tilt plate to compensate for any misalignment with HARPS.
4) The calibration sources injection for both AO wavefront sensor and NIRPS spectrograph.
5) The fibre selector allowing selection between the two modes, HAM and HEM.

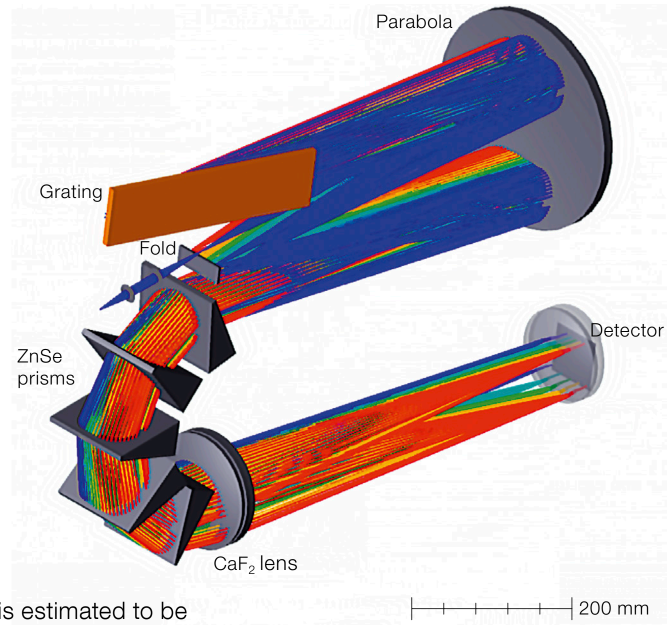

Figure 5. NIRPS optical design layout. The small fibre size enables a much more compact design than other seeing-limited spectrographs with similar resolving power on 4–8-metre telescopes.

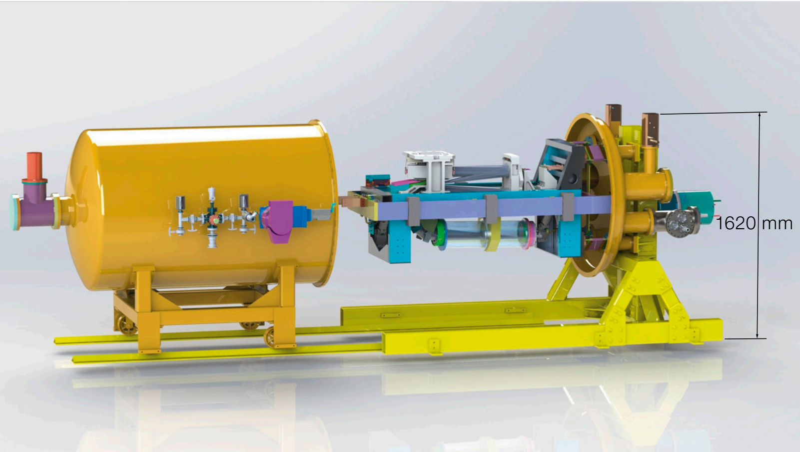

Figure 6. NIRPS optical bench and cryostat design layout.

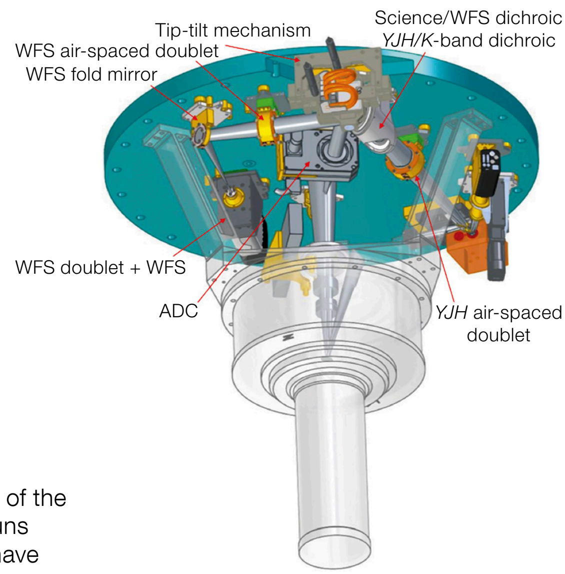

Figure 7. The NIRPS Front End to be installed on the 3.6-metre Telescope focus. The bottom grey part is the existing HARPS Cassegrain fibre adapter.

6) A magnification selector to change the magnification or field of view of the near-infrared acquisition camera.

Operations

In return for the manpower effort and financial contributions of the consortium to design, build, maintain and operate NIRPS for five years, ESO will grant the consortium a period of Guaranteed Time Observation (GTO) on the 3.6-metre Telescope using the combined NIRPS/HARPS instrument. GTO will amount to up to 40 % of the 3.6-metre Telescope time over this period, leaving ample time for community-driven science topics. The GTO will only target M dwarf exoplanet science, leaving room for a broad range of projects in other fields and from other groups.

Once NIRPS is operational in late-2019, the consortium will be in charge of the Science Operations of the 3.6-metre Telescope on behalf of the entire community. This will include the coordination of observations, quality control of the data collected with HARPS and NIRPS and delivery of the reduced data to the ESO archive. The so-called Phase 1, which includes, along with the Call for Proposals, the evaluation and scheduling of the selected projects, is fully organised by ESO.

Since 2009, a substantial fraction of the 3.6-metre Telescope observing runs (about 100 nights per semester) have been coordinated by principal investigators involved in different HARPS Large Programmes in the field of exoplanet science. Scheduled nights and observers are pooled together to optimise the observing sampling — critical to RV monitoring — and to guarantee the presence of competent observers on the mountain, ultimately reducing travel costs. Such coordination is paramount to maximising the science output and the operational efficiency, benefiting a large number of users.

It is foreseen that HARPS+NIRPS open-time programmes will require similar organisation in order to produce the highest scientific return from the 3.6-metre Telescope, optimising the use of available time while continuously adapting the observing queue to external, often unpredictable, observing conditions. Such coordination will be also very important in the context of the community organisation for the follow-up of incoming space missions.

Many of the impressive results obtained with HARPS have been achieved thanks to the intrinsic stability of the hardware. However, its advanced Data Reduction Software (DRS) plays an equally important role. The HARPS DRS delivers quality control indicators on-the-fly enabling the quality of the science frame and the health of the instrument to be assessed in real time. It also produces reduced and science-ready spectra and RV measurements in real time.

NIRPS will follow the same concept. Its DRS will be a fundamental part of the NIRPS system, assessing data quality in real time, and producing reduced spectra. Radial velocities will also be provided by the DRS. However, given the complexity of dealing with the telluric lines, an end-of-night reprocessing might be necessary to produce science-ready radial velocities. NIRPS raw and reduced data will be made available via the ESO archive. In addition, local data centres spread amongst the consortium are under consideration.

The arrival of NIRPS, with its extended near-infrared wavelength coverage and high RV stability, will be the final move towards making the La Silla Paranal Observatory the scientific hub for exoplanet discoveries. NIRPS will complement the scientific capabilities of existing instruments, open up new avenues for a wide range of applications, and provide ground support for future space missions, ensuring ESO's place at the forefront of exoplanet studies for many years to come.

The NIRPS consortium

The NIRPS consortium is jointly led by Université de Montréal and Université de Genève and includes partners from Brazil

(UFRN), France (IPAG, LAM), Portugal (IA, Universidade de Porto and IA, Universidade de Lisboa), Spain (IAC), Switzerland (University of Bern) and Canada (Université Laval, McGill University, Herzberg Institute of Astrophysics, Royal Military College of Canada, York University, University of Toronto, University of Western Ontario, University of British Columbia).

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Dedication

This paper is dedicated to the memory of Leslie Saddlemyer who passed away suddenly in January 2017. Les played a pivotal role in a number of major astronomical instrumentation projects, including recently the Gemini Planet Imager and the SPIRou (CFHT) spectrograph. He was the lead project engineer in the early phases of NIRPS. Les was very enthusiastic about the NIRPS project which he saw as his last major endeavour before retirement. The NIRPS team will remember him not only for his expertise, but also for his contagious enthusiasm and friendliness.

Table 1. Summary of NIRPS characteristics

Subsystem	Parameters
HAM-mode	Spectral resolution: $\lambda/\Delta\lambda$ = 100 000 0.4 arcsecond object fibre, AO-assisted feed 0.4 arcsecond simultaneous reference fibre
HEM-mode	Spectral resolution: $\lambda/\Delta\lambda$ = 75 000 0.9 arcsecond double slicing in the pupil plane 0.4 arcsecond simultaneous reference fibre
Environment	Vacuum: < 10^{-5} mbar Cryogenic: 80 K with 1 mK stability
Spectral domain	0.97–1.81 µm (*YJH* photometric bandpasses)
Calibration sources	Hollow cathode lamp, Stabilised Fabry-Perot, Laser Frequency Comb
Detector and format	Hawaii-4RG, 4 k × 4 k, 15 µm pixels
Limiting magnitude	1 m s^{-1} in 30 min for an M3 star with *H* = 9
Stability	< 1 m s^{-1} intrinsic stability over one night Calibration down to < 1 m s^{-1} over the lifetime of the instrument
Sampling	1 km s^{-1} per pixel, 3 pixels per FWHM
Operation	Simultaneous operation with HARPS without degrading HARPS's performance
Schedule	First light in 2019

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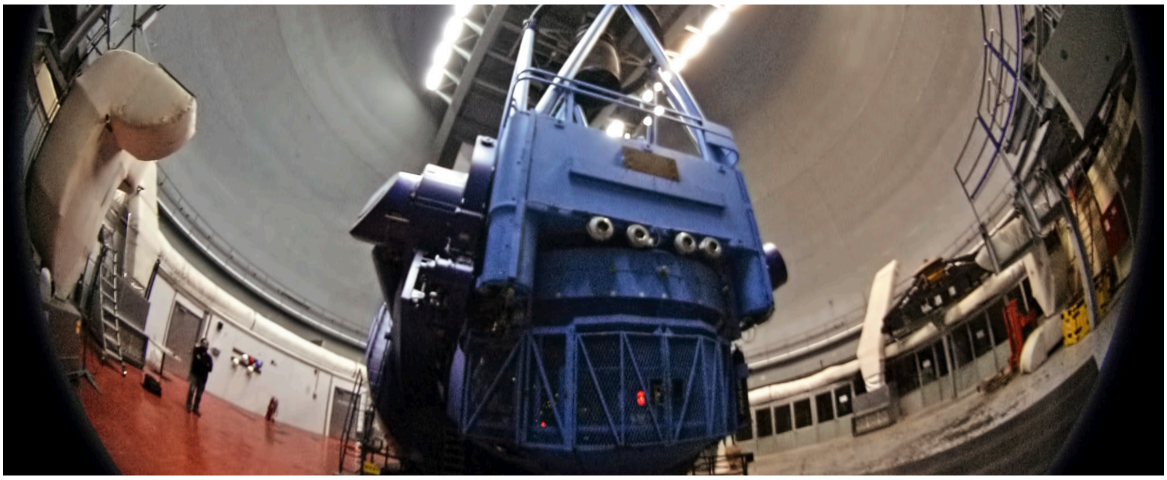
Links

[1] SOXS spectrograph: http://www.brera.inaf.it/~campana/SOXS/Son_of_X-Shooter.html

ESO/A. Santerne



Fish-eye lens view of the inside of the ESO 3.6-metre Telescope dome.