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NIRPS Joins HARPS: Setting New Standards at Infrared Wavelengths

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The Near-InfraRed Planet Searcher (NIRPS) is a high-resolution, near-infrared spectrograph optimised for detecting and characterising exoplanets around low-mass stars, working in tandem with the High Accuracy Radial velocity Planet Searcher (HARPS). While HARPS set new standards 20 years ago with its metre-per-second-level precision, NIRPS follows this successful path, achieving even better precision at infrared wavelengths. This article presents an overview of the design of NIRPS, its on-sky performance, its Guaranteed Time Observation programme, and its first scientific results.

Introduction

The discovery of the first exoplanet orbiting a solar-type star (Mayor and Queloz, 1995), and of the first transiting exoplanet (Charbonneau et al., 2000), stand as pivotal moments in astrophysics. The quest for nearby habitable worlds and evidence of biological activity beyond the Solar System has prompted the construction of powerful observatories such as Kepler (Koch et al., 2010), the Transiting Exoplanet Survey Satellite (TESS; Ricker et al., 2015), the James Webb Space Telescope (JWST; Gardner et al., 2023) and, very soon, ESO's Extremely Large Telescope (ELT; de Zeeuw, Tamai & Liske, 2014).

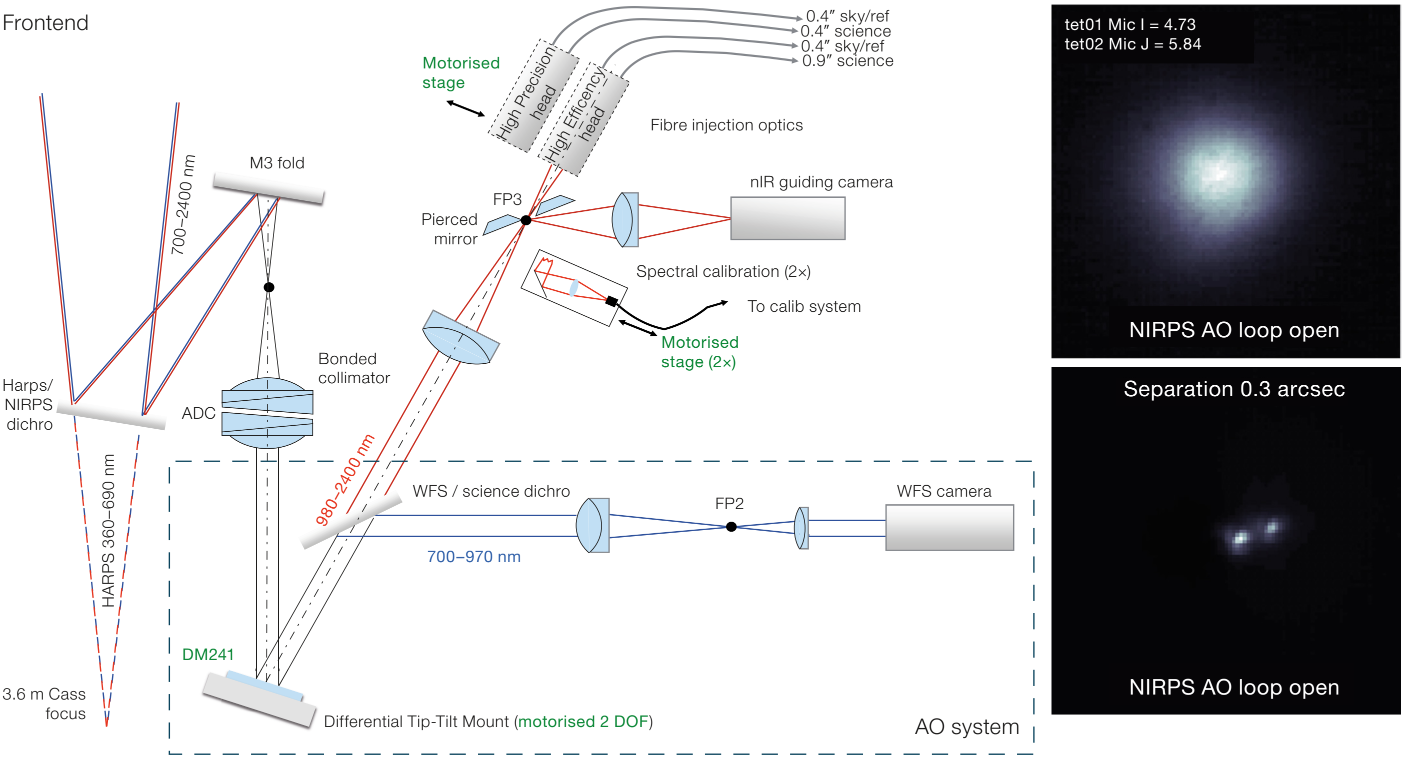


Figure 1. Left: schematic of the NIRPS frontend. Right: images from the guiding camera of a binary star (0.3 arcseconds separation) with the AO loop open (top) and closed (bottom). From Bouchy et al. (2025).

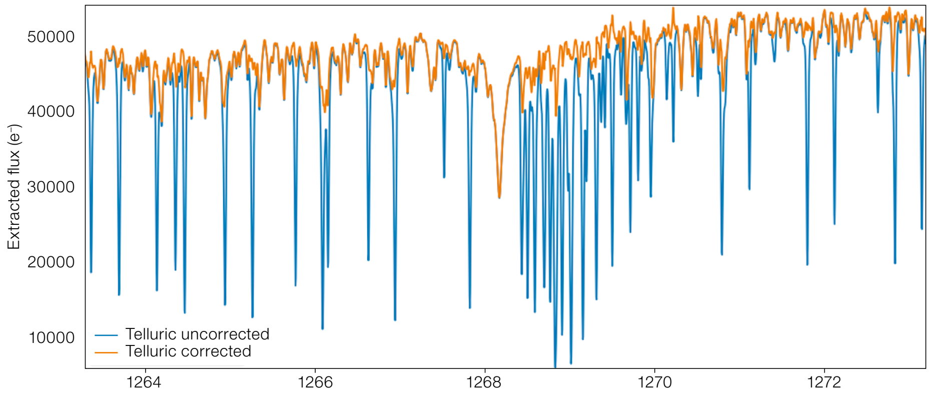


Figure 2. Extracted and wavelength-calibrated spectrum of Proxima Cen in HE mode, centered at 1268 nm. Blue: uncorrected spectrum; orange: telluric-corrected spectrum. From Bouchy et al. (2025).

The rapid progress in exoplanet research over recent decades was driven largely by precision velocimetry and in particular the development of fibre-fed optical spectrographs like the High Accuracy Radial velocity Planet Searcher (HARPS; Mayor et al., 2003), which set new standards by achieving metre-per-second precision. Advances in large-format infrared detectors, largely motivated by and developed for JWST, paved the way for a new generation of precision infrared spectrographs tailored to studying low-mass stars. This context prompted the Universities of Montreal and Geneva, in collaboration with the Institute of Astrophysics and Space Science (Portugal), the Canaries Institute of Astrophysics (Spain), Grenoble Alpes University (France), the Federal University of Rio Grande do Norte (Brazil), and ESO, to initiate the development of an 'infrared HARPS' for the southern hemisphere.

Low-mass M dwarfs, which dominate the Milky Way's stellar population (Reylé et al., 2021), are excellent targets for exoplanet studies. Their small radii and masses amplify detection signals via radial velocity (RV) and transit methods, while their low luminosity means that habitable zones lie closer to the star, with orbital periods measured in weeks rather than a year, greatly simplifying the characterisation of potentially habitable exoplanets.

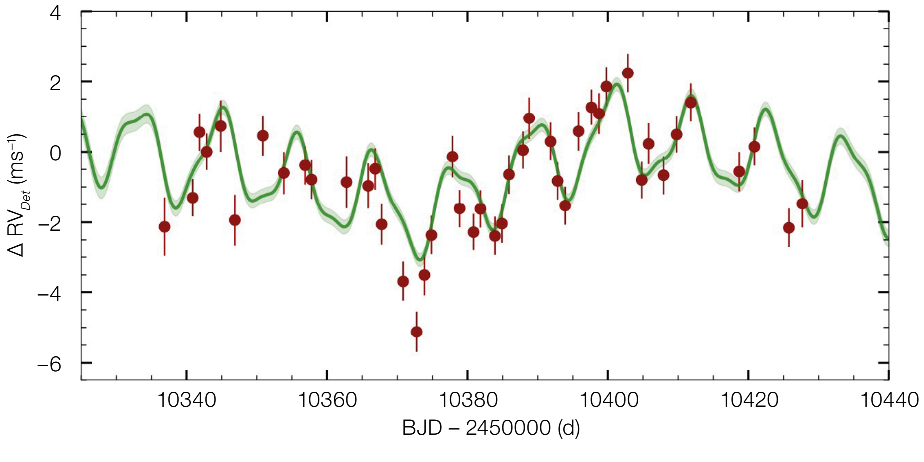
The near-infrared (NIR) is particularly suited to M dwarf studies, as it mitigates stellar activity jitter on RV measurements compared to the optical and provides access to helium and molecular signatures like H_2O, O_2, CO, CH_4, and CO_2, critical for atmospheric studies. These advantages have driven the development of high-resolution NIR spectrographs, including GIANO (Oliva et al., 2012), the Habitable-zone Planet Finder (HPF; Mahadevan et al., 2012), the Calar Alto high-Resolution search for M dwarfs with Exoearths with Near-infrared and optical Échelle Spectrographs (CARMENES; Quirrenbach et al., 2014), the InfraRed Doppler (IRD) instrument (Kotani et al., 2018), and SpectroPolarimètre InfraRouge (SPIRou; Donati et al., 2020).

The Near-InfraRed Planet Searcher (NIRPS), the newest addition to this suite, builds on the legacy of HARPS (Mayor et al., 2003) and the Echelle SPectrograph for Rocky Exoplanet and Stable Spectroscopic Observations (ESPRESSO; Pepe et al., 2021), while leveraging the infrared expertise and experience gained from SPIRou. Operating in tandem with HARPS, NIRPS provides an unparalleled optical-NIR capability for precision velocimetry. This dual-wavelength approach enhances the precision of RV measurements and significantly improves our ability to disentangle planetary signals from stellar jitter noise. This article presents a brief overview of NIRPS, including its design, on-sky performance, initial results, and highlights from its extensive Guaranteed Time Observation (GTO) programme. For a more comprehensive description of NIRPS, readers are referred to Bouchy et al. (2025).

NIRPS+HARPS: a unique dual optical-infrared precision velocimeter

NIRPS is a fibre-fed, highly-stabilised echelle spectrograph operating in the NIR and installed on the ESO 3.6-metre telescope at La Silla, Chile. The instrument includes a frontend bonnette at the Cassegrain focus, linked via optical fibres to the cryogenic spectrograph in the coudé room. The frontend integrates an adaptive optics (AO) system to enhance efficiency and minimise the instrument's size. As for HARPS, NIRPS's spectrograph is housed in a thermally-controlled enclosure to ensure optimal thermal stability.

Figure 3. High cadence of NIRPS RV detrended data of Proxima Cen, along with the best model fit, showing residuals with an RMS of 81 cm s^{-1}. From Suárez Mascareño et al. (2025).



NIRPS operates in the *Y*, *J*, and *H* bands, covering a wavelength range from 972.4 nm to 1919.6 nm. It offers two fibre sizes (0.4 and 0.9 arcseconds) yielding resolving powers of R = 90 000 for the high-accuracy (HA) mode and R = 75 000 for the high-efficiency (HE) mode. This spectral range enables the detection of molecular signatures such as water and methane in planetary atmospheres. The frontend module (Figure 1) houses the AO system, which corrects for atmospheric turbulence to improve light coupling into the fibres under variable seeing conditions. A dichroic beam splitter simultaneously directs light to both HARPS and NIRPS, enabling parallel optical and NIR observations.

The fibre link transports light to the spectrograph and incorporates a fibre stretcher and double scrambler to reduce modal noise that impacts radial velocity (RV) measurements. The calibration unit includes hollow-cathode (HC) uranium-neon lamps and a Fabry-Pérot (FP) étalon to illuminate a reference fibre alongside the science fibre. The HC provides absolute wavelength calibration, while the FP allows drift correction. Calibrations are performed daily, with a laser frequency comb currently under commissioning.

The backend spectrograph is housed within a vacuum vessel, with its optical bench stabilized to 75 K, maintaining thermal variations within 0.1 mK. The optical design features a reflective double-pass collimator, a 13-lines mm^{-1} R4 echelle grating, a carousel of five ZnSe prisms for cross-dispersion, and a refractive camera that feeds a 4096 × 4096-pixel Hawaii-4RG (H4RG) infrared detector with 15-µm pixels. The full wavelength range spans 71 orders, with the line spread function sampled by three pixels.

Data pipeline

The NIRPS data reduction pipeline (NIRPS-DRS) is adapted from the ESPRESSO pipeline, incorporating features inspired by the APERO pipeline (Cook et al., 2022), a versatile framework initially developed for SPIRou. While NIRPS-DRS and APERO share similarities, they differ in key aspects, such as their approaches to telluric correction (see Bouchy et al., 2025). The two independent pipelines are particularly valuable for cross-validation and assessing the robustness of scientific results.

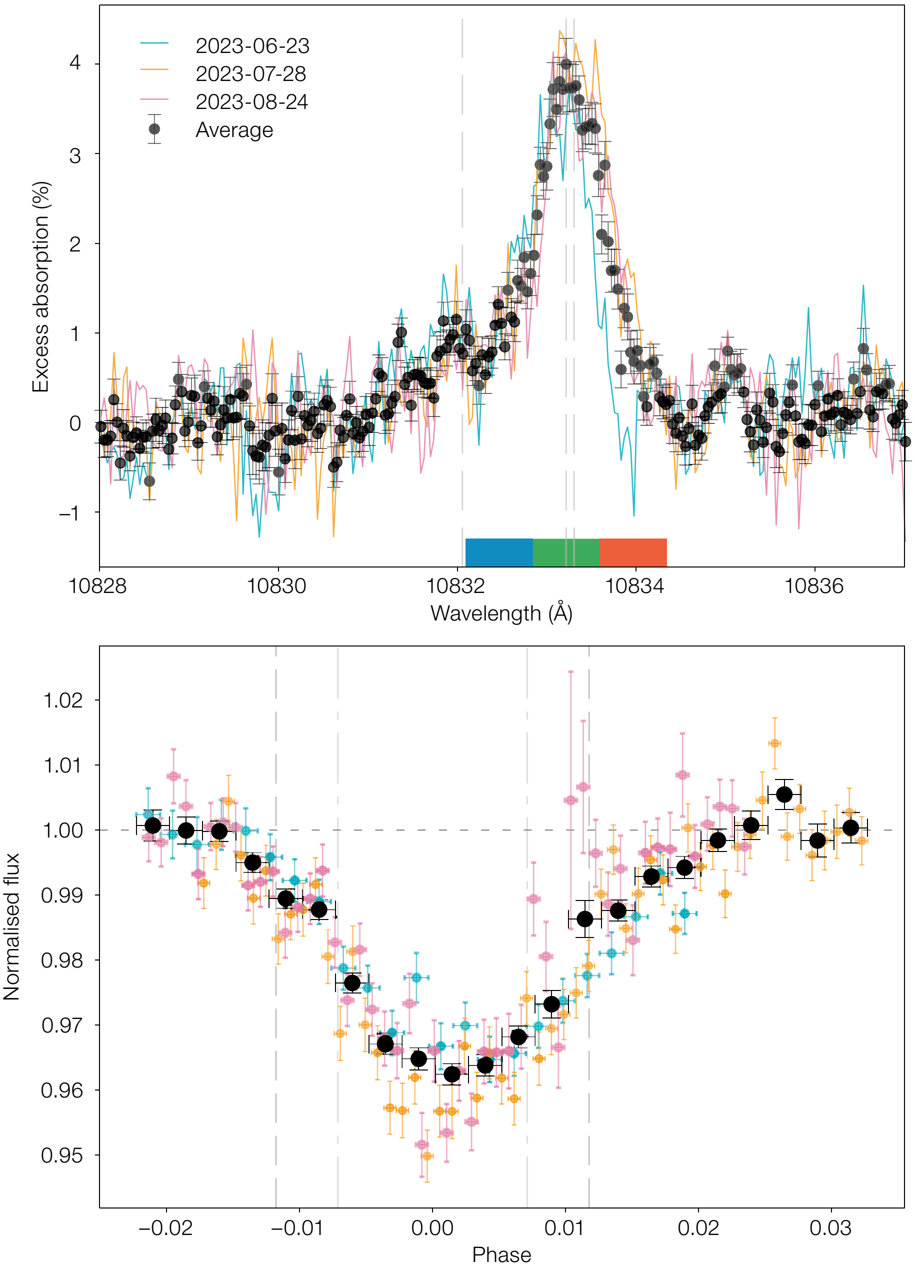


Figure 4. Transmission spectra (top) and excess helium light curves (bottom) comparison between transits (in cyan, orange, and rose) and the average in black. On the top panel, three spectral regions (blue, green, and red) are identified to measure the temporal variation of the helium signature. From Allart et al. (2025).

The pipeline begins with order localisation, flat-fielding, and wavelength calibration. The FP etalon ensures precise drift monitoring when necessary[a], while uranium-neon lamps, combined with FP frames, provide an estimate of the FP cavity length, forming the basis for the absolute calibration across nights and observing runs. A major challenge in NIR precision velocimetry is the contamination of stellar spectra by telluric absorption lines. The NIRPS-DRS pipeline includes a telluric subtraction module developed for

ESPRESSO (Allart et al., 2022), while APERO is using an ensemble of telluric standards, fast-rotating early-type stars, and a principal component analysis (PCA)-based method for modelling and removing telluric lines. Figure 2 displays a portion of the *J*-band spectrum of Proxima Cen, both before and after telluric correction, demonstrating the effectiveness of our method, which is absolutely crucial for achieving metre-per-second-level precision at infrared wavelengths.

Radial velocity extraction is performed using two complementary methods: the standard cross-correlation function (CCF) technique and the line-by-line (LBL) method (Artigau et al., 2022). The CCF provides immediate RV measurements for each observation, while the LBL method, which constructs a template spectrum from a time series, generally delivers more precise RVs with less sensitivity to outliers, achieving, for example, a twofold improvement on the ESPRESSO uncertainties for the temperate super-Earth LHS 1140b (Cadieux et al., 2024).

On-sky performance and first results

NIRPS commissioning took place over two years from November 2019 to March 2023 with the official first light on 17 May 2022. The commissioning phase of NIRPS demonstrated excellent performance, meeting or exceeding its design requirements.

The instrument's overall throughput peaks at 13% in the *H* band. The AO system significantly improves fibre coupling efficiency, achieving typical encircled energy of 55% and 70% for the HA and HE modes, respectively; this performance is constant up to $I = 11$. Modal noise is mitigated through the fibre stretcher and through AO scanning by using the tip/tilt mirror to move the star within the fibre core randomly during an exposure. Together, both stretching and AO-scanning yield a modal noise reduction by a factor of five for the HE mode, leaving a residual noise of 0.43% (SNR~230) similar to the flat-field stability of 0.65% which translates into RV noise of 0.9 m s^{-1}. The AO was successfully tested to lock onto small (< 2-arcsecond) Solar System objects, such as Saturn's and Jupiter's moons.

RV performance was characterised on several RV standards with known planetary systems such as Proxima Cen, featuring two planets including an Earth-mass one in the habitable zone (Proxima b). As shown in Figure 3, Proxima b is clearly detected with a residual noise of ~80 cm s^{-1} compared to 2.5 m s^{-1} from the HARPS data alone. NIRPS is the first NIR velocimeter to demonstrate sub-metre-per-second performance, partly due to the excellent sub-Kelvin thermal stability of the spectrograph yielding typical drifts of 3–4 cm s^{-1} day^{-1} and wavelength uncertainties at the level of 50–70 cm s^{-1}.

High-resolution spectroscopy is a powerful tool for probing exoplanetary atmospheres via transmission spectroscopy and constraining orbital architecture, including the spin-orbit angle, through the Rossiter–McLaughlin (RM) effect. This capability was demonstrated by observing three transit events of the warm Saturn WASP-69b. As shown in Figure 4, NIRPS successfully detected the helium triplet near 1083 nm in the planet's atmosphere, with evidence of variability indicative of cometary-like tail mass loss. The RM measurements suggest a slightly misaligned orbit.

NIRPS Guaranteed Time Observation programme highlights

In exchange for building and operating the instrument, ESO awarded the NIRPS consortium 725 nights over five years. These are allocated to three core science programmes, each receiving 225 nights, with an additional 50 nights reserved for 'other science' programmes.

Blind RV search for exoplanets orbiting nearby low-mass stars

This core sub-programme is primarily dedicated to a blind search for planets around M dwarfs (< 0.6 $M_{\odot}$) with three major objectives: (1) identifying the nearest exoplanetary systems amenable to atmospheric characterisation in reflected light with the ELT (Snellen et al., 2015; Pallé et al., 2023) and which are orbiting M dwarfs within approximately 6 pc; (2) searching for exoplanets around nearby ultra-cool dwarfs to estimate how frequently planet formation occurs around such stars with masses below 0.1 $M_{\odot}$; and (3) understanding the process of planet formation and dynamical evolution by searching for planets around young, very low-mass stars.

Mass characterisation of transiting planets orbiting M dwarfs

This programme is dedicated to providing mass measurements of transiting exoplanets unveiled by TESS and other transit surveys through various sub-programmes. Mass measurements are essential for interpreting transmission spectra obtained with JWST and constraining internal structure models. This programme aims to shed light on the nature, formation and evolution of super-Earths and mini-Neptunes. One sub-programme is dedicated to precise (~10%) mass measurements of small rocky planets to constrain their core mass fraction.

High-resolution spectroscopy of exoplanet atmospheres

The third core programme centres on atmospheric studies of exoplanets, primarily hot gas giants, using transmission and emission spectroscopy. Its objective is to uncover the chemistry, dynamics, and orbital architectures of exoplanet atmospheres. The programme combines a broad atmospheric reconnaissance survey with in-depth analyses of a carefully selected sample of exoplanets, aiming to establish critical reference datasets in preparation for the upcoming ELT era.

Other science

HARPS and NIRPS provide a unique capability, each performing at the metre-per-second level, for stellar activity studies as well as stellar characterisation, including abundance determination (for example, Jahandar et al., 2025), in particular refractory elements (Fe, Mg, Si) which are critical inputs for internal structure modelling. This approach was applied to LHS 1140 using commissioning data, revealing that the temperate super-Earth LHS 1140b is likely a water world with a 10–20% water mass fraction (Cadieux et al., 2024).

Solar observations

The HARPS Experiment for Light Integrated Over the Sun (HELIOS) solar telescope (Dumusque et al., 2015) feeds both HARPS and NIRPS, and continuously monitors the Sun as a star. High-cadence solar spectra enable detailed insight into solar variability and its effect on disc-integrated radial velocity and on the retrieval of planetary atmospheric parameters (Mercier et al., 2025).

Summary

NIRPS represents a major milestone in precision infrared velocimetry, achieving sub-metre-per-second precision through advanced telluric subtraction techniques and post-processing algorithms like LBL. Early results demonstrate its considerable potential for precise mass determination, exoplanet atmospheric characterisation, and stellar studies, including activity analysis and abundance measurements.

With its exceptional performance and ambitious GTO programme, NIRPS is poised to play a central role in exoplanet research. NIRPS lays the foundation and expertise needed for the ELT era, where high-resolution infrared spectroscopy will be essential for characterising the atmospheres of nearby exoplanets through reflected light.

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Notes

[a] In practice, NIRPS is so stable that the FP is not used during science observations.

ESO/Digitized Sky Survey 2. Acknowledgment: Davide De Martin

This image shows the RCW 38 star cluster in visible light. Dust absorbs most light at these wavelengths, hiding large areas of this cluster from us.