 DOI: 10.18727/0722-6691/5354

HARPS at 20: Evolving Through Continuous Improvements

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The High Accuracy Radial velocity Planet Searcher (HARPS), operational since October 2003, has been pioneering exoplanetary research, with over 1300 publications and more than 200 exoplanet detections, and is still in high demand. Its continued success has been achieved thanks to its extraordinary stability, the continuous improvement of its data reduction pipeline and the integration of innovative technologies whenever they became available. Here we report on the recent maintenance mission to enhance the detector's cryostat reliability and thermal stability. Additionally we tested a novel cryogenic concept on HARPS, and the positive outcome of the test opens up new possibilities.

The High Accuracy Radial velocity Planet Searcher (HARPS) started science operations at ESO's 3.6-metre telescope in La Silla on 1 October 2003 (Mayor et al., 2003; Pepe et al., 2003). The twenty years that have passed since then have seen more than 1300 HARPS publications. The 1 m s^{-1} radial velocity (RV) precision barrier has been largely surpassed, and we have learned much about extra-solar planets thanks to the more than 200 detections made with this instrument (see, for example, the NASA Exoplanet Archive[1]). We have understood how common and how diverse extra-solar planetary systems are, and we are now characterising some of these planets, determining their density with the help of transit measurements (Armstrong et al., 2023), and even their atmospheres (Prinoth et al., 2022). Today, HARPS remains one of the most requested instruments at ESO.

One of the main performance indicators for Extremely Precise Radial-Velocity (EPRV) spectrographs like HARPS is measurement repeatability over a long period of time. To achieve this the instrument is optimised for mechanical stability, operated in a vacuum, thermally stabilised and closely monitored. These features put HARPS at the top of its class of instruments. Furthermore, and for all these years, HARPS's performance has been continuously improved whenever the conditions and the technology made it possible. In 2010, for instance, a new guiding system was integrated at the 3.6-metre telescope, enabling faster and more accurate corrections (Ihle et al., 2010). HARPS was the first high-resolution spectrograph to routinely use a Fabry-Pérot source for drift monitoring (Wildi et al., 2011) and a laser frequency comb (LFC) for wavelength calibration (Wilken et al., 2012; Lo Curto et al., 2012), a strategy today employed by most EPRV spectrographs.

In 2015 the HARPS vacuum vessel was opened for the first time after 11 years of continuous operation to replace (following the successful example of its northern twin HARPS-N), the old fibre link with new octagonal fibres for better light scrambling and thus improved RV precision (Lo Curto et al., 2015). This intervention, accompanied by an optimisation of the image quality (refocusing), caused, however, a RV discontinuity of the order of 10 m s^{-1}, depending slightly on stellar temperature and rotational velocity; users must take this into account when combining RV datasets from before and after this intervention, which was in May 2015.

The hardware is not the only component that underwent various improvements over the years; the software, in particular the reduction pipeline, was in continuous evolution, as the instrument enabled us to explore uncharted territories.

A new upgrade, aimed at refurbishing the vacuum gauges and a faulty temperature sensor in the cold plate of the liquid-nitrogen-cooled detector cryostat was executed between 14 and 28 November 2023. Although this intervention had been planned and prepared for more than a year, just three weeks before the start of the mission a leak developed in the cryostat which caused operational troubles; the intervention did not come a minute too early.

During the technical mission, the vacuum line was upgraded with new gauges and three-way valves for ease of future gauge maintenance; additionally, a comprehensive rewiring of the detector unit Continuous Flow Cryostat (CFC) was undertaken to prevent electrical short-circuits. More importantly, the faulty sensor regulating the cold plate temperature

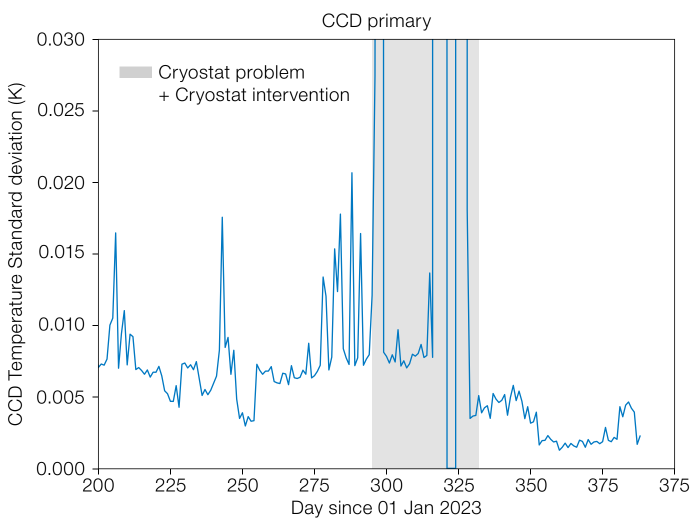

Figure 1. One-night peak-to-valley (PtV) temperature variation of the HARPS CCD with time. The increase in thermal stability after the intervention is clearly visible on the plot (rightwards from the grey band).

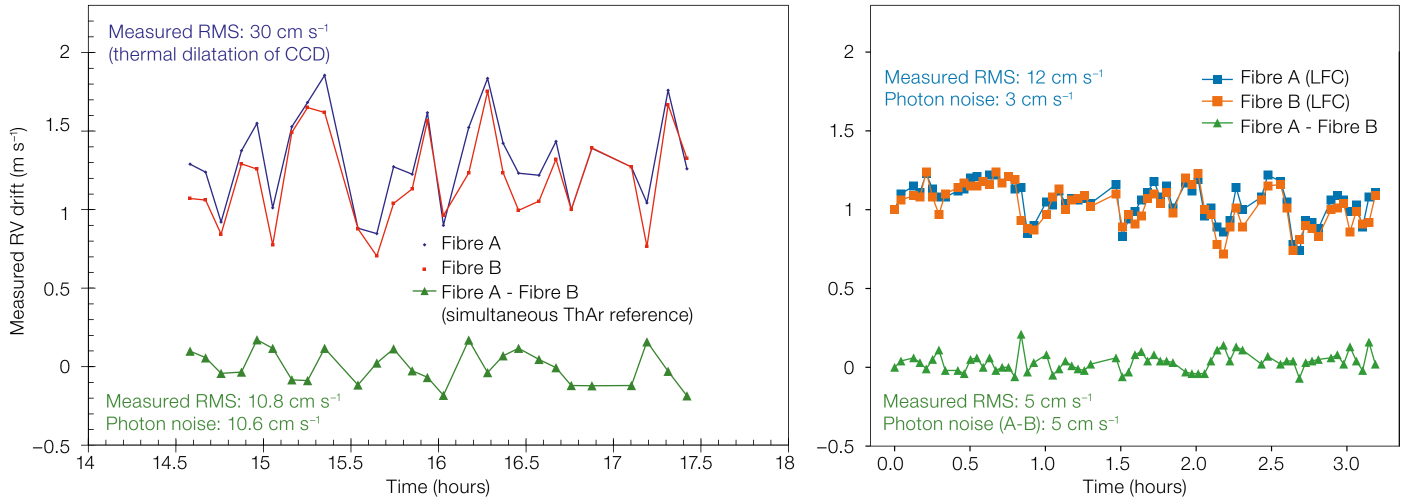

Figure 2. Instrument stability measured with the ThAr hollow-cathode lamp in 2003 (left), and with the LFC in 2023 (right). Plots are on the same scale; the improved instrumental stability is clearly visible. The plot on the left is from Mayor et al. (2003).

and the cold plate itself were exchanged. The purpose of this operation was to improve operational reliability and possibly increase the thermal stability of the detector. As illustrated in Figure 1, this latter goal was fully achieved and the results are impressive: while before the upgrade the CCD temperature could vary by up to a few times 0.1 K, after the upgrade the system is capable of maintaining temperature stability at the level of the resolution of the Lakeshore temperature controller, i.e., to better than 0.01 K. The improved thermal stability of the detector is reflected directly in improved repeatability of the RV measurements. Indeed, the standard deviation of the drift measurement on each of the two HARPS fibres over a short-duration sequence of LFC spectra has decreased by almost a factor of two, (from approximately 22 cm s^{-1} to about 12 cm s^{-1}; Figure 2) after the mission, very close to the photon noise. This induces, in turn, an overall decrease in instrumental noise in the wavelength calibration and in the consequent RV measurements.

The intervention on the cryostat required opening the vacuum vessel, a very delicate operation with a possible impact on the spectral format of the instrument; utmost care was needed to prevent any modification of the spectral format and the line profiles. The (physical) movement of the spectrum on the detector has been quantified at 0.7 pixels along the main dispersion direction and 1 pixel in the cross-dispersion direction. More importantly, no RV offset was measured within the measurement scatter (photon noise around 30 cm s^{-1}) on a set of three standard stars of different spectral types acquired before and after the mission (Figure 3).

The access to the current CFC during this latest maintenance mission, and the timing alongside other ongoing upgrade projects at ESO, made it possible to also test on HARPS a novel cryogenic cooling concept, with the goal of replacing both the ESO standard liquid nitrogen CFC and the bath cryostat with a very compact commercial off-the-shelf Stirling cryocooler[2]. The extreme metrological precision of HARPS was the main motivation for performing the test, because even tiny displacements of the spectral lines — due to vibrations — of a calibration source could have been detected. The result is extremely promising, showing no effect on the positions of the spectral lines induced by the residual vibrations of the CryoTel GT Stirling cooler. The uncertainty of the measurement was of the order of 30 cm s^{-1} in RV, corresponding to a global displacement of the spectral lines on the detector of about 5 nm, only about 10 times larger than the silicon lattice constant.

The success of this test opens the window to considering the possibility of an upgrade of the HARPS detector system with a new cryostat cooled with a CryoTel GT AVC generation II, and possibly an improved, 4k × 4k monolithic detector, in place of the current mosaic of two 2k × 4k chips. While this upgrade might improve the instrument performance even further (in terms of stability and spectral coverage), it would certainly address the issue of the technological obsolescence of the control electronics, now 25 years old, and also possible failures of the current and quite aged CFC on an instrument that is still one of the best of its kind worldwide. Furthermore, it could be used as the perfect test bench in view of the deployment of new controllers and cryocoolers on various other instruments, such as the Echelle SPectrograph for Rocky Exoplanet and Stable Spectroscopic Observations (ESPRESSO) on the Very Large Telescope and the future ArmazoNes high Dispersion Echelle Spectrograph (ANDES) on ESO's Extremely Large Telescope.

The future of HARPS therefore remains bright as regards its own capabilities and scientific mission, its combination with the Near InfraRed Planet Searcher (NIRPS), its infrared twin on the 3.6-metre telescope, and the connection of both instruments to the HARPS Experiment for Light Integrated Over the Sun (HELIOS)

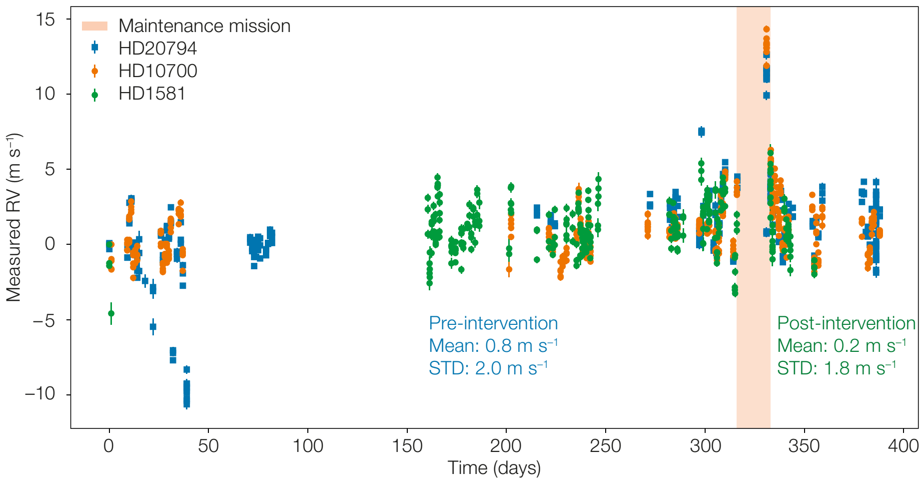

Figure 3. Radial velocity variation of a sample of quiet stars used for instrument stability monitoring. Within the scatter of the measurements no discontinuity is visible in the radial velocities after the completion of the mission.

solar telescope. HARPS and La Silla are furthermore the ideal platform on which to implement and test cutting edge technology.

References

Armstrong, D. J. et al. 2023, MNRAS, 524, 5804
Ihle, G. et al. 2010, Proc. SPIE, 7739, 77393R
Lo Curto, G. et al. 2012, The Messenger, 149, 2
Lo Curto, G. et al. 2015, The Messenger, 162, 9
Mayor, M. et al. 2003, The Messenger, 114, 20
Pepe, F. et al. 2003, Proc. SPIE, 4841,1045
Prinoth, B. et al. 2022, Nat. Astron.,6, 449
Wildi F. et al. 2011, Proc. SPIE, 8151, 81511F
Wilken, T. et al. 2012, Nature, 485, 611

Links

[1] NASA Exoplanet Archive: https://exoplanetarchive.ipac.caltech.edu/
[2] Stirling cryo-cooler used in this test: https://www.sunpowerinc.com/products/stirling-cryocoolers/cryotel-cryocoolers/gt

This is an image of the spiral galaxy NGC 4303, also known as Messier 61, which is one of the largest galactic members of the Virgo Cluster. Being a so-called starburst galaxy, it has an unusually high number of stars being born, and has been used by astronomers as a laboratory to better understand the fascinating phenomena of star formation.

The golden glow is a result of combining observations taken at different wavelengths of light with the Multi-Unit Spectroscopic Explorer (MUSE) instrument on ESO's Very Large Telescope (VLT) in Chile. Here gas clouds of ionised oxygen, hydrogen and sulphur are shown in blue, green and red, respectively. The observations were made as part of the Physics at High Angular resolution in Nearby GalaxieS (PHANGS) project, aiming to study nearby galaxies across all wavelengths of the electromagnetic spectrum.