

The GAPS programme with HARPS-N at TNG

II. No giant planets around the metal-poor star HIP 11952^{*,**}

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ABSTRACT

In the context of the programme Global Architecture of Planetary Systems (GAPS), we have performed radial velocity monitoring of the metal-poor star HIP 11952 on 35 nights during about 150 days using the newly installed high-resolution spectrograph HARPS-N at the TNG and HARPS at the ESO 3.6 m telescope. The radial velocities show a scatter of 7 m s^{-1} , compatible with the measurement errors for such a moderately warm metal-poor star ($T_{\text{eff}} = 6040 \pm 120 \text{ K}$; $[\text{Fe}/\text{H}] = -1.9 \pm 0.1$). We exclude the presence of the two giant planets with periods of $6.95 \pm 0.01 \text{ d}$ and $290.0 \pm 16.2 \text{ d}$ and radial velocity semi-amplitudes of $100.3 \pm 19.4 \text{ m s}^{-1}$ and $105.2 \pm 14.7 \text{ m s}^{-1}$, respectively, which have recently been announced. This result is important because HIP 11952 was thought to be the most metal-poor star hosting a planetary system with giant planets, which challenged some models of planet formation.

Key words. stars: individual: HIP 11952 – techniques: radial velocities – planetary systems

1. Introduction

Identifying planets around stars with heavy-element abundances significantly lower than those of the Sun is a revealing test for models of the formation of planetary systems. On the one hand, assuming stellar metallicity ($[\text{Fe}/\text{H}]$) to be a natural proxy for the actual heavy metal content of the primordial circumstellar disk, the core-accretion scenario for giant planet formation predicts

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** Table 1 is available in electronic form at <http://www.aanda.org>

that the planet frequency f_p should increase with higher $[\text{Fe}/\text{H}]$ (Ida & Lin 2004; Mordasini et al. 2009a), because the increased surface density of solids facilitates the growth of embryonic cores, thus greatly enhancing the formation of gas giant planets around more metal-rich stars. Indeed, there exist theoretical expectations for threshold values of $[\text{Fe}/\text{H}]$ below which giant planets cannot form, $[\text{Fe}/\text{H}] \approx -0.5$ (Johnson & Li 2012; Mordasini et al. 2012). On the other hand, gas giant planet formation by gravitational instability is less sensitive to the disk metal content, therefore f_p is expected to be independent of $[\text{Fe}/\text{H}]$ (Boss 2002).

The observational evidence of a strong dependence of f_p on $[\text{Fe}/\text{H}]$ for giant planets (Santos et al. 2004; Fischer & Valenti 2005) is commonly considered to support the core-accretion mechanism (Mordasini et al. 2009b). No significant trends of f_p with $[\text{Fe}/\text{H}]$ are observed for low-mass planets (Neptunes and super-Earths) in radial-velocity (RV) surveys, for the metal abundance range $-0.5 \leq [\text{Fe}/\text{H}] \leq +0.1$ (Mayor et al. 2011; Sousa et al. 2011). This result was recently confirmed by statistical analyses of *Kepler* transiting-planet candidates (Buchhave et al. 2012). Moreover, low-mass planets seem to be rare around super-metal-rich stars (Jenkins et al. 2013).

The f_p - $[\text{Fe}/\text{H}]$ relation for giant planets is firmly established on a solid statistical basis for $[\text{Fe}/\text{H}] > 0.0$. In this regime, a simple power-law fit with $\alpha \times 10^{\beta[\text{Fe}/\text{H}]}$, and β in the range 1.5–2.0, well represents the observed trend (e.g. Fischer & Valenti 2005; Sozzetti et al. 2009; Johnson et al. 2010). Stars with $[\text{Fe}/\text{H}] \sim +0.3$ appear 4–5 times more likely to host a giant planet than solar-metallicity dwarfs. At $[\text{Fe}/\text{H}] \approx 0.0$, f_p is about 3–5%. The situation is less clear for $[\text{Fe}/\text{H}] < 0.0$, and recent studies (Mortier et al. 2012) indicate the possibility that a power law might not describe the relation in the low-metallicity regime correctly.

The uncertainties still apparent in statistical studies stem primarily from the relatively limited sample sizes of metal-poor stars in large RV surveys. Attempts at mitigating this limitation have been made in the past, with experiments focusing on RV searches for giant planets around about 250 metal-poor stars carried out by Sozzetti et al. (2006, 2009) with Keck/HIRES and Santos et al. (2011) using HARPS on the ESO 3.6 m telescope. The outcome of the first survey was a null result, while the HARPS survey yielded three detections at the metal-rich end ($[\text{Fe}/\text{H}] \sim -0.5$) of the sample (Santos et al. 2007, 2010). Another project started in June 2009 around a sample of 96 metal-poor stars with the FEROS spectrograph. Detections have been reported from this survey of a short-period ($P = 16$ d) giant planet around the metal-poor horizontal branch star HIP 13044 (Setiawan et al. 2010) and of a two-planet system orbiting the F dwarf HIP 11952 (Setiawan et al. 2012, hereafter S12).

The HIP 11952 system is of particular interest. The primary is a high-proper-motion, nearby ($d = 112$ pc), relatively bright ($V = 9.85$) early F-type dwarf (possibly a subgiant), with $[\text{Fe}/\text{H}] = -1.9 \pm 0.1$ (S12). The two planets reported by S12 have $P = 6.95 \pm 0.01$ d and minimum masses $m_2 \sin i = 0.78 \pm 0.16 M_J$ and $2.93 \pm 0.42 M_J$, respectively. The HIP 11952 system, with a metallicity ten times lower than the second-lowest metallicity giant-planet hosting dwarf, poses a severe challenge to the core-accretion model (Johnson & Li 2012; Mordasini et al. 2012).

HIP 11952 was included in our programme, which focuses on known planetary systems within the framework of the long-term project Global Architecture of Planetary Systems (GAPS) recently started in open time using HARPS-N at the Telescopio

Nazionale *Galileo* (TNG). The programme is described in Covino et al. (2013). We aimed at a) improving the quality of the orbital solutions reported by S12, and b) looking for evidence of lower-mass companions. In this paper, we report a non-detection of the two giant planets announced by S12, based on RV measurements with typical internal errors 5–10 times lower than the originally published FEROS values.

2. HARPS-N

HARPS-N is an échelle spectrograph that covers the visible wavelength range between 383 and 693 nm (Cosentino et al. 2012). It is a near-twin of the HARPS instrument mounted at the ESO 3.6-m telescope in La Silla (Mayor et al. 2003). It was installed at the TNG in March 2012. After instrument commissioning in mid 2012, it was offered for open-time programmes starting in August 2012.

The instrument is located in a temperature-controlled room within a vacuum-controlled enclosure to ensure the required stability, and is fed by two fibres at the Nasmyth B focus of the TNG. The second fibre can be used for simultaneous calibration (currently with a Th-Ar hollow-cathode lamp) or for monitoring of the sky depending on the science goal and target brightness. Both fibres have an aperture on the sky of 1 arcsec. The spectra are recorded on an E2V 4k4 CCD 231 with a $15 \mu\text{m}$ pixel size. The resulting sampling is about 3.3 pixels (FWHM) and the spectral resolution is about 115 000. Early observing tests yielded an instrument total efficiency of $\varepsilon = 7\%$ at 550 nm, including losses due to the Earth's atmosphere and the telescope mirrors.

A failure of the red side of the CCD in late Sep. 2012 caused the observations between Sep. 29 and Oct. 25 2012 to be performed using the blue side only. A new CCD was installed at the beginning of Nov. 2012, and observations after this date were performed with the full spectral range. The possible impact of the observations taken with only half of the spectral range is discussed in Sect. 4.

3. Observations and data reduction

HIP 11952 was observed with HARPS-N on 25 nights from 2012, Aug. 7 to 2013, Jan. 6. The Th-Ar simultaneous calibration was used in all observations. The drift correction with respect to the reference calibration was almost always below 1 m s^{-1} . The integration time of 900 s adopted for all observations led to a typical signal-to-noise ratio of ~ 70 –80 per pixel on the extracted spectrum at 460 nm. Additional observations on 14 nights in two runs from 2012, Dec. 11 to 2013, Jan. 5 were also gathered at the ESO 3.6 m telescope using HARPS. An integration time of 1200 s was adopted.

Radial velocity measurements and their internal errors were obtained using the online pipelines of HARPS and HARPS-N, which are based on the weighted cross-correlation function (CCF) method (Baranne et al. 1996; Pepe et al. 2002). The G2 mask was adopted (the earliest-type one available). The median of the internal errors is $\sigma_{\text{RV}} = 5.8 \text{ m s}^{-1}$ for HARPS-N (full CCDs in use) and $\sigma_{\text{RV}} = 5.6 \text{ m s}^{-1}$ for HARPS. The relatively large RV errors are due to the paucity of spectral lines of this moderately warm, metal-poor star. The HARPS-N spectra between JD 2 456 199 and 2 456 228 were acquired with only the spectral orders falling on the blue side of the CCD. In addition to the increase of the RV uncertainties due to the lower number of lines (median $\sigma_{\text{RV}} = 8.3 \text{ m s}^{-1}$), using only half of the spectral range also introduced a systematic RV zero-point

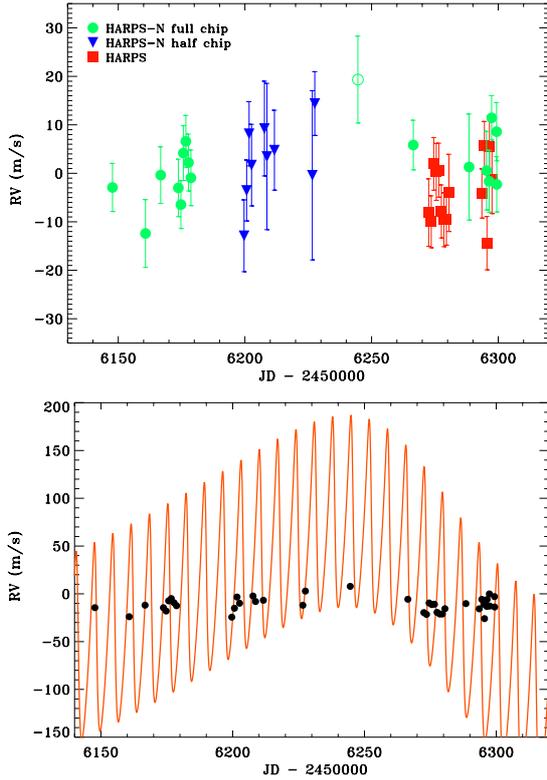


Fig. 1. Relative RVs of HIP 11952 obtained with HARPS-N and HARPS. In the upper panel, green circles represent full-chip HARPS-N data, blue triangles blue-chip HARPS-N data and red squares HARPS data. An offset of -7.4 m/s was applied to the blue-chip data. The open green circle is not included in the analysis. In the lower panel the predicted RV signature of the two planets by S12 is overlaid as a solid line.

shift, with possible additional shifts due to the slight change in dispersion and spectral resolution required for the optimisation of the échelle grating angle. We estimated this shift by deriving the RVs of full-chip spectra including only the spectral orders on the blue side of the CCD, i.e. with $\lambda < 534.75$ nm. The average offset is 7.4 ± 0.9 m s $^{-1}$, the half-chip RVs being higher. Such a shift is consistent with RV differences observed for other stars in the GAPS programme using the same mask. Additional offsets should also be present between the RVs obtained with HARPS and HARPS-N, because they cover slightly different spectral ranges, and possibly for the RVs taken with the new HARPS-N CCD because focus adjustments were made and chip properties may be different. However, from the available data, these offsets appear to be below the measurement uncertainties.

4. Analysis

The relative RV time series is shown in Fig. 1. We report the full dataset in Table 1. We included the correction of $+7.4$ m s $^{-1}$ for the half-chip RVs. We anticipate that, whilst this has an obvious impact when attempting to search for RV variations with an amplitude close to the measurement uncertainties or to investigate a possible long-term trend, the main result of the paper is entirely unaffected by this procedure. The RV measurement obtained on 2012 Nov. 12 (the blue open circle at JD 2 456 244.5992 in the upper panel of Fig. 1), immediately after operations were re-summed with the new HARPS-N CCD in place, is not included in the analysis because it has discrepant values of CCF contrast and activity index, pointing to a temporary calibration problem with the new setup.

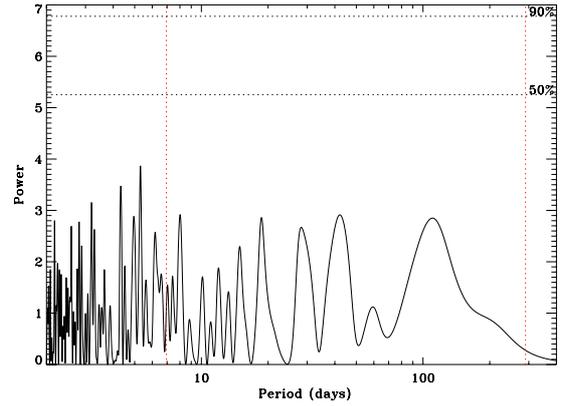


Fig. 2. Lomb-Scargle periodogram of RVs of HIP 11952 obtained with HARPS-N and HARPS. Confidence levels from the bootstrap simulations are shown. The vertical dotted lines mark the periodicities identified by S12 based on FEROS RVs.

The offset-corrected scatter (6.9 m s $^{-1}$) is consistent with the internal errors. Considering our sampling, RV variations with periods and semi-amplitudes (~ 100 m s $^{-1}$) close to those reported in Setiawan et al. (2012) are clearly ruled out. A Lomb-Scargle periodogram of the RVs does not indicate any significant periodicities in the range 2–400 days (Fig. 2). The confidence levels in Fig. 2 were obtained by random permutations as in Desidera et al. (2011).

Furthermore, there are neither significant periodicities nor correlations of the RVs with the CCF FWHM, the CCF contrast, and the bisector velocity span, as obtained by the instruments’ pipelines, as well as with the Ca II H&K activity indicator, measured as in Desidera et al. (2006). S12 also suggested that HIP 11952 could be a pulsating variable. This possibility would be of great relevance, since in this case the RV measurements should primarily show the effect of the pulsation. The power spectra of the HIPPARCOS and All-Sky Automated Survey (ASAS; Pojmanski 2002) photometric data are very noisy due to their poor spectral windows, but no significant periodic signal is detected.

Our RVs do not show significant long-term trends. To additionally constrain the existence of a stellar companion on a long-period orbit, we considered the 14 RVs obtained by Latham et al. (2002) with the CfA Digital Speedometers (DS) between 1984 and 1998. Typical errors are 0.7 km s $^{-1}$ and no obvious trend in the RVs during that time span is apparent. Furthermore, Latham (private communication) obtained five new RVs with the Tillinghast Reflector Echelle Spectrograph (TRES) at the FLWO observatory in eight nights during December 2012 with typical errors of 0.1 km s $^{-1}$. The average velocity for these RVs, when shifted to the velocity zero point of the CfA DS (determined from extensive observations of standard stars), is 23.90 ± 0.05 km s $^{-1}$ (uncertainty of the mean), compared to 23.64 ± 0.25 km s $^{-1}$ for the 14 old RVs from the CfA DS. The probability that the star has a constant velocity, given the internal errors of the 19 observations, is $P(\chi^2) = 0.47$. Thus there is no evidence for a secular drift in the velocities of HIP 11952 over a span of 29 years.

Following Sozzetti et al. (2009), upper limits on the minimum mass of possible planetary companions with $3 \leq P \leq 350$ days and eccentricity $e < 0.6$ were derived from our data with 99% confidence level, based on the F-test and χ^2 statistics (Fig. 3). They show that both the inner and outer planet claimed by S12 are ruled out by our observations at the $6\text{-}\sigma$ and $4\text{-}\sigma$ level,

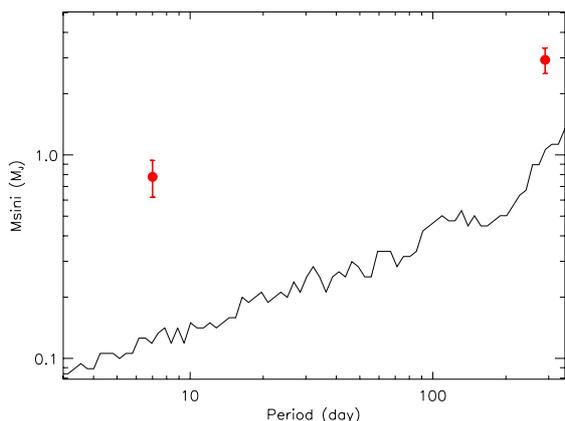


Fig. 3. Upper limits on the minimum mass of possible planetary companions around HIP 11952 with a 99% confidence level from HARPS-N and HARPS data. Filled circles show the mass and period of the two planets claimed by S12, which are clearly incompatible with our data.

respectively. Indeed, at the given level of confidence this test excludes any planet with masses and periods as given by S12, whatever their orbital parameters. Planets with masses, periods, and other orbital parameters as given by S12 are excluded at higher levels of confidence by our data.

5. Discussion and conclusions

Based on high-precision RV measurements carried out with HARPS-N and HARPS we found no evidence of the two giant planets with $P = 6.95$ d and $P = 290$ d, and projected masses $0.78 \pm 0.16 M_J$ and $2.93 \pm 0.42 M_J$, respectively, announced by S12 to orbit the metal-poor star HIP 11952. Saturn-mass and Jupiter-mass planets with periods shorter than 30 and 250 days, respectively, are also excluded. Our observations are within the measurement errors, which are about 5–10 times lower than those of the FEROS observations, thanks to the optimised performance of HARPS-N in delivering RVs and the larger telescope aperture. This case shows that care should be taken in interpreting RV variations as indicating orbital motion, because stellar and instrumental effects may impact the measurements, particularly when inferred RV amplitudes are only slightly larger than the measurement accuracy.

Our result has important consequences, because it clears the observational sample of a system that constituted a severe challenge to the core-accretion model of giant planet formation. A giant planet system around HIP 11952 was indeed very hard to explain within the context of the most recent calculations based on this mechanism (Johnson & Li 2012; Mordasini et al. 2012).

On the one hand, giant planets formed by core accretion are expected to be very rare around low-metallicity dwarfs, and the

observational evidence presented here directly supports this assumption. On the other hand, low-mass planets can theoretically form around metal-poor stars, so it is highly desirable to obtain statistically useful observational inferences on the actual value of f_p for super-Earths and Neptunes across orders of magnitude in the host stars' metal content. New programmes to search for low-mass planets around metal-poor stars (such as the on-going ESO large programme 190.C-0027 on HARPS and our dedicated GAPS programme on HARPS-N) will therefore significantly improve our knowledge of the relative roles of competing planet formation processes.

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Table 1. Radial velocities of HIP 11952.

BJD -2 450 000	<i>RV</i> (km s ⁻¹)	Error (km s ⁻¹)	Instrument/CCD
6147.72121	24.2530	0.0050	F
6160.74007	24.2435	0.0070	F
6166.74103	24.2556	0.0058	F
6173.72276	24.2529	0.0059	F
6174.73851	24.2495	0.0049	F
6175.69620	24.2601	0.0056	F
6176.68467	24.2625	0.0053	F
6177.71773	24.2582	0.0059	F
6178.68027	24.2550	0.0058	F
6199.65825	24.2505	0.0074	H
6200.67111	24.2598	0.0063	H
6201.65011	24.2715	0.0066	H
6202.61782	24.2650	0.0084	H
6207.70025	24.2726	0.0098	H
6208.68055	24.2668	0.0151	H
6211.64234	24.2681	0.0082	H
6226.61110	24.2629	0.0175	H
6227.58001	24.2777	0.0066	H
6244.59921	24.2753	0.0090	N
6266.46650	24.2618	0.0051	N
6272.54203	24.2478	0.0070	S
6273.54629	24.2459	0.0054	S
6274.53914	24.2579	0.0054	S
6275.53456	24.2562	0.0059	S
6276.53597	24.2566	0.0056	S
6277.54178	24.2481	0.0055	S
6278.54057	24.2464	0.0056	S
6279.53845	24.2464	0.0052	S
6280.53859	24.2519	0.0080	S
6288.48127	24.2573	0.0109	N
6293.54512	24.2518	0.0051	S
6294.53344	24.2616	0.0050	S
6294.86975	24.2565	0.0081	N
6295.53899	24.2415	0.0055	S
6295.91839	24.2543	0.0064	N
6296.53505	24.2615	0.0062	S
6296.88798	24.2674	0.0046	N
6297.53385	24.2547	0.0071	S
6299.33693	24.2645	0.0060	N
6299.40581	24.2537	0.0057	N

Notes. The last column indicates the instrument and CCD status: F is HARPS-N original full chip; H is HARPS-N half chip only (blue side); N is HARPS-N new chip; S is HARPS at ESO 3.6 m. The tabulated RVs do not include any offset between the data obtained with different observational setups.