A&A 512, A48 (2010)
DOI: 10.1051/0004-6361/200913523

Astronomy & Astrophysics

The HARPS search for southern extra-solar planets⋆,⋆⋆

XXII. Multiple planet systems from the HARPS volume limited sample

G. Lo Curto[1], M. Mayor[2], W. Benz[3], F. Bouchy[4], C. Lovis[2], C. Moutou[4], D. Naef[1,2], F. Pepe[2], D. Queloz[2], N. C. Santos[5], D. Segransan[2], and S. Udry[2]

[1] ESO – European Southern Observatory, Karl-Schwarzschild-Strasse 2, 85748 Garching bei München, Germany
e-mail: glocurto@eso.org
[2] Observatoire de Genève, Université de Genève, 51 Ch. des Maillettes, 1290 Sauverny, Switzerland
[3] Physikalisches Institut Universität Bern, Sidlerstrasse 5, 3012 Bern, Switzerland
[4] Laboratoire d'Astrophysique de Marseille, Traverse du Siphon, 13376 Marseille, France
[5] Centro de Astrofisica, Universidade do Porto, Rua das Estrelas, 4150-762 Porto, Portugal

Received 22 October 2009 / Accepted 29 December 2009

ABSTRACT

We present the detections of three multiple systems within the HARPS volume-limited sample. Among the six planets discussed in this paper, we have identified a "super-Earth" planet with a minimum mass of 6.6 $M_{\rm Earth}$ and a "Neptune" planet with minimum mass of 18 $M_{\rm Earth}$, both orbiting their parent stars within a distance of 0.05 AU and a period of approximately four days. These detections strengthen the argument that low-mass planets are primarily found in multiple-planetary systems.

Key words. planets and satellites: individual: HD 125612 – planets and satellites: individual: HD 215497 – planets and satellites: individual: HIP 5158 – techniques: radial velocities – techniques: spectroscopic – planets and satellites: general

1. Introduction

In this paper we present the detections of two multiple-planet systems and one system with a planet and a second companion, whose mass we were not able to determine because of its long period and the limited time span of our observations. The data were collected with the HARPS[1] instrument mounted at the ESO 3.6m telescope in Cerro La Silla, in Chile. HARPS is the ESO high-resolution spectrograph optimized for planet searches (Mayor 2003). This fiber-fed spectrograph achieves a spectral resolution of 115 000, and it is operated in vacuum under strict temperature control to avoid variations of the index of refraction along the light path in the optical bench and to improve its thermo-mechanical stability both on the short and on the long term (several years). With a signal to noise ratio of ≈100 on solar type stars, it can achieve, on a single measurement, a precision of 1 m s^{-1} in the measurement of the radial velocity, with the uncertainty dominated by photon noise. During the six years of operations it demonstrated its superb stability, reaching sub-m s^{-1} overall precision (Lovis 2007; Mayor 2009).

Since the discovery of the first extra-solar planet orbiting a main sequence star in 1995 (Mayor 1995), more than 350 planets have been discovered at an increasing pace. Such a sample begins to be suitable for statistical studies of the property of exoplanets. However, when attempting to compare five-dimensional distributions (M_1, m_2, a, e, [Fe/H]), these studies suffer heavily from the lack of statistics. A complete and well defined sample is mandatory for assessing statistically robust orbital elements distributions aiming to put strong constraints on the various scenarios of planet formation and evolution. Our program, which is part of the HARPS GTO, aims to obtain accurate orbital elements of Jupiter-mass planets in a well defined volume (the largest so far) of the solar neighborhood. The detection of lighter planets with this program is also possible, although these objects are not specifically targeted. The full exploitation of the sample will allow definition of the solid statistics over which to measure the occurrence of planetary systems and the distribution of their orbital elements. Moreover, thanks to the efficiency of the telescope and of the spectrograph, with this program we will deepen the magnitude limit at which exoplanets are detected by almost one magnitude, as confirmed by the 14 planets detections already published by this program (Pepe 2004; Moutou 2005; Lo Curto 2006; Naef 2007; Moutou 2009).

Among main sequence, planet host stars, 39 of them host multi-planet systems, with a total of 92 planets altogether, or 25% of the total number of planets discovered so far (Schnider 2009). Multi-planet systems are common, and their study is playing an important role in understanding planet formation and evolution (Ford 2006).

Despite the modest number of multi-planetary systems discovered so far, some trends begin to appear: e.g. light planets ("super-Earths", Neptunes) are detected primarily in multiple systems (Mayor 2009). It is also noticeable that the multiple-planet systems show a less pronounced bimodality of the period and semi-major axis distributions (Wright 2009) with respect to single-planet systems. The eccentricity distributions are instead quite similar, with the exception of the very low eccentricity range, mainly populated by single-planet systems.

Multi-planet system detection is generally more difficult, as it requires more data points and longer time spans. With this paper we add two more systems to the statistics of multi-planet

⋆ Based on observations made with the HARPS instrument on the ESO 3.6 m telescope at La Silla (Chile), under the GTO program ID 072.C-0488.

⋆⋆ RV tables are only available in electronic form at the CDS via anonymous ftp to cdsarc.u-strasbg.fr (130.79.128.5) or via http://cdsweb.u-strasbg.fr/cgi-bin/qcat?J/A+A/512/A48

[1] High Accuracy Radial velocity Planet Searcher.

Table 1. Observed and inferred stellar parameters of the three stars of this study.

Parameter		HD 125612	HD 215497	HIP 5158
Spectral type		G3V	K3V	K5V
V	[mag]	8.31	8.96	10.16
$B-V$	[mag]	0.63	0.95	1.08
π	[mas]	18.45 ± 1.09	22.97 ± 1.25	22.32 ± 2.12
d	[pc]	54 ± 3	44±2	45±4
M_V	[mag]	4.64	5.76	7.08
$T_{\rm eff}$	[K]	5900 ± 18	5113 ± 93	4962 ± 89
$\log g$	[cgs]	4.41 ± 0.05	4.31 ± 0.17	4.37 ± 0.20
[Fe/H]	[dex]	0.23 ± 0.014	0.23 ± 0.07	0.10 ± 0.07
L	[$L_\odot$]	1.09	0.39	0.11
M_*	[$M_\odot$]	1.091 ± 0.027	0.872 ± 0.023	0.780 ± 0.021
$v \sin i$	[km s^{-1}]	3.11	1.67	1.57
$\log R'_{\rm HK}$		−4.83 ± 0.14	−5.01 ± 0.06	−4.80 ± 0.07
$P_{\rm rot}(\log R'_{\rm HK})$	[days]	21.2	49.7	42.3
age	[Gyr]	<3	<7	<6

systems. A third star is found to host a planet and a long period companion, which will be defined once a longer time span is available.

2. The sample

With this program we are exploring the solar neighborhood up to a radius of 57.5 pc from the Sun. This planet search survey was started with the CORALIE[2] spectrograph (Udry 2000), and HARPS is complementing it to fainter magnitudes and to a larger volume. Thanks to the high efficiency of the HARPS spectrograph attached to the ESO 3.6 m telescope, we are detecting planets around stars one magnitude fainter than the average planet host star. The stars within this volume were selected to be suitable for radial velocity surveys, meaning solar type dwarf stars with spectral type between F2 and M0, with a low level of activity and a low rotational velocity. Binaries and known variable stars were discarded. The entire HARPS sample counts 850 stars. To increase the efficiency of the survey, as we are not specifically targeting low mass planets, we limit our precision to about 2 m s^{-1}.

3. Stellar characteristics

The spectroscopic analysis of the three stars was conducted assuming local thermodynamical equilibrium and using a grid of Kurucz atmosphere models. Equivalent widths of the spectral lines were computed via the ARES code (Sousa 2007). From this analysis we inferred the values of $T_{\rm eff}$, $\log g$ and [Fe/H] (see Table 1). We computed the star luminosity via the HIPPARCOS magnitude and parallax (ESA 1997) and the bolometric correction as defined in Flower 1996. The estimate of the rotation period of the star is given following the prescription of Noyes via the activity index and the color index (Noyes 1984). The age and the mass estimates are obtained via theoretical isochrones and a Bayesian estimation method (da Silva 2006).

A summary of the characteristics of the three stars is presented in Table 1. The activity indicator $\log R'_{\rm HK}$ was measured on each individual stellar spectra. For each star, its average is displayed in the table and the RMS is used as an estimation of the uncertainty.

[2] CORALIE is the high resolution spectrograph installed at the Euler 1.2 m Swiss national telescope in La Silla.

4. Radial velocity data and orbital solutions

The strategy we used during the data taking favored efficiency over radial velocity accuracy. We only observed for the time needed to acquire a spectrum with a signal to noise ratio between 40 and 50 at 550 nm, without taking care to average out the possible granulation or pulsation of the stars. Thanks to this we could keep our exposure times short, and the average time needed to acquire one data point was eight minutes, overheads included (pointing of the telescope, start guiding etc.). The radial velocity drifts of the spectrograph over one night are on average below 0.5 m s^{-1}, so the simultaneous Th calibration was not used. In fact, the main limiting factors to the precision of our measurements was the signal to noise ratio that we had chosen, and the fact that we did not average out the stellar "jitter". Despite these limitations, the photon noise uncertainty in the radial velocity determination was generally below 2 m s^{-1}. At this level of precision, radial velocity errors introduced by the guiding during standard operations are negligible. Thanks to the use of the new ThAr atlas (Lovis 2007) and with the exclusion of the Ar lines, the wavelength calibration errors are below 30 cm s^{-1}. Because the instrumental effects are limited below 0.5 m s^{-1}, the remaining contribution to the radial velocity uncertainty comes from the star itself.

Data reduction and radial velocity extraction was performed by the HARPS pipeline in its current release 3.4. Only measurements with a signal to noise ratio above 25 at the wavelength of 550 nm are used in our analysis. As a general data analysis strategy, once a signal has been identified in the radial velocity sequence, a series of checks is performed to insure that the origin of the signal is indeed an orbiting body and not the stellar activity or the blending with another star. The usefulness of the analysis of the bisector span of the cross correlation function has been put in evidence by Queloz (2001). We searched for correlations between the bisector span and the radial velocity data, and in case of multi-planet systems we also study the correlation between the bisector span and the radial velocity residuals of the fit of the first planet. A correlation would indicate likely that the signal is being injected by the activity of the star or by the blend with another star. We also compared the extracted orbital period with the stellar rotation period and with periodic signals emerging from the periodograms of the $\log R'_{\rm HK}$ indices. In our analysis we do not find any correlation of the radial velocity or the residuals with the bisector span of the cross correlation function for any of the stars. The $\log R'_{\rm HK}$ indices do not show any

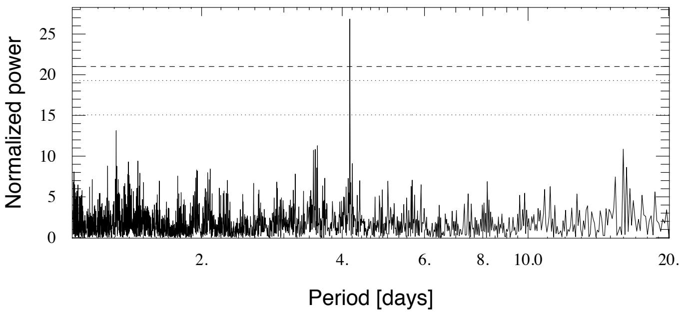

Fig. 1. The periodogram of the residuals of the two Keplerian fits to the radial velocity data set of HD 125612. The two horizontal dotted lines indicate the 10% and 1% FAP (from bottom to top), while the dashed line on top indicates the three sigma limit (0.23% FAP).

periodicity for any of the stars, and the periods of the orbits we identify are different from the rotation periods of the stars by an order of magnitude. Once all these checks were done and all have shown a negative result, and considering the low activity level of the stars as indicated by their $\log R'_{\rm HK}$ indices, we conclude that our signals are not generated by the photospheric activity of the stars.

In accordance with Scargle (Scargle 1982), we define the false alarm probability (FAP) as the probability that a peak in the periodogram comes from pure noise. We ran the FAP tests on all the candidate orbits and required a potential signal to have an FAP lower than 10^{-3}. F-tests are used to compare different models fitting the same data set. A new model is accepted only if it improves the fit at the three sigma level or above. Finally Montecarlo simulations are performed around the best solution to check for its stability.

The radial velocity data presented in this paper are available in electronic form in the CDS archive.

4.1. HD 125612

A planetary companion to HD 125612 was first found by Fischer et al. (Fischer 2007) with Keck+HIRES data. The object they identify orbits the star at a distance of 1.2 AU with a period of 510 days, an eccentricity of 0.38, and a semi-amplitude of 90 m s^{-1}. The object is a 3.5 Jupiter-mass planet. They also notice a linear trend and some power in the periodogram at a period of 3.5 days, which they do not find statistically significant (Fischer 2007). To the Keck data we add 58 HARPS measurements taken over five years, with an average exposure time of about three minutes and the signal to noise ratio averaging around 50 at the HARPS central wavelength of 550 nm. Even to the naked eye, the distribution of the radial velocity data of this object, is suggesting the existence of at least two Keplerian signals. The periodogram of the residuals of the two planets fit is undoubtedly indicating a third signal (see Fig. 1), well above the three sigma level (0.23% FAP). The computation of the FAP is performed in the restricted period range from one to twenty days to minimize the computing time. Only much smaller peaks were detected outside of this range. Analysis of the residuals from the three planets fit does not show any additional significant signal. We are able to supply improved orbital elements for planet b and to define the orbital elements for the newly discovered planets c and d. The radial velocity curves of this three planet system are shown in Fig. 2, while the orbital elements are shown in Table 2.

We checked the bisector span of the cross correlation function, and found that it is not correlated with either the radial velocity or the residuals of the one-planet or the two-planet fits. Moreover the activity index does not show any periodicity, and the rotation period of the star is significantly different from the orbital periods detected. All these elements suggest that the most likely origin of the detected signals is Keplerian.

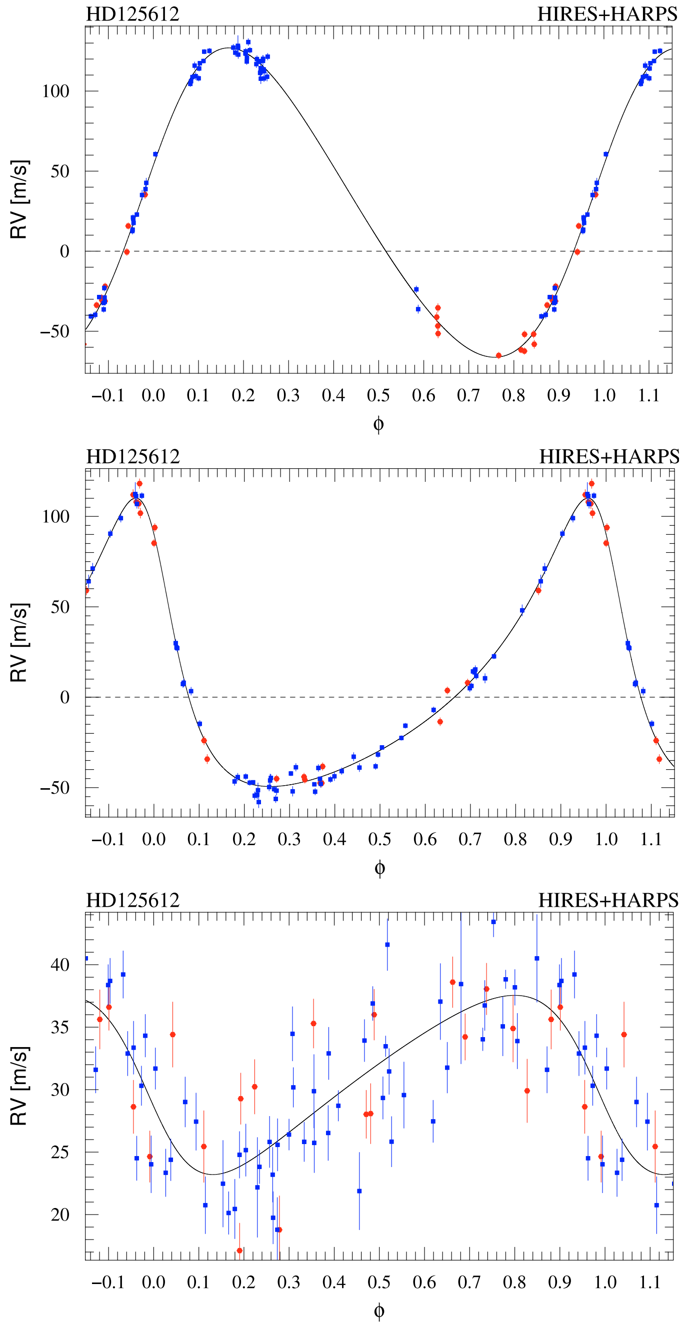

Fig. 2. The radial velocity curves for the three-planet system HD 125612, from HD 125612b (*top*) to HD 125612d (*bottom*). The HIRES data are marked in red, while the HARPS data are marked in blue. Only two thirds of the orbit of the outer planet have been covered up to now (*top panel*).

The F-test indicates that the three-orbit model improves the fit to the data with respect to the two-orbit model at more than a three sigma level. The stability of the three-orbit solution is confirmed by Montecarlo analysis. The period of the outer planet has a large uncertainty, because the data cover only two thirds of the full orbit.

Table 2. Orbital parameters for the planets orbiting the star HD 125612.

Parameter		HD 125612c	HD 125612b[a]	HD 125612d
P	[days]	4.1547 ± 0.0005	559.4 ± 1.3	3008 ± 202
T	[JD-2 400 000]	54 420.17 ± 0.23	54 894.9 ± 2.5	57174^{+396}_{-17}
e		0.27 ± 0.12	0.46 ± 0.01	0.28 ± 0.12
V	[km s^{-1}]	−18.214 ± 0.002 (HIRES) −18.193 ± 0.002 (HARPS)		
ω	[deg]	103 ± 23	41.5 ± 1.7	−76 ± 8
K	[m s^{-1}]	7.2 ± 1.2	79.8 ± 2.3	96.6 ± 4.7
$m_2 \sin i$	[$M_{\rm Jup}$]	0.058	3.0	7.2
$m_2 \sin i$	[$M_{\rm Earth}$]	18	968	2286
a	[AU]	0.05	1.37	4.2
$N_{\rm meas}$		19 (HIRES)+58 (HARPS)		
$Span$	[days]	2016		
$\langle \delta \mathrm{RV} \rangle$	[m s^{-1}]	2.1		
σ (O–C)	[m s^{-1}]	3.7		
$\chi^2_{\rm red}$		5.6 ± 0.4		

Notes. [a] Planet b was discovered by Fischer et al. (Fischer 2007), and we improve its orbital elements after discovery of the planets c and d.

Given the relatively high value of the projected rotational velocity of the star and of the value of the $\log R'_{\rm HK}$ index (−4.83 ± 0.14), this star appears to be moderately active. Considering that the short exposure time adopted does not allow averaging out granulation or pulsations effects, the excess of the residuals (3.7 m s^{-1}) with respect to the measurement uncertainty (2.1 m s^{-1}) appears fully justified.

Mugrauer & Neuhaüser (2009) report the possible existence of a proper motion companion to the star HD 125612. The putative companion is an M 4 dwarf with $H = 11.761 \pm 0.034$ mag, and it is estimated to be at a distance of ≈4750 AU from the primary star. Therefore we do not expect a measurable effect on our Doppler data, because of the relatively short time span of our data set.

Anglada-Escude et al. (2009) discuss how eccentric orbital solutions could hide planetary systems in resonant orbits. They used HD 125612 as a case study and predict a planet in a 2:1 resonance with HD 125612b, with a period of ≈250 days. We tried to fit the 19 HIRES data points with a two Keplerian model and a drift and we found a solution with periods of ≈550 days and ≈270 days and with a residual of less than 4 m s^{-1}. However, when we also add the 58 HARPS data points, we are unable to fit an orbits in the 250 days range. Indeed, as also pointed out by Anglada-Escude, although eccentric orbits could fit resonant orbital configurations under some circumstances, only a large number of high precision data points can distinguish among the two possibilities.

4.2. HD 215497

We collected 88 measurements on this star in a five years period, using an exposure time of five minutes on average. The average signal to noise ratio in our data set is approximately 50 at 550 nm. The adopted exposure time and the achieved signal to noise ratio depended on weather conditions. A clear periodic trend in the RV data of this K3V, metal rich star is already visible in the raw data. After the first Keplerian fit to the data, the amplitude and the periodogram of the residuals suggest the presence of a second companion. Figure 3 shows the periodogram of the residuals after the fit of the first companion. A clear peak around four days is visible, as well as its one day alias. The FAP for the four days signal is less than one part in 10^{-4} when computed in the period range between two and ten days (see Fig. 3).

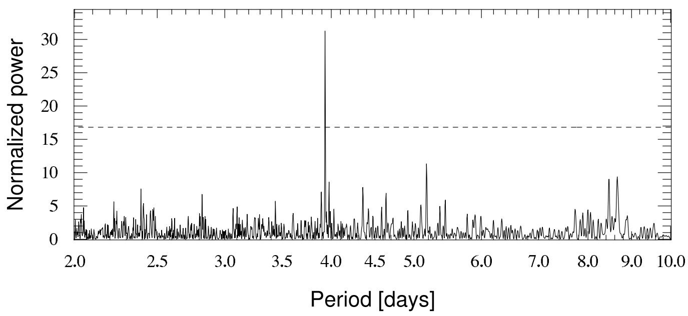

Fig. 3. The periodogram of the residuals after the fit of the first orbit to the HD 215497 data. The ≈four days period is clearly visible. The horizontal line specifies the 10^{-4} FAP limit computed within the period range from two to ten days.

We verified that, within the error bars, there is no correlation between the radial velocity data, the residuals of the fit to the first planet, and the bisector span. Moreover, the absence of significant peaks in the periodogram of the calcium index $\log R'_{\rm HK}$ and the low level of activity of the star suggest that our signals do not come from stellar activity. We also notice that the periods of the Keplerian signals are very different from the rotation period of the star. The orbital parameters are shown in Table 3, and the radial velocity curves for the two planets are displayed in Fig. 4. The presence of the second planet is confirmed by the F-test, which indicates that the two orbits model effectively improves the fit at the three sigma level. The two planets are not bound in a mean motion resonance due to their very different orbital periods (≈4 and 567 days), although it is worth noticing that their major axis projected in the orbital plane are aligned within 17 degrees, which is of the same order of magnitude as the uncertainty on the periastron angle.

The deviation from the residuals (1.75 m s^{-1}) is greater than the average measurement error (1.40 m s^{-1}). This discrepancy might derive from systematics originating either from the instrument or from the star itself, or from the presence of another planet. In fact, after the fit with two planets, we find one more peak in the periodogram of the residuals, but with an FAP less than 10^{-3}. From the F-test we see that the 3 planets fit improves the solution at the 2 sigma level. If this signal were confirmed to originate from an orbiting body, this would have a period of 8.46 days and a mass of only 3.2 times the mass of the Earth, one of the lightest extra-solar planets discovered so far. To confirm

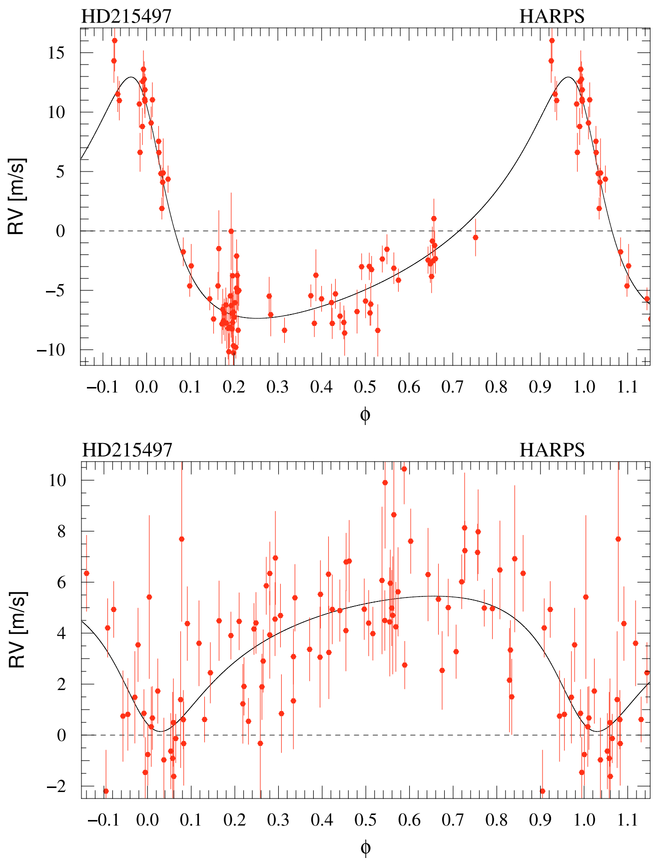

Fig. 4. The radial velocity curves for the two companions of HD 215497. The *top panel* shows the 567 days period planet, with a mass of 0.33 $M_{\rm Jup}$, and the *bottom panel* shows the ≈four days period planet with a mass only 6.6 times the mass of the Earth.

Table 3. Orbital parameters for the two planets orbiting the star HD 215497.

Parameter	HD 215497b	HD 215497c
P [days]	3.93404 ± 0.00066	567.94 ± 2.70
T [JD-2 400 000]	54 858.95 ± 0.37	55 003.48 ± 5.15
e	0.16 ± 0.09	0.49 ± 0.04
ω [deg]	96 ± 34	45 ± 4
K [m s^{-1}]	2.98 ± 0.34	10.10 ± 0.65
V [km s^{-1}]	49.3107 ± 0.0006	
$m \sin i$ [$M_{\rm Jup}$]	0.02	0.33
$m \sin i$ [$M_{\rm Earth}$]	6.6	104.3
a [AU]	0.047	1.282
$N_{\rm meas}$	105	
Span [days]	1855	
$\langle \delta \rm RV \rangle$ [m s^{-1}]	1.40	
σ (O–C) [m s^{-1}]	1.75	
$\chi^2_{\rm red}$	2.83	

the validity of this signal, we are acquiring more radial velocity data using the high precision strategy.

This system hosts one of the lightest planets detected so far, with only 6.6 times the mass of the Earth, orbiting very near to the parent star, at a distance of only 0.049 AU.

4.3. HIP 5158

The star HIP 5158 was observed 57 times in the course of this program, with an average signal to noise ratio of approximately 50. Due to its faintness, the exposure time was generally in the 10 min range. The radial velocity data of this star can be fitted by a combination of a keplerian curve and a second degree polynomial (see Fig. 5). The polynomial is clearly indicating that another body is orbiting the star, but unfortunately we still do not cover enough of the phase to be able to constrain this orbit. The orbital parameters of the keplerian curve that we reconstructed are shown in Table 4. No other significant signal is detected from the periodogram. The FAP of the strongest remaining feature, located at a period comparable to the rotation period of the star, is 20%,

Also in this case the residuals from the fit (2.47 m s^{-1}) are larger than the average photon noise (1.46 m s^{-1}). We assume that this could be entirely justified by the observational strategy used and by contribution from the star.

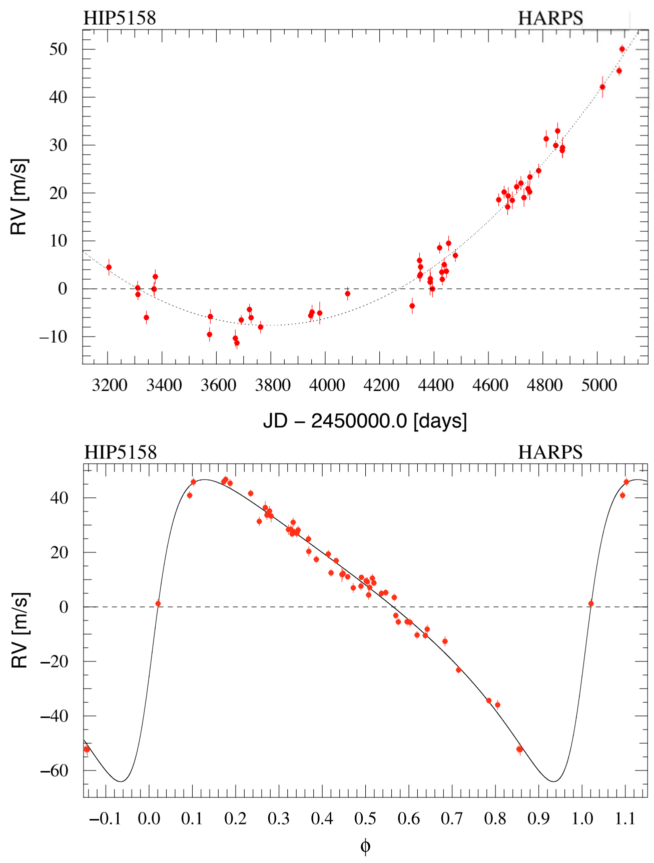

Fig. 5. The radial velocity curves for HIP 5158.

Table 4. Orbital parameters for the planet orbiting the star HIP 5158.

Parameter	HIP 5158b
P [days]	345.72± 5.37
T [JD-2 400 000]	54 580.49 ± 15.21
e	0.52 ± 0.08
ω [deg]	−108 ± 11
K [m s^{-1}]	57 ± 11
V [km s^{-1}]	14.88 ± 0.14
$m \sin i$ [$M_{\rm Jup}$]	1.42
a [AU]	0.89
$N_{\rm meas}$	57
Span [days]	1901
$\langle \delta \rm RV \rangle$ [m s^{-1}]	1.46
σ (O–C) [m s^{-1}]	2.47
$\chi^2_{\rm red}$	3.68

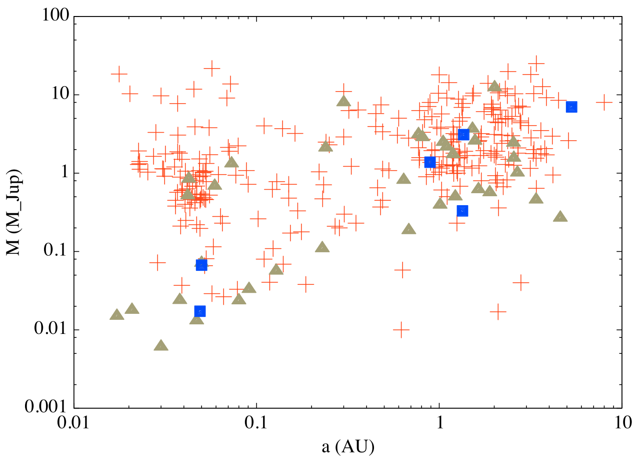

Fig. 6. The mass-separation diagram. The single-planet and the multi-planet systems are shown separately and are marked with crosses and filled triangles, respectively. The detections from this work (together with HD 125612b) are marked with filled squares. The plot is truncated to a semi-major axis lower than 10 AU.

Attempting a Keplerian fit of the quadratic drift gives an idea of what could be the minimum mass and period of the orbiting body. We assume that the minimum period is reached when forcing the fit to lower periods increases the value of the χ^2 above 10. In this situation we find $P_{\rm min} \approx 2000$ days and $m \sin i_{\rm min} \approx 1.2\ M_{\rm Jup}$.

5. Discussions and conclusions

We have presented the detections and the orbital elements of 5 extra-solar planets in three multiple systems, and we have improved the orbital elements of HD 125612b. The nature of a seventh body is still uncertain and the orbit unconstrained. We need a longer time span to be able to obtain precise orbital elements for this object. These are the first multiple systems detected in the HARPS volume limited sample.

Even though the program is not optimized for very high precision measurements, we succeeded in finding a close-in "super-Earth" planet, once more demonstrating the extraordinary capabilities of HARPS. Our findings add to the statistics of multi-planetary systems and to that of "light" planets, and strengthen the argument that low mass planets such as "super-Earths" and "Neptunes" are found primarily in multi-planetary systems.

Within each of the studied systems, the ratios of the periods of the planets are not close to small integers, giving no evidence of mean motion resonance among the planets.

Figure 6 shows the location of multiple-planetary systems, and of the 6 planets we discuss here, in the mass-separation diagram, together with the single-planet systems.

Interestingly, all planets presented in this paper show high eccentricity, in the 0.16–0.52 range. Multiple-planet systems play a key role in the understanding of the excitation and damping of the eccentricity in planetary systems, as well as the migration mechanisms; however, the statistics are still weak and call for a major effort to increase the sample of detected extra-solar planetary systems.

Acknowledgements. The authors thank the ESO staff on the 3.6-m telescope at La Silla for their diligent and competent help during the observations.
The HARPS spectrograph was built by the contributions of the Swiss FNRS, the Geneva University, the French Institut National des Sciences de l'Univers (INSU) and ESO.
N.C.S. would like to acknowledge the support by the European Research Council/European Community under the FP7 through a Starting Grant, as well from the Fundação para a Ciência e a Tecnologia (FCT), Portugal, through program Ciência 2007, and in the form of grants reference PTDC/CTE-AST/098528/2008 and PTDC/CTE-AST/098604/2008.
This research made use of the Simbad database, operated at the CDS, Strasbourg, France.

References

Anglada-Escude, G., López-Morales, M., & Chambers, J. E. 2010, ApJ, 709, 168
Bouchy, F., Pont, F., Santos, N. C., et al. 2004, A&A, 421, L13
Bouchy, F., Pont, F., Melo, C., et al. 2005, A&A, 431, 1105
da Silva, L., Girardi, L., Pasquini, L., et al. 2006, A&A, 458, 609
ESA 1997, ESA-SP 1200, The HIPPARCOS and TYCHO catalogue
Ford, E. B. 2006, ASPC, 352, 15
Fischer, D. 2007, ApJ, 669, 1336
Flower, P. J. 1996, ApJ, 469, 355
Lo Curto, G., Mayor, M., Clausen, J. V., et al. 2006, A&A, 451, 345
Lovis, C., & Pepe, F. 2007, A&A, 468, 1115
Lovis, C., Mayor, M., Bouchy, F., et al. 2005, A&A, 437, 1121
Mayor, M., & Queloz, D. 1995, Nature, 378, 355
Mayor, M., Pepe, F., Queloz, D., et al. 2003, The Messenger, 114, 20
Mayor, M., Pont F., & Vidal-Madjar, A. 2005, PThPhS, 158, 43
Mayor, M., Bonfils, X., Forveille, T., et al. 2009, A&A, 507, 487M
Moutou, C., Mayor, M., Bouchy, F., et al. 2005, A&A, 439, 367
Moutou, C., Mayor, M., Lo Curto, G., et al. 2009, A&A, 496, 513
Mugrauer, M., & Neuhäuser, R. 2009, A&A, 494, 373
Naef, D., Mayor, M., Benz, W., et al. 2007, A&A, 470, 721
Noyes, R. W., Hartmann, L. W., Baliunas, S. L., Duncan, D. K., & Vaughan, A. H. 1984, ApJ, 279, 763
Pace, G., & Pasquini, L. 2004, A&A, 426, 1021
Pepe, F., Mayor, M., Rupprecht, G., et al. 2002, The Messenger, 110, 9
Pepe, F., Mayor, M., Queloz, D., et al. 2004, A&A, 423, 385
Queloz, D., Eggenberger, A., Mayor, M., et al. 2000, A&A, 359, L13
Queloz, D., Henry, G. W., Sivan, J. P., et al. 2001, A&A, 379, 279
Scargle, J. D. 1982, ApJ, 263, 835
Schnider, J. 2009, http://exoplanet.eu
Sousa, S., Santos, N. C., Israelian, G., Mayor, M., & Monteiro, M. J. P. F. G. 2007, A&A, 469, 783
Udry, S., Mayor, M., Queloz, D., Naef, D., & Santos, N. 2000, Conf. Proc.: The VLT opening symposium, 571
Wright, J. T. 2009, [arXiv:0909.0957W]