ELODIE metallicity-biased search for transiting Hot Jupiters

V. An intermediate-period Jovian planet orbiting HD 45652

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ABSTRACT

We present the detection of a 0.47 M\textsubscript{Jup} planet in a 44-day period eccentric trajectory (e=0.39) orbiting the metal-rich star HD 45652. This planet, the seventh giant planet discovered in the context of the ELODIE metallicity-biased planet search program, is also confirmed using higher precision radial-velocities obtained with the CORALIE and SOPHIE spectrographs. The orbital period of HD 45652b places it in the middle of the “gap” in the period distribution of extra-solar planets.

Key words. stars: individual: HD 45652 – stars: planetary systems – planetary systems: formation – techniques: radial-velocity – stars: fundamental parameters

1. Introduction

More than 280 exoplanets have been found orbiting solar-type stars, most of them discovered using radial-velocity techniques (for a review see Udry & Santos [2007]). In about 40 cases, the discovered planets are known to transit their host stars. The detection of a photometric signature of a transiting planet, when complemented with its dynamical detection by means of the radial-velocity technique, provides the possibility of deriving its mass, radius, and mean density (e.g. Charbonneau et al. [2000], Pont et al. [2005]). These data provide invaluable information about the physical properties of the planet (e.g. its composition – Valencia et al. [2006], Fortney et al. [2007]), as well as about its formation and evolution.

It is well known that the probability of finding a giant planet is a strongly rising function of stellar metallicity (Gonzalez [1998], Santos et al. [2004], Fischer & Valenti [2005]). This correlation is generally accepted to reflect the higher probability of forming planets around stars with a higher dust content in the proto-planetary disk, and supports the core-accretion model for giant planet formation (e.g. Ida & Lith [2004], Benz et al. [2006], Matsuo et al. [2007]).

Using the metallicity-giant planet relation, several programs are now searching for planets around high metal-content stars (e.g. Tinney et al. [2002], Fischer et al. [2005], Da Silva et al. [2006], Melo et al. [2007]). These programs mostly unveiled short-period planets (as expected due to their observing strategy), and increased the number

\footnote{Based on observations collected at the La Silla-Paranal Observatory, ESO (Chile) with the CORALIE spectrograph at the Euler 1.2-m Swiss Telescope, and with the ELODIE and SOPHIE spectrographs at the 1.93-m telescope of the Observatoire de Haute Provence (OHP), France.}

\footnote{See updated tables at http://www.exoplanets.eu and http://www.exoplanet.eu}
of detected transiting planets orbiting bright stars (e.g. Sato et al. 2005; Bouchy et al. 2005).

One of these programs was based on the former ELODIE spectrograph (Baranne et al. 1996), mounted on the 1.93-m telescope at the OHP observatory (for details of the program see Da Silva et al. 2006). The results of this survey were presented in a series of four papers (Da Silva et al. 2006; Bouchy et al. 2005; Montou et al. 2006; Da Silva et al. 2007), announcing the discovery of 6 giant planets, one of which transits star (HD 189733b).

In this paper, we announce the discovery of a ~0.5 Jupiter-mass companion orbiting HD 45652, one star from the ELODIE metallicity-biased survey. In Sect. 2 we describe the stellar characteristics of HD 45652. In Sects. 3 and 4, we present the radial-velocity measurements used to detect HD 45652b, as well as the derived orbital solution and planetary characteristics. We present our conclusions in Sect. 4, discussing how this new intermediate-period planet is placed in the general picture of giant-planet formation models.

### 2. Stellar properties of HD 45652

According to the SIMBAD database, HD 45652 (HIP 30905, BD +11 1197) is a high-proper-motion V = 8.1, K5 star (B−V = 0.85). In the Hipparcos catalogue (ESA 1997), the star is listed as having a parallax of π = 27.67 ± 1.29 mas, a value that implies a distance of 36 ± 2 pc. No reference for a close companion to HD 45652 is mentioned in this catalogue, and no significant photometric variability was detected.

We used a high-resolution (R = 50 000) CORALIE spectrum with a signal-to-noise-ratio (S/N) ~100 to derive the stellar parameters and metallicity of HD 45652, using the methodology described in Santos et al. (2004). The resulting effective temperature, surface gravity, and [Fe/H] are 5312 K, 4.32 dex, and +0.29 dex, respectively (see Table 1). These parameters are typical of a metal-rich main-sequence late-G or early-K dwarf, and slightly disagree with the spectral type of K5 listed in the Hipparcos catalogue (ESA 1997) and in SIMBAD. The above-mentioned temperature is also in good agreement with the value expected on the basis of its B−V colour and metallicity (5315 K, using the calibration presented in Santos et al. 2004), as well as with other temperature estimates in the literature, namely by Strassmeier et al. (2000, $T_{\text{eff}} = 5150$ K), Allende Prieto & Lambert (1999, $T_{\text{eff}} = 5730$ K), and Robinson et al. (2007, $T_{\text{eff}} = 5349$ K).

Using stellar evolution tracks from Schaerer et al. (1993), we derived a stellar mass of 0.83 ± 0.05 $M_{\odot}$, and an age above 12 Gyr for HD 45652. Strassmeier et al. (2000) classified this star as chromospherically non-active, in agreement with its derived age. From SOPHIE spectra, we also derived a value of log $R'_{HK} = -4.90 \pm 0.10$. The low activity level is confirmed by an inspection of the center of the Ca II H and K line regions (see Fig. 1). Such a low level of activity is also compatible with the low value of projected rotational velocity ($v \sin i < 2$ km s$^{-1}$) as derived from the Cross-Correlation Function (CCF) of the ELODIE spectra (Table 1).

### 3. A giant planet orbiting HD 45652

HD 45652 was part of the ELODIE metallicity-biased planet search sample (Da Silva et al. 2006). A series of 14 radial velocities were obtained with this instrument between October 2005 and March 2006 (Table 3), using the 1.93-m telescope at the Observatoire de Haute Provence (France). The data showed the presence of a clear radial-velocity variation, although the time coverage of the data did not allow us to confirm the nature of the observed sig-

### Table 1. Stellar parameters for HD 45652.

| Parameter          | Value                  | Reference          |
|--------------------|------------------------|--------------------|
| Spectral type      | K5/G8-K0               | Hipparcos/This Paper |
| $m_v$              | 8.1                    | Hipparcos          |
| $B-V$              | 0.85                   | Hipparcos          |
| Distance [pc]      | 36.4                   | Hipparcos          |
| $v \sin i$ [km s$^{-1}$] | $< 2$†                | This paper         |
| log $R'_{HK}$      | $-4.90 \pm 0.10$††     | This paper         |
| $T_{\text{eff}}$  | 5312 ± 68              | This paper         |
| log $g$ [cgs]      | 4.32 ± 0.21            | This paper         |
| $\xi_i$           | 0.89 ± 0.09            | This paper         |
| [Fe/H]            | +0.29 ± 0.07           | This paper         |
| Mass [$M_{\odot}$] | 0.83 ± 0.05            | This paper         |

† From ELODIE spectra using a calibration similar to that presented by Santos et al. (2002)
†† From SOPHIE spectra using a calibration similar to that presented by Santos et al. (2000)
The average photon-noise error of the measurements is 12.6 m s\(^{-1}\). HD 45652 was then monitored using the CORALIE spectrograph, at the Euler 1.2-m Swiss telescope (La Silla observatory, ESO, Chile – between October 2006 and March 2007), and with the SOPHIE spectrograph, at the 1.93-m OHP telescope (France – between November 2006 and March 2007). The average photon-noise error of the 18 CORALIE and 12 SOPHIE radial-velocities is 5.5 m s\(^{-1}\) and 4.4 m s\(^{-1}\), respectively. Both sets of higher quality radial-velocities obtained (Table 3) confirm our earlier results, showing a clear radial-velocity signal (Fig. 2).

The combined ELODIE, CORALIE, and SOPHIE radial-velocity measurements are best fitted using a Keplerian function with a semi-amplitude \(K=33\) m s\(^{-1}\), an eccentricity \(e=0.38\), and a period \(P=43.6\) days (see Figs. 2 and 3 and Table 2). The residuals around the fit (8.9 m s\(^{-1}\)) are within the expected value given the photon-noise errors of the data. Monte Carlo simulation results shows that the false-alarm probability is only 0.1%. The observed Keplerian fit corresponds to the expected radial-velocity variation induced by the presence of a giant planet with a minimum mass of 0.47 M\(_{\text{Jup}}\), orbiting HD 45652 in an eccentric orbit with a semi-major axis of 0.23 AU.

A look at the residuals of the Keplerian function fitting (Fig. 2) suggests that the adopted orbital solution does not well describe the ELODIE data. The observed residuals are probably due to the higher quality CORALIE and SOPHIE measurements which are then weighted more significantly than the ELODIE measurements when fitting the data. Since we do not have any overlap between the ELODIE and CORALIE datasets, it may be that the zero point of radial-velocity measurements for the different instruments is not well constrained. Alternatively, a second signal could be present in the data. A scrutiny of old CORAVEL data, which has a precision of \(\sim 300\) m s\(^{-1}\), does not uncover the existence of any long-term radial-velocity trend. We also studied the residuals of the Keplerian fit for the presence of a second significant signal.

### Table 2. Elements of the fitted orbit for HD 45652b, derived using the ELODIE, CORALIE, and SOPHIE data.

| \(P\)  | 43.6±0.2 [d] |
| \(T\)  | 2454120.3±1.2 [d] |
| \(a\)  | 0.23 [AU] |
| \(e\)  | 0.38±0.06 |
| \(V_r\) (ELODIE) | \(-5.117±0.006\) [km s\(^{-1}\)] |
| \(V_r\) (CORALIE) | \(-5.044±0.002\) [km s\(^{-1}\)] |
| \(V_r\) (SOPHIE) | \(-4.999±0.002\) [km s\(^{-1}\)] |
| \(\omega\) | 273±12 [deg] |
| \(K_1\) | 33.1±2.5 [m s\(^{-1}\)] |
| \(\sigma(O-C)\) | 8.9 [m s\(^{-1}\)] |
| \(N\) | 44 |
| \(m_2 \sin i\) | 0.47 [M\(_{\text{Jup}}\)] |
Table 3. ELODIE and CORALIE radial-velocity measurements of HD 45652.

| JD      | $V_r$ [km s$^{-1}$] | $\sigma(V_r)$ [km s$^{-1}$] |
|---------|---------------------|-----------------------------|
| ELODIE  |                     |                             |
| 2453692.65990 | −5.108             | 0.012                       |
| 2453724.51830 | −5.146             | 0.010                       |
| 2453750.52140 | −5.140             | 0.011                       |
| 2453755.52560 | −5.135             | 0.014                       |
| 2453756.46230 | −5.136             | 0.014                       |
| 2453757.49900 | −5.141             | 0.017                       |
| 2453758.44960 | −5.145             | 0.017                       |
| 2453773.45970 | −5.092             | 0.011                       |
| 2453774.42840 | −5.069             | 0.012                       |
| 2453775.42810 | −5.043             | 0.012                       |
| 2453776.41300 | −5.060             | 0.015                       |
| 2453777.41290 | −5.057             | 0.012                       |
| 2453780.42370 | −5.060             | 0.015                       |
| 2453808.29880 | −5.171             | 0.010                       |
| CORALIE  |                     |                             |
| 2454029.79264 | −5.0607            | 0.0063                      |
| 2454029.80422 | −5.0757            | 0.0063                      |
| 2454038.83579 | −5.0093            | 0.0057                      |
| 2454038.84718 | −5.0125            | 0.0060                      |
| 2454046.79822 | −5.0759            | 0.0076                      |
| 2454046.81454 | −5.0807            | 0.0063                      |
| 2454132.62897 | −5.0005            | 0.0050                      |
| 2454132.64037 | −5.0107            | 0.0050                      |
| 2454137.62078 | −5.0233            | 0.0056                      |
| 2454137.63218 | −5.0301            | 0.0050                      |
| 2454144.58745 | −5.0442            | 0.0049                      |
| 2454144.59885 | −5.0368            | 0.0052                      |
| 2454151.59608 | −5.0445            | 0.0048                      |
| 2454156.52101 | −5.0726            | 0.0052                      |
| 2454160.52499 | −5.0747            | 0.0066                      |
| 2454163.57158 | −5.0404            | 0.0044                      |
| 2454167.58467 | −5.0250            | 0.0053                      |
| 2454173.53990 | −5.0061            | 0.0050                      |
| 2454176.55337 | −5.0187            | 0.0052                      |
| SOPHIE   |                     |                             |
| 2454044.67360 | −4.9763            | 0.0035                      |
| 2454044.68380 | −4.9805            | 0.0034                      |
| 2454050.66630 | −4.9847            | 0.0038                      |
| 2454053.63090 | −4.9862            | 0.0036                      |
| 2454078.56860 | −4.9790            | 0.0045                      |
| 2454088.56780 | −4.9865            | 0.0051                      |
| 2454138.40400 | −5.0001            | 0.0056                      |
| 2454142.48580 | −5.0048            | 0.0055                      |
| 2454152.40650 | −5.0194            | 0.0034                      |
| 2454152.41540 | −5.0308            | 0.0051                      |
| 2454154.37280 | −5.0088            | 0.0059                      |
| 2454174.29350 | −4.9789            | 0.0033                      |

low-amplitude signal in the data, without success. We thus
do not endorse the idea that a second signal is present.

Given the low projected rotational velocity and ac-
tivity level of the star, we do not expect that activity-
related phenomena could induce the observed periodic
radial-velocity signal. Although not a fully effective di-
agnostic for stars rotating very slowly (Santos et al. 2003;
Desort et al. 2007), an analysis of the CCF bisectors also
lends support to this idea (Fig. 4). No significant corre-
lation is found between the observed radial-velocity and
the shape of the CCF denoted by a measurement of the
Bisector Inverse Slope, BIS (defined as in Queloz et al.
2001). The observed radial-velocity variation of HD 45652
is therefore best explained by the presence of a planetary-
mass companion in a $\sim 44$-day period orbit.

4. Discussion and concluding remarks

Statistical studies of the properties of observed extras-
solar planets have shown that the orbital period distrib-
ution is characterized by a well-defined peak for $P < 10$
days, followed by some sort of period valley for values of
$P$ up to $\sim 100$ days. Above this latter value, the distrib-
ution is again an increasing function of orbital period
(Cumming et al. 1999; Udry et al. 2003; Udry & Santos
2007). The observed shape of the period distribution is
predicted by some models of planet formation and evolu-
tion (Ida & Lin 2004a; Mordasini et al. 2007).

With an orbital period of $\sim 44$-days, HD 45652b is
placed in the middle of the so-called period valley.

Interestingly, Burkert & Ida (2007) pointed out that the observed period valley is more pronounced for plan-
ets orbiting more massive stars (F-dwarfs with mass above $\sim 1.2 M_{\odot}$). Furthermore, the period gap appears
to be more significant for the higher mass planets
($> 0.8 M_{\text{Jup}}$). Burkert & Ida (2007) attributed this obser-
vation to shorter timescales of disk depletion for higher-
mass stars.
HD 45652b, a 0.47 M$_{\text{Jup}}$ planet with an orbital period of $\sim$44 days orbiting a 0.83 M$_{\odot}$ star perfectly fits this scenario.

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