Elodie metallicity-biased search for transiting Hot Jupiters[★]

I. Two Hot Jupiters orbiting the slightly evolved stars HD 118203 and HD 149143

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ABSTRACT

We report the discovery of a new planet candidate orbiting the subgiant star HD 118203 with a period of $P = 6.1335$ days. The best Keplerian solution yields an eccentricity $e = 0.31$ and a minimum mass $m_2 \sin i = 2.1 M_{\text{Jup}}$ for the planet. This star has been observed with the ELODIE fiber-fed spectrograph as one of the targets in our planet-search programme biased toward high-metallicity stars, on-going since March 2004 at the Haute-Provence Observatory. An analysis of the spectroscopic line profiles using line bisectors revealed no correlation between the radial velocities and the line-bisector orientations, indicating that the periodic radial-velocity signal is best explained by the presence of a planet-mass companion. A linear trend is observed in the residuals around the orbital solution that could be explained by the presence of a second companion in a longer-period orbit. We also present here our orbital solution for another slightly evolved star in our *metal-rich* sample, HD 149143, recently proposed to host a 4-d period Hot Jupiter by the N2K consortium. Our solution yields a period $P = 4.09$ days, a marginally significant eccentricity $e = 0.08$ and a planetary minimum mass of $1.36 M_{\text{Jup}}$. We checked that the shape of the spectral lines does not vary for this star as well.

Key words. stars: individual: HD 118203 – stars: individual: HD 149143 – planetary systems – techniques: radial velocities

1. Introduction

Stars hosting planets are significantly metal rich in comparison to field stars in the solar neighbourhood (Gonzalez 1997; Santos et al. 2001, 2003, 2005; Fischer & Valenti 2005). These authors have also shown that the probability of hosting a giant planet is a strongly rising function of the star metal content. According to their estimate, we can expect that up to 25–30% of the more metal-rich stars ($[\text{Fe}/\text{H}] > 0.2\text{--}0.3$) host a giant planet.

On the basis of this argument, a new survey was started in March 2004 at the Haute-Provence Observatory with the high-precision ELODIE fiber-fed echelle spectrograph. The main idea of this new programme is to bias our target sample towards high-metallicity stars, much more likely to host planets. This will strongly increase our probability of finding new planets in a sample of yet non-observed stars. The survey uses the cross-correlation technique for the radial-velocity and

metallicity estimates. The programme mainly targets giant planets with short periods (Hot Jupiters). They are the ideal candidates in the search for photometric transits. From this survey, we present here a new short-period planet candidate ($P = 6.1335$ d) with an eccentric orbit around the star HD 118203.

A similar planet-search programme was simultaneously started by the N2K consortium (Fischer et al. 2004) aiming at the detection of short-period planets orbiting metal-rich stars. Fischer (2005; also in Fischer 2005) recently announced two new Hot-Jupiter detections around HD 149143 and HD 109749. HD 149143 is amongst the stars already observed in our sample and we present here our orbital description of the system.

Together, the N2K and ELODIE metallicity-biased planet-search programmes have detected five new Hot Jupiters in less than one year. One of them, HD 149026, is transiting in front of its parent star (Sato et al. 2005) allowing for the determination of the planet radius and mean density. The planet is found to have an unexpectedly large core. This result clearly illustrates the importance of such programmes for our understanding of

[★] Based on radial velocities collected with the ELODIE spectrograph on the 193-cm telescope and photometric data on the 120-cm telescope, both at the Observatoire de Haute Provence, France.

planet interiors. However, when examining possible statistical trends between orbital and stellar parameters to derive constraints for planet formation models, we have to keep in mind the built-in bias of this subsample of exoplanets. In particular these planets must be removed when considering correlations with the star metallicity.

The sample selection and observations of the new ELODIE programme are described in Sect. 2. Stellar parameters, radial-velocity measurements of HD 118203 as well as the orbital solution derived for the new Hot Jupiter candidate are presented in Sect. 3. This section also provides information on stellar activity and in particular the results of the bisector analysis for the star. Section 4 reports our results for HD 149143 and conclusions are presented in Sect. 5.

2. Sample and observational strategy

The star sample was selected from the HIPPARCOS catalogue (ESA 1997). Initially, the bright northern dwarf stars ($V < 8.5$) of colours compatible with spectral types ranging from F8 to M0 ($0.45 < B - V < 1.4$) were considered. Then:

- i) evolved stars were removed from the list, using a criteria of proximity to the main sequence in the HR diagram (2 mag);
- ii) all stars already members of the known main programmes of search for extra-solar planets in the northern hemisphere were removed;
- iii) we eliminated stars known as binaries from previous CORAVEL measurements;
- iv) we also eliminated stars with high rotational velocities in order to avoid active stars in the sample. In practice, stars with $v \sin i > 5 \text{ km s}^{-1}$ were excluded from the sample.

The final selection comprises 1061 stars. They lie at distances up to 100 pc from the Sun.

Observations were conducted with the high-precision ELODIE fiber-fed echelle spectrograph (Baranne et al. 1996) mounted on the 1.93-m telescope at the Haute-Provence Observatory (France). The spectra have a resolution ($\lambda/\Delta\lambda$) of about 42 000. Typical signal-to-noise ratios obtained in 20 min exposures range from ~ 20 to 100 for the programme stars, corresponding to photon-noise errors between 5 and 20 ms^{-1} on individual measurements. The data reduction is performed online during the observations by the automatic reduction software (see Baranne et al. 1996, for a detailed description).

After a single radial-velocity measurement, it is possible to obtain a very good estimate of the star metallicity by measuring the surface of the cross correlation function (CCF) of the ELODIE spectra (Santos et al. 2002; Naef 2003). The typical uncertainty of the resulting metallicities is ~ 0.05 dex compared to values obtained from a high-resolution spectroscopic analysis. The expected percentage of >10 – 30% of giant planets orbiting stars with $[\text{Fe}/\text{H}] \geq 0.10$ (Santos et al. 2001, 2004; Fischer & Valenti 2005) should lead to the discovery of a few tens of new planets in our programme, about ten of them in short-period orbits.

Table 1. Observed and estimated parameters for HD 118203. (See text for references on the quoted values.)

Spectral type	K0	
V	8.05	
$B - V$	0.699	
π	11.29 ± 0.82	[mas]
M_V	3.31	
T_{eff}	5600 ± 150	[K]
$M_\star$	1.23 ± 0.03	$M_\odot$
age	4.6 ± 0.8	Gyr
$\log g$	-3.87	cgs
[Fe/H]	0.10 ± 0.05	
$v \sin i$	4.7	[km s $^{-1}$]

3. A short-period planet orbiting HD 118203

3.1. Stellar characteristics of HD 118203

HD 118203 (HIP 66192) is listed in the HIPPARCOS catalogue (ESA 1997) as a K0 dwarf in the northern hemisphere, with a visual magnitude $V = 8.05$, a colour index $B - V = 0.699$, and an astrometric parallax $\pi = 11.29 \pm 0.82 \text{ mas}$, setting a distance of 88.6 pc from the Sun. The corresponding absolute magnitude $M_V = 3.31$ is too high for a K0 dwarf, indicating that the star is already slightly evolved and is in a subgiant stage. This is confirmed by the astrometric surface gravity $\log g = 3.87$ dex estimated from the effective temperature and stellar mass (see below) and Hipparcos precise parallax (Santos et al. 2004).

From calibrations of the width and the surface of the ELODIE cross-correlation functions (Santos et al. 2002; Naef 2003), we have estimated a projected rotation velocity $v \sin i = 4.7 \text{ km s}^{-1}$ and a metallicity $[\text{Fe}/\text{H}] = 0.10$ for the star. Comparing these *observable* stellar characteristics with the stellar evolution models of Girardi et al. (2002), we can infer the following intrinsic properties for HD 118203: a coarse estimate of the effective temperature $T_{\text{eff}} = 5600 \pm 150 \text{ K}$, a mass $M_\star = 1.23 \pm 0.03 M_\odot$ and an age of $4.6 \pm 0.8 \text{ Gyr}$. A similar value of the effective temperature $T_{\text{eff}} = 5695 \pm 50 \text{ K}$ is also derived from the calibration in Santos et al. (2004) using the color index and metallicity of the star. The stellar parameters are gathered in Table 1.

A check for stellar chromospheric activity was also performed by looking at the Ca II H absorption line in the spectra. Figure 1 shows the co-added ELODIE spectra where the clear absence of an emission feature indicates a low activity level, as expected for slightly evolved subgiants (Wright 2004). The activity-induced radial-velocity jitter is thus also expected to be low for this moderately rotating star.

3.2. Orbital solution for HD 118203 b

ELODIE observations of HD 118203 were conducted from May 2004 (JD = 2 453 151) to July 2005 (JD = 2 453 553), stimulated by the difference in radial velocity found among the

Fig. 1. $\lambda 3968.5 \text{ \AA}$ Ca II H absorption line region of the summed ELODIE spectra for HD 118203. No clear emission feature is observed. For clarity, spectral features due to pollution by the thorium spectrum have been removed (e.g. around $\lambda 3966.5 \text{ \AA}$).

first three observations. A set of 43 precise radial-velocity measurements were then gathered. They are provided in Table 2.

A clear 6.1-d periodic variation is seen in this data set. The residuals around a Keplerian fit with this period are however unexpectedly large ($>40 \text{ ms}^{-1}$) and shows a clear additional radial-velocity drift as a function of the Julian date. A simultaneous Keplerian + linear-drift adjustment then provides a very satisfactory solution for the system with a period $P = 6.1335 \pm 0.0006$ days and an eccentricity $e = 0.309 \pm 0.014$. The slope of the linear drift is found to be $49.7 \pm 5.7 \text{ ms}^{-1} \text{ yr}^{-1}$. It is most probably accounted for by the presence of a second companion in the system, on a longer-period orbit. This could explain the significantly non-zero value found for the eccentricity at such a short period¹.

A plot with the last-season radial-velocity measurements of HD 118203 is shown in Fig. 2, together with the derived solution. The residuals around the solution are displayed as well in the bottom panel of the figure. The phase-folded radial-velocity curve with the complete set of data points corrected for the observed linear drift is displayed in Fig. 3. The weighted rms around the solution is $\sigma(\text{O}-\text{C}) = 18.1 \text{ ms}^{-1}$, slightly larger than the individual photon-noise errors ($\sim 15 \text{ ms}^{-1}$). The orbital elements are listed in Table 3 with the inferred planetary parameters.

3.3. Low chromospheric activity for HD 118203

Physical events in the stellar atmosphere, like the presence of spots on the stellar surface, can change the observed

Table 2. ELODIE radial velocities of HD 118203. All data are relative to the solar system barycentre. Given uncertainties correspond to photon-noise errors.

JD-2 400 000	RV	Uncertainty
[days]	[km s^{-1}]	[km s^{-1}]
53 151.4302	-29.263	0.013
53 153.4235	-29.231	0.014
53 155.3946	-29.640	0.011
53 217.3409	-29.523	0.011
53 218.3429	-29.320	0.011
53 219.3450	-29.243	0.013
53 220.3498	-29.215	0.012
53 224.3411	-29.300	0.009
53 226.3539	-29.152	0.017
53 227.3547	-29.232	0.026
53 228.3326	-29.533	0.012
53 229.3231	-29.549	0.011
53 230.3545	-29.338	0.025
53 231.3597	-29.257	0.013
53 232.3270	-29.209	0.018
53 233.3267	-29.261	0.009
53 234.3264	-29.474	0.010
53 392.6777	-29.201	0.014
53 394.6422	-29.598	0.027
53 396.6787	-29.257	0.015
53 397.6810	-29.153	0.015
53 398.6756	-29.202	0.015
53 399.6799	-29.369	0.014
53 421.6764	-29.187	0.024
53 422.6439	-29.189	0.017
53 424.6543	-29.556	0.013
53 425.6554	-29.543	0.014
53 426.6586	-29.351	0.012
53 428.6526	-29.190	0.025
53 429.5865	-29.166	0.028
53 430.5650	-29.446	0.016
53 431.6340	-29.570	0.012
53 486.5332	-29.565	0.012
53 487.4809	-29.386	0.011
53 488.4736	-29.260	0.012
53 489.5168	-29.184	0.017
53 490.4763	-29.185	0.010
53 491.4789	-29.298	0.011
53 492.4688	-29.594	0.011
53 517.4910	-29.547	0.011
53 519.4450	-29.212	0.011
53 520.3896	-29.152	0.011
53 553.3845	-29.463	0.025

¹ The period is however close to (higher than?) the observed circularisation period determined from the sample of known exoplanets around 6 days (Halbwachs et al. 2004).

Fig. 2. *Top*: last 5-months radial-velocity measurements of HD 118203 superimposed on the best Keplerian + linear drift solution indicative of a second longer-period companion in the system. *Bottom*: residuals around the solution. Error bars represent the photon-noise errors.

spectral-line profiles and induce a transient periodic radial-velocity signal similar to the one expected from the presence of a planet. The bisector analysis is one of the best tools to discriminate between radial-velocity variations due to changes in the spectral-line shapes and variations due to the real orbital motion of the star (see Queloz et al. 2001, for a description of this method).

The bisector inverse slope (BIS value) computed from the HD 118203 spectra are plotted in Fig. 4 in comparison to the corresponding radial-velocities. If the line-shape and the radial-velocity variations share the same origin, the BIS and radial velocities are expected to be correlated. This is not the case. Furthermore, no coherent signal is observed when the BIS are phased with the orbital period of 6.1335 days.

Moreover, data gathered during the still negative search for a photometric transit (presented elsewhere) show that the star is constant at a 0.0047 mag level and thus further support its low-activity level. Consequently, the explanation of the observed radial-velocity variations due to stellar activity can be discarded.

4. A Hot Jupiter around HD 149143

During the preparation of this publication, another new Hot Jupiter candidate was identified in our programme, orbiting the star HD 149143. While gathering more points to characterize the system, we learned that the planet had just been announced by the N2K consortium (Fischer 2005; Fischer et al. 2005). We thus present here our ELODIE solution for the system, relying on the N2K photometric measurements for the transit non-detection.

Fig. 3. *Top*: phase-folded ELODIE radial-velocity measurements for the star HD 118203 after correction for the linear radial-velocity drift observed in the data. *Bottom*: corresponding residuals around the solution. Error bars represent the photon-noise errors.

Table 3. ELODIE best Keplerian orbital solution obtained for HD 118203 as well as the inferred planetary parameters. For eccentric orbits T is defined as the time of the peri-astron passage.

P	6.1335 ± 0.0006	[days]
T	53394.23 ± 0.03	[JD - 2 400 000]
e	0.309 ± 0.014	
V	-29.387 ± 0.006	[km s ⁻¹]
ω	155.7 ± 2.4	[deg]
K	217 ± 3	[m s ⁻¹]
N_{meas}	43	
$\sigma(\text{O-C})$	18.1	[m s ⁻¹]
Linear drift	49.7 ± 5.7	[m s ⁻¹ yr ⁻¹]
$a_1 \sin i$	11.61	[10 ⁻⁵ AU]
$f(m)$	5.55	[10 ⁻⁹ M _☉]
$m_2 \sin i$	2.13	[M _{Jup}]
a	0.07	[AU]

4.1. HD 149143: stellar characteristics

HD 149143 is listed in the Hipparcos catalogue (HIP81022) with a G0 spectral type, a visual magnitude $V = 7.90$, and a colour index $B - V = 0.68$. From calibrations of the width and the surface of the ELODIE cross-correlation functions we have estimated a projected rotation velocity $v \sin i = 3.9 \text{ km s}^{-1}$ and a metallicity $[\text{Fe}/\text{H}] = 0.2$.

The measured Hipparcos parallax of HD 149143 is $\pi = 15.75 \pm 1.07 \text{ mas}$ setting the star 63.5 pc away from the Sun. The inferred absolute magnitude is then $M_V = 3.88$, also slightly overluminous for a metallic G0 dwarf. This is confirmed by the astrometric estimate of $\log g = 4.10 \text{ dex}$. From the

Fig. 4. Radial velocities (RV, *upper panel*) and inverse bisector slope (BIS, *middle panel*) phased with the orbital period $P = 6.1335$ d for HD 118203. The independence of the two quantities is shown by the radial velocity vs. BIS plot (*bottom panel*).

Table 4. Observed and estimated parameters for HD 149143. (See text for references on the quoted values.)

Spectral type	G0	
V	7.9	
$B - V$	0.68	
π	15.75 ± 1.07	[mas]
M_V	3.88	
T_{eff}	5730 ± 150	[K]
$M_\star$	1.1 ± 0.1	$M_\odot$
age	7.6 ± 1.2	Gyr
$\log g$	4.10	cgs
[Fe/H]	0.20 ± 0.05	
$v \sin i$	3.9	[km s ⁻¹]

models of Girardi et al. (2002) we obtain an effective temperature $T_{\text{eff}} = 5730 \pm 150$ K, a primary mass $M_1 = 1.1 \pm 0.1 M_\odot$ and an age of 7.6 ± 1.2 Gyr. A calibration of the stellar effective temperature based on the stellar colour and metallicity (Santos et al. 2004, only slightly sensitive to the gravity of the star) leads then to $T_{\text{eff}} = 5790 \pm 50$ K, compatible with the value given above. The stellar parameters are given in Table 4.

Table 5. ELODIE radial velocities of HD 149143. All data are relative to the solar system barycentre.

JD-2 400 000	RV	Uncertainty
[days]	[km s ⁻¹]	[km s ⁻¹]
53 550.4467	12.226	0.013
53 554.4224	12.174	0.010
53 587.3709	12.232	0.014
53 589.3393	11.880	0.013
53 592.3736	12.102	0.012
53 611.3172	12.121	0.010
53 613.3130	11.992	0.010
53 614.3141	11.928	0.010

Table 6. ELODIE derived Keplerian orbital solution obtained for HD 149143 as well as the inferred planetary parameters. Both the quasi-circular and circular solutions are given because the derived eccentricity is only marginally significant. For the eccentric orbit T is defined as the time of the peri-astron passage whereas for the circular orbit T indicates the maximum of radial velocities.

	e free	$e = 0$	
P	4.088 ± 0.006	4.089 ± 0.006	[days]
T	53588.0 ± 0.4	53587.4 ± 1.0	[JD - 2 400 000]
e	0.08 ± 0.04	0.	
V	12.059 ± 0.004	12.056 ± 0.003	[km s ⁻¹]
ω	42 ± 35	0.	[deg]
K	163 ± 8	156 ± 6	[m s ⁻¹]
$\sigma(\text{O-C})$	13.3	16.0	[m s ⁻¹]
$a_1 \sin i$	6.105	5.847	[10 ⁻⁵ AU]
$f(m)$	1.82	1.59	[10 ⁻⁹ $M_\odot$]
$m_2 \sin i$	1.36	1.30	[M_{Jup}]
a	0.052	0.052	[AU]

4.2. Orbital solution for HD 149143 b

Although the number of ELODIE observations is small for this star (Table 5), thanks to the large amplitude of the radial-velocity variation ($K = 163 \text{ m s}^{-1}$), we can easily derive a quasi-circular Keplerian solution ($e = 0.08 \pm 0.04$) with a period of 4.088 days, in agreement with the Fischer (2005) and Fischer et al. (2005) announcement. The eccentricity of the orbit is small and marginally significant, we thus also provide the corresponding circular solution fixing $e = 0$ (Table 6). The derived orbital elements coupled with the above estimate of the primary mass of $1.1 M_\odot$ lead to a minimum mass $m_2 \sin i = 1.36 M_{\text{Jup}}$ and a separation of 0.052 AU for the planetary companion.

Figures 5 and 6 present the temporal and phased ELODIE radial-velocity measurements superimposed on the derived Keplerian model as well as the residuals around the solution. The inferred orbital and planetary parameters are given in Table 6.

As for the case of HD 118203, the bisector inverse slope of the cross-correlation function has been calculated. No correlation is found between these bisector slopes and the radial

Fig. 5. ELODIE radial velocities of HD 149143 superimposed on the derived Keplerian quasi-circular model. Residuals around the solution are displayed in the bottom panel. Error bars represent the photon-noise errors.

Fig. 6. Phase-folded ELODIE radial velocities of HD 149143 superimposed on the derived quasi-circular Keplerian solution. Error bars represent the photon-noise errors.

velocities, excluding activity-induced variations of the shape of the spectral lines as the source of the radial-velocity variations.

5. Summary and concluding remarks

We have presented the characteristics of a new planet candidate in orbit around the subgiant star HD 118203, detected by the new ELODIE planet-search programme biased towards metal-rich stars. The planet is in a rather eccentric orbit ($e = 0.31$), with a period of $P = 6.1335$ days, and is close to its parent star ($a = 0.06$ AU).

An additional trend of the radial-velocity measurements increasing as a function of Julian date with a slope

of $49.7 \text{ ms}^{-1} \text{ yr}^{-1}$ is observed, suggesting the presence of a second companion around the main star on a longer-period orbit. This additional companion could explain the somewhat high eccentricity of the orbit of this new planet at short period.

We have also reported the ELODIE solution for another Hot Jupiter in our programme, HD 149143, recently announced by the similar-goal N2K project. The derived best Keplerian quasi-circular solution presents a period of 4.09 days and the inferred planetary mass is $1.36 M_{\text{Jup}}$.

By selection these planets are orbiting metal-rich stars. They increase to five the number of Hot Jupiters detected in less than one year by dedicated metallicity-biased programmes. One of these candidates, HD 149026 (Sato et al. 2005), transits in front of its parent star and thus allows the determination of its radius and mean density when combining photometric and radial-velocity measurements. This demonstrates the efficiency of such approaches to find candidates suitable for constraining planet-interior models. However, the built-in biases of the sample have to be kept in mind when examining possible statistical relations between the star metallicity and other orbital or stellar parameters.

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References

- Baranne, A., Queloz, D., Mayor, M., et al. 1996, A&AS, 119, 1
- ESA 1997, The HIPPARCOS and THYCO catalogue, ESA-SP, 1200
- Fischer, D. A., Valenti, J., & Marcy, G. 2004, in Stars as suns: activity, evolution and planets, Proc. IAU Symp., 219, 29
- Fischer, D. A., & Valenti, J. 2005, ApJ, 622, 1102
- Fischer, D. A. 2005, in 10th anniversary of 51 Peg b Status of and prospects for hot Jupiter studies, Conference at the Haute-Provence Observatory, August 2005
- Fischer, D. A., et al. 2005, ApJ, in preparation
- Halbwachs, J.-L., Mayor, M., & Udry, S. 2005, A&A, 431, 1129
- Girardi, L., Bertelli, G., Bressan, A., et al. 2002, A&A, 391, 695
- Gonzalez, G. 1997, MNRAS, 285, 403
- Naef, D. 2003, Ph.D Thesis, Geneva University
- Queloz, D., Henry, G. W., Sivan, J. P., et al. 2001, A&A, 379, 279
- Santos, N. C., Israelian, G., & Mayor, M. 2001, A&A, 373, 1019
- Santos, N. C., Mayor, M., Naef, D., et al. 2002, A&A, 392, 215
- Santos, N. C., Israelian, G., Mayor, M., Rebolo, R., & Udry, S. 2003, A&A, 398, 363
- Santos, N. C., Israelian, G., & Mayor, M. 2004, A&A, 415, 1153
- Santos, N. C., Israelian, G., & Mayor, M. 2005, A&A, 437, 1127
- Sato, B., Fischer, D., Henry, G. W., et al. 2005, ApJ, in press [arXiv:astro-ph/0507009]
- Wright, J. T. 2004, AJ, 128, 1273