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The ELODIE survey for northern extra-solar planets

III. Three planetary candidates detected with ELODIE⋆,⋆⋆

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Abstract. We present our ELODIE radial-velocity measurements of HD 74156 and 14 Her (HD 145675). These stars exhibit low-amplitude radial-velocity variations induced by the presence of low-mass companions. The radial-velocity data of HD 74156 reveal the presence of two planetary companions: a 1.86 $M_{\rm Jup}$ planet on a 51.64–d orbit and a 6.2 $M_{\rm Jup}$ planet on a long-period (≃5.5 yr) orbit. Both orbits are fairly eccentric ($e = 0.64$ and 0.58). The 4.7 $M_{\rm Jup}$ companion to 14 Her has a long period (4.9 yr) and a moderately eccentric orbit ($e = 0.34$). We detect an additional linear radial-velocity trend superimposed on the periodic signal for this star. We also compute updated orbital solutions for HD 209458 and 51 Peg (HD 217014). Finally, we present our ELODIE radial-velocity data and orbital solutions for 5 stars known to host planetary companions: Ups And (HD 9826), 55 Cnc (HD 75732), 47 UMa (HD 95128), 70 Vir (HD 117176) and HD 187123. We confirm the previously published orbital solutions for Ups And, 70 Vir and HD 187123. Our data are not sufficient to fully confirm the orbital solutions for 55 Cnc and 47 UMa.

Key words. techniques: radial velocities – planetary systems

1. Introduction

The *ELODIE Planet Search survey*, a programme aimed at detecting and characterising planetary companions in orbit around solar-type stars of the solar neighbourhood, started in 1994. This survey uses the ELODIE echelle spectrograph (Baranne et al. 1996) mounted on the Cassegrain focus of the 1.93–m Telescope of the Observatoire de Haute-Provence (CNRS, France).

The original Mayor & Queloz (1996) sample consisted of 142 stars, including 51 Peg, the first solar-type star known to host a planetary companion (Mayor & Queloz 1995). A new sample of 330 stars was defined in 1997. The new sample, the observing procedure and the achieved precision are described in details in Perrier et al. (2003, Paper I). The complete list of planets detected with ELODIE can also be found in Paper I.

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⋆ Based on observations made with the ELODIE echelle spectrograph mounted on the 1.93–m Telescope at the Observatoire de Haute-Provence (CNRS) and with the CORALIE echelle spectrograph mounted on the 1.2–m Euler Swiss Telescope at ESO–La Silla Observatory.

⋆⋆ The ELODIE and CORALIE measurements discussed in this paper 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/414/351

In this paper, we present two systems hosting long-period planets. We present in Sect. 2.2 our ELODIE radial-velocity measurements for the solar-type stars HD 74156 and 14 Her. Updated velocities and orbits for HD 209458 and 51 Peg are presented in Sect. 3. Section 4 contains the description of the ELODIE radial-velocity data and orbital solutions for Ups And, 55 Cnc, 47 Uma, 70 Vir and HD 187123. Our results are summarized in Sect. 5.

2. New ELODIE planet candidates

2.1. Stellar characteristics

In this section, we briefly describe the main properties of the stars hosting the new planet candidates detected with ELODIE, namely HD 74156 and 14 Her. The properties of the other stars appearing in this paper are described elsewhere.

The main characteristics of HD 74156 and 14 Her are listed in Table 1. Spectral Type, m_V, $B-V$, π, $\mu_\alpha \cos(\delta)$ and μ_δ are from the HIPPARCOS Catalogue (ESA 1997). The effective temperature $T_{\rm eff}$, the surface gravity $\log g$, the metallicity [Fe/H], the microturbulance velocity $\xi_{\rm t}$ and the stellar masses M_* are taken from Santos et al. (2003). The bolometric correction $B.C.$ is computed from the effective temperature with the calibration in Flower (1996).

The projected rotational velocity $v \sin i$ is derived from the ELODIE cross-correlation function widths using the calibration

Table 1. Observed and inferred stellar parameters for HD 74156 and 14 Her.

		HD 74156	14 Her
HIP		42723	79248
Sp.Type		G0[†]	K0V
m_V		7.61	6.61
$B-V$		0.585 ± 0.014	0.877 ± 0.006
π	(mas)	15.49 ± 1.10	55.11 ± 0.59
Distance	(pc)	$64.56 \pm ^{4.93}_{4.28}$	$18.15 \pm ^{0.20}_{0.19}$
$\mu_\alpha \cos(\delta)$	(mas yr^{-1})	24.96 ± 1.20	132.52 ± 0.52
μ_δ	(mas yr^{-1})	−200.48 ± 0.81	−298.38 ± 0.55
M_V		3.56	5.32
B.C.		−0.031	−0.208
L	($L_\odot$)	3.06	0.71
$T_{\rm eff}$	(°K)	6105 ± 50	5255 ± 50
$\log g$	(cgs)	4.40 ± 0.15	4.40 ± 0.15
ξ_t	(km s^{-1})	1.36 ± 0.10	0.68 ± 0.10
[Fe/H]		0.15 ± 0.06	0.51 ± 0.06
M_*	($M_\odot$)	1.27	0.9
$v \sin i$	(km s^{-1})	4.06 ± 0.62	<1
$\log R'_{\rm HK}$		–	−5.07
$P_{\rm rot}$	(d)	–	41
$age_{\rm HK}$	(Gyr)	–	3.9

[†] The rather large luminosity of this star probably reveals a slightly evolved status (IV-V luminosity class).

in Queloz et al. (1998). We only have a $v \sin i$ upper limit for 14 Her because this star does not exhibit any rotational broadening measurable with ELODIE. The $\log R'_{\rm HK}$ chromospheric activity indicator for 14 Her is from Butler et al. (2003). No quantitative activity value is available for HD 74156. We do not see any trace of emission in the core of the λ 3968.5 Å Ca II H line on our ELODIE coadded spectra. This star is thus probably not very active although moderately fast rotating. $P_{\rm rot}$ and *age*(HK) are derived from the activity indicator using the calibrations in Noyes et al. (1984) and Donahue (1993)[1], respectively.

HD 74156 and 14 Her are not photometrically variable. Their measured HIPPARCOS photometric scatter is 11 and 9 mmag, respectively. Moreover, 14 Her is flagged as constant star in this catalogue.

We have 3 adaptive optics high-angular resolution images of 14 Her. They were obtained between May 1997 and August 2001 using the PUE'O adaptive optics system mounted on the 3.6–m Canada-France Hawaii Telescope. No visual companion is detected around this star.

2.2. Radial-velocity analysis

2.2.1. HD 74156 (HIP 42723)

The detection of a two-planet system orbiting HD 74156 was already announced by our team in April 2001 (April 4th 2001 ESO Press Release). The long-period of the outer companion required however further observations of this system.

[1] Also quoted in Henry et al. (1996).

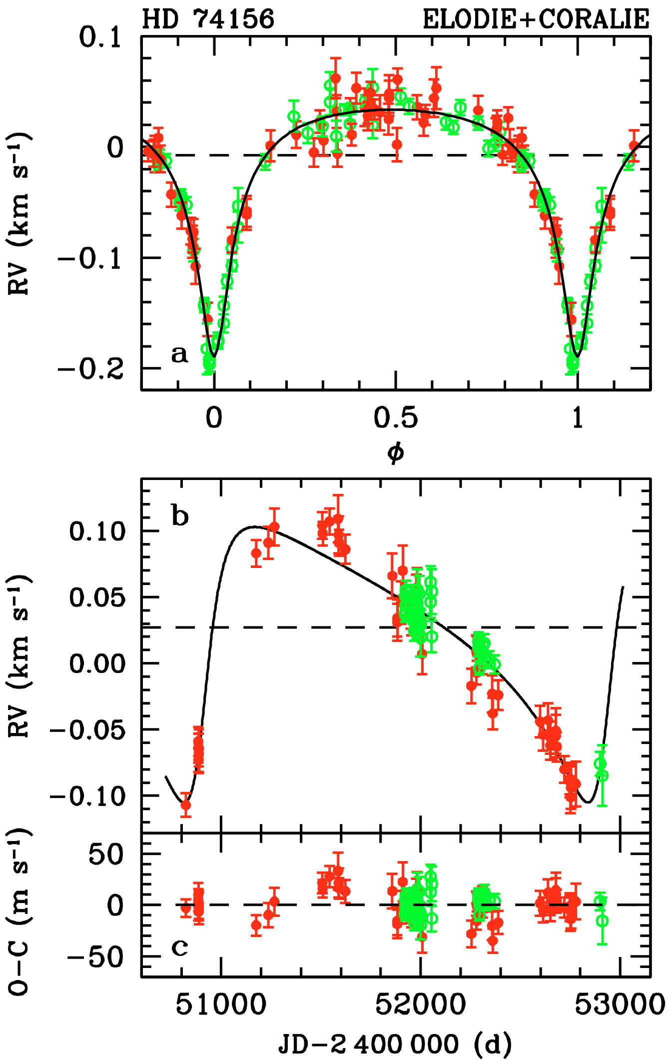

Fig. 1. ELODIE (filled dots) and CORALIE (open dots) radial-velocity data for HD 74156. **a)** Phase-folded velocities for the short-period planet. **b)** Temporal velocities for the long-period planet. **c)** Residuals to the fitted 2–planet orbital solution.

We now have 51 ELODIE and 44 CORALIE radial-velocity measurements of HD 74156. These velocities have been obtained between JD = 2 450 823 (January 1998) and JD = 2 452 910 (September 2003). The mean velocity uncertainty of these measurements is 12.7 m s^{-1} for the ELODIE data and 8.5 m s^{-1} for the CORALIE data. The total measurement time span is 2087 d.

The fitted orbital elements for HD 74156 are presented in Table 2. Figure 1 shows the fitted orbits and the residuals around the solution. Assuming a primary mass of 1.27 $M_\odot$ (Santos et al. 2003), we compute the planetary minimum masses $m_{\rm b} \sin i = 1.86\,M_{\rm Jup}$ and $m_{\rm c} \sin i = 6.17\,M_{\rm Jup}$ as well as the semi-major axes $a_{\rm b} = 0.294$ AU and $a_{\rm c} = 3.40$ AU.

2.2.2. 14 Her (HD 145675, HIP 79248, GJ 614)

The detection with ELODIE of a long-period planetary companion to 14 Her was announced during the *Protostars & Planets IV* conference by M. Mayor (1998, oral contribution,

Table 2. Orbital solution obtained for HD 74156 by combining the ELODIE (E) and CORALIE (C) radial-velocity data. $\Delta RV_{\rm E-C}$ is the radial-velocity offset between the ELODIE and CORALIE measurements. $\sigma_{\rm O-C}$ is the weighted rms of the residuals. $\chi^2_{\rm red}$ is the reduced χ^2 value (χ^2/ν where ν is the number of degrees of freedom).

		HD 74156 b	HD 74156 c	14 Her b
P	(d)	51.643 ± 0.011	2025 ± 11	1796.4 ± 8.3
T	(JD†)	51 981.321 ± 0.091	50 901 ± 10	49 582.0 ± 12.4
e		0.636 ± 0.009	0.583 ± 0.039	0.338 ± 0.011
w	(°)	181.5 ± 1.4	242.4 ± 4.0	22.58 ± 1.98
K_1	($\rm m\,s^{-1}$)	112.0 ± 1.9	104.0 ± 5.5	90.3 ± 1.0
Slope	($\rm m\,s^{-1}\,yr^{-1}$)	–		3.6 ± 0.3
$a_1 \sin i$	(10^{-4} AU)	4.10 ± 0.06	157 ± 6	140 ± 2
$f_1(m)$	($10^{-9}\,M_\odot$)	3.45 ± 0.15	126 ± 14	114 ± 4
$m \sin i$	($M_{\rm Jup}$)	1.86 ± 0.03	6.17 ± 0.23	4.74 ± 0.06
a	(AU)	0.294	3.40	2.80
γ	($\rm km\,s^{-1}$)	3.840 ± 0.003		−13.8226‡ ± 0.0007
$\Delta RV_{\rm EC}$	($\rm m\,s^{-1}$)	24.8 ± 2.8		–
N		95		119
$N_{\rm E}$		51		119
$N_{\rm C}$		44		–
$\sigma_{\rm O-C}$	($\rm m\,s^{-1}$)	10.6		11.3
$\sigma_{\rm O-C,E}$	($\rm m\,s^{-1}$)	14.0		11.3
$\sigma_{\rm O-C,C}$	($\rm m\,s^{-1}$)	8.9		–
$\chi^2_{\rm red}$		1.63		2.59

† = JD−2 400 000, ‡ at JD = 2 451 500.

also in Marcy et al. 2000). An updated orbital solution was presented by Udry et al. (2000). This detection was recently confirmed by Butler et al. (2003).

The orbital solution of Table 2 was obtained by fitting a Keplerian orbit to the 119 ELODIE radial-velocity measurements. These measurements were obtained between JD = 2 449 464 (April 1994) and JD = 2 452 857 (August 2003). The time span of these data is thus 3392 d. Our velocities have a mean velocity uncertainty of 7.2 $\rm m\,s^{-1}$.

The residuals to a simple Keplerian fit are abnormally large: 14 $\rm m\,s^{-1}$. We thus computed another solution including an additional linear velocity drift. The fitted drift parameter is highly significant: $3.6 \pm 0.3\,\rm m\,s^{-1}\,yr^{-1}$. The residuals around the Keplerian+drift solution are much smaller: $\sigma_{\rm O-C} = 11.3\,\rm m\,s^{-1}$. This value is still a bit large compared to our uncertainties.

Figure 2 shows the ELODIE radial-velocity data, the fitted Keplerian + linear drift solution and the residuals to the solution. The residuals of the oldest measurements have clearly a higher scatter value. We computed an orbital solution using only the most recent observations (velocities taken after JD = 2 450 500, the date of the set up of the double scrambling device). The solution we obtained in this case was compatible with the solution quoted in Table 2 (slightly longer period $P = 1853 \pm 35$ d, same eccentricity and semi-amplitude) but with a significantly smaller residuals value: $\sigma_{\rm O-C} = 8.6\,\rm m\,s^{-1}$ ($\chi^2_{\rm red} = 1.54$). The linear drift slope of this solution was slightly less significant: $3.9 \pm 1.1\,\rm m\,s^{-1}\,yr^{-1}$ which is not a surprise since only one radial-velocity minimum is present in the most

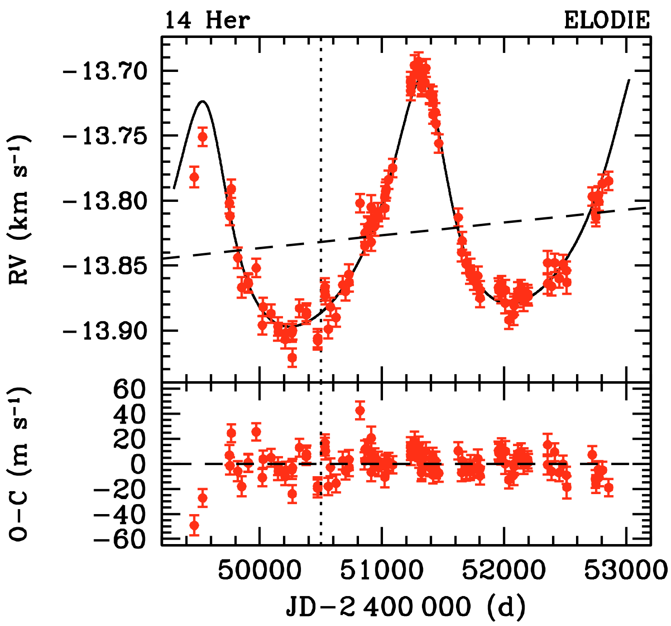

Fig. 2. ELODIE radial-velocity data and orbital solution for 14 Her. **Top**: temporal velocities. The dashed line shows the drifting systemic velocity. **Bottom**: residuals to the fitted orbit. We note the significantly larger scatter of the measurements taken before the set up of the double scrambling device (indicated by the dotted line).

recent data. The temporal coverage of these latter data approximately corresponds to the coverage of the Butler et al. (2003) measurements. We also computed an orbital solution to this velocity set without including the drift parameter. The fitted parameters obtained in this case are in good agreement with the Butler et al. (2003) values but the residuals are slightly larger than for the drift-included solution. This shows that the non detection of the velocity drift by these authors is probably due to their much shorter observing span (1882 d). Moreover, their data only cover one velocity maximum and one minimum.

The computed minimum mass of 14 Her b, assuming $M_1 = 0.9\,M_\odot$ (Santos et al. 2003), is $4.74\,M_{\rm Jup}$ and its semi-major axis is 2.80 AU.

3. Updated orbits of known extra-solar planets

In this section, we present updated orbital solutions for HD 209458 and 51 Peg. These two stars host planetary companions that were detected with ELODIE (Mazeh et al. 2000; Mayor & Queloz 1995). The new orbital solutions are based on larger and more precise radial-velocity sets.

3.1. HD 209458 (HIP 108859)

The detection of HD 209458 b was simultaneously announced by Mazeh et al. (2000) and Henry et al. (2000). Since the discovery paper, we have obtained more radial-velocity measurements of HD 209458. Moreover, the numerical template we use for computing the cross-correlation function has been changed in order to reduce the effect of telluric atmospheric lines (Pepe et al. 2002). Another effect of this new template is the change of the radial-velocity zero point.

We now have 46 ELODIE and 141 CORALIE radial-velocity measurements of HD 209458 spanning from JD = 2 450 681 (August 1997) and JD = 2 452 566 (October 2002). The mean velocity uncertainty of these measurements is $11.0\,{\rm m\,s^{-1}}$ with ELODIE and $10.2\,{\rm m\,s^{-1}}$ with CORALIE.

HD 209458 b is known to be a transiting extra-solar planet (Charbonneau et al. 2000). It has also been shown by Queloz et al. (2000) that the passage of the planet in front of the star was also affecting the measured radial-velocity (departure from the Keplerian model). We thus have removed all the measurement taken at or near the phase of the transit (measurements with $\phi_{\rm trans} - 0.025 \le \phi \le \phi_{\rm trans} + 0.025$).

We first tried to fit an orbital solution with the eccentricity as a free parameter. The obtained value was very low: $e = 0.015 \pm 0.019$. We then compared the residuals around this solution with the value obtained from a circular solution. We found the same residuals for both solutions. According to the Lucy & Sweeney (1971) test, the probability of significant eccentricity is zero for these data. Monte-Carlo simulations performed with the ORBIT software (Forveille et al. 1999) give the following $3\,\sigma$ uncertainty for this parameter: +0.063/−0.067. An eccentricity larger than 0.08 can thus be rejected with a very high confidence level.

We present in Table 3 the circular orbital solution fitted to the ELODIE+CORALIE radial velocities.

The velocities and orbital solution are displayed in Fig. 3. This figure also shows the residuals to the fitted orbit. We note a spectacular improvement of the solution quality since the initial publication (Mazeh et al. 2000). It results from the new template used for the cross-correlation (Pepe et al. 2002).

Table 3. ELODIE (E) + CORALIE (C) updated orbital solution for HD 209458 and ELODIE updated orbital solution for 51 Peg. The parameters have the same definitions as in Table 2.

		HD 209458 b	**51 Peg b**
P	(d)	3.5246 ± 0.0001	4.23077 ± 0.00004
T	(JD†)	765.790 ± 0.021	497.0 ± 0.022
e		0 (fixed)	0 (fixed)
w	(°)	0 (fixed)	0 (fixed)
K_1	(m s^{-1})	85.1 ± 1.0	57.3 ± 0.8
$a_1 \sin i$	(10^{-5} AU)	2.76 ± 0.03	2.23 ± 0.03
$f_1(m)$	($10^{-10}\,M_\odot$)	2.25 ± 0.07	0.82 ± 0.03
$m \sin i$	($M_{\rm Jup}$)	0.699 ± 0.007	0.468 ± 0.007
a	(AU)	0.048	0.052
γ	(km s^{-1})	-14.741 ± 0.002	-33.2516 ± 0.0006
$\Delta RV_{\rm EC}$	(m s^{-1})	14.3 ± 1.8	–
N		187	153
$N_{\rm E}$		46	153
$N_{\rm C}$		141	–
$\sigma_{\rm O-C}$	(m s^{-1})	14.9	11.8
$\sigma_{\rm O-C,E}$	(m s^{-1})	13.7	11.8
$\sigma_{\rm O-C,C}$	(m s^{-1})	15.2	–
$\chi^2_{\rm red}$		2.36	2.72

† = JD−2 452 000.

Wittenmyer et al. (2003) have recently presented updated high-precision period and transit time for HD 209458. Their determinations, based on space and ground-based photometric measurements of transits, are: $P = 3.5247542 \pm 0.0000004$ d and $T_{\rm trans} = 2\,452\,618.66774 \pm 0.000007$. Our period is compatible with their value ($1.5\,\sigma$ away). Our transit time prediction obtained from the fitted time of maximum radial velocity ($T_{\rm trans} = 2\,452\,618.639 \pm 0.021$) is $1.3\,\sigma$ away from their value. We have computed an orbital solution with P fixed to the Wittenmyer et al. (2003) value and T fixed to the time of maximum velocity computed from their $T_{\rm trans}$. The obtained values for the three remaining free parameters are less than $1\,\sigma$ away from the values in Table 3.

With a mass of $1.15\,M_\odot$ for HD 209458 (Santos et al. 2003), we compute the planetary minimum mass and semi-major axis: $m_2 \sin i = 0.699\,M_{\rm Jup}$ and $a = 0.048$ AU.

3.2. 51 Peg (HD 217014, HIP 113357, GJ 882)

The detection of the first extra-solar planet around a Solar-type star, 51 Peg b, was published in Mayor & Queloz (1995). This detection was rapidly confirmed by Marcy et al. (1997). Since the discovery, we have gathered many ELODIE radial-velocity measurements of 51 Peg.

The number of measurements for this star now amounts to 153. The time span of these observations is 3278 days (from JD = 2 449 610 (September 1994) to JD = 2 452 888 (September 2003) and their mean velocity uncertainty is $7.3\,{\rm m\,s^{-1}}$.

The updated orbital solution for 51 Peg is presented in Table 3. As for HD 209458, the Lucy & Sweeney (1971) test shows that a fitted non-zero eccentricity is not significant. We thus fitted a circular orbit. Figure 4 shows the phase-folded velocities and fitted orbit together with the residuals to the

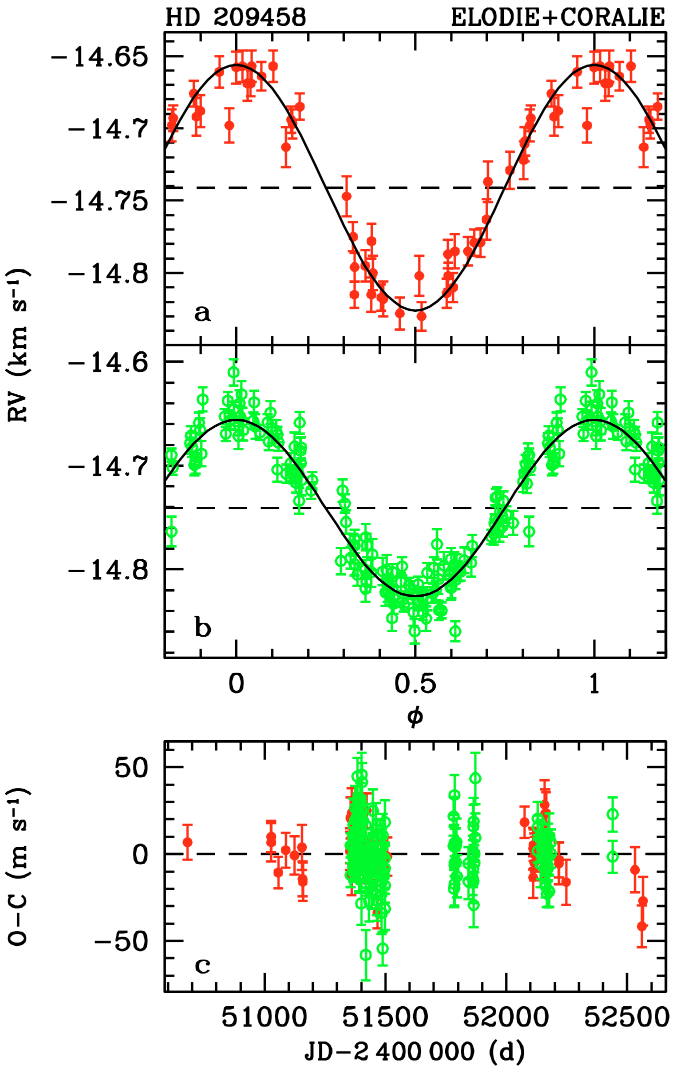

Fig. 3. Radial-velocity data and orbital solutions for HD 209458. The measurements taken at or near the transits have been removed. **a)** ELODIE Phased-folded velocities and combined solution. **b)** CORALIE Phased-folded velocities and combined solution. **c)** ELODIE (filled dots) and CORALIE (open dots) residuals to the combined orbit.

solution. The weighted rms of the residuals for this solution is 11.8 m s^{-1}, a value slightly smaller than the 13 m s^{-1} obtained by Mayor & Queloz (1995).

Assuming a mass of 1.04 $M_\odot$ for 51 Peg (Santos et al. 2003), we compute the planetary minimum mass and semi-major axis: $m_2 \sin i = 0.468\, M_{\rm Jup}$ and $a = 0.052$ AU.

4. Confirmations of planetary companions

In the same way as the presence of the companion to 51 Peg was confirmed by Marcy et al. (1997), we decided to start a follow-up of some of the stars with planetary companions announced by other teams. Confirming and cross-checking the claimed detections is very important, especially when the signal is close to the detection limits.

In this section, we present our radial-velocity measurements for Ups And, 55 Cnc, 47 UMa, 70 Vir and HD 187123.

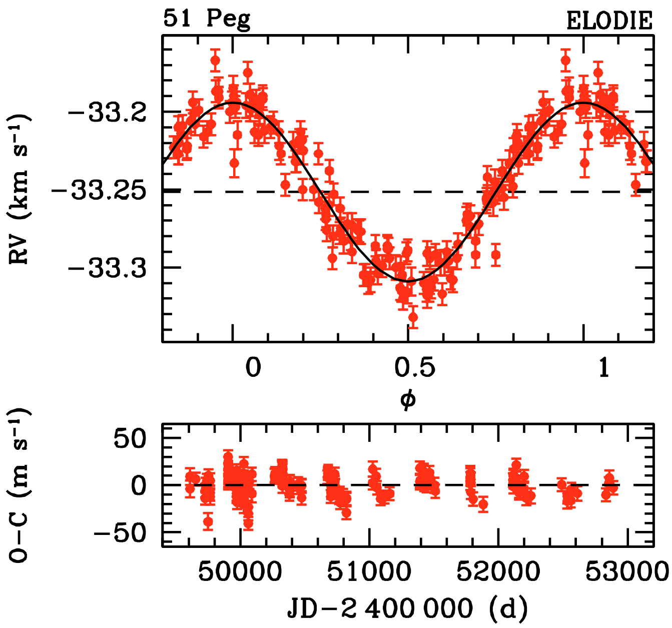

Fig. 4. ELODIE radial-velocity data spanning over 3000 days and fitted orbital solutions for 51 Peg. **Top**: Phased-folded velocities. **Bottom**: Residuals to the fitted orbit.

These stars host one or several planetary companions detected by the *California & Carnegie Planet Search* team. We confirm the orbital solutions for Ups And, 70 Vir and HD 187123. We are not able to fully confirm the published solutions for 55 Cnc and 47 UMa because of insufficient data (too short measurement span or poorer precision).

4.1. Ups And (HD 9826, HIP 7513, GJ 61)

The presence of 4.61–d planet in orbit around Ups And was announced by Butler et al. (1997). Two additional longer-period planets were later uncovered (Butler et al. 1999) by the same team in collaboration with the Advanced Fiber-Optic Echelle spectrometer (AFOE, Brown et al. 1994) planet search team (Korzennik et al. 1998).

71 ELODIE radial-velocity measurements have been gathered between JD = 2 450 319 (August 1996) and JD = 2 452 886 (September 2003). The mean velocity uncertainty of these measurements is 8.3 m s^{-1}. We present in Table 4 the 3-planet orbital solution derived from our data. We note some small differences between our solution and the Butler et al. (1999) solution as e.g. a slightly lower period value for Ups And c and a slightly longer period for Ups And d.

The ELODIE radial velocities and orbital solution are shown in Fig. 5. The residuals to the fitted orbit are clearly too large as it can be seen from the $\chi^2_{\rm red}$ value: 4.34. The residuals obtained with the orbital parameters fixed to the Butler et al. (1999) values are even worse: 22.4 m s^{-1} ($\chi^2_{\rm red} = 7.75$) We have no explanation for these facts but we are nevertheless able to confirm the presence of the three planets around Ups And.

Adopting the same primary mass as in Butler et al. (1999), $M_1 = 1.3\, M_{\rm sun}$, we compute the planetary minimum masses: $m_{\rm b} \sin i = 0.75\, M_{\rm Jup}$; $m_{\rm c} \sin i = 2.25\, M_{\rm Jup}$; $m_{\rm d} \sin i = 3.95\, M_{\rm Jup}$.

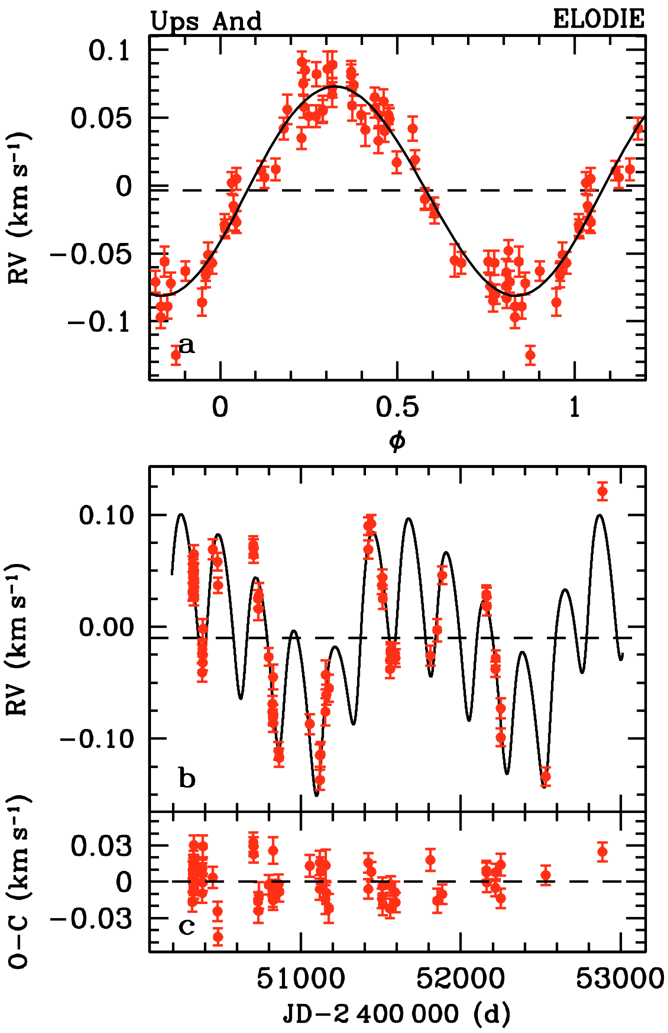

Fig. 5. ELODIE radial-velocity data and orbital solution for Ups And **a)** Phased-folded velocities for Ups And b. The velocity effect induced by the outer planets has been removed. **b)** Temporal velocities for Ups And c and d. The signal induced by the inner planet has been removed. **c)** Residuals to the fitted 3-planet orbital solution. The residuals value is larger than the expected value.

The semi-major axes are: $a_b = 0.059$ AU; $a_c = 0.82$ AU; $a_d = 2.57$ AU.

Table 4. ELODIE orbital solutions for Ups And and 55 Cnc. The parameters have the same definitions as in Table 2.

		Ups And b	**55 Cnc b**
P	(d)	4.61712 ± 0.00009	14.647 ± 0.001
T	(JD†)	4.28 ± 0.48	0.80 ± 0.48
e		0.020 ± 0.023	0.030 ± 0.023
w	(°)	242 ± 37	63 ± 12
K_1	($\mathrm{m\,s^{-1}}$)	77.2 ± 1.3	78.3 ± 1.8
$a_1 \sin i$	(10^{-5} AU)	3.28 ± 0.05	10.54 ± 0.24
$f_1(m)$	(10^{-10} $M_\odot$)	2.20 ± 0.11	7.28 ± 0.50
$m \sin i$	($M_{\rm Jup}$)	0.75 ± 0.01	0.91 ± 0.02
a	(AU)	0.059	0.115
		Ups And c	**55 Cnc d**
P	(d)	238.10 ± 0.46	4545 ± 1421
T	(JD†)	159.4 ± 8.0	568 ± 200
e		0.185 ± 0.028	0.24 ± 0.13
w	(°)	214 ± 11	347 ± 23
K_1	($\mathrm{m\,s^{-1}}$)	63.0 ± 1.7	37.8 ± 3.9
$a_1 \sin i$	(10^{-2} AU)	0.136 ± 0.003	1.54 ± 0.56
$f_1(m)$	(10^{-9} $M_\odot$)	5.85 ± 0.43	23 ± 11
$m \sin i$	($M_{\rm Jup}$)	2.25 ± 0.06	2.89 ± 0.47
a	(AU)	0.821	5.28
		Ups And d	
P	(d)	1319 ± 18	
T	(JD†)	-37 ± 53	
e		0.269 ± 0.036	
w	(°)	248 ± 11	
K_1	($\mathrm{m\,s^{-1}}$)	63.8 ± 2.3	
$a_1 \sin i$	(10^{-3} AU)	7.45 ± 0.25	
$f_1(m)$	(10^{-8} $M_\odot$)	3.17 ± 0.30	
$m \sin i$	($M_{\rm Jup}$)	3.95 ± 0.13	
a	(AU)	2.57	
γ	($\mathrm{km\,s^{-1}}$)	-28.655 ± 0.002	27.252 ± 0.009
N		71	48
$\sigma_{\rm O-C}$	($\mathrm{m\,s^{-1}}$)	14.9	9.0
$\chi^2_{\rm red}$		4.34	1.99

† = JD−2 450 000.

4.2. 55 Cnc (HD 75732, HIP 43587, GJ 324 A)

55 Cnc b, a 14.6–d planet was announced by Butler et al. (1997). These authors also quoted the presence of an additional radial-velocity drift superimposed to the periodic signal. Marcy et al. (2002) have recently announced the detection of two additional signals with periods of 44.3 d and 14.7 yr. The interpretation of the 44.3–d signal is uncertain since it corresponds to the rotational period of the star. It thus could be due to stellar intrinsic effects. The 14.7–yr signal is interpreted as the result of the presence of a 4 $M_{\rm Jup}$ planet more than 5 AU away from the star.

48 ELODIE radial-velocity measurements of 55 Cnc have been obtained between JD = 2 450 207 (May 1996) and JD = 2 452 779 (May 2003). They have a mean uncertainty of 7.3 $\mathrm{m\,s^{-1}}$. Our measurement time span (2571 d) is shorter than the announced long period by a factor of 2. Also, the radial-velocity semi-amplitude of the 44.3–d signal is only 13 $\mathrm{m\,s^{-1}}$. These features make difficult the characterization of the outer planets with the ELODIE measurements but they however allow us to partially confirm the orbital solution presented in Marcy et al. (2002).

We present in Table 4 a 2-Keplerian orbital solution for 55 Cnc. This solution does not account for the intermediate signal. We are able to fit a 44–d orbit to the residuals around this solution but the fit parameters are too poorly constrained to be significant. Thus, they do not appear in this paper. Our data are insufficient for confirming the presence of the intermediate planet. Figure 6 shows the fitted orbits to our velocities as well as the residuals around our solution.

Assuming a primary mass of 0.95 $M_\odot$ for 55 Cnc, we compute the minimum masses of the two companions: $m_b \sin i = 0.91$ $M_{\rm Jup}$ and $m_d \sin i = 2.89$ $M_{\rm Jup}$. The orbital semi-major axes are: $a_b = 0.115$ AU and $a_d = 5.28$ AU.

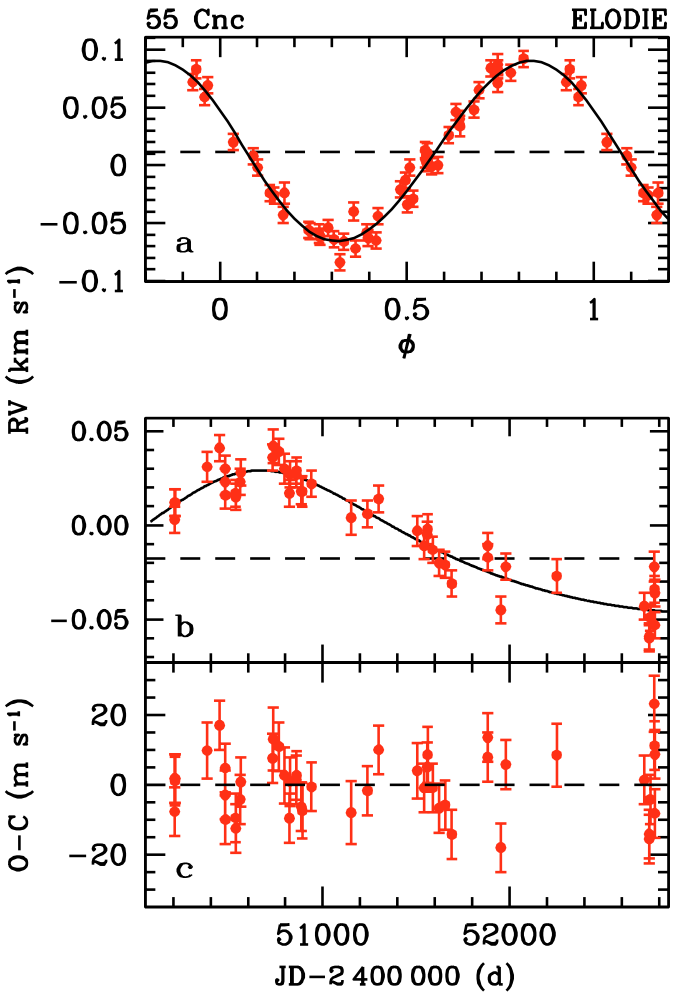

Fig. 6. ELODIE radial-velocity data and orbital solution for 55 Cnc. **a)** Phased-folded velocities for 55 Cnc b. The signal induced by the outer planet is removed. **b)** Temporal velocities for 55 Cnc d. The signal of the inner planet is removed. **c)** Residuals around the solution.

4.3. 47 UMa (HD 95128, HIP 53721, GJ 407)

The detection of a long-period planet in orbit around 47 UMa was announced in Butler & Marcy (1996). A preliminary ELODIE orbit for this companion was published in Naef et al. (2001). More recently, Fischer et al. (2002) have presented an updated orbital solution including another planetary companion on a longer-period orbit.

We have obtained 44 ELODIE radial-velocity measurements of 47 UMa between JD = 2 450 150 (March 1996) and JD = 2 452 752 (April 2003). The mean velocity uncertainty of these measurements is 7.3 m s^{-1}. We are unable with our data to confirm the presence of the second planetary companion. The solution presented in Table 5 only includes one Keplerian orbit. The residuals to this solution (7.4 m s^{-1}) are in good agreement with our uncertainties. We do not see any clear velocity trend in these residuals (Fig. 7). With the same primary mass as in Fischer et al. (2002), $M_1 = 1.03\,M_\odot$, we compute the planet minimum mass and its orbital semi-major axis: $m_2 \sin i = 2.76\,M_{\rm Jup}$ and $a = 2.11$ AU.

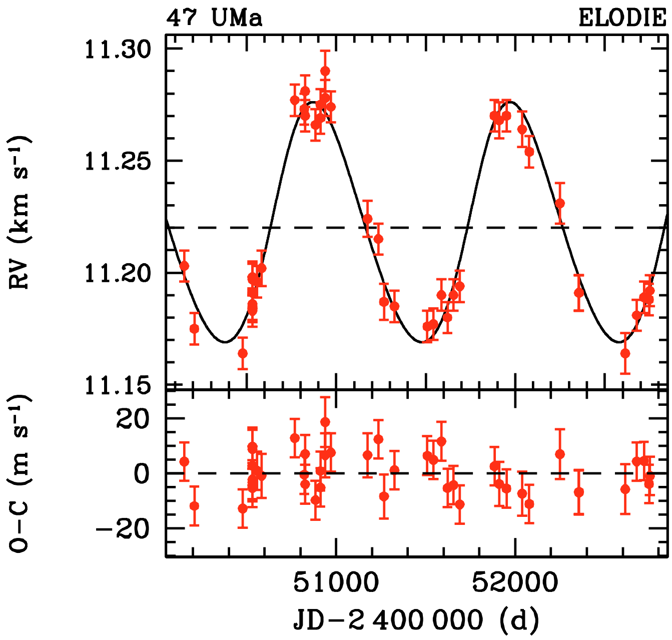

Fig. 7. Top: ELODIE temporal velocities and fitted orbital solution for 47 UMa. **Bottom**: residuals to the solution.

We have tried without success to adjust a 2-Keplerian orbital solution to our velocities, starting from the solution published in Fischer et al. (2002). Moreover, the residuals we obtain by fixing the Fischer et al. (2002) solution to our data are large: $\sigma_{\rm O-C} = 13$ m s^{-1}. This solution is thus not compatible with the ELODIE data. In a recent paper, Ford (2003) has shown that the orbital solution for 47 UMa was almost unconstrained by the Fischer et al. (2002) velocities. For example, he has obtained a statistically equivalent solution with a period three times longer and an eccentricity eight times larger than the published values. At this point, the ELODIE data are not sufficient for confirming or ruling out the presence of another body in the system. They are well fitted by a single planet orbit. These facts demonstrate that the Fischer et al. (2002) orbit is very preliminary.

4.4. 70 Vir (HD 117176, HIP 65721, GJ 512.1)

The detection of a massive planet on a moderately eccentric 116–d orbit around 70 Vir was announced in Marcy & Butler (1996). A preliminary ELODIE orbit confirming the Marcy & Butler (1996) solution was presented in Naef et al. (2001).

We now have 35 ELODIE radial-velocity measurements. They have been obtained between JD = 2 450 150 (March 1996) and JD 2 452 777 (May 2003). They have a mean velocity uncertainty of 7.1 m s^{-1}. We present in Table 5 the orbital solution fitted to our velocities. This solution is in full agreement with the Marcy & Butler (1996) solution. It is also much more precise than our preliminary solution (Naef et al. 2001). The improvement is due to the use of the new cross-correlation template reducing the influence of the atmospheric telluric lines (Pepe et al. 2002). With residuals of 6.1 m s^{-1}, it is to date the most precise published ELODIE orbital solution and it thus illustrates well the level of precision presently achieved with this

Table 5. ELODIE orbital solution for 47 UMa, 70 Vir and HD 187123. The parameters have the same definitions as in Table 2.

		47 UMa b	70 Vir b	HD 187123 b
P	(d)	1100.8 ± 7.2	116.689 ± 0.011	3.0966 ± 0.0001
T	(JD†)	$52\,915 \pm 64$	$48\,990.39 \pm 0.33$	$51\,010.972 \pm 0.027$
e		0.097 ± 0.039	0.397 ± 0.005	0 (fixed)
γ	(km s^{-1})	11.220 ± 0.001	4.951 ± 0.001	$-16.986^{\ddagger} \pm 0.002$
w	(°)	300 ± 20	359.40 ± 0.92	0 (fixed)
K_1	(m s^{-1})	53.6 ± 1.9	314.1 ± 2.0	70.7 ± 1.7
Slope	(m s^{-1} yr^{-1})	–	–	-8.9 ± 0.9
$a_1 \sin i$	(10^{-5} AU)	540 ± 20	309 ± 2	2.01 ± 0.06
$f_1(m)$	(10^{-10} $M_{\odot}$)	173 ± 19	2897 ± 55	1.14 ± 0.10
$m \sin i$	($M_{\rm Jup}$)	2.76 ± 0.10	6.56 ± 0.04	0.52 ± 0.01
a	(AU)	2.11	0.456	0.042
N		44	35	57
$\sigma_{\rm O-C}$	(m s^{-1})	7.4	6.1	10.5
$\chi^2_{\rm red}$		1.19	0.87	1.37

† = JD−2 400 000, ‡ at JD = 2 451 500.

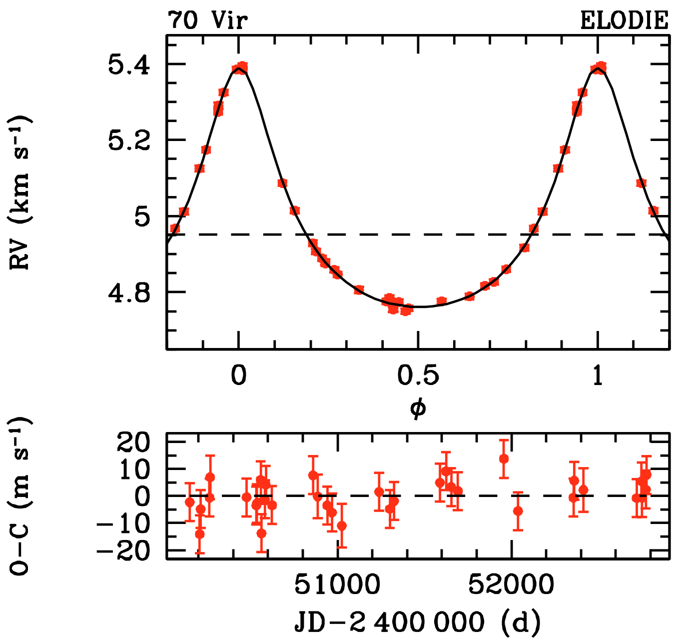

Fig. 8. ELODIE radial-velocity data and orbital solutions for 70 Vir. **Top**: Phased-folded velocities. **Bottom**: Residuals to the fitted orbital solution.

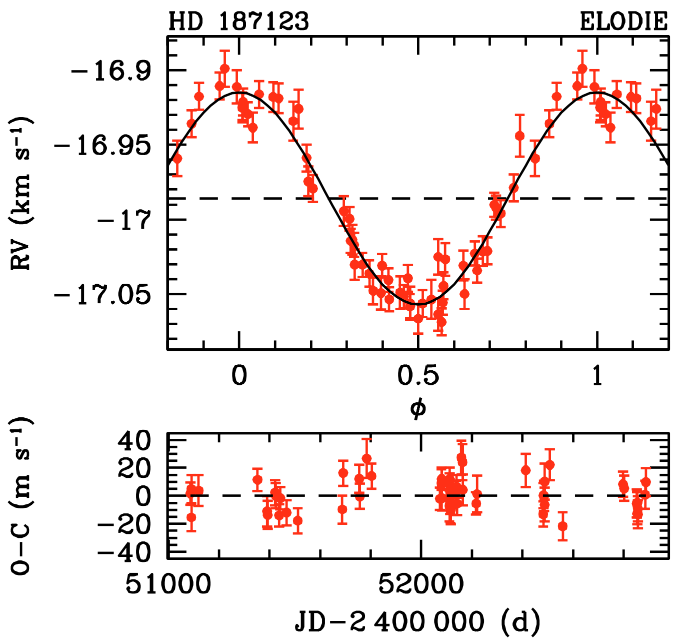

Fig. 9. ELODIE radial-velocity data and orbital solutions for HD 187123. **Top**: Phased-folded velocities. The velocities are corrected for a linear drift of −8.8 m s^{-1} yr^{-1}. **Bottom**: Residuals to the fitted orbit.

instrument. Figure 8 shows our radial velocities and the fitted solution.

With the primary mass quoted in Marcy & Butler (1996), $M_1 = 0.92\,M_{\odot}$, we find a minimum mass of $6.56\,M_{\rm Jup}$ for 70 Vir b. Its orbital semi-major axis is 0.456 AU.

4.5. HD 187123 (HIP 97336)

The presence of a 3.1–d planet in orbit around HD 187123 was announced by Butler et al. (1998). An updated orbital solution including an additional linear velocity drift was presented in Vogt et al. (2000).

We started our ELODIE measurements of HD 187123 shortly after the discovery announcement. We now have 57 radial-velocity measurements of this star spanning from JD 2 451 087 (September 1998) to JD 2 452 889 (September 2003). They have a mean velocity uncertainty of 9.6 m s^{-1}. The orbital solution fitted to these velocities is presented in Table 5. We fitted a circular orbit since our data do not exhibit a significant eccentricity according to the Lucy & Sweeney (1971) test. Our solution also includes an additional linear velocity drift. The derived parameters are in full agreement with those presented in Vogt et al. (2000). We therefore confirm the presence of the short-period planet and the linear drift probably due to another massive body in the system. Figure 9 shows the ELODIE velocities and the fitted orbital solution.

Using the primary published in Santos et al. (2003), $M_1 = 1.05\,M_\odot$, we derive $m_2 \sin i = 0.52\,M_{\rm Jup}$ and $a = 0.042$ AU for HD 187123 b.

5. Summary

In this paper, we have presented our ELODIE radial-velocity data and derived planetary solutions for HD 74156, 14 Her, HD 209458, 51 Peg, Ups And, 55 Cnc, 47 UMa, 70 Vir and HD 187123, including three new ELODIE planets, updated orbital solutions of previously published candidates and confirmations of detections from other planet search programmes.

The radial-velocity variations detected for HD 74156 are found to be due to the presence of a planetary system consisting of a 1.86 $M_{\rm Jup}$ planet at 0.294 AU and a 6.17 $M_{\rm Jup}$ planet on a 5.5–yr orbit. For 14 Her, a 4.74 $M_{\rm Jup}$ planet at 2.80 AU induces the main detected signal. An additional linear velocity drift revealing the presence of another not yet characterized massive body in the system is detected as well for 14 Her.

We have presented updated more precise orbits for HD 209458 and 51 Peg, two stars hosting short-period planets detected with ELODIE.

We have confirmed the previously published orbital solutions for Ups And, 70 Vir and HD 187123. We have also partially confirmed the solutions for 55 Cnc and 47 UMa. The velocity signals of the inner and the outer planet orbiting 55 Cnc are clearly detected. We have no evidence for the presence of 47 UMa c. Our data is not compatible with the Fischer et al. (2002) solution. However, the radial-velocity semi-amplitude induced by this object (11 m s^{-1}) is small compared to our measurement precision (7.3 m s^{-1}). We thus cannot rule-out this claimed detection.

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