Contribution to the study of composite spectra. XI – Orbital elements of some faint systems.

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Received April 27, 2019; accepted

We present the results of a radial-velocity study of nine new faint SB1 spectroscopic binaries with composite spectra: HD 137975-6, 177984, HDE 226489, 231613-4, 255387-8, 256138-9, 264997-8, 276787 and 293041-2. The observations were made at Haute-Provence and Cambridge observatories with CORAVEL instruments between 1982 and 2006. From the radial-velocity measurements of the cool components, we derive the orbital elements of those spectroscopic binaries for the first time. Using all the available data, we propose a model for each system that describes the nature of the individual components, with an estimation of the angular separation and orbital inclination. Finally we discuss the rotation–revolution synchronism of the cool components.

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1 Introduction

This is the eleventh paper devoted to the detection and study of spectroscopic binaries (SBs) among a sample of stars with *composite spectra*, i.e. that exhibit in the blue region of their spectra both the features of a hot spectrum (strong Balmer lines) and those of a cool spectrum (numerous metallic-lines). If we except the cases of hot metallic-lined stars (Am), such composite spectra arise from binaries associating a dwarf star of type A or B and a red giant or supergiant (Ginestet et al. 1980, Paper I, Ginestet & Carquillat 2002). This association corresponds to a small magnitude difference in V between the two stars, which allows a composite spectrum to be observed.

Hynek (1938, hereafter HYN) published an extensive list of stars with composite spectra and introduced the term of “spectrum binaries” to designate the class of binaries whose duplicity was revealed by the aspect of their spectra only. Since the early 1980’s we have been working on a radial velocity monitoring with the CORAVEL instrument at Haute-Provence Observatory (OHP) of a large sample of “spectrum binaries”, whose main source is Hynek’s list. Our goal was to investigate whether those systems were really binaries and in this case monitor their orbital motion. Actually we have found that some of those objects were Am stars. For the others, our long-term program allowed us to obtain accurate orbital elements and derive physical parameters of the stars constituting those systems, even when the orbital periods were rather long ($P \approx 20$ yr).

In the two previous papers of this series (Carquillat, Prieur & Ginestet 2003, Paper IX; Carquillat, Prieur &

Ginestet 2005, Paper X) we presented the results concerning 15 rather bright systems ($6.9 < m_v < 8.2$ for 14 of them), for which we had made a complementary work on spectral classification by using a spectra subtraction method (Ginestet & Carquillat 2002, hereafter GIN 2002). In this paper we present, in terms of orbital elements of new SBs, the results of our observations for nine faint systems ($8.6 < m_v < 10.3$) of our sample, namely HD 137975-6, 177984, HDE 226489, 231613-4, 255387-8, 256138-9, 264997-8, 276787 and 293041-2. To our knowledge our results are new. No data about the radial velocities (here after RVs) were previously available in the literature for those stars before this paper.

In Sect. 2 we describe our observational material and the computation of the orbital elements that we obtained. In Sect. 3.1 we give for each system some general information about the intrinsic data available for those stars (duplicity, spectral classification, etc). In Sect. 3.2 we propose estimates of the orbital inclinations and separations of the components for those binaries. Finally in Sect. 3.3 we examine the occurrence of rotation–revolution synchronism among this sample of SBs.

2 Observations and derivation of orbital elements

The RV measurements that we used for this work are presented in Tables 1 to 9. The first observations for this program started in the early 1980’s. They were mainly obtained with the CORAVEL instrument mounted at the Cassegrain focus of the Swiss 1-m telescope of OHP. This instrument is a spectrophotometer that allows measurements of heliocentric RVs by performing

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Table 1 Radial velocities and $(O - C)$ residuals for HD 137975-6.

Date (JD) 2400000+	Cycle	RV km s ⁻¹	$(O - C)$ km s ⁻¹
46228.46	-0.25	-32.6	-0.3
46230.42	-0.24	-32.0	0.5
46486.70	0.85	-35.0	0.1
47608.65	5.63	-29.7	-0.2
47969.63	7.16	-26.6	0.1
48672.69	10.15	-27.6	-0.8
49142.45	12.15	-26.2	0.6
49426.64	13.36	-25.8	0.1
49783.69	14.88	-36.6	-0.7
49787.68	14.90	-36.5	-0.3
50124.74	16.34	-26.1	-0.4
50192.55	16.63	-29.8	-0.3
50478.70	17.84	-35.2	-0.3
50609.46	18.40	-26.2	0.0
50615.50	18.43	-26.5	0.0
50836.73	19.37	-25.5	0.5
50974.42	19.95	-36.1	0.2
50978.43	19.97	-36.2	-0.3
51186.76	20.86	-34.9	0.4
51281.59	21.26	-25.6	0.0
51352.40	21.56	-28.0	0.4
51687.45	22.99	-35.1	0.1
52409.48	26.06	-30.9	-0.1
52820.39	27.81	-33.6	0.4
53087.64	28.95	-36.1	0.2
53089.63	28.96	-36.0	0.2
53144.46	29.19	-26.0	0.1
53445.65	30.47	-27.4	-0.4

Table 2 Radial velocities and $(O - C)$ residuals for HD 177984.

Date (JD) 2400000+	Cycle	RV km s ⁻¹	$(O - C)$ km s ⁻¹
46226.54	-0.28	-3.8	1.1
46227.60	-0.27	-4.8	-0.3
46333.31	1.38	-10.2	-0.1
46336.29	1.42	-10.4	-0.8
46671.41	6.63	-6.6	-0.2
47093.26	13.19	-10.8 ^{Cam}	0.3
47098.29	13.27	-10.9	0.1
47108.50	13.43	-9.6 ^{ESO}	-0.1
47285.59	16.19	-11.5	-0.5
47460.27	18.90	-1.2	-0.1
47462.30	18.93	-1.0	0.1
47472.26	19.09	-8.7	0.2
47608.68	21.21	-11.1	0.0
47831.23	24.67	-6.2	-0.4
48128.38	29.29	-10.7	0.2
48136.40	29.42	-9.4	0.3
48849.33	40.50	-8.8	-0.2
49141.55	45.05	-7.1	-0.4
49640.31	52.80	-3.5	-0.6
50324.37	63.44	-9.2	0.2
50416.25	64.87	-1.3	0.2
50611.62	67.91	-1.4	-0.3
50746.33	70.00	-3.6	0.1
50975.56	73.57	-7.2	0.4
51105.29	75.58	-7.1	0.2
52822.49	102.29	-10.7	0.2
53261.41	109.11	-9.8	0.0
53345.22	110.42	-9.9	-0.2
53626.40	114.79	-3.0	0.3
53703.25	115.98	-2.5	0.2

a cross-correlation of the stellar spectrum with a physical mask placed in the focal plane of the spectrograph (Baranne, Mayor & Poncet 1979). Owing to the nature of this mask, obtained from the Arcturus spectrum, only the RVs of the cool components of the spectrum binaries can be measured.

For HDE 226489 fifteen additional observations were made to our request by R.F. Griffin at Cambridge Observatories (indicated with the superscript ^{Cam} in Col. 3) with another CORAVEL instrument mounted at the coudé focus of the 36-inch reflector. For HD 177984 and HDE 256138, four other observations were also made by R.F. Griffin with CORAVEL instruments at La Silla Observatory (ESO, indicated with ^{ESO} in Col. 3), DAO (Victoria, indicated with ^{DAO} in Col. 3) and Cambridge Observatories.

All the RVs were reduced to the system of the Geneva Observatory data base (Udry, Mayor & Queloz 1999), via the observations of RV standard stars conjointly with the program stars; an offset of -0.8 km.s^{-1} was applied to the Cambridge observations. The mean standard error of the RVs is about 0.5 km.s^{-1} . A same weight (unity) was given to each RV because all the measurements were carried out with similar instruments.

The spectroscopic orbital elements that we derived from those RVs are given in Table 10. They were computed using a fully automatic procedure described in Prieur, Carquillat & Imbert (in press). All the prelim-

inary elements, including the period were first determined by the program PERIOD_RESID, and the final elements we computed with our least-square program BS1 (Nadal et al. 1979).

The radial velocity curves are given in Figs. 1 and 2 and the $(O - C)$ residuals of the RV measurements with our computed orbits are listed in Tables 1 to 9. For each orbit, the typical mean residual $\sigma_{(O-C)}$ is consistent with the mean RV error, which indicates the absence of detectable spectroscopic third bodies in those systems.

Note the very long period (for a spectroscopic binary) of HDE 276787: $P \approx 24.5 \text{ yr}$. This is the longest orbital period that we determined in our sample. Hardly an orbital revolution has been covered during our observations, which explains the unusually large error on the period (with a relative error of $\sigma_P/P = 3.9\%$). Another 20-year monitoring would be desirable to reduce this error... Nevertheless the data that we obtained are fortunately already satisfactory and the computation well converges to a unique solution.

Please note also the very small mass-function of HD 177984, $0.0007 \text{ M}_\odot$, which is rather unusual for composite spectrum binaries that generally have relatively massive secondary components. Two explanations may be proposed:

- (i) the orbital inclination has an unusually small value;

Table 10 Orbital elements of the spectroscopic binaries. In Col. 3, T_0 is the epoch of periastron passage.

HD	P days	T_0 (JD) 2400000+	ω deg.	e	K_1 km.s ⁻¹	V_0 km.s ⁻¹	$a_1 \sin i$ Gm	$f(m)$ M _⊙	$\sigma_{(O-C)}$ km s ⁻¹
137975-6	234.897 ±0.097	46287.3 ±3.7	228.2 ±4.6	0.319 ±0.018	5.45 ±0.10	-29.87 ±0.09	16.69 ±0.43	0.0034 ±0.0003	0.34
177984	64.3063 ±0.0058	46244.8 ±0.7	60.5 ±3.7	0.353 ±0.020	5.06 ±0.11	-6.98 ±0.07	4.18 ±0.13	0.00071 ±0.00007	0.35
226489	2301.6 ±6.7	47577 ±18	277.6 ±2.0	0.342 ±0.011	11.57 ±0.15	19.53 ±0.10	344.0 ±7.0	0.307 ±0.017	0.42
231613-4	651.00 ±0.20	45690.8 ±4.5	96.1 ±3.0	0.178 ±0.007	21.06 ±0.15	-1.28 ±0.14	185.6 ±1.6	0.602 ±0.015	0.45
255387-8	530.81 ±0.23	50453.7 ±3.0	324.7 ±2.1	0.235 ±0.008	19.97 ±0.16	38.99 ±0.12	141.7 ±1.5	0.403 ±0.012	0.33
256138-9	3628 ±20	47091 ±30	329.7 ±2.8	0.293 ±0.012	9.48 ±0.11	27.14 ±0.09	452.1 ±9.4	0.280 ±0.015	0.42
264997-8	4813 ±80	53547.1 ±8.6	85.9 ±1.4	0.681 ±0.008	14.40 ±0.27	31.21 ±0.25	698 ±31	0.586 ±0.060	0.41
276787	8967 ±346	47516 ±53	350.6 ±3.1	0.425 ±0.027	4.44 ±0.10	9.11 ±0.09	496 ±37	0.0604 ±0.0091	0.34
293041-2	2900 ±11	45716 ±21	273.2 ±2.0	0.660 ±0.042	14.2 ±1.1	2.16 ±0.24	425 ±55	0.36 ±0.14	0.40

Table 3 Radial velocities and $(O - C)$ residuals for HDE 226489.

Date (JD) 2400000+	Cycle	RV km s ⁻¹	$(O - C)$ km s ⁻¹
45599.32	-0.86	31.3	-0.2
45600.33	-0.86	31.2	-0.3
46225.60	-0.59	21.3	-0.6
46333.38	-0.54	20.5	0.4
48137.42	0.24	29.1	0.5
49146.59	0.68	12.5	0.5
49318.27	0.76	9.6	-0.2
49319.27	0.76	10.2	0.5
49640.39	0.90	9.4	-0.3
50325.46	1.19	30.6	0.3
50418.31	1.23	28.6	-0.3
50611.57	1.32	26.2	0.6
50738.43	1.37	23.5	0.1
50836.25	1.42	21.1	-0.6
50975.57	1.48	18.8	-0.6
51106.35	1.53	16.4	-0.9
51185.27	1.57	15.8	-0.2
52121.56	1.97	17.8 ^{Cam}	0.2
52136.41	1.98	18.5 ^{Cam}	-0.1
52175.39	2.00	21.6 ^{Cam}	0.3
52201.36	2.01	22.5 ^{Cam}	-0.5
52227.33	2.02	24.9 ^{Cam}	0.2
52252.22	2.03	26.1 ^{Cam}	0.0
52279.23	2.04	28.0 ^{Cam}	0.5
52360.68	2.08	30.5 ^{Cam}	0.1
52384.64	2.09	30.2 ^{Cam}	-0.7
52410.59	2.10	31.6 ^{Cam}	0.3
52448.52	2.12	31.5 ^{Cam}	-0.1
52470.54	2.13	31.5 ^{Cam}	-0.1
52501.52	2.14	32.2 ^{Cam}	0.6
52526.50	2.15	31.3 ^{Cam}	-0.1
52551.42	2.16	31.0 ^{Cam}	-0.2
52824.57	2.28	27.6	0.4
53261.45	2.47	19.7	0.0
53344.23	2.51	19.1	0.8
53626.46	2.63	13.9	0.1

Table 4 Radial velocities and $(O - C)$ residuals for HDE 231613-4.

Date (JD) 2400000+	Cycle	RV km s ⁻¹	$(O - C)$ km s ⁻¹
45204.42	-0.75	-21.0	-0.5
45206.44	-0.74	-20.8	-0.5
45207.40	-0.74	-19.6	0.6
45597.32	-0.14	16.5	-0.7
45598.32	-0.14	17.2	0.1
46228.62	0.83	18.9	0.1
46333.33	0.99	-1.6	-0.2
46337.36	0.99	-2.3	0.3
49641.34	6.07	-15.8	-0.2
50325.47	7.12	-20.5	0.3
50328.44	7.12	-20.8	0.3
50418.28	7.26	-19.8	0.1
50611.56	7.56	6.0	0.1
50738.33	7.75	18.6	-0.3
50746.30	7.77	18.7	-0.5
50975.58	8.12	-21.2	-0.5
51108.33	8.32	-15.7	0.0
52822.51	10.96	4.8	0.2
53258.40	11.62	11.2	-0.3
53262.39	11.63	11.7	-0.2
53345.23	11.76	20.4	1.4
53625.36	12.19	-22.7	0.0
53705.24	12.31	-16.1	0.4

- (ii) the spectroscopic companion is not the A-type star and the system is triple: the G-type component and a close faint low mass unseen companion constitute the spectroscopic pair, whereas the A-type component is a more distant third component.

Those two hypotheses will be re-examined in relation with synchronism in Sect. 3.3.

Fig. 1 RV curves computed with the orbital elements of Table 10: (a) HD 137975-6, (b) HD 177984, (c) HDE 226489, (d) HDE 231613-4, (e) HDE 255387-8 and (f) HDE 256138-9. The origin of the phases corresponds to the periastron passage.

3 Discussion

3.1 Notes on individual systems

HD 137975-6 – HIP 75858 – HYN 386. Hynek (1938) reports the composite classification F5 + A2 given in the Henry Draper Catalogue (here after HDC). Houk & Smith-Moore (1988) propose A2/3 V + G8 III and GIN 2002 G8 III + A2.5: V. Let us remark that the spectral types given in the HDC for the cool components of composite spectrum stars are generally slightly misclassified, with a trend of giving a spectral type ear-

lier than what is attributed by recent classifications (GIN 2002).

The photometric model proposed by GIN 2002, based on G8 III + A2.5 V is consistent with the available data, including the Hipparcos parallax $\pi = 2.11 \pm 1.28$ mas (ESA 1997) which has unfortunately a bad accuracy ($\sigma_\pi/\pi = 0.61$).

HD 177984 – HIP 93842 – HYN 465. The HDC quotes the spectral classification A2p but notes “*the spectrum is composite; the fainter spectrum appears to be of class G.*” No recent classification is available in the literature, but we confirm that the spectrum is

Table 5 Radial velocities and $(O - C)$ residuals for HDE 255387-8.

Date (JD) 2400000+	Cycle	RV km s^{-1}	$(O - C)$ km s^{-1}
50416.60	-0.07	47.3	-0.4
50476.50	0.04	62.7	0.2
50478.39	0.05	62.4	-0.2
50738.68	0.54	24.5	-0.5
50835.42	0.72	24.0	0.0
51106.64	1.23	47.7	-0.5
51108.65	1.23	47.8	0.0
51185.49	1.38	34.2	0.2
53012.42	4.82	31.0	0.1
53089.34	4.97	54.6	0.6
53339.52	5.44	30.2	0.2
53445.37	5.64	23.0	0.1
53628.61	5.98	56.3	-0.3
53704.60	6.12	59.5	-0.1
53746.44	6.20	51.8	0.5

Table 6 Radial velocities and $(O - C)$ residuals for HDE 256138-9.

Date (JD) 2400000+	Cycle	RV km s^{-1}	$(O - C)$ km s^{-1}
47099.66	0.00	38.5	0.6
47100.64	0.00	37.7	-0.2
47609.34	0.14	36.3	1.1
47868.54	0.21	31.1	0.0
47870.55	0.21	30.5	-0.6
47936.68	0.23	29.7 ^{ESO}	-0.4
47966.41	0.24	29.2	-0.5
48137.66	0.29	28.3	0.8
48261.57	0.32	26.3	0.2
48637.52	0.43	23.3	0.4
48672.43	0.44	22.2	-0.5
48675.47	0.44	22.1	-0.6
48680.78	0.44	22.5 ^{DAO}	-0.1
48937.62	0.51	21.6	0.4
48969.44	0.52	21.2	0.1
48975.58	0.52	21.3	0.3
49318.56	0.61	19.9	-0.2
49325.57	0.62	19.8	-0.3
49427.35	0.64	20.3	0.2
49642.60	0.70	20.3	-0.1
49785.41	0.74	21.2	0.2
50124.41	0.84	23.9	-0.5
50325.63	0.89	27.5	-0.8
50416.48	0.92	31.0	0.5
50420.57	0.92	31.3	0.7
50477.51	0.93	32.1	0.0
50738.65	1.01	37.9	-0.1
50746.61	1.01	37.6	-0.5
50798.57	1.02	38.5	-0.2
50835.49	1.03	39.0	0.1
50876.34	1.04	38.8	-0.2
51106.65	1.11	37.3	0.1
51185.48	1.13	35.8	-0.2
53012.43	1.63	20.2	0.1
53088.36	1.65	20.1	0.0
53625.67	1.80	22.9	0.2

Table 7 Radial velocities and $(O - C)$ residuals for HDE 264997-8.

Date (JD) 2400000+	Cycle	RV km s^{-1}	$(O - C)$ km s^{-1}
49319.50	-0.88	19.3	-0.5
49325.58	-0.88	20.4	0.5
49427.40	-0.86	20.5	-0.3
49643.59	-0.81	22.3	-0.2
49786.31	-0.78	24.3	0.8
50124.50	-0.71	25.6	-0.1
50127.48	-0.71	26.2	0.5
50194.34	-0.70	26.3	0.2
50418.64	-0.65	27.6	0.3
50477.48	-0.64	26.9	-0.7
50740.65	-0.58	28.4	-0.5
50803.65	-0.57	29.7	0.5
50835.48	-0.56	29.1	-0.3
51107.65	-0.51	30.3	-0.4
51185.55	-0.49	31.2	0.1
53014.45	-0.11	43.2	-0.1
53087.35	-0.10	44.8	0.6
53343.63	-0.04	45.8	-0.5
53446.36	-0.02	43.6	0.2
53628.64	0.02	23.3	0.0
53705.55	0.03	18.7	-0.2
53746.54	0.04	18.2	0.2

composite because the correlation dip with CORAVEL is the signature of a cool star, not that of a metallic hot star.

The parallax as measured by the HIPPARCOS satellite has unfortunately a too large uncertainty to be useful: $\pi = 1.27'' \pm 1.36''$.

HDE 226489 – BD +36°3762 – HYN 497. The HDC gives a single classification of “G” but the spectrum is suspected to be composite. No recent classification is available. The mass-function of $0.3 M_{\odot}$ (Table 10) is typical of that of a composite spectrum binary (Griffin 1990).

HDE 231613-4 – BD +11°3863 – HYN 483. The HDC gives the composite classification F5 + A5 reported by Hynek, and later Stephenson & Nassau (1961) classify the star as (A0 + G0). The mass-function, $f(m) = 0.6 M_{\odot}$, is consistent with the composite spectrum nature of the system with a massive hot component.

HDE 255387-8 – BD +19°1307 – HYN 213. The HDC gives the composite spectral type of A3 + F5. Ginestet et al. (1997) classify the cool component of the system, G7: III, from a CCD spectrum obtained at OHP in the near infrared spectral region. Tentatively we can adopt G7 III + (A3)V for the classification of the system, given the available data and the statistical properties of such binaries (GIN 2002).

HDE 256138-9 – HIP 30379 – HYN 215. The HDC classification is F5 + A3. Ginestet et al. (1997) gives G7 III for the MK spectral type of the cool com-

Table 11 Other parameters of the systems.

HD	V	$B - V$	Spectral type	$v \sin i$ km.s ⁻¹	$v_{ps} \sin i_{orb}$ km.s ⁻¹	M_2 M _☉	i_{orb} deg.	a au
137975-6	8.56	0.72	G8III + A2.5V	3.0	0.7	2.4	11 ± 1	1.3 ± 0.2
177984	9.30	0.51	(A2p + G)	13.0	1.5	2.5	~ 6	~ 0.5
226489	10.3	—	(G) composite	4.5	≤ 0.4	—	—	—
231613-4	9.51	0.68	(A0 + G0)	4.4	0.9	2.9	90 ⁺⁰ ₋₂₀	2.7 ± 0.3
255387-8	8.93	0.58	G7III + (A3)V	3.8	1.2	2.4	69 ± 11	2.2 ± 0.2
256138-9	8.98	0.64	G7III + (A3)V	1.7	0.2	2.4	56 ± 7	8.0 ± 0.9
264997-8	9.4	~ 0.6	G8III + (A2)V	4.8	0.6	2.5	90 ⁺⁰ ₋₁₂	9.6 ± 1.3
276787	8.87	1.16	K1III + A2.5V	2.9	0.1	2.4	30 ± 4	14.7 ± 2.4
293041-2	9.64	0.66	G8III-IV + (A3)V	2.8	0.8	2.4	64 ± 22	6.9 ± 1.5

ponent. In the lack of more data we will adopt the classification G7 III + (A3)V. Unfortunately the parallax quoted in the Hipparcos Catalogue (ESA 1997), $\pi = -1.81 \pm 1.62$, is nonsensical.

HDE 264997-8 – BD +21°1404 – HYN 242. The HDC classification reported by Hynek is G0 + A2. Ginestet et al. (1997) classified the cool component in the near infrared as G8 III. We thus propose the classification G8 III + (A2)V, retaining the HDC spectral type of the hot component. The lack of observations between the phases 0.5 and 0.9 corresponds to the unavailability of the OHP CORAVEL during the period 1999–2003.

HDE 276787 – BD +40°1043 – HYN 165. Hynek (1938) reports the classification F5 + A5. GIN 2002 give K1 III + A2.5 V and propose a photometric model for the system that could not fully validated because the parallax is unknown. Note that the entry of this object in the Hynek (1938) list is erroneous: it is “BD +40°1043”, according to the coordinates and magnitude, and not “BD +40°1023”.

HDE 293041-2 – BD +00°1775 – HYN 255. Classified F5 + A3 (HDC). Ginestet, Carquillat & Jaschek (1999) classify G8: III-IV the cool component from a near infrared spectrum taken at OHP. Assuming the HDC classification for the hot component, we adopt the classification G8 III-IV + (A3)V.

3.2 Estimation of orbital inclinations and linear separations of the components

The mass-function can be expressed by the formula:

$$f(m) = M_2 \sin^3 i / (1 + \rho)^2 \quad (1)$$

where $\rho = M_1/M_2$ (M_1 and M_2 are the masses of the cool and hot components, respectively). The mean separation of the components corresponds to the semi-major axis a of the mutual orbit. It can be computed with the expression:

$$a = a_1 + a_2 = (a_1 \sin i)(1 + \rho) / \sin i \quad (2)$$

where a_1 and a_2 are the semi-major axes of the cool and hot component orbits, respectively, relative to the center of mass of the system.

To estimate the values of i and a with the relations (1 and 2), we can proceed as in paper IX, i.e.:

- the mass M_2 of the dwarf hot secondary is estimated by the Schmidt-Kaler (1982) calibration of the mass versus spectral type relation;
- the mass-ratio ρ is approximated by the statistically most likely value $\rho = 1.2 \pm 0.2$, on the basis of precedent investigations on composite spectrum binaries (Griffin, Carquillat & Ginestet 2002, GIN 2002). Indeed in such systems the components have generally similar luminosities and close masses.

The corresponding values of i and a obtained with those assumptions are given in Table 11 in Col. 8 and 9 respectively. The assumed masses M_2 of the dwarf hot components used for this estimation are given in Col. 7. Note that HDE 231613-4 and 264997-8, which have the largest mass-functions (0.6 M_☉), could be eclipsing systems since their inclination estimates are close to 90°.

In Table 11, we also display the global V magnitude in Col. 2 and the global $B - V$ index in Col. 3 that we found in the literature. In Col. 4, the spectral type in brackets originates from old classifications (from Stephenson & Nassau (1961) for HDE 231613-4 and the HDC for the others). The other spectral types come from our recent investigations (see Sect. 3.1). The projected rotational velocities of the cool components deduced from the CORAVEL correlation dips are given in Col. 5.

For HD 177984 the HDC indicates that the cool component is fainter than the hot one. In composite spectrum pairs, the hot component dominates the spectrum when the cool evolved component is a star of luminosity class IV or III-IV. It is likely that this is the case of HD 177984. If the hot component is the spectroscopic companion, the mass ratio is likely to be $\rho \approx 1$, which leads to the values of i and a quoted in Table 11.

With a linear separation near 15 au, it is worth estimating the expected angular separation of the components of the wide spectroscopic pair HDE 276787.

Table 8 Radial velocities and $(O - C)$ residuals for HDE 276787.

Date (JD) 2400000+	Cycle	R_V km s ⁻¹	$(O - C)$ km s ⁻¹
45338.48	-0.24	7.8	0.3
45339.55	-0.24	8.3	0.8
45343.41	-0.24	7.8	0.3
45600.62	-0.21	7.5	-0.4
46335.62	-0.13	9.0	-0.8
46723.65	-0.09	11.5	0.0
47098.64	-0.05	14.1	0.4
47101.53	-0.05	13.6	-0.1
47459.56	-0.01	15.4	0.1
47463.52	-0.01	15.1	-0.2
47868.52	0.04	14.9	0.0
47967.36	0.05	14.5	0.0
48131.65	0.07	13.7	-0.1
48136.65	0.07	13.7	0.0
48262.30	0.08	12.8	-0.3
48672.30	0.13	11.7	0.4
48676.29	0.13	11.4	0.1
48936.56	0.16	10.7	0.3
48967.47	0.16	10.0	-0.3
49318.47	0.20	9.5	0.2
49325.47	0.20	9.4	0.1
49428.29	0.21	9.6	0.5
49641.53	0.24	8.3	-0.4
49783.40	0.25	8.6	0.2
50123.36	0.29	7.4	-0.5
50325.65	0.31	7.6	-0.1
50419.55	0.32	7.5	0.0
50479.44	0.33	7.6	0.1
50739.63	0.36	7.3	0.1
50837.43	0.37	6.8	-0.4
51106.63	0.40	6.8	-0.2
51185.47	0.41	7.0	0.1
52676.32	0.58	6.5	0.0
53011.42	0.61	6.7	0.1
53088.29	0.62	6.6	0.0
53258.60	0.64	5.9	-0.8
53445.27	0.66	7.3	0.5
53626.61	0.68	7.0	0.1
53704.58	0.69	6.3	-0.6
53747.41	0.69	7.4	0.5

In the absence of trigonometric parallax data, we can determine its distance-modulus from the photometric model that we proposed in GIN 2002 (see table 3 of that paper). The colour index given by this model is $(B - V)_0 = 0.87$, and the observed value is $(B - V) = 1.16$ (Table 11), so that we have a colour-excess $E_{(B-V)} = 0.29$, and a interstellar absorption $A_V \approx 3 E_{(B-V)} = 0.87$ mag. Therefore the de-reddened apparent visual magnitude of the system is $m_V \approx 8.00$. Given the absolute magnitude $M_V = -0.47$ of the system (GIN 2002), its distance-modulus $(m_V)_0 - M_V = 8.47$, we obtain $d = 494$ pc via the Pogson law. At such a distance, $a = 14.7$ au (Table 11) corresponds to a mean angular separation of $0.030''$ and to a maximum angular separation of $0.043''$. We conclude that the components of this binary should be resolved by the speckle-interferometry technique with a 3-meter telescope.

Table 9 Radial velocities and $(O - C)$ residuals for HDE 293041-2.

Date (JD) 2400000+	Cycle	R_V km s ⁻¹	$(O - C)$ km s ⁻¹
45343.57	-0.13	-8.8	0.4
45344.52	-0.13	-9.0	0.2
47609.36	0.65	-1.1	0.8
47870.70	0.74	-5.2	-0.7
47967.34	0.78	-5.9	-0.4
48673.37	1.02	12.9	0.0
48674.40	1.02	13.1	0.0
48940.64	1.11	14.6	0.2
48967.60	1.12	13.7	-0.2
49318.58	1.24	8.7	-0.2
49325.55	1.24	8.7	-0.1
49427.41	1.28	8.4	0.7
49640.68	1.35	5.6	0.0
49783.37	1.40	4.3	0.0
50123.45	1.52	1.3	-0.1
50127.42	1.52	1.3	-0.1
50193.34	1.54	0.4	-0.4
50416.59	1.62	-1.2	-0.1
50477.53	1.64	-2.1	-0.5
50481.47	1.64	-1.8	-0.1
50746.67	1.73	-3.6	0.6
50836.45	1.77	-5.5	-0.3
51107.67	1.86	-9.2	-0.6
51185.53	1.89	-9.9	-0.1
53087.33	2.54	0.7	-0.2
53343.58	2.63	-1.6	-0.3
53345.60	2.63	-1.1	0.2
53445.39	2.67	-1.9	0.3
53705.60	2.76	-3.9	1.0

3.3 Rotation-revolution synchronism

Like in our previous papers we now investigate the possibility of synchronism. It is well known that tidal effects can lead to circularising the orbits of binary systems and to synchronising the axial rotation and the orbital motion. Hut (1981) extended this notion to “pseudo-synchronism” in the case of eccentric orbits. We will only consider the possibility of pseudo-synchronism since all the systems studied here have eccentric orbits.

When the state of pseudo-synchronism is reached by a component of a binary system, its equatorial rotational velocity v is equal to v_{ps} defined as:

$$v_{ps} = R/P_{ps}, \quad (3)$$

where P_{ps} is the period of pseudo-synchronism and R is the radius of the star. Using the units generally chosen in the field of spectroscopic binary studies (i.e. velocity in km.s⁻¹ and period in days), it comes: $v_{ps} = 50.6 (R/R_\odot)/P_{ps}$.

In our case, since the observed quantity is $v \sin i$, the test for pseudo-synchronism is:

$$v \sin i = v_{ps} \sin i \quad (4)$$

When the value of i is unknown, the test (4) is reduced to the following inequality:

$$v \sin i \leq v_{ps} \quad (5)$$

Fig. 2 RV curves computed with the orbital elements of Table 10: (a) HDE 264997-8, (b) HDE 276787 and (c) HDE 293041-2. The origin of the phases corresponds to the periastron passage.

For each system we computed the value of P_{ps} using Hut (1981)'s formulae and the orbital elements of Table 10. We then derived the value of v_{ps} for the cool component assuming a radius of $10 R_{\odot}$, which corresponds to the expected radius of a G-type evolved component (Schmidt-Kaler 1982). We performed the test (4) for the systems for which i was estimated (see Col. 8 of Table 11). Here we assumed that the orbit and the equator of the star were coplanar, which is the basic assumption of all synchronism tests. We then compared the values of $v_{ps} \sin i$ given in Col. 6 of Table 11

with the observed values deduced from the width of the correlation dips observed with CORAVEL (Col. 5 of Table 11). We concluded that pseudo-synchronism was not reached for any of those systems since $v_{ps} \sin i > v_{ps} \sin i$.

For HD 177984 let us discuss the two hypotheses presented in Sect. 3.1:

- If we assume that this object is a single binary system with a very low orbital inclination the observed value $v \sin i = 13 \text{ km.s}^{-1}$ should correspond, with $i = 6^\circ$, to a true equatorial velocity of 124 km.s^{-1} , which is much too large for a G star. This would be an indication that the orbit and the equator of the star are not coplanar.
- If HD 177984 is a triple system and the spectroscopic companion is an invisible faint star, pseudo-synchronism is plausible. Indeed the necessary condition for pseudo-synchronism (5) becomes $v \sin i \leq 14.1 \text{ km.s}^{-1}$ which agrees with the observed value of 13 km.s^{-1} (Table 11). In this case the occurrence of pseudo-synchronism would explain why the G component of HD 177984 has maintained a larger rotational velocity than the other cool components of the systems studied in this paper.

3.4 Diagram ($e, \log P$)

We present in Fig. 3 the location in the ($e, \log P$) diagram of the composite spectrum systems for this paper and for the previous papers of this series. This diagram brings to light the peculiarity of HD 177984. With its high eccentricity ($e = 0.35$) and its short period ($P = 64$ days), the location of HD 177984 is peculiar compared to that of the other systems.

It has been shown that red giant binaries with periods smaller than about 100 days have circular orbits, and that this threshold is smaller for main sequence stars (Mermilliod & Mayor, 1992). Therefore a possible explanation to this discrepancy would be that the cool component of HD 177984 is not a true giant, as it is the case for most spectrum binaries, but a subgiant, as already proposed in Sect. 3.2.

Acknowledgements. This work is based on observations made, for the most part, at the Haute-Provence Observatory (France). We are grateful to M. Mayor (Geneva Observatory) for the use of the Swiss telescope and the CORAVEL instrument at OHP, and to S. Udry for the processing of our observations in the Geneva RV data base until the year 1999. We are indebted to R.F. Griffin for observing HD 226489 at Cambridge Observatories at our request and for giving us some measurements of HD 177984 and HDE 256138 that he made at OHP, ESO and DAO. We thank M. Imbert (Marseille Observatory) for carrying out the reduction of our recent observations with CORAVEL and for doing some observations of HD 137975. We also thank the anonymous referee

Fig. 3 e versus $\log P$ diagram for the systems studied in this paper (filled circles) and in the previous few papers of this series (open circles). HD 177984 appears as a peculiar system in this diagram.

for his useful comments about HD 177984.

For bibliographical references, we used the SIMBAD data base operated by the “Centre de Données Astronomiques de Strasbourg” (France).

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