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New spectroscopic components in multiple systems. V.*

A. A. Tokovinin[1] and N. A. Gorynya[2]

[1] Cerro Tololo Inter-American Observatory, Casilla 603, La Serena, Chile
atokovinin@ctio.noao.edu
[2] Institute of Astronomy of Russian Acad. Sci., 48 Pyatnitskaya Str, 109017 Moscow, Russia
e-mail: gorynya@sai.msu.ru

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ABSTRACT

Aims. This paper aims to improve the knowledge of orbits, physical parameters, and statistics of nearby multiple systems.
Methods. Radial velocities were measured with a correlation spectrometer during 2001–2006 to determine or improve the spectroscopic orbits of the components of some visual multiple systems. We compiled all available observational data and estimated masses and orbital periods in these hierarchical multiple systems. The masses and ages of evolved components are derived by fitting isochrones.
Results. We determined three new spectroscopic orbits of close sub-systems (HD 52452B, 157358Aab, 219877B) and improved one more orbit (HD 139461). The composite-spectrum system HD 157358Aab was resolved by speckle-interferometry, and its preliminary combined orbit was computed to guide future interferometric observations. A tentative 21-day orbit for HD 219877A based on published velocities is computed.

Key words. binaries: spectroscopic – binaries: visual – techniques: radial velocities – stars: binaries: general

1. Introduction

Our knowledge of the multiplicity of nearby stars is still incomplete. To improve it, a program of radial-velocity (RV) observations of the components of visual multiples was conducted in 1994-2000, as summarized by Tokovinin & Smekhov (2002, TS2002). Some spectroscopic sub-systems discovered in the course of this work still had undetermined orbits because of their long periods and/or a lack of sufficient data. A subset of these stars was observed by N.A.G during 2001–2006. Here we derive 3 new orbits for these spectroscopic components.

Some orbits published by us previously (e.g. Tokovinin & Gorynya 2001, Paper IV) were only preliminary. For example, it remained unknown how high the eccentricity of HD 139461 actually is, while a provisional value $e = 0.9$ was adopted. Here we give an improved orbit for this star and show that $e = 0.835 \pm 0.006$. The 9.4-yr subsystem in the intriguing spectroscopic triple HD 27368 B with a massive yet invisible tertiary also required more observations. Our new data from 2001–2005 are now merged by Torres (2006) with a comparable number of his own observations in a definitive orbital solution.

The observational technique, data reduction, and the method of orbit calculation have been described in the previous papers of this series e.g. in Paper IV (see also the references in TS2002). The new observations were made in 2001–2006 with the 1-m telescope of the Simeis Observatory in Crimea. The results of this study are incorporated into the current version of the Multiple Star Catalogue (Tokovinin 1997b; see also the online version[1]).

* Table 4 is 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/465/257

[1] http://wwww.ctio.noao.edu/~atokovin/stars

Table 1. Object identification.

WDS (2000)	ADS	HD	HIP	HR
10433 + 0443	7902	92841	52452	4193
15387 − 0848	9728	139461	76603	5816A
17215 + 2845	–	157358	84934	6466
23194 − 0507	16676	219877	115142	8868

2. Basic data

Table 1 contains the identifications for the four systems: WDS (2000) index, ADS number (Aitken 1932), HD number, Hipparcos number (ESA 1997), and HR number (Hoffleit & Jaschek 1991). The two visual components of HR 5816 have separate HD and HIP numbers, so only the A-component is discussed here.

Basic data on the components (spectral types, visual magnitudes, and $B-V$ colors) are given in the left columns of Table 2 and were collected from the literature or from SIMBAD, as discussed below. Precise combined magnitudes and colors are taken from Kornilov et al. (1991), and the proper motions and trigonometric parallaxes from the Hipparcos catalogue (ESA 1997). The last four columns of Table 2 summarize the results of our study and contain the mean radial velocities, the number of measurements, the mean equivalent width EW of the cross-correlation (CC) dip, and the projected axial rotational velocities $V \sin i$, as found from the width of CC dip. The method of $V \sin i$ determination and the dependence of EW on $B-V$ color and metallicity are described in Tokovinin (1990, 1997a).

Table 2. Basic observational data.

HD HR	Comp.	Sp. type	V	$B-V$	μ_α mas/y	μ_δ mas/y	$\pi_{\rm HIP}$ mas	V_r km s^{-1}	$N_{\rm obs}$	EW km s^{-1}	$V \sin i$ km s^{-1}
92841	A	K3III	6.11	1.23	20	−33	4.7 ± 1.1	−3.39 ± 0.10	18	4.90 ± 0.05	3.8 ± 0.3
4193	B	K0III	7.15	0.96	24	−22		−2.30 ± 0.23	17	3.80 ± 0.05	3.6 ± 0.5
157358	AB	G0III	6.39	0.73	12	1	6.1 ± 0.8	−0.43 ± 0.18	33	2.29 ± 0.02	2.8 ± 0.5
6466	B		9.53	0.60	–	–					
219877	AB	F3IV-V	5.56	0.40	201	−20	28.7 ± 0.8	−5.3 ± 1.4			
8868	B		10.92	1.37	199	−14		−7.17 ± 0.35	25	2.05 ± 0.10	5.5 ± 1.3

Table 3. Elements of spectroscopic orbits and their errors.

HD HR	Comp.	P days	T JDH	e	ω °	K_1 km s^{-1}	γ km s^{-1}	N σ_V	$f(m)$ $M_\odot$
92841	B	1568.7	51911	0.388	311.8	5.55	−2.30	23	0.0217
4193	B	±2.2	27	0.057	3.3	0.15	0.23	0.29	0.0014
139461		844.74	51020.76	0.835	107.0	10.48	−1.26	29	0.0168
5816	A	±0.34	1.14	0.006	1.7	0.20	0.10	0.50	0.0011
157358	Aab	2330.0	51860.9	0.596	329.9	14.67	−0.43	33	0.394
6466	Aab	±8.2	7.8	0.026	4.5	1.01	0.18	0.31	0.053
219877	A	21.2371	22478.56	0.60	314	42.7	−5.3	20	0.088
8868	A	0.0020	0.38	*	7	3.6	1.4	4.45	–
219877	B	659.9	51429.1	0.70	59.3	8.49	−7.17	25	0.0152
8868	B	±3.6	7.2	*	10.6	1.05	0.35	1.44	–

Table 4. Models of multiple systems.

HD π, mas m-M	Comp.	V	$B-V$	Sp. type	Mass, $M_\odot$	Sys.	Type	Period	Sep. ″
92841	A	6.11	1.23	K3III	2.45	AB	CPM	23000 y	6.80
4.7	Ba	7.15	0.96	K0III	2.44	Bab	SB1	1580 d	0.021
6.64	Bb				>0.6				
157358	Aa	6.99	1.04	K0III	1.77	AB	v	470 y	0.72
7.1	Ab	7.49	0.40	F3IV	1.76	Aab	V,SB1	6.37 y	0.037
5.7	B	9.40	0.50	F7V	1.25				
219877	Aa	5.57	0.39	F3V	1.5	AB	CPM	4400 y	9.8
28.7	Ab				>0.76	Aab	SB1	21 d	0.006
2.71	Ba	10.92	1.37	M3V	0.40	Bab	SB1	660 d	0.045
	Bb				>0.15				

3. Spectroscopic orbits and system parameters

The elements of single-lined spectroscopic orbital solutions are given in Table 3, together with the number of individual observations $N_{\rm obs}$ and the error of unit weight σ_V. An asterisk is used to mark an unfitted element. The last column contains the mass functions. Individual observations, their errors, and residuals can be found in Table 4, available only in electronic form at the CDS. It also contains the measurements of non-variable components. A few measurements rejected in orbit computations are marked by colons.

As in Papers I–IV, the best guess of the component's parameters ("models") is given in Table 5, as explained in Tokovinin (1997a,b). The parameters that have not actually been measured, e.g. masses, are adopted by fitting absolute magnitudes and colors to the standard relations for main-sequence stars or to the evolutionary tracks. The periods of wide sub-systems are estimated very roughly from their apparent separations. Each multiple system is discussed individually below.

Table 5. Interferometric observations and residuals of HR 6466Aab = CHR 194.

Epoch	θ, °	ρ, mas	$\Delta\theta$, °	$\Delta\rho$, mas	Ref.
1991.3247	120.2	52	3.1	2	[1]
1992.3104	130.1	52	−2.2	0	[1]
1998.7766	130.8	45	−2.8	−6	[2]

References: [1] Hartkopf et al. (1994); [2] Balega et al. (2002).

4. Discussion of individual systems

HD 23841 = HR 4193. This pair of giant stars STF 1466 at 6.″8 separation has been known since 1822 and the relative position of the two stars has not changed since then. The system is undoubtedly physical. The component B has a higher temperature according to both the spectral classification and the Tycho photometry (ESA 1997) given in Table 2. The combined Tycho magnitudes $(V, B-V) = (5.755, 1.149)$ are in good

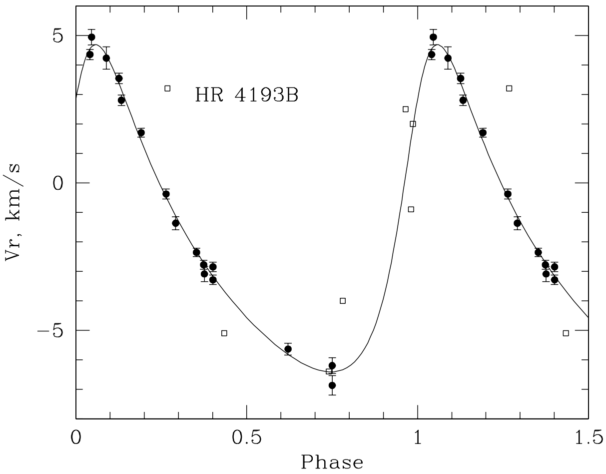

Fig. 1. Radial velocity curve of HD 92841B = HR 4193B. Circles with error bars – our data, squares – historical data from Abt (1970) and Plaskett et al. (1921).

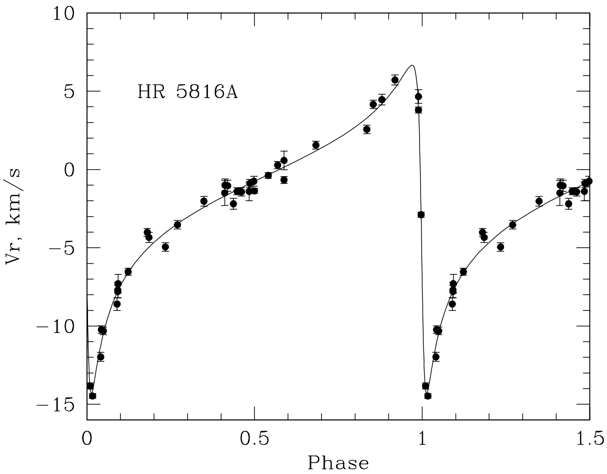

Fig. 2. Radial velocity curve of HD 139641 = HR 5816A.

agreement with the $(V, B-V) = (5.790, 1.195)$ measured by Kornilov et al. (1991). Double stars where both components are giants are rare and provide useful constraints on stellar evolutionary models. Griffin (1986) made this point and indicated HR 4193 as one such system. The masses of the components are estimated by fitting the photometry to the 0.6 Gyr isochrone of Girardi et al. (2000), but some ambiguity remains in this fit.

The A-component is flagged as a radial-velocity (RV) variable in the Bright Star Catalogue (Hoffleit & Jaschek 1991). Our observations show that in fact A is constant and B variable. The light of components was mixed in the slit under bad seeing conditions, but our orbit (Fig. 1) is well defined, despite this difficulty, with 2.8 cycles covered. To improve the period, we included old observations of HR 4193B with low weight – 4 made at Mt. Wilson (Abt 1970) and 3 made at DAO (Plaskett et al. 1921). The minimum mass of Bb is 0.58 $M_\odot$. The magnitude difference between Ba and Bb will be large and, despite the expected separation of 20 mas, the system will be difficult to resolve by interferometry.

HD 139461 = HR 5816A. This multiple system was introduced in Paper IV, so we do not discuss the component parameters and models here. The high and still undetermined eccentricity suggested that the spectroscopic binary is worth further observation. If the eccentricity were very close to 1, this object would be astrophysically interesting like the 41 Dra system (Tokovinin et al. 2003).

Highly-eccentric orbits present an observational challenge and require careful planning and patience extended over several years. The periastron passage in May 2003 was missed because of bad weather. At the next periastron passage in November 2005, the object was supposed to be invisible behind the Sun, with the next periastron only in 2008. Fortunately, the 2005 periastron occurred earlier than predicted by the preliminary orbit and was actually observed in September 2005 when the star was visible very low above the horizon in the evening dusk. This effort resulted in the now definitive orbit with an eccentricity of 0.835 ± 0.006 (Fig. 2).

HD 157358 = HR 6466. The primary component A is a giant paired to a fainter star B at 0.″7, KUI 80. In 1991 the primary was resolved by speckle interferometry into a closer 0.″05 pair CHR 194. The relative photometry of all 3 resolved components is provided by Balega et al. (2002). The photometry of the Aab-B pair by Fabricius & Makarov (2000) (quoted for B in Table 2) does not match the combined photometry of Kornilov et al. (1991), with colors $0.1^{\rm m}$ too red, hence the $B-V$ color of B is probably 0.50 rather than 0.60. Individual V-magnitudes matching the ΔV by Balega et al. are given in Table 5. The magnitude difference between Aab and B is $\Delta V = 2.94$, in accord with ΔHp = 2.99 measured by Hipparcos.

Christie (1924) announced that this star is a spectroscopic binary. His data show a large scatter and offset compared to the modern RV measurements, so they could not be used for the period refinement. The two CORAVEL measurements published by de Medeiros & Mayor (1999) help to improve the period and are included in our orbital solution. These authors measure $V \sin i < 1$ km s^{-1}. The RV data cover more than 3 orbits.

CHR 194 has not been observed systematically by speckle interferometry; only 3 measurements have been published (Hartkopf et al. 1994; Balega et al. 2002). It is evident that the spectroscopic binary and CHR 194 are one and the same system, so we included the speckle points in the combined speckle-spectroscopic solution that gives a rough idea of the "visual" elements: $a = 37.3 \pm 1.6$ mas, $\Omega = 330° \pm 5°$, $i = 50° \pm 10°$. The orbital ellipse with 3 points is shown in Fig. 3. While the inclination is determined with a very large error, the semi-major axis is well-defined. When we combine it with the estimated component masses, the dynamical parallax $\pi_{\rm dyn} = 7.1$ mas results. We prefer this estimate over the less precise Hipparcos parallax $\pi_{\rm HIP} = 6.1 \pm 0.8$ mas, very likely biased by the unmodeled orbital motion of Aab.

In order to get the model given in Table 5, we have to assign individual $B-V$ colors to each component so as to match the combined color and to put them on a plausible isochrone. The result of this guesswork is reflected in Fig. 4 and matches the combined photometry of Kornilov et al. (1991) perfectly. The known dependence of the correlation profile on the color and this model predict $EW = 2.4$ km s^{-1}, close to the observed 2.3 km s^{-1}. The estimated component masses depend on the adopted age, assumed here to be 1.6 Gyr. If future resolved multi-color photometry of Aab confirms this model, it will mean that the masses of Aa and Ab are very similar and that the system is undergoing a rare and rapid evolutionary phase. Observations of this system with long-baseline optical interferometers may provide a valuable test of stellar evolution models.

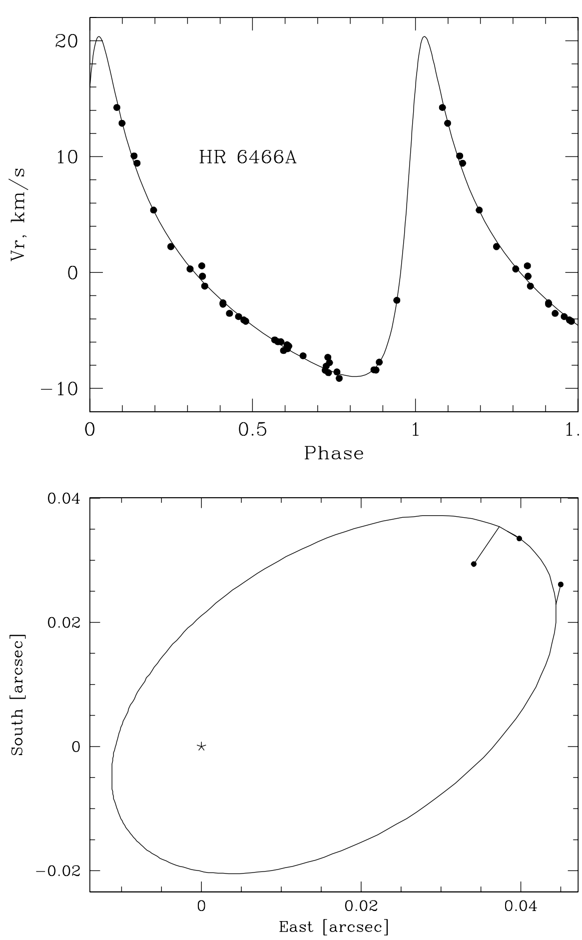

Fig. 3. Spectroscopic (*top*) and visual (*below*) orbits of HD 157358Aab = HR 6466Aab.

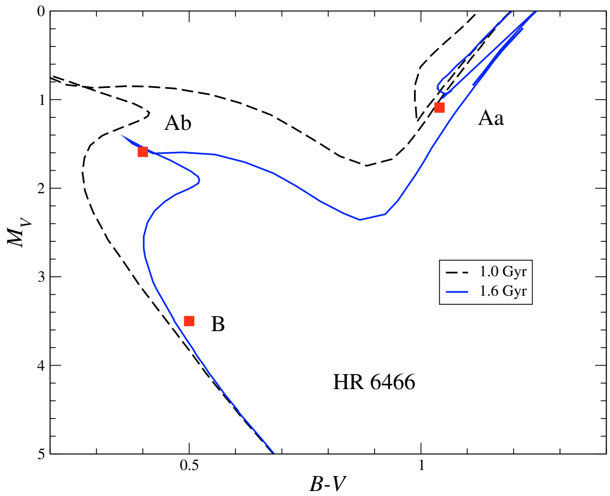

Fig. 4. Likely position of the components of HD 157358 = HR 6466 on the isochrones of Girardi et al. (2000).

HD 219877 = HR 8868. The nearby 10″ wide pair HJ 5394 is physical, with both components sharing the large proper motion of 0.″2/yr. The photometry of B in Table 2 is by Eggen (1966). Both components are on the main sequence, thus the age is no more than 1 Gyr.

The spectroscopic binary nature of the component A was discovered at Mt. Wilson by Adams et al. (1924). These 10

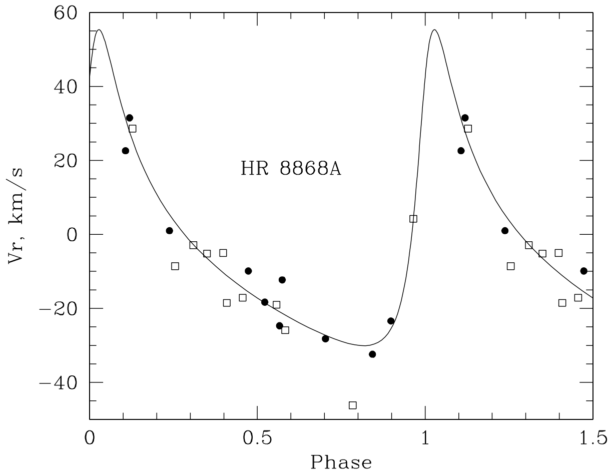

Fig. 5. Radial velocity curve of HR 8868A corresponding to the 21-day period. The radial velocities from Mt. Wilson (Abt 1973) are plotted as filled circles, those by Albitsky & Shain (1933) as empty squares.

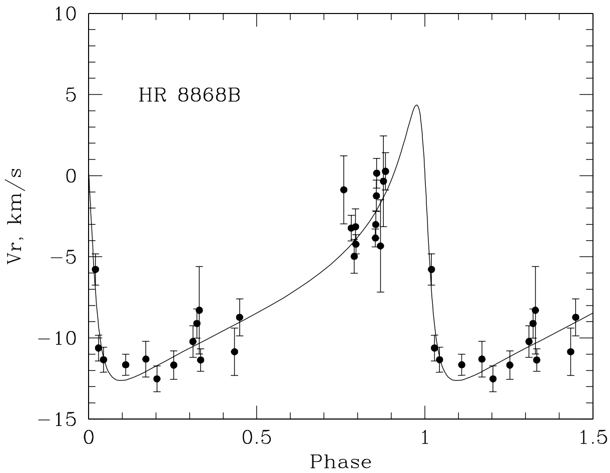

Fig. 6. Radial velocity curve of HR 8868B.

observations were published by Abt (1973). An additional 11 measurements confirming the RV variability were announced by Shain & Albitsky (1932) and published by Albitsky & Shain (1933). The spectral type F3 is too early for radial-velocity spectrometers like CORAVEL, so Nordström et al. (2004) do not provide new RVs for the component A. It is regrettable that there are so few observations of this 5^{m} star after 80 yr.

Following the referee's suggestion, we searched for a possible period in the available data and found that they can be represented by a 21-day orbit (Table 3 and Fig. 5). The eccentricity was fixed, we can only state that $e > 0.4$. One deviant point from Albitsky & Shain (1933) with $RV = -46.2\,\mathrm{km\,s^{-1}}$ was rejected. An alternative orbital solution with $P = 1.046$ d (alias of the 21-day period), $e = 0.62$, and $K_1 = 42.8\,\mathrm{km\,s^{-1}}$ fits the data even better, $\sigma_V = 3.8\,\mathrm{km\,s^{-1}}$. However, no other binaries with such short periods and high e are known. The minimum distance between the companions at periastron is only 1.8 solar radii, so tidal forces should have circularized this orbit rapidly. For this reason we believe that our tentative 21-day orbit is more likely.

The faint secondary B turned out to have a variable RV (TS2002). However, this is a very difficult object. The wings of the bright primary component image impede measurements under mediocre seeing. Moreover, the star is close to the ecliptic, and the background from bright Moon can occasionally distort the correlation profiles (we checked Moon's positions and phases and rejected some points). For these reasons, the orbit computed here should be considered only as tentative. The eccentricity was fixed in order to get a convergent fit.

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