

SPECKLE INTERFEROMETRY AND ORBITS OF “FAST” VISUAL BINARIES

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ABSTRACT

Results of speckle observations at the 4.1 m SOAR telescope in 2012 (158 measures of 121 systems, 27 non-resolutions) are reported. The aim is to follow fast orbital motion of recently discovered or neglected close binaries and sub-systems. Here, eight previously known orbits are defined better, two more are completely revised, and five orbits are computed for the first time. Using differential photometry from *Hipparcos* or speckle and the standard relation between mass and absolute magnitude, the component’s masses and dynamical parallaxes are estimated for all 15 systems with new or updated orbits. Two astrometric binaries HIP 54214 and 56245 are resolved here for the first time, another eight are measured. We highlight several unresolved pairs that may actually be single despite multiple historic measures, such as 104 Tau and f Pup AB. Continued monitoring is needed to understand those enigmatic cases.

Key words: binaries: general – techniques: interferometric

Online-only material: machine-readable and VO table

1. INTRODUCTION

Close binaries with fast orbital motion resolved by speckle interferometry and adaptive optics require frequent measures to compute their orbits. This shifts the main problem of visual orbits from insufficiently long time coverage, as typical for binaries studied in the past two centuries, to sparse time sampling. Many close pairs discovered by W. S. Finsen in the 1960s have completed several revolutions, but their orbits still remain undetermined for the lack of data. This is also true for speckle and *Hipparcos* binaries discovered in the 1980s and 1990s but not followed further. We try to address this issue here by re-visiting close pairs recently resolved and other binaries in need of follow-up.

Knowledge of binary-star orbits is of fundamental value to many areas of astronomy. They provide direct measurements of stellar masses and distances, inform us on the processes of star formation through statistics of orbital elements, and allow dynamical studies of multiple stellar systems, circumstellar matter (Kennedy et al. 2012), and planets (Roberts et al. 2011). A large fraction of visual binaries are late-type stars within 100 pc amenable to search of exoplanets. The current orbit catalog contains some poor or wrong orbital solutions based on insufficient data. The only way to improve the situation is by getting new measures and revising those orbits.

Data on binary-star measures and orbits are collected by the Washington Double Star (WDS) Catalog (Mason et al. 2001)¹ and associated archives such as the Fourth Catalog of Interferometric Measurements of Binary Stars, INT4,² and the Sixth Orbit Catalog of Orbits of Visual Binary Stars, VB6 (Hartkopf et al. 2001).³ These resources are extensively used here.

This paper continues series of speckle interferometry observations published by Tokovinin et al. (2010b, hereafter TMH10), Tokovinin et al. (2010a, hereafter SAM09), and Hartkopf et al. (2012, HTM12). We used same equipment and data reduction methods.

Section 2 recalls the observing technique and presents new measures and non-resolutions. Updated and new orbits for 15 systems are given in Section 3, with estimates of masses and dynamical parallaxes and brief comments on each system. In Section 4, we draw attention to two particular groups: resolved pairs with astrometric accelerations and unresolved binaries which are either false discoveries or enigmatic. Section 5 summarizes the results.

2. NEW SPECKLE MEASURES

2.1. Instrument and Observing Method

The observations reported here were obtained with the high-resolution camera (HRCam)—a fast imager designed to work at the 4.1 m SOAR telescope, either with the SOAR Adaptive Module (SAM; Tokovinin et al. 2008) or as a stand-alone instrument. The HRCam is described by Tokovinin & Cantarutti (2008). The first series of measurements in THM10 used HRCam installed at the infrared port of SOAR. In 2009, the HRCam worked at SAM during its first-light tests and produced some binary-star measures published in SAM09. It was further used in this mode in HTM12 and here.

The HRCam receives light through the SAM instrument, including its deformable mirror. However, the adaptive optics system was not compensating for turbulence during these observations. It was tuned for the ultraviolet laser guide star, while all visible light was sent to HRCam. The atmospheric dispersion was compensated by two rotating prisms inside SAM. The filter transmission curves are given in the instrument manual.⁴ We used mostly the Strömrgren y filter (543/22 nm) and the near-infrared I filter.

The pixel scale of HRCam is 15.23 mas. Observation of an object consists in accumulation of 400 frames of 200×200 pixels, each with an exposure time of 20 ms or shorter. Frames of 400×400 pixels were recorded for pairs with separation larger than $1''.5$. Each object was recorded twice and these two image cubes were processed independently.

¹ See current version at <http://ad.usno.navy.mil/wds/>.

² <http://ad.usno.navy.mil/wds/int4.html>

³ <http://ad.usno.navy.mil/wds/orb6.html>

⁴ <http://www.ctio.noao.edu/new/Telescopes/SOAR/Instruments/SAM/archive/hrcaminst.pdf>

Table 1
Measurements of Binary Stars at SOAR

WDS (2000)	Discoverer Designation	Other Name	Epoch +2000	Filter	N	θ (deg)	$\rho\sigma_\theta$ (mas)	ρ ($''$)	σ_ρ (mas)	Δm (mag)	$[O-C]_\theta$ (deg)	$[O-C]_\rho$ ($''$)	Reference VB6 Code
06003–3102	HU 1399 AB	HIP 28442	11.9353	y	2	113.5	0.4	0.6945	0.3	1.2	–1.5	0.014	Tok2005
06359–3605	FIN 19 Aa,Ab	HIP 31509	11.9353	y	2	351.5	0.1	0.2824	0.1	1.3	0.8	–0.001	Hrt2011d
			12.1839	y	2	350.3	0.0	0.2887	0.3	1.2	0.2	0.000	Hrt2011d
06359–3605	RST 4816 Ba,Bb	HIP 31547	11.9353	y	2	139.0	0.1	0.1791	0.1	0.8	33.5	–0.180	*Cve2008b
			12.1839	y	2	136.4	0.0	0.1849	0.1	0.7	31.3	–0.169	*Cve2008b
07187–2457	FIN 313 Aa,Ab	HIP 35415	11.9353	y	2	128.8	1.4	0.1181	2.0	0.9			
07187–2457	TOK 42 Aa,E	HIP 35415	11.9353	y	2	88.1	1.2	0.9454	0.4	4.4			
07294–1500	STF 1104 AB	HIP 36395	11.9353	y	2	34.4	0.6	1.8309	0.4	1.3 *	–1.8	0.200	WSI2004a
07374–3458	FIN 324 AC	HIP 37096	11.9353	y	2	317.5	0.0	0.1740	0.2	1.6	1.5	–0.000	Hrt2012a
			11.9353	H α	2	317.6	0.2	0.1742	0.6	1.8	1.6	0.000	Hrt2012a

(This table is available in its entirety in machine-readable and Virtual Observatory (VO) forms in the online journal. A portion is shown here for guidance regarding its form and content.)

Parameters of resolved binary and triple systems are determined by fitting a model to the power spectrum, as explained in [TMH10](#).

Speckle interferometry of binary stars was carried out serendipitously during five engineering runs of the SAM instrument, from 2011 December to 2012 May. These observations used short time periods where the SAM engineering could not be pursued either for technical reasons (hardware failures) or for poor observing conditions (transparent clouds, bad seeing). Cumulative time used by these observations is about one night.

We calibrated the transfer optics of the SAM instrument by imaging a single-mode fiber at the telescope focus. The fiber was translated by a micrometer stage, allowing us to accurately determine detector orientation relative to the instrument frame and the physical pixel scale in microns. We rely on the SOAR telescope pointing model and its mechanics to ensure correct orientation of the SAM focal plane on the sky (which, however, was not checked independently here) and constant scale. Therefore, we refer the position angle to the telescope and use the same pixel scale as in [TMH10](#) and [HTM12](#). Observations of control wide binaries indicate that there are no detectable calibration errors at the level of $<1\%$ in separation and 1° in angle. If, in the future, the orbital motion of those wide binaries becomes known with a high accuracy, then the present data can be re-calibrated post factum.

2.2. Data Tables

Table 1 lists 158 measures of 121 resolved binary stars and sub-systems, including two new pairs. Its columns contain (1) the WDS designation, (2) the “discoverer designation” as adopted in the WDS, (3) an alternative name, mostly from the *Hipparcos* catalog, (4) Besselian epoch of observation, (5) filter, (6) number of individual data cubes, (7 and 8) position angle θ in degrees (not precessed) and internal measurement error in tangential direction $\rho\sigma_\theta$ in mas, (9 and 10) separation ρ in arcseconds and its internal error σ_ρ in mas, and (11) magnitude difference Δm . An asterisk follows the value if Δm and the true quadrant are determined from the resolved long-exposure image; a colon indicates that the data are noisy and Δm is likely overestimated (see [TMH10](#) for details). Note that in the cases of multiple stars, the positions and photometry refer to the pairings between individual stars, not with photocenters of sub-systems.

For stars with known orbital elements, Columns 12–14 of Table 1 list the residuals to the ephemeris position and the code

of reference to the orbit adopted in VB6.⁵ References to the orbits revised here are preceded by asterisk; large residuals to those orbits show why the revisions were needed.

Table 2 contains the data on 27 unresolved stars, some of which are listed as binaries in the WDS or resolved here in other filters. Columns 1–6 are the same as in Table 1, although Column 2 also includes other names for objects without discoverer designations. Columns 7 and 8 give the 5σ detection limits Δm_5 at $0''.15$ and $1''$ separations determined by the procedure described in [TMH10](#). When two or more data cubes are processed, the best detection limits are listed.

2.3. New Pairs

11056–1105 = HIP 54214. Gontcharov et al. (2000) discovered photocenter motion with a 30 yr period and a large amplitude of $0''.2$, but did not derive the full set of orbital elements. The faint companion at $0''.6$ and 60° is resolved here in the *I* band, but not in *y* ($\Delta y > 6^m$). Its position angle roughly matches the plots of that paper. This is an F0V star with fast axial rotation and the *Hipparcos-2* (van Leeuwen 2007) parallax $\pi_{\text{HIP}} = 16.75 \pm 0.34$ mas. The projected separation of 35 AU and the 30 yr period hint at a large mass sum. Gontcharov et al. (2000) suggested that the actual parallax is about 18 mas and that the astrometric companion is massive. Yearly observations will be ideal to follow this interesting system.

11318–2047 = HIP 56245 = HR 440. A new faint companion at $1''.05$ is found here. This is a $\Delta\mu$ astrometric binary according to Makarov & Kaplan (2005), spectral type F8V, $\pi_{\text{HIP}} = 25.98 \pm 0.34$ mas. The projected separation of 40 AU implies an orbital period on the order of ~ 200 yr. The companion with $\Delta I = 4.9$ must be brighter in the *K* band, but it was not detected by Boden et al. (2005) when this star served as a calibrator for interferometry.

3. UPDATED AND NEW ORBITS

In this section, we derive corrected or first orbits for some pairs observed here. Although calculation of orbital elements is accessible to anyone with a computer, it is still a challenging task when the measures are scarce and their interpretation is ambiguous (erroneous measures or quadrant flips). Additional help is provided by the availability of *Hipparcos* parallaxes, allowing us to reject tentative orbits with improbably large

⁵ See <http://ad.usno.navy.mil/wds/orb6/wdsref.html>.

Table 2
Unresolved Stars

WDS (2000)	Discoverer Designation or Other name	HIP	Epoch +2000	Filter	<i>N</i>	5σ Detection Limit	
						$\Delta m(0'.15)$ (mag)	$\Delta m(1'')$ (mag)
05074+1839	A 3010	HIP 23835	12.0253	H α	1	3.82	4.51
			12.0253	y	1	4.91	6.20
			12.0253	V	1	4.62	5.56
07383–2522	B 731	HIP 37173	11.9353	y	2	5.01	6.85
07522–4035	TOK 195	HIP 38414	11.9354	y	2	4.83	6.95
08095–4720	TOK 2 Aa,Ab	HIP 39953	12.1019	y	4	5.17	6.98
09024–6624	TOK 197	HIP 44382	12.1020	y	2	4.93	6.49
09380–5924	HIP 47263	HIP 47263	12.0285	y	2	4.69	5.17
09416–3830	TOK 198	HIP 47543	12.0285	y	1	4.57	5.08
11056–1105	New	HIP 54214	12.1024	y	2	4.98	6.66
11126–4906	HIP 54746	HIP 54746	12.1842	y	2	4.79	6.70
			12.1842	<i>I</i>	2	4.04	5.72
11154–5249	HIP 54977	HIP 54977	12.1842	y	2	4.02	4.75
			12.1842	<i>I</i>	2	3.09	4.60
11234–1847	HIP 55598	HIP 55598	12.1023	<i>I</i>	2	3.85	5.56
11317+1422	WSI 9107 Aa,Ab	HIP 56242	12.1840	y	2	5.00	6.15
13069–3407	HIP 64006	HIP 64006	12.1842	<i>I</i>	2	3.97	5.73
13143–5906	HIP 64583	HIP 64583	12.1024	y	2	5.22	6.67
			12.1024	<i>I</i>	2	3.79	6.12
13526–1843	WSI 78	HIP 67744	12.1843	y	2	4.74	5.66
15168–1302	CHR 44	HIP 74765	12.1845	y	2	4.64	5.54
			12.1845	<i>I</i>	1	3.87	5.35
15384–1955	CHR 48	HIP 76582	12.3539	y	2	4.80	6.60
			12.3539	<i>I</i>	2	3.97	5.86
15355–1447	WRH 20 Aa,Ab	HIP 76333	12.1845	y	2	5.05	7.03
15453–5841	FIN 234 AB	HIP 77160	12.1844	y	2	4.19	4.76
15467–4314	I 1276	HIP 77282	12.1845	y	1	4.47	5.22
			12.1845	<i>I</i>	1	3.57	5.14
16057–3252	SEE 264C	HIP 78842	12.3539	y	1	3.31	3.63
			12.3539	<i>I</i>	1	3.99	5.22
16245–3734	B 868AB	HIP 80390	12.3539	y	2	5.02	7.10
16534–2025	WSI 86	HIP 82621	12.3540	y	2	5.11	7.25
16542–4150	CHR 252Aa,Ab	HIP 82691	12.3539	<i>I</i>	1	3.65	5.28
16544–3806	HDS2392	HIP 82709	12.3539	<i>I</i>	2	3.87	4.92
16571–1749	HIP 82956	HIP 82956	12.3540	y	2	4.78	6.30
			12.3540	<i>I</i>	2	4.06	5.89
17213–5107	HIP 84924	HIP 84924	12.3540	y	2	4.90	6.29
			12.3540	<i>I</i>	2	3.67	5.67

or small mass sums. On the other hand, motion in a visual orbit affects *Hipparcos* reductions and should be included in the astrometric solution whenever possible; otherwise, the parallax and proper motion can be biased (Shatskii & Tokovinin 1998; Soderhjelm 1999).

The focus here is on fast-moving pairs where new observations allow a substantial progress, as in [HTM12](#), where 42 orbits were computed. We refrain from correcting orbits with large current separations. Of the 15 orbits presented in [Table 3](#), 8 are corrections of prior orbits, 2 are drastic revisions, and 5 are new. Final orbital elements are obtained by least-squares fitting with weights inversely proportional to the squares of observational errors. The errors of visual measures are assumed to be 0'.05, speckle interferometry at 4 m telescopes is assigned errors of 2 mas, with few exceptions such as uncertain measures marked by colons in INT4 and obvious outliers. The much larger weight of speckle measures enforces their good fit to the orbit. For some preliminary orbits where the least-squares fits did not converge, we fixed one or more elements (marked by asterisk instead of formal error). Considering that errors of the input data do not obey the Gaussian statistics, formally derived errors of

orbital elements and goodness-of-fit criteria such as χ^2 should be taken with reservation, as order-of-magnitude estimates at best. [Table 3](#) also gives orbital grades in the system adopted by VB6 (1, definitive; 4, preliminary).

Figures 1–4 present orbits in the plane of the sky, in standard orientation (north up, east left) with a scale in arcseconds. The primary components at coordinate center are marked by large asterisks. The orbits are plotted in full lines, the prior orbits in dashed lines where appropriate. The measures (empty squares for visual, filled squares for speckle) are connected to their positions on the orbit. Non-resolutions are shown by connecting predicted positions of the secondary to the coordinate origin. Some dates of speckle measures are shown.

[Table 4](#) lists astrophysical parameters of pairs with new orbits. Columns 1 and 2 repeat the WDS and HIP identifies, and Column 3 lists the trigonometric parallax and its error from van Leeuwen (2007). The spectral type in Column 4 and combined visual magnitude *V* in Column 5 are taken from SIMBAD, the magnitude difference in the *Hipparcos* band ΔH_p in Column 6 is compared to Δy from speckle photometry in Column 7. When several measures of Δy are available, we

Table 3
New and Revised Orbital Elements

WDS (Figure)	Discoverer HIP	P (yr)	a (")	i (°)	Ω (°)	T_o (yr)	e	ω (°)	Gr	Published Orbit VB6 Reference
06359–3605 (1a)	RST 4816 Ba,Bb 31547	14.00 ± 0.04	0.1824 ± 0.0076	111.6 ± 1.5	289.7 ± 0.9	1990.036 ± 0.061	0.577 ± 0.031	296.1 ± 1.6	3	Cve2008b
07518–1354 (1b)	BU 101 38382	23.330 ± 0.010	0.6179 ± 0.0024	80.82 ± 0.06	282.65 ± 0.09	1985.923 ± 0.011	0.7647 ± 0.0021	253.64 ± 0.12	1	Pbx2000b
08270–5242 (1c)	B 1606 41426	14.778 ± 0.077	0.1496 ± 0.0062	59.5 ± 2.5	96.5 ± 2.5	1952.54 ± 0.46	0.337 ± 0.023	183.8 ± 8.1	2	Fin1963c
08345–3236 (1d)	FIN 335 42075	17.35 ± 0.05	0.1445 ± 0.0056	37.5 ± 4.5	100.1 ± 3.5	1997.00 ± 0.16	0.5564 ± 0.0099	217.2 ± 4.2	3	Sod1999
09173–6841 (1e)	FIN 363 AB 45571	3.4400 ± 0.0049	0.0894 ± 0.0014	140.2 ± 2.1	158.3 ± 3.1	2009.892 ± 0.020	0.4505 ± 0.0125	118.2 ± 3.5	2	Sod1999
11009–4030 (1f)	FIN 365 53840	27.09 ± 0.37	0.1523 ± 0.0047	105.1 ± 1.0	102.6 ± 1.5	1993.15 ± 0.31	0.188 ± 0.044	96.4 ± 6.0	4	Hrt2012a
11190+1416 (2a)	STF 1527 55254	415.0 ± 15.9	2.225 ± 0.045	55.6 ± 0.5	188.0 ± 0.5	2010.503 ± 0.042	0.8511 ± 0.0033	0.50 ± 0.59	3	Pru2009
11210–5429 (2b)	I 879 55425	39.00 ± 0.19	0.2263 ± 0.0011	19.4 ± 4.9	327.8 ± 3.9	2010.410 ± 0.037	0.8530 ± 0.0040	340.3 ± 4.0	2	Msn1999a
12357–1650 (2c)	FIN 368 Aa,Ab 61463	20.07 ± 0.10	0.1416 ± 0.0009	100.5 ± 0.8	116.4 ± 0.6	1985.52 ± 0.09	0.33 *	260.0 *	4	First orbit
13106–3128 (2d)	RST 1706 64292	91.0 *	0.463 ± 0.014	111.9 ± 1.0	63.4 ± 1.7	1999.66 ± 0.39	0.532 ± 0.0035	168.6 ± 2.6	4	First orbit
13129–5949 (2e)	HDS 1850 Aa,Ab 64478	31.60 ± 0.80	0.3136 ± 0.0070	90.0 *	278.8 ± 0.2	2005.26 ± 0.11	0.340 ± 0.016	50.0 *	5	First orbit
13169–3436 (2f)	I 1567 64804	41.07 ± 0.19	0.3292 ± 0.0017	120.2 ± 0.66	145.8 ± 0.5	2006.456 ± 0.042	0.4582 ± 0.0042	275.4 ± 0.8	2	Hei1986a
13513–2433 (3)	WSI 77 67620	10.485 ± 0.06	0.2827 ± 0.0014	96.4 ± 0.2	351.3 ± 0.3	2009.218 ± 0.028	0.3462 ± 0.0080	137.5 ± 1.4	2	First, combined
15088–4517 (4a)	SEE 219 AB 74117	70.8 ± 0.8	0.2597 ± 0.0021	71.59 ± 0.41	26.64 ± 0.61	1997.907 ± 0.105	0.6283 ± 0.0090	299.9 ± 1.1	2	Doc2007d
15339–1700 (4b)	HDS 2185 138648	60.0 *	0.5391 ± 0.0018	40.0 *	324.0 ± 1.0	2011.53 ± 0.02	0.3681 ± 0.0030	152.3 ± 1.0	5	First orbit

Table 4
Parameters of Orbital Pairs

WDS	HIP	π_{HIP} (mas)	Sp. Type	V (mag)	ΔHp (mag)	Δy (mag)	P (yr)	M_1 (M_{\odot})	M_2 (M_{\odot})	π_{dyn} (mas)
06359–3605	31547	25.39 \pm 0.43	G1V	7.23	0.83	0.8	14.0	1.08	0.80	25.5
07518–1354	38382	60.59 \pm 0.59	G0V	5.16	0.90	1.0	23.3	1.16	0.86	59.8
08270–5242	41426	18.50 \pm 0.44	F5V	6.50	0.87	1.0	14.8	1.61	1.28	17.5
08345–3236	42075	14.86 \pm 0.57	G5IV	6.43	0.38:	0.5	17.35	1.71	1.54	14.6
09173–6841	45571	30.64 \pm 0.70	F5V	5.40	1.37:	0.8	3.44	1.63	1.37	27.2
11009–4030	53840	15.42 \pm 0.42	F7V	6.79	...	0.3	27.1	1.75	1.65	11.2
11190+1416	55254	32.52 \pm 1.39	F9V	6.95	1.08	1.1	415	0.98	0.61	34.2
11210–5429	55425	9.12 \pm 0.34	B9V	3.90	1.49	1.5	39.0	6.43	3.68	9.1
12357–1650	61463	13.56 \pm 0.76	F3IV	6.70	3.10:	1.7	20.1	1.79	1.23	13.3
13106–3128	64292	19.27 \pm 1.23	K0V	9.10	1.93	1.9	91.0	0.90	0.71	19.6
13129–5949	64478	23.72 \pm 0.60	G0V	6.20	3.32	3.6	31.6	1.56	0.79	23.6
13169–3436	64804	23.18 \pm 1.10	G5V	8.06	1.00	1.1	41.1	0.96	0.84	22.7
13513–2433	67620	51.35 \pm 0.45	G5V	6.45	...	3.5	10.5	0.99	0.63	50.3
15088–4517	74117	4.20 \pm 0.66	B3V	4.04	0.80	0.8	70.8	8.14	5.84	6.3
15339–1700	76203	25.85 \pm 0.94	G9IV	8.14	1.74	1.8	60.0	0.90	0.72	29.9

select the best one (widest separation) and round it to the nearest 0^{th} 1.

The last four columns of Table 4 recall the orbital period P and give estimates of component masses M_1 and M_2 and the dynamical parallax π_{dyn} . Individual magnitudes of the components are computed from V and ΔHp . When the *Hipparcos* differential photometry is missing or considered unreliable (marked by colons), Δy is used instead. Masses of the components are found from the standard relation with absolute V magnitude (Lang 1992) using those magnitudes and the *Hipparcos*

distance modulus. Then, the dynamical parallax is computed from the mass sum and orbital elements P , a . With this parallax, the masses are estimated again and the process is iterated to convergence. These estimates of mass and parallax based on standard relations for main sequence stars should not be mistaken for direct measurements, but can be useful for statistics; no meaningful errors can be assigned. When the dynamical and *Hipparcos* parallaxes match and the mass estimates correspond to the spectral type, it is a good indication that the data are mutually consistent.

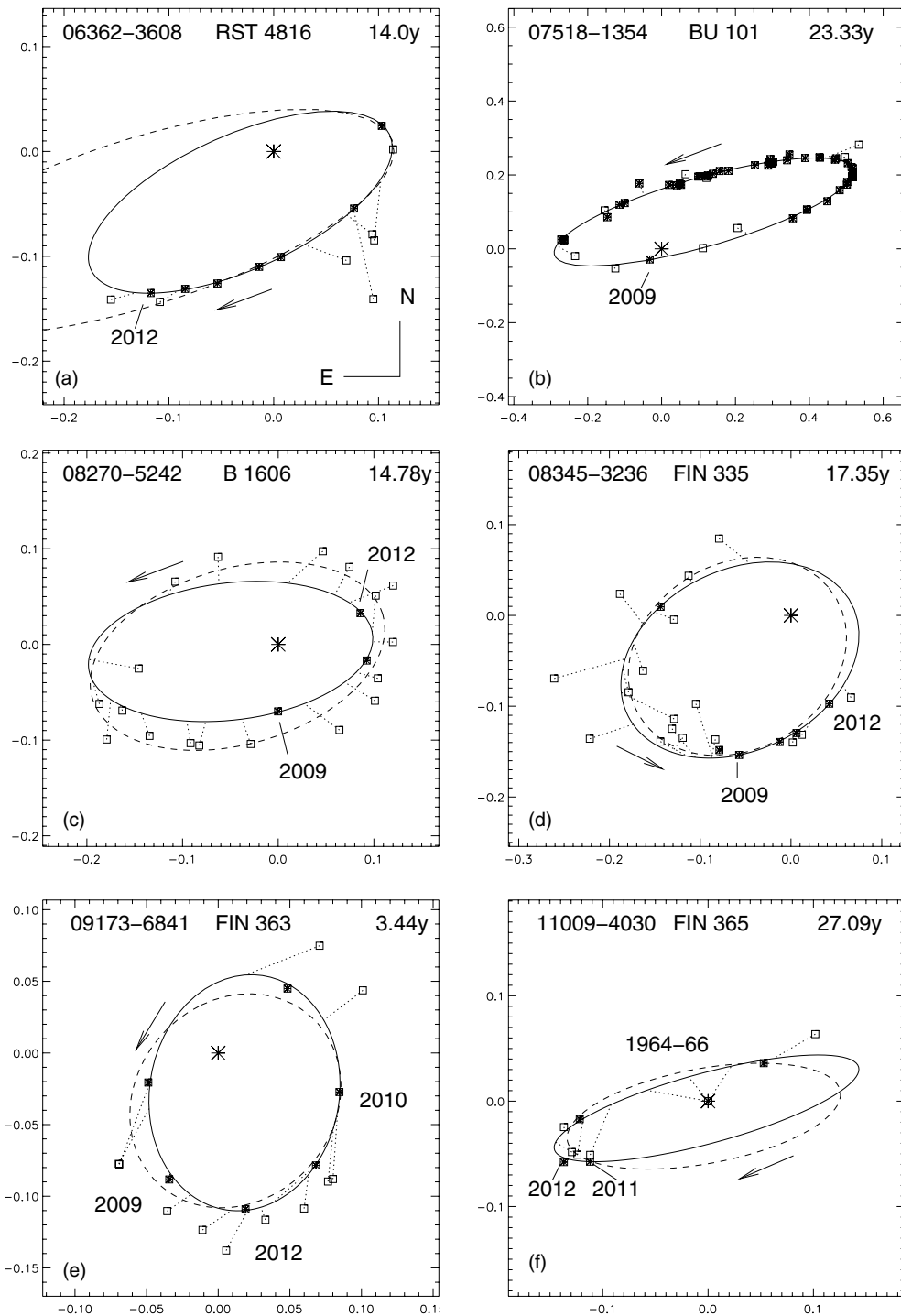


Figure 1. New orbits (I). See the text.

$06359-3605 = RST\ 4816\ Ba, Bb$. The new orbit with a 14 yr period is radically different from the 28.5 yr orbit of Cvetkovic (2008), but closer to the three solutions proposed by Branham (2009). A large part of the orbit remains unobserved. This pair forms a physical quadruple with another binary, HIP 31509 = FIN 19 Aa, Ab, also measured here.

$07518-1354 = BU\ 101$. This is a minor revision of the orbit by Pourbaix (2000) needed to reduce its large residual from our measure in 2009. Radial velocities (RVs) from the above paper were included in the combined orbital solution, but have little

influence on the final elements which are primarily constrained by speckle interferometry. The orbit is now extremely well defined.

$08270-5242 = B\ 1606$. The orbit by Finsen (1963) is revised here using the three available speckle measures, leading to a more accurate period and to the reduced orbit size. Systematic overestimation of the separation by Finsen's visual interferometry is apparent in Figure 1(c).

$08345-3236 = FIN\ 335$. We confirm and slightly correct the orbit by Soderhjelm (1999). The 17.35 yr period is very

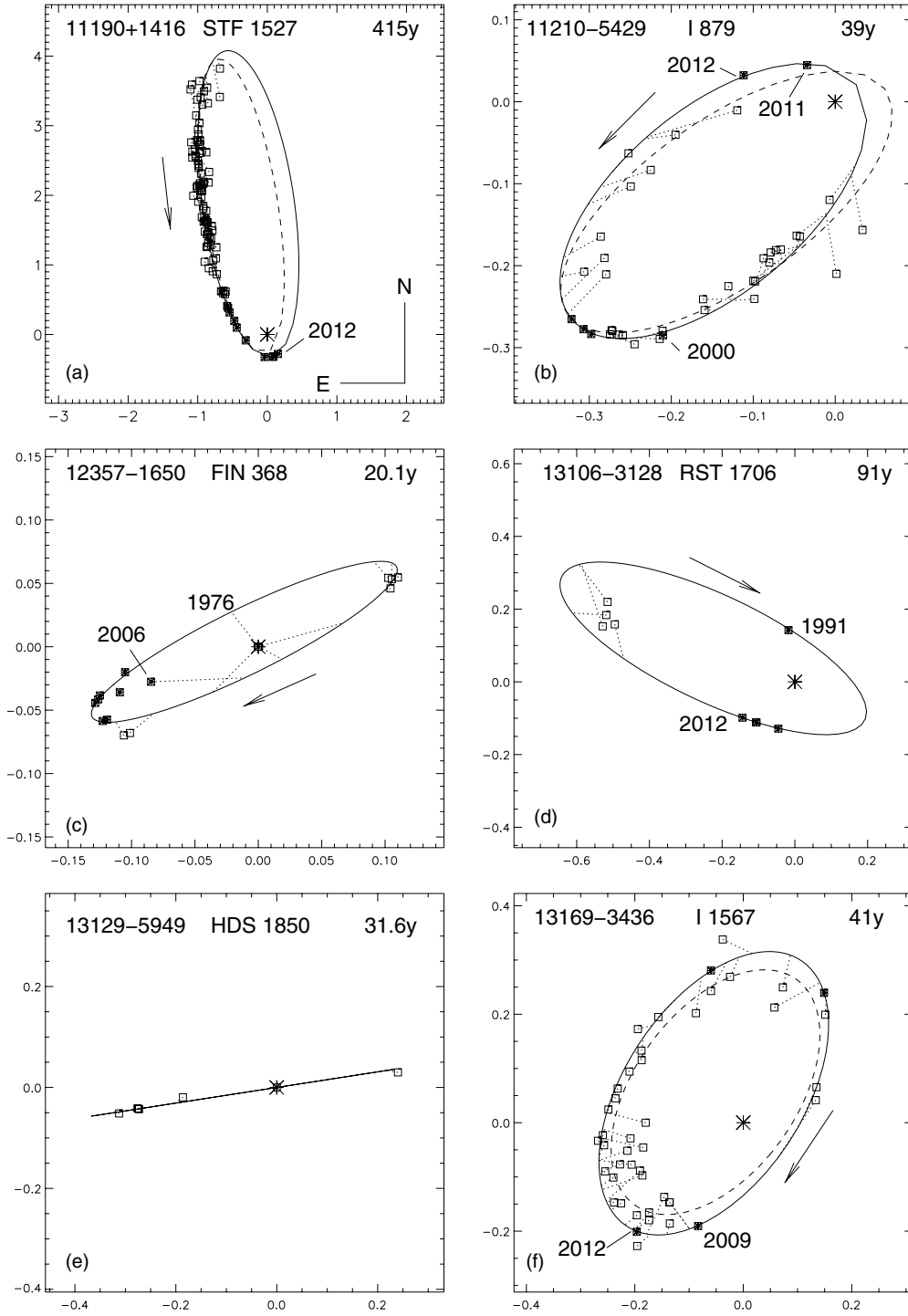


Figure 2. New orbits (II).

well defined now, but further coverage by speckle is still needed. The system is evolved, judging from its luminosity, estimated masses, and spectral type G5IV. The speckle Δy is very consistent and preferred to $\Delta H\beta$.

09173–6841 = FIN 363 AB has an unusually short period of only 3.44 yr. The *Hipparcos* photometry is doubtful because of close 0.1 separation.

11009–4030 = FIN 365. The latest measure contradicts the first orbit published in HTM12, which, in fact, predicts an unrealistically small mass sum. We propose here an alternative

orbit with retrograde motion that reproduces the non-resolutions by Finsen in 1963–1966 (Figure 1(f)) and corresponds to a reasonable mass sum. Double lines were noted by Nordström et al. (2004). The star appears to be evolved. The *Hipparcos* parallax could be affected by the orbital motion unaccounted for in its data reduction.

11190+1416 = STF 1527 has a long orbital period of 415 yr, but it moved fast through the periastron in 2009–2012, allowing us to compute a better orbit. The recent orbit revision by Scardia et al. (2011) with $P = 551$ yr is not yet included in VB6.

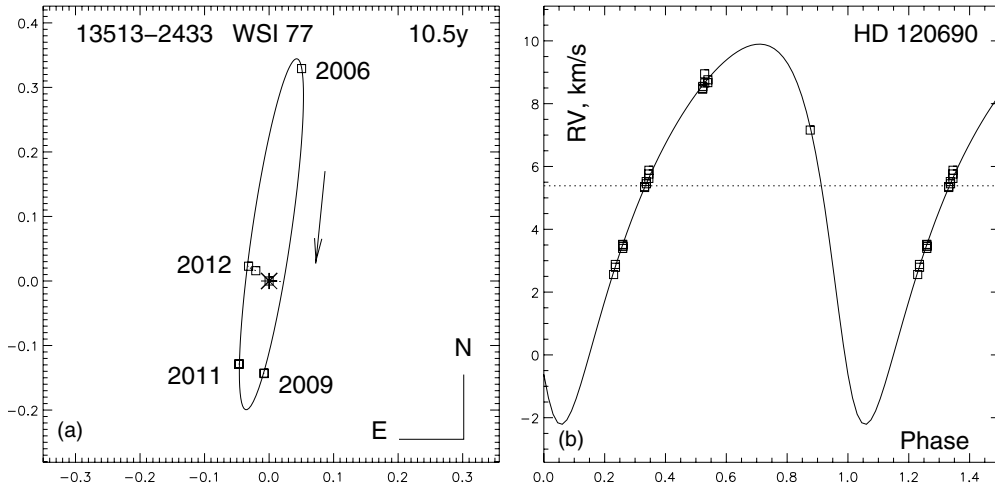


Figure 3. New orbits (III): the combined orbit of WSI 77 = HD 120690. Speckle measures are plotted on the left (a), radial velocities on the right (b).

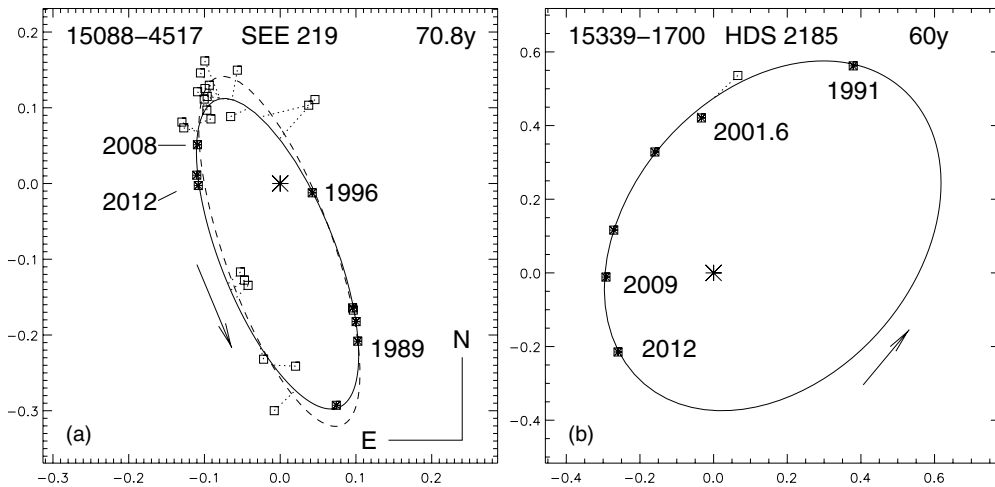


Figure 4. New orbits (IV).

11210–5429 = I 879 = π Cen. The orbit by Mason et al. (1999) had to be revised using our measures near the periastron. The high eccentricity $e = 0.853$ is now well established.

12357–1650 = FIN 368 Aa,Ab is the first orbit determination. Speckle measures of 1989–1991 and 2009–2011 repeat themselves, hinting at 20 yr period. However, the measure by Mason et al. in 2006.2 does not fall on the same ellipse and had to be ignored. It could refer to another star, as FIN 368 should have been unresolved at that time according to our preliminary orbit, which also matches the speckle non-resolution in 1976.3 and the non-resolutions in 1964–1966 by Finsen. An alternative orbit with $P = 10.13$ yr and $e = 0.9$ can also be fitted to the data. The *Hipparcos* measure on 1991.25 contradicts speckle interferometry on 1991.39; it had to be ignored. Nordström et al. (1997) noted double lines broadened by fast axial rotation of 100 km s^{-1} and 20 km s^{-1} . However, individual RVs measured by these authors during 1987–1991 (near the apastron) do not show any systematic behavior that could be related to the orbit. Continued speckle monitoring will be critical for confirming the orbit. The tertiary companion B at $11''.8$ is physical.

13106–3128 = RST 1706 is an example of a neglected binary discovered by R. A. Rossiter in 1934 but observed so rarely that only now, after a nearly full revolution, the first orbit could be proposed.

13129–5949 = HDS 1850 = HR 4980 has a tentative edge-on first orbit with $P = 31.6$ yr. This is a chromospherically active G0V dwarf and a *ROSAT* X-ray source. There are at least four components in the system: Aa1,Aa2 is a double-lined spectroscopic and eclipsing binary with a 4.2 day period, Aa,Ab is the pair considered here, and the visual companion B at $25''.5$ is physical. The orbits of Aa1,Aa2 and Aa,Ab may be coplanar.

13169–3436 = I 1567 has a well-established orbit by Heintz (1986), which is corrected here to better match the new speckle data. Heintz notes that this pair is a “puzzling case” because of some very discordant historical measures; these deviant points were omitted from Figure 2(f) and ignored in the calculation.

13513–2433 = WSI 77 = HD 120690 is a chromospherically active G5 dwarf within 20 pc from the Sun. According to Abt & Willmarth (2006), it is also a single-lined spectroscopic binary with a 10.3 yr period. We used RVs from that work and the average RV from Nidever et al. (2002) together with four speckle points for the combined orbital solution presented in Figure 3. The spectroscopic elements are $K_1 = 6.06 \pm 0.25 \text{ km s}^{-1}$ and $V_0 = 5.38 \pm 0.10 \text{ km s}^{-1}$, the rms residual in RV is 0.11 km s^{-1} . The node ω listed in Table 3 corresponds to the primary component, therefore Ω was chosen to describe the secondary’s relative motion. The pair was “caught” at close separation in 2012.

Table 5
Astrometric Binaries

WDS	HIP	Discoverer Code	ρ (")	ΔV (mag)	P (yr)	Comment
07456–3410	37853	TOK 193	0.310	4.0	10?	$\dot{\mu}$, $\Delta\mu$, SB
07490–2455	38146	TOK 194	0.051	1.7	2.4	Orbit (Goldin & Makarov 2007)
07522–4035	38414	TOK 195	0.044	1.0	7.0	Orbit (Jancart et al. 2005), SB1
09191–4128	45705	CHR 239	0.105	2.4	10?	$\dot{\mu}$, $\Delta\mu$
09275–5806	46388	CHR 240	0.039	0.3	4?	$\dot{\mu}$ in HIP2
09276–3500	46396	B 2215	0.034	1.5	1.97	Orbit (ESA 1997)
09416–3830	47543	...	...	...	?	$\dot{\mu}$ in HIP2
11056–1105	54214	New	0.592	5.4	30	Orbit (Gontcharov et al. 2000)
11234–1847	55598	...	...	...	?	$\dot{\mu}$, $\Delta\mu$, SB
11318–2047	56245	New	1.058	4.9	200?	$\Delta\mu$
13069–3407	64006	New?	0.025?	?	1?	Elongation? $\dot{\mu}$, $\Delta\mu$
13518–2423	67620	WSI 77	0.283	0.5	10.5	$\Delta\mu$, orbit here, SB1
16534–2025	82621	WSI 86	0.185	2.9	10?	$\dot{\mu}$, $\Delta\mu$
16571–1749	82956	...	...	...	?	$\dot{\mu}$, $\Delta\mu$, SB
17213–5107	84924	...	...	...	3.94	Orbit (ESA 1997), SB

15088–4517 = *SEE 219 AB* = λ *Lup* is a B3V binary belonging to the Sco–Cen association. A minor revision of the orbit by Docobo & Ling (2007) proposed here turns it into a definitive one, with both sides of the ellipse now covered by speckle measures and one full revolution observed (Figure 4(a)). The *Hipparcos* parallax corresponds to an uncomfortably large mass sum. The true parallax should be around 6 mas, matching the distance to the association.

15339–1700 = *HDS 2185* has its first 60 yr orbit determined here, with nearly half of it covered (Figure 4(b)). The orbit is still preliminary. The speckle measure on 2001.56 was given a lower weight.

4. OTHER RESULTS

4.1. Astrometric Binaries

The *Hipparcos* satellite detected accelerated proper motion $\dot{\mu}$ in some stars (ESA 1997). Accelerated motion is also inferred from the difference $\Delta\mu$ between *Hipparcos* short-term proper motion and ground-based catalogs (Makarov & Kaplan 2005; Frankowski et al. 2007). These astrometric observables do not constrain orbital periods and mass ratios, therefore direct resolution and follow-up with adaptive optics and speckle interferometry is needed. Such work has been started recently (Tokovinin et al. 2012). We continue to follow astrometric binaries, collecting data for the eventual orbit calculation. The list of 15 such systems observed here (including 5 unresolved) is given in Table 5.

Astrometric orbits for HIP 38146, 38414, 46396, and 84924 are published. However, they are inaccurate and do not match speckle measures in position angle. With a few more measures, it will be possible to determine true visual orbits, but so far this appears premature. For the remaining resolved pairs, the separation and parallax are used to estimate order-of-magnitude orbital periods. The two newly resolved astrometric pairs are commented on in Section 2.3. HIP 64006 shows elongation at 77° indicative of its partial resolution, unless caused by vibrations or other artifacts; we do not consider this resolution secure. The estimated mass ratio of HIP 84494 is 0.3, the semimajor axis $0''.06$, therefore the companion is below the detection limit.

4.2. Spurious or Enigmatic Pairs

Binaries may be unresolved temporarily when their orbital motion makes them too close. However, repeated non-resolutions of a binary with a short estimated period put in doubt its veracity. For example, some CHARA speckle pairs were later retracted by McAlister et al. (1993). Artifacts that may lead to such spurious discoveries are discussed in TMH10.

In some cases, however, binaries were observed on multiple occasions by different people before disappearing. It is difficult to “write off” these binaries as spurious; rather, they may point to some new phenomena. Such “ghost” binaries are brought to light here. We do not propose any explanation; the purpose is to attract attention and to stimulate further collection of data on those stars. Table 6 lists close binaries and sub-systems which were repeatedly unresolved in recent speckle runs at SOAR. It also gives the π_{HIP} , spectral type, and V magnitude. Comments on individual stars follow.

05074+1839 = *104 Tau* is a G4V dwarf at 16 pc resolved into equal components at $0''.1$ by R. Aitken in 1912. The WDS contains 16 resolutions of this pair (Figure 5(a)). Apart from Aitken himself, it has been resolved on multiple occasions by R. H. Wilson in 1934–1971, by W. Finsen (1953–1955), and by others, although in other instances those observers found it to be single. The measures plotted in Figure 5(a) suggest a near-circular orbit seen face-on with a semimajor axis on the order of $0''.1$ or 1.5 AU. Assuming a mass sum of $2 M_\odot$, the orbital period should be around 1.3 yr; in fact, two orbits with periods of 1.19 yr and 2.38 yr were published by Eggen (1956). This binary should be an easy target for speckle interferometry at 4 m telescopes. It was observed 10 times from 1976.9 to 1980.7 with speckle and, surprisingly, was found unresolved on all occasions, excluding any short-period orbits. Later, however, two measures were made by the author at 1 m telescope with a phase-grating interferometer. The first resolution in 1984.8 at $0''.04$ was tentative (below the diffraction limit), but the second one in 1985.7 was secure, being the average of two observations. It was followed by the speckle resolution at 4 m telescope in 1988.17, after which the pair disappeared again. It was found unresolved in 2012 (Figure 6).

The star is well studied. Two statistical surveys of binaries within 25 pc consider it to be single (Duquenooy & Mayor 1991; Raghavan et al. 2010). Heintz & Borgman (1984) state that measures cannot be fitted by any orbit and conclude: “Although

Table 6
Spurious or Enigmatic Binaries

WDS	HIP	π_{HIP} (mas)	Sp. Type	V (mag)	Discoverer Code	Comment
05074+1839	23835	64.8 ± 0.3	G4V	5.01	A 3010	104 Tau, ADS 3701
07374–3458	37096	9.1 ± 0.4	B8IV	4.52	FIN 324 AB	AC orbit in HTM12
09125–4337	45189	4.7 ± 0.5	B8V	5.56	FIN 317 Aa,Ab	AB is HJ 4188 at 2"9
15462–2804	77235	14.1 ± 1.1	F2IV	6.51	CHR 50 Aa,Ab	AB is BU 620 at 0".63
15467–4314	77282	21.4 ± 1.0	G5V	8.08	I 1276	Spurious?

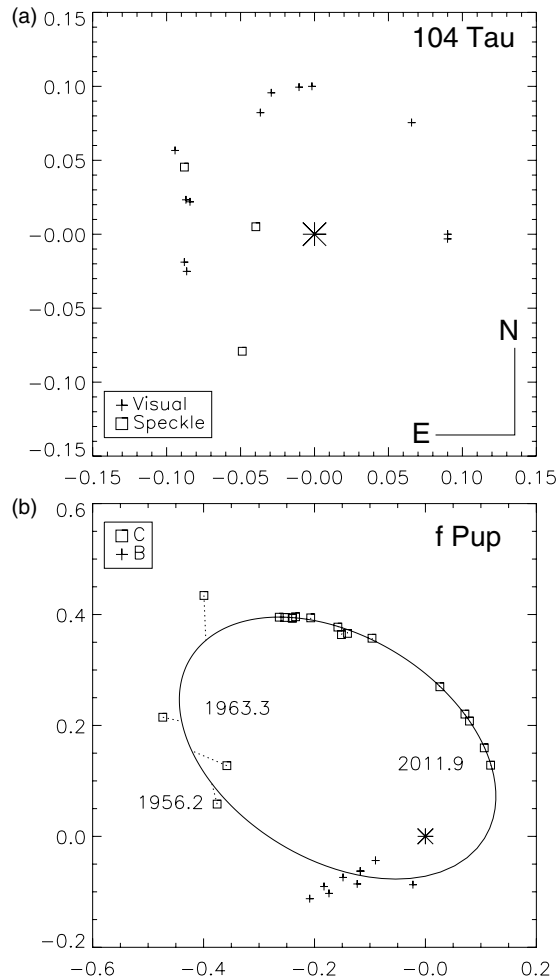


Figure 5. (a) Motion on the sky of 104 Tau. Visual observations are plotted as crosses, speckle measures as squares. (b) f Pup = FIN 324 AC (elliptical orbit connected to squares) and measures of AB (crosses). The scale on both plots is in arcseconds.

this alleged visual binary (ADS 3701) has three published orbits, it is probably spurious.” Several independent RV studies have shown that this star is not a spectroscopic binary. Precise RVs measured by Nidever et al. (2002) are stable to better than 100 m s^{-1} over 388 days, excluding orbital periods from one to two years with high confidence. Data with lower precision show a constant RV of $+21 \text{ km s}^{-1}$ over many years (Duquennoy & Mayor 1991; Abt & Willmarth 2006; Raghavan et al. 2010).

The star is located about 1^m above the main sequence, supporting the thesis of an equal-component binary. If the orbit is seen face-on, then the RV variation would be small, especially if the components are of equal brightness (blended lines move in opposite directions, the centroid stays constant). However, the lines in this star remain narrow and the speckle non-resolution

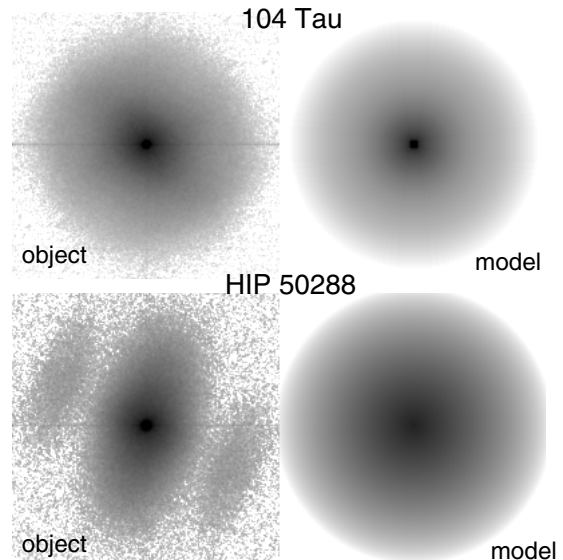


Figure 6. Power spectrum of 104 Tau recorded at SOAR on 2012.0253 in the y filter (top) shows no sign of fringes (left side: data; right side: their model for a single star). The gray levels display power on negative logarithmic scale from 10^{-7} (white) to 10^{-3} (black). For comparison, the power spectrum of resolved binary HIP 50288 ($0'.035$, $\Delta y = 0.8$) recorded with the same equipment on 2012.0258 is shown in the bottom.

during 3.8 yr firmly excludes a face-on orbit. Remember that 104 Tau is bright (no identification errors possible) and that the components are supposedly equally bright, and hence are easy to resolve by speckle.

If this star is single (as everything seems to suggest), then we cannot dismiss its multiple resolutions with micrometer, eyepiece interferometer, and speckle as spurious; occasional image doubling (or at least elongation) must be real.

07374–3458 is the bright star f Puppis (HR 2937, HIP 37096, HD 61330). It was resolved as $0'.2$ binary FIN 324AB in 1954.31 by Finsen (1956) using double-slit interferometer at the 0.7 m Innes refractor. The components were comparable in brightness with Δm from 0.3 to 0.6. Finsen published seven mean positions resulting from 25 nights (the last one in 1960.26). His measures show considerable scatter (crosses in Figure 5(b)); the motion of AB looks erratic rather than regular.

Finsen could not resolve AB since 1960.29, despite repeated attempts. However, on 1963.305, he found another companion C at $0'.52$ with $\Delta m = 0.8$. In fact, W. H. van den Bos saw both companions earlier and measured AB and AC simultaneously in 1956.2 and 1959.7 (van den Bos 1957, 1961). The pair AC was measured later by R. H. Wilson, *Hipparcos*, and various speckle interferometers. All speckle observations show no trace of the sub-system AB, except the one on 1989.305 where B looks doubtful and much fainter than C (B. D. Mason 2011,

private communication). No trace of B was seen at SOAR in 2008–2011 (four speckle runs).

The binary system AC follows a Keplerian orbit with an 81 yr period (HTM12) which was slightly corrected here using the latest measure. This excludes confusion between the companions (i.e., B and C being the same star). Besides, both companions were measured concurrently by van den Bos.

The companion B cannot be real. The closest separation of AC is 0′.09 according to the orbit and excludes any sub-system with comparable separation because such a triple star would be dynamically unstable. The fact that the orbit of AC is known does not allow us to explain the apparent non-hierarchical configuration by projection. If B were real, then its orbital period would be on the order of 10 yr (scaling from the orbit of AC) and it would have shown up in our speckle data. Like 104 Tau, we have here a binary AB which actually is not a binary—a “ghost.”

09125–4337 = FIN 317 Aa,Ab is a close sub-system in the 2′.9 pair AB = HJ 4188. After the discovery of Aa,Ab in 1951 at 0′.116, Finsen (1951) was unable to resolve the star again on 12 occasions until 1968, except one other tentative measure in 1962. Yet the object was resolved by speckle in 1989.94 at 0′.144 and in 2006.18 at 0′.123. Despite the orbital period of ~ 50 yr estimated from projected separation, the sub-system was not detected in three runs at SOAR (2009–2012), while the wider pair AB was measured. This may be yet another case of erratic measures and non-resolutions.

15462–2804 = HR 5856 = HD 140722. The binary companion B discovered by S. W. Burnham in 1878 moved since then by $+6^\circ$ in angle, now at 0′.63 separation. Considering this slow motion, the pair is likely much wider than it seems, being seen in projection. The sub-system CHR 50 Aa,Ab was discovered by speckle interferometry in 1983.42 at 0′.20 (McAlister et al. 1987). A total of four measures are listed in the INT4 catalog, the last one in 2006.19. Curiously, the wide pair AB was measured with speckle at 4 m telescopes several times (in 1985.50, 1989.31, 1991.39) without resolving the sub-system. We measured the AB and found no trace of CHR 50 in three runs at SOAR in 2009–2012. The separation of CHR 50 implies an orbital period of ~ 50 yr. Yet the few speckle resolutions show a fast motion or a random scatter. If the sub-system CHR 50 were real, we would expect it to cause some wobble in the motion of AB, but no such signal is seen.

15467–4314 is a G5V dwarf at 47 pc. The WDS catalog notes its resolution in 1926 by Innes at 0′.3 and the last measure in 1935. The separation corresponds to an orbital period of ~ 50 yr, yet the system was not resolved by *Hipparcos* in 1991.25 and by speckle in 2001.56, 2008.54, and 2012.18. Nordström et al. (2004) found only a marginal variability of RV during 8 yr. The binarity is thus questionable.

5. CONCLUSIONS

This work provides follow-up measures of close binary stars to be used in calculation or refinement of their orbits. Fifteen orbits are contributed to the VB6 catalog. Speckle interferometry is very efficient. Only a modest investment of telescope time (few nights per year at 4 m telescopes) is needed to supply good-quality speckle measures for calculating orbits of fast binaries and making the existing orbits accurate and definitive. Bright stars can be observed in twilight or through transparent clouds.

One class of objects to benefit from the speckle follow-up are *Hipparcos* astrometric binaries, mostly nearby low-mass

dwarfs. Two such stars are resolved here for the first time, few more are measured. Astrometry of these and other binaries requires knowledge of their orbits to disentangle them from parallax and proper motion. Future space astrometric missions like *Gaia* will be too short to do this and will rely heavily on the VB6 catalog. This is one more reason to follow the motion of fast binaries with speckle interferometry *now*.

Determination of a large number of orbits is a routine task. However, any large sample contains unusual or particularly interesting objects. This might be the case of “ghost” binary companions that have been resolved several times, yet seem non-existent. Here, we attract attention to two such cases, 104 Tau and f Pup, and to some other visual companions with seemingly erratic motion and frequent disappearances. It is difficult to accept that these resolutions, some by very accomplished observers, are all spurious. Continued monitoring of such “ghosts” is needed in the hope of collecting crucial observations and eventually explaining this phenomenon.

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Facility: SOAR

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