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SPECKLE INTERFEROMETRY AT SOAR IN 2014*

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ABSTRACT

The results of speckle interferometric observations at the Southern Astrophysical Research Telescope (SOAR) telescope in 2014 are given. A total of 1641 observations were taken, yielding 1636 measurements of 1218 resolved binary and multiple stars and 577 non-resolutions of 441 targets. We resolved for the first time 56 pairs, including some nearby astrometric or spectroscopic binaries and ten new subsystems in previously known visual binaries. The calibration of the data is checked by linear fits to the positions of 41 wide binaries observed at SOAR over several seasons. The typical calibration accuracy is $0\overset{\circ}{.}1$ in angle and 0.3% in pixel scale, while the measurement errors are on the order of 3 mas. The new data are used here to compute 194 binary star orbits, 148 of which are improvements on previous orbital solutions and 46 are first-time orbits.

Key words: binaries: general

Supporting material: machine-readable and VO tables

1. INTRODUCTION

Binary stars matter in astronomy in many different ways: as calibrators of various stellar properties, as tracers of star formation, and as hosts to diverse astrophysical phenomena such as mass transfer, circumstellar and circumbinary disks, or dynamical resonances, to name a few. Knowledge of orbital elements is needed in these applications. However, only a small fraction of known visual binaries have known orbits, mostly because of orbital periods being much longer than the time covered by observations. Even known orbits are not always reliable for the same reason: lack of sufficient data.

We report here a large set of binary star measurements made at the 4.1 m Southern Astrophysical Research Telescope (SOAR) with the speckle camera. This paper continues the previous series published by Tokovinin et al. (2010b, hereafter TMH10), Tokovinin et al. (2010a), Hartkopf et al. (2012), Tokovinin (2012), and Tokovinin et al. (2014, hereafter TMH14). Our primary goal is improvement of known orbital elements and determination of new orbits. The emphasis is placed on close and nearby pairs resolvable at SOAR, where orbital periods are measured in years rather than decades or centuries. The orbits of these fast binaries can be computed or improved only after a few years of speckle interferometry monitoring. Many orbits were already computed for the first time or improved using data obtained during previous speckle runs. An "orbit optimizer" was used to select binaries where observations in the coming three years could potentially yield noticeable orbit improvement.

The second, overlapping program is the characterization of multiplicity of solar-type stars within 67 pc (the FG-67 sample, Tokovinin 2014a). By resolving known binaries with astrometric acceleration (Makarov & Kaplan 2005) or variable radial velocity (RV), we obtain estimates of their periods and mass ratios and lay a foundation for future orbit determination. The spectroscopic discoveries are mostly furnished by the Geneva-Copenhagen Survey of Nordström et al. (2004, hereafter GCS). On the other hand, by observing relatively wide binaries with separations up to 3″ we constrain the existence of subsystems around their components. Several such subsystems are discovered here. In addition, we have now specially targeted distant physical secondary components to the main FG-67 stars, looking for subsystems. This work (Tokovinin 2014b) complements the large survey of the northern sky done with Robo-AO (Riddle et al. 2015) and shows that subsystems in the secondary components are as frequent as in the main components.

In this paper we also observed *Hipparcos* binaries within 200 pc with southern declinations, so far largely neglected. These observations allow us to evaluate orbital motion and to find a subset of "fast movers" for further monitoring. Some nearby tight binaries from *Hipparcos* were monitored from the outset of the SOAR speckle program. This strategy of focusing on fast binaries has resulted in several new orbits, with more still to come. Our approach for this program was therefore similar and complementary to that of the speckle program active at the WIYN 3.5 m telescope at Kitt Peak in recent years (e.g., Horch et al. 2011a, 2011b, 2012). To date, that program has resolved over 150 close companions from the *Hipparcos* list.

We re-observed some close (hopefully, fast) pairs resolved at the Blanco telescope in 2008. Some of them moved substantially in 6 years, and may yield first orbits. As a "filler," several neglected pairs were also measured or found unresolved.

This paper is structured as follows. Section 2 describes briefly the instrument and data processing and gives an estimate of data consistency for the whole series of measurements at SOAR. The results are presented in Section 3 in the form of data tables with comments on the newly resolved pairs and multiple systems. In Section 4, the new and revised orbits are given, and Section 5 concludes the paper.

* Based on observations obtained at the Southern Astrophysical Research (SOAR) telescope, which is a joint project of the Ministério da Ciência, Tecnologia, e Inovação (MCTI) da República Federativa do Brasil, the U.S. National Optical Astronomy Observatory (NOAO), the University of North Carolina at Chapel Hill (UNC), and Michigan State University (MSU).

2. OBSERVATIONS

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 (Tokovinin & Cantarutti 2008). For practical reasons, the camera was mounted on the SOAR Adaptive Module (SAM, Tokovinin et al. 2008). However, the laser guide star of SAM was not used; the deformable mirror of SAM was passively flattened and the images are seeing-limited. The SAM module corrects for atmospheric dispersion and helps to calibrate the pixel scale and orientation of HRCam, as explained in TMH14. The transmission curves of HRCam filters are given in the instrument manual.[5] We used mostly the Strömgren y filter (543/22 nm) and the near-infrared I filter (788/132 nm). The response curve of the latter was re-defined as a product of the filter transmission and detector response furnished by the respective manufacturers.

The electron multiplication CCD (EM CCD) Luca-S used in HRCam failed in 2014 July. It was sent to its manufacturer (Andor) for repair and received back in 2014 December. For the two runs in the fall of 2014, we used the EM CCD Luca-R, kindly loaned by G. Cecil. It has a larger format of 1004 × 1002 pixels, with smaller pixels of 8 μm compared to Luca-S (658 × 496, 10 μm pixels). The second lens in HRCam was replaced by the achromatic doublet of 75 mm focal length to get the pixel scale of 14.33 mas. The detector software driver was also upgraded on this occasion.

Although the two Luca cameras look exactly the same and come from the same manufacturer, their CCDs are radically different. Luca-S uses a line-transfer CCD, while Luca-R has a frame-transfer CCD. We found that Luca-R had poor charge transfer efficiency (CTE) in the vertical direction. Weak signals such as cosmic-ray hits and dark current from hot pixels are smeared vertically over ~5 pixels, while strong signals are transferred with less spread. This results in the signal-dependent loss of resolution in the vertical direction (along CCD columns), which was accounted for in the data processing by an additional adjustable parameter. This problem was revealed unexpectedly during the 2014 October run. In the next run, we placed stars closer to the line register, improving slightly the vertical CTE by reducing the number of charge transfers.

We studied the distribution of the bias signal of both cameras. It is very well modeled by the sum of a Gaussian component (readout noise) and a negative exponent that corresponds to the single-electron events amplified stochastically by the gain register. Most events are generated by the CCD clocking (clock-induced charge, CIC) typical for EM CCDs. The width (decrement) of the exponential term depends on the EM gain. The rate of CIC events is found as the ratio of the areas below these two terms. For Luca-R, the readout noise is 4.5 ADU and the CIC rate is 0.03. The CIC events are not smeared vertically because no charge transfer is involved. For Luca-S, the readout noise is 9 ADU, the exponential decrement is 30 ADU (for the gain setting of 200 used here), and the rate of CIC events is 0.13 per pixel. About half of the CIC events are removed by the threshold of 17 ADU applied in the power spectrum calculation.

[5] http://www.ctio.noao.edu/soar/sites/default/files/SAM/archive/hrcaminst.pdf

Table 1
Observing Runs

Run	Dates	θ_0 (degree)	Pixel (mas)	$N_{\rm obj}$
1	2014 Jan 15–16, 22	1.26	15.23	309
2	2014 Mar 7–8	−1.30	15.23	201
3	2014 Apr 19–20	−1.40	15.23	385
4	2014 Oct 5–7	−0.69	14.33	553
5	2014 Nov 7–8	0.66	14.33	253
6	2015 Jan 10–11	−0.20	15.23	248

The SOAR telescope suffers from 50 Hz vibration (see TMH14). The vibrations are non-stationary, causing variable loss of resolution if the 20 ms exposure time is used. Most data were taken with an exposure of 5 ms, sampling 1/4 of the vibration period. The resolution is then recovered and the effect of vibrations becomes less dramatic. It disappears completely at an exposure time of 2 ms, used on the brightest targets. With such short exposures, the power spectra extend to the cut-off frequency and are very symmetric. The Luca-R detector suffering from the CTE problem was used mostly with a 10 ms exposure as a compromise between vibrations and poor CTE at low signal levels.

The observations consist of taking a cube of 400 images of 200 × 200 pixels each. For binaries wider than 1$''$.5, the 400 × 400 format was used. Each object and filter combination is normally recorded twice, these data are processed independently, and the result is averaged. We used 2 × 2 detector binning on the faintest targets observed in the I filter, with a minor under-sampling and loss of resolution. Measurements of binaries made with and without binning agree well mutually. Faint red dwarfs with $I \sim 12$ still produced useful data.

2.2. Observing Runs

The observing time for this program was allocated through NOAO (proposals 2013B-0172, 2014A-0038, 2014B-0019, eight nights total) and by the Chilean National TAC (proposal CN2014B-27, four nights).

Table 1 lists the observing runs, the calibration parameters (position angle offset θ_0 and pixel scale in mas), and the number of objects covered in each run. The calibration of angle and scale was done by referencing to the SAM imager, as described in TMH14.

Run 1 was affected by transparent clouds. Two hours on 2014 January 22 were added as a backup program. During this run, the Nasmyth rotator of SOAR had a large offset of +2°.8. The seeing was mediocre to poor. The instrument was not dismounted between runs 1 and 2, but the Nasmyth rotator was re-initialized, explaining the difference in θ_0. The sky was clear, and two hours were added on March 7 as a backup from other program. The sky was also clear on the two nights of run 3, with seeing good to excellent.

Runs 4 and 5 used the substitute detector Luca-R and were affected by the CTE problem. For this reason the observations were performed mostly in the I filter with 10 ms exposure. All three nights of run 4 were clear, and mostly with good seeing (the median full width at half maximum, FWHM, of re-centered average images was 0$''$.60, the best FWHM was around 0$''$.45). The detector was removed between runs 4 and 5 in an attempt to improve the CTE by tuning the electronic parameters; however, this turned out to be impossible. During run 5, the seeing varied from average to poor. In the worst case, the star did not fit in the 3″ field, illuminating all pixels. In such cases, the image is truncated, the power spectrum contains bright vertical and horizontal lines, and the detection limits are poor. Under poor seeing, data obtained with the 400 pixel field and 2 × 2 binning are of better quality, without image truncation.

The two nights of run 6 were clear, with seeing average to poor. The HRCAM was returned to its original configuration with the Luca-S detector. Measurements with the SAM internal light source confirmed that the pixel scale did not change compared to runs 1–3.

2.3. Data Processing

The data processing is described in TMH10. As a first step, power spectra and average re-centered images are calculated from the data cubes. The auto-correlation functions (ACFs) are computed from the power spectra. They are used to detect companions and to evaluate the detection limits. The parameters of binary and triple stars are determined by fitting the power spectrum to its model, which is a product of the binary (or triple) star spectrum and the reference spectrum. We used as a reference the azimuthally averaged spectrum of the target itself in the case of binaries wider than 0″.1. For closer pairs, the "synthetic" reference was used (see TMH10).

The signal-dependent vertical smearing of the image caused by the CTE problem required a modification of the reference spectrum. We model the smearing by an additional Gaussian term in the reference spectrum $P(f_x, f_y)$:

$$P(f_x, f_y) = T_{\rm DL}(\kappa)\ 10^{p_0+p_1\kappa}\ e^{-2\pi^2\left(\Delta y f_y/2.35\right)^2},$$
$$\kappa = \sqrt{f_x^2 + f_y^2}\Big/f_c, \qquad (1)$$

where f_x and f_y are spatial frequency coordinates along CCD lines and columns respectively, $T_{\rm DL}$ is the diffraction-limited transfer function, f_c is the cut-off frequency, $\kappa = |f|/f_c$, p_0 and p_1 describe the speckle signal attenuation (both are negative, p_0 is related to seeing), and the new parameter Δy is the FWHM of the CTE smear in the column direction in pixels. This "elliptical" synthetic reference was used for all binaries, both wide and close, observed in runs 4 and 5. The parameters of the reference (p_0, p_1, Δy) were fitted to the power spectrum jointly with the binary parameters (θ, ρ, Δm).

In the case of close binaries, the parameters of the elliptical reference and of the binary itself are mutually correlated, so the resulting measures could be biased. The close binary star B 430 (19155–2515) was observed with position angles of the instrument differing by 90°. The "fringes" in the power spectrum had different orientations relative to the CCD. However, the binary parameters (θ, ρ, Δm) fitted to these power spectra are mutually consistent, (283°.7, 0″.0673, 0.785) and (285°.0, 0″.0690, 0.722). Therefore, the CTE effect is, to first order, accounted for by the modified reference model. Still, measurements of close binaries from runs 4 and 5 (2014.77 and 2014.86) should be taken with some caution.

Wide binaries resolvable in the re-centered long-exposure images are processed by another code that fits only the magnitude difference Δm, using the binary position from speckle processing. This procedure corrects the bias on Δm caused by speckle anisoplanatism and establishes the correct quadrant (flag * in the data table).

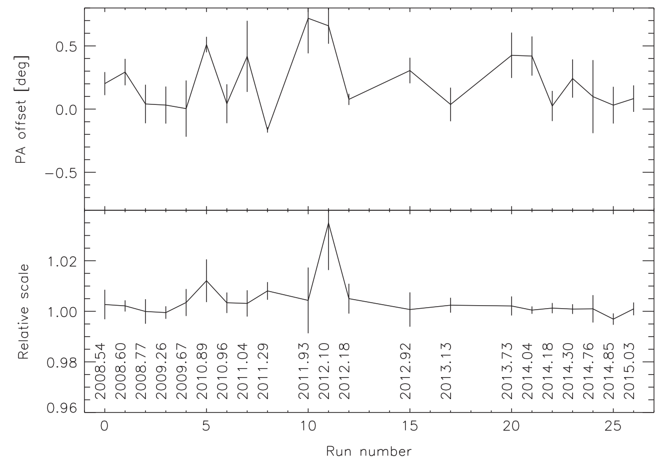

Figure 1. Systematic offsets in angle (in degrees) and relative scale determined from wide binaries. The beginning date of each run is shown in the lower plot.

For run 5, we also calculated shift-and-add (SAA or "lucky") images, centered on the brightest pixel in each frame and weighted proportionally to the intensity of that pixel. All frames without rejection were co-added. Binary companions, except the closest and the faintest ones, are detectable in these SAA images, helping to identify the correct quadrant. Such cases are marked by the flag q in the data table. Quadrants of the remaining binary stars are guessed based on prior data or orbits, not measured directly.

2.4. Recalibration

Calibration of scale and angular offset in speckle interferometry is challenging because the accuracy of modern measurements with 4 m telescopes exceeds the accuracy of even the best orbits. Comparison with ephemerides is useful only as a sanity check. Recognizing this problem, we observed several wide binaries during each run. Their motions are slow and can be modeled by linear functions of time. These models can then be used to check the calibration of the archival data. This approach tests only the mutual consistency of speckle runs, rather than absolute calibration of the whole data set.

We selected 41 binaries wider than 0″.5 that do not contain resolved subsystems and were observed during at least 4 runs each. The angle and separation of each binary is approximated by linear functions of time. If the fitted slope is less than twice its rms error, a zero slope is assumed. Deviations from these models are interpreted as calibration corrections. For each run, they are median-averaged. We then iterate by fitting new linear models corrected for the run's systematics, determining new calibration parameters of the runs, etc.

Figure 1 shows the offsets in angle and scale determined by this procedure for those of 26 runs where at least $N = 2$ calibrators were observed. Run 0 refers to observations at the Blanco telescope in 2008.5 (TMH10). Runs 1–6 in this paper correspond to numbers 21–26 in the plot. Vertical bars show the rms scatter between calibrators (not errors of the mean, which are smaller by $\sqrt{N}$). A typical rms scatter is 0°.1 in angle and 0.3% in scale.

This analysis reveals good mutual consistency of ∼5000 speckle measurements produced by HRCam to date. The largest systematics are found in runs 10 and 11 (2011.9 and

Table 2
Measurements of Double Stars at SOAR (Fragment)

WDS (2000)	Discoverer Designation	Other Name	Epoch +2000	Filt	N	θ (degree)	$\rho\sigma_\theta$ (mas)	ρ ($''$)	$\sigma\rho$ (mas)	Δm (mag)	[O–C]$_\theta$ (degree)	[O–C]$_\rho$ ($''$)	Reference Code*
00026–0829	A 428	HIP 210	14.7632	I	2	317.6	0.3	0.1197	0.9	0.4 :	−1.0	0.003	This work
			14.8535	I	2	315.6	1.4	0.1165	0.8	0.3	−2.5	0.000	This work
00028+0208	BU 281 AB	HIP 223	14.8561	I	2	160.3	0.2	1.5938	0.2	1.4 *	…	…	…
00058–6833	HDS 4	HIP 488	14.7661	I	2	229.3	4.8	0.1971	1.9	1.9	…	…	…
00115–5545	HDS 25	HIP 927	14.7661	I	3	75.3	0.7	0.1546	0.6	0.8	…	…	…
00135–3650	HDS 32	HIP 1083	14.7662	I	2	226.3	1.0	0.2565	0.6	0.8	…	…	…
00143–2732	HDS 33	HIP 1144	14.8534	I	2	55.5	0.3	0.1117	0.3	0.9	0.6	−0.002	This work
			14.8534	y	1	55.4	0.6	0.1115	0.6	1.0	0.4	−0.002	This work

(This table is available in its entirety in machine-readable and Virtual Observatory (VO) forms.)

Table 3
Unresolved Stars (Fragment)

WDS (2000) α, δ (J2000)	Discoverer Designation or Other Name	*Hipparcos* or Other Name	Epoch +2000	Filter	N	$\rho_{\rm min}$ (arcsec)	5σ Detection Limit Δm (0$''$.15) (mag)	Δm (1$''$) (mag)	Δm Flag
00006–6641	GLI 289	HIP 55	14.7661	I	2	0.039	1.95	3.07	…
00052–6251	HIP 425	HIP 425	14.7661	I	2	0.039	2.78	4.10	…
00174–5131	HDS 40	HIP 1393	14.7662	I	2	0.039	2.56	3.97	…
00250–3042	HIP 1976	HIP 1976	14.8534	I	2	0.039	3.42	4.82	…
00301+0452	HIP 2358	HIP 2358	14.8561	I	2	0.039	2.28	3.69	…
00310–3138	HDS 69	HIP 2433	14.7662	I	2	0.039	1.69	4.01	…
00324+0657	MCA 1 Aa,Ab	HIP 2548	14.7632	I	2	0.039	3.01	4.25	…

(This table is available in its entirety in machine-readable and Virtual Observatory (VO) forms.)

2012.1). The published data can be corrected by subtracting the angular offsets found here and dividing the separations by the new scale factors. We plan to observe more calibrators and publish improved systematic corrections in the future. The data of this paper rely only on the original instrument calibrations and *are not corrected* for the offsets found so far.

This study gives an estimate of the accuracy of speckle measurements. After correction for run systematics, the median rms deviations from the models for the 41 calibrator binaries are $0^\circ.1$ in angle and 1.9 mas in separation. The actual errors should be a factor of ~1.5 larger (~3 mas), considering that the number of independent measurements is about twice the number of fitted parameters. This study will be repeated in the future with additional speckle runs and calibrators.

3. RESULTS

3.1. Data Tables

The data tables have almost the same format as in the previous papers of this series. They are available in full only electronically. Table 2 lists 1636 measures of 1218 resolved binary stars and subsystems, including 56 newly resolved pairs. The columns of Table 2 contain (1) the WDS (Mason et al. 2001) 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 averaged individual data cubes, (7, 8) position angle θ in degrees and internal measurement error in tangential direction $\rho\sigma_\theta$ in mas, (9, 10) separation ρ in arcseconds and its internal error σ_ρ in mas, and (11) magnitude difference Δm. An asterisk follows 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 over-estimated (see TMH10 for details); the flag "q" means the quadrant is determined from the SAA image. Note that in the cases of multiple stars, the positions and photometry refer to the pairings between individual stars, not the photo-centers of subsystems.

For stars with known orbital elements, columns (12)–(14) of Table 2 list the residuals to the ephemeris position and code of reference to the orbit adopted in the Sixth Catalog (Hartkopf et al. 2001, hereafter VB6).[6] New and revised orbits computed in this work (Section 4) are referenced as "This work."

We did not use image reconstruction, and measured the position angles modulo 180° (except the SAA images in run 5). Plausible quadrants are assigned on the basis of orbits or prior observations, but they can be changed if required by orbit calculation. For triple stars, however, *both* quadrants of inner and outer binaries have to be changed simultaneously; usually the slowly moving outer pair defines the quadrant of the inner subsystem without ambiguity.

Table 3 contains the data of 441 unresolved stars, some of which are listed as binaries in the WDS or resolved here in other filters. Columns (1) through (6) are the same as in Table 2, although Column (2) also includes other names for objects without discoverer designations. For stars that do not have entries in the WDS, fictitious WDS-style codes based on the position are listed in Column (1). Column (8) is the estimated resolution limit, the largest of the diffraction radius λ/D and the vertical CTE smear Δy (applicable to runs 4 and 5 only). Columns (8, 9) give the 5 σ detection limits Δm_5 at $0''.15$ and $1''$ separations determined by the procedure described in TMH10 (please note that this is not the resolution of the observations). When two or more data cubes are processed, the

[6] See http://ad.usno.navy.mil/wds/orb6/wdsref.html.

largest Δm value is listed. The last column marks by colons noisy data mostly associated with faint stars. In such cases, the quoted Δm might be too large (optimistic); however, the information that these stars were observed and no companions were found is still useful for statistics (Tokovinin 2014b).

3.2. Newly Resolved Pairs

Table 4 lists 56 newly resolved pairs. The last two columns of Table 4 contain the spectral type (as given in SIMBAD or estimated from absolute magnitude) and the *Hipparcos* parallax (van Leeuwen 2007, hereafter HIP2). Fragments of ACFs of newly resolved triple systems are shown in Figure 2. We comment on the newly resolved binaries below. The following abbreviations are used: PM—proper motion, CPM—common proper motion, RV—radial velocity, SB1 and SB2—single- and double-lined spectroscopic binaries, INT4—4th Interferometric Catalog (Hartkopf et al. 2001).

01379–8259. HIP 7601 is a nearby (27 pc) dwarf also known as GJ 67.1 or HR 512. According to Wichman et al. (2003), it is a young spectroscopic triple detected in X-rays (1RXS J013755.4–825838). GCS also recognized the star as SB2. Spectroscopic monitoring (A. Tokovinin 2015, in preparation) shows that all three components are similar stars of approximately one solar mass. Here we resolved the outer subsystem AB and observed its fast motion. In fact it was already resolved at SOAR on 2011.036 at 221°.0 and 0″.044, but this low-quality observation has not been published. The available data indicate that the period of AB is 1.7 years; the pair completed nearly two revolutions since its first resolution in 2011.

02098–4052. HIP 10096 is SB2 according to GCS. The separation corresponds to a period of ∼5 years.

03046–5119. HIP 14307 and 14313 form the 38″ pair DUN 10 AB belonging to the FG-67 sample. The component B is resolved here at 0″.19. The estimated period of Ba,Bb is ∼25 years. No motion is seen in 2 months. The subsystem Ba,Bb is also manifested by asymmetric line profiles (A. Tokovinin 2015, in preparation). The A component has never been observed at high angular resolution.

04386–0921. HIP 21265 is an X-ray source and an SB2 according to GCS (one observation only). It is resolved here at 56 mas, which corresponds to a period of ∼5 years.

04469–6036. First resolution of HIP 22229 at 0″.043, ΔI = 1.2. The measure is uncertain, but the elongation is confirmed with 2 ms exposure and is not seen in other observed stars, so it is not caused by vibration. This is a triple system containing an eclipsing binary AL Dor of Algol type with an eccentric orbit (Bulut & Demirkan 2007). The separation implies an orbital period of the outer system on the order of 5 years.

05354–0450. This is HIP 26237, HD 37018, HR 1892, 42 Ori, a young star in Orion which has not been observed at high angular resolution so far, according to INT4. We resolved the known binary AB = DA 4 and discovered the spectacular subsystem Aa,Ab at 0″.16 (Figure 2).

06303–5252. HIP 30995 is an SB2 according to GCS. The new companion at 0″.2 with ΔI = 4.1 mag is unlikely to correspond to the SB2, so the system is probably triple.

06497–7433. HIP 32735 has an acceleration detected in HIP2, but no RV data. The resolved 0″.3 pair implies a period of ∼80 years. The spectral type K0IV given in SIMBAD may be inaccurate because the luminosity and color of the components correspond to main sequence stars with masses of 1.0 and 0.6 $\mathcal{M}_\odot$.

06499–2806. The 0″.2 pair HDS 947 had not been observed since its discovery by *Hipparcos*. Here it is revealed as a triple system (Figure 2) with comparable separations between components. HDS 947 probably corresponds to AB, while the fainter C component is new.

07038–4334. HIP 34052 = HD 53680 = HIP 34065C = GJ 264 is a spectroscopic and astrometric binary for which Sahlmann et al. (2011) give an orbit with P = 1688 days = 4.62 years and an estimated semi-major axis of 0″.15. There is also an astrometric orbit (Makarov et al. 2008) with P = 4.11 years that predicts θ = 327° for the moment of our first observation. The binary is resolved at 0″.23, ΔI = 4.4 mag and shows some orbital motion. The binary makes a quadruple system together with components A and B (GJ 264.1 and 264) that form a 20″.5 pair at 185″ from C. The B component was also observed here and found unresolved.

07294–1500 is another nearby multiple system. The main component HIP 36395 is a visual binary with a known 728-year orbit, also measured here. The C component (NLTT 17952) at 20″.4 is physical, and yet another CPM component F is found at 1072″ (Tokovinin & Lépine 2012), while the WDS components D and E are optical. We observed C and resolved it at 0″.09. The orbital period of Ca,Cb is on the order of 6 years, estimated masses are 0.6 and 0.4 $\mathcal{M}_\odot$. We also targeted F and did not resolve it. The magnitudes and colors of C and F are quite similar.

07304+1352 is a quadruple system. The 7″.7 pair AB (STF 1102) is HIP 36485, the CPM component D = HIP 36497 = HD 59450 is located at 112″ from it, while the WDS components C and E are optical. The physical nature of AD is established by common PM, distance, and RV. D is a known SB1 with P = 2708 days = 7.4 years (Halbwachs et al. 2012) and an estimated semi-major axis of 93 mas, also an acceleration binary. We resolved the Da,Db pair at 0″.11, ΔI = 2.6. The minimum mass of Db derived from its SB orbit is 0.27 $\mathcal{M}_\odot$, while we estimate the masses of Da and Db as 1.05 and 0.6 $\mathcal{M}_\odot$ from their luminosity. A previous non-resolution of D is reported in INT4; it was also unresolved with Robo-AO (Riddle et al. 2015).

07312+0210, HIP 36557 = HD 59688. According to observations by D. Latham (2012, private communication), this is a spectroscopic triple with an inner period of 70 days (double-lined, also detected by GCS, mass ratio 0.7) and an outer period of 2007 days or 5.5 years. The outer system is also detected by astrometric acceleration (Makarov & Kaplan 2005). We resolve it here at 0″.057, ΔI = 2.0, Δy = 2.5 mag, and see the orbital motion. The estimated mass of Ab is 0.88 $\mathcal{M}_\odot$. The semi-major axis of the 70 days inner binary Aa,Ab is 7 mas, so accurate measurements of AB can detect the sub-motion to determine the orientation of the inner orbit.

08021–1710. This is the high-PM M-dwarf LP 784–12 (HIP 39293) at 30 pc from the Sun. A new distant component C was found at 1″.8 in addition to the known pair HDS 1140 which closed from 0″.4 in 1991.25 to 0″.33 now (Figure 2). It is confirmed as physical by its fixed position during one year, the quadrant of the triple was determined in run 5.

08447–2126. Like the previous object, the late-type nearby binary HDS 1260 was discovered by *Hipparcos* and is expected to move rapidly (HIP 42910, BD−20° 2665). It was targeted at SOAR for the first time. To our surprise, the

Table 4
Newly Resolved Pairs

WDS (2000)	Discoverer Designation	Other Name	Epoch +2000	Filt	θ (degree)	ρ ($''$)	Δm (mag)	Sp. Type	$\pi_{\rm HIP2}$ (mas)
01379–8259	TOK 426	HIP 7601	14.7661	I	112.8	0.0640	0.5	G1V	36.5
02098–4052	TOK 427	HIP 10096	14.7689	I	218.3	0.0397	1.4	F3V	14.1
03046–5119	TOK 428 Ba,Bb	HIP 14313	14.7635	I	107.9	0.1911	0.5 :	G6V?	18.7
04386–0921	TOK 387	HIP 21625	14.0457	I	47.0	0.0557	0.6	F8?	16.1
04469–6036	TOK 388	HIP 22229	14.0456	I	266.2	0.0431	1.2	F8V	16.1
05354–0450	TOK 430 Aa,Ab	HIP 26237	14.8567	I	6.2	0.1589	0.2	B1V	3.7
06303–5252	TOK 435 Aa,Ab	HIP 30995	15.0288	I	176.1	0.2134	4.1 q	G4V	14.0
06497–7433	TOK 389	HIP 32735	14.0597	I	330.7	0.3343	3.1	K0IV	15.7
06499–2806	HDS 947 AC	HIP 32767	15.0289	I	231.3	0.4237	3.2 q	K1V	14.6
07038–4334	TOK 390 Ca,Cb	HIP 34052	14.0431	I	10.8	0.2268	4.4	K6V	57.4
07294–1500	TOK 391 Ca,Cb	HIP 36395	14.1853	I	121.2	0.0902	1.2	M0V	28.5
07304+1352	TOK 392 Da,Db	HIP 36497	14.0596	I	67.6	0.1143	2.5	F8	22.0
07312+0210	TOK 393	HIP 36557	14.0433	I	168.6	0.0572	2.0	G0	15.7
08021–1710	TOK 394 AC	HIP 39293	14.0460	I	332.5	1.8351	3.0	M1.5	33.3
08447–2126	TOK 395 BC	HIP 42910	14.0460	I	184.6	0.1645	0.1	K7V	27.5
09299–3629	TOK 440 BC	HIP 46572	15.0317	I	90.4	0.1126	1.4 q	sdF2	5.0
09586–2420	TOK 437	HIP 48906	15.0317	I	292.6	0.0640	1.3 q	F3V	8.9
10056–8405	TOK 396 Aa,Ab	HIP 49442	14.0436	I	192.6	0.1760	1.4	F8V	15.6
10070–7129	TOK 397	HIP 49546	14.3027	y	345.5	0.0263	1.7	F5V	16.7
10223–1032	TOK 398	HIP 50796	14.3002	I	147.7	1.6626	2.8	K4V	25.8
10530+0458	TOK 438	HIP 53212	15.0292	y	194.9	0.0486	0.8 q	G5	11.9
12176+1427	TOK 399 Aa,Ab	HIP 59933	14.3004	I	95.2	0.0429	1.0	F8	17.5
12250–0414	TOK 400	HIP 60574	14.1855	I	71.2	0.2194	2.6	G5	21.5
12528+1225	TOK 401	HIP 62933	14.3004	y	141.3	0.0598	1.6	A7III	16.4
13132–0501	TOK 402	HIP 64499	14.1858	I	314.8	0.1062	1.8	G5	19.2
13321–1115	TOK 291 Aa,Ab	HIP 66018	14.1858	I	159.4	0.8947	4.6	G0	18.0
13344–5931	TOK 403	HIP 66230	14.1857	I	314.3	0.1037	2.5	G0V	18.6
13382–2341	TOK 404 Aa,Ab	HIP 66530	14.1857	I	63.4	0.1570	3.9	G4V	20.6
13401–6033	TOK 292 B,Ca	HIP 66676B	14.1857	I	293.3	0.9178	3.7	G6V	16.9
13401–6033	TOK 292 Ca,Cb	HIP 66676B	14.1857	I	5.2	0.1614	0.0	G6V	16.9
13495–2621	TOK 405	HIP 67458	14.1858	I	15.0	0.7306	4.4	G9V	24.3
14014–3137	TOK 159 Aa,Ab	HIP 68507	14.3031	I	101.6	0.0652	2.1	F5	16.2
14382+1402	TOK 406	HIP 71572	14.1859	I	153.9	0.0900	1.5	G5	21.2
14464–3346	TOK 407 Ba,Bb	HIP 72235B	14.3031	I	41.3	0.4116	4.1	K4	24.0
15362–0623	TOK 301 Aa,Ab	HIP 76400	14.1860	I	78.1	0.1908	3.9	G5	15.7
15367–4208	TOK 408 Ca,Cb	HIP 76435C	14.3007	I	97.2	0.0562	0.4	K4	20.6
16142–5047	TOK 409	HIP 79576	14.1833	I	145.4	0.0791	3.0	G8V	24.2
16195–3054	TOK 410 Ba,Bb	HIP 79979	14.1833	I	85.0	0.0396	1.4	G1/G2	20.7
16454–7150	TOK 411 Aa,Ab	HIP 82032	14.3034	I	267.2	1.3373	4.1	F8V	18.3
16563–4040	TOK 412 AC	HIP 82876	14.3034	y	144.0	1.4585	5.1	O7V	–0.7
17054–3346	TOK 413 Aa,Ab	HIP 83612	14.3035	y	82.3	0.0303	1.7 :	G1V	18.4
17098–1031	TOK 414	HIP 83962	14.1833	y	59.1	0.0325	1.8 :	F5IV	24.2
17264–4837	TOK 415 Ba,Bb	HIP 85326	14.3035	I	118.6	1.0059	2.4 *	K1V	20.7
17266–3258	TOK 416	HIP 85360	14.3035	I	26.9	1.1597	5.9 *	G3V	26.4
17341–0303	TOK 417	HIP 85963	14.3010	I	88.9	0.0907	2.6	F8	15.3
17342–1910	TOK 418 AC	HIP 85965	14.3036	I	133.6	0.2163	3.3	F2V	2.5
17342–5454	TOK 419	HIP 85969	14.1833	I	72.1	0.5544	3.4	G4V	23.7
18243–0405	TOK 420 Aa,Ab	HIP 90198	14.3037	I	83.6	0.0477	0.8	A3	8.7
18267–3024	TOK 421	HIP 90397	14.3036	I	100.4	0.0690	2.5	G0V	21.4
18346–2734	TOK 422 Aa,Ab	HIP 91075	14.3037	I	101.7	0.0864	1.7	G5V	15.0
19206–0645	TOK 432 AC	HIP 95068	14.3011	I	56.4	0.9751	6.4 *	K0	3.0
19209–3303	TOK 433 Aa,Ab	HIP 95106	14.7683	I	160.0	0.2721	2.5	G0.5 V	21.2
19221–2931	TOK 423 Aa,Ab	HIP 95203	14.3010	y	36.4	0.7672	5.8 *	G0IV	19.6
19409–0152	TOK 424	HIP 96834	14.3011	I	102.2	0.0355	1.3 :	F8	20.8
19453–6823	TOK 425 Ba,Bb	HIP 97196	14.3038	I	312.1	0.0829	1.4	K3	21.3
22259–7501	TOK 434 Ba,Bb	HIP 110719	14.7657	I	58.1	0.1917	1.4 :	K5	43.4

object turned out to be a resolved triple, with the secondary being a $0\overset{''}{.}16$ pair of equal stars (Figure 2). *Hipparcos* failed to recognize the triple nature of this star. The estimated period of BC is 15 years. The outer pair AB has closed from $0\overset{''}{.}8$ to $0\overset{''}{.}5$ and moved in position angle since its discovery. The separations between components are comparable, so this triple system may be interesting dynamically.

09299–3629. HIP 46572 is called a "high proper motion star" in SIMBAD, although its PM and RV are actually quite moderate. The binary AB has moved little in the 24 years since

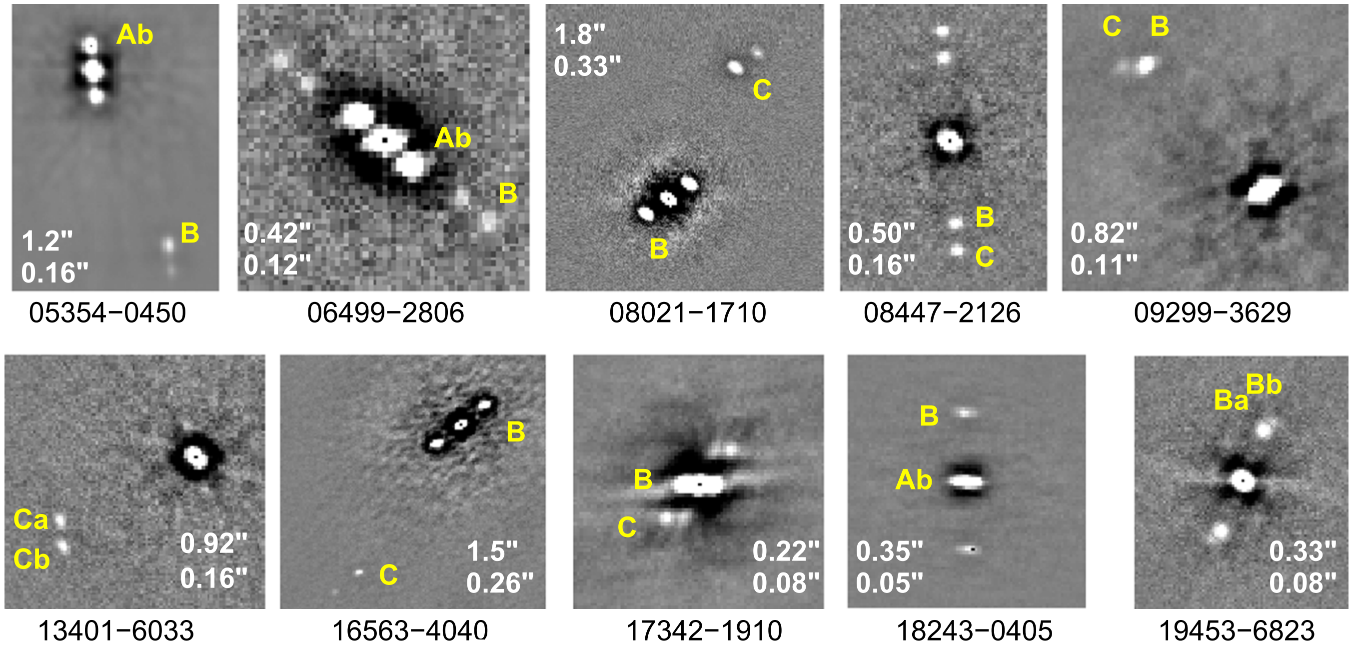

Figure 2. Fragments of ACFs of newly resolved triple systems (north up, east left, arbitrary scale). The peaks in the ACFs are labeled by component designations. Angular separations in the wide and close pairs are listed in the images.

its resolution by *Hipparcos*. We discover the subsystem BC (Figure 2) with an estimated period of ∼100 years.

09586–2420. HIP 48906 is a double-lined binary according to the GCS, first resolved here at 64 mas. The period should be ∼20 years.

10056–8405. HIP 49442 = HD 88948 is a nearby dwarf in the 3″.9 visual binary HJ 4310 AB. According to GCS, the RV of the main component A varies by 3.5 km s^{-1}. Here it is resolved into a 0″.18 Aa,Ab pair with an estimated orbital period of 25 years. No astrometric acceleration was detected, however. The visual secondary B was targeted separately and found unresolved.

10070–7129. HIP 49546 is an astrometric binary of 1.5 year period (Goldin & Makarov 2006) with variable RV. The period corresponds to a semi-major axis of 25 mas. The star is resolved here tentatively at 26 mas (with 2 ms exposure). This resolution is below the diffraction limit and needs confirmation. The measured position angle of 346° is close to 342° predicted by the astrometric orbit.

10223–1032. HIP 50796 is a single-lined and astrometric binary according to Torres (2006), with a period of 570.98 days (1.56 years), $K_1 = 20.76$ km s^{-1}, $e = 0.611$. The *Hipparcos* parallax corrected for the binary motion is 20.6 ± 1.9 mas. The spectroscopic secondary companion is over-massive, most likely a close pair of M-dwarfs. If so, the new speckle companion at 1″.66 with a period on the order of 500 years makes the system quadruple. The speckle companion might contribute to the IR excess found by Torres. The system is an X-ray source, and is possibly young.

10530+0458. D. Latham (2012, private communication) identified HIP 53212 = HD 94292 as SB2 with a period of 8.3 years and a highly eccentric orbit. It is resolved here securely at 50 mas.

12176+1427. HIP 59933 has a variable RV according to GCS. The 32 mas separation corresponds to an orbital period of ∼2 years. However, the separations in the y and I filters are somewhat discordant; further confirmation is needed.

12250–0414. HIP 60574 is a spectroscopic triple with periods 14 days and 22 years (D. Latham 2012, private communication), also an acceleration binary. We resolved the outer pair at 0″.22 separation, matching the spectroscopic period. The lines of the visual secondary Ab could potentially be detected in the spectrum by cross-correlation, leading eventually to a full 3D orbit.

12528+1225. HIP 62933 (41 Vir) was observed on request by F. Fekel who studies its spectroscopic orbit. Apparently it is resolved for the first time.

13132–0501. HIP 64499 has a variable RV, with a preliminary spectroscopic orbit of 17 years period (D. Latham 2012, private communication). It is resolved at 0″.1 and shows no motion in one month.

13321–1115. No previous indication of binarity was available for HIP 66018, apart from the CPM companion B at 84″. We discovered another faint component Ab at 0″.89, $\Delta I = 4.6$, likely to be physical (low background density). The B component ($V = 14.8$) was targeted, but its speckle signal was weak and no obvious close companions to B were found.

13344–5931. HIP 66230 has a variable RV in the GCS and an astrometric acceleration. We resolved it at 0″.1, $\Delta I = 2.5$, estimated period ∼10 years. The pair moved by 4° in one month.

13382–2341. HIP 66530 has a variable RV according to the GCS. It is resolved at 0″.16 in the I band only, estimated period ∼20 years. This is a triple system, considering the CPM companion B at 28″ (LDS 4385 AB).

13401–6033. HIP 66676 (A) and HD 118735 (B, G6V, $V = 9.17$) at 77″ share common PM (although it is small, 58 mas yr^{-1}) which, together with photometry, indicates with high probability that it is a physical pair AB (Tokovinin & Lépine 2012). We targeted the secondary component B and found it to be a resolved triple. The faint star C, at 0″.92 from B, is itself a close 0″.16 pair Ca,Cb (Figure 2). Note that this is a region of the sky with very high stellar density, raising suspicion that the Ca,Cb pair might be a random background object. Re-observation of the triple in 2015 (to be published) shows, however, that it is physical because the center of C = (Ca,Cb) moves relative to B with a speed of 11 mas yr^{-1} (or 3 km s^{-1}), compatible with the expected orbital motion of BC and much less than the system's PM of 58 mas yr^{-1}. The estimated period of Ca,Cb is ∼30 years, the period of BC is ∼300 years.

13495–2621. HIP 67458 is a double-lined chromospherically active binary with orbital period of 7.2 days (D. Latham 2012, private communication). We found a faint tertiary companion at 0″.73 with an estimated orbital period on the order of 100 years. The speckle survey of chromospherically active stars by Mason et al. (1998) did not detect this tertiary, lacking the dynamic range of HRCam.

14014–3137. HIP 68507 is an acceleration binary with a variable RV resolved here at 0″.06. The period of Aa,Ab is on the order of 5 years. There is a faint physical companion B at 6″.7 found in 2MASS (Tokovinin 2011). Another visual companion at 14″, SEE 195, is optical, as revealed by its fast relative motion.

14382+1402. HIP 71572 is an acceleration binary without RV data. It is found to be a tight 90 mas pair with a small Δm and an estimated period under 10 years (some motion is seen in one month). Very likely it can be studied as a double-lined SB.

14464–3346. HIP 72235B is located at 9″ from the primary star and shares its proper motion (AB = HDS 2082). Pre-discovery measurements of this *Hipparcos* pair were published by Wycoff et al. (2006). The RV of A may be variable (D. Latham 2012, private communication). The star B turns out to be a 0″.4 binary Ba,Bb with masses of 0.70 and 0.17 $\mathcal{M}_\odot$ estimated from the luminosity. Its period is on the order of 100 years. The whole system could thus be quadruple.

15362–0623. HIP 76400 is identified by the GCS as an SB2 with a mass ratio $q = 0.93$, but there is no spectroscopic orbit available. We resolved the 0″.19 pair with $\Delta I = 3.9$, indicating a mass ratio of ∼0.5 and an orbital period of ∼30 years. Very likely the resolved binary does not match the spectroscopic double-lined system. Considering the CPM component B at 80″ (Tokovinin & Lépine 2012), this system could be a quadruple with a 3-tier "3+1" hierarchy.

15367–4208. HIP 76435 is a G5V star from the FG-67 sample. Its companion C (AC = FAL 78) at 13″.5 is physical, while the *Hipparcos* companion B at 4″.3 is not seen in the 2MASS images and has not been confirmed otherwise. We targeted C and resolved it into a close binary. Estimated masses of Ca and Cb are 0.70 and 0.66 $\mathcal{M}_\odot$, period ∼4 years.

16142–5047. HIP 79576 has a variable RV (GCS). The 79 mas separation implies an orbital period of ∼5 years. This is the high-PM star LTT 6467 with a low metallicity [Fe/H] = −0.78. Ivanov et al. (2013) found no CPM companions.

16195–3054. HIP 79980 and HIP 79979 form a 23″ CPM pair AB where the F6III primary is slightly evolved, while the G1/G2 secondary is closer to the main sequence, but still above it. The *Hipparcos* parallax of B, −4.7 mas, is obviously wrong, so we assume the parallax of the primary, 20.7 mas. The RV (B) is variable (GCS), and we resolve it into a 40 mas pair with an estimated period on the order of 1 year. The pair moved by 10° in a month. Binary motion is the likely cause of the incorrect *Hipparcos* parallax.

16454–7150. HIP 82032 is located in a crowded field, so the new faint Ab companion found here at 1″.3 could be optical. The star was observed because of its suspected variable RV (GCS), but the newly found companion, even if physical, is too distant to explain this variability. Another visual companion B at 11″.5 (AB = B 2392) is optical, as evidenced by its fast relative motion. The star is on the HARPS exo-planet program.

16563–4040. HIP 82876 is a distant O7V star. The 0″.26 pair AB (HDS 2394) was measured among other neglected binaries. We found another faint companion C at 1″.46 (Figure 2). The star has an extensive literature, including multiplicity surveys with speckle interferometry and RV (Chini et al. 2012). Owing to the large distance, no detectable orbital motion is expected. Indeed, the AB pair was measured with HRCam in 2008.5 at the same position as it is now. Those observations in the y band did not detect the companion C owing to a lower signal-to-noise ratio.

17054–3346. The RV of HIP 83612 varies by 52 km s^{-1} (GCS). It is a very close pair with an estimated period of ∼1.5 years, and the measure near the diffraction limit derived from the elongated power spectrum is tentative. The *Hipparcos* parallax is likely biased by the binary. The visual component B = HIP 83609 (AB = WNO 5) at 25″ is optical.

17098–1031. HIP 83962 = HR 6375 has a variable RV according to the GCS, while N. Gorynya (2013, private communication) detected double lines. It is resolved tentatively at 33 mas with $\Delta y = 1.8$ mag (the 5 ms exposure makes it unlikely that the asymmetry is caused by vibrations). The separation corresponds to an orbital period on the order of 1 year, which could bias the *Hipparcos* parallax. However, Eggleton & Tokovinin (2008) consider the star as single. The new pair was not resolved in 2014.3; presumably it became closer.

17264–4837. HIP 85342 and HIP 85326 form a physical pair AB at 127″ separation (common PM, RV, and parallax). The B component = HIP 85326 has a variable RV and an astrometric acceleration which could hardly be produced by the 1″ speckle companion Bb found here, owing to its long estimated period of ∼300 years. It seems that B is triple and the whole system is quadruple. This companion Bb was not detected in the previous speckle observations because it is red: $\Delta I = 2.4$, $\Delta y = 4$ mag; its color matches a dwarf star at the same distance as the system. However, the field is crowded and the newly found companion could still be optical.

17266–3258. HIP 85360 is an acceleration and spectroscopic binary. Its preliminary spectroscopic period (D. Latham 2012, private communication) corresponds to a semi-major axis of 80 mas. The star is chromospherically active and possibly young. The faint companion found here at 1″.16 is most likely optical, as the field is extremely crowded. Re-observation within a year will resolve its status.

17341–0303. HIP 85963 has a variable RV and is an acceleration binary. The 91 mas separation implies an orbital period of ∼10 years; the estimated masses are 1.37 and 0.81 $\mathcal{M}_\odot$. Despite extensive literature (51 references in SIMBAD), there is no published spectroscopic orbit, while several high-resolution spectroscopic studies addressed the abundance.

17342–1910. B 1863 is a known close binary which has been unexpectedly found to be a triple (Figure 2). The new distant component C is detectable also in the y filter, but we measured only the inner binary in y. The star was observed at the Blanco telescope in 2008.5397, and the pair actually measured then was AC, at 133°.8, 0″.217, $\Delta y = 3.7$ (same as

Table 5
Orbital Elements

WDS (Figure)	Discoverer Designation	P (year)	T_0 (year)	e	Ω (°)	a (″)	i (°)	ω (°)	Gr	Orbit Reference
00026–0829	A 428	414.95	2005.35	0.503	192.2	0.505	111.9	226.8	4	Zul1984b
		±20.96	±2.47	±0.013	±2.0	±0.021	±1.2	±4.2		
00143–2732	HDS 33	10.22	2013.47	0.609	215.3	0.124	28.4	80.0	2	Cve2012
		±0.07	±0.04	±0.009	±5.3	±0.002	±2.5	±4.3		
00155–1608	HEI 299	4.550	1995.363	0.360	60.8	0.306	145.6	344.5	2	Hry1998
		±0.002	±0.016	±0.005	±1.4	±0.002	±1.3	±2.2		
00315–6257	I 260 CD	44.73	2011.62	0.810	241.6	0.495	124.7	112.2	3	Msn2001c
		±0.34	±0.01	±0.001	±0.2	±0.001	±0.3	±0.2		
00321–0511	A 111 AB	10.64	2015.19	0.538	206.5	0.122	155.7	101.6	2	Sta1978b
		±0.02	±0.19	±0.014	±18.5	±0.003	±4.2	±14.9		
00533+0405	A 2307	57.78	2012.51	0.419	222.4	0.233	74.3	357.9	2	USN1999b
		±3.87	±1.25	±0.029	±1.4	±0.005	±1.6	±13.2		
01024+0504	HDS 135 AB	28.23	2002.69	0.671	268.6	0.461	144.8	22.1	2	Bag2006
		±0.17	±0.01	±0.002	±1.0	±0.002	±0.7	±1.2		
01028+0214	A 2308	141.80	1958.95	0.124	306.6	0.367	62.9	10.5	3	Baz1984a
		±5.52	±4.96	±0.025	±1.7	±0.006	±2.2	±13.9		
01104–6727	GKI 3	1.778	1986.193	0.112	68.2	0.147	133.3	73.0	3	(Gln2007)
		±0.006	±0.176	±0.033	±9.8	±0.009	±7.0	±30.8		
01196–0520	A 313	128.51	2014.72	0.161	171.5	0.274	133.7	245.5	2	USN1999a
		±2.24	±1.42	±0.009	±2.4	±0.004	±0.9	±4.5		
01220–6943	I 263	272.15	1936.56	0.374	231.3	0.791	68.6	297.3	4	Msn1999a
		±47.48	±5.30	±0.059	±2.8	±0.075	±1.9	±14.1		
01308–5940	TOK 183	4.66	2012.83	0.462	349.5	0.0458	75.0	13.9	4	…
		±0.23	±0.23	±0.067	±3.4	±0.0030	±0.0	±16.2		
01350–2955	DAW 31 AB	4.562	1932.600	0.317	224.3	0.174	19.5	244.6	1	Msn1999c
		±0.002	±0.034	±0.007	±9.9	±0.003	±2.9	±9.4		
01424–0645	A 1	637.62	1888.34	0.454	232.1	0.844	42.0	264.7	5	Sca2008c
01528–0447	RST 4188	618.71	2619.26	0.553	22.7	1.048	72.1	10.9	5	Hei1996a
02158–1814	HTG 1	295.93	1681.32	0.151	187.1	2.184	35.5	270.2	5	Sod1999
02166–5026	TOK 185	16.00	2011.32	0.467	243.6	0.132	63.2	312.4	5	…
02374–5233	TOK 186	3.22	2011.31	0.083	52.0	0.0785	115.5	17.0	3	…
		±0.06	±0.23	±0.020	±3.0	±0.0031	±2.5	±25.4		
02405–2408	SEE 19	310.26	2016.80	0.839	225.6	0.393	147.2	73.2	4	Lin2010c
		±146.13	±0.32	±0.009	±39.0	±0.098	±3.3	±22.9		
02415–7128	B 1923	101.50	2011.42	0.376	222.9	0.522	116.3	252.3	4	Hrt2012a
		±2.77	±0.33	±0.015	±2.8	±0.010	±0.9	±2.0		
02517–5234	HU 1562	65.00	2021.92	0.876	237.4	0.264	111.7	6.1	4	Hei1979b
		±6.18	±0.35	±0.029	±3.1	±0.005	±5.2	±10.4		
02572–2458	BEU 4 Ca,Cb	1.518	2007.088	0.540	2.0	0.062	160.4	341.8	2	Tok2014a
		±0.001	±0.021	±0.024	±9.1	±0.002	±12.0	±11.0		
03014+0615	HDS 385	15.27	2012.90	0.397	347.4	0.117	52.5	2.7	2	Bag2005
		±0.09	±0.07	±0.004	±1.0	±0.001	±0.7	±2.4		
03236–4005	I 468	237.68	1971.45	0.505	319.5	2.548	41.6	30.9	5	Sod1999
03272+0944	HDS 433	50.81	2008.43	0.571	109.4	0.439	26.7	8.0	3	Cve2010c
		±0.62	±0.04	±0.004	±2.9	±0.004	±1.2	±2.9		
03339–3105	B 52	19.36	1997.19	0.363	140.8	0.224	85.7	11.1	2	Hei1996c
		±0.05	±0.17	±0.011	±0.7	±0.003	±0.8	±4.1		
03544–4021	FIN 344 AB	14.03	2008.05	0.579	247.4	0.0614	32.4	49.7	2	Hrt2012a
		±0.04	±0.04	±0.008	±2.0	±0.0005	±1.5	±2.3		
03545+0510	A 1831 BC	216.02	1986.20	0.099	231.8	0.187	56.0	300.1	4	Ole1998a
		±42.23	±25.43	±0.144	±5.3	±0.013	±5.4	±47.3		
04008+0505	A 1937	42.93	2014.94	0.550	25.9	0.1000	47.1	14.7	2	Tok2014a
		±1.13	±0.15	±0.019	±4.4	±0.0012	±3.1	±8.0		
04070–1000	HDS 521 AB	21.42	1996.78	0.687	219.0	0.225	122.9	76.4	3	Msn2011a
		±0.37	±0.06	±0.009	±1.8	±0.005	±1.0	±0.5		
04163+0710	WSI 97	5.6805	1997.088	0.808	358.1	0.1011	148.0	47.6	3	RAO2014
		±0.0058	±0.011	±0.005	±1.7	±0.0009	*	±1.7		
04368–1733	A 2915	109.99	2012.35	0.470	151.8	0.305	62.0	94.1	3	Baz1986a
		±7.99	±1.14	±0.053	±4.1	±0.025	±5.0	±12.9		
04374–0951	RST 3401	126.18	1967.68	0.366	98.9	0.325	146.2	52.9	3	Nov2007d
		±6.11	±1.47	±0.026	±10.9	±0.011	±5.2	±14.5		
04389–1207	HDS 599	48.48	2003.67	0.828	152.5	0.333	78.4	281.2	4	Cve2014
		±4.70	±0.22	±0.032	±0.9	±0.006	±1.0	±0.8		

Table 5
(Continued)

WDS (Figure)	Discoverer Designation	P (year)	T_0 (year)	e	Ω (°)	a (″)	i (°)	ω (°)	Gr	Orbit Reference
04422+0259	A 2424	55.79	2011.46	0.348	228.8	0.147	85.0	90.8	3	WRH1976a
		±4.07	±0.64	±0.012	±0.6	±0.009	±0.5	±9.0		
04505+0103	A 2622	403.34	1956.27	0.477	259.9	0.345	127.1	270.1	4	Sca2003a
		±62.54	±5.59	±0.046	±10.2	±0.044	±4.9	±23.0		
04506+1505	CHR 20	5.734	2003.829	0.058	130.1	0.0904	114.4	92.8	3	Sod1999
		±0.005	±0.096	±0.007	±0.7	±0.0010	±1.7	±6.0		
04515–3454	FIN 320	42.92	2006.48	0.826	198.4	0.227	111.6	292.1	3	Doc2013d
		±0.39	±0.13	±0.004	±0.6	±0.001	±0.3	±0.2		
04545–0314	RST 5501	84.66	2004.32	0.515	219.1	0.243	120.8	310.3	3	Msn2011c
		±1.42	±0.39	±0.011	±1.0	±0.003	±1.4	±1.9		
05025–2115	DON 91 AB	43.55	1997.46	0.720	246.5	1.062	60.7	280.6	4	Sod1999
		±0.27	±0.86	±0.028	±3.9	±0.049	±2.1	±1.2		
05073–8352	HDS 669	26.45	2014.41	0.669	6.1	0.272	61.0	71.3	4	…
		±1.01	±0.03	±0.016	±2.8	±0.009	±1.4	±2.8		
05245–0224	MCA 18 Aa,Ab	9.399	2011.613	0.435	129.0	0.0462	103.5	34.7	3	Bag1999b
		±0.040	±0.000	±0.432	±6.4	±0.0195	±15.3	±27.1		
05289–0318	DA 6	1491.21	1995.70	0.846	247.1	1.021	48.3	349.7	4	Lin2010c
		±672.53	±1.14	±0.045	±4.3	±0.287	±2.3	±1.1		
05484+2052	STT 118 AB	227.52	1986.06	0.869	137.9	0.792	89.7	290.8	4	Pal2005b
		±15.48	±0.09	±0.026	±2.0	±0.037	±0.8	±1.4		
05532–6150	SLR 15	1251.74	1970.32	0.824	138.4	1.303	122.1	292.2	4	Hei1993d
		±78.90	±0.75	±0.008	±1.7	±0.061	±2.2	±3.6		
05542–2909	FIN 382	20.16	2014.80	0.473	169.2	0.154	129.5	110.8	3	Hrt2012a
		±0.03	±0.08	±0.018	±4.0	±0.003	±2.4	±5.1		
06293–0248	B 2601 AB	16.53	1999.33	0.387	209.6	1.072	53.3	42.0	3	Sgr2000
		±0.01	±0.01	±0.002	±0.3	±0.002	±0.2	±0.4		
06314+0749	A 2817	31.55	2015.34	0.281	57.3	0.192	37.3	320.8	2	Pop1969b
		±1.41	±0.28	±0.015	±4.4	±0.007	±1.9	±11.7		
06359–3605	RST 4816 Ba,Bb	14.03	2004.09	0.577	288.8	0.182	111.9	296.2	2	Tok2012b
		±0.02	±0.03	±0.005	±0.3	±0.001	±0.2	±0.4		
06439–5434	HDS 934	12.37	2014.21	0.216	93.4	0.132	18.5	70.3	3	Hrt2012a
		±0.02	±0.04	±0.004	±4.6	±0.001	±1.9	±4.2		
06454–3148	EHR 9 Ba,Bb	6.865	2014.728	0.224	189.7	0.126	138.9	5.6	4	…
		±0.137	±0.318	±0.038	±13.6	±0.010	±8.3	±15.5		
06481–0948	A 1056	616.86	1962.17	0.522	256.0	0.501	56.7	280.6	4	Sca1983f
		±513.30	±10.30	±0.282	±13.7	±0.255	±7.0	±32.6		
06490–1509	AC 4	581.32	2031.70	0.761	157.5	0.957	52.6	280.6	5	…
06493–0216	FIN 322	58.69	1969.56	0.293	241.6	0.148	112.2	68.0	3	Hrt2011d
		±1.61	±0.78	±0.015	±0.9	±0.006	±1.2	±6.0		
07026+1558	A 2462 AB	44.45	2012.79	0.661	67.3	0.204	134.4	45.5	3	Baz1976
		±0.44	±0.02	±0.002	±0.7	±0.001	±0.5	±0.8		
07043–0303	A 519 AB	90.40	2012.50	0.260	93.6	0.397	96.6	283.0	3	Tok2014a
		±1.44	±0.42	±0.026	±0.7	±0.006	±0.7	±3.4		
07113–1032	A 2122	169.68	2021.25	0.712	150.3	0.203	120.2	228.6	4	USN2002
		±13.75	±2.39	±0.021	±5.1	±0.007	±3.7	±2.5		
07143–2621	FIN 323	118.54	1971.01	0.747	131.3	0.178	80.2	85.0	4	Ole2004b
		±11.14	±0.74	±0.094	±3.0	±0.012	±1.0	±3.6		
07155–7552	I 312	847.09	2012.33	0.859	152.9	2.308	97.5	86.1	5	…
07175–4659	I 7	85.01	1958.70	0.955	236.0	0.891	104.4	244.8	3	Msn2011c
		±1.22	±0.44	±0.014	±5.1	±0.048	±2.3	±2.5		
07374–3458	FIN 324 AC	80.68	2016.58	0.648	262.1	0.323	158.6	32.7	3	Hrt2012a
		±1.63	±0.37	±0.014	±8.4	±0.004	±4.9	±8.2		
07435–2711	B 737	290.20	1967.59	0.566	86.2	0.335	105.7	324.4	4	…
		±14.74	±1.93	±0.014	±2.1	±0.016	±1.2	±4.3		
07456–3410	TOK 193	15.00	2010.83	0.305	58.4	0.473	67.7	342.5	4	…
		*	±0.15	±0.032	±0.8	±0.016	±1.4	±6.8		
07490–2455	TOK 194	2.422	2011.557	0.408	212.	0.0374	29.5	295.3	3	…
		±0.075	±0.084 s	±0.072	±32.	±0.0031	±13.9	±28.8		
07522–4035	TOK 195	7.388	2012.067	0.380	90.3	0.0624	86.2	170.0	4	(Jnc2005)
		±0.657	±0.206	±0.000	±6.8	±0.0071	±7.0	±0.0		
08061–0047	A 1971	572.52	1910.43	0.409	202.8	1.070	125.6	99.1	5	Ole1993
08125–4616	CHR 143 Aa,Ab	31.42	2017.49	0.339	173.6	0.0738	71.7	257.6	3	Msn2010c
		±0.33	±0.21	±0.020	±1.0	±0.0012	±1.7	±2.0		

Table 5
(Continued)

WDS (Figure)	Discoverer Designation	P (year)	T_0 (year)	e	Ω (°)	a (″)	i (°)	ω (°)	Gr	Orbit Reference
08144–4550	FIN 113 AB	385.48	1973.09	0.700	103.4	0.566	81.6	346.0	5	Cve2010e
08251–4910	RST 321	25.78	2000.85	0.219	128.6	0.310	40.9	232.1	2	Hrt2012a
		±0.41	±0.15	±0.005	±0.8	±0.004	±0.7	±4.1		
08270–5242	B 1606	14.66	2011.84	0.353	277.0	0.152	61.7	11.9	2	Tok2012b
		±0.08	±0.01	±0.002	±0.2	±0.000	±0.1	±0.2		
08317–2601	I 807	720.66	1936.16	0.370	134.2	0.631	129.4	244.5	5	…
08345–3236	FIN 335	17.36	2014.08	0.572	268.9	0.139	30.6	43.8	2	Doc2013d
		±0.03	±0.03	±0.004	±1.9	±0.001	±1.3	±2.0		
08380–0844	HDS 1242	41.66	2014.55	0.392	198.2	0.249	24.9	254.0	4	Hrt2012a
		±4.50	±0.53	±0.011	±14.8	±0.020	±6.3	±5.1		
08391–5557	HU 1443 AB	876.85	1860.89	0.644	104.3	1.400	128.1	314.0	5	…
08421–5245	B 1624	74.05	1995.69	0.240	89.7	0.474	71.4	0.1	3	Hrt2012a
		±0.43	±0.31	±0.003	±0.2	±0.002	±0.2	±2.1		
08431–1225	RST 3603	98.92	1964.70	0.393	155.5	0.268	154.5	14.1	3	Hrt2010a
		±3.48	±1.39	±0.031	±13.1	±0.007	±10.0	±17.8		
08447–4238	CHR 238	2.257	2012.557	0.615	42.4	0.0785	145.8	332.8	3	Hrt2012a
		±0.004	±0.056	±0.042	±7.1	±0.0046	±14.0	±7.9		
08474–1703	BU 586	442.24	2009.74	0.529	239.7	0.538	63.9	317.3	5	Msn2009
08538–4731	FIN 316	7.209	2007.601	0.253	108.5	0.0781	11.1	106.8	2	Hrt2012a
		±0.004	±0.009	±0.002	±8.8	±0.0003	±1.6	±8.7		
08539+0149	A 2554	43.86	2021.18	0.502	112.4	0.210	162.4	339.7	3	Zir2007
		±0.80	±0.30	±0.030	±16.7	±0.005	±11.4	±17.3		
08589+0829	DEL 2	5.566	2006.445	0.778	281.8	0.398	122.2	23.7	3	Hrt2012a
		±0.024	±0.039	±0.019	±1.7	±0.008	±3.1	±3.2		
09149+0427	HEI 350	198.56	2000.40	0.574	84.6	1.856	122.2	344.7	5	(Hei1994a)
09173–6841	FIN 363 AB	3.445	2013.376	0.455	154.6	0.0888	140.7	117.2	2	Doc2013d
		±0.002	±0.007	±0.003	±0.8	±0.0004	±0.6	±0.7		
09194–7739	KOH 83 Aa,Ab	19.84	1999.00	0.795	20.2	0.146	65.0	276.2	5	…
09228–0950	A 1342 AB	52.98	2020.20	0.074	202.4	0.169	68.5	58.7	2	Msn2011a
		±0.37	±0.45	±0.008	±0.4	±0.001	±0.6	±3.3		
09252–1258	WSI 73	27.3	2014.80	0.860	101.1	0.235	86.0	283.4	5	…
09275–5806	CHR 240	2.621	2014.453	0.173	267.4	0.0478	111.4	125.6	3	…
		±0.025	±0.049	±0.029	±2.3	±0.0018	±2.3	±6.6		
09278–0604	B 2530	34.80	2010.11	0.270	330.8	0.428	85.4	341.9	2	Sod1999
		±0.06	±0.10	±0.003	±0.1	±0.001	±0.1	±1.1		
09313–1329	KUI 41	18.38	2002.17	0.335	230.8	0.647	139.9	105.3	3	Sod1999
		±0.11	±0.03	±0.004	±0.9	±0.002	±0.2	±0.6		
09327+0152	FIN 349	40.57	1972.12	0.420	138.6	0.154	54.7	72.6	2	Msn2011a
		±0.19	±0.16	±0.009	±0.6	±0.001	±0.6	±0.8		
09387–3937	I 202	163.69	2005.49	0.414	178.6	0.932	111.4	203.4	4	Hrt2012a
		±3.53	±0.67	±0.012	±1.1	±0.017	±0.9	±2.2		
09407–5759	B 780	10.63	2005.86	0.338	86.1	0.123	128.6	17.6	2	DRs2012
		±0.01	±0.02	±0.002	±0.3	±0.000	±0.3	±0.8		
09495–1033	A 1344	260.75	1991.89	0.781	119.5	0.355	116.2	90.9	4	Hei1986b
		±25.54	±1.16	±0.030	±2.4	±0.009	±2.6	±1.8		
10050–5119	HU 1594	134.51	2028.97	0.629	87.3	0.281	64.4	21.0	3	USN2002
		±3.76	±2.28	±0.033	±1.6	±0.009	±3.3	±4.6		
10120–2836	B 194	91.89	2003.58	0.676	198.3	0.226	76.0	59.7	3	USN2002
		±0.85	±0.22	±0.012	±0.5	±0.003	±0.7	±1.1		
10161–2837	TOK 199	2.507	2014.734	0.353	278.5	0.0450	114.5	51.8	4	…
		±0.022	±0.020	±0.017	±1.7	±0.0013	±1.8	±3.0		
10282–2548	FIN 308 AB	32.76	2018.13	0.739	155.4	0.144	48.6	270.6	3	Hrt2012a
		±2.67	±1.28	±0.135	±4.5	±0.033	±16.2	±2.7		
10375–0932	RST 3708	154.81	1971.26	0.457	183.9	0.416	54.6	24.4	4	Hei1991
		±55.88	±11.57	±0.197	±17.0	±0.026	±19.7	±37.9		
10419–7811	HDS 1530	43.48	2007.33	0.637	114.9	0.277	55.2	121.2	5	…
10426+0335	A 2768	81.66	1976.39	0.550	57.8	0.401	140.1	354.9	2	Hrt2010a
		±2.05	±0.21	±0.005	±1.0	±0.002	±1.7	±2.9		
10465–6416	FIN 364 AB	13.25	2020.60	0.025	316.7	0.0805	115.2	17.6	2	Hrt2012a
		±0.20	±2.49	±0.022	±1.7	±0.0014	±2.2	±64.8		
10529–1717	HDS 1556	14.93	2002.74	0.544	110.5	0.173	99.2	51.4	3	Hrt2012a
		±0.26	±1.39	±0.056	±2.1	±0.028	±3.6	±17.3		
10557+0044	BU 1076	138.90	1921.62	0.714	219.3	0.750	125.7	323.4	4	Hrt2010a

Table 5
(Continued)

WDS (Figure)	Discoverer Designation	P (year)	T_0 (year)	e	Ω (°)	a (″)	i (°)	ω (°)	Gr	Orbit Reference
		±3.02	±5.07	±0.036	±4.0	±0.069	±9.5	±10.8		
11009–4030	FIN 365	26.86	1990.21	0.087	107.4	0.168	100.5	50.5	3	Tok2012b
		±0.23	±1.14	±0.029	±1.1	±0.004	±0.9	±16.3		
11014–1204	HDS 1572	18.64	2013.69	0.686	142.4	0.173	98.7	133.8	3	…
		±0.72	±0.03	±0.013	±0.4	±0.003	±0.8	±1.5		
11102–1122	HDS 1590	20.63	1995.82	0.698	255.8	0.136	129.4	72.2	3	Hrt2012a
		±1.62	±1.68	±0.011	±5.4	±0.006	±0.9	±1.5		
11125–1830	BU 220	365.68	1983.93	0.434	325.3	0.553	99.8	337.3	4	Hei1995
		±8.02	±3.59	±0.014	±0.6	±0.022	±0.8	±6.7		
11272–1539	HU 462	48.40	2008.46	0.087	127.6	0.445	166.5	347.7	2	WSI2006b
		±0.11	±0.49	±0.004	±11.7	±0.003	±2.9	±10.5		
11297–0619	A 7	204.32	2050.54	0.656	93.3	0.447	105.1	59.8	4	USN2002
		±11.20	±19.37	±0.017	±4.9	±0.077	±5.8	±13.4		
11544–3745	HWE 71	248.80	2008.48	0.720	276.3	1.004	99.6	162.0	5	…
12396–3717	DAW 63	56.85	2021.02	0.287	194.5	0.387	21.6	3.7	3	Hrt2010a
		±0.32	±0.55	±0.015	±13.8	±0.004	±5.3	±16.4		
13145–2417	FIN 297 AB	60.81	1957.92	0.691	188.3	0.233	66.0	295.0	2	Msn2010c
		±3.27	±3.17	±0.041	±2.7	±0.010	±1.7	±2.2		
13169–3436	I 1567	40.88	2006.40	0.457	145.5	0.326	121.6	274.0	2	Tok2012b
		±0.18	±0.01	±0.002	±0.2	±0.000	±0.1	±0.4		
13310–3924	SEE 179	83.14	1956.12	0.521	146.5	0.161	145.2	244.4	2	Fin1964b
		±1.26	±1.91	±0.013	±8.6	±0.004	±4.0	±3.6		
13342–1623	RST 3844	121.85	2010.94	0.432	264.5	0.255	117.6	19.4	3	USN2002
		±2.70	±0.49	±0.007	±1.1	±0.003	±0.7	±2.4		
13472–0943	KUI 65	155.21	2014.17	0.854	99.0	0.268	144.2	22.7	3	Zir2012
		±20.85	±0.11	±0.006	±4.5	±0.012	±6.1	±7.6		
13571–2731	I 234	200.72	2057.91	0.725	165.9	0.773	117.3	83.9	4	Mro1966b
		±17.44	±10.04	±0.023	±8.6	±0.043	±1.3	±1.1		
14020–2108	WSI 79	30.00	2015.16	0.746	123.3	0.239	135.3	119.4	4	…
		*	±0.17	±0.037	±9.9	±0.011	±2.7	±9.2		
14025–2440	B 263	161.43	2014.56	0.499	20.4	0.480	38.8	81.7	4	…
		±28.68	±1.92	±0.019	±9.9	±0.072	±9.0	±10.0		
14190–0636	HDS2016 AB	18.67	2003.74	0.302	285.0	0.348	107.9	71.0	3	…
		±0.33	±0.03	±0.011	±0.8	±0.001	±0.5	±2.2		
14295–3702	HDS 2045 Aa,Ab	18.39	2008.92	0.468	160.0	0.137	126.9	137.3	3	…
		±0.74	±0.06	±0.018	±2.6	±0.006	±2.0	±2.2		
14375+0217	CHR 42 Aa,Ab	21.54	1994.64	0.844	312.4	0.143	53.7	41.9	3	Hrt2000a
		±0.10	±0.20	±0.016	±3.6	±0.007	±3.0	±5.6		
14581–4852	WSI 80	23.40	1998.44	0.724	267.3	0.342	113.1	297.0	4	…
		±0.94	±2.07	±0.020	±4.9	±0.050	±6.6	±8.6		
15047–5625	RST 2937	146.05	2006.50	0.809	173.6	0.214	105.9	113.4	4	…
		±24.74	±0.03	±0.054	±2.0	±0.028	±4.3	±6.0		
15226–4755	SLR 20	429.60	1972.88	0.469	56.0	1.899	109.7	344.6	4	Hei1993d
		±4.57	±1.56	±0.004	±0.9	±0.019	±0.5	±2.0		
15227–4441	COP 2 AB	736.69	2009.83	0.808	125.1	1.409	117.6	19.6	5	Zir2007
15246–4835	B 1288 AB	449.82	2013.70	0.742	143.4	0.326	67.5	284.9	4	USN2002
		±50.91	±0.60	±0.019	±1.7	±0.028	±2.3	±6.1		
15252–4659	RST 767	249.27	1921.63	0.504	116.6	0.525	136.0	335.4	5	Csa1975c
15262–2819	RST 769	201.47	1977.28	0.379	163.2	0.392	141.9	238.0	5	Doc1996b
15355–4751	HDS 2191	62.52	2005.25	0.315	201.9	0.302	88.6	267.1	4	…
		±14.96	±1.10	±0.243	±1.1	±0.037	±0.9	±14.6		
15420+0027	A 2176	52.68	1987.16	0.653	97.7	0.148	27.2	279.3	2	USN2006b
		±2.04	±0.38	±0.027	±12.9	±0.008	±7.4	±9.9		
16035–5747	SEE 258 AB	26.84	1990.87	0.515	42.0	0.328	168.7	320.0	2	Sod1999
		±0.09	±0.21	±0.012	±43.2	±0.006	±9.9	±44.1		
16065–4027	RST 1876	96.95	2037.31	0.006	97.5	0.303	97.5	338.1	4	…
		±2.07	±1.54	±0.027	±0.8	±0.011	±0.9	±6.2		
16085–1006	BU 949	56.33	2018.34	0.774	198.1	0.289	82.3	157.8	2	Hrt2009
		±0.20	±0.35	±0.016	±0.5	±0.003	±0.5	±2.9		
16170–5342	I 987	102.47	1952.08	0.262	59.3	0.384	15.9	12.2	3	Hei1986a
		±1.77	±1.72	±0.021	±39.9	±0.012	±10.8	±43.4		
16224–3220	JSP 691	264.96	1958.53	0.590	101.9	0.870	122.0	307.2	4	Hei1981a
		±43.30	±0.81	±0.046	±2.9	±0.102	±2.2	±4.7		

Table 5
(Continued)

WDS (Figure)	Discoverer Designation	P (year)	T_0 (year)	e	Ω (°)	a (″)	i (°)	ω (°)	Gr	Orbit Reference
16229–1701	CHR 54	39.89	2011.76	0.634	236.6	0.183	101.9	306.0	3	Lin2011c
		±1.21	±1.14	±0.049	±2.7	±0.008	±2.1	±2.8		
16318–0216	A 693	96.18	1991.33	0.278	220.9	0.195	129.3	344.2	2	Hrt2010a
		±0.89	±0.68	±0.011	±2.2	±0.003	±1.7	±3.8		
16391–3713	FIN 340 AB	23.99	2013.87	0.621	149.6	0.102	55.4	143.3	2	Hrt2012a
		±0.06	±0.02	±0.004	±0.4	±0.000	±0.4	±0.8		
16544–3806	HDS 2392	37.25	2010.49	0.325	166.5	0.187	60.2	321.9	5	…
16589–3737	SEE 315	38.73	1984.63	0.154	243.9	0.186	39.4	102.4	2	Sta1981a
		±4.48	±1.11	±0.106	±1.7	±0.006	±8.6	±11.2		
17156–1018	BU 957	90.33	1934.61	0.554	23.0	0.296	102.0	7.0	3	Hei1984b
		±1.52	±2.41	±0.067	±2.1	±0.013	±4.6	±11.3		
17156–3836	FIN 355	14.23	1985.97	0.476	191.9	0.249	115.3	137.2	2	Msn2010c
		±0.03	±0.06	±0.010	±0.6	±0.002	±0.6	±1.0		
17157–0949	TOK 53 Ba,Bb	5.10	2010.25	0.416	349.0	0.0305	150.0	326.3	2	…
		±0.18	±0.52	±0.076	±556	±0.0056	±35.0	±78.0		
17157–0949	A 2592 AB	157.60	2013.20	0.330	31.7	0.381	133.6	267.0	3	Tok2014a
		±9.0	±1.56	±0.017	±1.4	±0.017	±1.6	±7.5		
17166–0027	A 2984	140.76	1890.53	0.866	220.5	0.959	65.1	287.5	4	Ole1993
		±0.23	±0.36	±0.003	±0.0	±0.008	±0.0	±0.0		
17181–3810	SEE 324	300.00	1997.49	0.484	249.6	0.439	106.5	42.2	5	…
17283–2058	A 2244 AB	44.52	2015.23	0.578	265.5	0.168	40.2	25.0	2	Msn1999c
		±2.18	±0.26	±0.044	±9.7	±0.003	±3.9	±15.3		
17305–1006	RST 3978	49.24	1981.10	0.343	96.8	0.547	83.0	79.5	3	…
		±1.19	±1.52	±0.090	±1.8	±0.044	±2.2	±7.4		
17471–3807	I 1336	36.06	2017.29	0.578	15.8	0.132	45.0	11.3	3	Hei1986b
		±2.08	±0.19	±0.050	±8.4	±0.001	±0.1	±14.2		
18018+0118	BU 1125 AB	213.97	2028.73	0.601	161.3	0.787	55.1	66.0	4	Hrt2009
		±23.83	±1.62	±0.074	±4.4	±0.033	±5.1	±5.1		
18044–5953	RST 5099	45.64	2009.10	0.513	114.4	0.259	68.2	107.1	4	Hrt2010a
		±2.10	±0.10	±0.010	±1.0	±0.004	±1.0	±2.7		
18092–2211	RST 3157	9.325	2015.286	0.423	250.8	0.154	49.6	54.5	3	Hei1990c
		±0.021	±0.175	±0.042	±6.5	±0.005	±5.2	±6.3		
18171–4336	HDS 2583	153.90	2016.88	0.724	58.5	0.153	129.9	24.2	4	…
		±308.47	±2.38	±0.025	±15.5	±0.082	±44.0	±81.0		
18281–2645	HDS 2615	150.28	1990.48	0.609	166.6	0.897	96.4	328.7	4	…
		±211.19	±6.64	±0.004	±3.2	±0.366	±4.2	±76.5		
18305–2848	HDS 2624	42.93	2007.53	0.531	42.3	0.0979	144.5	14.0	3	…
		±10.94	±1.05	±0.104	±22.1	±0.0211	±33.2	±24.7		
18323–1439	CHR 73	2.774	2012.600	0.602	213.9	0.0365	135.6	2.0	3	Ole2005d
		±0.002	±0.189	±0.166	±10.6	±0.0053	±23.2	±22.7		
18439–0649	YSC 133	13.52	2002.36	0.124	97.6	0.0787	112.1	290.2	3	…
		±2.60	±4.77	±0.023	±2.4	±0.0117	±3.2	±77.4		
18465–0058	MCA 53 Aa,Ab	42.48	2012.42	0.665	163.7	0.102	131.1	355.5	3	Msn2010c
		±2.20	±1.12	±0.057	±21.8	±0.008	±11.3	±39.0		
18516–6054	RST 5126	54.16	2011.97	0.492	195.0	0.130	21.7	12.8	3	…
		±3.17	±0.36	±0.020	±34.5	±0.005	±13.8	±36.1		USN2002
19029–5413	I 1390	47.36	2009.65	0.682	241.2	0.198	56.0	51.0	3	…
		±0.80	±0.60	±0.052	±7.8	±0.012	±4.2	±7.5		
19040–3804	I 1391	47.38	2006.14	0.641	271.3	0.178	35.8	56.4	4	Hei1973b
		±0.22	±0.23	±0.019	±5.2	±0.003	±1.3	±5.7		
19105–5813	B 2468	182.29	2013.45	0.891	168.5	0.655	140.0	5.0	5	…
19155–2515	B 430	19.95	2014.98	0.506	285.1	0.132	82.1	7.5	2	Hrt2001b
		±0.09	±0.41	±0.042	±0.5	±0.004	±1.0	±5.7		
19164+1433	CHR 85 Aa,Ab	13.673	2008.572	0.022	242.3	0.0583	131.3	262.7	2	McA1993
		±0.069	±1.101	±0.010	±4.5	±0.0014	±3.7	±28.7		
19194–0136	HDS 2734 Aa,Ab	41.19	2021.53	0.506	27.8	0.321	30.4	348.2	4	…
		±5.46	±2.07	±0.068	±39.7	±0.018	±7.2	±57.6		
19296–1239	HU 75	129.67	2009.47	0.652	183.1	0.496	31.5	245.3	3	Sca2003d
		±2.70	±0.29	±0.012	±5.9	±0.013	±3.4	±4.7		
19398–2326	SEE 389	46.20	1976.63	0.088	327.9	0.221	93.5	0.4	2	Doc1994a
		±0.10	±0.60	±0.007	±0.3	±0.001	±0.2	±4.7		
19407–0037	CHR 88 Aa,Ab	20.56	1996.01	0.058	185.7	0.0854	150.8	328.1	3	Msn2010c
		±0.14	±1.04	±0.030	±12.6	±0.0024	±7.0	±27.5		

Table 5
(Continued)

WDS (Figure)	Discoverer Designation	P (year)	T_0 (year)	e	Ω (°)	a ($''$)	i (°)	ω (°)	Gr	Orbit Reference
19573+0513	A 604	228.15	1935.43	0.268	94.7	0.291	108.0	306.0	3	Hei1991
		±17.63	±5.63	±0.019	±1.9	±0.016	±1.2	±12.2		
19581–4808	HDS 2842	32.04	2015.65	0.807	254.7	0.273	74.1	67.2	4	…
		±7.08	±0.23	±0.061	±7.9	±0.031	±0.9	±6.0		
20210–1447	BLA 7 Aa,Ab	3.765	2015.704	0.043	34.3	0.0665	80.9	120.0	3	Msn1994
		*	±0.035	*	±2.1	±0.0023	±3.2	*		
20347–6319	HU 1615	357.17	1999.08	0.851	257.5	0.387	46.0	263.0	5	USN2002
20507–3116	B 997	63.67	2014.34	0.179	281.1	0.207	41.5	306.4	3	Hrt2010a
		±34.66	±14.29	±0.142	±27.2	±0.053	±8.1	±141.1		
20562–3146	B 1001	265.93	1969.51	0.369	187.0	0.322	131.2	219.0	4	USN2002
		±10.98	±2.93	±0.021	±5.1	±0.016	±3.7	±9.4		
21051+0757	HDS 3004 AB	80.42	2016.78	0.691	88.1	0.463	58.0	48.7	4	Lin2012a
		±163.73	±1.39	±0.062	±32.2	±0.326	±21.2	±63.5		
21058–5744	HU 1625	560.04	2072.29	0.000	222.1	0.657	81.6	118.5	5	…
21074–0814	BU 368 AB	345.28	1954.64	0.665	270.1	0.576	87.6	304.2	3	Pal2005b
		±15.75	±1.11	±0.020	±0.5	±0.013	±0.6	±1.9		
21158–5316	FIN 329	36.04	1997.91	0.115	260.5	0.179	107.1	284.8	3	Doc2013d
		±0.59	±3.77	±0.035	±3.3	±0.006	±0.7	±29.5		
21243+0343	A 2288	122.72	1950.41	0.659	135.4	0.300	139.4	86.1	3	Sca2003e
		±2.29	±0.50	±0.011	±4.3	±0.007	±1.8	±3.3		
21255+0203	A 2289 AB	159.45	2008.15	0.652	141.1	0.207	111.0	51.1	4	USN2002
		±21.43	±1.85	±0.025	±4.2	±0.013	±3.1	±7.1		
21274–0701	HDS 3053	20.93	2015.86	0.349	152.8	0.166	51.1	148.5	2	Msn2010c
		±0.84	±0.35	±0.043	±2.2	±0.005	±1.7	±3.3		
21436–1108	LV 10	1219.17	2038.43	0.494	9.1	2.039	36.2	4.2	5	USN2002
21477–1813	CHR 223	113.86	2018.85	0.748	284.3	0.365	99.8	71.5	5	
21536–1019	FIN 358	49.38	1976.32	0.770	289.4	0.0791	30.5	9.2	3	Msn2001c
		±1.98	±1.86	±0.054	±40.9	±0.0025	±11.4	±49.2		
21552–6153	HDO 296 AB	27.94	1997.59	0.420	282.0	0.276	83.2	41.4	2	Doc2011f
		±0.32	±0.41	±0.031	±0.4	±0.009	±0.5	±5.0		
22029+1547	HDS 3129	20.57	2005.43	0.777	230.1	0.100	124.9	273.1	3	Hor2010
		±0.07	±0.02	±0.002	±0.5	±0.000	±0.2	±0.3		
22156–4121	CHR 187	25.87	2014.92	0.386	91.6	0.201	68.8	66.7	3	…
		±0.13	±0.05	±0.006	±0.4	±0.004	±0.7	±0.6		
22241–0450	BU 172 AB	145.07	1987.66	0.702	113.5	0.402	161.4	296.9	2	Doc2007d
		±1.85	±0.05	±0.003	±3.0	±0.003	±0.7	±3.0		
22384–0754	A 2695	132.45	2027.46	0.576	285.5	0.252	76.8	47.9	3	Hrt2010a
		±4.91	±6.74	±0.039	±1.4	±0.022	±2.8	±7.8		
22500–3248	HDO 301	26.46	2015.07	0.516	194.6	0.184	162.9	255.8	2	Hrt2010a
		±0.04	±0.04	±0.003	±5.2	±0.001	±1.5	±4.9		
22546+1054	HDS 3257	249.14	2007.00	0.415	51.2	0.344	67.1	20.9	4	…
		±99.01	±45.27	±0.361	±18.4	±0.255	±26.0	±122.6		
23227–1502	HU 295	64.33	2006.96	0.148	276.3	0.406	77.8	1.6	2	USN1999b
		±0.31	±0.45	±0.003	±0.3	±0.002	±0.5	±2.9		
23374+0737	FOX 102 AB	127.12	2006.75	0.292	139.1	0.263	22.2	259.4	3	Hrt2014b
		±3.20	±0.64	±0.010	±6.6	±0.005	±2.8	±7.8		

now, see Table 2). The inner pair AB with a smaller Δm was unresolved in 2008.5, while it is clearly resolved now. Owing to the large distance from the Sun, we expect only a slow motion, so even the inner pair observed since 1929 may not yet be ready for computing its first orbit.

17342–5454. HIP 85969 has a variable RV according to the GCS and confirmed by Jones et al. (2002). The $0\overset{''}{.}55$ separation implies a period on the order of 80 years. The star is on the exo-planet program at the Anglo-Australian Telescope.

18243–0405. The neglected pair YSC 67 turned out to be a new triple (Figure 2). The outer $0\overset{''}{.}35$ binary AB was known previously, now we detect elongation that implies an inner subsystem Aa,Ab. We compared with stars in the same area of the sky observed before and after to assure that the elongation is not of instrumental origin; it is seen in two filters.

18267–3024. HIP 90397 is an acceleration binary with a variable RV (GCS), resolved here at 69 mas (estimated period ~4 years). The star is targeted by exo-planet programs.

18346–2734. HIP 91075 was noted as a double-lined binary by the GCS (one observation only). The separation of 86 mas implies a period of ~10 years, while the double-lined observation matches the moderate magnitude difference (estimated masses 1.04 and 0.77 $\mathcal{M}_\odot$). The star is an X-ray source, so a future combined orbit could determine masses for testing evolutionary models of young stars. The sky around the object is quite crowded; the $9''$ companion I 1026 is optical (it moves too fast).

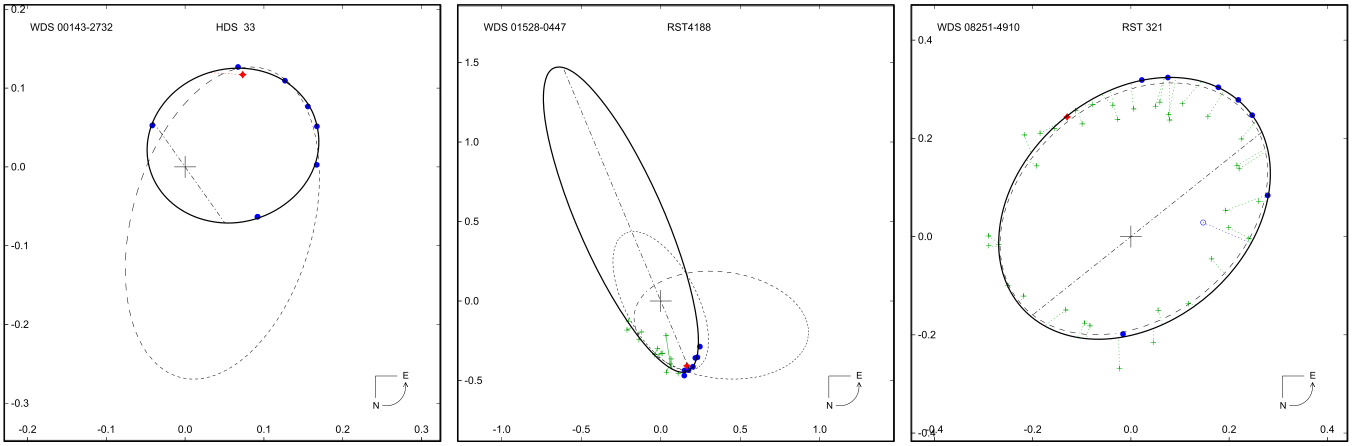

Figure 3. Examples of revised orbits. New orbits are plotted with solid lines, previous orbits in dashed lines. The position of the primary at the coordinate center is marked by a large cross, the line of nodes is traced by a dash–dotted line. The scale is in arcseconds. Interferometric (solid blue), *Hipparcos* (red), and micrometer (green crosses) measures are connected to their expected positions on the new orbit. A dotted "O–C" line indicates a measure given zero weight in the orbit solution. Left: a dramatic orbit revision for 01143–2732 (HDS 33, period 10.2 years). Center: the long-period system 01528–0447 (RST 4188, 619 years), where new interferometric observations caused a substantial orbit revision; two more centuries of data are still needed to cover the extremity of the ellipse and to constrain period and semi-major axis. Right: a minor revision of 08251–4910 (RST 321, 25.8 years) demonstrating systematic errors of the historic micrometer measures.

19206–0645. HIP 95068 is the neglected *Hipparcos* binary HDS 2735 AB, a distant K-type giant. We did not resolve this 0″.1 binary, which remains unconfirmed, but detected instead another faint star at 1″. The stellar background is crowded, the PM is small, and the status of the new companion remains uncertain.

19209–3303. HIP 95106 and 95110 form the 13″.7 pair HJ 5107 AB. The RV variability of A was suspected by the GCS, it is now resolved as a 0″.27 binary with estimated period of ~35 years. The component B was also observed and found unresolved. It contains a spectroscopic pair (A. Tokovinin 2015, in preparation), the whole system is quadruple.

19221–2931. HIP 95203 is another acceleration binary with variable RV resolved here. The relatively large separation of 0″.77 corresponds to a period of ~180 years. The actual period can be as short as 60 years if the pair is seen now near its maximum separation (it would then have been closer at the time of the *Hipparcos* mission). Most likely, however, the faint visual companion found here and the spectroscopic/acceleration pair make a triple system. There is another companion HIP 95164 at 435″. The status of this wide pair (is it a real binary or just two members of a moving group?) is not clear, but the association of those stars leaves no doubt (common RV, PM, and parallax).

19409–0152. HIP 96834 has a spectroscopic orbit with a period of 1 year and expected semi-major axis of 27 mas (D. Latham 2012, private communication). We resolved this pair, although the measurement near the diffraction limit is uncertain. However, there are some unsolved questions. Why, despite the small magnitude difference $\Delta y = 1.2$ mag, were double lines not seen? Why, despite the 1 year period, was the *Hipparcos* parallax not strongly affected and the star appears to be on the main sequence?

19453–6823. We resolved the secondary component of HDS 2806 AB into a close pair Ba,Bb (Figure 2). This is a K3 dwarf within 50 pc from the Sun. The pair Ba,Bb should be fast and turn around in about 10 years.

22259–7501. HIP 110712 and 110719 form the 20″.6 pair DUN 238 AB. We observed both components. The A component has a variable RV according to the GCS, but not confirmed by Jones et al. (2002); it was unresolved. The newly found pair Ba,Bb has a period on the order of 10 years. Considering the distant companion C found by Caballero (2012), the system contains at least 4 stars.

4. NEW AND IMPROVED ORBITS

The measurements reported here served to improve or compute anew orbits of 194 binary stars. The orbital elements in standard notation and their formal errors are given in Table 5. Its last column lists the VB6 code to a prior orbit if it exists (astrometric orbits in brackets). Errors of the elements (except provisional orbits of grade 5) are given in the following line. For the elements that were fixed (from, for example, a spectroscopic orbit), an asterisk replaces the error. As discussed in TMH14, orbit improvements range from minor "cosmetic" upgrades to some quite drastic revisions. Blanks in the last column indicate the 43 first-time orbit solutions (plus three with prior astrometric orbits). The grades are assigned according to the general grading rules adopted in VB6 (Hartkopf et al. 2001). Most orbital elements are derived using the USNO orbit code.

We do not publish figures for all new orbits here, as they will be available online in VB6.[7] Figure 3 illustrates orbit revisions ranging from dramatic to minor. Three first-time orbits are presented in Figure 4. Below we comment on some pairs.

04163–0710. WSI 97 is a single-lined nearby binary. Using the radial velocities measured by D. Latham (2012, private communication), we computed a combined orbit (the previous visual orbit reported by Riddle et al. (2015) had a wrong period). The inclination is close to 180° and had to be fixed in order to match the RV amplitude. The complete orbit including RVs will be published later.

04506–1505. CHR 20 is a Hyades binary for which Griffin (2012) published an SB2 orbit. We combined his RVs with the speckle data, resulting in a very accurate period. The combined orbit corresponds to a mass sum of 2.1 $\mathcal{M}_\odot$ and an orbital

[7] http://www.usno.navy.mil/USNO/astrometry/optical-IR-prod/wds/orb6.html

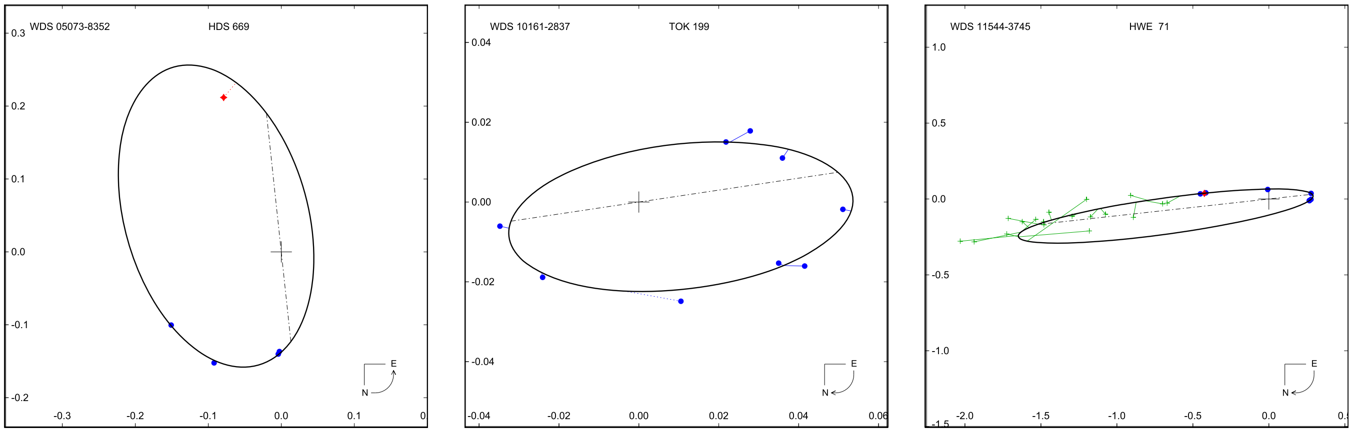

Figure 4. Examples of new orbits (see the caption to Figure 3). Left: the *Hipparcos* binary 05073–8352 (HDS 699, period 26.5 years). Center: "fast" spectroscopic binary 10161–2837 (TOK 199, 2.5 years). Right: visual binary 11544–3745 (HWE 71, 249 years) that passed recently through periastron.

parallax of 22 mas, in good agreement with the HIP2 parallax of 23.69 ± 0.87 mas.

05245–0224. MCA 18 Aa,Ab has an SB1 orbit with $P = 9.44$ years. The orbit given here uses only the speckle data, however.

07490–2455. The period of TOK 194 matches the astrometric orbit of Goldin & Makarov (2007). The mass sum in this pair composed of a giant primary and possibly an A-type secondary is $5.9\,\mathcal{M}_\odot$. The measure on 2011.93 was ignored as spurious (it was affected by vibrations).

07522–4035. TOK 195 is the bright star a Pup (HD 64440, HR 3080) known as a spectroscopic binary. However, examination of the RV data reveals that the orbit by Parsons (1983) is only approximate. The binary is difficult to measure, always close to the diffraction limit and with $\Delta m \sim 3$. Instead of the spectroscopic period of 6.99 years, our orbit has $P = 7.4$ years and is still preliminary. More RV coverage is obviously needed.

08391–5557. HU 1443 A,BC is a triple system. We provide the first very tentative orbit for the outer binary, but note its large residuals from the recent measures of AB. Strictly speaking, the orbit should describe the motion of the center-of-gravity of BC around A, rather than the measures of AB. Such refinement was made for the orbit of A 2592 AB (17156–0949), but it is not warranted for this preliminary orbit.

10161–2837. TOK 199 is marked as an SB2 in the GCS, while D. Latham (2012, private communication) derived an orbital period of 916 days, now independently confirmed by our orbit (Figure 4).

17157–0949. This is the triple system HIP 84430. We computed the first orbit of the secondary subsystem Ba,Bb which was discovered at SOAR in 2009 and has just completed one full revolution since. Its separation is always close to the diffraction limit. Adopting a mass sum of $2.6\,\mathcal{M}_\odot$ for Ba,Bb, the resulting dynamical parallax is 7.6 ± 1.5 mas, while the HIP2 parallax is 4.9 ± 0.9 mas. The latest orbit of the outer pair A 2592 AB published in TMH14 does not account for the fact that the speckle measurements at SOAR refer to A,Ba and not to AB. Here we give a more accurate solution that uses the positions of AB computed from the measures of A,Ba under the assumption that Ba and Bb have equal masses. After this correction and orbit adjustment, the weighted residuals are 4.3 mas in separation and $1^\circ\!.3$ in angle. Interestingly, there were a considerable number of speckle interferometry measures of this pair obtained in the 1980s and 1990s at 4 m telescopes, but none of them recognized the subsystem Ba,Bb, despite its small Δm.

Ignoring the multiplicity, the spectroscopic survey of Guillout et al. (2009) determined a moderate axial rotation $V \sin i = 10.8$ km s^{-1} and detected the lithium line of 52.8 mÅ equivalent width which, together with the X-ray detection by *ROSAT* (RasTyc 1715-0948), normally indicates youth. These authors do not mention this star in particular, but discuss a group of active lithium-rich giants in their sample, to which this system apparently belongs. Even with the larger dynamical parallax (instead of the HIP2 parallax), all three resolved components of HIP 84430 are located above the main sequence in the color–magnitude diagram. This multiple system is peculiar and merits further study.

5. SUMMARY

We present here a large set of new speckle interferometry measurements of close binary stars, mostly with southern declinations. The total number of measurements made with HRCam since 2008 now exceeds 5000. This unique data set is used for calculation of 46 new orbits and for improvement of 148 known orbits. For comparison, the data in TMH14 resulted in 13 new orbits and in the improvement (sometimes drastic) of 45 previously known orbits. We demonstrate the good internal consistency of speckle astrometry with HRCam by repeated measurements of relatively wide binaries. Typical errors are on the order of 3 mas even for these wide pairs.

The high angular resolution and dynamic range of HRCam give access to close binaries never resolved before. Some of those objects had prior indication of binarity from variable RV or astrometric acceleration. In such cases, direct resolution allows us to estimate statistically orbital periods (which are typically short) and to evaluate masses. This clarifies the statistics of binary and multiple stars in the solar neighborhood. We also resolved a number of components in previously known nearby wide binaries, converting them into triple or higher-order hierarchies.

A total of 56 newly resolved pairs are reported here, ten of those being inner or outer subsystems in visual binaries (Figure 2). Most of those subsystems are totally unexpected. Some of the newly resolved binaries or subsystems are interesting for various reasons, such as being young (e.g., X-ray sources), having comparable separations and approaching the dynamical stability limit, such as HIP 9497 with periods of 138 and 13.9 years (TMH14), or being targets of exo-planet programs.

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Facilities: SOAR.

Note added in proof. The component C in 16563–4040 (TOK 412 AC) was independently discovered by Sana et al. (2014) and is designated in the WDS as SNA 60 AC. By error, the newly discovered close companion in 04308–5727 (TOK 429 Aa,Ab) was omitted from Table 4, Figure 2, and Section 3.2, but its measurements are found in Table 2. The total number of newly resolved companions is still 56.

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