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Dynamical and physical properties of 22 binaries discovered by W. S. Finsen

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ABSTRACT

Using recent speckle measurements performed by different observers, in this paper we present revised orbital elements and dynamical masses for the binaries WDS 02396−1152 (FIN 312), 04515−3454 (FIN 320), 06253+0130 (FIN 343), 07003−2207 (FIN 334 Aa,Ab), 08291−4756 (FIN 315 Aa,Ab), 08345−3236 (FIN 335), 09173−6841 (FIN 363 AB), 09442−2746 (FIN 326), 12064−6543 (FIN 367 Aa,Ab), 12446−5717 (FIN 65 AB), 13117−2633 (FIN 305), 13320−6519 (FIN 369), 14373−4608 (FIN 318 Aa,Ab), 16057−0617 (FIN 384 Aa,Ab), 16115+0943 (FIN 354), 17221−7007 (FIN 373), 17542+1108 (FIN 381), 19035−6845 (FIN 357), 21044−1951 (FIN 328), 21158−5316 (FIN 329), 21477−3054 (FIN 330 AB) and 21579−5500 (FIN 307) discovered by W. S. Finsen using his eyepiece interferometer. A brief historical comment on Finsen's work on binaries is included. The orbital and physical properties of these stars are discussed with detail. In addition to this, quantitative results about a likely overestimation of Finsen's angular separations are provided. Moreover, the evaluation as well as the statistical significance determination of a suspected underestimation of the *Hipparcos* trigonometrical parallaxes at large distances is also accomplished.

Key words: astrometry – binaries: visual – stars: fundamental parameters.

1 INTRODUCTION

William Stephen Finsen (1905 July 28–1979 May 16) was a South African astronomer who was an expert on binary stars as well as asteroid observation. He developed an eyepiece interferometer to measure close binary stars (Finsen 1964b, 1971). Its final version of 1954 was used to discover 73 binary stars in two decades. In addition, during the favourable opposition of Mars in 1956, he took about 50 000 photographs of the red planet using the 26.5 inch refractor of the Union Observatory (Johannesburg). A combination of the best of those exposures was made into pictures which were considered to be the best photographs of Mars until the space probes became available (Overbeek 1997).

In 1957, Finsen succeeded van den Bos as the Director of the Union Observatory (Johannesburg) until 1965. The name of this Observatory was changed to the Republic Observatory when South Africa became a Republic in 1961. Both prominent astronomers were fiercely opposed (van den Bos & Finsen 1971) to the decision of the South African Government to close the Republic Observatory and amalgamate it with the Cape Observatory (Cape Town) and the Radcliffe Observatory (Pretoria) into what became known in 1974 as the South African Astronomical Observatory (SAAO), located in the Karoo near Sutherland. The argument of the authorities was that they were badly affected by light pollution but the fact of the matter is that van den Bos and Finsen's worst fears came true and the very long and fruitful tradition of the study of binary stars and asteroids through well-established programmes of observation was terminated.

In this paper, we want to pay homage to this pioneer of interferometric observation of binary systems by presenting new orbits and fundamental parameters of 22 binaries discovered by Finsen. The paper is structured as follows. After the introduction in Section 1, Section 2 contains the recalculated orbital elements and masses (accompanied by uncertainty estimates) of these systems as well as a plot of their apparent orbits and the ephemerides for the coming years. All of these orbital solutions have been previously announced in the Information Circulars of the IAU Commission 26 (IAUDS), although, in some cases, we present refined orbital elements in this paper. Some questions about other physical and orbital properties of each binary system are analysed separately in Section 3. Finally, some conclusions derived from results and questions about the accuracy of Finsen's measurements as well as the reliability of the *Hipparcos* parallax at large distances are also discussed in Section 4.

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2 ORBITAL ELEMENTS AND DYNAMICAL MASSES

2.1 Methodology

The observations were taken from journals and especially from the *Fourth Catalog of Interferometric Measurements of Binary Stars* (*INT4*) maintained at the United States Naval Observatory (USNO) (Hartkopf, Mason & McAlister 2012). In fact, we have primarily used interferometric data, both from visual observations performed by Finsen and from speckle measurements obtained by different observers (to the greatest extent by McAlister, Hartkopf, Mason, Tokovinin and Horch); in addition, we consider one *Hipparcos* measurement available for almost all systems. Precession corrections were applied to the observations to refer position angles to the 2000.0 equinox.

Photometric data have been obtained mainly from the *Hipparcos* catalogue, excluding some cases in which differences of apparent magnitudes were obtained from speckle observations collected in the *Third Photometric Magnitude Difference Catalog* maintained at USNO (Mason & Wycoff 2012).

Orbital elements have been calculated by using Docobo's analytical method (Docobo 1985, 2012). In the case that the position angle or angular separation had a residual greater than 15° or 50 mas, respectively, both in late orbits and in ours, the corresponding observation was excluded from the calculations.

Regarding mass determination, we have applied Kepler's third law:

$$\mathrm{M}_1 + \mathrm{M}_2 = \frac{1}{\pi^3}\frac{a^3}{P^2}, \quad (1)$$

where M_1 and M_2 are the component masses expressed in units of solar mass, π is the parallax in arcsecs, a is the semimajor axis in arcsecs and P is the period in years. An expression for the corresponding uncertainty has also been derived from this formula.

Initially, we computed the total mass taking into account the updated *Hipparcos* parallax. However, since some of these systems are located at more than 200 pc, it is possible that this trigonometric parallax is not as accurate as desirable. Thus, we have also obtained the dynamical parallax using the Baize–Romani algorithm (Baize & Romani 1946) with magnitudes and spectral types taken from different authors. Calculations have been accomplished considering updated parameters of the bolometric correction (Straižys & Kuriliene 1981) and of the mass–luminosity relation:

$$\log \mathrm{M} = -\frac{2}{5}\,\kappa\,(M_b - M_0)\,, \quad (2)$$

where M is the mass of the star in $\mathrm{M}_\odot$ and M_b is its absolute bolometric magnitude. On the other hand, κ and M_0 are two constants that must be obtained from the fit. The second one is, indeed, the bolometric magnitude of the Sun. We have adjusted this relation to data given by Straižys & Kuriliene (1981) for the luminosity classes V ($\kappa = 4.23$ and $M_0 = 4.74$) and IV ($\kappa = 3.64$ and $M_0 = 3.88$) in the spectral ranges B3–M1 and B3–K1, respectively. Here, we have considered the fact pointed out by Torres (2010) that there is a need to use a bolometric magnitude of the Sun consistent with the zero-point of the empirical bolometric corrections for stars (BC_V).

Moreover, we have obtained the mass ratio between both components, $q = \mathrm{M}_2/\mathrm{M}_1$, from

$$q = 10^{-\frac{2}{5}\frac{\Delta m_b}{\kappa}}, \quad (3)$$

assuming $\Delta m_b \approx \Delta m_V$.

Usually, we compare individual masses obtained in this way with masses obtained from spectral type–mass formulae shown in Docobo & Andrade (2006) after applying the spectral class decomposition procedure of Edwards (1976) in each case.

2.2 Results

Orbital elements along with their uncertainties are shown in Table 1 for each binary system. We indicate the Washington Double Star Catalog (WDS) identification (Mason, Wycoff & Hartkopf 2012) and the discoverer's designation (*Name*) in column 1. The orbital elements are listed in the following order: revolution period (P), epoch of passage through the periastron (T), eccentricity (e), semimajor axis (a), orbital inclination (i), angle of the node (Ω) and argument of the periastron (ω). The precession correction used to refer position angles to the 2000.0 equinox as well as the last observation used in the computations is also given in column 9. The last column shows the number of the IAUDS Information Circular in which the present orbit (and the preliminary one, between brackets) was already announced.

Taking into account these orbital elements, we have computed the ephemerides of each of the 22 binary systems for the present and the next four years which are listed in Table 2. The name of each star (column 1) is followed by the position angle (θ) and the angular separation (ρ) consecutively for the beginning of the year between 2012 and 2016.

Table 3 includes the spectral types for the 22 binaries studied. The name of each star (column 1) is followed by the spectral types given in the WDS and *Hipparcos* catalogues (columns 2 and 3), whereas column 4 lists spectral types given by different authors in chronological order.

Some stellar data as well as the results obtained in this paper are summarized in Table 4. The name of each star (column 1) is followed by the spectral type taken to calculate the dynamical parallax (column 2). Its apparent magnitudes with uncertainties (if they exist) and trigonometric parallax obtained from *Hipparcos*, as updated by the new reduction (van Leeuwen 2007), are listed in columns 3–5, respectively. To contrast with that, the dynamical parallax is shown in column 6. Finally, columns 7 and 8 show the corresponding masses for each stellar component obtained from both the dynamical parallax and the new orbital elements.

Apparent orbits along with observational data of stars are drawn in Figs 1–4. In all of the drawings, two orbits are shown. The solid orbit corresponds to the our orbit presented in this paper. The dotted line represents the current orbit reported in catalogues. Finsen's observations are indicated by empty circles, whereas speckle measurements (and *Hipparcos*, if it exists) are shown as filled circles. In addition, the last available measurement is marked with a filled square. Each observation is connected by a line to the position predicted for the corresponding epoch. The dashed line is the line of nodes, whereas the arrow shows the direction of the orbital motion.

Table 5 lists all of the binary systems indicating whether one or more measurements have been flipped to calculate the orbits in the second and fifth columns. Differences of magnitudes along with their uncertainties are shown in the third and sixth columns.

3 DISCUSSION OF INDIVIDUAL SYSTEMS

3.1 WDS 02396−1152, FIN 312, HIP 12390, HD 16620 AND ϵ Cet

This binary with a very short period was discovered early in 1951 (Finsen 1951a) and subsequently observed by Finsen himself 140

Table 1. Orbital elements.

WDS name	P (yr)	T (yr)	e	a (arcsec)	i (°)	Ω (°)	ω (°)	Prec. (°) last ob.	IAUDS Inf. Circ. No.
02396−1152	2.6512	2012.3109	0.230	0.1063	24.2	90.2	40.8	0.0036	(174)
FIN 312	±0.0005	±0.0005	±0.001	±0.0005	±0.2	±0.2	±0.2	2009.7535	178
04515−3454	43.25	2006.38	0.865	0.256	107.5	19.6	108.9	0.0064	(171)
FIN 320	±0.30	±0.20	±0.015	±0.006	±1.0	±2.0	±2.0	2010.9657	177
06253+0130	68.69	2019.94	0.494	0.133	144.6	44.8	228.9	0.0056	177
FIN 343	±2.00	±2.00	±0.030	±0.002	±2.0	±3.0	±3.0	2011.0368	
07003−2207	475.0	2013.7	0.603	0.275	107.3	153.2	178.9	0.0058	177
FIN 334 Aa,Ab	±50.0	±2.0	±0.040	±0.020	±2.0	±2.0	±3.0	2010.9686	
08291−4756	340.0	1947.7	0.748	0.427	78.9	114.7	300.0	0.0064	177
FIN 315 Aa,Ab	±50.0	±2.0	±0.030	±0.030	±2.0	±2.0	±5.0	2012.1019	
08345−3236	17.366	2014.467	0.557	0.146	39.6	98.5	220.3	0.0051	177
FIN 335	±0.075	±0.540	±0.015	±0.002	±5.0	±12.0	±20.0	2011.9354	
09173−6841	3.4398	2013.3248	0.453	0.0917	139.1	160.4	120.1	0.0095	177
FIN 363 AB	±0.0010	±0.0500	±0.005	±0.0030	±5.0	±5.0	±5.0	2012.1020	
09442−2746	18.266	2020.143	0.404	0.110	123.6	3.5	141.2	0.0035	177
FIN 326	±0.185	±0.200	±0.005	±0.002	±1.0	±1.0	±3.0	2012.0284	
12064−6543	48.37	2001.27	0.800	0.171	119.4	176.0	276.0	−0.0004	(176)
FIN 367 Aa,Ab	±0.80	±0.50	±0.015	±0.005	±2.0	±3.0	±3.0	2011.0373	177
12446−5717	200.00	1952.75	0.518	0.404	111.3	48.7	143.7	−0.0020	176
FIN 65 AB	±10.00	±0.50	±0.010	±0.010	±0.5	±1.0	±2.0	2010.0688	
13117−2633	18.915	2019.167	0.931	0.104	153.7	3.9	87.1	−0.0019	177
FIN 305	±0.100	±0.050	±0.004	±0.004	±5.0	±5.0	±5.0	2009.2600	
13320−6519	24.786	2021.716	0.473	0.176	75.2	16.6	81.4	−0.0051	(174)
FIN 369	±0.300	±1.500	±0.060	±0.012	±2.0	±2.0	±5.0	2012.1844	177
14373−4608	101.49	1977.47	0.674	0.194	117.8	172.1	260.0	−0.0051	177
FIN 318 Aa,Ab	±0.80	±0.60	±0.006	±0.002	±1.0	±1.0	±1.0	2011.3027	
16057−0617	4.963	2013.371	0.559	0.046	154.7	108.5	8.4	−0.0049	177
FIN 384 Aa,Ab	±0.015	±0.030	±0.006	±0.003	±2.0	±10.0	±15.0	2009.2630	
16115+0943	50.16	2014.57	0.093	0.122	92.2	82.9	214.7	−0.0051	175
FIN 354	±2.00	±0.57	±0.030	±0.002	±1.0	±1.0	±10.0	2009.2631	
17221−7007	59.32	2008.55	0.172	0.115	69.4	119.6	270.5	−0.0161	177
FIN 373	±3.00	±1.50	±0.050	±0.005	±3.0	±4.0	±7.0	2009.2631	
17542+1108	9.008	2016.305	0.327	0.0853	160.9	173.6	58.3	−0.0057	177
FIN 381	±0.015	±0.050	±0.002	±0.0020	±5.0	±10.0	±10.0	2008.4610	
19035−6845	14.159	2018.474	0.355	0.154	155.9	116.0	205.8	−0.0139	178
FIN 357	±0.100	±0.050	±0.010	±0.003	±2.0	±2.0	±4.0	2008.7724	
21044−1951	27.85	2002.46	0.410	0.265	162.6	171.1	238.2	−0.0041	176
FIN 328	±0.15	±0.09	±0.005	±0.003	±0.5	±15.0	±15.0	2010.5861	
21158−5316	36.55	2003.61	0.041	0.151	122.7	79.9	154.2	−0.0061	(171)
FIN 329	±0.60	±0.90	±0.013	±0.001	±6.0	±3.0	±20.0	2009.7552	177
21477−3054	19.957	2006.000	0.256	0.137	103.0	29.1	199.0	−0.0035	(171)
FIN 330 AB	±0.050	±0.070	±0.030	±0.004	±2.0	±2.0	±6.0	2010.5861	177
21579−5500	12.237	2007.518	0.032	0.176	76.3	90.8	64.9	−0.0050	177
FIN 307	±0.080	±0.480	±0.032	±0.004	±2.0	±2.0	±11.0	2009.6678	

times (plus 58 non-resolutions) during 18 consecutive years. This star was also observed one night by Wilson (1979) using visual interferometry in 1971. From 1975 until 2009, there were 54 observations (and three non-resolutions) taken by speckle interferometry, the great majority of them performed with 4-m class telescopes, as well as two obtained with a phase-grating interferometer attached to a 1-m telescope and another registered by the *Hipparcos* satellite. Thus, at present, it has completed 23 revolutions since its discovery.

A preliminary orbit with a period of 1.59 yr along with a dynamical parallax of 68 mas was given by Finsen using 21 interferometric measurements. This orbit was published in a note whose illustrative title already announced the singularity of this system: 'ϵ Ceti, φ 312, a Visual Binary with Shortest Known Period?'

Table 2. Ephemerides.

	2012.0		2013.0		2014.0		2015.0		2016.0	
Name	θ (°)	ρ (arcsec)	θ (°)	ρ (arcsec)	θ (°)	ρ (arcsec)	θ (°)	ρ (arcsec)	θ (°)	ρ (arcsec)
FIN 312	68.8	0.090	251.3	0.112	342.3	0.115	136.8	0.078	284.1	0.126
FIN 320	135.5	0.092	126.2	0.096	117.7	0.101	110.0	0.106	103.1	0.113
FIN 343	268.3	0.097	261.1	0.093	253.2	0.089	244.6	0.085	235.0	0.081
FIN 334 Aa,Ab	335.5	0.109	334.3	0.109	333.2	0.109	332.0	0.109	330.9	0.109
FIN 315 Aa,Ab	202.2	0.102	204.6	0.103	206.9	0.104	209.2	0.105	211.4	0.106
FIN 335	204.7	0.106	234.9	0.089	279.7	0.070	0.5	0.055	59.8	0.093
FIN 363 AB	194.6	0.115	128.9	0.062	284.8	0.078	215.1	0.109	167.6	0.102
FIN 326	21.3	0.139	15.2	0.143	9.3	0.141	2.9	0.133	355.4	0.119
FIN 367 Aa,Ab	116.2	0.130	112.5	0.131	108.9	0.135	105.4	0.137	102.1	0.139
FIN 65 AB	88.0	0.282	86.8	0.289	85.8	0.296	84.8	0.303	83.8	0.310
FIN 305	92.3	0.173	89.9	0.166	87.3	0.155	84.3	0.142	80.5	0.124
FIN 369	314.0	0.071	331.1	0.084	343.1	0.100	351.8	0.116	358.4	0.131
FIN 318 Aa,Ab	128.3	0.182	126.9	0.181	125.5	0.180	124.1	0.179	122.6	0.177
FIN 384 Aa,Ab	252.3	0.059	184.1	0.028	345.2	0.037	301.2	0.065	277.6	0.071
FIN 354	262.4	0.109	262.1	0.104	261.6	0.096	261.2	0.087	260.5	0.076
FIN 373	88.4	0.057	95.7	0.067	101.2	0.076	105.5	0.085	109.0	0.093
FIN 381	292.4	0.108	269.0	0.102	241.0	0.090	202.6	0.075	141.8	0.058
FIN 357	84.7	0.202	71.5	0.192	56.3	0.176	37.7	0.156	13.3	0.135
FIN 328	141.4	0.343	134.9	0.352	128.6	0.358	122.5	0.361	116.4	0.362
FIN 329	215.0	0.101	201.9	0.091	186.1	0.085	168.7	0.083	151.6	0.087
FIN 330 AB	36.0	0.138	32.6	0.157	29.8	0.168	27.3	0.169	24.6	0.163
FIN 307	275.6	0.170	285.2	0.127	312.2	0.063	44.5	0.058	75.6	0.121

(Finsen 1953a). Yet, a set of revised orbital elements with a period of 2.62 yr were given by Finsen along with a dynamical parallax of 42 mas taking into account observations until the end of 1955 (Finsen 1955).

A few years later, Finsen suggested recalculating this orbit to Baize, considering new measurements obtained until 1962.044. The dynamical parallax and total mass with new orbital elements (not very different from those obtained by Finsen) were, respectively, 43.83 mas and 2.47 $M_\odot$ (Baize 1962). In 1970, Finsen himself published a new orbit with a period of 2.667 yr and a dynamical parallax of 39 mas (Finsen 1970a,b).

It was known that the spectral type of ϵ Ceti was F5IV/V (Roman 1952) but, in the 1970s, it was noticed that this system was itself a SB1 (Abt & Levy 1976). In subsequent years, Duquennoy & Mayor (1988) were able to measure the spectra of both components (F5V and G0V) with the Correlation Radial Velocities (CORAVEL) spectrometer and determined a SB2 orbit along with component masses (1.10 ± 0.21 and 0.74 ± 0.22 $M_\odot$), a dynamical parallax (66 ± 10 mas) and an absolute semimajor axis (2.35 ± 0.29 au), taking into account Finsen's orbital inclination ($i = 31\overset{\circ}{.}9$). Component masses (1.886 ± 0.171 and 0.990 ± 0.092 $M_\odot$) were also given by Martin & Mignard (1998) by using a methodology based on *Hipparcos* data. Also, Söderhjelm (1999) calculated individual masses (1.41 ± 0.15 and 1.19 ± 0.13 $M_\odot$) considering only astrometric information as well as the dynamical parallax (40.59 ± 1.31 mas).

We must note that this is really a line width spectroscopic binary (LWSB) system (Duquennoy & Mayor 1991) as some observers have already suggested (Abt & Levy 1976). Hence, spectra are never individually separated and some extra assumptions must be made in order to untangle them. Taking that into account, a simultaneous adjustment of the visual and spectroscopic data accomplished by Pourbaix (2000) provided new orbital elements as well as component masses (2.39 ± 0.74 and 1.55 ± 0.48 $M_\odot$), parallax (36.99 ± 1.76 mas) and new spectral types for each component (F5V and F6V). Despite that, this system continues to be catalogued in many recent studies as a single-lined system of spectral type, F5V (Gray et al. 2006) or F4V (Abt 2009).

As we already mentioned, the last orbit for this system (VB–SB2 system) was given from a simultaneous adjustment of the visual and spectroscopic data (Pourbaix 2000). It satisfies the set of available observations very well. Despite that, we have calculated orbital elements which represent a refinement of those. In this way, root mean square (rms) values are slightly improved for both Finsen and speckle measurements. Moreover, the mean values for speckle residuals in angular separations as well as position angles are very close to zero.

In agreement with the fact highlighted by Hartkopf, McAlister & Franz (1989) and Pourbaix (2000) that most of Finsen's visual interferometric observations have overestimated angular separations (thus leading to an overestimated orbital parallax), our computation takes into account the entire large set of accurate speckle observations (more than twelve revolutions) while considering position angles of Finsen's measurements as well.

With the already reported new improved orbit (Docobo & Andrade 2012c) whose preliminary version was reported last year (Docobo & Andrade 2011a), along with the *Hipparcos* parallax, a total mass of 1.69 ± 0.28 $M_\odot$ is obtained. However, if we use the methodology discussed in Section 2.1 for the calculation of the dynamical parallax, we obtain 41.43 ± 0.68 mas as well as a mass ratio, $q = 0.756 \pm 0.076$. With these values we obtain a more reliable dynamical mass of 2.42 ± 0.16 $M_\odot$, distributed in such a way that $M_1 = 1.37 \pm 0.09\,M_\odot$ and $M_2 = 1.03 \pm 0.08\,M_\odot$ strongly agree with the individual mass expected (considering the spectral type along with $\Delta m = 1.287 \pm 0.462$) for a F2 star (1.4 $M_\odot$) and a F7/G4V star (1.1–0.9 $M_\odot$).

3.2 WDS 04515−3454, FIN 320, HIP 22573 AND HD 31093

Finsen discovered this binary star early in 1952 (Finsen 1952a) and observed it 12 times (plus three non-resolutions) during 16 years. Regarding speckle observations, there were seven measurements

Table 3. Spectral types.

Name	Sp_{WDS}	Sp_{Hip}	Sp (authors)
FIN 312	F5V+F5V	F5 V	F5IV/V (Roman 1952); F5IV (Malaroda 1975)
			F6V (Edwards 1976); F5V (Houk & Smith-Moore 1988)
			F5V+G0V (Duquennoy & Mayor 1988); F5V+F6V (Pourbaix 2000)
			F5V (Gray et al. 2006); F4V (Abt 2009)
FIN 320	A1Vn	A2/A3V	A1V (de Vaucouleurs 1957); A1Vn (Evans, Menzies & Stoy 1957)
			A2/A3V (Houk 1982); A2V (Abt & Morrell 1995)
FIN 343	B9V	B9V	B9V (Abt & Morrell 1995)
FIN 334 Aa,Ab	B2IV/Vne	B3Vnn	B4Vne (Morris 1961); B4Vne (Buscombe 1969)
			B2IV-V (Hiltner, Garrison & Schild 1969); B3Vnn (Houk & Smith-Moore 1988)
FIN 315 Aa,Ab	B2IV	B2IV	B2IV (Hiltner et al. 1969); B1.5V (Corbally 1984)
FIN 335	G5IV/V	G5V	G5IV/V (Edwards 1976); G5V (Houk & Smith-Moore 1988)
			G5IV/V (Duflot, Figon & Meyssonnier 1995)
FIN 363 AB	F4V	F4V	F2 (Jenkins 1950); dF5 (Stokes 1972)
			F4V (Malaroda 1975); F5V Fe-0.7 CH-0.5 (Gray et al. 2006)
FIN 326	F7V	G8III+A7V	F7II-III+A8V (Malaroda 1973); A7V+G8III (Houk & Cowley 1975)
			F6V (Edwards 1976); A8V + F7II (Baize & Petit 1989)
			G7III(+Am?) (Ginestet et al. 1997); g]G1+A8− (Parsons & Ake 1998)
			F7/8V (Montes et al. 2001); G7III+A8m (Ginestet & Carquillat 2002)
FIN 367 Aa,Ab	G8/K0III	G8/K0III	G8/K0III (Houk & Cowley 1975); K0III+A7V (Corbally 1984)
			K1III+A6 (Parsons & Ake 1998)
FIN 65 AB	A0IV/V	A0IV/V	A0IV/V (Houk & Cowley 1975)
FIN 305	A5Vn	A5V	A3 (Stokes 1972); A5V (Weis 1974)
			A7IV (Mersch & Heck 1980); A5V (Houk 1982)
			A5V+A5V (Guthrie 1985); A6V (Eggen 1985)
			A3V (Abt & Morrell 1995); A3+A5V (Pasinetti Fracassini et al. 2001)
FIN 369	A8/A9IV	A8/A9IV	A8/A9IV (Houk & Cowley 1975)
FIN 318 Aa,Ab	G8III+A1V	K0III+A1V	K0III (Evans et al. 1957); K0III+A1V (Cousins & Stoy 1962)
			G8III+A1V (Jaschek, Conde & de Sierra 1964); K0III (Olsen 1979)
			K0III+A1V (Duflot et al. 1995)
FIN 384 Aa,Ab	F3V	F2IV	F2IV (Malaroda 1975); F3V (Harlan 1974)
			F7IV (Cowley 1976); F3V (Abt 1981)
FIN 354	F0IV	F0IV	F0IV (Cowley et al. 1969); A7V (Abt & Morrell 1995)
			A7V (Paunzen et al. 2001)
FIN 373	B9V+B9.5V	B8/B9Vn	B8/B9Vn (Houk & Cowley 1975); B9III (Cucchiaro et al. 1977)
			B9V+B9.5V (Davidson, Claflin & Haisch 1987)
FIN 381	F5Vn	F5Vn	F5 (Crissman 1957); F5Vn (Harlan & Taylor 1970)
			F2IVn (Cowley 1976); F5Vn (Cowley & Bildelman 1979)
			A5m+F0 (Rodríguez et al. 1998); F3V (Rucinski et al. 2002)
			F2V+G5 (Rucinski, Pribulla & van Kerkwijk 2007)
FIN 357	F8V	F8V	G0IV (Houk & Cowley 1975); F8V (Malaroda 1975)
FIN 328	A4V+F2V	A5V	A5V (Cowley et al. 1969); A5V (Houk & Smith-Moore 1988)
			A3IV (Abt & Morrell 1995); A4V+F2V (ten Brummelaar et al. 2000)
FIN 329	A6IV	A6IV	A5III (de Vaucouleurs 1957); A7V (Evans, Menzies & Stoy 1959)
			A5III (Buscombe 1962); A6IV (Levato 1972)
			A3V (Houk & Cowley 1975); A7V (Edwards 1976)
			A2.5V (Abt & Morrell 1995)
FIN 330 AB	A2V	A1V	A2IIIn (Evans et al. 1957); A2V (Levato 1972)
			A1V (Houk 1982); A1V (Abt & Morrell 1995)
FIN 307	F0IV	F0IV	F0IV (de Vaucouleurs 1957); F0IV (Houk & Cowley 1975); F0IV (Malaroda 1975)

(and one non-resolution) between 1989 and 2008, most of them performed with 4-m class telescopes, as well as a measurement made by the *Hipparcos* astrometry satellite. This system has completed a little more than one revolution since its discovery to the present.

The former spectral type obtained for this system was A1V (de Vaucouleurs 1957; Evans et al. 1957). More recently, Abt & Morrell (1995) classified it as A2V.

The previous orbit of this system (Heintz 1993) showed very large residuals for the last speckle measurements. A preliminary version of our improved orbit was announced two years ago (Docobo & Andrade 2010).

The already announced new orbital elements (Docobo & Andrade 2012b) along with the *Hipparcos* parallax give a total mass of 4.98 $\pm$ 0.62 $M_{\odot}$. However, if we calculate the dynamical parallax, we obtain 13.78 $\pm$ 0.41 mas as well as a mass ratio, $q = 0.850 \pm 0.006$. With these values we obtain a dynamical mass of 3.43 $\pm$ 0.39 $M_{\odot}$ distributed in such a way that $M_1 = 1.85 \pm 0.21\,M_{\odot}$ and $M_2 = 1.58 \pm 0.18\,M_{\odot}$, somewhat small for the individual mass expected (considering the spectral type along with $\Delta m = 0.745 \pm 0.030$) for a A1V star (2.7 $M_{\odot}$) and a A4V star (2.3 $M_{\odot}$). In this case, it seems that the *Hipparcos* parallax provides a more reasonable mass.

Table 4. Stellar data and results (dynamical parallaxes and component masses).

Name	Sp (considered)	m_1	m_2	π_{Hip} (mas)	$\pi_{\rm dyn}$ (mas)	M_1 ($M_\odot$)	M_2 ($M_\odot$)
FIN 312	F4V	5.216 ± 0.135	6.503 ± 0.442	46.55 ± 2.53	41.43 ± 0.68	1.37 ± 0.09	1.03 ± 0.08
FIN 320	A2V	6.306 ± 0.014	7.051 ± 0.027	12.17 ± 0.41	13.78 ± 0.41	1.85 ± 0.21	1.58 ± 0.18
FIN 343	B9V	7.082 ± 0.051	7.896 ± 0.108	2.77 ± 0.89	4.61 ± 0.16	2.77 ± 0.36	2.32 ± 0.30
FIN 334 Aa,Ab	B3V	7.2	7.2	1.55 ± 0.52	2.03 ± 0.25	5.51 ± 2.64	5.51 ± 2.64
	B2IV				1.91 ± 0.25	6.62 ± 3.28	6.62 ± 3.28
FIN 315 Aa,Ab	B1.5V	5.9	6.4	1.53 ± 0.34	3.88 ± 0.56	6.08 ± 3.43	5.45 ± 3.08
	B2IV				3.85 ± 0.58	6.27 ± 3.63	5.53 ± 3.20
FIN 335	G5V	7.129 ± 0.057	7.508 ± 0.080	14.86 ± 0.57	15.42 ± 0.28	1.47 ± 0.10	1.35 ± 0.09
	G5IV				16.24 ± 0.39	1.26 ± 0.11	1.15 ± 0.10
FIN 363 AB	F5V	5.760 ± 0.191	7.129 ± 0.676	30.64 ± 0.70	29.71 ± 1.33	1.43 ± 0.25	1.06 ± 0.20
FIN 326	G7III+A8V	5.30	6.18	9.61 ± 0.46	10.08 ± 0.47^a	(See Subsection 3.8)	
FIN 367 Aa,Ab	K1III+A6V	6.788 ± 0.136	7.142 ± 0.188	7.94 ± 4.49	8.11 ± 0.42^a	(See Subsection 3.9)	
FIN 65 AB	A0V	6.985 ± 0.034	8.176 ± 0.100	8.99 ± 0.61	7.51 ± 0.37	2.20 ± 0.42	1.69 ± 0.33
	A0IV				7.84 ± 0.40	1.97 ± 0.39	1.45 ± 0.29
FIN 305	A3V	7.197 ± 0.096	7.432 ± 0.119	9.04 ± 0.56	9.71 ± 0.45	1.76 ± 0.32	1.67 ± 0.30
FIN 369	A8/A9IV	7.358 ± 0.133	7.540 ± 0.158	12.07 ± 0.52	15.87 ± 1.35	1.14 ± 0.37	1.08 ± 0.36
FIN 318 Aa,Ab	K0III+A1V	6.216 ± 0.093	6.503 ± 0.119	2.39 ± 7.26	5.32 ± 0.20^a	(See Subsection 3.13)	
					4.65 ± 0.12^b		
FIN 384 Aa,Ab	F3V	7.1	7.1	11.45 ± 1.11	10.43 ± 0.81	1.74 ± 0.53	1.74 ± 0.53
	F2IV				10.98 ± 0.88	1.50 ± 0.47	1.50 ± 0.47
FIN 354	A7V	7.193 ± 0.480	7.515 ± 0.646	6.16 ± 0.57	5.45 ± 0.28	2.31 ± 0.46	2.15 ± 0.43
	F0IV				5.64 ± 0.32	2.09 ± 0.45	1.93 ± 0.43
FIN 373	B9V	5.897 ± 0.096	6.456 ± 0.160	2.47 ± 0.50	3.89 ± 0.26	3.89 ± 1.02	3.45 ± 0.90
FIN 381	F3V	7.0	7.2	12.00 ± 0.82	13.45 ± 0.38^c	1.76 ± 0.22	1.38 ± 0.18
	F3V				13.82 ± 0.39^d	1.72 ± 0.24	1.18 ± 0.16
FIN 357	F8V	6.576 ± 0.088	6.957 ± 0.125	17.76 ± 0.58	18.51 ± 0.46	1.49 ± 0.15	1.38 ± 0.14
	G0IV				19.69 ± 0.52	1.25 ± 0.13	1.14 ± 0.12
FIN 328	A5V	5.017 ± 0.006	7.390 ± 0.051	20.20 ± 0.82	19.49 ± 0.29	2.03 ± 0.12	1.21 ± 0.07
	A3IV				20.46 ± 0.32	1.75 ± 0.11	1.05 ± 0.06
FIN 329	A2.5V	6.331 ± 0.111	6.803 ± 0.172	7.62 ± 0.59	8.36 ± 0.17	2.32 ± 0.18	2.09 ± 0.16
	A6IV				8.74 ± 0.17	2.04 ± 0.15	1.82 ± 0.14
FIN 330 AB	A1V	5.8	5.8	10.16 ± 0.40	11.17 ± 0.41	2.32 ± 0.33	2.32 ± 0.33
FIN 307	F0IV	4.799 ± 0.074	5.959 ± 0.216	17.34 ± 0.48	22.71 ± 0.69	1.78 ± 0.21	1.33 ± 0.16

[a]Obtained from our orbital elements and masses expected from spectral types.
[b]Obtained from our orbital elements and masses given by Tokovinin (2008).
[c]Obtained considering photometry given by Yakut, Kalomeni & İbanoğlu (2004).
[d]Obtained considering photometry given by Rucinski et al. (2002).

3.3 WDS 06253+0130, FIN 343, HIP 30547 AND HD 45050

This binary system was first observed by Finsen in the first part of 1959 (Finsen 1959a). He measured it 10 times during 9 yr. In addition, there are 17 speckle measurements between 1978 and 2011, almost all of them performed with 4-m class telescopes, as well as one made by the *Hipparcos* astrometry satellite. Despite the period of about 100 yr, this system has already completed one-half of a revolution since the first observation until now. The spectral type given in both the WDS and *Hipparcos* catalogues is B9V (Abt & Morrell 1995).

The previous orbit of this system (Olević et al. 2003) showed very large residuals for the last speckle measurements. This improved orbit has already been reported (Docobo & Andrade 2012b).

With respect to the mass of these hot stars, unfortunately, the small value of the *Hipparcos* parallax along with its high relative uncertainty provides a useless value of $23 \pm 23\,M_\odot$.

Therefore, the dynamical parallax computation becomes a still more helpful tool in this case. We obtain 4.61 ± 0.16 mas and a mass ratio for the components of $q = 0.838 \pm 0.022$. Thus, a more reliable total mass of $5.09 \pm 0.65\,M_\odot$ ($M_1 = 2.77 \pm 0.36\,M_\odot$ and $M_2 = 2.32 \pm 0.30\,M_\odot$) is obtained. Component masses match reasonably well the expected masses (considering the spectral type along with $\Delta m = 0.814 \pm 0.119$) for B8V ($3.7\,M_\odot$) and A1V ($2.7\,M_\odot$) stars. In addition, this calculation places this star 144 pc (40 per cent) closer to the Sun than when considering the *Hipparcos* parallax.

3.4 WDS 07003−2207, FIN 334 Aa,Ab, HIP 33721 AND HD 52437

This binary system (Aa,Ab) is orbiting around the mutual centre of mass of a distant companion, B (with visual magnitude, 11.07) located at about 13 arcsec. This triple system (SEE 74 AB) is itself orbiting around the mutual centre of mass of a very distant pair, SEE 74 CD (with component visual magnitudes, 10.72 and 11.7, respectively) located at about 2 arcmin.

This binary system was discovered by Finsen in the first part of 1955 (Finsen 1956). He measured it nine times (plus one non-resolution) during 11 yr. In addition, there are seven speckle measurements between 1989 and 2010, all of them accomplished with 4-m class telescopes, as well as an unresolved measurement of the *Hipparcos* astrometry satellite. Despite the long period of 475 yr, this system has already completed an arc of about 150° due to the fact that the observations have been circumstantially

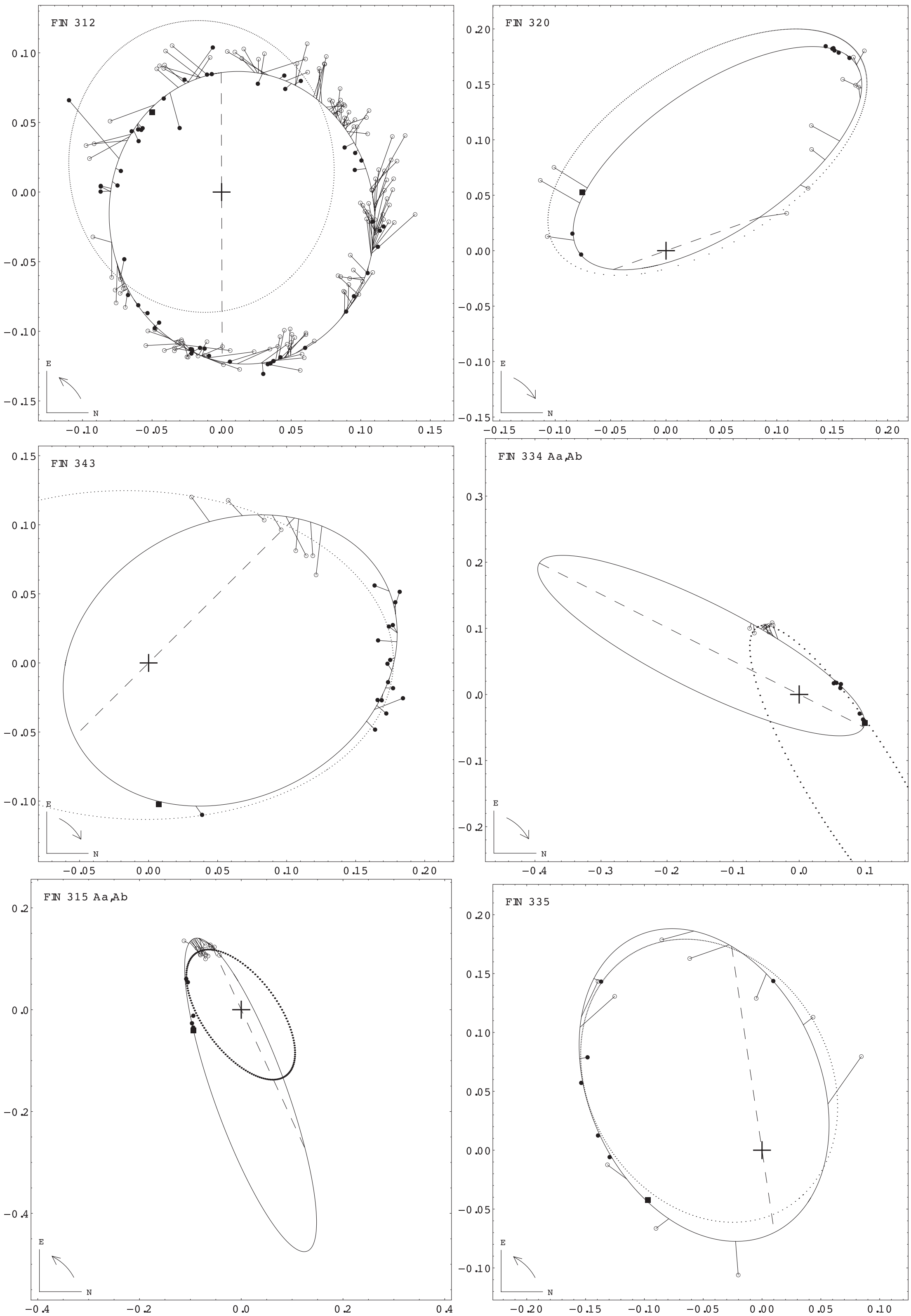

Figure 1. Apparent orbits for Fin 312, Fin 320, Fin 343, Fin 334 Aa,Ab, Fin 315 Aa,Ab and Fin 335.

performed close to the periastron passage. The WDS and *Hipparcos* catalogues provide two different spectra, B2IV/Vne (Hiltner et al. 1969) and B3Vnn (Houk & Smith-Moore 1988), respectively.

There are three previous solutions for this orbit. One of 213.27 yr (Mante 2002) and another two with shorter (105.52 yr) and longer (385.52 yr) periods, respectively (Olević 2002). The best solution, that with the longest period, showed high residuals for three speckle

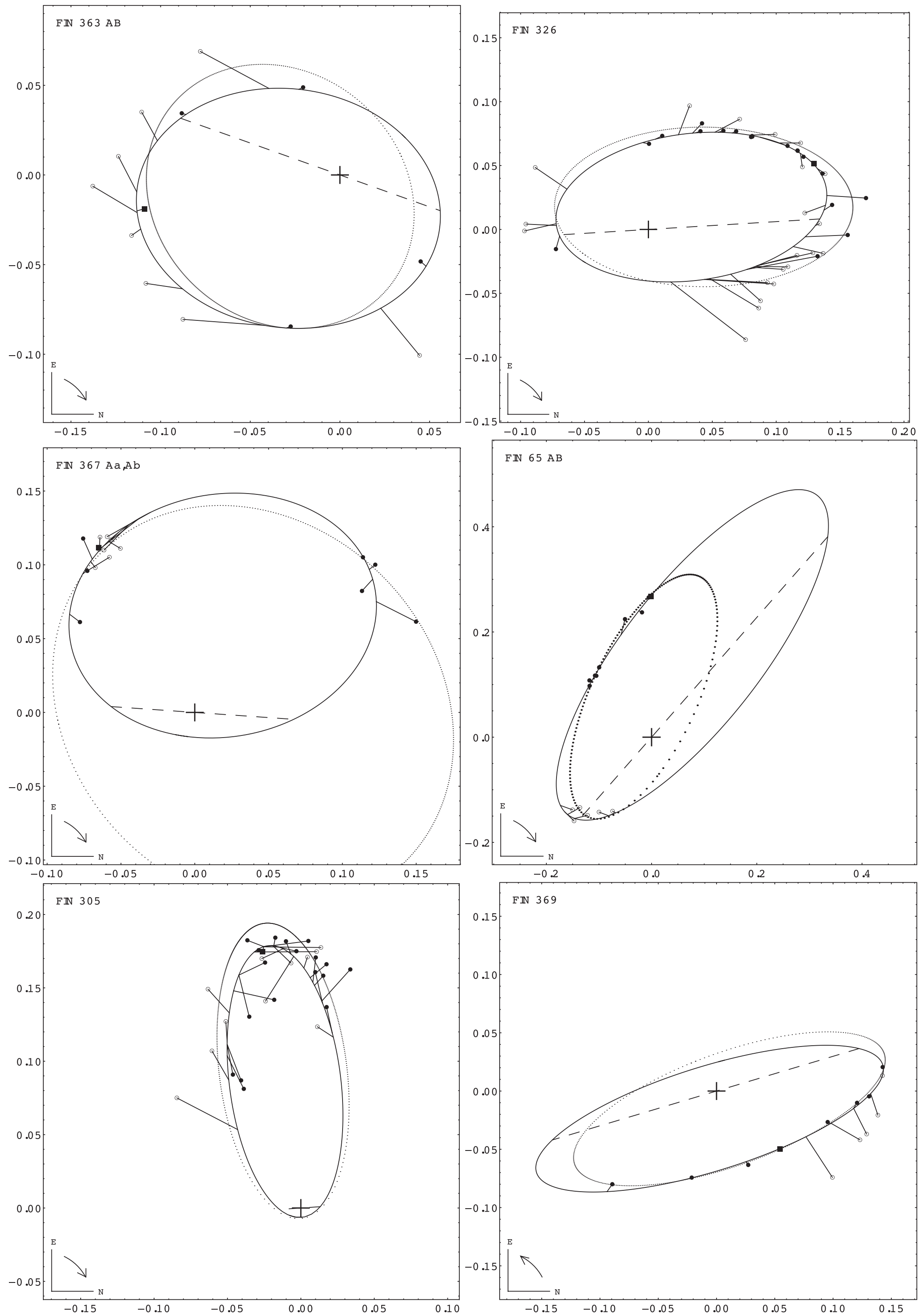

Figure 2. Apparent orbits for Fin 363 AB, Fin 326, Fin 367 Aa,Ab, Fin 65 AB, Fin 305 and Fin 369.

measurements (2006, 2009 and 2010). We have calculated a new orbit which gives better residuals with a longer period (Docobo & Andrade 2012b).

As in the previous case, the small value of the *Hipparcos* parallax along with its high relative uncertainty provides a useless value of $25 \pm 26\,M_\odot$ for the total mass.

Regarding dynamical parallax computation, we must only take into account that it will differ slightly depending on the luminosity class considered. So, we obtain 2.03 ± 0.25 mas for a B3V and 1.91 $\pm$ 0.25 mas for a B2IV. Mass ratios for the components would be $q = 1.000 \pm 0.030$ and 1.000 ± 0.035, respectively. With these data, a total mass of $11.02 \pm 5.27\,M_\odot$ ($M_1 = M_2 = 5.51 \pm 2.64\,M_\odot$)

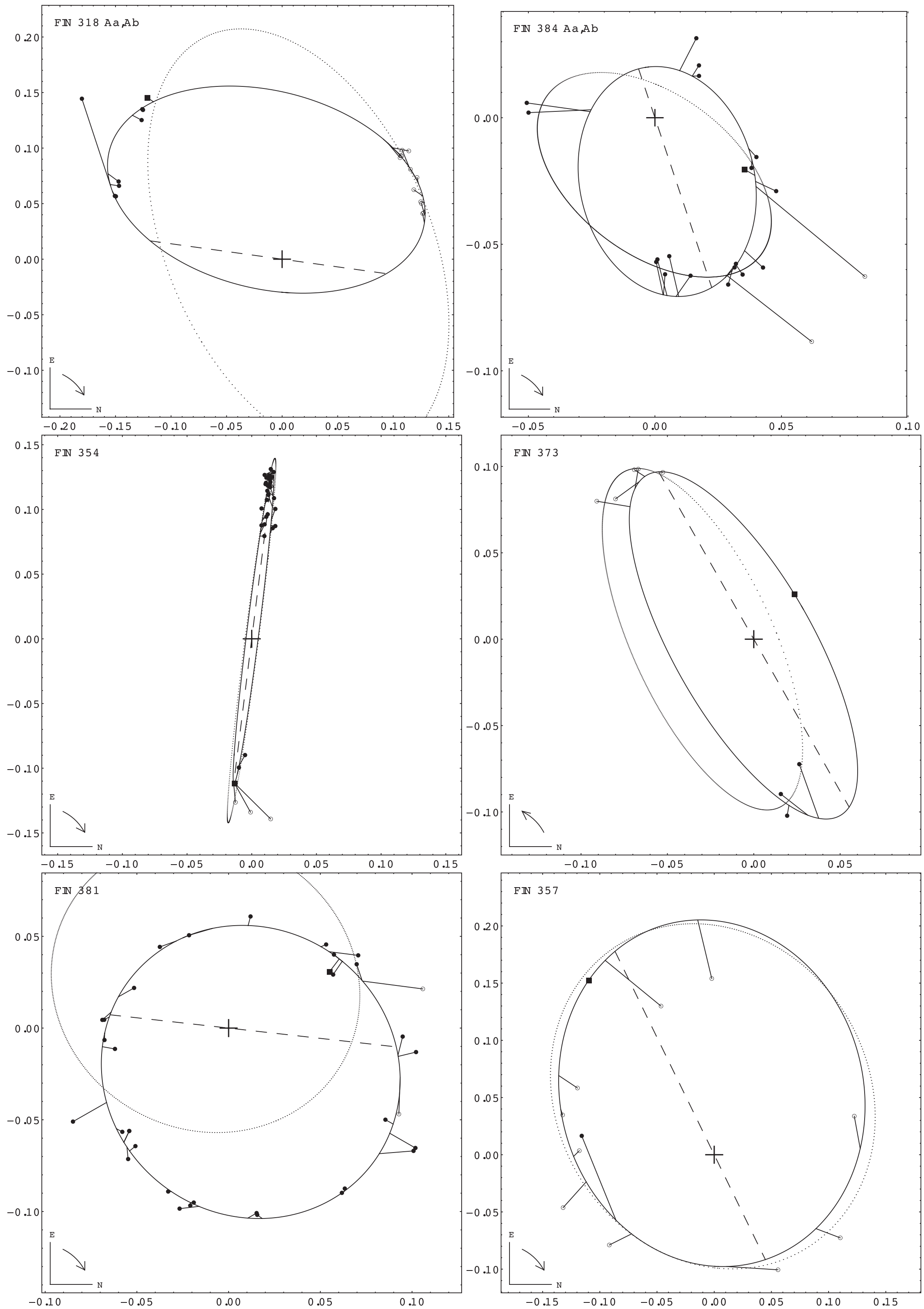

Figure 3. Apparent orbits for Fin 318 Aa,Ab, Fin 384 Aa,Ab, Fin 354, Fin 373, Fin 381 and Fin 357.

is obtained in the first case, whereas that of $13.23 \pm 6.56\,M_{\odot}$ ($M_1 = M_2 = 6.62 \pm 3.28\,M_{\odot}$) is obtained in the second case.

Therefore, the dynamical parallax would provide a much more reliable mass than the *Hipparcos* parallax, similar to the expected individual mass for B3V stars ($7.1\,M_{\odot}$) or even better, for B2IV stars (about $7.3\,M_{\odot}$). In addition, in this last case, it places this star 121 pc (about 19 per cent) closer to the Sun than when considering the *Hipparcos* parallax.

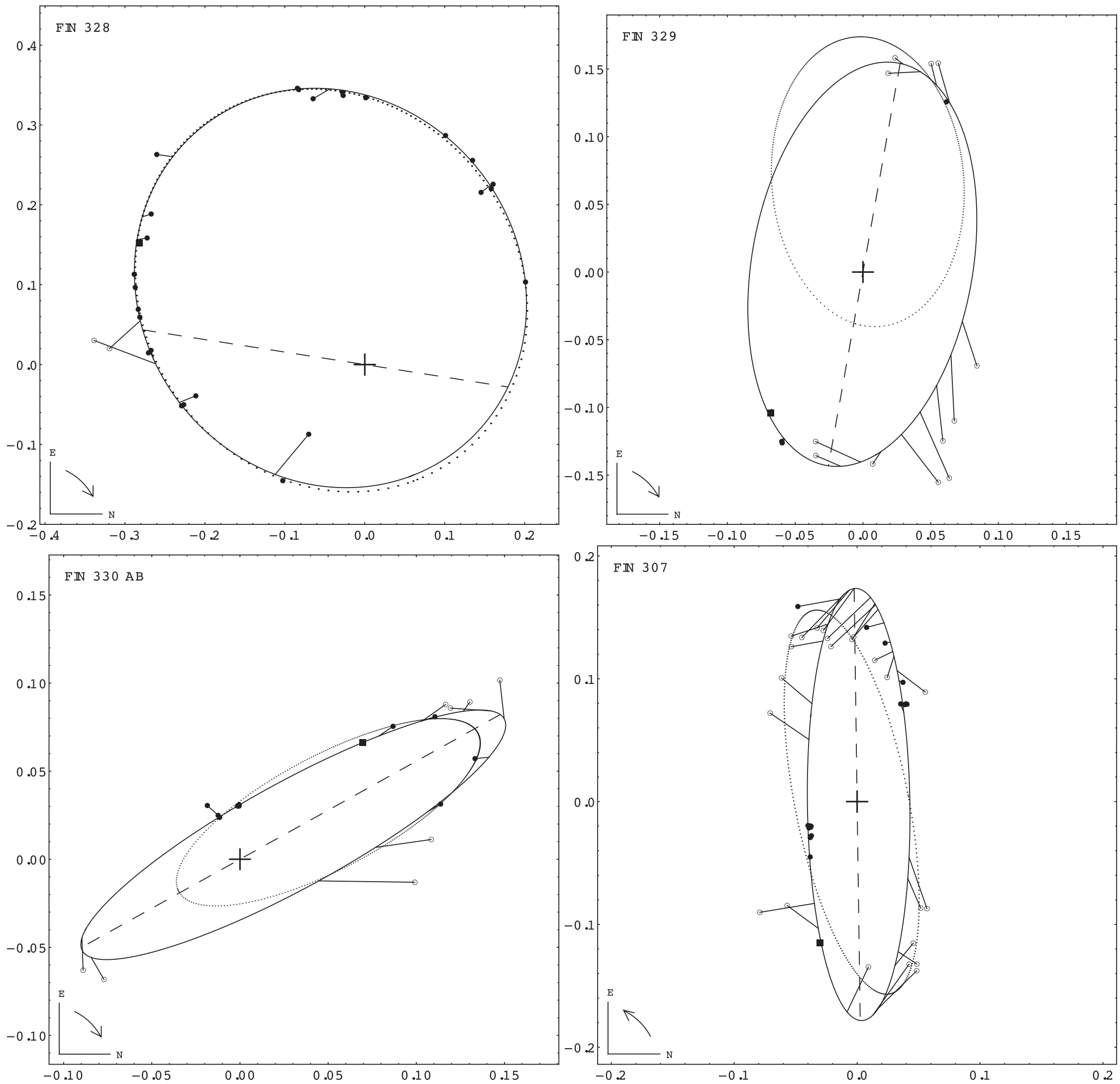

Figure 4. Apparent orbits for Fin 328, Fin 329, Fin 330 AB and Fin 307.

Table 5. Flipped measurements and difference of magnitudes.

Name	Flipping	Δm	Name	Flipping	Δm
FIN 312	Yes	1.287 ± 0.462	FIN 369	No	0.182 ± 0.207
FIN 320	No	0.745 ± 0.030	FIN 318 Aa,Ab	Yes	0.287 ± 0.151
FIN 343	Yes	0.814 ± 0.119	FIN 384 Aa,Ab	Yes	0.0
FIN 334 Aa,Ab	No	0.0	FIN 354	No	0.322 ± 0.805
FIN 315 Aa,Ab	No	0.5	FIN 373	No	0.559 ± 0.187
FIN 335	No	0.379 ± 0.098	FIN 381	No	0.2
FIN 363 AB	No	1.369 ± 0.702	FIN 357	No	0.381 ± 0.153
FIN 326	No	0.88	FIN 328	Yes	2.373 ± 0.051
FIN 367 Aa,Ab	Yes	0.354 ± 0.232	FIN 329	Yes	0.472 ± 0.205
FIN 65 AB	No	1.191 ± 0.106	FIN 330 AB	Yes	0.0
FIN 305	No	0.235 ± 0.153	FIN 307	Yes	1.160 ± 0.228

3.5 WDS 08291−4756, FIN 315 Aa,Ab, HIP 41616 AND HD 72108

This binary system (Aa,Ab) has two fainter companions, B and C, located at about 3.5 and 19 arcsec, respectively. These systems are named HJ 4104 AB and HJ 4104 AC. Moreover, one component of A is itself a spectroscopic binary.

Duplicity of the A component was discovered in the first part of 1951 by Finsen (1952b) and this inner binary was observed by him 17 times in the following 17 yr. There are also five speckle measurements since 1989 until 2011 accomplished with 4-m class telescopes and another one with the *Hipparcos* astrometry satellite. Therefore, this system has completed one-quarter of a revolution since 1951.

The MK classification, B2IV (Hiltner et al. 1969), is included both in the WDS and in the *Hipparcos* catalogues. Later, a composite spectrum B1.5V+B4V was obtained for A and B components by Corbally (1984) who estimated that ΔV for Aa and Ab components would be 1.7 rather than the 0.0 mag given in the Index Catalogue of Visual Double Stars (IDS).

The previous available orbit for the Aa–Ab system (Cvetković & Ninković 2010) already showed residuals of a few degrees in position angles and in angular separations. In this work, we present an improved orbit which has already been announced (Docobo & Andrade 2012b).

Computation of the total mass obtained from the orbital elements and the updated *Hipparcos* parallax gives an absolutely meaningless value. To calculate the dynamical parallax, we have taken into account the two different available spectra. However, results are very similar. In this way, we obtain 3.88 ± 0.56 mas for a B1.5V and 3.85 ± 0.58 mas for a B2IV. Mass ratios for the components would be $q = 0.897 \pm 0.027$ and 0.881 ± 0.031, respectively. With these data, a total mass of $11.53 \pm 6.51\,M_\odot$ ($M_1 = 6.08 \pm 3.43$ and $M_2 = 5.45 \pm 3.08\,M_\odot$) is obtained in the first case, whereas that of $11.80 \pm 6.83\,M_\odot$ ($M_1 = 6.27 \pm 3.63$ and $M_2 = 5.53 \pm 3.20\,M_\odot$) is obtained in the second case. This total mass is very similar to the median mass, $11.92 \pm 0.36\,M_\odot$, derived from luminosity and effective temperature using several evolutionary models (Hohle, Neuhäuser & Schutz 2010).

With a magnitude difference of about 0.5, we can suppose that this binary would comprise to equal components B1.5V or B2IV. In the first case, the total expected mass would be around $20\,M_\odot$ whereas in the second one, it would be a bit smaller, around $15\,M_\odot$. According to the second case and to the obtained dynamical mass, it appears that the most feasible spectral type would be B2IV. In addition, it places this star 394 pc (60 per cent) closer to the Sun than when considering only the *Hipparcos* parallax.

3.6 WDS 08345−3236, FIN 335, HIP 42075 AND HD 72954

This binary system was first observed by Finsen in the middle of 1955 (Finsen 1956). He measured it 12 times (plus three non-resolutions) during 13 yr. In addition, there are five speckle measurements (and one non-resolution) between 1999 and 2010, all of them performed with 4-m class telescopes as well as one measurement made by the *Hipparcos* astrometry satellite. This system has completed a little more than three revolutions since its discovery to the present. The spectral type given in the WDS is G5IV/V, whereas that given in *Hipparcos* is G5V (Edwards 1976; Duflot et al. 1995).

The previous available orbit for this system (Söderhjelm 1999) showed somewhat high residuals either in position angles or in angular separations for the subsequent computation of speckle measurements. In this paper, we present a new orbit (Docobo & Andrade 2012b) whose orbital elements (in addition to the updated *Hipparcos* parallax) provide a total mass of $3.14 \pm 0.39\,M_\odot$. However, this does not match very well with some results about masses published in previous studies. According to Eggen (1989), the photometric parallax gives a mean mass of $0.9\,M_\odot$ whereas, more recently, a mass of $1.5\,M_\odot$ has been estimated by comparison with evolutionary tracks (Randich et al. 1999). While we were preparing this paper, it came to our knowledge that another improved orbit had been calculated as well (Tokovinin 2012). Both new orbits show small residuals and very similar masses.

With the aim to provide accurate individual masses, we have calculated the dynamical parallax and mass ratio for V and IV luminosity class stars. In the first case, we obtain 15.42 ± 0.28 and $q = 0.921 \pm 0.020$, respectively, and in the second one, 16.24 ± 0.39 and $q = 0.909 \pm 0.023$ (both parallax values being a little higher than that of *Hipparcos*). With these values we obtained a total mass of $2.82 \pm 0.19\,M_\odot$, distributed in such a way that $M_1 = 1.47 \pm 0.10\,M_\odot$ and $M_2 = 1.35 \pm 0.09\,M_\odot$ for the first fit. For the second one, we obtained a total mass of $2.41 \pm 0.20\,M_\odot$, distributed in such a way that $M_1 = 1.26 \pm 0.11\,M_\odot$ and $M_2 = 1.15 \pm 0.10\,M_\odot$. Above all, the last one is in very close agreement with masses expected for a G0/2IV ($1.3\,M_\odot$) and a G7IV ($1.2\,M_\odot$), the individual spectral supposed for a G5IV with a difference of apparent magnitudes of 0.379 ± 0.098.

3.7 WDS 09173−6841, FIN 363 AB, HIP 45571, HD 80671 AND 120 Car

This star has a distant component, C, with a 12.2 mag at 18 arcsec from the close pair, AB. Finsen discovered this close star in the middle of 1960 (Finsen 1960a) and observed it nine times (plus three non-resolutions) during 8 yr. Regarding speckle observations, there were four measurements between 1993 and 2010, all of them performed with 4-m class telescopes, as well as one measurement made by the *Hipparcos* astrometry satellite. This system has already completed 15 revolutions since its discovery to the present.

The spectral type given in both the WDS and *Hipparcos* catalogues is F4V (Malaroda 1975). However, a more recent spectrum F5V has been obtained from the 1.5-m Cassegrain spectrograph at Cerro Tololo Inter-American Observatory (Gray et al. 2006).

On the other hand, this is an example of a binary system with a debris disc. It would be made up of dust in unstable locations at only 2.9 au, lesser than the separation (3.4 au) between components (Trilling et al. 2007; Rodríguez & Zuckerman 2012).

The last measurements performed in 2006–2010 showed huge residuals in angular separations and, above all, in angular separations taking into account the previous orbit (Söderhjelm 1999). Our orbit has been previously announced (Docobo & Andrade 2012b). The total mass obtained from the orbital elements and the *Hipparcos* parallax is $2.27 \pm 0.27\,M_\odot$, a value compatible with the spectral data considering that the expected mass for a F5V star is $1.2 \pm 0.1\,M_\odot$ (despite the fact that Martin et al. 1998 obtained a non-compatible mass of $3.661 \pm 0.338\,M_\odot$ for each component, suggesting a pair of G7 giant stars or a pair of A0 dwarfs). Also in this case it has come to our knowledge that another improved orbit had been calculated (Tokovinin 2012) while preparing this paper. Both new orbits show very small residuals and slightly different masses.

However, taking into account that the difference of apparent magnitudes given by *Hipparcos* is poor (1.369 ± 0.702), we will try to estimate individual spectra using dynamical masses. First, we calculate a value for the dynamical parallax, 29.71 ± 1.33 mas, slightly different in comparison with that given by *Hipparcos* and a mass ratio of 0.742 ± 0.113. A total mass of $2.49 \pm 0.41\,M_\odot$, distributed in such a way that $M_1 = 1.43 \pm 0.25\,M_\odot$ and $M_2 = 1.06 \pm 0.20\,M_\odot$, is obtained. These would be in strong agreement with that expected (according to the spectral type and $\Delta m = 1.369 \pm 0.702$) for a F4/3V (1.3–1.4 $M_\odot$) and a F8/G7V (1.1–0.8 $M_\odot$).

3.8 WDS 09442−2746, FIN 326, HIP 47758, HD 84367 AND θ Ant

Finsen discovered this binary star early in the first part of 1952 (Finsen 1953b) and observed it 21 times (plus three non-resolutions) during 16 yr. Regarding speckle observations, there were 19 measurements between 1977 and 2011, practically all of them performed with 4-m class telescopes, as well as a measurement made by the *Hipparcos* astrometry satellite. This system has completed a little more than three revolutions since its discovery to the present.

Regarding spectral types, several authors (see Table 3) agree that this system fits luminosity class III. The last investigation (Ginestet & Carquillat 2002) classified it as G7III+A8m; they also gave a difference of apparent magnitudes obtained from a spectroscopic estimation of ∼−0.2, less than that obtained by *Hipparcos* (0.88).

The first orbit of this system was calculated by himself (Finsen 1967). He obtained a dynamical parallax of 0.0091 arcsec and concluded that 'The dynamical parallax is not in good agreement with the trigonometrical parallax (0.045 ± 0.011 arcsec, Yale) or with the spectral type, but it does not seem possible to fit a shorter period to the observations'. Furthermore, Baize & Petit (1989) gave individual spectral types, A8V and F7II. They also noticed disagreement between the trigonometrical parallax (0.048 ± 0.010 arcsec) and the dynamical one (0.011 arcsec); they indicated that both gave rise to incompatible masses with spectral types.

The previous available orbit (Mason & Hartkopf 1999) showed somewhat high residuals with a total mass obtained from the orbital elements and the updated *Hipparcos* parallax of 6.27 ± 0.90 $M_{\odot}$. In this work, we present an improved orbit (Docobo & Andrade 2012b) with significant differences in the angle of the node and in the argument of the periastron. Thus, the total mass obtained from the orbital elements and *Hipparcos* parallax is 28 per cent smaller, 4.49 ± 0.70 $M_{\odot}$.

Note that the Baize–Romani algorithm cannot be applied to this system because one of its components is supposed to be a giant star and thus the dynamical parallax cannot be derived. However, according to the spectral types given for each component, A and B (Ginestet & Carquillat 2002), G7III and A8V, their individual masses would be 2.1 ± 0.5 and 1.8 ± 0.1 $M_{\odot}$, respectively. If we take into account the computed orbital period and semimajor axis, we obtain a dynamical parallax of 10.08 ± 0.47 mas, in agreement with that obtained by *Hipparcos*.

3.9 WDS 12064−6543, FIN 367 Aa,Ab, HIP 59050 AND HD 105151

This binary system (Aa,Ab) is orbiting around the mutual centre of mass of a distant companion, B, located at about 9 arcsec. Thus, it is part of the triple system, HJ 4498 AB.

Duplicity of the A component was discovered in the middle of 1960 by Finsen (1960b) and this inner binary was observed by him eight times in the following 7 yr. There were also seven speckle measurements since 1989 until 2011 accomplished with 4-m class telescopes and another one with the *Hipparcos* astrometry satellite. Therefore, this system has completed one-half of a revolution since 1960.

A composite spectrum G8/K0III+A3 given for the triple system (Houk & Cowley 1975) is included in the WDS. Furthermore, a composite spectrum K0III+A7V was obtained for Aa and Ab components, as well as spectral type F2V for the B component (Corbally 1984). Taking into account this last classification, the Aa and Ab components of the binary system were catalogued as giant K1 and as A6 by Parsons & Ake (1998) after applying a methodology where hot companions in binaries with luminous cool primaries are classified accurately by temperature class from their far-ultraviolet spectra.

The previous available orbits for the Aa–Ab system (Olević & Cvetković 2004; Mante 2006) showed huge residuals in position angles and separations of the subsequent speckle measurements for its computation. In this paper, we present a completely new orbit (Docobo & Andrade 2012b) in comparison with that previously announced (Docobo & Andrade 2012a). This shows a much shorter period and higher eccentricity. The total mass obtained from the orbital elements and the updated *Hipparcos* parallax, 4.27 ± 7.25 $M_{\odot}$, would be in high agreement with the mass expected for this system. We note that almost all of the uncertainty (99 per cent) is due to the huge relative uncertainty of 57 per cent in the *Hipparcos* parallax.

Again, we cannot take advantage of the dynamical parallax computation according to the Baize–Romani algorithm since one of its components is probably a giant star. However, according to the spectral types given for each component, A and B, by Parsons & Ake (1998), K1III and A6V, their individual masses would be 2.0 ± 0.5 and 2.0 ± 0.1 $M_{\odot}$, respectively. If we take into account the computed orbital period and semimajor axis, we obtain an accurate dynamical parallax of 8.11 ± 0.42 mas.

3.10 WDS 12446−5717, FIN 65 AB, HIP 62179 AND HD 110698

This binary system was first observed by Finsen in the middle of 1952 (Finsen 1953c). He measured it six times during 12 yr. In addition, there are seven speckle measurements between 1989 and 2010, all of them performed with 4-m class telescope, as well as one measurement accomplished by using adaptive optics on a 3.6-m telescope and another one made by the *Hipparcos* astrometry satellite. With a relatively long period of 200 yr, this system has only completed roughly one-third of one revolution since the first observation until now. The spectral type given in both the WDS and *Hipparcos* catalogues is A0IV/V (Houk & Cowley 1975).

The previous available orbits (Olević & Cvetković 2004; Mante 2005) showed high residuals for the last three speckle measurements. The improved orbit presented in this paper was already reported (Docobo & Andrade 2012a). The total mass obtained from the orbital elements and the *Hipparcos* parallax is 2.27 ± 0.54 $M_{\odot}$.

The dynamical parallax differs slightly depending on the luminosity class considered. So, we obtain 7.51 ± 0.37 mas for a A0V and 7.84 ± 0.40 mas for a A0IV. Mass ratios for the components would be $q = 0.772 \pm 0.018$ and 0.740 ± 0.020, respectively. With these data, a total mass of 3.89 ± 0.75 $M_{\odot}$ ($M_1 = 2.20 \pm 0.42\,M_{\odot}$ and $M_2 = 1.69 \pm 0.33\,M_{\odot}$) is obtained in the first case, whereas that of 3.42 ± 0.68 $M_{\odot}$ ($M_1 = 1.97 \pm 0.39\,M_{\odot}$ and $M_2 = 1.45 \pm 0.29\,M_{\odot}$) is obtained in the second case.

Therefore, the dynamical parallax would provide a much more reliable mass than the *Hipparcos* parallax since the expected individual mass (considering spectral type and $\Delta m = 1.191 \pm 0.106$) for a B9V/IV star and A4V stars are 3.4–3.3 and 2.3 $M_{\odot}$, respectively. In addition, considering the case of a pair of main-sequence stars, it would place this system 22 pc (20 per cent) further away from the Sun than when considering only the *Hipparcos* parallax.

3.11 WDS 13117−2633, FIN 305, HIP 64375 AND HD 114576

Finsen discovered this binary star in mid-1951 (Finsen 1951c) and observed it 13 times (plus two non-resolutions) during 15 yr. In addition, there were 18 speckle measurements between 1976 and 2009, most of them performed with 4-m class telescope, as well as one measurement made by the *Hipparcos* astrometry satellite. This system has completed more than three revolutions since its discovery until now. Most of the spectral analysis classifies it as A3V or A5V, this last spectral type being that given in both the WDS and *Hipparcos* catalogues.

Finsen (1968) himself gave the first (and present) orbit of this system with a period of 19.0 yr. He also obtained a dynamical parallax of 9.9 mas. Now we have improved this orbit, already announced in Docobo & Andrade (2012b), so that the total mass obtained from the orbital elements and the *Hipparcos* parallax is 4.26 ± 0.93 $M_\odot$ (as compared to 6.2 $M_\odot$ of Finsen's orbit, somewhat high for a pair of A3V stars).

The calculation of the dynamical parallax provides a value of 9.71 ± 0.45 mas as well as a mass ratio, $q = 0.950 \pm 0.032$. With these values we obtain a dynamical mass of 3.43 ± 0.62 $M_\odot$ distributed in such a way that $M_1 = 1.76 \pm 0.32\,M_\odot$ and $M_2 = 1.67 \pm 0.30\,M_\odot$.

In this case, it seems that the *Hipparcos* parallax provides a more reasonable mass, since, the expected mass (considering spectral type and $\Delta m = 0.235 \pm 0.153$) for a A3/2V and A3/4V are 2.4–2.6 and 2.4–2.3 $M_\odot$.

3.12 WDS 13320−6519, FIN 369, HIP 66005 AND HD 117432

Finsen discovered this binary star in the middle of 1960 (Finsen 1960b) and observed it seven times (plus one non-resolution) during 7 yr. Regarding speckle observations, there were six measurements between 1989 and 2011, all of them performed with 4-m class telescopes, as well as one measurement made by the *Hipparcos* astrometry satellite. This system has already completed two revolutions since its discovery to the present, the spectral type given in both the WDS and *Hipparcos* catalogues is A8/A9IV (Houk & Cowley 1975).

The previous available orbit for the Aa–Ab system (Olević & Cvetković 2004) showed huge residuals for the subsequent speckle measurements related to its computation, either in position angles or in angular separations. A preliminary version of the orbit presented in this paper was announced the past year (Docobo & Andrade 2011a), in addition to another one given by Cvetković (2011). Total mass obtained from the current orbital elements (Docobo & Andrade 2012b) and the *Hipparcos* parallax is 5.05 ± 1.23 $M_\odot$.

Calculation of the dynamical parallax provides a value of 15.87 ± 1.35 mas as well as a mass ratio, $q = 0.955 \pm 0.050$. With these values we obtain a dynamical mass of 2.22 ± 0.73 $M_\odot$ distributed in such a way that $M_1 = 1.14 \pm 0.37\,M_\odot$ and $M_2 = 1.08 \pm 0.36\,M_\odot$. That would be somewhat far from the expected mass (considering the spectral type and $\Delta m = 0.182 \pm 0.207$) for a A9/7IV (2.0–2.2 $M_\odot$) and a A9/8F0IV (2.1–1.9 $M_\odot$) star.

3.13 WDS 14373−4608, FIN 318 Aa,Ab, HIP 71500 AND HD 128266

This binary system (Aa,Ab) orbits around the mutual centre of mass of a distant companion, B (with visual magnitude 7.65), located at about 20 arcsec. Thus, it is part of the triple system, HJ 4690 AB, whose orbital stability could not be guaranteed in such a way that scape of the distant companion would be possible in the future (Li, Fu & Sun 2009).

Duplicity of the A component was discovered in the middle of 1951 by Finsen (1951c) and this inner binary was observed by him 12 times in the following 15 yr. There were also 10 speckle measurements since 1989 until 2011 accomplished with 4-m class telescopes and another two with the *Hipparcos* astrometry satellite. Therefore, this system has completed three-quarters of a revolution since 1951 to the present. This system shows a composite spectrum, G8III+A1V (Jaschek et al. 1964) or K0III+A1V (Cousins & Stoy 1962; Duflot et al. 1995).

With respect to the previous orbit (Olević & Cvetković 2004), the last speckle measurements showed residuals of a few degrees in position angles. We have calculated a new orbit (Docobo & Andrade 2012b) which gives reasonably small residuals if we flip the whole set of speckle measurements by 180°. In exchange for that, we must manage without the *Hipparcos* parallax if we do not want to obtain absolutely meaningless values for the system mass. Anyway, this choice is well justified taking into account the extremely poor precision of the *Hipparcos* parallax.

Proceeding in this manner, we calculated a dynamical parallax of 5.32 ± 0.20 mas from the new orbital elements as well as from the estimated values for the mass (about 4.7 ± 0.5 $M_\odot$) according to the well-known composite spectrum of this system (note that one component is suppose to be a giant star, thus we cannot apply the Baize–Romani algorithm). Yet, if we take into account the Tokovinin (2008) estimation of the component masses (3.68 and 3.35 $M_\odot$) obtained from the spectral type or the $B - V$ colour index from Allen's tables, the corresponding dynamical parallax would be 4.65 ± 0.12 mas.

Moreover, this dynamical parallax would place this system 230 pc (55 per cent) closer to the Sun than when considering only the *Hipparcos* parallax.

3.14 WDS 16057−0617, FIN 384 Aa,Ab, HIP 78849 AND HD 144362

This binary system, Aa,Ab, is a spectroscopic binary that has a companion, B, at about 1 arcsec. This triplet is part of a hierarchical sextuple system (ADS 9918) whose more distant component, E, is located at about 4.5 arcmin. The inner pair, Aa,Ab, was resolved by Finsen using his interferometer in the second part of 1964 (Finsen 1965). He measured it two times (plus one non-resolution) during 2 yr. In addition, there were 20 speckle measurements (and three non-resolutions) between 1976 and 2009, practically all of them performed with 4-m class telescopes. The spectral type given in the WDS is F3V (Harlan 1974; Abt 1981), whereas that given in the *Hipparcos* catalogue is F2IV (Malaroda 1975).

Some measurements of this binary are incompatible among themselves. For example, the Mason & Hartkopf (2001) orbit fits quite well with observations except those by Tokovinin in 2008. An early orbit by Baize (1992) fits reasonably well with the last but not with the Tokovinin's 2009 measurement.

In our case, we have obtained a new orbit that not only satisfies practically all of the observational material (except the separations of 1988.253 and 1993.206 and the angle of 1992.307) but which, along with the *Hipparcos* parallax, gives a total mass of 2.63 ± 0.92 $M_\odot$ that agrees with the spectral type F3V.

Thus, we will have to calculate more reliable masses by means of the dynamical parallax. In this way, we obtain 10.43 ± 0.81 mas for a F3V and 10.98 ± 0.88 mas for a F2IV. Mass ratios for the components would be $q = 1.000 \pm 0.030$ and 1.000 ± 0.035, respectively. With these data, a total mass of 3.48 ± 1.06 $M_\odot$ ($M_1 = M_2 = 1.74 \pm 0.53\,M_\odot$) is obtained in the first case, whereas that of 2.99 ± 0.93 $M_\odot$ ($M_1 = M_2 = 1.50 \pm 0.47\,M_\odot$) is obtained in the second case.

3.15 WDS 16115+0943, FIN 354, HIP 79337 AND HD 145589

Finsen discovered this binary star in the middle of 1959 (Finsen 1959b) and observed it five times (plus four non-resolutions) during 7 yr. Regarding speckle observations, there were 33 measurements between 1976 and 2009, most of them performed with 4-m class telescopes as well as one measurement made by the *Hipparcos* astrometry satellite. Indeed, we observed it one night with the Special Astrophysical Observatory of the Russian Academy of Science (SAO RAS) 6-m telescope using speckle interferometry in 2007 (Docobo et al. 2010). This system has already completed one revolution since its discovery to the present.

With respect to the spectral type, both the WDS and *Hipparcos* catalogues classify it as F0IV (Cowley et al. 1969). On the contrary, it has been more recently classified as A7V (Abt & Morrell 1995; Paunzen et al. 2001).

Four measurements performed in 2006–2009 showed appreciable residuals in angular separations taking into account the previous orbit (Olević & Cvetković 2004). Our orbit was previously announced (Docobo & Andrade 2011b). The total mass obtained from the orbital elements and the *Hipparcos* parallax is $3.09 \pm 0.90\,M_\odot$.

The calculation of the dynamical parallax yields a value of 5.45 ± 0.28 mas as well as a mass ratio, $q = 0.932 \pm 0.163$, considering the spectral type A7V. With these values we obtain a dynamical mass of $4.46 \pm 0.80\,M_\odot$ distributed in such a way that $M_1 = 2.31 \pm 0.46\,M_\odot$ and $M_2 = 2.15 \pm 0.43\,M_\odot$. That would be compatible with the mass expected for a A7V spectral type with a difference of apparent magnitudes of 0.63 (Docobo et al. 2010), which could comprise a A6V star ($2.0\,M_\odot$) and a A9V star ($1.7\,M_\odot$). In this case, we have not calculated the difference between magnitudes from the *Hipparcos* catalogue because of its large uncertainty (0.322 ± 0.805).

If we consider the spectral type F0IV to be more probable, we obtain a dynamical parallax of 5.64 ± 0.32 along with a mass ratio of 0.922 ± 0.188 which gives a dynamical mass of $4.02 \pm 0.78\,M_\odot$, distributed in such a way that $M_1 = 2.09 \pm 0.45\,M_\odot$ and $M_2 = 1.93 \pm 0.43\,M_\odot$. This would be in high agreement with the masses expected for a F0IV system comprised of a A9IV star ($2.0\,M_\odot$) and a F5IV star ($1.6\,M_\odot$).

3.16 WDS 17221−7007, FIN 373, HIP 84979, HD 156190 AND ι Aps

Finsen discovered this binary star in the middle of 1960 (Finsen 1960c) and observed it five times during 6 yr. Moreover, there were three speckle measurements between 1989 and 2009, all of them performed with 4-m class telescopes as well as one measurement made by the *Hipparcos* astrometry satellite. This system has already completed an arc of about 290°.

Spectral classification of this system shows a peculiarity (Cucchiaro et al. 1977; Eggen 1984) since it is classified as B9III spectroscopically but, photometrically, it is a B8/B9 luminosity class V star (Houk & Cowley 1975; Eggen 1977). Furthermore, its spectrum exhibits features of a composite spectrum, B9V+B9.5V (Davidson et al. 1987).

The last measurement (2009.2631) showed huge residuals in position angles and in angular separation taking into account the two previous orbits (Olević & Cvetković 2003, 2004). We have calculated an improved orbit (Docobo & Andrade 2012b) that passes through this measurement. The total mass obtained from the orbital elements and the *Hipparcos* shows an excess ($29 \pm 18\,M_\odot$) in comparison with the expected mass for a B9V+B9.5V system (roughly $6.4 \pm 0.1\,M_\odot$). This could be due to an inaccurate *Hipparcos* parallax that places this system at an overestimated distance.

In fact, if we calculate the dynamical parallax (3.89 ± 0.26 mas), we can conclude that this system would be situated at a distance of 37 per cent below the value given by *Hipparcos*, i.e. 148 pc closer to the Sun. Total mass would be $7.34 \pm 1.91\,M_\odot$ and mass ratio, $q = 0.885 \pm 0.036$, in such a way that individual masses would be $M_1 = 3.89 \pm 1.02\,M_\odot$ and $M_2 = 3.45 \pm 0.90\,M_\odot$, in reasonable agreement with values given by several calibrations for late B-type main-sequence stars (in this case, about 3.3–3.7 and 3.3–2.7 $M_\odot$ for a B9/8V and a B9/A1V star, respectively).

3.17 WDS 17542+1108, FIN 381, HIP 87655, HD 163151 AND V* V2388 Oph

This binary system was first observed by Finsen in the middle of 1959 (Finsen 1963). He measured it five times (plus nine non-resolutions) during 5 yr. In addition, there were 33 speckle measurements between 1979 and 2008, almost all of them performed with 4-m class telescopes, as well as an unresolved measurement of the *Hipparcos* astrometry satellite. With a relatively short period of 9 yr, this system has already completed almost six revolutions since the first observation until today. A few years ago it was determined (Rodríguez et al. 1998) that the brighter component was itself a W UMa-type eclipsing binary (V2388 Oph) with a luminosity variation in the primary minimum of about 0.3 mag. They also measured an orbital period of 0.8023 d and a mass ratio, $q = 0.27$. In addition, it was confirmed that V2388 Oph had a high degree of overcontact with a parameter of $f = 0.65$ (Yakut et al. 2004).

With respect to the spectral type, both the WDS and *Hipparcos* catalogues classify it as F5Vn (Harlan & Taylor 1970; Cowley & Bildelman 1979). Recently, the Aa and Ab components of the eclipsing binary have been classified as A5m and F0, respectively (Rodríguez et al. 1998). Actually, the eclipsing binary has been a subject of numerous investigations in the last years; as a result, many physical parameters have reliable values at present.

The better available orbit (Hartkopf, Mason & McAlister 1996) showed residuals of some degrees (Rucinski et al. 2007) for the subsequent measurements. In this paper, we give an improved orbit taking into account new speckle measurements until 2008. It has already been announced (Docobo & Andrade 2012b). The total mass obtained from this orbit as well as from the updated *Hipparcos* parallax is $4.43 \pm 0.96\,M_\odot$. Possibly, this orbit is in the minimum mass threshold (keeping small residuals) using this parallax. Despite that, it would be within the margins of uncertainty for the mass of three main-sequence F stars, about $3.6\,M_\odot$. Indeed, the last is close to the total mass obtained exclusively from astrometric information collected by *Hipparcos*, $3.05 \pm 0.51\,M_\odot$ (Söderhjelm 1999).

Nevertheless, a feasible explanation for this discrepancy could be that the updated *Hipparcos* parallax is underestimated. Really, starting from the previous *Hipparcos* value of 14.72 ± 0.81 mas, we estimated that the most probable value for the parallax would be between 12.4 ± 0.3 and 14.2 ± 0.5 mas (Docobo & Andrade 2006).

In fact, the calculation of the dynamical parallax, considering the total visual magnitude of the triple system to be 6.16 ± 0.01 as well as the magnitude difference between the third star and the eclipsing pair as 1.09 ± 0.05 (taken from the detailed analysis of *ubvy* light curves performed by Yakut et al. 2004), provides a value of 13.45 ± 0.38 mas as well as a mass ratio, $q = 0.789 \pm 0.009$. With these values we obtain a dynamical mass of $3.14 \pm 0.40\,M_\odot$ distributed in such a way that $M_A = 1.76 \pm 0.22\,M_\odot$

and $M_B = 1.38 \pm 0.18\,M_\odot$. Moreover, if we consider the visual magnitude of the primary given by *Hipparcos*, 6.34 ± 0.01, along with a larger magnitude difference between the third star and the eclipsing pair, 1.75 ± 0.02, derived using the broadening function formalism (Rucinski et al. 2002), we obtain a dynamical parallax of 13.82 ± 0.39 mas as well as a mass ratio, $q = 0.683 \pm 0.005$. With these values we obtain a dynamical mass of $2.90 \pm 0.40\,M_\odot$ distributed in such a way that $M_A = 1.72 \pm 0.24\,M_\odot$ and $M_B = 1.18 \pm 0.16\,M_\odot$. We must note that, in any case, both dynamical solutions are very similar.

Now, if we consider the mass ratio for the components of the eclipsing binary, 0.186 ± 0.002 (Rucinski et al. 2002), we find that $M_{Aa} = 1.48 \pm 0.19\,M_\odot$ and $M_{Ab} = 0.28 \pm 0.03\,M_\odot$ for the first dynamical solution, while $M_{Aa} = 1.45 \pm 0.20\,M_\odot$ and $M_{Ab} = 0.27 \pm 0.04\,M_\odot$ for the second one. Just the same values are found by considering the mass ratio, 0.187 ± 0.005 (Karami et al. 2009).

These results are also in agreement with masses estimated by D'Angelo, van Kerkwijk & Rucinski (2006) for the components Aa, Ab and B: 2.10, 0.39 and $1.36\,M_\odot$, respectively. This would indicate that the distant component is more massive than expected as compared to the eclipsing binary using only astrometric information which gives a mass ratio between those of 0.41 ± 0.04 with $M_A = 2.16 \pm 0.47\,M_\odot$ and $M_B = 0.89 \pm 0.20\,M_\odot$ (Söderhjelm 1999). Indeed, smaller masses have been obtained for each component ($M_A = 1.653 \pm 0.289\,M_\odot$ and $M_B = 0.522 \pm 0.126\,M_\odot$) from astrometric analysis after obtaining a dynamical parallax of 15.66 ± 0.81 mas (Martin & Mignard 1998).

Furthermore, masses obtained for Aa and B would be in agreement with those expected (considering the spectral type and $\Delta m = 0.2$) for a F3/2V ($1.4\,M_\odot$) and a F4V ($1.3\,M_\odot$) star.

3.18 WDS 19035−6845, FIN 357, HIP 93574 AND HD 175986

This binary system was first observed by Finsen in the second part of 1959 (Finsen 1959b). He measured it 10 times during 9 yr. In addition, there was one speckle measurement in 2008 performed with a 4-m class telescope, as well as one measurement made by the *Hipparcos* astrometry satellite. With a relatively long period of about 13.6 yr, this system has almost completed four revolutions since the first observation until the present.

This system has been classified as G0IV (Houk & Cowley 1975) as well as F8V (Malaroda 1975), this last value being that collected in both the WDS and *Hipparcos* catalogues.

Finsen (1969) himself gave the first (and present) orbit of this system with a period of 13.58 yr. He also obtained a dynamical parallax of 14 mas. Now we have improved this orbit and it better fits the dynamical parallax. This improved orbit has been already announced (Docobo & Andrade 2012c). The total mass obtained from the orbital elements and the *Hipparcos* parallax is $3.25 \pm 0.37\,M_\odot$.

Calculation of the dynamical parallax provides a value of 18.51 ± 0.46 mas as well as a mass ratio, $q = 0.920 \pm 0.031$ (for the spectral type, F8V). With these values, we obtain a dynamical mass of $2.87 \pm 0.28\,M_\odot$ that is distributed in such a way that $M_1 = 1.49 \pm 0.15\,M_\odot$ and $M_2 = 1.38 \pm 0.14\,M_\odot$. That would be somewhat large in comparison with the masses expected (considering the spectral type and $\Delta m = 0.381 \pm 0.153$) for a F7/8V star ($1.1\,M_\odot$) and a F9/G0V star ($1.0\,M_\odot$). Otherwise, if we consider the spectral type, G0IV, the dynamical parallax would be 19.69 ± 0.52 mas and the mass ratio, $q = 0.908 \pm 0.035$. In this case, we obtain a dynamical mass of $2.39 \pm 0.24\,M_\odot$ that is distributed in such a way that $M_1 = 1.25 \pm 0.13\,M_\odot$ and $M_2 = 1.14 \pm 0.12\,M_\odot$. In this case, masses are in close agreement with those expected for a F8/6IV star ($1.4–1.5\,M_\odot$) and a G2/7IV star ($1.3–1.2\,M_\odot$).

3.19 WDS 21044−1951, FIN 328, HIP 104019, HD 200499 AND η Cap

This binary system is one of the two analysed in this study whose first measurement, in the second part of 1951, was not performed using the eyepiece interferometer. According to Finsen's own comments (Finsen 1951b), 'duplicity of η Cap was detected (with slits withdrawn) as the result of a special examination and the measures were made with the micrometer'. He remarks that 'the occultation of this star on 1950 November 15 was noted as occurring in two stages by R. H. Stoy and A. W. J. Cousins at the Royal Observatory, Cape, and by J. A. Bruwer at the Union Observatory'. Another visual observation would be made by him in the next year. In addition, there were 28 speckle measurements (plus five non-resolutions) from 1976 to 2011, almost all of them performed with 4-m class telescopes as well as one measurement accomplished by using adaptive optics on a 2.5-m telescope and another one made by the *Hipparcos* astrometry satellite.

The spectral type for this system was given by Cowley et al. (1969) who classified it as A5V. Subsequently, Abt & Morrell (1995) obtained A3IV and, a few years later, the spectral types A4V and F2V were given for the A and B components, respectively, based on adaptive optics measurements consisting of differential photometry with several filters (ten Brummelaar et al. 2000).

The current orbits of this binary in catalogues are contemporary: one by Mason, Douglass & Hartkopf (1999) and one by Söderhjelm (1999). Amazingly, this last orbit shows very acceptable residuals in both coordinates, better than those obtained from the former. Despite this, we give an improved orbit (Docobo & Andrade 2012a) taking into account 10 speckle measurements between 2006 and 2010. Total masses obtained from these three orbits are, respectively, 2.67 ± 0.87, 2.87 and $2.91 \pm 0.37\,M_\odot$. For calculation of the last, we considered improved orbital elements as well as the updated *Hipparcos* parallax.

On the other hand, if we calculate the dynamical parallax, we obtain 19.49 ± 0.29 mas as well as a mass ratio, $q = 0.596 \pm 0.008$, which provide a dynamical mass of $3.24 \pm 0.19\,M_\odot$ distributed in such a way that $M_1 = 2.03 \pm 0.12\,M_\odot$ and $M_2 = 1.21 \pm 0.07\,M_\odot$. Otherwise, if we consider the spectral type, A3IV, the dynamical parallax would be 20.46 ± 0.32 mas and the mass ratio, $q = 0.596 \pm 0.009$. In this case, we obtain a dynamical mass of $2.80 \pm 0.17\,M_\odot$ that is distributed in such a way that $M_1 = 1.75 \pm 0.11\,M_\odot$ and $M_2 = 1.05 \pm 0.06\,M_\odot$.

Such masses would be in close agreement with those expected (considering the spectral type and $\Delta m = 2.373 \pm 0.051$) for a pair A4V ($2.3\,M_\odot$) and F7/8V ($1.1\,M_\odot$) or, somewhat worse, with a pair, A1IV ($2.9\,M_\odot$) and F5/6V ($1.2\,M_\odot$).

3.20 WDS 21158−5316, FIN 329, HIP 104978 AND HD 202103

This binary system was first observed by Finsen at the end of 1951 (Finsen 1951b). He measured it 12 times (plus three non-resolutions) during 17 yr. In addition, there were six speckle measurements between 1978 and 2009, all of them performed with 4-m class telescopes, as well as one measurement made by the *Hipparcos* astrometry satellite. With a relatively long period of about 17.6 yr, this system has already completed more than three revolutions since the first observation until today.

The first spectral type for this system was given by de Vaucouleurs (1957) who classified it as A5III. In subsequent years, different spectral types were obtained: A7V (Evans et al. 1959; Edwards 1976), A5III (Buscombe 1962) and A6IV (Levato 1972). More recently, the spectral type, A2.5V, was obtained by Abt & Morrell (1995).

Finsen (1964a) himself gave the first orbit of this system with a period of 21.0 yr. He also obtained a dynamical parallax of 11 mas. Some years later, Heintz (1973) calculated a new orbit with a period of 17.0. With his orbital elements, a dynamical parallax of 10 mas and a total mass of 4.5 $M_\odot$ were also obtained.

Very huge residuals, either in position angles or in angular separations, are shown for the subsequent speckle measurements for the computation of the Heintz's orbit.

Two years ago we announced an improved orbit (Docobo & Andrade 2010) with a period similar to that of Heintz and with a high eccentricity. Now, in this paper we present a different orbit that was previously reported (Docobo & Andrade 2012b), with a period that is twice that of the earlier one and almost circular. This gives a dynamical parallax closer to the *Hipparcos* parallax and a total mass compatible with that expected for a A2.5V or a A6IV.

Taking into account the new orbital elements as well as the *Hipparcos* parallax, we obtain a total mass of 5.82 ± 1.37 $M_\odot$. The calculation of dynamical parallaxes and mass ratios considering spectral types, A2.5V and A6IV, gives 8.36 ± 0.17 mas and $q = 0.902 \pm 0.040$ as well as 8.74 ± 0.17 mas and $q = 0.888 \pm 0.046$ for each case. The corresponding total masses are 4.41 ± 0.32 and 3.86 ± 0.27 $M_\odot$, respectively, and splitting that into both components, we obtain 2.32 ± 0.18 and 2.09 ± 0.16 $M_\odot$ in the first case and 2.04 ± 0.15 and 1.82 ± 0.14 $M_\odot$ in the second one, in agreement with those expected (considering the spectral type and $\Delta m = 0.472 \pm 0.205$) for a pair, A2V (2.6 $M_\odot$) and A4/5V (2.3–2.1 $M_\odot$), or for a pair, A5IV (2.4 $M_\odot$) and A7IV/A9V (2.2–1.7 $M_\odot$).

3.21 WDS 21477−3054, FIN 330 AB, HIP 107608 AND HD 207155

Finsen discovered this binary at the end of 1951 (Finsen 1951b). He observed it nine times (plus three non-resolutions) during 15 yr. In addition, there are 11 speckle measurements between 1978 and 2010, practically all of them performed with 4-m class telescopes, as well as an unresolved measurement of the *Hipparcos* astrometry satellite. Having a period of about 21 yr, this system has almost completed three revolutions since the first observation until today.

After the first spectral classification as A2III (Evans et al. 1957), this system has been classified as A2V (Levato 1972) and, more recently, as A1V (Houk 1982; Abt & Morrell 1995).

Considering that both components have the same apparent magnitudes, initial orbital calculations show that there were two possible solutions for the binary when changing the quadrants for 1951–1996 observations (except 1964.852). Both preliminary orbits were reported two years ago by Docobo & Andrade (2010). Despite that, a recent calculation that takes into account a later speckle measurement has provided improved orbital elements (Docobo & Andrade 2012b) that we show in this paper. The total mass obtained from the orbital elements and the *Hipparcos* parallax is 6.16 ± 0.91 $M_\odot$.

Calculation of the dynamical parallax provides a value of 11.17 ± 0.41 mas as well as a mass ratio, $q = 1.000 \pm 0.030$. With these values we obtain a dynamical mass of 4.63 ± 0.65 $M_\odot$, distributed in such a way that $M_1 = M_2 = 2.32 \pm 0.33$ $M_\odot$. That is in agreement with the mass expected for a A1V star (2.7 $M_\odot$).

3.22 WDS 21579−5500, FIN 307, HIP 108431, HD 208450 AND δ Ind

This binary system was first observed by Finsen at the end of 1932 (Finsen 1936) using a micrometer (there are 10 micrometric measurements between 1932 and 1935) and then he measured it using interferometry one night in 1935. He observed it again 278 times (plus 292 non-resolutions) during 18 yr from 1950 to 1968. In addition, there were 17 speckle measurements between 1978 and 2009, practically all of them performed with 4-m class telescopes, as well as one measurement made by the *Hipparcos* astrometry satellite. With a period of about 12.2 yr, this system has already completed six and one-half revolutions since the first observation until today. Regarding its spectral type, it has been classified as F0IV according to many authors (de Vaucouleurs 1957; Houk & Cowley 1975; Malaroda 1975; Edwards 1976).

Despite the huge amount of measurements available, only two orbits (Churms 1965) have been calculated for this system up to now: one with a period of 12.2 yr and low eccentricity (I) and another with a period of 6.1 yr and high eccentricity (II). This can be easily explained taking into account that both components have the same apparent magnitude (5.8) and that Finsen's observations show an unusual distribution; these factors allow different sets of orbital elements to show similar residuals. However, not both solutions (along with the *Hipparcos* parallax) give system mass in agreement with that expected for a pair of F0IV (3.8 $M_\odot$). From this point of view, solution (I) is better than (II) since the mass obtained from the former (5.24 ± 0.44 $M_\odot$) is more probable than that obtained from the latter (10.6 ± 0.9 $M_\odot$).

Considering the previous comment about system mass as well as large residuals observed in speckle measurement for both mentioned solutions, we have calculated a new orbit which improves residuals and gives a mass of 6.98 ± 0.76 $M_\odot$. This improved orbit has been already announced (Docobo & Andrade 2012b).

Nevertheless, this seems to be a somewhat large mass for a F0IV spectral type with a difference of apparent magnitudes of 1.16. Supposing that the first component is a A8IV star (2.1 $M_\odot$) and the second one is a G0/7IV (1.3–1.2 $M_\odot$) star, system mass would be about 3.3 $M_\odot$. Thus, considering that the *Hipparcos* parallax could be underestimated, we have calculated the dynamical parallax. A larger value of 22.71 ± 0.69 mas has been obtained as well as a mass ratio of 0.746 ± 0.043 which provide a dynamical mass of 3.11 ± 0.36 $M_\odot$, distributed in such a way that $M_1 = 1.78 \pm 0.21$ $M_\odot$ and $M_2 = 1.33 \pm 0.16$ $M_\odot$, in agreement with the above-indicated individual mass expected (considering the spectral type and $\Delta m = 1.160 \pm 0.228$).

In addition, such a dynamical parallax would place this star almost 13.7 pc (24 per cent) closer to the Sun than when considering the *Hipparcos* parallax.

Note that in the plot of this orbit, many Finsen's measurements with very close instants of observation have been averaged.

4 CONCLUSIONS

In this paper, we have reported the improved orbits of 22 binaries discovered by W. S. Finsen (3 northern and 19 southern). In each case and in order to check the quality of the orbits, we have calculated the rms and the mean of the residuals, given different weights for the observations taking into account both the observational technique and the telescope used.

For each binary, some orbits from several authors have been compared. On the other hand, precise individual masses of the

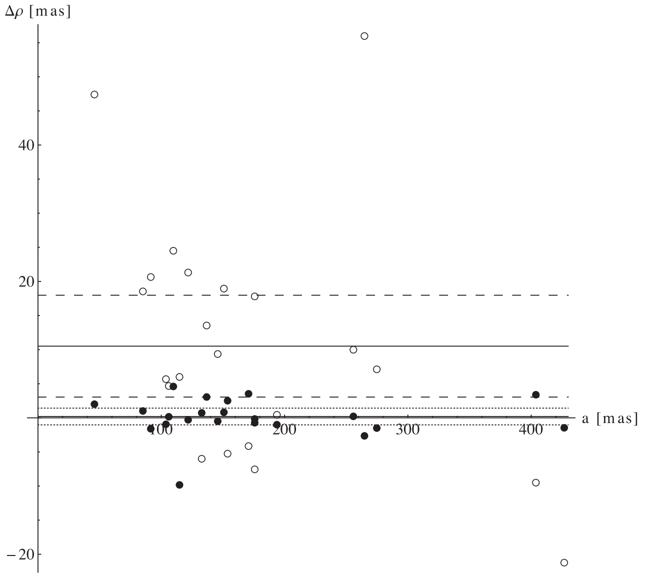

Figure 5. Means of the residuals for the Finsen and speckle sets of measurements.

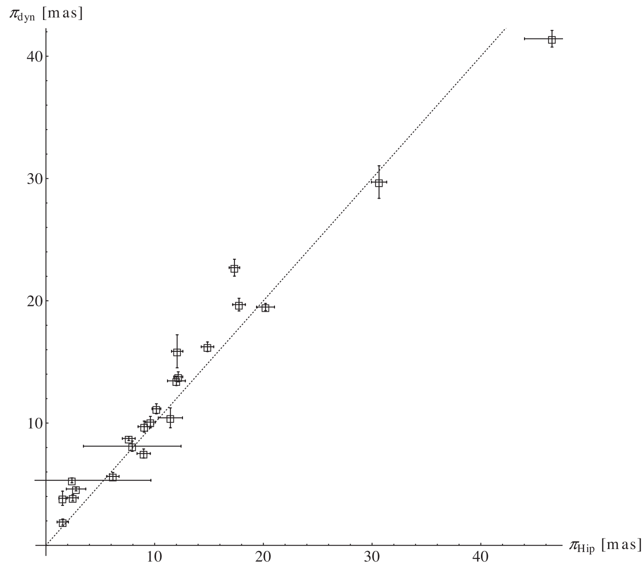

Figure 6. Dynamical parallax versus *Hipparcos* parallax.

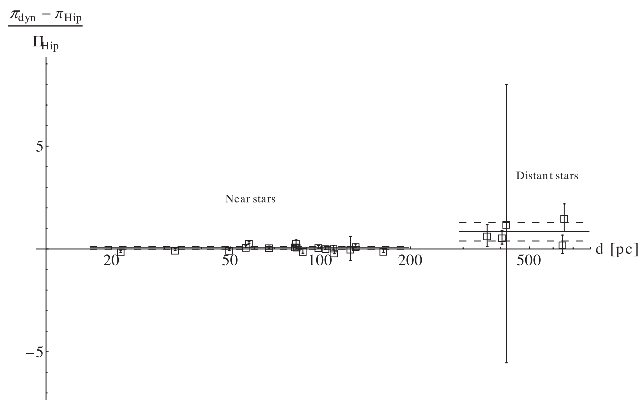

Figure 7. *Hipparcos* parallax dependence on distance.

components are provided from the *Hipparcos* parallax and/or from the dynamical parallax. In this last case, we have considered updated parameters for both the bolometric correction and the mass–luminosity relation. Complete information on the spectral types of the objects studied is also included.

Another question that we have investigated is that commented by Hartkopf et al. (1989) and Pourbaix (2000) some years ago about the likely overestimation of angular separations in the interferometric measurements performed by Finsen. In Fig. 5, we have plotted the mean value of the residuals in angular separations against the corresponding semimajor axis (both expressed in mas) for each star. This has been accomplished for each set of measurements so that Finsen's mean values are indicated by empty circles and the speckle ones by filled circles. From a preliminary inspection we see that the former are widely distributed by all the plane, mainly by the upper part, whereas the latter are much more concentrated around the x-axis. In fact, the computation of the total means for each set of measurements provides different values, 10.51 ± 3.81 and 0.19 ± 0.62 mas for the Finsen and speckle groups, respectively. These total mean values are indicated by solid lines in Fig. 5 (note that the line corresponding to the mean of the speckle group almost meets the x-axis). In addition, the upper and lower 95 per cent confidence limits for the Finsen and speckle values are indicated by two dashed and two dotted lines, respectively.

To conclude whether these values are significantly different from the ideal case (mean value of the residuals equal zero), we have applied the statistical hypothesis test technique to each group. Therefore, the fact that both means are zero will be the null hypotheses in each case. As usual, the p-value of 0.05 is considered as the criterion to determine whether such differences are statistically significant or not. We find that the null hypothesis cannot be rejected for the speckle group (with a very high level of significance of 0.50). Nevertheless, results obtained for the Finsen group show that the null hypothesis can be rejected at the significance level of 0.02; therefore, there is sufficient sample evidence to support the overestimation of the angular separation with a mean value about 10.5 mas.

Considering the accurateness of the dynamical parallaxes obtained for this relatively extent set of binary systems in this paper, we have accomplished a statistical study to check the reliability of the *Hipparcos* parallaxes at large distances.

Apart from the rather large uncertainties obtained at large distances by *Hipparcos*, we have observed that its parallaxes undergo a systematic deviation from the expected values according to the dynamical methodology used by us. A plot displaying the dynamical parallax ($\pi_{\rm dyn}$) against the *Hipparcos* (π_{Hip}) for each star (in mas), along with the corresponding uncertainty bars in both axes, is shown in Fig. 6. The dotted line is the straight where points with equal values would be laid. Notwithstanding, we note a trend for the points as a whole to be above this line.

To investigate this issue in more detail, we have plotted the quotient of the difference between the dynamical and *Hipparcos* parallaxes with respect to the second one against the *Hipparcos* distance (in parsecs), along with the corresponding uncertainty bars in the vertical axis, on a logarithmic scale for each star (see Fig. 7). We note that stars under analysis are separated in two groups according to the distance to the Sun. The first group consists of 17 near stars (with distances between 20 and 180 pc), whereas the second one comprises five distant stars (with distances between 360 and 660 pc). Solid lines show the mean value for each group, 0.056 ±

0.033 and 0.843 ± 0.232, respectively (in this way, dashed lines show the upper and lower 95 per cent confidence limits).

We have again applied the statistical hypothesis test technique to the differences between both sets of parallaxes for each group, considering as the null hypothesis the fact that the means of these differences be zero and treating, as usual, the p-value of 0.05 as a border line acceptable level of statistical significance. We conclude that we cannot reject the null hypothesis for the near stars; thus, there is insufficient sample evidence to claim that the dynamical and the *Hipparcos* parallaxes are different for this group at the 0.20 level of significance. In contrast, the null hypothesis is rejected for the distant stars at the significance level of 0.02, so that we can claim that there is a significant difference between the dynamical and the *Hipparcos* parallaxes at the 2 per cent level of significance for the distant stars.

This conclusion can be easily illustrated considering a typical distant star with e.g. a parallax of 2.00 mas, i.e. placed at 500 pc according to *Hipparcos*. Actually, it would be 229 pc (about 46 per cent) on average closer to the Sun according to dynamical estimations.

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