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Orbits of new Hipparcos binaries. I★

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Abstract. We present first orbits for 6 new Hipparcos binaries. The orbits were determined from speckle interferometric measurements collected mainly at the 6 m BTA telescope of the Special Astrophysical Observatory in Zelenchuk. Three of the systems, HIP 11352, HIP 14075 and HIP 14230, have late G- or early K-type components, while HIP 14669 = GJ 125, HIP 106972 = GJ 4210 and HIP 111685 = GJ 4287 have M-type components. The periods of the orbits are in the range of 6−28 years. Mass sums and their errors are derived for the systems. The Hipparcos parallax error is the dominating error source of the mass determination.

Key words. stars: binaries: visual – stars: fundamental parameters – stars: late-type

1. Introduction

The most fundamental parameters of stars, stellar masses, can only be derived from detailed studies of the orbital motion of binary systems. To test the models of stellar structure and evolution, stellar masses must be determined with a ∼2% accuracy, while for other applications, such as the study of empirical distributions of mass ratios, periods and eccentricities, an accuracy of ∼10% is sufficient.

Until very recently, very accurate masses were available only for double-lined detached eclipsing binaries (Andersen 1991). The empirical mass-luminosity relation (hereafter MLR) is therefore well-constrained only for late-B to late-F stars of the main sequence (hereafter MS). For later spectral types the basic MLR remains poorly determined, despite the fact that in the solar neighbourhood at least 90% of stars have smaller masses than the Sun. The low-mass stellar population plays an important role in the study of the luminosity and mass function in the local volume of our Galaxy.

The empirical masses and luminosities of low-mass stars are mostly based on long-term visual observations, ground-based astrometric data and infrared speckle interferometry (Henry & McCarthy 1993). They need further refinement because visual orbits never reach the required accuracy since masses are proportional to the cube of the parallax and the semimajor axis of the visual orbit.

New accurate masses below 1 $M_\odot$ can be obtained by speckle imaging in combination with long-term, high-precision radial velocity monitoring of binaries. First priority targets are the nearest G, K, and M dwarfs with orbital periods shorter than 20 yr.

To obtain orbits for a sample of nearby stars, we have performed speckle interferometric observations of new binaries discovered by the Hipparcos astrometric satellite. We have defined a sample of ∼150 Hipparcos northern binaries for speckle observations following the criteria: MS components, spectral types from early G to M, distances within ∼50 pc, Hipparcos angular separation less than ∼0.5″ (up to ∼1″ for M dwarfs) (Balega et al. 2002, hereafter Paper I). For such binaries the orbital elements can be determined in a reasonably short period. The high-precision parallaxes will lead to small errors of the absolute magnitudes of the components.

Our observations of the new Hipparcos binaries started in 1998, when the Hipparcos catalogue data became available (ESA 1997). During six years of observations, nearly two dozen binaries with fast orbital motion were selected from the stars of our sample. In this article, we present the first orbits for six pairs with G and M components.

2. Observations and binary star orbits

Six pairs with fast relative motion were selected as candidates for new orbit determinations after our first speckle observations in 1998 (Paper I; Balega et al. 2004, hereafter Paper II), namely, HIP 11352, HIP 14075, HIP HIP 14230, HIP 14669 = GJ 125, HIP 106972 = GJ 4210 and HIP 111685 = GJ 4287. The first 3 are G-type MS stars, while the other three are M-dwarfs. Speckle observations were obtained using two different imaging detectors, namely, a camera for the visible wavelength

★ Based on observations made with the 6-m BTA telescope, which is operated by the Special Astrophysical Observatory, Russia.

Table 1. Orbital elements and total masses for six Hipparcos binaries.

HIP	P (yr)	T	e	a (mas)	i (degr)	Ω (degr)	ω (degr)	M_{total} ($M_\odot$)
11352	6.85 ± 0.05	1995.12 ± 0.06	0.284 ± 0.006	100 ± 1	50.0 ± 0.6	15.1 ± 0.9	4.4 ± 1.6	1.71 ± 0.27
14075	13.89 ± 0.11	1998.32 ± 0.06	0.474 ± 0.017	111 ± 1	50.6 ± 1.9	165.8 ± 1.8	184.9 ± 2.8	2.03 ± 0.58
14230	5.91 ± 0.07	1999.31 ± 0.04	0.876 ± 0.009	110 ± 5	68.5 ± 2.1	21.4 ± 0.9	144.1 ± 1.9	1.47 ± 0.26
14669	28.31 ± 0.07	2009.16 ± 0.07	0.138 ± 0.004	569 ± 7	96.8 ± 0.3	13.2 ± 0.2	165.6 ± 1.0	0.84 ± 0.17
106972	18.57 ± 0.06	2005.23 ± 0.06	0.186 ± 0.005	268 ± 1	71.0 ± 0.3	144.7 ± 0.3	42.2 ± 1.3	0.89 ± 0.25
111685	16.77 ± 0.15	1991.78 ± 0.08	0.256 ± 0.009	330 ± 3	55.9 ± 0.6	69.0 ± 1.0	118.7 ± 2.2	0.86 ± 0.10

range with a fast 1280 × 1024 px CCD coupled to a three-stage image intensifier (Maksimov et al. 2004), and an infrared 512 × 512 HAWAII array camera. The modulus of the Fourier transform of the object (visibility) was obtained using the Labeyrie (1970) method. Diffraction-limited images were reconstructed by means of bispectrum speckle interferometry (Weigelt 1977; Lohmann et al. 1983). The accuracy of relative position measurements with the 6 m telescope typically ranges from 1.5 mas to 3 mas.

Preliminary orbital elements were estimated using the Monet (1977) method. Then, the orbits were improved using differential correction of the elements. The position angles θ were reduced to a common equinox 2000.0. All BTA relative positions were given unit weight, while the Hipparcos measurements for a single epoch were taken with the weight 0.5. We assigned the weight 0.6 for the speckle observations of Horch et al. (1999, 2002). This assignment was made because of the difference in aperture between our telescope and the WIYN 3.5 m telescope. Similar weighting of speckle measurements was made by Hartkopf et al. (1989) between the 4 m and the 2.1 m telescope at Kitt Peak. Note that the assignment of the weights in the range from 0.5 to 0.7 for the observations made with the WIYN telescope does not change the orbital parameters noticeably. We plan to perform an accurate study of the effect of the aperture size on the scatter of speckle observations when more data will be available.

The elements of the orbits are listed in Table 1, where the first column gives the HIP number of the object, and the following columns list, respectively, the period P (in years), periastron passage T, eccentricity e, semimajor axis a of the true orbit (in milliarcseconds), orbit inclination i (in degrees), position angle of the node Ω (in degrees, refers to the epoch 2000.0) and the longitude of periastron ω (in degrees), together with their formal errors. In the last column of Table 1, the total masses of the six systems derived from their orbits and the Hipparcos parallaxes are given. The speckle measurements and the residuals of position angles θ and separations ρ from the determined orbital elements are collected in Tables 2 through 7. Figure 1 illustrates the orbits listed in Table 1. In this figure, our speckle measurements are plotted as filled circles, while other speckle measurements are plotted as open circles. The Hipparcos 1991.25 discoveries are indicated by triangles.

Table 8 lists 27 magnitude difference measurements obtained at the 6 m BTA telescope together with 12 measurements appearing in the literature. The six 1991.25 measurements are the Hipparcos first observations (Hp filter, $\lambda/\Delta\lambda$ = 476/210 nm). Note that none of the objects is noted in the Hipparcos Catalogue as potentially variable.

Although the orbits appear very reasonable, we must wait several more years before they can all be declared definitive. Short comments on individual systems are given below.

Table 2. Measurements and residuals for HIP 11352.

Epoch	θ	ρ	$\Delta\theta$	$\Delta\rho$	Reference
1991.2500	177.0	133	12.1	−7	ESA (1978)
1997.8242	186.8	122	−3.6	−1	Horch et al. (1999)
1998.7747	202.9	127	−0.4	−1	Paper I
1998.7773	202.7	126	−0.1	1	Paper I
1998.9246	205.8	124	−0.2	1	Horch et al. (2002)
1999.8130	228.3	97	0.2	1	Paper II
1999.8856	230.1	92	0.9	3	Horch et al. (2002)
2000.7622	283.7	62	−1.3	−1	Horch et al. (2002)
2001.7527	4.2	70	−0.1	1	This paper
2002.7993	85.5	59	−0.5	−3	This paper
2003.7885	158.0	91	−0.5	−2	This paper
2003.9249	163.5	95	−0.8	0	This paper
2003.9249	163.2	94	−0.5	1	This paper

Table 3. Measurements and residuals for HIP 14075.

Epoch	θ	ρ	$\Delta\theta$	$\Delta\rho$	Reference
1991.2500	168.0	164	0.1	−1	ESA (1978)
1997.7208	10.7	132	53.9	−76	Mason et al. (1999)
1998.7774	14.8	54	−0.1	−0	Paper I
1999.8184	86.0	55	−0.2	1	Paper II
1999.8261	UR				Mason et al. (2001)
2001.7528	140.2	118	−0.5	−1	This paper
2002.7255	150.2	140	0.0	0	This paper
2002.7993	150.0	140	0.9	2	This paper
2003.7883	158.6	158	0.2	−2	This paper
2003.9469	160.7	156	−0.8	2	This paper

Table 4. Measurements and residuals for HIP 14230.

Epoch	θ	ρ	$\Delta\theta$	$\Delta\rho$	Reference
1991.2500	15.0	165	−5.1	10	ESA (1978)
1997.8269	13.3	166	−0.3	−6	Horch et al. (1999)
1998.7774	20.3	97	−0.0	−0	Paper I
1999.8131	335.6	45	0.7	0	Paper II
1999.8206	UR				Mason et al. (2001)
2000.7650	357.3	123	0.4	−4	Horch et al. (2002)
2001.7527	4.7	162	−0.5	0	This paper
2001.8376	4.3	165	0.3	−1	This paper
2002.7255	8.3	177	0.2	−0	This paper
2002.7993	8.8	175	0.0	2	This paper
2003.7883	12.6	160	0.6	−2	This paper
2003.9249	14.6	152	−0.6	1	This paper

Table 5. Measurements and residuals for HIP 14669.

Epoch	θ	ρ	$\Delta\theta$	$\Delta\rho$	Reference
1991.2500	23.0	393	−1.3	−0	ESA (1997)
1998.7749	10.4	581	−0.1	−4	Paper I
1999.8186	8.6	509	0.0	1	Paper II
2001.7583	3.3	333	−0.1	−2	This paper
2002.7362	357.2	222	−0.4	−1	This paper
2003.7885	334.0	101	−0.2	1	This paper
2003.9250	327.7	87	−1.2	2	This paper

Table 6. Measurements and residuals for HIP 106972.

Epoch	θ	ρ	$\Delta\theta$	$\Delta\rho$	Reference
1991.2500	315.0	248	−0.1	−0	ESA (1997)
1998.7742	30.9	104	0.1	2	Paper I
1999.7414	75.0	101	0.2	−1	Paper I
1999.8152	77.9	105	0.6	−3	Paper II
2000.7700	108.8	140	0.5	0	This paper
2001.7577	125.8	190	0.1	−2	This paper
2001.8451	128.4	189	−1.4	3	This paper
2002.7361	136.1	223	0.1	−1	This paper
2003.9273	147.0	224	−0.5	0	This paper
2003.9273	146.0	224	0.5	0	This paper

2.1. HIP 11352

Hipparcos and Tycho photometry give the integral color index $(B-V)_{Hp} = 0.74$ and $(B-V)_T = 0.82$ for this pair, corresponding to late-G type. From $m_V = 8.00$, $\pi_{Hp} = 23.19 \pm 1.21$ mas, and our speckle interferometric $\Delta m = 0.18 \pm 0.06$, spectral types G8−G9 were proposed for the components (Paper I). Following its peculiar and radial velocity, Montes et al. (2001) classified HIP 11352 as a late-type member of the Local Association moving group with an age of 20−150 Myr.

Table 7. Measurements and residuals for HIP 111685.

Epoch	θ	ρ	$\Delta\theta$	$\Delta\rho$	Reference
1991.2500	175.0	144	−0.2	−1	ESA (1997)
1997.7286	UR				Mason et al. (1999)
1998.7716	356.9	242	−0.2	−6	Paper I
1998.9269	0.7	237	−0.5	3	Horch et al. (2002)
1999.7414	16.4	265	−0.1	3	Paper I
1999.8153	17.5	272	0.1	−1	Paper II
2000.6170	29.7	300	0.3	3	Horch et al. (2002)
2001.7578	44.1	343	−0.3	−0	This paper
2001.8452	44.3	347	0.4	−2	This paper
2002.7361	53.4	367	0.3	−4	This paper
2003.9466	65.5	359	−0.3	1	This paper

Good coverage of the ellipse by speckle observations allows us to consider the orbit as definitive. However, the small magnitude difference between the components makes the pair difficult to assign the right quadrant. Therefore two position angles in Table 2 (1999.8856 and 2000.7622 epochs) have been changed by 180 degrees from the original publications (Horch et al. 2002). It should also be noted that the Hipparcos uncertainties in the separation and in the magnitude difference are uncommonly high, correspondingly 8 mas and 0.5 mag. Therefore the Hipparcos first point was deleted from the orbit calculation. Taking only speckle measurements into account, the 6.89 yr orbit shows an average absolute value residual of $\langle|\Delta\rho|, |\rho\Delta\theta|\rangle = 1.1$ mas. The mass sum 1.69 $M_\odot$, resulting from the orbital elements, is in agreement with the late-G type MS components.

2.2. HIP 14075

This pair has completed one full revolution since it was first resolved by Hipparcos. The orbit was estimated using only 8 measurements with a mean square (O-C) residuals of 1.7 mas. The measurements of Mason et al. (1999, 2001), taken with a 2.1 m telescope, were deleted from the orbit calculation. At these epochs our orbit predicts a separation of 55−56 mas, which is below the resolution limit of a 2.1 m instrument at 560 nm. The large error for the system mass sum in Table 1 is completely explained by the dominating parallax error. Following our differential speckle photometry and $\pi_{Hp} = 15.17 \pm 1.44$ mas, the system consists of two G8 dwarfs. The estimated speckle interferometric $\Delta m \simeq 0$ at all wavelengths and is noticeably smaller than ΔHp.

2.3. HIP 14230

The spectral type G0 for this new nearby ($\pi_{Hp} = 29.62 \pm 1.09$ mas) binary results from a four-color survey by Olsen (1983). The large magnitude difference between the components, $\Delta V = 1.74$, measured by speckle interferometry and Hipparcos, is evidence of an early K-type secondary. The highly eccentric orbit results from 10 speckle observations

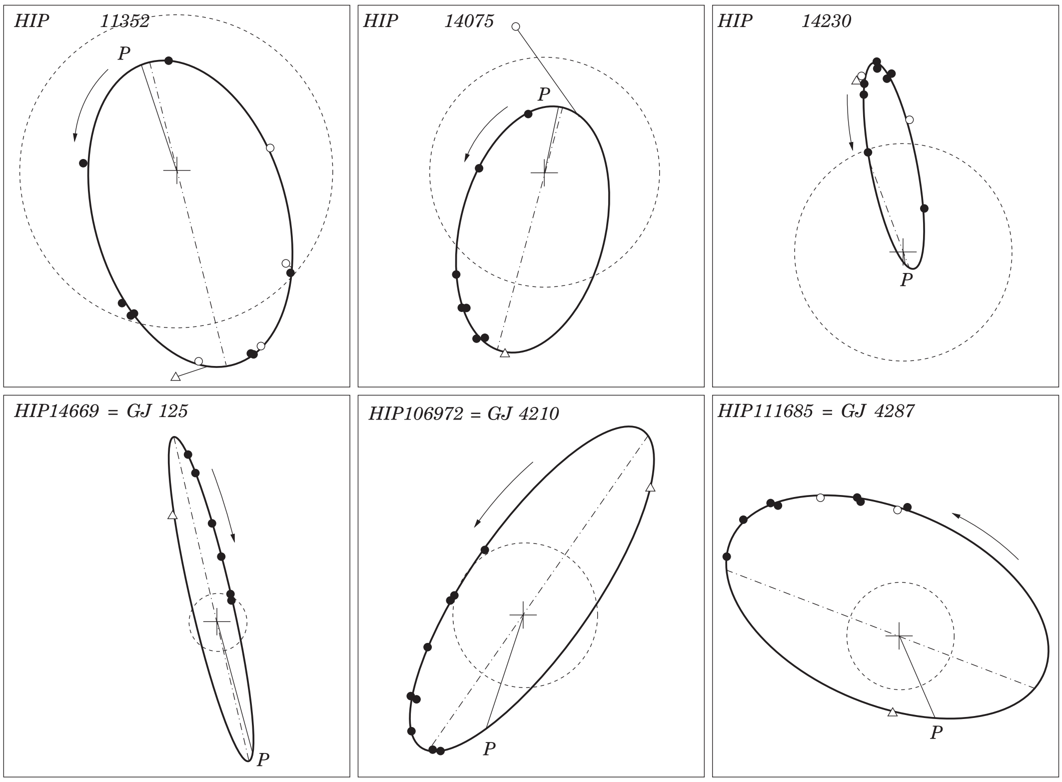

Fig. 1. Apparent ellipses representing the orbital elements for HIP 11352, HIP 14075, HIP 14230, HIP 14669, HIP 106972, and HIP 111685 (*top left to bottom right*). BTA speckle data are indicated by filled circles, other interferometric data by open circles, Hipparcos first measurements by triangles. Residual vectors for all measures are plotted, but in most cases they are smaller than the points themselves. The orbital motion direction is indicated by an arrow. The solid line shows the periastron position, while the dot-dashed line represents the line of nodes. North is up and east is to the left. The dashed circle has a radius of 0.1″.

covering two revolutions and can be accepted as definitive. When combined with the published parallax, the orbit predicts a total mass of the system of 1.47 $M_{\odot}$, which is 20% lower than expected for a pair of early G and K dwarfs. However, the error of the mass estimate is too large for final conclusions.

2.4. HIP 14669 = GJ 125

This is a pair of dwarfs at a distance of 15 pc with components of M 2 and M 4 spectral types (Paper I). The comparatively long-period orbit of this high-proper motion binary was computed based on 7 observations non-uniformly distributed over 12 years. Due to the high accuracy of speckle measurements, the residuals to the orbit, listed in Table 5, range from 0 to 4 mas with an average absolute value residual of $\langle|\Delta\rho|, |\rho\Delta\theta|\rangle = 0.9$ mas. The orbital plane of the binary lies close to the line of sight. However, the large magnitude difference between the M 2 primary and M 4–M 5 secondary ($\Delta m \sim 2$ in the visible) makes observations of the lines of both components in the spectrum rather difficult.

2.5. HIP 106972 = GJ 4210

This is a relatively faint pair ($m_V = 11.62$) of M dwarfs at a distance of 25 pc. The estimated spectral types of the components are M 2 and M 4 (Paper I). All speckle measurements of the binary were performed with the 6 m BTA telescope. They cover only 1/3 of the ellipse, but with the Hipparcos first measure included, the shape of the orbit is well defined. The total mass 0.89 $M_{\odot}$ is determined with an accuracy of only 28%.

2.6. HIP 111685 = GJ 4287

Also known as G216-7, this nearby ($\pi_{Hp} = 52.94 \pm 1.94$ mas) high proper motion ($\mu = 0.33$ arcsec/yr) binary was classified as K7 by Reid et al. (1995) from the measured depth of TiO absorption at 705 nm. Recently, Kirkpatrick et al. (2001) proposed it to be of spectral type M 0 independently using the same criterion. $(V-R) = 0.85$ and $(R-I) = 0.66$ colors, found earlier by Weis (1987), are also consistent with the M 0 type. The low chromospheric activity of the star and its space motion $(U, V, W = 18, -54, 0)$ (Hawley et al. 1997) indicate an old-disk object with an age exceeding 1 Gyr.

Hipparcos has resolved the star as a binary with ρ = 144 mas and $\Delta Hp = 0.44 \pm 0.96$. However, speckle interferometry indicates significantly larger magnitude differences (see Table 8). Given the differential speckle photometry in different spectral bands, from V to K, the secondary star in the system can be classified with confidence as M 3. Thus, the two close components of GJ 4287 have absolute magnitudes $M_V(\mathrm{Aa}) = 8.3$ and $M_V(\mathrm{Ab}) = 10.4$, in agreement with our first estimates (Paper I). Because of dominating light from

Table 8. Speckle interferometric magnitude differences and Hipparcos ΔHp measurements (HMA04 = Horch et al. 2004).

HIP	Date	Δm	$\lambda/\Delta\lambda$, nm	Ref.
11352	1991.25	0.44 ± 0.23	V_{Hp}	ESA (1997)
	1998.77	0.21 ± 0.06	545/30	Paper I
	1998.78	0.15 ± 0.06	545/30	Paper I
	2001.75	0.00 ± 0.16	600/30	This work
	1998.92	0.01 ± 0.15	648/41	HMA04
	1999.89	0.00 ± 0.15	648/41	HMA04
	2000.76	0.04 ± 0.15	648/41	HMA04
14075	1991.25	0.44 ± 0.15	V_{Hp}	ESA (1997)
	1999.82	0.17 ± 0.16	545/30	Paper II
	2001.75	0.00 ± 0.22	600/30	This work
	1998.78	0.00 ± 0.29	780/60	Paper I
	2002.73	0.34 ± 0.15	2115/214	This work
14230	1991.25	1.73 ± 0.20	V_{Hp}	ESA (1997)
	1998.78	1.74 ± 0.05	545/30	Paper I
	1999.81	1.74 ± 0.03	545/30	Paper II
	2001.75	1.55 ± 0.01	600/30	This work
	2000.77	1.31 ± 0.08	648/41	HMA04
	2002.73	0.91 ± 0.15	2115/214	This work
14669	1991.25	2.17 ± 0.18	V_{Hp}	ESA (1997)
	2001.76	2.15 ± 0.07	545/30	This work
	1998.77	1.72 ± 0.05	780/60	Paper I
	1999.82	1.72 ± 0.02	780/60	Paper II
	2001.76	1.49 ± 0.03	850/75	This work
	2002.74	1.23 ± 0.15	2115/214	This work
106972	1991.25	1.27 ± 0.88	V_{Hp}	ESA (1997)
	1998.77	1.17 ± 0.14	780/60	Paper I
	1999.82	1.23 ± 0.03	780/60	Paper II
	2001.76	1.18 ± 0.06	780/60	This work
	1999.74	1.13 ± 0.12	2115/214	Paper I
	2002.74	1.12 ± 0.15	2115/214	This work
111685	1991.25	0.44 ± 0.57	V_{Hp}	ESA (1997)
	2001.76	2.08 ± 0.03	545/30	This work
	2000.62	1.93 ± 0.13	648/41	HMA04
	1998.77	2.03 ± 0.12	658/20	Paper I
	1999.82	1.43 ± 0.03	780/60	Paper II
	2001.76	1.25 ± 0.03	850/75	This work
	1998.93	1.29 ± 0.05	853/39	HMA04
	1999.74	1.03 ± 0.16	2115/214	Paper I
	2002.74	1.07 ± 0.15	2115/214	This work

the primary, the binary could not be resolved as a double-lined spectroscopic binary, as expected by Gizis et al. (2002).

Similar to the previous binaries, the orbit can only be determined if the Hipparcos observation is taken into account. Note that the first Horch et al. (2002) point in Table 7 is the average of three separate observations by those authors. The mean square error of the speckle measurements is comparatively large, 3.7 mas. However, because of the small parallax error, the mass sum of 0.86 $M_\odot$ is known with 11% accuracy. The masses of the components are 0.53 $M_\odot$ and 0.33 $M_\odot$. This pair with a semimajor axis of ~6 AU almost meets the 10% mass accuracy criterion for inclusion in the new M dwarf MLR (Delfosse et al. 2000). Its visual orbit might be improved after the next periastron passage in 2008. Note that at a 100 times further distance from G216-7A, the third common proper motion component, G216-7B, with a mass close to the hydrogen-burning limit, was found during the photometric survey for candidate M and L dwarfs (Kirkpatrick et al. 2001).

3. Summary

Speckle observations of six new Hipparcos binaries over a 5 yr period yielded new orbits. Three of the systems are G and K dwarfs, while the other three are composed of M components. To derive the physical properties of these main-sequence binaries, we provide in Table 8 a list of magnitude differences measured by speckle interferometry in a wide spectral range from the V band to the infrared K band.

The total masses of the 6 systems under analysis are still known with low accuracy: GJ 4287 has a minimum relative error of 11%, while for HIP 14075 and GJ 4210 the error is ~30%. At present, none of the M dwarf systems, except GJ 4287, can be included in the new M dwarf MLR with a 10% mass accuracy limit (Delfosse et al. 2000). In all cases, with the exception of HIP 14230, the total mass error is completely dominated by the error of parallax. Therefore, it is unlikely that the accuracy of their masses will be significantly improved over next few years based on interferometric data alone. They might be specified only by spectroscopic radial velocity observations or by using much more precise parallaxes from future astrometric missions. Only in the case of HIP 14230 the contribution of the semimajor axis error $9(\sigma_a/a)^2 = 0.0186$ in the total mass error $(\sigma_{M_\odot}/M_\odot)^2 = 0.0313$ is larger than the parallax error $9(\sigma_\pi/\pi)^2 = 0.0122$. With more data collected near periastron, a revision of the HIP 14230 and GJ 4287 orbits might be possible.

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