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Speckle observations with PISCO in Merate (Italy): XV. Astrometric measurements of visual binaries in 2014, and new orbits for ADS 671, 1615, 1709, 5447, 10075 and 12447.

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We present relative astrometric measurements of visual binaries, made in 2014 with the speckle camera PISCO at the 102-cm Zeiss telescope of Brera Astronomical Observatory, in Merate. Our observing list contains orbital couples as well as binaries whose motion is still uncertain. We obtained 224 new measurements of 218 visual binary stars, with angular separations in the range $0''.15$ — $10''$, and an average accuracy of $0''.015$. The mean error on the position angles is $0^\circ.5$. Most of the position angles were determined without the usual 180° ambiguity with the application of triple-correlation techniques and/or by inspection of the long integration files. We complete this data with the results of a study of the multiple system ADS 6993 with PISCO during the period 2004-2014 and propose a new method to resolve part of the 180-degree ambiguity with the autocorrelations only. We then present new revised orbits for ADS 671, 1615, 1709, 5447, 10075 and 12447, partly derived from PISCO observations. The corresponding estimated values for the masses of those systems are compatible with the spectral types.

1 Introduction

This paper presents the results of speckle observations of visual binary stars made in Merate (Italy) in 2014 with the Pupil Interferometry Speckle camera and COronagraph (PISCO) on the 102-cm Zeiss telescope of *INAF – Osservatorio Astronomico di Brera* (OAB, Brera Astronomical Observatory). It is the fifteenth of a series whose purpose is to contribute to the determination of binary orbits (Scardia et al. 2005, 2006, 2007, 2008a, Prieur et al. 2008, Scardia et al. 2009, Prieur et al. 2009, Scardia et al. 2010, Prieur et al. 2010, Scardia et al. 2011, Prieur et al. 2012, Scardia et al. 2013, Prieur et al. 2014, and Scardia et al. 2015a, herein: Papers I to XIV). The focal instrument PISCO was developed at *Observatoire Midi-Pyrénées* (France) and first used at *Pic du Midi* from 1993 to 1998. It was moved to Merate in 2003 and installed on the INAF Zeiss telescope that has been dedicated to binary star observations since that epoch.

In Sect. 2, we briefly describe our observations. In Sect. 3, we present and discuss the astrometric measurements. We also compare those measurements with the ephemerides computed with the published orbital elements, when available. In Sect. 4, we describe the results of a study of the multiple system ADS 6993 with PISCO in Merate during the period 2004-2014. Finally in Sect. 5 we present the new revised orbits that we have computed for ADS 671, 1615, 1709, 5447, 10075 and 12447, and discuss the estimated values for the masses of those systems.

2 Observations

The observations were carried out with the PISCO speckle camera and the ICCD (Intensified Charge Coupled Device) detector belonging to Nice University (France). This instrumentation is presented in Prieur et al. (1998) and our observing procedure is described in detail in Paper VI.

Our observing list basically includes all the visual binaries for which new measurements are needed to improve their orbits, that are accessible with our instrumentation. It consists of a few thousands objects. A detailed description can be found in our previous papers (e.g., Paper VI).

The distribution of the angular separations measured in this paper is displayed in Fig. 1a and shows

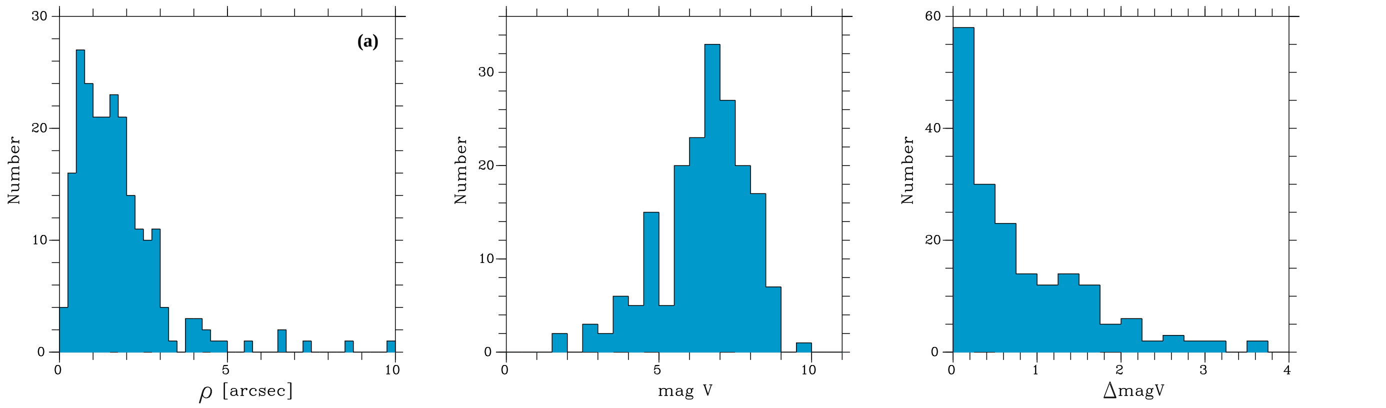

Fig. 1 Distribution of the angular separations of the 224 measurements of Table 1 (a), the total visual magnitudes of the corresponding binaries (b) and the differences of magnitude between their two components (c).

a maximum for $\rho \approx 0''.6$. The largest separation of $8''.72$ was obtained for STF 948 AC (ADS 5400). The smallest separations were measured for ADS 8804 and ADS 5447, with $\rho = 0''.15$ and $\rho = 0''.18$, respectively. Let us recall that the diffraction limit is $\rho_d = \lambda/D \approx 0''.13$ for the Zeiss telescope (aperture $D = 1.02$ m) and the R filter ($\lambda = 650$ nm).

The distribution of the apparent magnitudes m_V and of the difference of magnitudes Δm_V between the two components are plotted in Figs. 1b and 1c, respectively. The telescope aperture and detector sensitivity led to a limiting magnitude of $m_V = 10$ (Fig. 1b) and a maximum Δm_V for speckle measurements of about 4.0 (Fig. 1c).

Using the Hipparcos parallaxes from ESA (1995), we have been able to construct the HR diagram of those binaries, which is displayed in Fig. 2. We only plotted the 183 objects for which the relative uncertainty on the parallax was smaller than 50%.

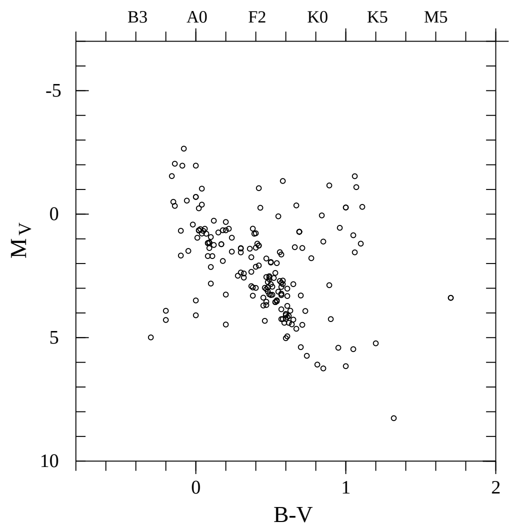

Fig. 2 HR diagram of the binaries measured in Table 1, for which Hipparcos parallaxes were obtained with a relative error smaller than 50% (i.e., 183 objects).

3 Astrometric measurements

The 224 astrometric measurements obtained with the observations made in 2014 are displayed in Table 1. They concern 218 visual binaries. For each object, we report its WDS name (Washington Double Star Catalog, Mason et al. 2016, hereafter WDS catalog) in Col. 1, the official double star designation in Col. 2 (sequence is "discoverer-number"), and the ADS number in Col. 3 (Aitken, 1932) when available. For each observation, we then give the epoch in Besselian years (Col. 4), the filter (Col. 5), the focal length of the eyepiece used for magnifying the image (Col. 6), the angular separation ρ (Col. 7) with its error (Col. 8) in arcseconds, and the position angle θ (Col. 9) with its error (Col. 10) in degrees. In Col. 11, we report some notes and some information about the secondary peaks of the autocorrelation files (e.g. diffuse, faint or elongated) or about the power spectrum (NF: no fringes).

For the systems with a known orbit, the $(O-C)$ (Observed minus Computed) residuals of the ρ and θ measurements are displayed in Cols. 13 and 14, respectively. The corresponding authors are given in Col. 12, using the bibliographic style of the "Sixth Catalog of Orbits of Visual Binary Stars" (Hartkopf & Mason, 2016, hereafter OC6).

When not explicitly specified, the measurements refer to the AB components of those systems. In Col. 14, the symbol ^{Q} indicates that there was a quadrant inconsistency between our measures and the positions derived from the orbital elements published for this object.

The characteristics of the R and RL filters used for obtaining those measurements are given in Table 1 of Paper XII. Some objects were observed without any filter because they were too faint. This is indicated with W (for "white" light) in the filter column (Col. 5 of

Table 1 Table of speckle measurements and O-C residuals with published orbits (begin.)

WDS	Name	ADS	Epoch	Fil.	Eyep. (mm)	ρ (″)	σ_ρ (″)	θ (°)	σ_θ (°)	Notes	Orbit	$\Delta\rho$(O-C) (″)	$\Delta\theta$(O-C) (°)
00134+2659	STT2	161	2014.042	R	20	0.419	0.013	157.2*	1.0		Hrt2008	0.01	0.9
00210+6740	HJ1018	283	2014.042	R	32	1.691	0.015	86.2*	0.7		Sod1999	−0.08	−1.5
00214+6700	STT6AB	293	2014.042	R	20	0.660	0.017	153.4*	1.2	NF	Sca2000b	−0.04	−0.8
02020+0246	STF202	1615	2014.042	R	20	1.812	0.007	263.9*	0.3		Sca1983f	0.05	2.2
”	”	”	”	”	”	”	”	”	”		This paper	−0.02	0.0
02037+2556	STF208AB	1631	2014.042	R	20	1.333	0.007	342.4*	0.3		Pop1969b	0.04	−3.2
02062+2507	STF212	1654	2014.042	R	32	2.000	0.053	160.8*	0.4				
03122+3713	STF360	2390	2014.146	R	32	2.883	0.035	124.2*	0.3	Diffuse	WSI2004a	0.03	−1.6
03344+2428	STF412AB	2616	2014.042	R	20	0.724	0.010	352.8	0.6		Sca2002a	−0.02	0.8
”	”	”	2014.146	R	20	0.724	0.008	351.8	0.6	Diffuse	Sca2002a	−0.02	−0.2
04301+1538	STF554	3264	2014.198	R	20	1.526	0.008	16.0*	0.7	Diffuse	Baz1980a	−0.07	0.7
04433+5931	A1013	3391	2014.201	R	10	0.391	0.003	296.9	0.9		Doc1990c	−0.01	−1.1
05135+0158	STT517AB	3799	2014.198	R	20	0.722	0.010	239.7	0.5		Tok2014a	0.04	−0.7
05148+1232	HU1224	3822	2014.198	R	32	1.071	0.017	114.3*	0.8		Hrt2011a	0.04	0.3
05308+0557	STF728	4115	2014.198	R	20	1.289	0.013	45.1*	0.4		USN1999b	−0.02	0.6
05352+3358	AG97	4165	2014.201	R	32	2.091	0.017	269.9*	0.8				
05355−0422	STF750	4192	2014.201	R	32	4.344	0.022	59.5*	0.3				
05371+2655	STF749AB	4208	2014.198	R	20	1.172	0.008	139.9*	0.5		Sca2007a	0.00	−0.3^{Q}
06221+5922	STF881Aa-B	4950	2014.198	R	20	0.638	0.028	149.1*	0.7		Zirm2013	0.00	1.8
06275+2432	AG112AB	5071	2014.198	R	32	2.903	0.039	208.6	1.8				
06404+4058	STF945	5296	2014.264	R	20	0.472	0.010	334.4*	1.1		Nov2007d	-0.00	−1.5
06425+6612	MLR318	–	2014.264	R	20	1.685	0.008	308.8*	0.4		Pal2005b	−0.01	0.1
06462+5927	STF948AB	5400	2014.196	R	20	1.906	0.010	67.4*	0.3		WSI2006b	0.01	0.2
06462+5927	STF948AC	5400	2014.196	R	32	8.722	0.044	308.3*	0.3				
06474+1812	STT156	5447	2014.239	R	10	0.184	0.004	143.7	1.7		Sca2005a	−0.04	−12.6
”	”	”	”	”	”	”	”	”	”		This paper	0.01	−1.9
06487+0737	A2731	5469	2014.239	R	32	1.363	0.027	64.8*	0.6		Pru2012	−0.01	−1.4
06531+5927	STF963	5514	2014.239	R	10	0.259	0.004	348.1*	0.7		Sca2008d	−0.01	1.4
06546+1311	STF982	5559	2014.239	R	32	7.394	0.042	143.0*	0.4		Msn2014b	0.09	−0.1
06555+3010	STF981	5570	2014.196	R	32	0.877	0.027	120.8*	1.3		Hop1971	−0.11	6.6^{Q}
06573+5825	STT159	5586	2014.239	R	10	0.674	0.003	232.9*	0.3		Sod1999	0.02	1.4
07128+2713	STF1037	5871	2014.196	R	20	0.943	0.008	305.9*	0.4		Sca2015	−0.01	−0.6
07176+0918	STT170	5958	2014.201	R	10	0.389	0.004	303.7	0.3	Elongated	Doc2007e	0.01	−7.8
07303+4959	STF1093	6117	2014.198	R	20	0.899	0.012	204.4*	1.2		Hrt2009	0.02	0.5
07345+1218	STF1116	6180	2014.201	R	32	1.697	0.017	96.1*	0.5				
07346+3153	STF1110	6175	2014.196	R	20	4.966	0.025	55.1*	0.3	Elongated	Doc2014g	−0.02	−0.1
07401+0514	STF1126	6263	2014.198	R	20	0.859	0.010	174.6*	0.6		Zir2015a	0.02	−1.5
07417+3726	STT177	6276	2014.245	R	20	0.529	0.008	150.1	1.9		Hei1982c	−0.01	4.9
07486+2308	WRH15	6378	2014.201	R	10	0.259	0.003	31.6	1.9		USN2002	-0.00	2.6
07573+0108	STT185	6483	2014.239	R	20	0.345	0.012	20.8*	1.2		Doc1994d	−0.05	1.7
08024+0409	STF1175	6532	2014.239	R	32	1.366	0.033	284.9*	0.8		Ole2001	−0.02	−5.3
08041+3302	STT187	6549	2014.201	R	10	0.424	0.004	337.4	0.3		Msn1999a	0.01	−0.7
08095+3213	STF1187	6623	2014.239	R	32	3.072	0.017	21.4*	0.3		Ole2001	0.12	0.9
08122+1739	STF1196AB	6650	2014.198	R	20	1.120	0.008	24.5*	0.3		WSI2006b	0.01	1.6
08122+1739	STF1196AC	6650	2014.198	R	32	6.567	0.042	62.3*	0.5				
08198+0357	FIN346	–	2014.245	R	10	0.229	0.003	54.6	1.6	Elongated			
08213−0136	STF1216	6762	2014.245	R	10	0.526	0.006	306.4	0.3	Elongated	Tok2014a	0.00	−0.8
08468+0625	SP1AB	6993	2014.201	R	10	0.261	0.003	194.0*	0.5		Sod1999	−0.01	0.2
08468+0625	STF1273AB,C	6993	2014.201	RL	20	2.787	0.014	305.2*	0.3	Elongated	Dru2014	−0.03	−1.2
08468+0625	STF1273AC	6993	2014.201	RL	20	2.769	0.014	304.5*	0.3				
08531+5457	A1584	7054	2014.196	R	20	0.651	0.012	89.4*	0.5		Msn2014a	−0.02	−1.2
08542+3035	STF1291	7071	2014.201	R	20	1.507	0.008	308.9*	0.3				
08554+7048	STF1280	7067	2014.239	R	32	3.005	0.022	354.9*	0.3		Hei1997	0.10	−0.7
09012+0245	STF1302AB	7141	2014.245	R	32	2.707	0.055	235.8	0.9				
09020+0240	BU211	7152	2014.245	W	32	2.170	0.082	269.2*	0.6	Diffuse			
09036+4709	A1585	7158	2014.196	R	10	0.272	0.005	288.8*	0.8	Elongated	Hrt2000a	−0.01	1.1
09051+3931	AG160	7167	2014.264	R	32	3.987	0.020	59.3*	0.7				

Table 1 Table of speckle measurements and O-C residuals with published orbits (cont.)

WDS	Name	ADS	Epoch	Fil.	Eyep. (mm)	ρ (″)	σ_ρ (″)	θ (°)	σ_θ (°)	Notes	Orbit	$\Delta\rho$(O-C) (″)	$\Delta\theta$(O-C) (°)
09071+3037	AG162	7183	2014.264	W	32	4.121	0.040	106.0*	0.6				
09080+8102	STF1284	7163	2014.264	R	32	2.528	0.017	167.6*	0.4				
09095+0256	STT197	7215	2014.245	R	32	1.373	0.017	67.1*	0.6				
09103+5223	STF1312	7212	2014.264	R	32	4.686	0.033	147.8*	0.3				
09104+6708	STF1306	7203	2014.196	R	20	4.330	0.022	348.0*	0.3	NF	Sca2015	0.02	−0.2
09149+0413	BU455	7257	2014.245	W	20	1.770	0.029	69.1*	0.5				
09184+3522	STF1333	7286	2014.201	R	20	1.929	0.010	49.7*	0.3				
09210+3811	STF1338AB	7307	2014.196	R	20	1.118	0.008	306.6*	0.4		Sca2002b	−0.03	−0.3
09235+3908	STF1344	7332	2014.269	W	32	3.803	0.019	102.6*	0.4	Diffuse			
09273+0614	STF1355	7380	2014.240	R	32	1.811	0.017	354.0*	0.3		Lin2011b	−0.01	−0.4
09285+0903	STF1356	7390	2014.264	R	20	0.785	0.010	107.7*	0.7		Mut2010b	−0.02	−0.8
09435+0612	A2761	7499	2014.264	R	32	1.023	0.020	251.0	1.4				
09521+5404	STT208	7545	2014.196	R	10	0.396	0.003	301.9*	0.3		Hei1996c	−0.02	−1.3
09524+2659	STF1389	7551	2014.264	R	32	2.452	0.017	288.3*	0.4				
10163+1744	STT215	7704	2014.245	R	20	1.480	0.008	176.6*	0.3		Zae1984	−0.07	−2.0
10269+1713	STT217	7775	2014.313	R	20	0.771	0.012	148.5*	0.5	Diffuse	Sca2013b	−0.01	0.1
10556+2445	STF1487	7979	2014.395	R	32	6.609	0.033	112.2*	0.3				
11037+6145	BU1077	8035	2014.395	R	10	0.714	0.004	355.4*	0.4		Sca2011a	−0.01	−1.1
11182+3132	STF1523AB	8119	2014.264	R	20	1.728	0.009	180.1*	0.3		Hei1996b	0.00	−0.4
11190+1416	STF1527	8128	2014.264	R	10	0.286	0.005	237.2*	0.3		Tok2012b	−0.01	0.7
11239+1032	STF1536	8148	2014.264	R	20	2.066	0.010	96.9*	0.3		Sod1999	−0.02	0.4
11363+2747	STF1555	8231	2014.264	R	20	0.720	0.008	148.8*	0.3		Doc2007i	0.04	−1.3
11486+1417	BU603	8311	2014.396	R	20	0.981	0.008	331.5*	0.5		USN2006b	−0.10	−1.6
11561+4533	STF1581	8354	2014.396	W	32	2.424	0.017	170.4*	0.7				
12417−0127	STF1670	8630	2014.420	R	20	2.149	0.011	7.2	0.3		Sca2007c	−0.03	−0.1
12564−0057	STT256	8708	2014.428	R	32	1.056	0.022	99.4*	1.5		Zir2015a	-0.00	−0.9
”	”	”	2014.420	R	32	1.024	0.022	100.3*	1.0		Zir2015a	−0.04	0.0
13007+5622	BU1082	8739	2014.396	R	20	0.879	0.009	113.8*	0.4		Sca2012c	−0.05	0.5
13100+1732	STF1728	8804	2014.396	R	10	0.149	0.003	17.0	0.8	Uncertain	WSI2006b	−0.03	5.0
13235+2914	HO260	8887	2014.396	R	32	1.602	0.027	87.4*	1.2		Zir2013a	−0.02	0.4
13284+1543	STT266	8914	2014.396	R	32	1.972	0.017	357.1*	0.4		Hrt2011d	−0.03	−0.3
13288+5956	STF1752AB	8919	2014.442	W	20	0.950	0.008	106.9*	0.7				
13329+3454	STT269	8939	2014.437	R	10	0.292	0.004	224.7	1.1	NF	Hei1997	−0.02	0.0
13329+4908	STF1758	8940	2014.437	R	32	3.351	0.018	291.5*	0.3				
13343−0019	STF1757	8949	2014.442	R	32	1.756	0.027	138.5*	0.3		Hei1988d	-0.00	0.3
13356+4939	AG190	8964	2014.442	W	32	2.625	0.017	12.9*	0.6	Elongated			
13375+3618	STF1768	8974	2014.442	R	20	1.726	0.009	95.6*	0.3		Sod1999	0.03	0.4
13377+5043	STF1770	8979	2014.442	R	20	1.697	0.008	121.4*	0.3				
13577+5200	A1614	9071	2014.428	R	32	1.383	0.018	299.4*	0.8		RAO2015	−0.01	−0.9[Q]
14131+5520	STF1820	9167	2014.396	R	32	2.781	0.023	121.2*	0.4		Kiy1998	0.13	−1.0
14153+0308	STF1819	9182	2014.396	R	20	0.894	0.009	168.9*	0.3		Sca2012b	0.00	−0.1
14203+4830	STF1834	9229	2014.437	R	20	1.641	0.008	101.9*	0.3		USN2000c	0.06	−1.8
14270+0341	STF1842	9265	2014.437	R	32	2.737	0.027	198.1	0.5				
14317+0150	AG195	9293	2014.437	W	32	1.810	0.017	337.1	0.3				
14369+4813	A347	9324	2014.442	W	20	0.541	0.008	238.5	0.3	Elongated	Doc2004a	−0.03	−1.1
14380+5135	STF1863	9329	2014.442	R	20	0.656	0.008	60.7*	1.0		Zir2013a	0.01	0.4
14411+1344	STF1865	9343	2014.510	R	10	0.437	0.003	291.7*	0.3	Elongated	Sca2007f	−0.01	0.6
14417+0932	STF1866	9345	2014.510	R	20	0.747	0.008	203.6	0.5				
14428+0635	A1109AB	9353	2014.538	RL	32	1.806	0.039	87.3*	0.3		WSI2006b	0.08	−1.1
14463+0939	STF1879	9380	2014.437	R	32	1.714	0.018	82.4*	0.3		Msn1999a	−0.01	−0.7
14489+0557	STF1883	9392	2014.437	R	20	1.003	0.008	277.2	0.3		USN2000c	0.02	0.1
14497+0759	A1110	9400	2014.538	R	20	0.661	0.009	244.6*	0.9				
14515+4456	STT287	9418	2014.437	R	20	0.658	0.008	2.1	1.2		Hei1997	−0.07	1.8
14525+1844	BU31AB	9423	2014.538	R	32	1.997	0.017	220.5*	0.4		Hrt2014a	−0.01	−0.3
14534+1542	STT288	9425	2014.543	R	20	1.017	0.008	158.9*	0.3		Hei1998	-0.00	0.0
15038+4739	STF1909	9494	2014.543	R	20	1.057	0.008	64.8*	0.4		Zir2011	0.01	−1.4
15056+1138	STF1907	9498	2014.543	W	20	0.858	0.008	347.8	0.6	Elongated			

Table 1 Table of speckle measurements and O-C residuals with published orbits (cont.)

WDS	Name	ADS	Epoch	Fil.	Eyep. (mm)	ρ ($''$)	σ_ρ ($''$)	θ ($^\circ$)	σ_θ ($^\circ$)	Notes	Orbit	$\Delta\rho$(O-C) ($''$)	$\Delta\theta$(O-C) ($^\circ$)
15232+3017	STF1937AB	9617	2014.511	R	10	0.651	0.003	202.4*	0.4	Elongated	Sod1999	−0.00	0.1
15245+3723	STF1938BC	9626	2014.511	R	20	2.256	0.011	4.4*	0.3		Sca2013a	0.04	0.4
15246+5413	HU149	9628	2014.511	R	20	0.673	0.008	270.2*	0.7		Zir2015a	0.02	−0.5
15382+3615	HU1167AB	9731	2014.582	R	32	1.358	0.023	77.2*	1.9	NF	Dru1995	0.11	−3.6
15382+3615	STF1964CD	9731	2014.582	R	32	1.585	0.028	20.2*	0.4		Dru1995	0.07	0.8
15413+5959	STF1969	9756	2014.582	R	32	1.033	0.017	28.1*	0.6		RAO2015	−0.01	−0.6
15589−0304	STF3101	9864	2014.538	R	32	2.226	0.017	73.3*	0.6				
16009+1316	STT303AB	9880	2014.543	R	20	1.577	0.009	173.2*	0.3		Zir2015a	−0.01	−0.2
16115+1507	A1799	9952	2014.543	W	20	0.783	0.009	116.4	0.7	Elongated	Zir2014a	-0.00	0.7
16289+1825	STF2052AB	10075	2014.511	R	20	2.350	0.012	118.7*	0.3		Lmp2001a	0.03	0.1
”	”	”	”	”	”	”	”	”	”		This paper	−0.01	−0.9
16309+0159	STF2055AB	10087	2014.511	R	20	1.387	0.008	40.7*	0.4		Hei1993b	−0.05	0.0
16413+3136	STF2084	10157	2014.511	R	10	1.191	0.006	139.2*	0.3		Sod1999	−0.01	−2.3
16433+2508	STF2089	10174	2014.582	W	32	2.710	0.030	61.0*	0.5	Faint			
16442+2331	STF2094AB	10184	2014.582	R	20	1.150	0.011	72.3	0.3				
16448+3544	STF2097AB	10193	2014.664	W	32	1.826	0.017	79.8*	0.7				
16492+4559	BU627AB	10227	2014.664	RL	20	2.102	0.011	42.5*	0.3		FMR2012a	−0.04	0.4
16492+4559	BU627A,BC	10227	2014.664	RL	20	2.021	0.010	38.9*	0.3				
16492+4559	BU627AC	10227	2014.664	RL	20	1.941	0.010	35.3*	0.3				
16511+0924	STF2106	10229	2014.511	R	20	0.754	0.008	171.4*	0.3		Sca2001g	−0.04	0.1
16514+0113	STT315	10230	2014.658	R	20	0.689	0.008	310.6*	0.3		Doc2007d	−0.03	0.2
16518+2840	STF2107AB	10235	2014.511	R	20	1.424	0.008	103.4*	0.3		Sca2003c	0.03	−1.3
16564+6502	STF2118AB	10279	2014.511	R	20	0.995	0.008	65.8*	0.3		Sca2002d	−0.15	−0.9
16588+0358	STF3107AB	10285	2014.658	R	32	1.404	0.032	69.4*	0.5				
17020+0827	STF2114	10312	2014.582	R	20	1.341	0.008	195.5*	0.5				
17053+5428	STF2130AB	10345	2014.582	A	20	2.497	0.012	3.4*	0.4		Pru2012	0.01	0.1
17082−0105	A1145	10355	2014.655	R	20	0.663	0.008	343.0*	0.4		WSI2006b	0.00	−0.0
17178+4535	STF2152	10458	2014.672	W	32	2.000	0.027	237.4*	0.6				
17179+4918	STF2153	10460	2014.672	W	32	1.468	0.017	244.5*	0.3				
17237+3709	MCA48AB	10526	2014.656	R	20	4.054	0.020	320.0*	0.3				
17358+0100	STF2186	10650	2014.658	R	32	2.993	0.018	78.1*	0.3				
17386+5546	STF2199	10699	2014.658	R	32	2.049	0.017	54.8*	0.3		Pop1995d	0.12	2.0
17403+6341	STF2218	10728	2014.664	R	32	1.458	0.017	309.6*	0.3		Zir2015a	0.01	−0.0
17412+4139	STF2203	10722	2014.664	W	20	0.759	0.008	291.3*	0.3	Elongated			
17506+0714	STT337	10828	2014.658	W	20	0.555	0.018	161.8*	2.0		Doc1990a	0.03	−1.6
17520+1520	STT338AB	10850	2014.582	R	20	0.822	0.008	163.7*	0.8		Pru2012	−0.01	−0.5
17533+3605	STF2243	10874	2014.740	R	32	1.133	0.023	39.5	0.9				
17541+2949	AC9	10880	2014.735	R	32	1.155	0.017	240.7*	0.7				
17564+1820	STF2245AB	10905	2014.735	R	20	2.635	0.017	111.3*	0.3	Elongated			
17571+0004	STF2244	10912	2014.735	R	20	0.673	0.008	98.9*	0.4		Hei1997	0.15	−2.5
17571+4551	HU235	10934	2014.658	R	20	1.554	0.013	285.2*	0.3				
18065+4022	STF2282	11074	2014.656	R	32	2.657	0.017	81.5*	0.3				
18097+5024	HU674	11128	2014.740	R	20	0.756	0.018	215.4	0.5		USN2002	0.25	5.6
18101+1629	STF2289	11123	2014.656	R	20	1.229	0.008	218.3*	0.3		Hop1964b	−0.01	2.5
18250−0135	AC11	11324	2014.754	R	20	0.852	0.008	354.3*	0.3		Hei1995	0.04	−0.1
18339+5221	A1377	11468	2014.754	R	10	0.236	0.005	131.1*	1.1		Pru2010	−0.02	1.8
18355+2336	STT359	11479	2014.825	R	20	0.736	0.012	4.8*	0.9		Sca2009a	−0.01	0.6
”	”	”	2014.828	R	20	0.742	0.008	4.9*	0.7		Sca2009a	-0.00	0.6
18359+1659	STT358	11483	2014.825	R	20	1.643	0.008	148.4*	0.3	Diffuse	Hei1995	0.13	1.9
18374+7741	STT363	11584	2014.836	R	20	0.544	0.008	339.5*	0.7		Sca2009a	0.03	−1.9
18389+5221	STF2368	11558	2014.836	R	20	1.888	0.009	139.9*	0.3				
18443+3940	STF2382AB	11635	2014.820	R	20	2.263	0.011	346.1*	0.3	Diffuse	Nov2006e	−0.01	0.1
”	”	”	”	”	”	”	”	”	”		WSI2004b	−0.08	0.1
18443+3940	STF2383Cc-D	11635	2014.820	R	20	2.382	0.012	76.2*	0.3	Diffuse			
18455+0530	STF2375AB	11640	2014.828	R	20	2.584	0.013	119.8*	0.3	Diffuse			
18497+1041	STF2402	11722	2014.735	R	32	1.309	0.017	202.3*	1.6				
18520+1047	STF2408	11766	2014.828	W	32	2.252	0.023	90.7*	0.3				

Table 1 Table of speckle measurements and O-C residuals with published orbits (cont.)

WDS	Name	ADS	Epoch	Fil.	Eyep. (mm)	ρ ($''$)	σ_ρ ($''$)	θ (°)	σ_θ (°)	Notes	Orbit	$\Delta\rho$(O-C) ($''$)	$\Delta\theta$(O-C) (°)
18526+1400	STF2412	11778	2014.828	W	20	1.412	0.009	55.8*	0.5	Elongated			
18594+2936	STF2430	11914	2014.740	R	32	1.527	0.017	186.8	0.6				
19143+1904	STF2484	12201	2014.830	R	32	2.159	0.020	240.0*	0.3		Hop1973b	−0.11	0.5
19148+4756	A706	12229	2014.830	W	20	1.555	0.009	73.8*	0.3	Elongated			
19169+6312	STF2509	12296	2014.831	R	20	1.838	0.009	328.0*	0.3		Zir2014a	0.00	−0.4
19252+3708	HJ1395	12427	2014.831	W	32	2.804	0.028	62.9*	0.5				
19266+2719	STF2525	12447	2014.740	R	32	2.181	0.023	289.2*	0.5		Hei1984b	0.03	−0.3
"	"	"	"	"	"	"	"	"	"		This paper	0.02	−0.3
"	"	"	2014.869	R	32	2.215	0.017	289.0*	0.5	Diffuse	Hei1984b	0.06	−0.5
"	"	"	"	"	"	"	"	"	"		This paper	0.05	−0.5
19420+4015	KUI94	–	2014.836	RL	10	0.467	0.003	157.9*	0.3		Hrt1996a	0.01	0.5
19429+4043	STT383	12831	2014.825	R	20	0.783	0.011	14.7*	1.1				
19438+3819	STT384	12851	2014.740	R	32	1.045	0.018	196.6*	1.0				
19450+4508	STF2579	12880	2014.740	RL	20	2.701	0.014	216.6*	0.3		Sca2012c	−0.02	−0.9
"	"	"	2014.836	RL	20	2.712	0.014	216.6*	0.3		Sca2012c	−0.01	−0.8
19464+3344	STF2576FG	12889	2014.740	R	32	3.018	0.017	156.8*	0.3		Sca1981f	−0.02	−0.9
19484+2212	STF2584	12957	2014.825	W	20	1.902	0.014	293.1	0.3	Elongated			
19487+1149	STF2583	12962	2014.741	R	20	1.432	0.008	105.0*	0.3				
19540+1518	STF2596	13082	2014.798	R	32	2.072	0.018	296.5*	0.5				
19556+5226	STF2605	13148	2014.828	R	20	2.840	0.014	175.2*	0.3				
19584−0214	AC12	13178	2014.893	R	32	1.535	0.018	296.3*	0.3				
19586+3806	STF2609	13198	2014.798	R	32	1.907	0.018	22.3*	0.3				
20011+4816	STF2619AB	13269	2014.893	R	32	4.187	0.037	238.7	0.3				
20020+2456	STT395	13277	2014.896	R	20	0.769	0.008	126.0*	0.4		Zir2013a	−0.08	−0.4
20035+3601	STF2624Aa-B	13312	2014.798	R	32	1.938	0.017	173.8*	1.1				
20042+1148	STF2620	13320	2014.893	R	32	1.887	0.030	284.9*	0.4				
20184+5524	STF2671	13692	2014.798	R	32	3.772	0.022	336.9*	0.6				
20248+3545	BU432	13830	2014.882	R	32	1.343	0.018	195.8*	0.8				
20377+3322	STF2705	14078	2014.798	R	32	3.164	0.017	261.3*	0.3				
20378+6045	STF2717	14102	2014.831	RL	20	1.987	0.010	257.4*	0.3				
20396+4035	STT410	14126	2014.836	R	10	0.886	0.004	3.7	0.3		Hrt2011a	0.02	−0.1
20410+3218	STF2716Aa-B	14158	2014.836	RL	20	2.756	0.014	44.7*	0.3	NF			
20423+5723	BU152	14196	2014.836	R	20	1.204	0.008	82.0*	0.3				
20450+1244	BU64	14238	2014.882	R	20	0.681	0.012	353.8	0.8	NF	USN2007a	0.03	−1.4
20474+3629	STT413AB	14296	2014.825	R	20	0.910	0.008	2.6*	0.3		Rab1948b	−0.01	3.0
20486+5029	BU366	14331	2014.882	R	32	1.399	0.025	128.5*	0.8				
20548+3242	STT418	14421	2014.893	R	32	0.932	0.017	282.8	0.3		Zir2013a	−0.02	−0.8
20585+5028	STF2741AB	14504	2014.798	R	32	1.954	0.017	25.2*	0.3				
21021+5640	STF2751	14575	2014.741	R	20	1.607	0.008	355.5*	0.3				
21022+0711	STF2742	14556	2014.893	R	32	2.960	0.020	213.6*	0.3	Diffuse			
21118+5959	STF2780Aa-B	14749	2014.741	R	20	1.027	0.008	212.9*	0.3				
21137+6424	H148	14783	2014.899	R	20	0.601	0.008	243.5*	0.5		Hrt2014b	−0.06	0.9
21208+3227	STT437AB	14889	2014.741	R	32	2.437	0.017	19.6*	0.6		Hrt2011a	0.01	0.8
21441+2845	STF2822AB	15270	2014.836	R	20	1.649	0.008	317.3*	0.3		Hei1995	0.09	−3.6
21516+6545	STF2843AB	15407	2014.893	R	20	1.326	0.014	149.7*	0.3				
21523+6306	STF2845AB	15417	2014.883	R	32	1.893	0.020	173.0*	0.6				
21555+1053	BU75	15447	2014.836	R	32	1.016	0.017	23.8*	0.9		Hei1996a	−0.03	−0.8
21555+5232	STT456AB	15460	2014.883	R	32	1.513	0.032	34.7*	1.0				
"	"	"	2014.894	R	32	1.629	0.017	37.2*	1.3				
22044+1339	STF2854	15596	2014.798	R	32	1.579	0.017	81.6*	0.4				
22086+5917	STF2872BC	15670	2014.935	R	20	0.837	0.012	297.2	0.4	NF	USN2002	0.03	0.1
22146+2934	STF2881	15769	2014.798	R	32	1.250	0.020	74.5*	0.5				
22288−0001	STF2909AB	15971	2014.836	R	20	2.250	0.011	164.3*	0.3	Diffuse	Sca2010c	0.01	−0.8
22514+6142	STF2950	16317	2014.836	R	20	1.187	0.008	274.6*	0.3		Zir2015a	0.00	−0.2
23595+3343	STF3050AB	17149	2014.894	R	20	2.365	0.012	339.2*	0.3	Diffuse	Hrt2011a	−0.00	−0.2

Note: In column 9, $*$ indicates that θ was determined with our quadrant value (or with the long integration).
In column 14, the exponent ^{Q} indicates discrepant quadrants between our measurements and the published orbits.

Table 1). In that case, the bandpass and central wavelength correspond to that of the ICCD detector (see Prieur et al., 1998).

As for the other papers of this series, position measurements were obtained by an interactive processing of the autocorrelation files computed in real time during the observations. This processing led to a series of measurements with different background estimates and simulated noise, from which we derived the mean values and the standard deviation of those multiple measurements (see Paper III for more details). The final measures and their errors are displayed in Table 1. The average error values of the measurements reported in this table are $\langle\sigma_\rho\rangle = 0''.015 \pm 0''.011$ and $\langle\sigma_\theta\rangle = 0^\circ.5 \pm 1^\circ.4$.

3.1 Quadrant determination

As our astrometric measurements were obtained from the *symmetric* autocorrelation files, the θ values first presented a 180° ambiguity. To resolve this ambiguity and determine the quadrant containing the companion, Aristidi et al. (1997) have proposed a method that can be considered as a restricted triple correlation (RTC hereafter). The quadrants of the measurements indicated in Table 1 were mostly derived from the RTC files that were computed in real time during the observations. However, for the couples with the largest separations, a straightforward determination was done when the companions could be directly spotted on the long integration files.

As a result, in Table 1, we are able to give the unambiguous (i.e. "absolute") position angles of 188 out of 224 measurements, i.e. 84% of the total. They are marked with an asterisk in Col 9. When our quadrant determination procedure failed, the angular measurement was reduced to the quadrant reported in the WDS catalog, which is extracted from the Fourth Catalog of Interferometric Measurements of Binary Stars (Hartkopf et al. 2016, hereafter IC4).

Our "absolute" θ values are consistent with the values tabulated in WDS for all objects except for ADS 4208, 10905 and 11558. We display some information about those objects in Table 2. In Col. 2, we indicate the quadrant (Q) that we obtained from our observations, using the usual convention of numbering it from 1 to 4 to indicate the North-East, South-East, South-West and North-West quadrants, respectively. In Col. 3 we indicate which filter we have used. We report the difference of magnitude between the two components from the IC4 in Col. 4, and the global spectral type found in the SIMBAD astronomical data base in Col. 5. For those objects, the small value or the uncertainty in of the magnitude difference Δm_V may account for the discrepancy.

In the case of triple systems, a new method to resolve the 180°ambiguity is presented in Sect. 3.3 and 4.

Table 2 Objects with discrepant quadrants

Name	Q	Filter	Δm_V	Spectral type
ADS 4208	2	R	0.01	B9IV-V
ADS 10905	2	R	—	A0III
ADS 11558	2	R	0.2	A3V

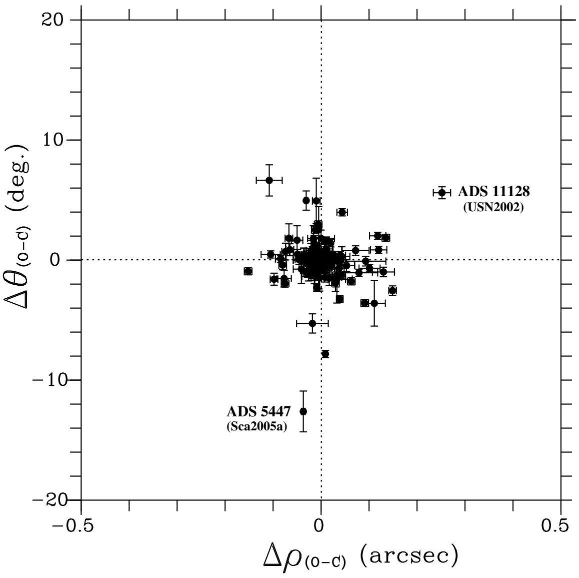

Fig. 3 Residuals of the measurements of Table 1 computed with the published orbits.

3.2 Comparison with published ephemerides

The $(O - C)$ (Observed minus Computed) residuals of the measurements for the systems with a known orbit in Table 1 are displayed in Cols. 13 and 14 for the separation ρ and position angle θ, respectively. Those residuals were obtained with a selection of valid orbits found in the OC6 catalog. We did not always use the most recent orbits since sometimes older orbits led to equivalent or even smaller residuals. For ADS 1615, 5447, 10075 and 12447, we also reported the residuals obtained with our revised orbit presented in Sect. 5.

The residuals are plotted in Fig. 3. They have a rather large scatter which is naturally explained by the (old) age of many orbits that need revision. For example the large residuals obtained for ADS 5447 with our previous orbit (Scardia et al. 2005) have been largely reduced with our new revised orbit (see Sect. 5). The mean values computed with the residuals of Table 1 are $\langle\Delta\rho_{O-C}\rangle = 0''.001 \pm 0''.05$ and $\langle\Delta\theta_{O-C}\rangle = -0^\circ.2 \pm 2^\circ.0$. The small values obtained for those offsets provide a good validation of our calibration (see Paper XII).

3.3 Measurements of triple systems

In Table 1, we have reported the measurements of the four triple systems that we observed in 2014: ADS 5400

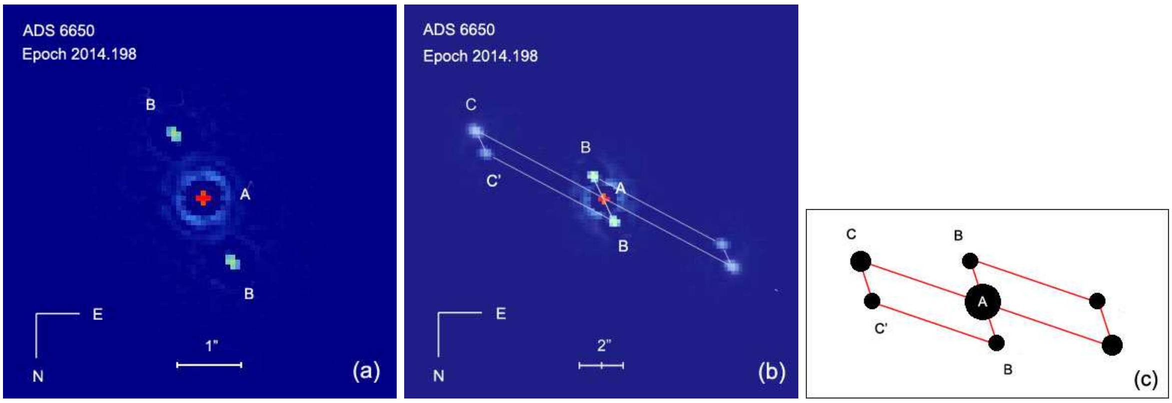

Fig. 4 Measurements of triple systems: case of ADS 6650. Autocorrelation obtained with a small field of view (a), and a wide field (b). As shown in (c), with the wide field autocorrelation, the AB (resp. AC) separation vector can also be determined with CC' (resp. BC').

(STF 948), ADS 6650 (STF 1196), ADS 6993 (STF 1273), and ADS 10227 (BU 627). In the literature, many measurements and orbits of triple systems refer to the couple AB-C. When the components AB are well separated the measurements (and the orbits) of AB-C may be ambiguous, since the "center of AB" is defined by some authors as the center of light, or by others as the center of mass of the two components. To avoid this problem, we reported the AC measurements in Table 1, when the closest pair AB was resolved. For example, this is the case of ADS 6650, as shown in Fig. 4. This figure clearly shows that the separation and position angle of CC' is the same as AB. So CC' can be used to determine AB, if necessary.

Fig. 5 illustrates the different aspects of the autocorrelations of triple systems, obtained for the objects of the first two columns with a small field centered on the brightest component (Col. 3), or with a wide field including the 3 components (Col. 4). The objects in the first two columns are symmetric to one another, relative to the brightest component. As a result they have the same autocorrelation functions. This figure shows that the wide field autocorrelation (Col. 4) gives the relative position angle between close and wide pairs and thus contains useful information about the absolute position angle of the closest pair. An example of application will be given in the next section.

4 Study of the multiple system ADS 6993 with PISCO in Merate (2004–2014)

4.1 Description of the system

SP 1 (ϵ Hya = 11 Hya): the AB pair was discovered at the Osservatorio Astronomico di Brera in 1888 by Schiaparelli with the 50 cm Merz-Repsold refractor (Schiaparelli, 1909). In fact, this object is a multiple system from which two couples could be observed in Merate: SP1AB and STF1273AB,C. The other components of this sytem are beyond the capabilities of our instrument, and could not be observed.

4.2 Observations with PISCO since 2004 and first data reduction

SP 1AB was observed in Merate in 2004, 2007, 2010, 2012, and 2014, with the 10 mm eyepiece (see Table 3). The observations of 2004 appeared first as unresolved (Paper I), because its separation was close to the diffraction limit of the Zeiss telescope. A subsequent processing of the same observations, by subtracting a model obtained from a single (or unresolved) star, allowed us to resolve this pair (see Paper IV). The AB pair was then directly resolved in our subsequent small-field observations with the 10 mm eyepiece.

STF1273AB,C was observed with the 20mm eyepiece in 2007, 2010, 2012, and 2014, at the same epochs as SP 1AB (see Table 3). In papers VII, XI, and XIII, we reported AB,C measurements since the AB pair appeared (in that time) as unresolved in those low-magnification observations.

4.3 New data reduction

In 2014, we improved our data reduction pipeline and implemented new high-contrast numerical filters based on strioscopy (elimination of the low frequency components of the image). When re-processing the wide-field autocorrelations of ADS 6993 with those filters, the two secondary peaks appeared as resolved into two tiny spots of different brightness. Furthermore, by subtracting a model of the background in the central regions, it was possible to detect the A and B components, for the observations of 2010, 2012 and 2014 (Fig. 6). In those cases, the secondary peaks became sixfold !

Since SP 1AB was resolved in the small-field autocorrelations obtained with the 10mm eyepiece, it appears that ADS 6993 is similar to the objects 4 or

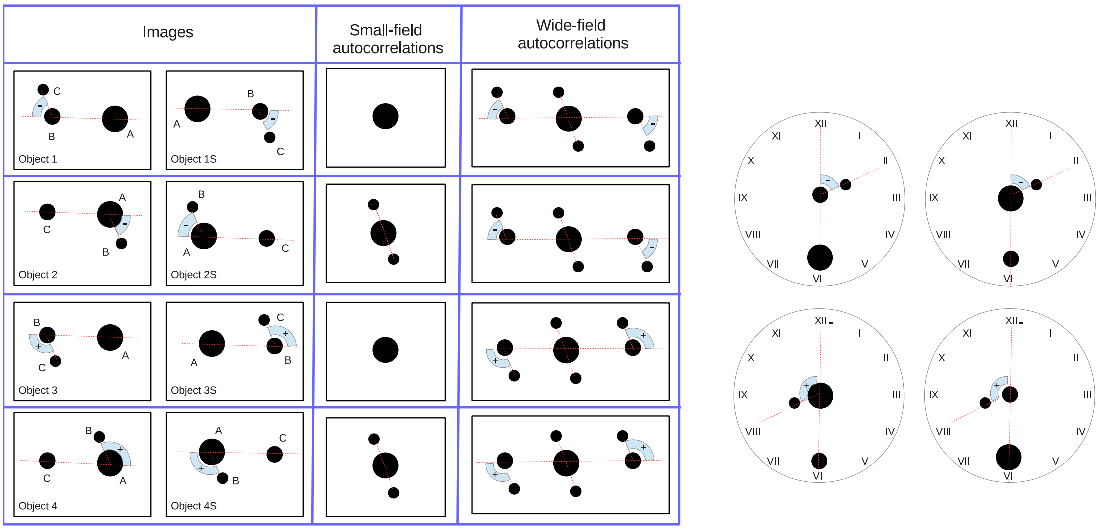

Fig. 5 Triple systems : the 180° ambiguity of the position angle of the companion of the closest pair can be resolved by examining the secondary peaks of the wide-field autocorrelation function. This is illustrated with the virtual clocks on the right, where the isolated component in the image plane (or the central peak of the autocorrelation) is drawn at 6 p.m.

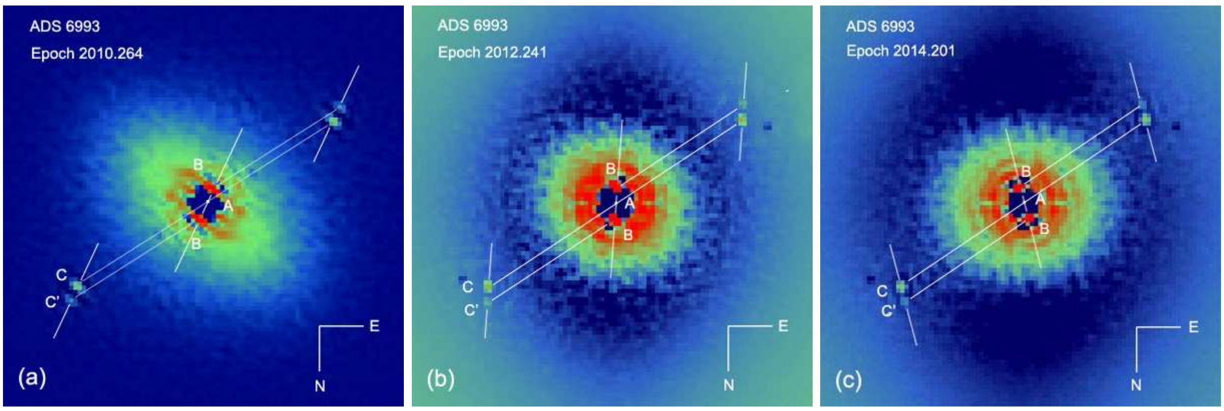

Fig. 6 ADS 6993: in the wide-field autocorrelations obtained in 2010 (a), 2012 (b) and 2014 (c), the couple AB appears both as secondary peaks close to the center, and as a splitting of the distant secondary peaks produced by the C component.

4S of Fig. 5. As the position angle of the AC pair is $\theta = 304°.5$ (see Table 1), we infer that we are here in the case of object 4. Therefore, the image of the pair AB looks like the upper right part of the autocorrelations of Fig. 6: from 2010 to 2014, the B component has moved from the second to the third quadrant. This in agreement with other published measurements (see IC4), and with an image of the ABC components obtained in Lucky-imaging by R. Gili in 2012 (private communication).

Our results are displayed in Table 3. The measurements of SP 1AB obtained with the 10 mm eyepiece (small-field autocorrelations) are in very good agreement with those obtained when measuring the separation CC' in the wide-field autocorrelations. Due to the small orbital period ($P \approx 15$ yr), the auto-correlation images have clearly changed between 2010 and 2014 (see Fig. 6).

5 Revised orbits of ADS 671, 1615, 1709, 5447, 10075 and 12447

In this section we present the new revised orbits that we have computed for ADS 671, 1615, 1709, 5447, 10075 and 12447. The revision of those orbits was justified by the appearance of a systematic trend in the residuals of our last measurements and/or the existence of substantial number of new measurements since the computation of the last known orbit. The orbital elements of the revised orbits were published in the circulars of the IAU Commission 26 (Scardia, 2015b, 2015c) and are in the Sixth Catalogue of Orbits of Visual Binary Stars (Hartkopf & Mason, 2016) under reference Scar2015c.

We have followed the same method for computing the orbits of those seven objects. Using our last measurements with PISCO and the other available observations contained in the data base maintained by the United States Naval Observatory (USNO), we first

Table 3 Observations of ADS 6993 with PISCO since 2004: old and new measurements.

Name	Epoch	Fil.	Eyep. (mm)	ρ ($''$)	σ_ρ ($''$)	θ (°)	σ_θ (°)	Orbit	$\Delta\rho$(O-C)	$\Delta\theta$(O-C)	Notes
SP 1AB	2004.208	V	10	0.195	0.004	258.5	2.7	Hrt1999a	−0.02	+1.4	New measure (data from Paper IV)
SP 1AB	2007.198	V	10	0.151	0.004	108.1	0.6	Hrt1999a	+0.00	+1.3	Paper VII
SP 1AB	2007.198	R	20	–	–	–	–				Paper VII : unresolved
STF1273CC' [2]	2007.198	R	20	–	–	–	–				Unresolved (data from Paper VII)
STF1273AB,C	2007.198	R	20	2.767	0.014	301.5	0.3	Dru2014	−0.05	+0.3	See note [1]
SP 1AB	2010.264	R	10	0.259	0.004	154.8	0.6	Hrt1999a	−0.01	−0.9	New measure (data from Paper XI)
STF1273CC' [2]	2010.264	R	20	0.289	0.004	154.3	0.4	"	+0.03	−1.4	New measure (data from Paper XI)
STF1273AB,C	2010.264	RL	20	2.765	0.018	302.9	0.5	Dru2014	−0.06	−0.6	New measure (data from Paper XI)
STF1273AC	2010.264	R	20	2.727	0.008	302.4	0.3				New measure (data from Paper XI)
SP 1AB	2012.241	R	10	0.269	0.003	176.2	1.6	Hrt1999a	−0.01	+0.2	Paper XIII
SP 1AB	2012.241	R	20	0.307	0.008	177.1	0.9	"	+0.03	+1.1	New measure (data from Paper XIII)
STF1273CC' [2]	2012.241	R	20	0.301	0.009	178.1	0.4	"	+0.03	+2.1	New measure (data from Paper XIII)
STF1273AB,C	2012.241	RL	20	2.756	0.017	303.4	0.3	Dru2014	−0.06	−1.5	See note [3]
STF1273AC	2012.241	R	20	2.741	0.008	303.1	0.3				New measure (data from Paper XIII)
SP 1AB	2014.201	R	10	0.261	0.003	194.0	0.5	Hrt1999a	−0.01	−1.8	New data (from this paper)
SP 1AB	2014.201	R	20	0.294	0.008	195.7	0.6	"	+0.02	−0.1	"
STF1273CC' [2]	2014.201	R	20	0.287	0.008	193.8	0.4	"	+0.02	−2.0	"
STF1273AB,C	2014.201	RL	20	2.786	0.009	305.2	0.3	Dru2014	−0.03	−1.2	"
STF1273AC	2014.201	R	20	2.768	0.008	304.5	0.3				"

(1) Reported in IC4 as 1273AC (Pru 2009) although it was published in Paper VII as 1273AB-C.
(2) STF1273CC' is an independant (unambiguous) measurement of SP1AB (see Fig 4)
(3) Published in Paper XIII as STF1273AC.

Table 4 New orbital elements of ADS 671, 1615, 1709, 5447, 10075 and 12447.

ADS	Ω_{2000} (°)	ω (°)	i (°)	e	T (yr)	P (yr)	n (°/yr)	a ($''$)	A ($''$)	B ($''$)	F ($''$)	G ($''$)
671	278.0	269.8	35.6	0.497	1889.93	479.27	0.75114	12.04	−9.70273	−1.32079	1.64217	11.92746
	±0.6	±1.0	±0.3	±0.006	±0.18	±8.2	±0.0013	±0.02				
1615	3.70	147.9	113.4	0.465	2188.6	3267.4	0.1102	7.4	−6.15485	−1.96300	−4.08482	2.23065
	—	—	—	—	—	—	—	—				
1709	99.07	322.66	63.75	0.2626	1899.07	145.41	2.4758	0.89	0.12353	0.73225	−0.39193	0.48102
	±0.25	±0.60	±0.17	±0.0016	±0.21	±0.47	±0.0080	±0.02				
5447	10.1	258.9	150.5	0.605	2017.76	205.3	1.75315	0.45	− 0.15100	0.35915	0.41683	0.14999
	±12	±8.5	±4.8	±0.031	±0.51	±8.2	±0.070	±0.02				
10075	93.86	130.75	108.42	0.7584	1921.116	230.06	1.56481	2.25	0.63483	−1.42594	−0.34751	−1.72805
	± 0.10	± 0.19	± 0.11	± 0.0022	± 0.021	± 3.0	± 0.020	± 0.05				
12447	155.3	62.5	150.7	0.958	1887.722	882.894	0.4078	1.87	−0.18002	1.67498	1.82161	−0.00901
	—	—	—	—	—	—	—	—				

computed the preliminary orbital elements with the analytical method of Kowalsky (1873). We then used them as initial values for the least-squares method of Hellerich (1925). When convergence was achieved, Hellerich's method led to an improvement of the orbital elements (with the exception of the major axis) and to an estimation of the corresponding errors. The final value of the major axis was then set to the value that minimized the residuals in separation of Hellerich's solution.

The final orbital elements are presented in Table 4. The errors reported in this table were obtained by Hellerich's least-squares method. For ADS 1615 and 12447, the errors could not be estimated since Hellerich's method did not converge. The format of the tables contained in this section is self-explanatory, but a detailed description of those formats can be found in Papers VI and VII.

The $(O - C)$ residuals of the new orbits, restricted to the last observations for reasons of space, are given in Tables 5, 6, 7, 8, 9, 10. The name of the observer is reported in the last column, using the US Naval Observatory convention.

Table 5 ADS 671: O-C residuals of our new orbit (after 2011).

Epoch	$\Delta\rho$ (O-C) ($''$)	$\Delta\theta$ (O-C) ($^\circ$)	Observer
2012.766	0.009	−0.178	Mwl
2012.801	0.018	0.107	Smr
2013.922	0.025	0.112	Mwl
2013.924	0.045	0.111	Mwl
2014.641	0.334	0.095	Ary

Table 6 ADS 1615: O-C residuals of our new orbit (after 2012). The symbol ^{P} indicates PISCO measurements.

Epoch	$\Delta\rho$ (O-C) ($''$)	$\Delta\theta$ (O-C) ($^\circ$)	Observer
2012.015	−0.151	0.687	WSI
2012.038	-0.001^P	0.201^P	Pru
2014.042	-0.019^P	0.164^P	Sca
2015.017	-0.008^P	-0.122^P	Sca
2015.112	0.006^P	-0.163^P	Sca

The ephemerides for 2017–2025 are presented in Table 11. The apparent orbits are shown in Fig. 7 as solid lines. The observational data used for the calculation of the orbital elements are plotted as small crosses or, in the case of PISCO observations, as filled circles (that appear in red in the electronic version). The orientation of the graphs conforms to the convention adopted by the observers of visual binary stars. For each object, the location of the primary component is indicated with a big cross. The straight line going through this point is the line of apsides. An arrow shows the sense of rotation of the companion.

In Table 12, we present some physical parameters of those systems. The (total) visual magnitudes (Col. 3) and the spectral types (Col. 5) were extracted from the SIMBAD data base. The difference of magnitude between the components (Col. 4) was taken from the IC4. The dynamical parallaxes (Col. 6) were derived from our orbital elements using Baize & Romani (1946)'s method, with our revised formulae presented in Scardia et al. (2008b). In Col. 7, we report the Hipparcos parallaxes from ESA (1997) or the revised values from van Leeuwen (2007), as indicated in Col. 11. In Cols. 8, 9 and 10, we give the corresponding angular and linear sizes of the semi-major axis a and the total mass $\mathfrak{M}_{\rm total}$, respectively, that were computed from our orbital elements and the Hipparcos parallaxes.

WDS 00491+5749 – STF 60AB – ADS 671 – HIP 3821 (η Cas)

This couple was discovered by W. Herschel on Aug. 18th 1779 (Herschel, 1782) with his famous Newtonian telescope (D=0.16 m, F=2.1m) that he built himself and installed in the backyard of his house of Bath. While commenting his numerous observations in the

Table 7 ADS 1709: O-C residuals of our new orbit (after 2009.7). The symbol ^{P} indicates PISCO measurements.

Epoch	$\Delta\rho$ (O-C) ($''$)	$\Delta\theta$ (O-C) ($^\circ$)	Observer
2009.829	−0.030	1.436	Los
2009.908	−0.033	1.735	FMR
2010.777	−0.044	3.505	Ant
2012.043	-0.026^P	-0.400^P	Pru
2015.113	-0.023^P	-0.053^P	Sca

Table 8 ADS 5447: O-C residuals of our new orbit (after 2004). The symbol ^{P} indicates PISCO measurements.

Epoch	$\Delta\rho$ (O-C) ($''$)	$\Delta\theta$ (O-C) ($^\circ$)	Observer
2004.211	0.001^P	1.038^P	Sca
2005.136	-0.002^P	0.820^P	Sca
2007.200	0.003^P	1.144^P	Pru
2008.240	0.011^P	2.671^P	Pru
2013.890	0.017	3.869	OCC
2014.239	0.012^P	-1.900^P	Pru

Table 9 ADS 10075: O-C residuals of our new orbit (after 2012). The symbol ^{P} indicates PISCO measurements.

Epoch	$\Delta\rho$ (O-C) ($''$)	$\Delta\theta$ (O-C) ($^\circ$)	Observer
2012.460	-0.029^P	-0.628^P	Pru
2012.516	−0.072	0.389	Wly
2013.296	0.022	−0.372	RAO
2013.583	−0.015	2.116	Ary
2013.601	0.012	−0.679	RAO
2014.511	-0.005^P	-0.605^P	Sca

Table 10 ADS 12447: O-C residuals of our new orbit (after 2011). The symbol ^{P} indicates PISCO measurements.

Epoch	$\Delta\rho$ (O-C) ($''$)	$\Delta\theta$ (O-C) ($^\circ$)	Observer
2011.663	0.027^P	-0.530^P	Sca
2011.823	–	1.893	Pal
2011.842	−0.215	−0.565	Pal
2013.630	−0.000	−0.767	RAO
2013.733	0.076^P	-1.058^P	Sca
2014.740	0.020^P	-0.274^P	Sca

Philosophical Transactions (Herschel, 1804), he noticed a significant relative motion: "...which gives a change of 8°42', in 20 years and 242 days. This arises probably from a real motion of eta in space...". More historical information about this couple can be found in the "Handbook of double stars" (Crossley et al. 1879).

This very wide couple is easily resolved by small telescopes and was extensively observed. More than 1100 observations are reported in the WDS data base.

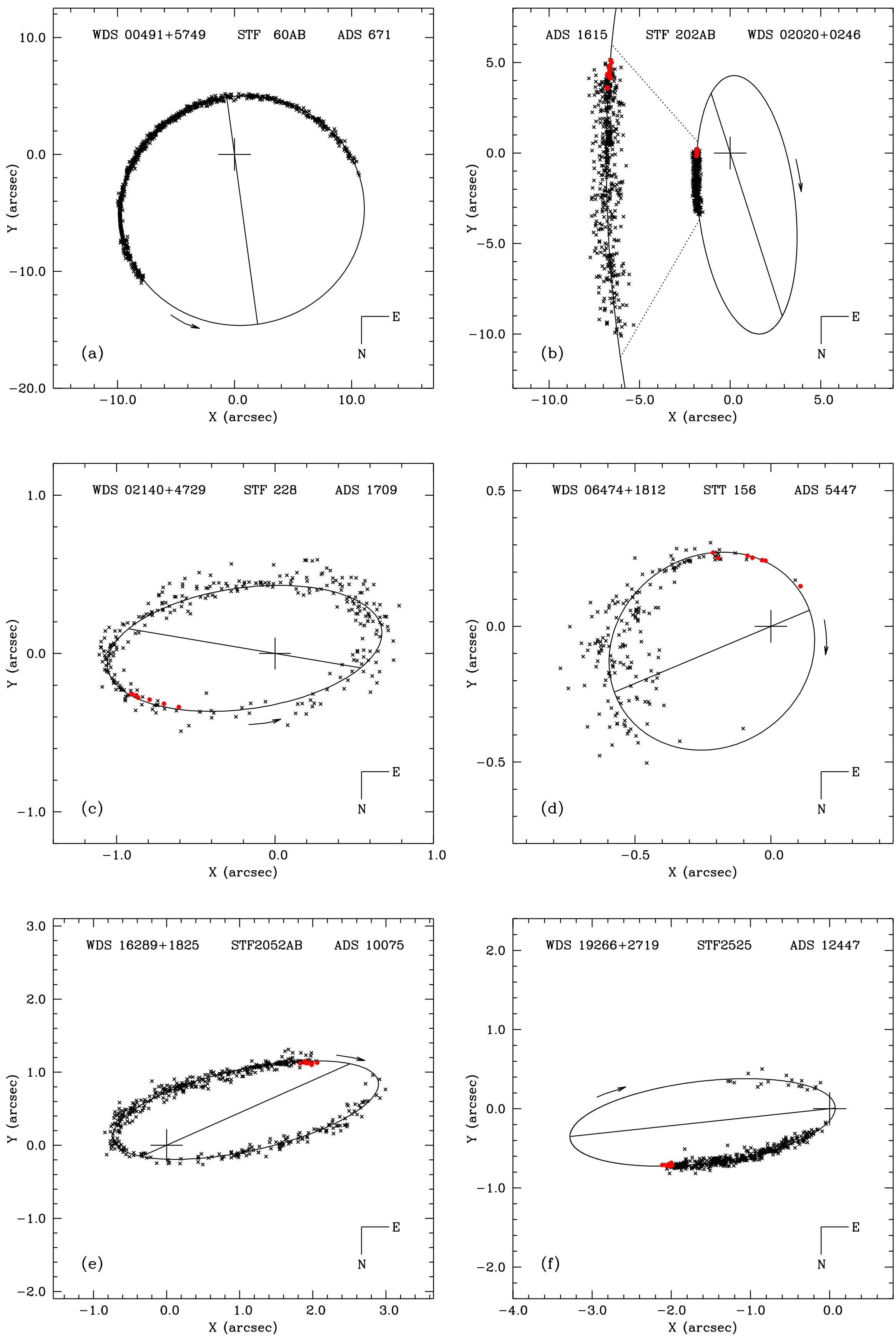

Fig. 7 New orbits of ADS 671 (a), ADS 1615 (b), ADS 1709 (c), ADS 5447 (d), ADS 10075 (e) and ADS 12447 (f). The observations by PISCO are plotted as filled circles that appear in red in the electronic version of this paper.

Table 11 New ephemerides of ADS 671, 1615, 1709, 5447, 10075 and 12447.

Epoch	ADS 671 ρ ($''$)	ADS 671 θ ($^\circ$)	ADS 1615 ρ ($''$)	ADS 1615 θ ($^\circ$)	ADS 1709 ρ ($''$)	ADS 1709 θ ($^\circ$)	ADS 5447 ρ ($''$)	ADS 5447 θ ($^\circ$)	ADS 10075 ρ ($''$)	ADS 10075 θ ($^\circ$)	ADS 12447 ρ ($''$)	ADS 12447 θ ($^\circ$)
2017.0	13.323	325.0	1.834	262.0	0.667	302.4	0.156	120.4	2.407	118.7	2.181	289.4
2018.0	13.351	325.4	1.835	261.4	0.639	304.4	0.154	110.3	2.427	118.4	2.189	289.3
2019.0	13.378	325.9	1.836	260.8	0.611	306.5	0.154	100.1	2.448	118.1	2.198	289.2
2020.0	13.405	326.3	1.838	260.1	0.582	308.8	0.157	90.1	2.467	117.9	2.207	289.2
2021.0	13.431	326.7	1.839	259.5	0.553	311.4	0.162	80.7	2.487	117.6	2.215	289.1
2022.0	13.458	327.1	1.841	258.9	0.523	314.3	0.170	71.9	2.506	117.3	2.224	289.0
2023.0	13.483	327.6	1.843	258.3	0.494	317.5	0.178	64.0	2.525	117.1	2.232	289.0
2024.0	13.509	328.0	1.846	257.6	0.465	321.1	0.188	56.8	2.544	116.8	2.240	288.9
2025.0	13.534	328.4	1.848	257.0	0.437	325.1	0.199	50.4	2.562	116.6	2.249	288.8

Table 12 Physical parameters ($\pi_{\rm dyn}$, a and $\mathfrak{M}_{\rm total}$) derived from the new orbital elements.

ADS	HIP	m_V	Δm_V	Spectral type	$\pi_{\rm dyn}$ (mas)	$\pi_{\rm HIP}$ (mas)	($''$)	a (AU)	$\mathfrak{M}_{\rm total}$ ($M_\odot$)	Source of $\pi_{\rm HIP}$
671	3821	3.52	3.8	G0V+K7V	170.4	167.99 $\pm$0.62	12.04	71.7 $\pm$0.3	1.60 $\pm$0.06	ESA (1997)
"	"	"	"	"	"	167.99 $\pm$0.62	"	71.7 $\pm$0.3	1.60 $\pm$0.06	van Leeuwen (2007)
1615	9487	3.82	1.1	F2 IV	20.0	23.45 $\pm$1.06	7.4	315 $\pm$14[(1)]	2.9 $\pm$0.4[(1)]	ESA (1997)
"	"	"	"	"	"	21.66 $\pm$1.06	"	342 $\pm$17[(1)]	3.7 $\pm$0.6[(1)]	van Leeuwen (2007)
1709	10403	6.08	0.6	F4 V	23.6	24.07 $\pm$0.96	0.89	36.8 $\pm$1.7	2.4 $\pm$0.3	ESA (1997)
"	"	"	"	"	"	25.26 $\pm$0.66	"	35.0 $\pm$1.3	2.0 $\pm$0.2	van Leeuwen (2007)
5447	32539	6.20	1.4	A2 V	8.0	7.56 $\pm$1.41	0.45	59 $\pm$11	4.8 $\pm$2.8	ESA (1997)
"	"	"	"	"	"	5.66 $\pm$0.71	"	79 $\pm$10	11.5 $\pm$4.7	van Leeuwen (2007)
10075	80725	7.02	0.2	K2 V	53.3	51.20 $\pm$1.49	2.45	43.9 $\pm$1.6	1.6 $\pm$0.2	ESA (1997)
"	"	"	"	"	"	50.87 $\pm$0.80	"	44.1 $\pm$1.1	1.6 $\pm$0.1	van Leeuwen (2007)
12447	95589	7.44	0.2	F8 V	15.5	13.96 $\pm$1.78	1.87	134 $\pm$17[(1)]	3.1 $\pm$1.2[(1)]	ESA (1997)
"	"	"	"	"	"	15.50 $\pm$1.27	"	121 $\pm$10[(1)]	2.3 $\pm$0.6[(1)]	van Leeuwen (2007)

[(1)] lower estimate of the error, using the parallax error only, and neglecting all the other (unknown) errors.

Although the two components of spectra G0V and K7V have a large magnitude difference: $\Delta m_V \approx 3.8$ mag, the separation of the components is sufficiently large to allow the system to be observed photographically, for example by the multiple-exposure method with an objective grating (Hertzsprung, 1915). That method is particularly well suited to measuring wide components with a large magnitude difference. The quality of the photographic measurements made by long focal instruments between 1914 and 1983 is very good. Unfortunately since the end of this program, the quality has decreased significantly, and most of the available measurements come now from amateur astronomers, using small telescopes with a short focal length.

More than twenty orbits have been computed up to now. The first one was done by Powell (1861), and the latest by Strand (1969), was "computed with special attention to multiple-exposure photographic observations from 1914 to 1968". More than 45 years of new observations are now at our disposal, corresponding to 247 measures, including many photographic measures with a very good accuracy. We thus decided to compute new orbital elements, that are displayed in Table 4. All the available measurements were corrected for precession, proper motion (see Fletcher, 1931a) and for radial velocity effects (see Fletcher, 1931b). The large number of available observations allowed us to applied rather strict selection criteria, and we rejected all the observations with residuals larger than 2 sigma (i.e., $2^\circ.2$ for θ and $0''.36$ for ρ). The new orbital elements are well determined, with small uncertainties (see Table 4). The period has the largest uncertainty, which is unavoidable, since only half of the orbit has been monitored yet (see Fig. 7). The fit is very good with mean residuals of $0''.123$ and $0^\circ.74$ for ρ and θ, respectively.

The values derived from this orbit are reported in Table 12. The parallax measured by Hipparcos leads to a total mass of 1.60 ± 0.06 $M_\odot$, which is in very good agreement with the theoretical values of 1.07 and 0.55 $M_\odot$ for G0V and K7V, respectively (Straizys and Kuriliene, 1981). The dynamical parallax is $0''.170$, very close to the Hipparcos measurement of $0''.168$.

WDS 02020+0246 – STF 202 – ADS 1615 – HIP 9487 (α Psc)

This couple was discovered by W. Herschel on Oct. 19th 1779, with his 7-inch Newtonian telescope that he also used for discovering ADS 671 (Herschel, 1782, page 125). In a paper published in the Philosophical Transactions about the first observations of this object, J. Herschel et J. South reported "...this star has undergone no appreciable change..." (Herschel & South, 1824, page 47). A clear motion was put to evidence for the first time much later by Secchi (1861, page 47) and Dawes (1867, page 310). The observations made in the following decades established that this motion is orbital. However, the motion has been very slow until now. The orbital period seems to be very large.

The observations are very numerous, but their quality is poor, especially before 1940. Only 2 orbits have been computed until now, by Rabe (1961) and by Scardia (1983). The later begins to show systematic errors on the residuals, both for ρ and θ. In particular, the most recent observations indicate that the period is larger than what was previously assumed.

Taking advantage of 32 years of additional observations, we have revised the orbit using Kowalsky (1873)'s method, and rejecting all the aberrant observations. Although provisional, the orbital elements that we obtained (see Table 4) fit well the observations, with mean residuals of $0''.105$ and $1^\circ.24$ for ρ and θ, respectively.

The two stars of this couple were classified as A0pSiSr and A3m (Gray and Garrison, 1989, Hoffleit and Jaschek, 1991). The total mass obtained with Hipparcos parallax from van Leeuwen (2007) is 3.7 $M_\odot$, in good agreement with theoretical values (i.e., 2.0 $M_\odot$ for A stars). The dynamical parallax obtained with our elements and our formula of Scardia et al. (2008b) is $0''.020$ which is also in fair agreement with van Leeuwen's value of $0''.022$.

WDS 02140+4729 – STF 228 – ADS 1709 – HIP 10403

This couple was discovered by F.G.W. Struve in Dorpat (now Tartu, Estonia) during the binary star survey he made in 1825–1827 with the famous 25-cm refractor built by Fraunhofer (Struve, 1827). The first measurement was made in February 1829 and this couple has been then regularly monitored by the observers, even near the periastron passage, when the angular separation was about $0''.3$.

Many orbits have been computed, from the first published by Gore (1889) and the last by Söderhjelm (1999). Our orbit (Scardia, 1981) is still valid, but leads to systematic residuals in separation. A few tens of new measurements, mostly from interferometry, had been published since 1999, so we decided to do a new calculation. The big number of measurements allowed us to reject the observations leading to the largest residuals ($6^\circ.0$ for θ and $0''.20$ for ρ). The companion has now accomplished more that one revolution since its discovery, and the orbital elements have a small uncertainty and can be considered as definitive.

The spectral of ADS 1709, is reported as F4V in SIMBAD, and as F2V+F7V in the WDS Catalog, which was determined by ten Brummelaar et al. (2000), from photometric measurements with the Hooker 2.5 m telescope of Mt.Wilson. The systemic mass with the Hipparcos parallax revised by van Leeuwen (2007), is 2.03 ± 0.22 $M_\odot$, and 2.35 ± 0.33 $M_\odot$ with the ESA (1997) original value. The latter is consistent with the value of 2.48 $M_\odot$ that is expected for a system F2V+F7V according to Straizys and Kuriliene (1981), and in good agreement with the values published by ten Brummelaar et al. (2000) and Malkov et al. (2012).

WDS 06474+1812 – STT 156 – ADS 5447 – HIP 32539

This couple was discovered by O Struve with the 38-cm Merz-Mahler Poulkova refractor, during his survey aiming at founding new double stars (August 1841 – December 1842) (Struve, 1843). Despite the small separation (about $0''.4$) and the difference of luminosity (1.4 mag.) between the two components, this discovery was doubtless for O. Struve who put the comment "certe oblonga" (certainly elongated) for this star. The first measurement was made in Dorpat by J.H. Madler on March 23rd 1843 with the famous 25 cm refractor built by Fraunhofer (Madler, 1845). This couple has been regularly observed since. The companion is now approaching the periastron that it should reach in 2017. The observations are becoming difficult with small instruments, since the separation is currently smaller than $0''.2$. Most of the published measurements over the last twenty years have been made by PISCO at Pic du Midi or in Merate.

The first orbit was computed by Dommanget (1953). The last one of Scardia et al. (2005) no longer represent the last observations. We thus revised our orbit of 2005, and computed new elements with the least squares Hellerich (1925)'s method. Unlike the last time, we obtained convergence and we can therefore give the uncertainties on the orbital elements. As usual, we have rejected all the aberrant observations, that had residuals larger than 7°.0 in θ and 0″.20 in ρ.

The Hipparcos parallax values given by ESA (1997) and by van Leeuwen (2007) are 0″.00756 and 0″.00566, which is significantly different. As a consequence, our estimates of the total mass derived from those values are also very different: 4.84 ± 2.80 $M_\odot$ (ESA) and 11.53 ± 4.66 $M_\odot$ (van Leeuwen, 2007). The dynamical parallax is 0″.0080 is in good agreement with the ESA value of the Hipparcos parallax. The dynamical mass is 4.55 $M_\odot$.

The spectral type is reported as A2V in SIMBAD, which would lead to a theoretical total mass of 4.18 $M_\odot$ according to Straizys and Kuriliene (1981). We thus obtain a good agreement with our determination when we use the ESA parallax value. Recently Malkov et al. (2012) have computed for this couple three different values of the total mass, according to the method they used: 8.51 $M_\odot$ (dynamic), 5.18 $M_\odot$ (photometric) and 2.09 $M_\odot$ (spectroscopic).

WDS 16289+1825 – STF 2052 – ADS 10075 – HIP 80725

F.G.W. Struve observed this object for the first time in Dorpat (Estonia), with the Troughton meridian refractor (D=95 mm), that was fitted with a filar micrometer built by Fraunhofer. He then repeated those observations during his big survey made in 1825–1827 with the 25 cm Dorpat refractor, and reported this pair as the number 2052 in his list. More historical information about this couple can be found in Scardia (1984).

Except when the companion is near the periastron, where $\rho \approx 0''.2$, this binary star is an easy target. It has been regularly observed since its discovery, and the measurements are plenty. The first orbit was computed by Jackson (1921) and the last by Lampens and Strigachev (2001). ADS 10075 belongs to the list of the targets we regularly observe with PISCO, and we decided to revise the elements of the first orbit published more than 30 years ago (Scardia, 1984). The orbital elements presented in Table 4 have small uncertainties and can be considered as definitive. The companion has nearly completed its first revolution since its discovery (see Fig. 7).

The sum of the masses, derived from the Hipparcos parallax is 1.62 ± 0.14 $M_\odot$, in good agreement with the theory. The dynamical parallax is also in good agreement with the Hipparcos value (see Table 12). When comparing our orbit of 1984 (408 observations) and our new determination (537 obs.) the uncertainties on the systemic mass have decreased from 0.42 to 0.14 $M_\odot$.

WDS 19266+2719 – STF 2525 – ADS 12447 – HIP 95589

F.G.W. Struve discovered this binary star on Sept. 16th 1828, during his survey made in 1825-1827 with the 25-cm Dorpat refractor (Struve 1827). This pair is not a difficult target for observers except when the companion is close to its periastron, where its angular separation goes down to about 0″.1. It has been regularly observed since its discovery and the observations are very numerous. However, because of the large eccentricity of the orbit, there is a lack of measurements around 1890.

The first orbit (very preliminary) was published by Gore (1892) and the last one by Heintz (1984). Although the latter is still valid, we have decided to compute a new orbit to take advantage of the 128 new measurements of good quality that have been published since 1984. We have followed our usual procedure, but did not obtained convergence of the Hellerich's least squares method, which explains why the uncertainties are not displayed in Table 4. Our orbit fit very well the observations with mean residuals of 0″.073 for ρ and 1°.92 for θ.

The total mass derived from our elements and the Hipparcos parallax (van Leeuwen, 2007), is 2.3 $M_\odot$, in good agreement with the theory (see Strazys and Kuriliene, 1981). The dynamical parallax is 0″.0155, which is in very good agreement with that value of the Hipparcos parallax (see Table 12).

6 Conclusion

We have presented here the 224 new measurements of 218 visual binaries that we have obtained with PISCO in 2014. The average accuracy was 0″.015 for the angular separation and 0°.5 for the position angles. We have completed this data with the results of a study of the multiple system ADS 6993 with PISCO during the period 2004-2014 and proposed a new method to resolve part of the 180-degree ambiguity with the autocorrelations only. The AB component (SP 1) of this system was discovered at the Osservatorio Astronomico di Brera in 1888 by Schiaparelli. About 120 years later and still at the same observatory, we have been able to resolve it and obtain measurements of some additional components with a modern and more efficient technique and a bigger telescope.

We also presented new orbital elements computed for ADS 671, 1615, 1709, 5447, 10075 and 12447, that were partly derived from PISCO observations. The total mass values we have obtained are compatible with the expected theoretical values. The dynamical parallaxes computed with our revised formulae presented in Scardia et al. (2008b) are in very good agreement with Hipparcos values.

The total number of measurements made with PISCO in Merate since its installation in 2004 now exceeds 3500. Our group has thus provided a good contribution to the continuing monitoring of long period visual binary systems, which is important for refining systemic stellar masses.

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