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Speckle observations with PISCO in Merate (Italy): XVI. Astrometric measurements of visual binaries in 2015, and new orbits for DUN 5, ADS 5958, 6276, 7294, 8211 and 13169.

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We present relative astrometric measurements of visual binaries, made in 2015 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 196 new measurements of 173 visual binary stars, with angular separations in the range $0''.27$ — $11.3''$, and an average accuracy of $0''.019$. The mean error on the position angles is $0^\circ.6$. 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 present new revised orbits for DUN 5, ADS 5958, 6276, 7294, 8211 and 13169, partly derived from PISCO observations. The corresponding estimated values for the masses of those systems are compatible with the spectral types. We also computed new rectilinear elements for ADS 4841 for which the physical connection is doubtful from our (and other recent) observations.

1 Introduction

This paper presents the results of speckle observations of visual binary stars made in Merate (Italy) in 2015 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 sixteenth 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, Scardia et al. 2015a, and Prieur et al. 2017, herein: Papers I to XV). 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 was dedicated to binary star observations since that epoch. In summer 2015, it was moved to Calern (Côte d’Azur Observatory) in France. It has been operated there since then. This paper presents the last observations made in Merate in the first semester of 2015, before the transfer of PISCO to Calern.

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. 3.4 we show that the physical connection of the two components of ADS 4841 is doubtful from our (and other recent) observations, and propose new rectilinear elements. In Sect. 4 we present the new revised orbits that we have computed for DUN 5, ADS 5958, 6276, 7294, 8211 and 13169, 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

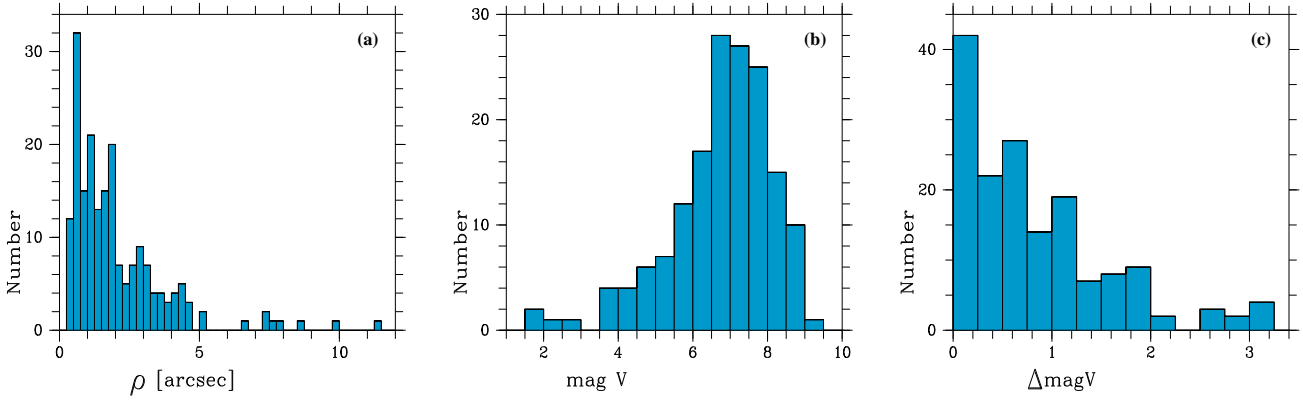


Fig. 1 Distribution of the angular separations of the 196 measurements of Table 1 (a), the total visual magnitudes of the corresponding binaries (b) and the differences of magnitude between their two components (c).

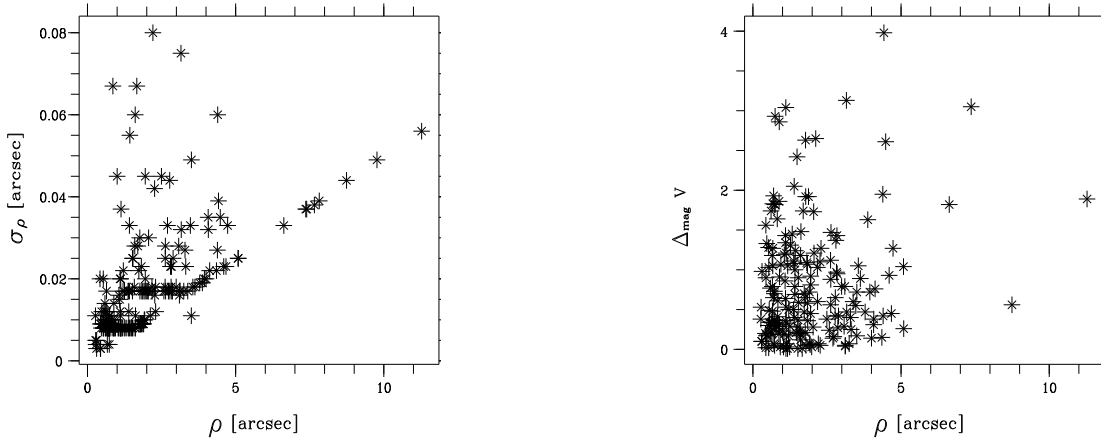


Fig. 2 Error σ_ρ as a function of the angular separation ρ of the measurements of Table 1. Our software imposes a lower limitation of the relative errors of 0.5% to take into account the scale calibration errors.

Fig. 3 Difference of magnitude Δ_{magV} between the two components versus the ρ measurements of Table 1.

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 a maximum for $\rho \approx 0''.6$. The largest separation of $11''.28$ was obtained for SE 5 AC. The smallest separations were measured for ADS 7158 and ADS 5514, with $\rho = 0''.269$ and $\rho = 0''.276$, 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 $m_V \approx 9.5$ (Fig. 1b) and

a maximum Δm_V for speckle measurements of about 3.3 (Fig. 1c).

Using the Hipparcos parallaxes, we were able to construct the HR diagram of those binaries, which is displayed in Fig. 4. We only plotted the 146 objects for which the relative uncertainty on the parallax was smaller than 50%.

3 Astrometric measurements

The 196 astrometric measurements obtained with the observations made in 2015 are displayed in Table 1. They concern 173 visual binaries. For each object, we report its WDS name (Washington Double Star Catalog, Mason et al. 2018, hereafter WDS catalog) in Col. 1, the official double star designation in Col. 2 (sequence is “discoverer-number”), and the ADS num-

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 ($^\circ$)	σ_θ ($^\circ$)	Notes	Orbit	$\Delta\rho(\text{O-C})$ (")	$\Delta\theta(\text{O-C})$ ($^\circ$)
00047+3416	STF3056AB	32	2015.003	R	20	0.711	0.008	142.6*0.3			Zir2015a	0.00	0.7
00063+5826	STF3062	61	2015.003	R	20	1.532	0.008	356.0*0.3			Sod1999	-0.02	-0.0
00134+2659	STT2AB	161	2015.017	R	10	0.442	0.003	157.4*0.4		Elongated	Sca2000b	-0.03	-2.1
00209+1059	BU1093	287	2015.017	R	20	0.752	0.008	117.6*0.3			Lin2010c	-0.01	-1.6
00442+4614	STF52	616	2015.017	R	20	1.392	0.008	3.0*0.3					
00491+5749	STF60Aa	671	2015.115	R	10	-	-	-	-	Unresolv.			
01213+1132	BU4	1097	2015.017	R	20	0.608	0.008	106.5*0.5			Sca2015b	0.02	-0.9
"	"	"	2015.055	W	20	0.612	0.008	108.2*1.3			Sca2015b	0.02	0.8
01532+3719	STF179	1500	2015.017	R	32	3.472	0.033	160.5*0.3					
01559+0151	STF186	1538	2015.017	R	20	0.731	0.008	250.1 0.4			USN2007b	-0.02	-0.1 ^Q
02020+0246	STF202	1615	2015.017	R	20	1.828	0.009	263.2*0.3			Pru2017	-0.00	-0.1
"	"	"	2015.112	R	20	1.839	0.009	263.0*0.3		Elongated	Pru2017	0.01	-0.3
02037+2556	STF208AB	1631	2015.115	R	20	1.393	0.012	343.3*0.3		Diffuse	Hei1996a	-0.10	-3.4
02062+2507	STF212	1654	2015.115	R	32	1.848	0.017	161.7*0.3					
02140+4729	STF228	1709	2015.112	R	20	0.690	0.008	299.5*1.0			Pru2017	-0.03	0.2
02213+3726	STF250	1790	2015.112	R	32	3.164	0.032	135.6*0.9					
02331+5828	STF272	1933	2015.137	R	32	1.984	0.017	216.0 0.5					
02389+6918	STF278	1985	2015.137	R	20	0.520	0.009	25.9 1.2					
02405+6129	STF283AB	2014	2015.137	R	32	1.769	0.017	207.9*0.4					
02422+4242	STT44AB	2052	2015.137	R	32	1.371	0.017	57.7*0.5					
02572+0153	A2413	2236	2015.134	R	20	0.619	0.012	163.5*0.7			Hrt2010a	0.04	-0.4
02589+2137	BU525	2253	2015.134	R	20	0.533	0.020	273.0 0.6			Rbr2018	-0.01	-1.2
02592+2120	STF333AB	2257	2015.113	R	20	1.397	0.008	209.7*0.3		Elongated	FMR2012g	0.05	-0.1
02594+0639	STF334	2261	2015.132	R	20	1.123	0.008	307.5*0.5					
03051+2755	STF342	2331	2015.113	R	32	3.291	0.027	302.1*0.4					
03054+2515	STF346AB	2336	2015.115	R	10	0.437	0.003	255.1 0.3		Elongated	Hei1981a	-0.05	-2.8
03122+3713	STF360	2390	2015.115	R	32	2.866	0.017	124.2*0.3			WSI2004a	0.01	-1.5
03127+7133	STT50AB	2377	2015.118	R	20	1.033	0.008	147.1*0.3			Sca2012b	0.12	1.9
03130+4417	STT51	2397	2015.115	R	20	0.601	0.010	343.6 1.2			Lin2012a	0.02	-2.5
03140+0044	STF367	2416	2015.118	R	20	1.239	0.008	129.9*0.3			RAO2015	0.00	-1.0
03158+5057	HU544	2425	2015.118	R	20	1.621	0.011	100.9*0.3					
03171+4029	STF369	2443	2015.118	R	32	3.626	0.018	29.7*0.3					
03175+6540	STT52AB	2436	2015.118	R	20	0.555	0.012	56.5*1.7			Msn2017e	0.05	2.0
03177+3838	STT53	2446	2015.118	R	20	0.589	0.014	234.8 1.3			Msn2017f	-0.01	-1.0
03196+6714	HU1056	2452	2015.132	R	32	1.200	0.017	77.7*1.4			Zir2015a	0.13	-2.5
03206+1911	STF377AB	2478	2015.132	R	32	1.122	0.020	108.4*0.9					
03233+2058	STF381	2504	2015.132	R	20	1.060	0.016	108.0*0.5					
03250+4013	HU1058	2518	2015.134	R	20	0.843	0.009	112.5*0.5					
03280+5511	STF386	2537	2015.134	R	32	2.700	0.033	58.5*0.3					
03285+5954	STF384AB	2540	2015.132	R	32	1.905	0.017	271.3*0.6					
03287+5026	STF388	2548	2015.134	R	32	2.822	0.018	213.2*0.3					
03293+4503	STF391	2559	2015.118	R	32	3.946	0.020	94.7*0.3					
03302+5922	STF389Aa-B	2563	2015.118	R	32	2.635	0.017	70.7*0.5					
03344+2428	STF412AB	2616	2015.017	R	20	0.744	0.008	352.0 0.3			Sca2002a	-0.01	0.3
"	"	"	2015.091	R	20	0.753	0.008	351.9 0.4			Sca2002a	0.00	0.2
"	"	"	2015.112	R	20	0.750	0.008	351.9 0.5			Sca2002a	0.00	0.2
03350+6002	STF400AB	2612	2015.017	R	20	1.609	0.008	267.3*0.4			Msn2017f	0.02	-0.6
03354+3341	STF413	2625	2015.091	R	20	1.114	0.008	123.8*0.3					
03356+3141	BU533	2628	2015.115	R	20	1.048	0.008	220.9*0.3			Zir2015a	0.01	-0.2
03362+4220	A1535	2630	2015.091	R	20	0.723	0.008	344.9*0.4			Hrt2008	0.00	0.4
03401+3407	STF425	2668	2015.091	R	20	1.915	0.010	59.5*0.3		Elongated			
03407+4601	STT59	2669	2015.115	R	32	2.844	0.017	355.4*0.5					
04159+3142	STT77AB	3082	2015.116	R	20	0.483	0.012	298.9 0.7			Sca1983c	-0.05	0.6

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	$\Delta\rho(\text{O-C})$ (")	$\Delta\theta(\text{O-C})$ ($^\circ$)
04179+5847	STF511	3098	2015.116	R	20	0.469	0.008	74.4*	1.1		Hei1996c	-0.04	-0.2
04182+2248	STF520	3114	2015.132	R	20	0.642	0.017	80.2	1.6		Hrt2001b	0.03	-2.0
04218+5002	STF521	3141	2015.132	R	32	2.051	0.017	257.1*	0.4				
04225+5136	STF522	3147	2015.137	R	32	1.517	0.017	210.9	0.8				
04233+1123	STF535	3174	2015.135	R	20	1.102	0.012	269.6*	0.3	Elongated	Hrt2000c	0.06	2.1
04239+0928	HU304	3182	2015.113	R	10	0.290	0.004	28.5	1.6	Elongated	Hrt2000b	-0.01	-1.6
04268+5539	STF531	3207	2015.135	R	20	0.944	0.008	324.2*	0.5				
04301+1538	STF554	3264	2015.113	R	20	1.489	0.008	16.0*	0.6		Baz1980a	-0.10	0.8
04335+1801	STF559	3297	2015.118	R	32	3.119	0.017	275.3*	0.3				
04367+1930	STF567	3330	2015.137	R	32	2.032	0.017	344.1*	0.7		USN2002	0.00	1.1
04381+4207	STF565AB	3338	2015.195	R	20	1.326	0.008	167.4*	0.3				
04385+2656	STF572AB	3353	2015.195	R	32	4.352	0.022	9.3*	0.3				
04400+5328	STF566AB-C	3358	2015.137	R	20	0.698	0.008	168.1*	0.3				
04422+3731	STF577	3390	2015.137	R	20	0.708	0.008	333.1*	0.4		RAO2015	0.01	1.4
04433+5931	A1013	3391	2015.195	R	20	0.455	0.009	294.7	0.7		Alz1999	0.02	1.8
05005+0506	STT93	3596	2015.135	R	32	1.535	0.025	245.9*	0.5		WSI2015	-0.04	2.2
05079+0830	STT98	3711	2015.137	R	20	0.898	0.010	289.8*	0.3		Sca2008d	-0.04	-0.9
05103+3718	STF644AB	3734	2015.137	R	20	1.614	0.008	221.6*	0.3				
05167+1826	STF670A-Bb	3854	2015.132	R	32	2.625	0.025	163.3*	0.3				
05172+3320	STF666	3853	2015.132	R	32	3.114	0.017	73.6*	0.3				
05247+6323	STF677	3956	2015.116	R	20	1.100	0.008	114.8*	0.3		Hrt2008	-0.04	1.4
05248+6444	STF676	3955	2015.116	R	32	1.415	0.017	265.1*	0.8				
05297+3523	HU217	4072	2015.132	R	20	0.652	0.012	254.3*	2.4				
05308+0557	STF728	4115	2015.113	R	20	1.269	0.008	44.7*	0.3		USN1999b	-0.05	0.3
05339+4447	STF727	4137	2015.113	R	32	2.176	0.018	58.4*	0.4				
05352+3358	AG97	4165	2015.195	R	32	1.733	0.022	269.9*	0.3				
05364+2200	STF742	4200	2015.214	R	32	4.078	0.032	273.2*	0.3		Hop1973b	-0.07	-2.4
05371+2655	STF749AB	4208	2015.116	R	20	1.168	0.008	319.6	0.3		Sca2007a	-0.00	-0.4
05371+4150	STF736	4204	2015.214	R	32	2.620	0.018	359.8*	0.4				
05399+3757	STT112	4243	2015.211	R	32	0.857	0.067	46.7	0.5				
05535+3720	BU1053	4472	2015.135	R	20	1.876	0.009	359.3*	0.4		Zir2014a	0.00	-0.2
05597+2228	STT125	4577	2015.135	R	20	1.421	0.008	360.0*	0.3				
06038+1816	HDS824	-	2015.135	R	32	2.265	0.042	148.3*	0.3				
06149+2230	BU1008	4841	2015.211	R	20	1.802	0.009	256.3*	0.3		Baize (1980)	0.20	3.6
"	"	"	"	"	"	"	"	"	"		This paper	-0.03	-0.8
"	"	"	2015.214	R	10	1.776	0.009	256.6*	0.3		Baize (1980)	0.17	4.0
"	"	"	"	"	"	"	"	"	"		This paper	-0.06	-0.5
06228+1734	STF899	4991	2015.138	R	32	2.181	0.017	17.8*	0.3				
06344+1445	STF932	5197	2015.132	R	32	1.580	0.018	300.8*	0.6		Hop1960a	-0.05	-0.2
06364+2717	STT149	5234	2015.269	R	20	0.671	0.008	277.1*	0.4		Hei1993d	-0.07	-5.4
06387+4135	STF941	5269	2015.132	R	32	1.950	0.020	82.7*	0.6				
06396+2816	STT152	5289	2015.138	R	20	0.822	0.010	35.3*	0.6				
06410+0954	STF950	5322	2015.214	RL	32	3.155	0.075	213.7*	1.3				
06462+5927	STF948AB	5400	2015.132	R	20	1.895	0.009	67.0*	0.3		WSI2006b	-0.00	0.1
"	STF948AC	5400	2015.132	R	32	8.742	0.044	308.2*	0.3	Diffuse			
"	STF948BC	5400	2015.132	R	32	9.769	0.049	298.6*	0.3				
06531+5927	STF963	5514	2015.214	RL	10	0.276	0.005	349.8	0.6		Sca2008d	-0.00	1.0
06546+1311	STF982AB	5559	2015.271	R	32	7.366	0.037	142.8*	0.3		Msn2014b	0.06	-0.2
06573+5825	STT159	5586	2015.214	R	10	0.670	0.004	233.6*	0.3	Elongated	Sod1999	0.02	1.5
07128+2713	STF1037	5871	2015.116	R	20	0.923	0.008	305.2	0.3		Sca2015b	-0.02	-0.8
07303+4959	STF1093	6117	2015.272	R	20	0.878	0.008	204.7	0.4		Hrt2009	-0.01	0.3
07346+3153	STF1110	6175	2015.116	R	32	5.081	0.025	54.4*	0.3		DRs2012	0.05	-0.3
07401+0514	STF1126	6263	2015.269	R	20	0.833	0.008	175.7*	1.0		Zir2015a	-0.01	-0.8
07417+3726	STT177	6276	2015.272	R	20	0.530	0.008	149.3	1.3		This paper	-0.03	2.5
07573+0108	STT185	6483	2015.288	R	20	0.422	0.020	17.7	5.8		Msn2009	0.03	-1.6
08024+0409	STF1175	6532	2015.285	R	32	1.430	0.055	284.7*	0.6		Ole2001	0.04	-6.1

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 (")	Notes	Orbit	$\Delta\rho(\text{O-C})$ (")	$\Delta\theta(\text{O-C})$ (")
08041+3302	STT187	6549	2015.285	R	20	0.437	0.009	337.9	2.1		Msn1999a	0.02	0.4
08056+2732	STF1177	6569	2015.285	R	32	3.507	0.049	349.7*	0.3				
08061-0047	A1971	6582	2015.302	R	32	1.001	0.045	2.7*	1.0		Tok2015c	0.04	0.3
08095+3213	STF1187	6623	2015.302	R	20	3.102	0.016	21.0*	0.3		Ole2001	0.15	0.6
08213-0136	STF1216	6762	2015.274	R	20	0.535	0.009	305.0	0.7		Tok2014a	0.01	-3.2
"	"	"	2015.280	R	20	0.537	0.008	306.0*	0.6		Tok2014a	0.02	-2.2
08432+3849	BU209	6946	2015.307	R	32	1.249	0.017	9.9*	1.6				
08508+3504	STF1282	7034	2015.307	R	32	3.504	0.011	277.5*	0.9				
08531+5457	A1584	7054	2015.280	R	20	0.673	0.008	88.9*	1.2		Msn2014a	-0.00	-3.0
08542+3035	STF1291	7071	2015.280	R	20	1.517	0.008	309.3*	0.4				
08554+7048	STF1280	7067	2015.280	R	32	3.078	0.028	355.4*	0.3		Hei1997	0.06	-0.9
09012+0245	STF1302AB	7141	2015.280	R	32	2.732	0.017	235.7*	0.3				
09013+1516	STF1300	7139	2015.288	R	32	5.089	0.025	179.1*	0.3		Zir2008	0.05	0.0
09014+3215	STF1298	7137	2015.304	R	32	4.481	0.035	134.9*	0.4				
09020+0240	BU211	7152	2015.280	R	20	1.100	0.020	268.8*	0.3				
09035+3750	MUG1	-	2015.304	R	20	-	-	-	-	Too Faint			
09036+4709	A1585	7158	2015.214	R	10	0.269	0.011	286.7*	0.3	Elongated	Hrt2000a	-0.02	0.2
09051+3931	AG160	7167	2015.285	R	32	4.001	0.020	58.6*	0.4				
09057+3227	AG161	7174	2015.304	W	32	4.394	0.060	224.2*	1.1				
09071+3037	AG162	7183	2015.285	R	32	4.073	0.035	105.5*	0.3				
09095+0256	STT197	7215	2015.285	R	32	1.379	0.017	67.6*	0.8				
09103+5223	STF1312	7212	2015.214	R	32	4.674	0.023	148.1*	0.3				
09104+6708	STF1306	7203	2015.214	RL	32	4.421	0.039	348.1*	0.3	Diffuse	Sca2015b	0.08	0.1
09149+0413	BU455	7257	2015.302	R	32	1.697	0.028	67.1*	0.7				
09179+2834	STF3121	7284	2015.307	R	10	0.308	0.005	190.6	1.0		Sod1999	-0.02	0.6 ^Q
09184+3522	STF1333	7286	2015.307	R	20	1.931	0.010	49.2*	0.3				
09210+3811	STF1338AB	7307	2015.272	R	20	1.109	0.008	308.3*	0.3		Sca2002b	0.10	-5.2
09235+3908	STF1344	7332	2015.272	R	32	3.787	0.019	102.6*	0.4				
09270+6421	STF1345	7364	2015.304	W	32	2.836	0.023	85.0*	0.3				
09273+0614	STF1355	7380	2015.272	R	20	1.789	0.009	354.6	0.3		Lin2011b	-0.02	-0.1
09277+1545	STF1353	7386	2015.285	W	32	3.249	0.017	124.5	0.3				
09315+0128	STF1365	7412	2015.302	R	32	3.383	0.017	156.1*	0.3	Diffuse			
09414+3857	STF1374	7477	2015.288	R	32	2.801	0.023	309.4*	0.3		Lin2013a	-0.01	-1.2
09521+1628	STF1390AB	7549	2015.310	W	32	1.949	0.045	208.0*	0.6				
"	SE5AC	-	2015.310	W	32	11.276	0.056	40.7*	0.3				
09524+2659	STF1389	7551	2015.288	R	32	2.496	0.045	289.4*	0.3		Lin2016a	-0.01	-0.8
09556+0806	AG170	7579	2015.302	R	32	1.610	0.060	44.6*	1.4				
09564+1040	STF1396	7585	2015.310	W	32	3.877	0.019	129.1*	0.3				
10057+4103	A2142	7631	2015.307	R	20	1.086	0.015	293.8*	0.5				
10123+1621	STF1413	7679	2015.302	W	32	1.664	0.067	270.5	0.6				
10131+2725	STT213	7685	2015.280	R	20	1.124	0.008	121.0	0.6		Sca2008e	0.05	0.3
10151+1907	STF1417	7695	2015.302	W	32	2.208	0.080	75.4	0.7				
10163+1744	STT215	7704	2015.272	R	20	1.465	0.008	176.3*	0.3		Zae1984	-0.09	-2.1
10181+2731	STF1421	7715	2015.307	R	32	4.598	0.023	330.9*	0.3				
10200+1950	STF1424AB	7724	2015.285	R	32	4.729	0.033	125.6*	0.4		WSI2006b	-0.10	-0.6
10205+0626	STF1426AB	7730	2015.272	R	20	0.896	0.008	312.1	0.3		Sca2006b	-0.00	-0.8
"	STF1426BC	7730	2015.272	R	32	7.397	0.037	14.6*	0.3				
"	STF1426AC	7730	2015.272	R	32	7.821	0.039	8.8*	0.3				
"	STF1426AB-C	7730	2015.272	R	32	7.657	0.038	10.9*	0.3				
10250+2437	STF1429	7758	2015.280	R	20	0.804	0.009	156.5	0.4		Zul1981	0.05	-0.2
10260+5237	STF1428	7762	2015.307	R	32	2.775	0.044	86.0*	0.3				
10269+1713	STT217	7775	2015.304	R	20	0.726	0.009	151.1*	0.5		Sca2015b	-0.06	2.6
10480+4107	STT229	7929	2015.280	R	20	0.646	0.008	260.0*	0.4		Alz1998a	0.01	3.0
10556+2445	STF1487	7979	2015.302	R	32	6.626	0.033	111.9*	0.3	Elongated			
10557+0044	BU1076	7982	2015.376	R	20	1.111	0.011	52.1*	0.5		Tok2015c	-0.01	0.4

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 (")	Notes	Orbit	$\Delta\rho(\text{O-C})$ (")	$\Delta\theta(\text{O-C})$ (")
11035+5432	A1590	8032	2015.285	R	32	1.415	0.033	332.9*	1.3		Baz1985b	-0.09	1.1
11037+6145	BU1077	8035	2015.280	R	10	0.736	0.004	350.1*	0.3		Sca2011a	-0.00	-2.5
"	"	"	2015.376	R	10	0.749	0.011	350.0*	0.4		Sca2011a	0.01	-2.1
11137+2008	STF1517	8094	2015.307	R	20	0.660	0.009	318.3	1.0		FMR2015b	-0.04	2.2
11182+3132	STF1523AB	8119	2015.305	R	20	1.732	0.009	175.0*	0.3		Sod1999	-0.01	-0.1
11190+1416	STF1527	8128	2015.280	R	10	0.307	0.003	251.4*	0.7		Tok2012b	0.01	0.3
11239+1032	STF1536	8148	2015.285	R	20	2.120	0.011	95.9*	0.3		Sod1999	0.01	0.2
11323+6105	STT235	8197	2015.403	R	20	0.883	0.008	38.2*	1.2		Sod1999	-0.01	2.3
11347+1648	STF1552	8220	2015.307	R	32	3.556	0.018	208.8*	0.3	Diffuse			
11363+2747	STF1555	8231	2015.305	R	20	0.740	0.011	148.6*	0.7		Doc2017a	0.05	-1.3
11390+4109	STT237	8252	2015.305	R	32	2.062	0.030	242.6*	0.4		USN2002	0.03	-1.7
11406+2102	STF1566	8263	2015.419	R	32	2.298	0.018	349.0*	0.8				
11563+3527	STT241	8355	2015.425	R	20	1.781	0.009	145.7*	0.3				
12108+3953	STF1606	8446	2015.403	R	20	0.549	0.008	149.3*	1.1		Msn1999a	-0.01	3.8
12126+3546	STF1613	8460	2015.403	R	32	1.132	0.037	7.2	0.7				
12160+0538	STF1621	8486	2015.425	W	32	1.520	0.025	44.6*	0.9		Sod1999	-0.14	-0.4
12244+2535	STF1639	8539	2015.403	R	20	1.818	0.023	322.8*	0.6		Ole2000b	-0.01	-0.3
12272+2701	STF1643	8553	2015.419	R	32	2.889	0.025	4.7*	0.3		WSI2004a	0.14	0.8
12417-0127	STF1670	8630	2015.280	R	20	2.270	0.016	5.3	0.3		Sca2007c	-0.04	-0.1
"	"	"	2015.376	R	20	2.300	0.012	4.9	0.3		Sca2007c	-0.02	-0.2
13007+5622	BU1082	8739	2015.376	R	20	0.889	0.014	116.5*	0.4		Sca2012c	0.01	-0.5
13084+1529	STF1722	8796	2015.425	R	32	2.628	0.028	336.0*	0.3				
13120+3205	STT261	8814	2015.425	R	32	2.578	0.017	337.6*	0.3		Kis2012	-0.01	-0.8
13166+5034	STT263	8843	2015.419	R	32	1.766	0.030	135.8	0.9				
13284+1543	STT266	8914	2015.420	R	32	1.945	0.017	355.6*	0.6		Hrt2011d	-0.05	-2.0
13324+3649	STF1755	8934	2015.425	R	32	4.123	0.022	129.3*	0.3				
13329+4908	STF1758	8940	2015.420	R	32	3.316	0.023	291.1*	0.3				
13346+3308	BU933AB	8958	2015.425	W	32	2.781	0.017	21.9*	0.6	Diffuse			
13491+2659	STF1785	9031	2015.425	R	32	2.993	0.018	186.3*	0.5		Hei1988d	0.08	0.2
14165+2007	STF1825	9192	2015.425	R	32	4.384	0.027	152.7*	0.4		Kiy2017	-0.05	-0.4
14203+4830	STF1834	9229	2015.420	R	32	1.595	0.028	102.2*	0.5		WSI2015	-0.00	-1.1
22514+6142	STF2950	16317	2015.016	R	20	1.174	0.008	274.6*	0.3		Zir2015a	-0.01	-0.1
22537+4445	BU382AB	16345	2015.003	R	20	0.735	0.010	241.5*	0.3		Sca2014a	0.02	1.0
22542+7620	STF2963	16371	2015.017	R	32	1.840	0.017	2.6*	0.4				
22557+1547	HU987	16373	2015.003	R	32	1.210	0.022	76.0*	1.8		USN2007a	0.08	-1.2
23103+3229	BU385AB	16561	2015.003	R	20	0.658	0.010	84.7*	0.9		Lin2010c	-0.02	0.3

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.

ber 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. More precisely, "Elongated" and "Diffuse" are related to those peaks only and the corresponding observations are fully resolved, unless explicitly mentioned by "Unresolved" in this column.

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, 2018, 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 de-

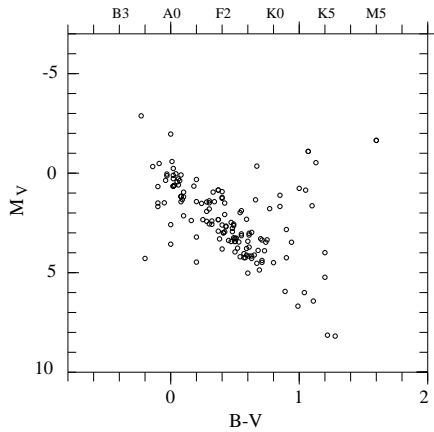


Fig. 4 HR diagram of the binaries measured in Table 1, for which Hipparcos parallaxes were obtained with a relative error smaller than 50% (i.e., 146 objects).

rived 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). 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 $\langle\sigma_\rho\rangle = 0''.019 \pm 0''.015$ and $\langle\sigma_\theta\rangle = 0^\circ.6 \pm 1^\circ.5$ for the angular separation ρ and the position angle θ , respectively.

3.1 Comparison between PISCO and Gaia relative astrometry

The second release of Gaia measurements (ESA, 2018) has provided astrometric measurements of some of our measured pairs at 2015.5, close to the date of the observations. We have thus been able to compare the measurements of 110 pairs observed by PISCO (from Table 1) with the corresponding entries in Gaia DR2.

The mean errors and standard deviations for ρ and θ are $-0''.0051 \pm 0.05$ and $-0^\circ.53 \pm 1^\circ.26$, respectively. The plots in ρ and θ do not show any deviation from

Table 2 Gaia versus PISCO relative astrometry: objects with the largest differences, i.e., $\Delta\rho > 0''.1$ or $\Delta\theta > 4^\circ$.

HIP (A comp.)	Name	PISCO		Gaia-DR2	
		ρ (")	θ ($^\circ$)	ρ (")	θ ($^\circ$)
HIP1670	BU 1093	0.752	117.6	0.745	121.5
HIP15482	HU 1056	1.200	77.7	1.079	79.6
HIP31345	STF 932	1.580	300.8	1.653	305.2
HIP54040	A 1590	1.415	332.9	1.467	328.4
HIP56601	STF1555	0.740	148.6	0.612	155.8
HIP59816	STF1621	1.520	44.6	1.666	45.6
HIP60579	STF1643	2.889	4.7	2.753	4.2
HIP63503	BU 1082	0.889	116.5	0.849	121.3

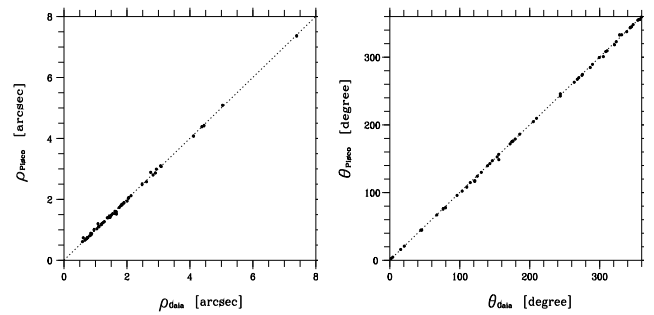


Fig. 5 Comparison between PISCO and Gaia relative astrometry.

linearity between PISCO and Gaia (Figs. 5). The agreement between PISCO and Gaia-DR2 relative astrometry is therefore very good in general.

However, there are some cases with significant discrepancies in ρ and θ , that are reported in Table 2, with differences in ρ and θ measurements as large as $0''.1$ and 4° , respectively. Such differences may be due to the fact that there was not any dedicated data-reduction program for measuring close binaries in DR2. This should come later with the future releases of Gaia measurements. In the mean time, it seems that ground-based speckle observations remain the most reliable source of information for close binary relative astrometry.

Note also that the parallaxes for the two components of STF 1126 = ADS 6263 are different (A = $4.96 \text{ mas} \pm 0.22$, B = $2.33 \text{ mas} \pm 0.37$), which is puzzling since the orbital motion of this pair is well established by the observations.

3.2 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 159 out of 196 measurements, i.e. 81% of the total. They are marked with an asterisk in Col 9. When our quadrant determination procedure failed, the angular measurement was reverted to the quadrant reported in the WDS catalog, which is extracted from the Fourth Catalog of Interferometric Measurements of Binary Stars (Hartkopf et al. 2018, hereafter IC4).

Our “absolute” θ values are consistent with the values tabulated in WDS for all objects except for ADS 3353. This determination was clear from our observations, since we directly saw the companion in the first quadrant (North-East). We already found such a result in March 2012 with PISCO (Paper XIII). The origin of this discrepancy may be due to the small difference of magnitude $\Delta m_V = 0.15$ between the two components, and the fact that our observations were made in R , whereas the other observers used a B filter. Moreover, a different spectral type of the two components could also account for a quadrant inversion.

3.3 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 6276 we also report the residuals obtained with our revised orbit presented in Sect. 4.

The residuals are plotted in Fig. 6. They have a rather large scatter which is naturally explained by the (old) age of many orbits that will need revision in the future. The mean values computed with the residuals of Table 1 are $\langle \Delta \rho_{O-C} \rangle = 0''.007 \pm 0''.05$ and $\langle \Delta \theta_{O-C} \rangle = -0''.2 \pm 1''.7$. The small values obtained for those offsets provide a good validation of our calibration (see Paper XII).

3.4 Rectilinear elements of ADS 4841

As shown in Fig. 6, large residuals have been found for ADS 4841 (BU 1008 – eta Gem) for our two observations made in 2015, when using the orbit of Baize (1980). We have investigated this problem, and

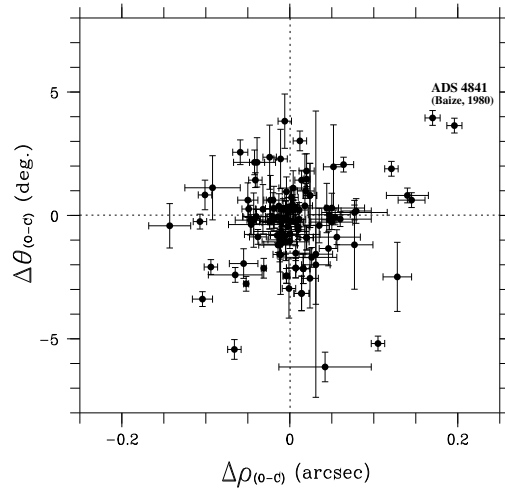


Fig. 6 Residuals of the measurements of Table 1 computed with the published orbits.

tried to improve this orbit. When examining the trajectory of the companion from the 105 observations made since 1881, it appears that the companion is moving along a straight line relative to the primary star, within the error bars (see Fig. 7). This linear trajectory seems to indicate that the two components are not gravitationally linked, which may also be corroborated by the large brightness difference of $\Delta m_V = 2.6$ between the two components. We hope that the future parallax measurements by Gaia will allow to answer to this question. In the meantime, we have computed a rectilinear trajectory that well accounts for the observations (see Table 4 of the residuals with Julian epochs since 2004). Following the WDS convention, we fitted the relative Cartesian coordinates (X, Y) of the companion with the model:

$$X = XA * (T - T0) + X0$$

$$Y = YA * (T - T0) + Y0$$

where T is the epoch, and $(X0, Y0, T0)$ is the relative location and epoch of closest approach. We used Julian epochs for this fit. The corresponding rectilinear elements are given in Table 3, where we also report the polar coordinates $(RHO0, THETA0)$ corresponding to that closest approach, i.e.,

$$X0 = -\sin(THETA0) * RHO0$$

$$Y0 = \cos(THETA0) * RHO0$$

The ephemerides of ADS 4841 for 2018–2028 are presented in Table 6.

Table 5 New orbital elements of DUN 5, ADS 5958, 6276, 7294, 8211 and 13169.

Name	Ω_{2000} ($^{\circ}$)	ω ($^{\circ}$)	i ($^{\circ}$)	e	T (yr)	P (yr)	n ($^{\circ}/\text{yr}$)	a ($''$)	A ($''$)	B ($''$)	F ($''$)	G ($''$)
DUN 5	16.50	24.90	139.6	0.499	1811.9	493.3	0.7297	7.98	7.66684	-0.39754	-1.65596	-6.23944
ADS 5958	93.30 ± 0.75	124.7 ± 6.1	109.5 ± 0.7	0.520 ± 0.008	2015.27 ± 0.94	289.2 $\pm 17.$	1.2447 ± 0.074	1.366 ± 0.026	0.41902	-0.75477	-0.19450	-1.13613
ADS 6276	60.70	105.60	180.0	0.792	1956.64	174.0	2.0689	0.334	0.23659	-0.23576	-0.23576	-0.23659
ADS 7294	60.20	203.7	139.9	0.664	1943.74	820.2	0.4389	0.905	-0.65329	-0.58081	-0.36927	0.63068
ADS 8211	11.50	95.6	55.6	0.487	1871.40	373.7	0.9635	0.645	-0.13398	0.34284	-0.62195	-0.16282
ADS 13169	107.50	251.3	12.5	0.379	1924.46	220.8	1.6301	0.410	0.40113	-0.01135	0.00561	0.40897

Table 6 New ephemerides of DUN 5, ADS 4841, 5958, 6276, 7294 and 13169.

Epoch	DUN 5		ADS 4841		ADS 5958		ADS 6276		ADS 7294		ADS 8211		ADS 13169	
	ρ ($''$)	θ ($^{\circ}$)	ρ ($''$)	θ ($^{\circ}$)	ρ ($''$)	θ ($^{\circ}$)	ρ ($''$)	θ ($^{\circ}$)	ρ ($''$)	θ ($^{\circ}$)	ρ ($''$)	θ ($^{\circ}$)	ρ ($''$)	θ ($^{\circ}$)
2018.0	11.593	186.3	1.855	256.6	0.508	290.5	0.563	145.6	0.607	96.5	0.540	264.1	0.547	164.6
2019.0	11.599	186.0	1.862	256.5	0.541	288.0	0.565	145.2	0.614	95.9	0.540	264.7	0.547	165.5
2020.0	11.604	185.8	1.870	256.3	0.572	285.9	0.568	144.7	0.620	95.4	0.539	265.4	0.548	166.3
2021.0	11.609	185.6	1.878	256.2	0.602	284.0	0.571	144.3	0.627	94.9	0.539	266.1	0.549	167.1
2022.0	11.613	185.4	1.886	256.0	0.630	282.2	0.573	143.9	0.634	94.3	0.539	266.8	0.550	167.9
2023.0	11.617	185.1	1.894	255.9	0.656	280.6	0.575	143.4	0.640	93.8	0.539	267.5	0.550	168.7
2024.0	11.621	184.9	1.901	255.7	0.680	279.1	0.578	143.0	0.647	93.3	0.538	268.1	0.551	169.6
2025.0	11.624	184.7	1.909	255.6	0.703	277.8	0.580	142.6	0.653	92.9	0.538	268.8	0.552	170.4
2026.0	11.627	184.5	1.917	255.5	0.723	276.5	0.582	142.2	0.660	92.4	0.538	269.5	0.552	171.2
2027.0	11.630	184.3	1.925	255.3	0.742	275.2	0.584	141.8	0.666	91.9	0.538	270.2	0.552	172.0
2028.0	11.632	184.0	1.933	255.2	0.759	274.1	0.585	141.3	0.672	91.5	0.538	270.9	0.553	172.8

Table 3 New rectilinear elements of ADS 4841.

$X0 = -0.7054200 \pm 0.0229$	$XA = -0.0064235 \pm 0.0002$
$Y0 = -0.6916823 \pm 0.0184$	$YA = +0.0065519 \pm 0.0002$
$RO0 = 0''.988$	$TETA0 = 314^{\circ}.44$
	$T0 = 1846.926$

4 Revised orbits of DUN 5, ADS 5958, 6276, 7294, 8211 and 13169

In this section we present the new revised orbits that we have computed for DUN 5, ADS 5958, 6276, 7294, 8211 and 13169. Those objects belong to our list of regularly monitored couples with PISCO in the Northern hemisphere and by one of us (Ary) in the Southern hemisphere. 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.

We have followed the same method for computing the orbits of those six objects. Using our last measurements with PISCO and the other available ob-

Table 4 ADS 4841: O-C residuals with our new rectilinear elements (after 2004). The symbol P indicates PISCO measurements.

Epoch	$\Delta\rho$ (O-C) ($''$)	$\Delta\theta$ (O-C) ($^{\circ}$)	Observer
2004.240	0.016	-0.3 P	Sca
2005.110	-0.053	-1.5 P	Sca
2006.127	-0.113	-2.3	Orl
2008.242	0.007	-1.0 P	Pru
2012.018	-0.138	1.9	Ary
2015.210	-0.031	-0.8 P	Sca
2015.212	-0.057	-0.5 P	Sca
2016.112	0.007	-0.4	Wss

servations contained in the data base maintained by the United States Naval Observatory (USNO), we first 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

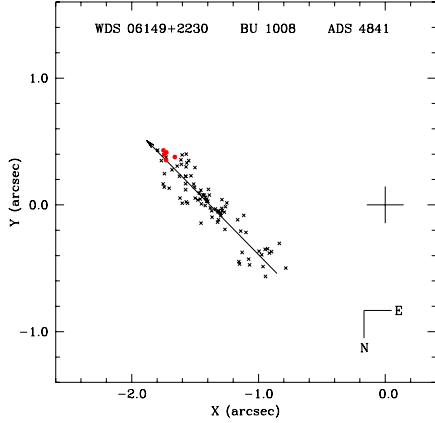


Fig. 7 ADS 4841: relative motion of the companion and plot of our new rectilinear trajectory. The observations by PISCO are plotted as filled circles that appear in red in the electronic version of this paper.

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 5, with the periastron passage T (Col. 6) in Julian epoch. The errors reported in this table for ADS 5958 were obtained by Hellerich’s least-squares method. For the other objects, Hellerich’s method did not converge, which is a good indicator that the overall quality of the data does not allow computing reliable error values. Although other methods (Gauss-Newton or Levenberg-Maquard for instance) always provide error values, our long-term experience has shown that those values were not reliable when the quality of the data was not good enough for Hellerich’s method to converge. We thus prefer not publishing the errors when the orbits have been not yet sufficiently monitored.

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 ephemerides for 2018–2028 are presented in Table 6. The apparent orbits are shown in Fig. 8 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 dashed straight line going through this point is the line of apsides. An arrow shows the sense of rotation of the companion.

The ($O - C$) residuals of the new orbits, restricted to the last observations for reasons of space, are given in Tables 7, 8, 9, 10, 11, 12 for DUN 5, ADS 5958,

Table 7 DUN 5: O-C residuals of our new orbit (after 2009).

Epoch	$\Delta\rho$ (O-C) ($''$)	$\Delta\theta$ (O-C) ($^\circ$)	Observer
2009.710	0.050	-0.2	Ant
2009.714	0.070	-0.2	Ant
2010.636	0.012	-0.4	Ary
2013.672	-0.184	-0.0	Ary
2013.710	-0.174	-0.0	Ant
2016.697	-0.135	-0.4	Ary

Table 8 ADS 5958: O-C residuals of our new orbit (after 2006). The symbol P indicates PISCO measurements.

Epoch	$\Delta\rho$ (O-C) ($''$)	$\Delta\theta$ (O-C) ($^\circ$)	Observer
2006.269	0.003	0.7 P	Pru
2008.202	-0.005	2.1 P	Pru
2009.265	-0.000	-0.7	Tok
2009.267	-0.007	0.3 P	Sca
2014.201	0.011	0.1 P	Sca
2016.266	-0.000	0.8 P	Sca
2016.268	0.001	0.7 P	Sca
2018.133	0.005	-1.9 P	Sca

6276, 7294, 8211 and 13169, respectively. The name of the observer is reported in the last column, using the US Naval Observatory convention. The “Epoch” in the first column is the Julian epoch of the observations.

In Table 13, 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), the revised values from van Leeuwen (2007), or the Gaia values (ESA, 2018) when available, as indicated in Col. 10. In Cols. 8 and 9, we give the corresponding linear size of the semi-major axis a and the total mass $\mathcal{M}_{\text{total}}$, respectively, that were computed from our orbital elements and the Hipparcos/Gaia parallaxes.

WDS 01398-5612 – DUN 5 – HIP 7751 (p Eri)

This couple was discovered by James Dunlop, in December 1825, with the 4.6-inch (12 cm) refractor of the Parramatta Observatory in Sydney (Australia). The first measurements were very rough and published in Dunlop (1829). This couple is made of two well separated stars of similar spectral type K2 V and visual magnitudes 5.78 and 5.90, which are very close to the sun, at distance of 26.7 light years only ($\pi_{\text{Gaia}} = 122$ mas). Since that epoch, the companion has cov-

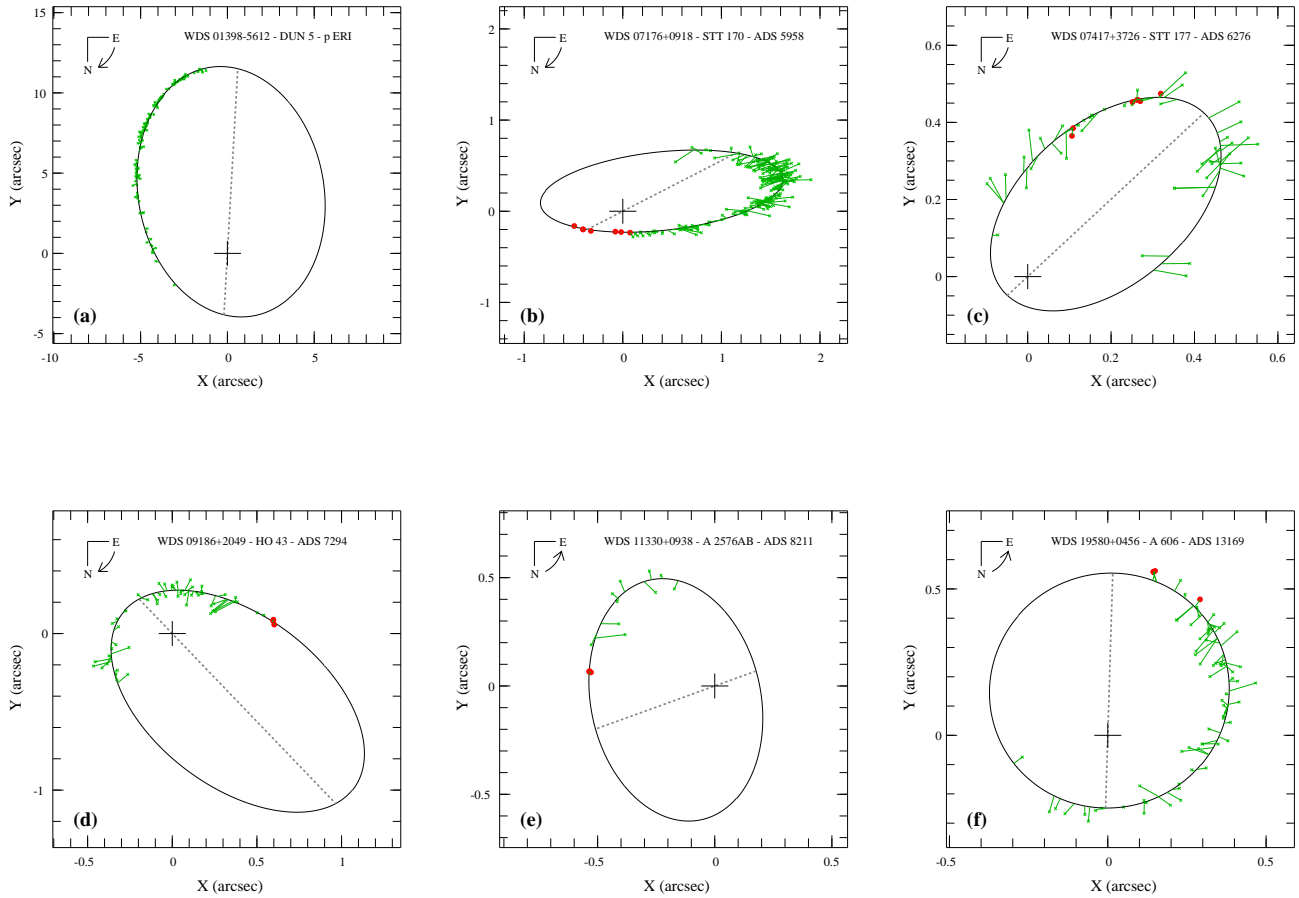


Fig. 8 New orbits of DUN 5 (a), ADS 5958 (b), ADS 6276 (c), ADS 7294 (d), ADS 8211 (e) and ADS 13169 (f). The observations by PISCO are plotted as filled circles that appear in red in the electronic version of this paper.

Table 9 ADS 6276: O-C residuals of our new orbit (after 2007). The symbol P indicates PISCO measurements.

Epoch	$\Delta\rho$ (O-C) (")	$\Delta\theta$ (O-C) ($^\circ$)	Observer
2007.192	-0.007	0.2 P	Pru
2007.802	-0.016	0.3	Hrt
2008.101	0.023	1.2	Gii
2009.267	-0.005	0.5 P	Sca
2014.245	-0.022	2.7 P	Sca
2015.272	-0.025	2.5 P	Sca
2018.147	0.009	0.5 P	Sca

Table 10 ADS 7294: O-C residuals of our new orbit (after 1991). The symbol P indicates PISCO measurements.

Epoch	$\Delta\rho$ (O-C) (")	$\Delta\theta$ (O-C) ($^\circ$)	Observer
1991.250	0.011	-0.0	HIP
1991.271	0.017	3.9	Gii
2004.196	0.006	-0.8	Hrt
2008.098	0.014	-0.4	Gii
2016.293	0.008	1.0 P	Sca
2016.296	0.005	0.4 P	Sca
2018.346	-0.004	-0.8 P	Sca

ered an arc of orbit of about 141° , and will reach its apastron in the next few years (see Fig. 8.a). In the last century, good quality measurements were made by using photographic observations with long focal length telescopes located in Southern Africa (Johannesburg) and in Indonesia (Bosscha Observatory, Lembang). After the end of those programs, only a few micrometric measurements have been made by one of us (R. Argyle)

with the 67-cm Innes refractor, in Johannesburg, and by R. Anton with CCD imaging and amateur instruments in Namibia. Five orbits have been published up to now, with the last one by Van Albada (1957).

We have taken profit of more than 60 years of additional observations to compute the new orbital elements presented in Table 5, and first published in

Table 13 Physical parameters (π_{dyn} , a and $\mathfrak{M}_{\text{total}}$) derived from the new orbital elements.

Name	HIP	m_V	Δm_V	Spectral type	π_{dyn} (mas)	$\pi_{\text{HIP/GAIA}}$ (mas)	a (AU)	$\mathfrak{M}_{\text{total}}$ (M_{\odot})	Source of $\pi_{\text{HIP/GAIA}}$
DUN 5	7751	5.07	0.1	K2V+K2V	110.7	122.13 ± 0.05	65.3 $\pm 0.03^{(1)}$	1.15 $\pm 0.01^{(1)}$	GAIA, ESA (2018)
"	"	"	"	"	"	127.84 ± 2.19	62.4 $\pm 1.1^{(1)}$	1.00 $\pm 0.05^{(1)}$	HIP, van Leeuwen (2007)
ADS 5958	35310	6.77	0.3	G0 V	24.2	22.85 ± 1.79	59.8 ± 4.8	2.6 ± 0.7	HIP, ESA (1997)
"	"	"	"	"	"	24.03 ± 1.04	56.8 ± 2.7	2.2 ± 0.4	HIP, van Leeuwen (2007)
ADS 6276	37483	7.63	1.2	A3 V	7.4	7.25 ± 1.4	46.1 $\pm 8.9^{(1)}$	3.2 $\pm 1.8^{(1)}$	GAIA, ESA (2018)
"	"	"	"	"	"	5.96 ± 1.34	56.0 $\pm 12.6^{(1)}$	5.8 $\pm 3.9^{(1)}$	HIP, van Leeuwen (2007)
ADS 7294	45671	8.64	0.1	F5 V	7.6	8.05 ± 2.45	112.4 $\pm 34.2^{(1)}$	2.1 $\pm 1.9^{(1)}$	HIP, ESA (1997)
"	"	"	"	"	"	9.25 ± 1.27	97.8 $\pm 13.4^{(1)}$	1.4 $\pm 0.6^{(1)}$	HIP, van Leeuwen (2007)
ADS 8211	–	9.47	0.1	G5 V	10.2	–	63.0	1.9	Not available.
ADS 13169	98272	8.70	0.1	G3V+G4V	8.4	5.63 ± 0.99	72.8 $\pm 12.8^{(1)}$	7.9 $\pm 4.2^{(1)}$	GAIA, ESA (2018)
"	"	"	"	"	"	7.53 ± 1.88	54.4 $\pm 13.6^{(1)}$	3.3 $\pm 2.5^{(1)}$	HIP, van Leeuwen (2007)

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

Table 11 ADS 8211: O-C residuals of our new orbit (after 1980). The symbol P indicates PISCO measurements.

Epoch	$\Delta\rho$ (O-C) ($''$)	$\Delta\theta$ (O-C) ($^{\circ}$)	Observer
1980.200	−0.066	−4.5	Hei
1988.180	0.001	5.7	Hei
1991.610	−0.107	−8.4	TYC
2016.340	−0.001	0.1 P	Sca
2016.342	−0.002	−0.2 P	Sca
2018.346	−0.008	−1.1 P	Sca

Table 12 ADS 13169: O-C residuals of our new orbit (after 1998). The symbol P indicates PISCO measurements.

Epoch	$\Delta\rho$ (O-C) ($''$)	$\Delta\theta$ (O-C) ($^{\circ}$)	Observer
1998.679	0.031	0.1 P	Sca
1999.504	−0.068	2.6	Lin
1999.504	−0.068	2.3	Pri
2003.784	0.013	0.7	WSI
2008.767	0.042	−0.3	Tok
2016.718	0.032	2.0 P	Sca
2016.729	0.031	1.9 P	Sca
2018.375	0.034	0.1 P	Sca

the IAU Information Circulars (Scardia et al., 2015b), without any detail of their computation, though. If we except the photographic long focal length measurements, the overall quality of the measurements is poor. In particular, the angular separation measurements are very scattered. Our fit of the 165 available measurements lead to an average rms error of $0''.1$ and $0^{\circ}.8$ for ρ and θ , respectively. The sum of the masses of the system that is obtained with Hipparcos or Gaia parallaxes, is of the order of one solar mass (see Table 13), which is slightly smaller than the expected theoretical value of $2 \times 0.79 M_{\odot}$ for two K2V stars according to Straizys & Kuriliene (1981). The dynamical parallax that is computed with our formula (Scardia, 2008b) is 111 mas, which is slightly smaller than Hipparcos and Gaia’s values, and leads to a larger systemic mass of $1.58 M_{\odot}$, which corresponds to the theoretical value.

Our elements are much more accurate than Van Albada (1957)’s elements, but they must still be considered as “provisional”, according to the standards commonly used for orbit calculation.

WDS 07176+0918 – STT 170 – ADS 5958 – HIP 35310

This couple was discovered by O Struve with the 38-cm Merz-Mahler Poulkova refractor, during his survey aimed at founding new double stars (August 1841 – December 1842) (Struve, 1843). The first measurement was made in Dorpat by J.H. Mahler with the famous 25-cm refractor built by Fraunhofer (Mahler, 1844). This couple has been regularly observed since, but the overall quality in angular separation is poor. Six orbits have been published for this couple, including

our orbit of Scardia et al (2016). Since the companion has moved recently through the periastron, we decided to take profit of the last PISCO observations made after the periastron passage to improve this orbit. Our fit of the 241 available measurements lead to average residuals of $0''.101$ and $1^\circ.47$ for ρ and θ , respectively. As shown in Table 13, the dynamical parallax π_{dyn} obtained with our formula (Scardia, 2008b) is close to the Hipparcos values and the systemic mass $\mathfrak{M}_{\text{total}}$ is in good agreement with the theoretical expected value of $2.1 M_\odot$ of Straizys & Kuriliene (1981).

WDS 07417+3726 – STT 177 – ADS 6276 – HIP 37483

This couple was also discovered by O Struve with the 38-cm Merz-Mahler Poulkova refractor, during his 1841–1842 survey (Struve, 1843). The first measurement was made in Dorpat by J.H. Mahler with the 25-cm Fraunhofer refractor (Mahler, 1844). This couple has been regularly observed since, but the quality of the measurements made before 1950 is poor. Four orbits have been published until now. The last one, computed by Heintz (1982), begins to show systematic errors on the position angle residuals.

We have computed a new orbit for this couple that was first published in the IAU Information Circulars (Scardia et al., 2016). The recent observation made with PISCO with the 1-m Epsilon telescope of OCA (Obs. de la Côte d’Azur, France) confirm our elements. Our fit of the 54 available measurements lead to average residuals of $0''.05$ and $2^\circ.70$ for ρ and θ , respectively.

The Hipparcos parallax is 5.96 mas according to Van Leeuwen (2007), and the Gaia value is 7.25 mas (ESA, 2018). Those two values lead to a systemic mass $\mathfrak{M}_{\text{total}}$ of $5.8 M_\odot$ and $3.2 M_\odot$, respectively (see Table 13). The latter value is in a fair agreement with the theory ($4.0 M_\odot$ according to Straizys & Kuriliene, 1981). The dynamical parallax π_{dyn} obtained with our formula (Scardia, 2008b) is in very good agreement with the Gaia parallax measurement (see Table 13).

WDS 09186+2049 – HO 43 – ADS 7294 – HIP 45671

This couple was discovered in April 1862 by G.W. Hough with the 47-cm refractor of Dearborn Observatory (Illinois, USA). It is one of the first binaries that have been discovered by this famous observer. In the original publication of his first discoveries (Hough, 1887), this object was reported as “A close and difficult pair”. This double star was then regularly observed but the measurements are rather scattered, both for the angular separation and for the position angle, especially at the beginning of the XXth century. The companion has covered an arc of about 210° in the orbit, and the periastron passage occurred around 1945. Five orbits have been yet published, and the last one by Baize (1989) does not account any longer for the observations: its period is much too short. We computed

a revised version of this orbit using our usual procedure (see above), and published it in the IAU Circular Information (Scardia et al., 2016), without any detail of that computation. Our fit of the 58 measurements lead to mean residuals of $0''.05$ and $3^\circ.1$ for ρ and θ , respectively. The recent observations made with PISCO at Calern have confirmed this orbit (see Table 10). For estimating the total mass and the semi-major axis in AU, we have only used the Hipparcos parallax measurements since the Gaia-DR2 does not include a value for the parallax. The mass value obtained with the Hipparcos parallax from ESA (1997) is $2.1 M_\odot$, is closer to the theoretical value than what is obtained with van Leeuwen (2007). The dynamical parallax computed with our formula (Scardia et al., 2008b) is 7.6 mas. It is close to the ESA (1997) value and leads to a total “dynamical” mass of $2.63 M_\odot$, also in good agreement with the theoretical value of $2.4 M_\odot$ that is expected for a F5 V stellar system (Straizys & Kuriliene, 1981).

WDS 11330+0938 – A 2576 AB – ADS 8211

This couple was discovered by R.G Aitken with the 91-cm refractor of Lick Observatory in May 1913 (Aitken, 1913). It belongs to a wide stellar system of 4 stars that are likely to be gravitationally linked. The CD couple of that system is made of two faint stars ($m_V = 12.0$ and $m_V = 13.0$) which is reported as J 428 CD in the WDS. The couple A2576 AB has been poorly observed since its discovery and forgotten for many years. Only more than a dozen of observations have been published as a whole, and no orbit has been computed yet. We observed A2576 AB with PISCO and the Epsilon telescope at Calern in 2016 after a gap in the observations of more than 25 years. Until now, the companion has been monitored over an arc of orbit of about 60° , and has been moving towards the apastron (see Fig. 8.f). The available data set is therefore sufficient to determine the first preliminary orbit for A 2576 AB. In 2016, we computed an orbit that was published in the IAU Information Circular (Scardia et al., 2016). The elements have been obtained with the method of Kowalsky (1870), which is based on the selection of the best orbital elements that generate an apparent ellipse that well match the plot of the actual measurements. The fit of the 13 available measurements lead to mean residuals of $0''.04$ and $3^\circ.3$ for ρ and θ , respectively. We have not found any trigonometric parallax in the literature for this object, neither from Hipparcos, Gaia nor in the Yale Trigonometric Parallaxes Catalog (Van Altena et al., 1995). The dynamical parallax of 10.2 mas reported in Table 13 was obtained using our formula of (Scardia et al, 2008b), with a spectral type of G5 V, a total visual magnitude of 9.47, and a difference of magnitudes of 0.08. The total dynamical mass would then be $1.85 M_\odot$ which is in fair agreement with the expected value of $2.1 M_\odot$ by the theory (Straizys & Kuriliene, 1981).

WDS 19580+0456 – A 606 AB – ADS 13169 – HIP 98272

This couple was also discovered by R.G. Aitken with the 91-cm refractor of Lick Observatory, in June 1903 (Aitken, 1904). It has been then regularly monitored by the observers. More than five orbits have been published yet. The last one, by Zaera (1982) is now outdated, and does not account for the observations any longer. We observed this object with PISCO and the Epsilon telescope of Calern in Sept. 2016 and computed a new orbit that was published in the IAU Information Circular (Scardia et al., 2016). That observation clearly showed that the companion was in the 2nd quadrant (i.e., South-East), whereas most observations reported in the IC4 are generally in the 4th quadrant (i.e. North-West). The few exceptions with a location in the 2nd quadrant are the Hipparcos observation of 1991 and our observation made with PISCO in 1998 (Scardia et al., 2000). The origin of this problem may be due to the small brightness difference of the two components, and a possible switch of the two components between the blue and red part of the spectrum (our observations were made with a red filter, whereas the other observers used a blue or green filter). For our orbit, we took the quadrant convention of the Hipparcos observation, and swapped all the other measurements, when needed. The new orbital elements that we obtained from the 71 available measurements are given in Table 5. They lead to mean residuals of $0''.04$ and $2^\circ.5$ for ρ and θ , respectively. The total mass inferred from those elements with the Gaia preliminary parallax of 5.6 mas (ESA, 2018) is $7.9 M_\odot$, which is in excess for a G3V+G4V couple whereas the Hipparcos value of 7.5 mas leads to $3.3 M_\odot$, which is closer to the theoretical value of $2.1 M_\odot$ (Straizys & Kuriliene, 1981). The dynamic parallax obtained with our formula (Scardia et al., 2008), is 8.4 mas and the dynamical mass is $2.5 M_\odot$, which is fair agreement with the theory. Note that this orbit must be considered as "provisional", and the elements are expected to change in the future.

5 Conclusion

We have presented here the 196 new measurements of 173 visual binaries that we have obtained with PISCO in 2015. The average accuracy was $0''.019$ for the angular separation and $0^\circ.6$ for the position angles.

We also presented new orbital elements computed for DUN 5, ADS 5958, 6276, 7294, 8211, and 13169, 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 the Hipparcos and Gaia values, when available. We also computed new rectilinear elements for ADS 4841 for

which the physical connection is doubtful from our (and other recent) observations.

The total number of measurements made with PISCO in Merate since its installation in 2003 now exceeds 3700. 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. This paper is the last of this series, since the observations with PISCO in Merate have stopped in June 2015. This instrument was moved to the Epsilon telescope of OCA in Calern (France) in July 2015, and since then we have been continuing our binary star program from there.

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