The Astronomical Journal, 156:240 (10pp), 2018 November https://doi.org/10.3847/1538-3881/aae484

Speckle Interferometry at the U.S. Naval Observatory. XXIII.

Brian D. Mason, William I. Hartkopf[1], Sean E. Urban[1], and Jordan D. Josties[2]
U.S. Naval Observatory 3450 Massachusetts Avenue, NW, Washington, DC 20392-5420, USA; brian.d.mason@navy.mil
Received 2018 August 22; revised 2018 September 21; accepted 2018 September 21; published 2018 November 1

Abstract

The results of 3989 intensified CCD observations of double stars, made with the 26-inch refractor of the U.S. Naval Observatory, are presented. Each observation of a system represents a combination of over 2000 short-exposure images. These observations are averaged into 1911 mean relative positions and range in separation from 0.″289 to 128.″638, with a median separation of 8.″669. Four orbits are improved. This is the 23rd in this series of papers and covers the period 2017 January 4 through 2017 September 13.

Key words: binaries: general – binaries: visual – techniques: interferometric

Supporting material: machine-readable tables

1. Introduction

This is the 23rd in a series of papers from the U.S. Naval Observatory's speckle interferometry program, presenting results of observations obtained at the USNO 26 inch telescope in Washington, DC (see, most recently, Mason & Hartkopf 2017a).

From January 4 through 2017 September 13, the 26-inch telescope was used on 60 of 184 (33%) scheduled nights. While most nights were lost due to weather conditions, time was also lost due to testing and upgrades of instrumentation and software, other mechanical or software issues, and a lack of observing personnel. Instrumentation and the observing technique were as described in Mason & Hartkopf (2017a). Observing was suspended in mid-September when upgrades to the motors and encoders began. After initial success in automation seen in this and recent previous entries of this series, a more ambitious automation project was initiated in September. This will be described in greater detail in the next entry in this series.

Individual nightly totals varied substantially, from 7 to 146 observations per night (mean 66.5). The results yielded 3989 observations (pointings of the telescope) and 3862 resolutions. After removing marginal observations, calibration data, tests, and "questionable measures" a total of 3333 measurements remained. These "questionable measures" are not all of inferior quality but may represent significant differences from the last measure, often made many decades ago. Before these measures are published, they will need to be confirmed in a new observing season to account for any possible pointing or other identification problems. The tabulated list of these is retained internally and forms a "high-priority observing list" for subsequent observing seasons. These 3333 measures were grouped into 1911 mean relative positions.

2. Results

Our 2017 observing list remained the same as the previous, discussed in Mason & Hartkopf (2017a). On a given night, a pair may be observed multiple times in different data collection modes and with different magnification as it is not always obvious which will produce the best result. Further, as object acquisition is the most time-consuming portion of the duty cycle, adding additional observations is less consequential. For those intranightly observations ($n = 832$), the rms values are quite low: $d\theta = 0.^{\circ}10$ and $\frac{d\rho}{\rho} = 0.0020$. A smaller number ($n = 262$) comprise those objects which appear to be slow moving[3] and were observed on multiple nights. For those internightly observations, the rms values are twice the intranightly values: $d\theta = 0.^{\circ}14$ and $\frac{d\rho}{\rho} = 0.0044$. We take these values as representative of the true error.

2.1. New Pair

Table 1 presents coordinates and magnitude information from CDS[4] for a pair that is presented here for the first time. It is a closer component to a known system. Column one gives the coordinates of the primary of the pair. Column two is the WDS identifier while Column three is the discoverer designation associated with the known pair, which is used here for the new component as well. Columns four and five give the visual magnitudes of the primary and secondary, and Column six notes the circumstance of the discovery. The mean double-star positions of our 26″ measures (T, θ, and ρ) of this system is given in Table 3.

As this pair is quite wide, we are able to provide two additional measures of relative astrometry from other catalogs using the same methodology as described in Wycoff et al. (2006) and Hartkopf et al. (2013). In Table 2, the first two columns identify the system by providing its epoch-2000 coordinates and discovery designation (as given in Table 1). Columns three through five give the epoch of observation (expressed as a fractional Julian year), the position angle (in degrees), and the separation (in seconds of arc). Note that in all tables, the position angle, measured from north through east, has not been corrected for precession and is thus based on the equinox for the epoch of observation.[5] Columns six and seven

[1] Retired.
[2] SEAP Intern.

[3] We assume $\Delta\theta = \Delta\rho = 0$ for these.
[4] Magnitude information is from one of the catalogs queried in the *Aladin Sky Atlas*, operated at CDS, Strasbourg, France. See http://aladin.u-strasbg.fr/aladin.gml.
[5] This has been the standard for double-star relative astrometry for several hundred years and is in accordance with IAU Resolutions from the Commissions governing double stars, most recently, Mason et al. (2016). See Section 4.1.1.

Table 1
New Pairs

Coordinates α, δ (2000)	WDS Designation	Discoverer Designation	Magnitudes		Note
			Primary	Secondary	
05 22 45.12 + 53 32 09.6	05228 + 5332	HJ 2258 AC	9.59	14.0	1

Note. 1: AB is the historically known pair. This is a closer pair.

Table 2
Data Mining Measures for New Pairs

WDS Desig. α, δ (2000)	Discovery Designation	JY	θ (°)	ρ (″)	Source	Reference or Note
05228 + 5332	HJ 2258 AC	1998.94	56.0	8.03	2MASS	1
		2003.053	56.1	8.310	UCAC4	Zacharias et al. (2013)

Note. 1: Cutri et al. (2003), All-sky Release. See `Vizier On-line Data Catalog: II/246`.

Table 3
ICCD Measurements of Double Stars

WDS Desig. α, δ (2000)	Discoverer Designation	JY	θ (∘)	$\sigma\theta$ (∘)	ρ (″)	$\sigma\rho$ (″)	n	Note
01201+3639	WEI 3 AB	2017.011	188.2	0.1	4.858	0.021	1	
01204+0937	GWP 171 AB	2017.011	214.0	0.1	46.474	0.204	1	
01223−0019	BAL 648	2017.012	259.4	0.1	9.307	0.041	1	
01241−1244	GAL 308	2017.012	17.1	0.1	24.729	0.109	1	
01251+0304	HDO 50 A,BC	2017.012	261.6	0.1	34.096	0.150	1	
01282+3441	HO 8 AB	2017.011	253.4	0.1	4.284	0.019	1	
01286+1440	ARN 88	2017.011	254.1	0.1	23.642	0.104	1	
01296+3025	ROE 105	2017.011	0.8	0.1	5.223	0.023	1	
01303+1239	STF 129	2017.011	283.2	0.1	8.861	0.039	1	
01320+1150	OCC 391 AB,C	2017.011	123.0	0.1	7.843	0.035	1	

Note.
A: First measure of this pair. See Tables 1 and 2. C: Confirming observation. $N = 63$–125: Number of years since last measure. V: Measure made by vector addition of other measured pairs in this multiple system.

(This table is available in its entirety in machine-readable form.)

provide the source of the measure and either a reference or note to the source.

2.2. Measures of Known Pairs

Tables 3 and 4 present the relative measurements of double stars made with the 26″ telescope. Table 3 presents those with no calculation for motion, either orbital or linear. As in Table 1, the first two columns identify the system by providing its epoch-2000 coordinates and discovery designation. Columns three and four give the epoch of observation (expressed as a fractional Julian year) and the position angle (in degrees). Column five gives the position angle error. This is the internightly rms value if one is available or the mean value of 0°.1 if it is not. Columns six and seven provide the separation (in seconds of arc) and its error. As above, the error is its internightly value or the mean error ($d\rho = 0.0044\rho$). Column eight is the number of nights in the mean position. When this is "1" the errors in Columns five and seven are the mean results as described above. Finally, Column nine is reserved for notes. One of the pairs listed in Table 3 is the pair listed in Tables 1 and 2, which has not been measured before. Five pairs, designated with a "C" code, are confirmed here for the first time. Eight very wide pairings, designated with a "V" code, in multiple systems have their positions determined from vector addition. Two pairs have not been measured in over fifty years. Those are WDS 10536−0742 = J 90BC, last measured in 1954 (Harshaw 2013) and WDS 17128+2433 = POU3264, last measured in 1892 (Pourteau 1933).

The 1726 measures presented in Table 3 have a mean separation of 13″.874 and a median value of 9″.156. The mean number of years since the pair was last observed is 7.05.

Table 4 presents measurements of doubles where some prediction of position (orbital or linear) is available. The first eight columns are the same as Table 3 above. Columns nine and ten provide the $O - C$ residual to the determination referenced in Column eleven. The final column, like that of Table 3, provides notes. In some cases, a measure has residuals to more than one calculation. In some of those cases, the second calculation refers to a new orbit (Table 5) or linear solution (Table 6), which is described below.

Not surprisingly, the objects in Table 4 are both closer and more frequently observed than those of Table 3. The 185 measures presented in Table 4 have a mean separation of 11″.507 and a median value of 4″.158. The mean number of years since the pair was last observed is 2.88.

Table 4
ICCD Measurements of Double Stars with Orbit and Linear Residuals

WDS Desig. α, δ (2000)	Discoverer Designation	JY	θ (°)	$\sigma\theta$ (°)	ρ (″)	$\sigma\rho$ (″)	n	$O-C_\theta$ (°)	$O-C_\rho$ (″)	Reference	Note
01399+1515	STF 142 AB	2017.011	68.6	0.1	23.188	0.102	1	0.6	0.082	Hartkopf & Mason (2017)	
02589+2137	BU 525	2016.860	274.6	0.2	0.530	0.003	5	−0.3	−0.013	Roberts & Mason (2018)	
02589+2137	BU 525	2017.129	274.9	0.8	0.504	0.003	2	0.0	−0.039	Roberts & Mason (2018)	
02589+2137	BU 525	2017.678	275.3	0.1	0.524	0.002	1	0.4	−0.019	Roberts & Mason (2018)	
03313−0542	HLD 65	2017.012	28.9	0.1	5.798	0.026	1	0.5	0.075	Table 6	A
04312+5858	STI 2051 AB	2017.129	58.7	0.1	10.306	0.045	1	0.9	−0.063	Hartkopf & Mason (2017)	
05239−0052	WNC 2 A,BC	2017.157	159.4	0.1	3.101	0.014	1	1.1	−0.015	Rica Romero (2013)	
05247+6323	STF 677 AB	2017.121	114.1	0.1	1.110	0.005	1	2.8	−0.041	Hartkopf & Mason (2008)	
05313−1834	B 2588	2017.137	307.8	0.1	19.366	0.085	1	0.5	0.063	Table 6	A
05328+8324	STF 629	2017.129	31.7	0.1	22.031	0.097	1	2.1	−0.147	Hartkopf & Mason (2017)	
05341+6940	STF 704	2017.129	32.2	0.1	12.958	0.057	1	1.1	−0.191	Hartkopf & Mason (2017)	
05364+2200	STF 742	2017.012	275.3	0.1	4.095	0.018	1	−0.5	−0.055	Hopmann (1973)	
06344+1445	STF 932	2017.187	304.9	0.1	1.630	0.007	1	5.3	0.010	Hopmann (1960)	
06386+4020	FRK 6 AB	2017.176	280.6	0.1	49.027	0.216	1	0.5	0.076	Hartkopf & Mason (2017)	
06386+4020	FRK 6 AC	2017.176	71.3	0.1	64.515	0.284	1	0.7	−0.361	Hartkopf & Mason (2017)	
06462+5927	STF 948 AB	2017.121	67.4	0.1	1.876	0.008	1	1.5	−0.031	Mason et al. (2006)	
06482+5542	STF 958 AB	2017.130	257.1	0.1	4.475	0.020	1	0.7	0.024	Kiselev et al. (2009)	
07002+4259	STF 996 AC	2017.195	294.5	0.1	15.315	0.075	2	0.5	−0.088	Hartkopf & Mason (2017)	
07057+5245	STF 1009 AB	2017.168	148.7	0.1	4.331	0.019	1	1.0	−0.024	Hartkopf & Mason (2017)	
07128+5548	STF 1025 AB	2017.168	129.7	0.1	26.806	0.118	1	0.8	−0.054	Hartkopf & Mason (2017)	
07309+2441	HJ 424 AB	2017.223	114.3	0.1	16.460	0.072	1	1.1	0.000	Hartkopf & Mason (2017)	
07377−1330	J 2840	2017.222	277.4	0.1	8.388	0.037	1	−0.3	0.043	Table 6	A
07546−0248	STF 1157	2017.138	171.3	0.1	0.647	0.003	1	−3.5	−0.037	Ling (2010)	
08095+3213	STF 1187 AB	2017.203	21.4	0.1	3.028	0.013	1	1.6	0.064	Olevic & Jovanovic (2001)	
08122+1739	STF 1196 AB,C	2017.121	64.5	0.1	5.911	0.026	1	−0.8	−0.019	Boule et al. (2017)	
08165+7930	STF 1169 AB	2017.121	16.1	0.1	20.770	0.091	1	−0.3	0.267	Kiselev et al. (2009)	
08211+4725	STT 190 AD	2017.176	288.1	0.1	78.359	0.345	1	0.7	−0.026	Table 6	A
08324−0056	HJ 96 AC	2017.184	138.1	0.1	75.034	0.330	1	0.6	−0.051	Hartkopf & Mason (2017)	
08369+2315	AG 154	2017.184	3.2	0.1	2.665	0.012	1	2.4	−0.012	Hartkopf & Mason (2011b)	
08554+7048	STF 1280 AB	2017.121	357.2	0.1	3.256	0.014	1	0.0	0.033	Heintz (1997)	
09013+1516	STF 1300 AB	2017.100	179.4	0.1	5.032	0.022	1	0.7	0.006	Zirm (2008)	
09079−0708	STF 1316 AC	2017.223	280.4	0.1	8.119	0.036	1	0.5	0.084	Hartkopf & Mason (2017)	
09144+5241	STF 1321 AB	2017.130	99.0	0.1	17.078	0.075	1	0.5	0.252	Chang (1972)	
09157−0114	STF 1329 AB	2017.223	266.2	0.1	8.164	0.036	1	0.6	0.026	Hartkopf & Mason (2017)	
09179+2834	STF 3121 AB	2017.223	205.1	0.1	0.487	0.002	1	2.7	−0.004	Söderhjelm (1999)	
09186+2049	HO 43	2017.223	97.6	0.1	0.609	0.003	1	1.4	−0.010	Tokovinin (2016a)	
09210+3811	STF 1338 AB	2017.203	312.1	0.1	1.095	0.005	1	−4.8	0.093	Scardia et al. (2002)	
								−0.6	−0.038	Table 5	B
09273+0614	STF 1355	2017.223	355.5	0.1	1.776	0.008	1	0.3	−0.006	Ling (2011)	
09524+2659	STF 1389	2017.203	289.6	0.1	2.441	0.011	1	−0.2	−0.068	Ling (2016)	
10110+7508	KUI 47	2017.122	123.3	0.1	1.913	0.008	1	−2.2	0.036	Heintz (1994)	
10163+1744	STT 215	2017.100	176.8	0.1	1.487	0.007	1	−1.3	−0.082	Zaera (1984)	
10200+1950	STF 1424 AB	2017.100	127.0	0.1	4.736	0.021	1	0.6	0.018	Romanenko & Kiselev (2014)	
10217−0946	BU 25	2017.272	129.8	0.1	1.500	0.007	1	0.4	−0.060	Zirm & Rica (2012)	
10387+0544	STF 1457	2017.223	334.7	0.1	1.847	0.008	1	1.0	0.004	Riddle et al. (2015)	
10596+2527	AG 342	2017.277	116.1	0.1	5.290	0.023	1	0.8	0.036	Kiselev et al. (1997)	
11000−0328	STF 1500	2017.232	299.8	0.1	1.299	0.014	2	0.2	−0.022	Hartkopf & Harshaw (2013a)	
11035+5432	A 1590	2017.181	327.6	0.1	1.458	0.002	5	−3.4	−0.051	Baize (1985)	
								−0.6	−0.008	Table 5	B
11080+5249	STF 1510	2017.199	328.4	0.1	5.580	0.002	2	0.3	0.099	Kiselev et al. (2012)	
11170−0708	BU 600 AC	2017.276	99.3	0.0	53.215	0.011	2	0.3	0.088	Hartkopf & Mason (2017)	
11268+0301	STF 1540 AB	2017.159	150.1	0.0	28.255	0.020	2	3.3	−0.357	Hopmann (1960)	
11317+1422	STF 1547 AB	2017.185	332.0	0.1	15.528	0.068	1	0.0	0.174	Hartkopf & Mason (2013)	
11368−1221	BU 456	2017.242	163.1	0.1	1.170	0.005	1	1.2	−0.005	Prieur et al. (2012)	
11387+4507	STF 1561 AB	2017.236	246.8	0.1	8.946	0.022	2	1.0	0.084	Hale (1994)	
11520+4805	HU 731	2017.294	307.4	0.1	1.184	0.016	2	−0.2	−0.013	Hartkopf & Mason (2008)	
12023+7222	STF 1588	2017.196	34.2	0.1	11.738	0.052	1	0.8	0.050	Hartkopf & Mason (2017)	
12095−1151	STF 1604 AB	2017.272	88.8	0.1	7.529	0.033	1	0.5	−1.464	Hartkopf & Mason (2017)	V
12095−1151	STF 1604 AC	2017.272	3.9	0.1	10.511	0.046	1	0.5	0.033	Hartkopf & Mason (2017)	
12095−1151	STF 1604 BC	2017.272	321.4	0.1	13.214	0.058	1	0.7	0.055	Hartkopf & Mason (2017)	
12114−1647	S 634	2017.276	301.7	0.1	4.668	0.015	2	1.0	0.034	Hartkopf & Mason (2017)	
12115+5325	STF 1608 AB	2017.223	221.1	0.0	13.556	0.008	2	0.5	0.027	Hartkopf & Mason (2017)	
12116+3605	STF 1607 AB	2017.195	28.1	0.1	26.965	0.119	1	0.7	−0.010	Hartkopf & Mason (2017)	

Table 4
(Continued)

WDS Desig. α, δ (2000)	Discoverer Designation	JY	θ (°)	$\sigma\theta$ (°)	ρ ($''$)	$\sigma\rho$ ($''$)	n	$O - C_\theta$ (°)	$O - C_\rho$ ($''$)	Reference	Note
12151−0715	STF 1619 AB	2017.320	266.2	0.1	6.840	0.002	2	0.5	0.015	Rica et al. (2017)	
12160+0538	STF 1621	2017.289	47.7	0.1	1.706	0.013	2	1.5	−0.005	Söderhjelm (1999)	
12202−1408	STF 1631	2017.272	305.3	0.1	14.782	0.065	1	2.0	0.051	Hartkopf & Mason (2017)	
12272+2701	STF 1643 AB	2017.322	4.3	0.2	2.758	0.014	2	1.0	0.033	Olevic & Cvetkovic (2003)	
12281+4448	STF 1645	2017.338	157.6	0.1	9.702	0.043	1	0.6	−0.007	Hartkopf & Mason (2017)	
12306+0943	STF 1647	2017.319	249.5	0.1	1.276	0.006	1	−2.7	0.038	Hopmann (1970)	
12357−1201	STF 1659 AC	2017.351	70.8	0.1	43.305	0.191	1	1.1	0.066	Hartkopf & Mason (2017)	
12454+1422	STF 1678	2017.319	170.0	0.1	37.655	0.166	1	0.6	0.037	Hartkopf & Mason (2017)	
12564−0057	STT 256	2017.351	103.2	0.1	1.056	0.005	1	2.4	−0.013	Zirm (2015)	C
								2.6	−0.029	Hartkopf & Mason (2017)	C
13120+3205	STT 261	2017.417	339.0	0.1	2.637	0.012	1	0.6	0.040	Kiselev et al. (2012)	
13235+2914	HO 260	2017.346	89.4	0.1	1.598	0.007	1	1.4	−0.062	Zirm (2013)	
13284+1543	STT 266	2017.319	358.3	0.1	1.981	0.009	1	0.4	−0.016	Hartkopf & Mason (2011b)	
13343−0019	STF 1757 AB	2017.373	141.7	0.1	1.640	0.007	1	0.3	−0.072	Heintz (1988)	
13550−0804	STF 1788 AB	2017.371	101.5	0.1	3.698	0.016	1	1.0	0.099	Hopmann (1970)	
13577+5200	A 1614	2017.417	299.8	0.1	1.414	0.006	1	0.5	0.017	Riddle et al. (2015)	
14024+4620	SWI 1	2017.346	25.6	0.1	3.801	0.017	1	−0.6	0.193	Seymour et al. (2002)	
14131+5520	STF 1820	2017.346	123.0	0.1	2.736	0.012	1	−0.3	0.068	Kiyaeva et al. (1998)	
14135+5147	STF 1821 AB	2017.346	236.1	0.1	13.671	0.060	1	0.8	−0.126	Kiyaeva (2006)	
14160−0704	HU 138	2017.444	37.5	0.1	0.573	0.003	1	3.6	−0.040	Docobo & Costa (1990)	
14161+5643	STF 1830 EF	2017.421	312.9	0.0	10.509	0.001	2	0.5	0.066	Hartkopf & Mason (2017)	
14165+2007	STF 1825	2017.346	153.0	0.1	4.435	0.020	1	0.1	0.004	Kiyaeva et al. (2017)	
14195−1343	BU 116	2017.444	274.9	0.1	4.051	0.018	1	0.6	0.020	Hartkopf & Mason (2017)	
14307+8308	LDS 1800	2017.422	226.2	0.6	1.596	0.015	2	37.9	−0.009	Hartkopf & Mason (2017)	
								8.7	0.069	Cvetkovic et al. (2015)	
14336+3535	STF 1858 AB	2017.423	38.5	0.1	3.049	0.013	1	0.6	0.018	Zirm (2015)	
14380+5135	STF 1863	2017.431	59.9	0.0	0.654	0.001	2	0.2	0.005	Zirm (2013)	
14485−1720	BU 346	2017.444	277.4	0.1	2.684	0.012	1	−0.1	−0.057	Hartkopf & Mason (2017)	
14538−0024	STTA 131 AB	2017.431	216.0	0.1	82.781	0.364	1	0.5	−0.196	Hartkopf & Mason (2017)	
15055−0701	BU 119 AB	2017.442	274.6	0.0	2.284	0.004	2	0.4	−0.028	Kiyaeva et al. (2017)	
15174+4348	STF 1934 AB	2017.436	13.4	0.1	9.833	0.043	1	0.6	−0.019	Hartkopf & Mason (2017)	
15206+1523	HU 1160	2017.445	181.0	0.1	0.454	0.002	1	5.6	−0.060	Hartkopf & Mason (2009)	
15210+2104	HU 146	2017.371	123.2	0.1	0.678	0.003	1	−0.1	−0.045	Zirm (2015)	
15246+5413	HU 149	2017.431	271.7	0.1	0.665	0.002	2	1.2	0.012	Zirm (2015)	
15280+1442	STF 1945 AB	2017.359	313.7	0.0	41.575	0.008	2	0.4	−0.011	Hartkopf & Mason (2017)	
15280+1442	STF 1945 AC	2017.359	308.0	0.0	49.498	0.014	2	0.3	0.039	Hartkopf & Mason (2017)	
15320−1123	*OSO 65*	2017.491	20.3	0.1	18.367	0.081	1	0.4	−0.062	Table 6	A
15348+1032	STF 1954 AB	2017.346	172.5	0.1	4.019	0.018	1	0.7	0.049	Mason et al. (2004a)	
15382+3615	STF 1964 CD	2017.491	21.1	0.1	1.557	0.007	1	1.3	0.051	Drummond et al. (1995)	
15405+1840	A 2076	2017.431	187.5	0.1	0.724	0.003	1	1.7	−0.009	Zirm (2014)	
15413+5959	STF 1969	2017.423	29.9	0.1	1.061	0.005	1	0.8	−0.016	Riddle et al. (2015)	
15517−0559	A 21 AB	2017.431	292.5	0.1	0.507	0.002	1	14.0	0.030	Hartkopf & Mason (2017)	
								12.7	0.017	Rica Romero & Zirm (2012)	
15598+1723	STF 1993 AB	2017.374	43.3	0.1	20.179	0.089	1	0.5	0.128	Hartkopf & Mason (2017)	
16009+1316	STT 303 AB	2017.346	174.6	0.1	1.587	0.007	1	0.8	−0.014	Zirm (2015)	
16060+1319	STF 2007 AB	2017.259	322.3	0.1	38.557	0.170	1	0.5	0.152	Hartkopf & Mason (2017)	
16081+1703	STF 2010 AB	2017.259	13.9	0.1	27.004	0.119	1	0.1	−0.030	Hartkopf & Mason (2017)	
16147+3352	STF 2032 AB	2017.259	239.2	0.1	7.267	0.032	1	0.6	0.049	Raghavan et al. (2009)	
16160+0721	STF 2026 AB	2017.515	17.0	0.1	3.562	0.013	2	0.2	0.022	Scardia et al. (2011)	
16489+1949	BRT 2425	2017.494	317.8	0.1	4.418	0.019	1	0.7	0.050	Hartkopf & Mason (2017)	
17033+5935	STF 2128	2017.423	43.3	0.1	12.194	0.054	1	−2.4	0.063	Kiselev et al. (2009)	
17121+2114	STF 2135 AB	2017.460	194.6	0.1	8.681	0.016	2	0.3	0.041	Hartkopf & Mason (2017)	
17146+1423	STF 2140 AB	2017.478	103.8	0.0	4.831	0.024	2	1.0	0.189	Baize (1978)	
17386+5546	STF 2199	2017.548	54.3	0.1	2.061	0.009	1	2.3	0.124	Popovic & Pavlovic (1995)	
17400−0038	BU 631	2017.445	88.1	0.1	0.289	0.001	1	10.0	−0.028	Heintz (1996)	
17471+1742	STF 2215	2017.606	249.8	0.1	0.410	0.002	1	3.7	−0.033	Cvetkovic & Novakovic (2006)	
17506+0714	STT 337	2017.606	164.2	0.1	0.586	0.003	1	0.3	−0.003	Docobo & Ling (2015)	
17520+1520	STT 338 AB	2017.565	163.7	0.1	0.810	0.004	1	0.3	−0.020	Prieur et al. (2012)	
17571+0004	STF 2244	2017.606	101.0	0.1	0.641	0.003	1	1.0	−0.027	Josties & Mason (2017)	
18002+8000	STF 2308 AB	2017.674	232.2	0.1	18.669	0.082	1	0.3	−0.130	Kiselev & Romanenko (1996)	C
								0.4	−0.128	Hartkopf & Mason (2017)	C
18029+5626	STF 2278 AC	2017.538	38.6	0.1	33.592	0.148	1	0.4	0.150	Hartkopf & Mason (2017)	
18031−0811	STF 2262 AB	2017.601	289.5	0.1	1.454	0.003	2	1.3	−0.058	Söderhjelm (1999)	

Table 4
(Continued)

WDS Desig. α, δ (2000)	Discoverer Designation	JY	θ (°)	σθ (°)	ρ (″)	σρ (″)	n	$O-C_\theta$ (°)	$O-C_\rho$ (″)	Reference	Note
18055+0230	STF 2272 AB	2017.579	124.4	0.2	6.524	0.007	3	0.8	0.050	Eggenberger et al. (2008)	
18101+1629	STF 2289	2017.606	218.8	0.1	1.215	0.005	1	3.4	−0.027	Hopmann (1964)	
18112−1951	BU 132 AB	2017.560	188.0	0.1	1.375	0.003	3	1.2	−0.030	Hartkopf & Mason (2011b)	
18130+4251	ES 47 BC	2017.565	173.3	0.1	22.390	0.099	1	0.3	−0.212	Table 6	A
18222−1505	STF 2306 AB	2017.538	222.1	0.1	9.124	0.040	1	0.2	−0.046	Hartkopf & Mason (2017)	
18250−0135	AC 11	2017.679	354.2	0.8	0.826	0.011	3	−0.6	−0.082	Tokovinin (2017)	
18253+4846	HU 66 BC	2017.674	27.0	0.1	0.771	0.003	1	1.5	−0.115	Novakovic (2008)	
18355+2104	STF 2345	2017.549	225.4	0.1	12.254	0.054	1	0.4	0.035	Hartkopf & Mason (2017)	
18359+1659	STT 358 AB	2017.668	148.1	0.3	1.584	0.012	4	3.1	0.092	Heintz (1995)	
								0.8	−0.059	Table 5	B
18360+1144	STT 357	2017.691	86.3	0.1	0.464	0.002	1	16.4	0.095	Scardia et al. (2011)	
18443+3940	STF 2382 AB	2017.680	345.8	0.1	2.258	0.007	2	0.6	−0.067	Mason et al. (2004b)	
								0.7	−0.021	Novakovic & Todorovic (2006)	
18443+3940	STF 2383 CD	2017.675	76.0	0.1	2.336	0.009	2	1.3	−0.056	Docobo & Costa (1984)	
18488−1836	KUI 88	2017.606	152.5	0.1	0.463	0.002	1	−1.9	−0.054	Hartkopf & Harshaw (2013b)	
19019+1910	STF 2437	2017.617	8.2	0.1	0.519	0.002	1	3.9	−0.042	Scardia et al. (2008)	
19022+0845	STF 2436 AB	2017.617	315.4	0.1	30.148	0.133	1	0.5	0.061	Hartkopf & Mason (2017)	
19027−0043	STF 2434 A,BC	2017.617	89.0	0.1	27.649	0.122	1	0.3	−0.022	Hartkopf & Mason (2017)	
19058+3831	STF 2456 AB	2017.565	340.9	0.1	17.468	0.077	1	0.6	0.070	Hartkopf & Mason (2017)	
19121+4951	STF 2486 AB	2017.674	204.6	0.1	7.135	0.031	1	0.7	−0.059	Hale (1994)	
19126+1651	BU 139 AB	2017.617	136.1	0.1	0.597	0.003	1	0.0	0.003	Zirm (2013)	
19143+1904	STF 2484	2017.617	241.7	0.1	2.109	0.009	1	1.7	−0.149	Hopmann (1973)	
19346+1808	STT 375	2017.606	188.7	0.1	0.592	0.003	1	0.4	−0.008	Zirm (2015)	
19370+6350	STF 2564	2017.374	146.3	0.1	9.193	0.040	1	0.3	−0.023	Hartkopf & Mason (2017)	
19418+5032	STFA 46 AB	2017.674	133.6	0.1	39.829	0.175	1	0.1	0.057	Hauser & Marcy (1999)	
19520−1021	BU 148 AB	2017.702	222.6	0.1	0.619	0.003	1	5.3	0.060	Ling (2004)	
19553−0644	STF 2597 AB	2017.606	100.8	0.1	0.647	0.003	1	0.8	−0.061	Hartkopf et al. (1996)	
19585+3317	STF 2606 AB	2017.677	146.2	0.0	0.658	0.008	2	−0.8	0.000	Zirm (2015)	
20014+1045	STF 2613 AB	2017.691	355.7	0.1	3.522	0.015	1	3.7	−0.621	Hopmann (1973)	
20020+2456	STT 395	2017.685	127.5	0.1	0.730	0.003	1	0.6	−0.120	Zirm (2013)	
20099+2055	STF 2637 AC	2017.702	221.9	0.1	91.250	0.401	1	0.5	−0.019	Hartkopf & Mason (2017)	
20099+2055	STF 2637 BC	2017.702	215.4	0.1	95.687	0.421	1	0.2	−0.098	Hartkopf & Mason (2017)	
20213+0250	HLD 158	2017.579	42.0	0.1	1.204	0.005	1	−0.0	−0.002	Mason & Hartkopf (2017b)	
20387+3838	STF 2708 AB	2017.684	323.3	0.0	57.662	0.002	2	0.3	0.116	Hartkopf & Mason (2017)	
20396+4035	STT 410 AB	2017.677	3.3	0.4	0.880	0.009	2	−0.3	0.009	Hartkopf & Mason (2011a)	
20462+1554	STF 2725 AB	2017.691	12.1	0.1	6.185	0.027	1	0.3	0.031	Mason & Hartkopf (2014)	
20467+1607	STF 2727 AB	2017.693	265.8	0.0	8.915	0.004	4	0.9	−0.006	Hale (1994)	
20524+2008	HO 144	2017.617	345.9	0.1	0.408	0.002	1	−1.5	0.046	Ling (2012)	
								−2.9	−0.018	Table 5	B
21031+0132	STF 2744 AB	2017.681	109.0	0.2	1.182	0.007	4	6.6	−0.010	Popovic (1969)	
21069+3845	STF 2758 AB	2017.684	153.3	0.0	31.699	0.026	2	1.1	−0.010	Gorshanov et al. (2006)	
21124−1500	H 1 47	2017.617	309.4	0.1	4.221	0.019	1	0.7	0.031	Hartkopf & Mason (2017)	
21141+5818	STF 2783	2017.702	351.9	0.1	0.658	0.003	1	0.8	−0.007	Zirm (2014)	
21200+5259	STF 2789 AB	2017.696	114.8	0.0	6.860	0.012	2	0.9	−0.044	Kiselev et al. (2009)	
21495+0324	STF 2828 AB	2017.617	140.9	0.1	33.652	0.148	1	0.6	0.065	Hartkopf & Mason (2017)	
21495+0324	STF 2828 AC	2017.617	135.0	0.1	33.132	0.146	1	0.5	0.077	Hartkopf & Mason (2017)	
21520+5548	STF 2840 AB	2017.696	196.6	0.0	17.687	0.005	3	0.7	0.005	Hartkopf & Mason (2017)	
21582+8252	STF 2873 AB	2017.694	66.4	0.1	13.792	0.061	1	0.5	0.052	Grosheva (2006)	
22033+6051	STF 2860 AB	2017.702	257.6	0.1	13.313	0.059	1	0.6	0.024	Hartkopf & Mason (2017)	
22038+6438	STF 2863 AB	2017.680	275.1	0.0	8.080	0.007	2	1.6	−0.350	Zeller (1965)	
22086+5917	STF 2872 BC	2017.677	296.7	0.0	0.827	0.008	2	0.0	0.027	Seymour et al. (2002)	
22128+6829	HJ 1747 AB	2017.702	86.1	0.1	12.900	0.057	1	0.5	−0.151	Hartkopf & Mason (2017)	
22143+1711	STF 2877 AB	2017.655	24.6	0.0	23.910	0.005	3	0.5	0.050	Hartkopf & Mason (2017)	
22207+2457	STF 2895 AB	2017.617	48.7	0.1	14.005	0.062	1	0.5	0.026	Hartkopf & Mason (2017)	
22266−1645	SHJ 345 AB	2017.672	78.5	0.2	1.126	0.008	2	5.1	−0.169	Hale (1994)	
22288−0001	STF 2909 AB	2017.691	162.3	0.1	2.299	0.003	4	4.6	0.067	Tokovinin (2016b)	
22326+0725	STF 2915 AB	2017.692	125.3	0.1	15.227	0.009	2	0.7	0.031	Hartkopf & Mason (2017)	
22490+6834	STF 2947 AB	2017.698	55.7	0.0	4.714	0.006	3	0.4	0.021	Hartkopf & Mason (2017)	
22514+2623	HO 482 AB	2017.702	15.2	0.1	0.539	0.002	1	0.5	−0.025	Prieur et al. (2014)	
23077+0636	STF 2976 AC	2017.691	209.5	0.1	21.393	0.094	1	0.6	0.073	Hartkopf & Mason (2017)	
23212+3526	STF 3006 AB	2017.617	151.8	0.1	7.330	0.032	1	0.7	0.015	Hartkopf & Mason (2017)	
23228+2034	STF 3007 AB	2017.691	92.2	0.1	5.857	0.026	1	−2.5	0.036	Tokovinin & Horch (2016)	
23238−0828	STF 3008	2017.694	147.8	0.1	7.013	0.031	1	0.8	0.079	Hartkopf & Mason (2017)	

Table 4
(Continued)

WDS Desig. α, δ (2000)	Discoverer Designation	JY	θ (∘)	$\sigma\theta$ (∘)	ρ ($''$)	$\sigma\rho$ ($''$)	n	$O-C_\theta$ (∘)	$O-C_\rho$ ($''$)	Reference	Note
23241+5732	STT 495	2017.702	122.1	0.1	0.401	0.002	1	−0.2	0.008	Alzner (2006)	
23340+3120	BU 720	2017.688	105.8	0.3	0.552	0.004	4	0.1	−0.024	Muterspaugh et al. (2010)	
23487+6453	STT 507 AB	2017.687	322.6	0.5	0.724	0.009	2	3.6	0.018	Zulevic (1977)	
23536+5131	STTA 251 AB	2017.690	208.8	0.0	48.056	0.017	2	0.6	0.058	Hartkopf & Mason (2017)	
23595+3343	STF 3050 AB	2017.687	341.5	0.0	2.463	0.005	2	0.4	0.032	Hartkopf & Mason (2011b)	

Note. A: New linear solution. See Tables 6, 7, Figure 2, and Section 2.4. B: New orbit solution. See Tables 5, 7, Figure 1, and Section 2.3. C: It is unclear if the pair is physical or not. An orbit and common proper motion indicates that it is; however, it appears to be equally well fit by a linear determination. V: Measure made by vector addition of other measured pairs in this multiple system.

(This table is available in machine-readable form.)

Table 5
Improved Orbital Elements

WDS Desig. α, δ (2000)	Discoverer Designation	P (years)	a ($''$)	i (°)	Ω (°)	T_0 (years)	e	ω (°)	Reference	Gr
				Improved but still Provisional Orbital Elements						
18359 + 1659	STT 358 AB	444.6	1.770	127.1	233.4	1754.7	0.575	256.6	Heintz (1995)	4
20524 + 2008	HO 144	2085.7	1.508	89.1	169.6	2071.5	0.730	209.0	Ling (2012)	5
				Reliable Orbital Elements						
09210 + 3811	STF 1338 AB	424.2	1.568	28.4	178.2	1992.2	0.255	94.8	Scardia et al. (2002)	4
			±6.9	±0.016	±1.5	±2.5	±1.8	±0.009	±4.9	
11035 + 5432	A 1590	183.7	0.8950	149.9	110.	1915.68	0.7538	313.6	Baize (1985)	5
			±8.9	±0.0350	±10.0	±10.	±2.13	±0.0220	±9.8	

Table 6
New Linear Elements

WDS Desig. α, δ (2000) (1)	Discoverer Designation (2)	x_0 ($''$) (3)	a_x ($''$ yr^{-1}) (4)	y_0 ($''$) (5)	a_y ($''$ yr^{-1}) (6)	T_0 (years) (7)	ρ_0 ($''$) (8)	θ_0 (deg) (9)
03313−0542	HLD 65	−1.387066	0.018936	−3.307647	−0.007941	1799.833	3.587	337.25
05313−1834	B 2588	−4.232138	−0.078973	3.165629	−0.105579	1876.193	5.285	233.20
07377−1330	J 2840	−5.459991	−0.043010	−4.515467	0.052006	1951.682	7.085	309.59
08211+4725	STT 190 AD	−76.353394	0.015329	−15.976615	−0.073260	1914.322	78.007	281.82
15320−1123	OSO 65	2.068836	0.385139	−17.819626	0.044714	2006.111	17.939	6.62
18130+4251	ES 473 BC	4.403793	−0.009231	0.332003	01224365	1836.467	4.416	94.31

2.3. *Improved Orbits*

Four systems with sufficient data to improve their orbits are presented in Table 5 and Figure 1. All of the individual measures were weighted by the procedures of Hartkopf et al. (2001) and calculated with the venerable "grid-search" method of Hartkopf et al. (1989).

Table 5 is broken into two groups. The first orbit we characterize as "improved but still provisional" and is given without errors. They fit the data better than the earlier orbit and should give reasonable ephemerides over the next several decades, but the elements will all require correction over the course of a complete orbit before they can be considered even approximately correct. As in earlier tables, the first two columns identify the system by providing its epoch-2000 coordinates and discovery designation. Columns three through nine provide the seven Campbell elements: the period (P in years), the semimajor axis (a'' in arcseconds), the inclination (i) and longitude of the node (Ω), both in degrees, the epoch of the most recent periastron passage (T_o in years), the eccentricity (e), and the longitude of periastron (ω in degrees). Column ten gives the reference to the previous "best" orbit and Column eleven the orbital "grade" following the procedures of Hartkopf et al. (2001).

In the second part of Table 5 are the two orbits we characterize as "reliable", all with shorter periods than those in the first group. All eleven columns are the same as the first part of the table; however, here under each element is its formal error. The precision of the element is defined by the precision of its error. Relative visual orbits of all four systems are plotted in Figure 1, with the x and y axes indicating the

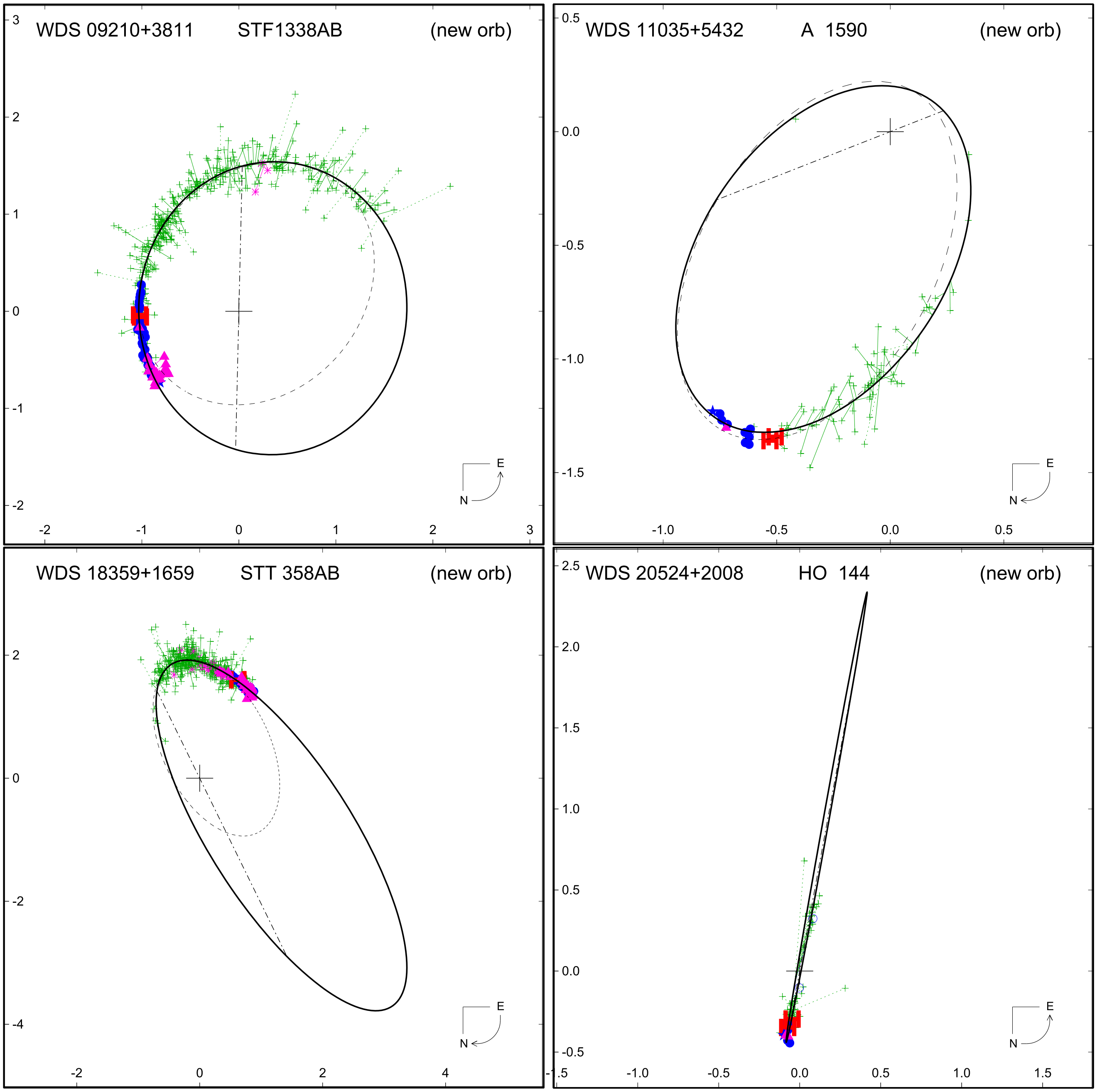

Figure 1. Figure 1 illustrates the new orbital solutions, plotted together with all published data in the WDS database as well as the new data in Table 4. In each of these figures, micrometric observations are indicated by plus signs, interferometric measures by filled circles, conventional CCD by pink triangles, space-based measures are indicated by the letter "H", new measure from Table 4 are plotted as a filled star. "$O - C$" lines connect each measure to its predicted position along the new orbit (shown as a thick solid line). Dashed "$O - C$" lines indicate measures given zero weight in the final solution. A dotted–dashed line indicates the line of nodes, and a curved arrow in the lower right corner of each figure indicates the direction of orbital motion. The earlier orbit referenced in Table 5 is shown as a dashed ellipse.

scale in arcseconds. Each solid curve represents the newly determined orbital elements presented in Table 5 and the dashed curve is the orbit of the earlier orbit referenced in Column ten.

2.4. New Linear Solutions

Inspection of all observed pairs with either a 30° change in their relative position angles or a 30% change in separations since the first observation cataloged in the WDS revealed six pairs whose motion seemed linear. These apparent linear relative motions suggest that these pairs are either composed of physically unrelated stars or have very long orbital periods. Linear elements to these doubles are given in Table 6, where Columns one and two give the WDS and discoverer designations and Columns three to nine list the seven linear elements: x_0 (zero point in x, in arcseconds), a_x (slope in x, in $'' \, yr^{-1}$), y_0 (zero point in y, in arcseconds), a_y (slope in y, in $'' \, yr^{-1}$), T_0 (time of closest apparent separation, in years), ρ_0 (closest apparent separation, in arcseconds), and θ_0 (position angle at T_0, in degrees). See Hartkopf & Mason (2017) for a description of all terms.

Figure 2 illustrates these new linear solutions, plotted together with all published data in the WDS database, as well

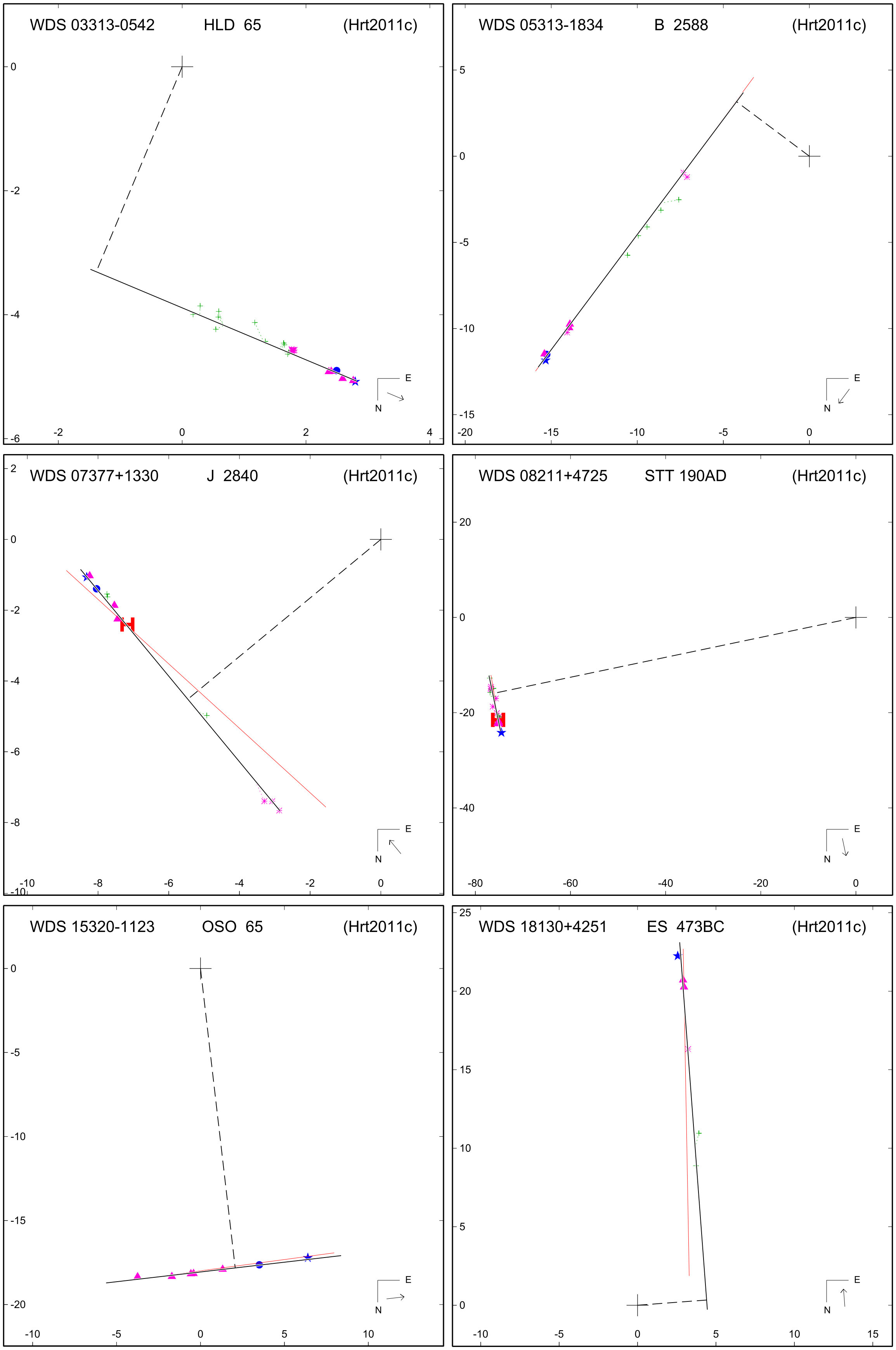

Figure 2. New linear fits for the systems listed in Table 6 and all data in the WDS database and Table 4. Symbols are the same as Figure 1. "$O - C$" lines connect each measure to its predicted position along the linear solution (shown as a thick solid line). An arrow in the lower right corner of each figure indicates the direction of motion. The scale, in arcseconds, is indicated on the left and bottom of each plot. When determined, cataloged proper motion differences between these components is plotted as a red line.

Table 7
Ephemerides for New Solutions

WDS Desig. α, δ (2000)	Discoverer Designation	2018.0		2020.0		2022.0		2024.0		2026.0	
		θ (°)	ρ (″)	θ (°)	ρ (″)	θ (°)	ρ (″)	θ (°)	ρ (″)	θ (°)	ρ (″)
03313−0542	HLD 65	28.6	5.739	28.8	5.771	29.1	5.803	29.3	5.835	29.6	5.868
05313−1834	B 2588	307.4	19.43	307.6	19.68	307.8	19.94	308.0	20.19	308.2	20.45
07377+1330	J 2840	277.3	8.380	276.5	8.453	275.8	8.528	275.0	8.604	274.3	8.681
08211+4725	STT 190 AD	287.5	78.39	287.6	78.41	287.7	78.42	287.8	78.44	287.9	78.45
09210+3811	STF 1338 AB	313.8	1.139	316.5	1.153	319.1	1.167	321.7	1.182	324.2	1.197
11035+5432	A 1590	327.8	1.465	327.0	1.463	326.2	1.459	325.3	1.455	324.5	1.449
15320−1123	*OSO* 65	21.0	18.52	23.3	18.73	25.6	18.97	27.8	19.23	29.9	19.53
18130+4251	ES 473 BC	173.1	22.72	173.2	22.96	173.3	23.21	173.5	23.45	173.6	23.69
18359+1659	STT 358 AB	147.1	1.642	146.2	1.637	145.2	1.632	144.3	1.627	143.3	2.622
20524+2008	HO 144	348.8	0.427	348.8	0.431	348.9	0.434	348.9	0.437	349.0	0.440

Table 8
Double Stars Not Found

WDS Desig. α, δ (2000)	Discoverer Designation	Most Recent Published Observation				Published Magnitudes		Notes
		Date (°)	θ (″)	ρ	Reference	Primary	Secondary	
06216−2002	HDO 82 AB	1869	180	12.0	Winlock & Pickering (1882)	9.0	11.0	1
14362−0636	BRT 455	1911	87	4.0	Barton (1931)	10.9	11.0	2

Note.
1: Triple system. While AC has six measures, AB has never been confirmed. The direction of the component is only approximately given as "south". Maybe the proper motion of B moved it out of the field of view of the A component when AC was confirmed in 1981 (Tobal 2005). 2: Remeasured more accurately in the AC reanalysis (Urban et al. 1998), but this may be nothing more than a more precise measure of a plate flaw.

as the previously unpublished data from Table 4. Symbols are the same as in Figure 1. In the case of linear plots, the dashed line indicates the time of closest apparent separation. As in Figure 1, the direction of motion is indicated at lower right of each figure. As the plots and solutions are all relative, the proper motion (μ) difference is assumed to be zero. In some cases, cataloged proper motion differences between the components are plotted as a red line.

Table 7 gives ephemerides for each orbit or linear solution over the years 2018 through 2026, in two-year increments. Columns (1) and (2) are the same identifiers as in the previous tables, while columns (3 + 4), (5 + 6), ... (11 + 12) give predicted values of θ and ρ, respectively, for the years 2018.0, 2020.0, etc., through 2026.0.

Notes to individual systems follow:

09210+3811 = STF1338AB: Also known as HD 80441. Based on the period and semimajor axis of Table 5 and the parallax (23.44 ± 1.08 mas; van Leeuwen 2007), the mass sum of this system is $1.66 \pm 0.33\,\mathcal{M}_{\odot}$. This is lower than expected for a pair of F3 dwarfs. Using the more recent parallax from *Gaia*'s DR2 (14.90 ± 0.59 mas; Gaia Collaboration et al. 2016, 2018), an even lower solution of $1.18 \pm 0.26\,\mathcal{M}_{\odot}$ is determined. If the spectral classification is approximately correct, an orbital solution of the same period with a semimajor axis about one-third larger would produce an expected mass sum. While it has been 188 years since the first resolution (Struve 1837), only continued observation, over a long timebase, can make the orbital solution more definitive. The wider C component is optical.

11035+5432 = A 1590: Also known as HD 95690. Based on the period and semimajor axis of Table 5 and the parallax (23.06 ± 1.48 mas; van Leeuwen 2007) the mass sum of this system is $1.73 \pm 0.70\,\mathcal{M}_{\odot}$. Using the more recent parallax from *Gaia*'s DR2 (23.49 ± 0.05 mas; Gaia Collaboration et al. 2016, 2018) a more precise result of $1.64 \pm 0.36\,\mathcal{M}_{\odot}$ is determined. Both seems reasonable for a K2V and its companion.

2.5. Double Stars Not Found

Table 8 presents two systems that were observed but not detected. Possible reasons for nondetection include orbital or differential proper motion making the binary too close or too wide to resolve at the epoch of observation, a larger than expected Δm, incorrect pointing of the telescope, and misprints and/or errors in the original reporting paper. It is hoped that reporting these will encourage other double-star astronomers to either provide corrections to the USNO observations or to verify the lack of detection.

This research has also made use of the SIMBAD database, operated at CDS, Strasbourg, France, NASA's Astrophysics Data System and made use of data from the European Space Agency (ESA) mission *Gaia* (https://www.cosmos.esa.int/gaia), processed by the *Gaia* Data Processing and Analysis Consortium (DPAC, https://www.cosmos.esa.int/web/gaia/dpac/consortium). Funding for the DPAC has been provided by national institutions, in particular the institutions participating in the *Gaia* Multilateral Agreement.

The continued instrument maintenance by the USNO instrument shop, Gary Wieder, Chris Kilian and Phillip Eakens, makes the operation of a telescope of this vintage a true delight.

ORCID iDs

Brian D. Mason https://orcid.org/0000-0003-4824-0938
William I. Hartkopf https://orcid.org/0000-0001-6111-4560

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