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SPECKLE INTERFEROMETRY AT THE US NAVAL OBSERVATORY. XI.

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ABSTRACT

The results of 1683 speckle interferometric observations of double stars, made with the 26 inch (66 cm) refractor of the US Naval Observatory, are presented. Each speckle interferometric observation of a system represents a combination of over 2000 short-exposure images. These observations are averaged into 805 mean relative positions and range in separation from 0.″23 to 43.″34, with a median separation of 4.″33. This is the 11th in a series of papers presenting measurements obtained with this system and covers the period 2004 January 4–December 30. Included in these data are two older measurements whose positions were previously deemed possibly aberrant but are no longer classified this way following a confirming observation. Two of these systems have new orbital elements, which are also presented here.

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

Online material: machine-readable tables

1. INTRODUCTION

From 2004 January 4 through December 30, the 26 inch (66 cm) telescope of the US Naval Observatory was used on 89 of 196 (45%) scheduled nights. While some nights were lost due to marginal weather conditions, the majority of unscheduled nights were due to upgrades of the relays and motors of the historic Clark refractor (see Appendix). Further details describing the techniques and methodology of speckle interferometry are contained in earlier papers in this series and references therein (most recently, Mason et al. 2004a).

While individual nightly totals varied substantially (from 2 to 61 objects per night) these nights together yielded 1683 observations and 1366 resolutions (double stars resolved and measured). After removing marginal observations, calibration data, and tests, a total of 1020 measurements remained, which have been grouped into 805 mean positions. Included in these are 125 confirmations of binaries with only one previous observation. While some of these are relatively recent discoveries of the *Hipparcos* or Tycho missions (Perryman et al. 1997), some remained unconfirmed for quite a while. Also included in these data are two observations from 2002. These measurements were not published in Mason et al. (2004b), as they were significantly different from previous observations or orbital predictions; however, they have now been confirmed with new measurements obtained in 2004. Some of these discrepancies reflect the prematurity of earlier orbit calculations; for one of these systems we were able to obtain new elements that, although still preliminary, allow for better ephemerides to be published. For the other three, consistent residual trends demonstrate systematic runoff from published orbits, although these data are not sufficient to justify new orbital calculations.

While the speckle camera has been off the 26 inch telescope many times over the past several years due to other observing projects, instrumental upgrades, and other reasons, Figure 1 illustrates the mean number of observations per night in a given month normalized to the number of actual scheduled nights in the given month over the years 2001–2004 (Mason et al. 2002, 2004a, 2004b; this paper). The most striking features are the good autumn observing conditions and the poorer climatic conditions in winter, characteristic of weather in Washington, DC.

2. OBSERVING LISTS AND CALIBRATION

The observing list was constructed using the same methodology discussed in Mason et al. (2004a). The majority of the systems are those considered neglected (the last date of observation was 10 or more years ago) or doubles needing confirmation. Several additional sets were added, including objects with uncertain motion, definitive orbits used to characterize errors, pairs with expected rapid motion, bright ($V < 5$) stars used for navigation, and others. Absolute calibration is determined by the use of a slit mask placed at the objective end of the telescope. Observation of a single star through this mask produces interference fringes that can then be used to determine spatial and angular calibration independent of any errors associated with using even "definitive" binaries.[2]

3. RESULTS

Table 1 presents the mean relative position of the members of 702 systems having no published orbital elements. The first two columns identify the system by providing the epoch 2000 coordinates and discovery designation. Columns (3)–(5) give the epoch of observation (expressed as a fractional Besselian year), the position angle (in degrees), and the separation (in arcseconds). Note that the position angle has not been corrected for precession and is thus based on the equinox for the epoch of observation. Objects whose measures are of lower quality are indicated by colons following the position angle and separation. These lower quality observations may be due to one or more of the following: close separation, large Δm, one or both components being very faint, a large zenith distance, and poor seeing or transparency. They are included primarily due to either the confirming nature of the observation or the number of years since the last measured position. Column (6) indicates the number of observations contained in the mean, and column (7) has any notes. While column (6) reflects the number of measurements, each measurement represents the

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[1] Retired.

[2] See http://ad.usno.navy.mil/wds/orb6/orb6c.html for more information.

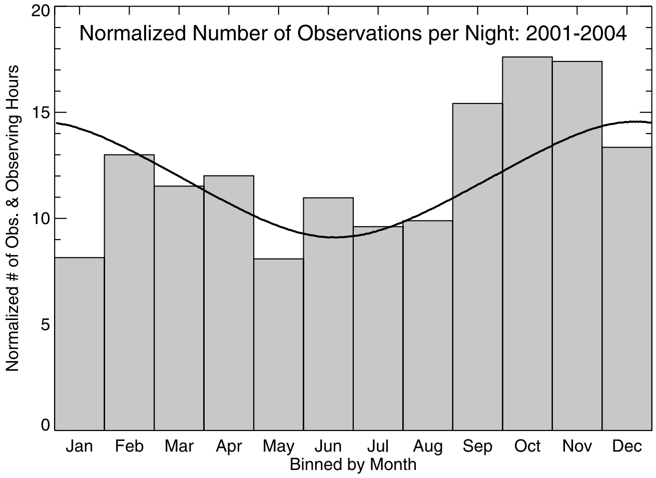

FIG. 1.—Number of mean observations per scheduled observing night binned by calendar month from 2001 to 2004 (Mason et al. 2002, 2004a, 2004b; and the data presented in Tables 1 and 2) and the number of nighttime hours in Washington, DC. The lowest numbers correspond to January (typically quite cloudy and occasionally too cold for the telescope to operate properly) and mid-summer when the nights are short and punctuated by late-afternoon and early evening thunderstorms. The best observing conditions occur when the moderately long nights in autumn couple with clear skies and good seeing, which is characteristic of Washington, DC. Spring is slightly better but often has more precipitation than autumn.

combination of over 2000 short-exposure images, from which a single measurement is obtained in autocorrelation space. The most common note indicators are "C," indicating a confirming observation, and a number (N), indicating the number of years since the system was last measured. This is only given for systems with $N \geq 50$ yr. One-hundred twenty-five systems are here confirmed. Since priority is given to both unconfirmed systems and systems not observed recently, the time since last observation can be surprisingly large; for the systems in Table 1 the average time since the last observation is 24 yr (58 yr for those entries with a colon, i.e., with reduced accuracy).

One-hundred forty-one systems have not been observed in the last 50 yr or more and 19 have not been observed in 100 yr or more; 14 of these were first resolved by J. Herschel in 1820 (Herschel 1826, 1829). The long delay in confirming these historic pairs was simply due to poor coordinates—most had only arcminute-precise coordinates, precessed without proper-motion correction from Herschel's original coarse α and δ values. Once they were found with the 26 inch telescope we were able to determine accurate arcsecond coordinates and in most cases obtain additional detections of both components in the Two Micron All Sky Survey data.[3] Of the other confirmed systems, 25 are relatively recent detections from Tycho (Høg et al. 2000b, 2000a; Mason et al. 2000; Fabricius et al. 2002). Of the 702 measurements in Table 1 (that is, systems without orbits), the median separation is $5''.03$.

Table 2 presents systems that were observed but not detected. Possible reasons for no detection 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, 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 verify the lack of detection. While one pair's discovery observation is quite old and its lack of detection may be due to unknown proper-motion drift (however, see the note to this system in Table 2), most are recent and so should not show significant differential motion. In addition to the 25 Tycho double stars confirmed in Table 1, six were not detected and thus are presented in Table 2.

Table 3 presents the mean relative positions for 104 double-star systems with published orbital determinations. The first six columns are identical to the corresponding columns of Table 1. Columns (7) and (8) give $O - C$ orbit residuals (in θ and ρ) to the orbit referenced in column (9). Notes are in column (10). The objects in Table 3 tend to be more frequently observed, closer pairs than those in Table 1, with a median separation of $1''.98$ and a mean time interval since last observed of 1.4 yr. Wider orbit systems were also observed, but only a few ($N = 16$) had separations greater than $4''.0$. While many objects have more than one observation generating a mean position, four objects have motion rapid enough that listing individual measurements is appropriate. Eleven of the pairs in Table 3 have residuals to more than one orbit. In four of these cases, more than one orbit is provided in the Sixth Catalog of Orbits of Visual Binary Stars[4] and the preferred

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[3] From the 2003 all-sky release; see http://pegasus.phast.umass.edu.

[4] See http://ad.usno.navy.mil/wds/orb6.html.

TABLE 1

SPECKLE INTERFEROMETRIC MEASUREMENTS OF DOUBLE STARS

WDS Designation α, δ (J2000.0) (1)	Discoverer Designation (2)	Epoch 2000+ (3)	θ (deg) (4)	ρ (arcsec) (5)	n (6)	Notes (7)
00000+4004	ES 2543	4.964	252.9:	4.39:	1	73, C
00099+0827	STF 4	4.044	275.6	5.12	1	
00140+2837	BRT 117	4.770	67.6	5.41	1	
00162−0359	ROE 115	4.781	302.1	5.42	1	
00167+3910	ES 1936	4.964	71.1	5.69	1	
00168−1427	GAL 11	4.781	318.5	5.77	1	
00208+2737	ROE 116	4.770	260.7	6.36	1	
00224−1432	HJ 1958	4.781	68.4:	14.12:	1	174, C, a
00237+0357	PLQ 5	4.781	273.2	5.87	1	
00309+2135	J 634	4.871	250.9	2.73	1	52

NOTES.—Table 1 is published in its entirety in the electronic edition of the *Astronomical Journal*. A portion is shown here for guidance regarding its form and content. (C) Confirming observation. (L) Linear elements determined; see W. I. Hartkopf et al. (2006a, in preparation). (a) Large change in separation and/or angle of position. (b) Much better measurement than the uncertain one of Mason et al. (2001). ($N = 50-184$) Number of years since last measurement.

TABLE 2
BINARIES NOT FOUND

			PUBLISHED ASTROMETRY		PUBLISHED MAGNITUDE		
WDS DESIGNATION α, δ (J2000.0)	DISCOVERER DESIGNATION	DATE	Position Angle (θ)	Separation (ρ)	Primary	Secondary	NOTES
03086+2534	TDS 104	1991	77	2.0	10.0	12.1	
03104+1552	TDS 2464	1991	78	1.6	10.7	11.6	
11205+1841	TDS 7797	1991	251	6.0	10.6	11.6	
11416+2223	HJ 2581	1830	90	2.0	11.0	12.0	1
22145+5001	TDS 1164	1991	240	1.3	10.2	12.0	
23484+5455	TDT 4205	1991	341	2.0	11.2	12.0	
23590+6337	TDS 1234	1991	187	1.7	10.3	11.9	

NOTE.—(1) Only arcminute coordinates are available for this pair, resolved by Herschel (1833), although he could "not define it. Night not good; telescopes give double images." Probably an erroneous detection.

TABLE 3
SPECKLE INTERFEROMETRIC MEASUREMENTS AND RESIDUALS TO SYSTEMS WITH ORBITS

WDS Designation α, δ (J2000.0) (1)	Discoverer Designation (2)	Epoch 2000+ (3)	θ (deg) (4)	ρ (arcsec) (5)	n (6)	$O-C$ (deg) (7)	$O-C$ (arcsec) (8)	Reference (9)	Notes (10)
00057+4549	STT 547	4.611	183.5	6.05	2	−0.6	0.09	Popovic & Pavlovic (1996)	*
						−0.3	−0.01	Kiyaeva et al. (2001)	
00134+2659	STT 2	4.798	164.1	0.37	1	3.4	0.01	Olevic & Jovanovic (2001)	
						0.0	−0.01	W. I. Hartkopf et al. (2006b, in preparation)	
00321+6715	VYS 2 Aa–B	4.923	172.9	3.98	1	−0.6	−0.04	Heintz (1993)	
00324+0657	MCA 1 Aa	4.798	281.4	0.30	2	4.2	0.05	Mason (1997)	
00352−0336	HO 212	4.923	268.4	0.30	7	1.4	0.01	Mason & Hartkopf (2005)	
00424+0410	STT 18	4.885	206.1	1.94	2	0.2	0.01	Hartkopf & Mason (2001)	
01234+5809	STF 115	4.798	166.1	0.27	2	1.6	0.02	Söderhjelm (1999)	
01559+0151	STF 186	4.061	63.6	0.89	1	−2.7	−0.01	Mourao (1977)	
02020+0246	STF 202	4.722	270.2	1.77	9	1.8	−0.03	Scardia (1983)	*
02291+6724	STF 262 Aa–B	4.680	229.7	2.86	3	−0.5	0.27	Heintz (1996)	1
03054+2515	STF 346	4.058	251.8	0.37	1	−3.2	−0.05	Heintz (1981a)	
03122+3713	STF 360	4.385	125.8	2.80	2	−0.6	0.01	Mason et al. (2004b)	
03177+3838	STT 53	2.963	246.0	0.63	1	−1.8	−0.08	Alzner (1998)	2
		4.055	247.8	0.68	3	1.0	−0.02	Alzner (1998)	
03344+2428	STF 412	4.055	355.5	0.71	3	0.0	0.00	Scardia et al. (2002a)	
03350+6002	STF 400	4.924	266.3	1.43	2	−0.4	−0.03	Seymour & Mason (2000)	
03368+0035	STF 422	4.637	271.0	6.67	1	0.4	−0.01	Hopmann (1964)	*
04076+3804	STT 531	4.924	357.6	2.28	1	2.2	0.02	Heintz (1986)	
04159+3142	STT 77	4.055	287.0	0.56	2	−2.2	−0.04	Starikova (1985)	
04227+1503	STT 82	4.558	340.1	1.19	3	−0.8	−0.09	Mason et al. (2004b)	
04233+1123	STF 535	4.872	275.9	1.12	1	−0.1	0.01	Hartkopf & Mason (2000)	*
04239+0928	HU 304	4.760	10.2	0.23	1	−0.5	0.00	Hartkopf (2000)	
04367+1930	STF 567	4.055	341.6	2.03	1	0.6	−0.01	Seymour et al. (2002)	
04422+3731	STF 577	4.055	351.2	0.75	2	0.8	0.01	Mason et al. (2004b)	
04478+5318	HU 612	4.924	357.0	0.65	3	−7.1	0.17	Heintz (1979)	
						0.3	−0.01	W. I. Hartkopf et al. (2006b, in preparation)	
05005+0506	STT 93	4.764	244.6	1.42	3	0.1	−0.01	Seymour & Mason (1999)	*
05055+1948	STT 95	4.146	298.4	0.86	3	−0.4	−0.09	Jasinta (1996)	
05079+0830	STT 98	4.146	311.5	0.71	3	−0.1	−0.12	Baize (1969)	
05135+0158	STT 517	4.056	240.5	0.66	2	0.6	0.03	Mason et al. (1999)	
05308+0557	STF 728	4.146	45.2	1.17	2	−0.3	−0.04	Seymour & Hartkopf (1999)	
05364+2200	STF 742	4.713	273.5	4.02	2	−0.7	−0.09	Hopmann (1973)	*
05558+3656	STT 122	4.167	84.3	0.31	1	−1.5	−0.05	Ling & Prieto (1990)	
06041+1101	J 335	4.058	272.3	1.19	1	−4.7	−0.02	Olevic & Jovanovic (2002)	
06344+1445	STF 932	4.146	308.0	1.64	1	4.2	−0.03	Hopmann (1960)	
06384+2859	MCA 27	4.138	288.0	0.25	1	−0.1	0.03	Hartkopf & Mason (2000)	
06546+1311	STF 982	4.269	326.3	7.30	3	0.7	0.36	Hopmann (1974)	
			146.3			3.6	0.15	Hopmann (1952)	
06555+3010	STF 981	4.146	307.0	1.19	2	5.2	−0.01	Hopmann (1971)	
06573+5825	STT 159	4.168	226.5	0.57	1	0.1	0.00	Alzner (2000)	
07346+3153	STF 1110	4.921	61.5	4.24	1	0.8	−0.02	Docobo & Costa (1985)	
08507+1800	A 2473	4.165	73.2	0.29	1	−0.7	0.04	Hartkopf & Mason (2000)	
08554+7048	STF 1280	4.154	342.8	1.50	1	0.0	−0.06	Heintz (1997)	*
09245+1808	A 2477	4.269	354.5	0.43	1	1.3	−0.03	Mason & Hartkopf (1998)	*

TABLE 3—*Continued*

WDS Designation α, δ (J2000.0) (1)	Discoverer Designation (2)	Epoch 2000+ (3)	θ (deg) (4)	ρ (arcsec) (5)	*n* (6)	*O* − *C* (deg) (7)	*O* − *C* (arcsec) (8)	Reference (9)	Notes (10)
						0.3	0.01	W. I. Hartkopf et al. (2006b, in preparation)	
10131+2725	STT 213	4.160	125.6	1.02	2	6.1	0.01	Heintz (1962)	
10163+1744	STT 215	4.269	179.9	1.44	1	−0.2	−0.07	Zaera (1984)	
10200+1950	STF 1424	4.242	126.5	4.59	1	1.3	0.17	Rabe (1958)	
11137+2008.............	STF 1517	4.365	321.2	0.60	1	7.5	0.37	Hopmann (1970)	1
11182+3132.............	STF 1523	4.146	251.0	1.71	2	0.3	−0.05	Mason et al. (1995)	*, 3
		4.165	250.6	1.75	1	0.0	−0.03	Mason et al. (1995)	*
		4.285	251.7	1.75	3	1.8	−0.02	Mason et al. (1995)	*
		4.379	251.0	1.77	10	1.7	0.00	Mason et al. (1995)	*
		4.922	245.4	1.68	2	−0.6	−0.07	Mason et al. (1995)	*
		4.993	244.8	1.71	3	−0.8	−0.04	Mason et al. (1995)	*
11190+1416.............	STF 1527	2.164	86.8	0.39	1	5.8	−0.08	Popovic & Pavlovic (1995)	
						3.1	−0.03	Mason et al. (2004a)	
		4.228	102.7	0.35	2	9.1	−0.07	Popovic & Pavlovic (1995)	
						1.8	−0.01	Mason et al. (2004a)	
11308+4117.............	STT 234	4.269	166.9	0.51	1	2.4	0.02	Docobo & Ling (2001)	
11363+2747	STF 1555	4.291	149.9	0.72	3	1.5	0.02	Docobo & Ling (2004)	
11387+4507	STF 1561	4.269	249.2	9.00	1	1.7	−0.03	Hale (1994)	
11390+4109	STT 237	4.269	246.6	1.98	1	0.9	−0.01	Seymour et al. (2002)	
12160+0538	STF 1621	4.763	37.5	1.33	3	0.1	−0.04	Söderhjelm (1999)	*
12244+2535	STF 1639	4.636	325.4	1.70	4	1.3	−0.05	Olevic & Popovic (2000)	
12306+0943	STF 1647	4.757	246.2	1.29	3	−2.4	0.02	Hopmann (1970)	*
12417−0127	STF 1670	4.147	213.9	0.64	2	2.4	0.05	Söderhjelm (1999)	3
		4.309	207.7	0.57	2	1.8	0.03	Söderhjelm (1999)	
		4.365	208.9	0.56	1	5.1	0.03	Söderhjelm (1999)	
		4.998	179.1	0.43	1	10.9	0.05	Söderhjelm (1999)	
13100+1732	STF 1728	4.360	193.9	0.37	2	1.4	−0.02	Hartkopf et al. (1989)	*
13169+1701	BU 800	4.275	106.6	7.47	1	1.3	−0.10	Hale (1994)	
13237−0043	A 2489	4.365	190.3	0.89	1	−2.3	0.06	Mason et al. (2004b)	
						−0.9	0.03	Alzner (2004)	
13396+1045	BU 612	4.365	193.9	0.26	1	−2.2	−0.01	Mason et al. (1999)	*
13550−0804	STF 1788	4.372	100.0	3.63	7	1.6	0.10	Hopmann (1970)	*
14234+0827	BU 1111 BC	4.554	270.4	0.26	1	4.9	0.06	Söderhjelm (1999)	*
14323+2641	A 570	4.554	91.7	0.24	1	0.1	0.04	Heintz (1991)	*
15038+4739	STF 1909	2.385	55.6	1.90	1	0.8	−0.12	Söderhjelm (1999)	2
		4.453	56.8	1.95	3	0.8	−0.04	Söderhjelm (1999)	
15183+2650	STF 1932 Aa–B	4.554	261.1	1.60	3	−0.3	−0.02	Heintz (1964)	
15232+3017	STF 1937	4.147	98.5	0.53	3	−2.4	0.01	Mason et al. (1999)	*, 3
		4.425	100.8	0.51	3	−3.5	0.00	Mason et al. (1999)	*
		4.554	101.0	0.50	3	−4.9	−0.01	Mason et al. (1999)	*
		4.998	106.9	0.53	3	−4.7	0.03	Mason et al. (1999)	*
15396+7959	STF 1989	2.407	24.6	0.66	1	0.1	−0.05	Giannuzzi (1956)	2
						−0.3	0.02	W. I. Hartkopf et al. (2006b, in preparation)	
		4.365	23.3	0.62	1	−0.7	−0.08	Giannuzzi (1956)	
						−1.1	−0.02	W. I. Hartkopf et al. (2006b, in preparation)	
15413+5959	STF 1969	4.425	27.2	0.90	2	−0.2	0.08	Heintz (1975)	
						0.5	−0.01	W. I. Hartkopf et al. (2006b, in preparation)	
15559−0210	STF 1985	4.363	353.9	5.99	2	0.5	−0.25	Hopmann (1973)	
						2.0	0.00	Table 4	4
16044−1122.............	STF 1998	4.363	341.0	0.65	1	2.1	−0.03	Söderhjelm (1999)	*
16147+3352	STF 2032	4.496	236.3	7.00	1	−0.3	−0.09	Scardia (1979)	*
16160+0721	STF 2026	4.365	19.7	3.28	1	0.8	−0.05	Heintz (1963)	*
16564+6502	STF 2118	4.425	66.7	1.03	2	−0.9	−0.13	Scardia et al. (2002b)	
						−1.0	−0.02	Table 4	4
17053+5428	STF 2130	4.496	13.7	2.32	2	1.3	0.05	Heintz (1981b)	*
17386+5546	STF 2199	4.496	57.3	1.96	3	1.6	0.05	Popovic & Pavlovic (1995)	*
18055+0230	STF 2272	4.363	140.9	4.75	1	1.5	0.01	Pourbaix (2000)	*
		4.633	138.4	4.82	2	−0.5	0.02	Pourbaix (2000)	*
18443+3940	STF 2383 Cc–D	4.560	81.7	2.35	4	1.2	0.00	Docobo & Costa (1984)	*
19121+4951	STF 2486	4.509	206.3	7.34	2	0.5	−0.09	Hale (1994)	*
19143+1904	STF 2484	4.576	239.0	2.19	1	0.6	−0.10	Hopmann (1973)	5
19266+2719	STF 2525	4.612	290.4	2.08	4	0.0	0.02	Heintz (1984)	*
19520−1021	BU 148	4.658	231.3	0.62	3	1.0	0.01	Ling (2004)	
20014+1045	STF 2613	4.655	354.1	3.66	1	2.3	−0.52	Hopmann (1973)	

TABLE 3—*Continued*

WDS Designation α, δ (J2000.0) (1)	Discoverer Designation (2)	Epoch 2000+ (3)	θ (deg) (4)	ρ (arcsec) (5)	*n* (6)	*O* − *C* (deg) (7)	*O* − *C* (arcsec) (8)	Reference (9)	Notes (10)
20289−1749	SHJ 323	4.669	193.9	1.30	1	2.2	−0.16	Heintz (1986)	
20462+1554	STF 2725	4.621	10.4	6.05	5	−0.6	−0.06	Hopmann (1973)	*
20467+1607	STF 2727	4.707	266.0	9.06	5	0.3	−0.11	Hale (1994)	*
21441+2845	STF 2822	4.724	310.6	1.82	1	−1.4	0.06	Heintz (1995)	*
22038+6438	STF 2863	4.519	275.4	7.88	2	1.1	−0.39	Zeller (1965)	*
22266−1645	SHJ 345	4.703	19.4	1.47	3	0.2	−0.01	Hale (1994)	*

Notes.—Table 3 is also available in machine-readable form in the electronic edition of the *Astronomical Journal*. (*) System used in characterizing errors. (1) This orbit might possibly be fitted better with linear elements; see W. I. Hartkopf et al. (2006a, in preparation). (2) This measurement was inconsistent with previous measurements, and so is not included in Mason et al. (2004b). However, available data are deemed insufficient for a new orbital calculation at this time. (3) This system was expected to show significant motion over the calendar year, so multiple observations have been obtained. (4) The new orbit is listed in Table 4, ephemerides based on these elements are listed in Table 5, and the orbit is illustrated in Fig. 2. (5) This orbit calculates the opposite quadrant for the position angle; however, it is clearly in this quadrant with an obvious Δm of ~1.5.

TABLE 4

NEW ORBITAL ELEMENTS

WDS Designation α, δ (J2000.0)	Discoverer Designation	Period *P* (yr)	Semimajor Axis *a* (arcsec)	Inclination *i* (deg)	Longitude of Node Ω (deg)	Epoch of Periastron T_0 (yr)	Eccentricity *e*	Longitude of Periastron ω (deg)
15559−0210	STF 1985	2465 ± 585	7.17 ± 1.04	39.3 ± 4.7	143 ± 12	1636 ± 118	0.278 ± 0.085	131 ± 23
16564+6502	STF 2118	291 ± 24	1.04 ± 0.12	94.18 ± 0.63	247.95 ± 0.95	1774 ± 32	0.298 ± 0.095	293 ± 16

TABLE 5

ORBITAL EPHEMERIDES

		2006		2008		2010		2012		2014	
WDS DESIGNATION α, δ (J2000.0)	DISCOVERER DESIGNATION	θ	ρ	θ	ρ	θ	ρ	θ	ρ	θ	ρ
15559−0210	STF 1985	352.2	5.989	352.5	5.990	352.8	5.992	353.1	5.994	353.4	5.995
16564+6502	STF 2118	67.5	1.039	67.4	1.020	67.2	0.999	67.0	0.977	66.8	0.952

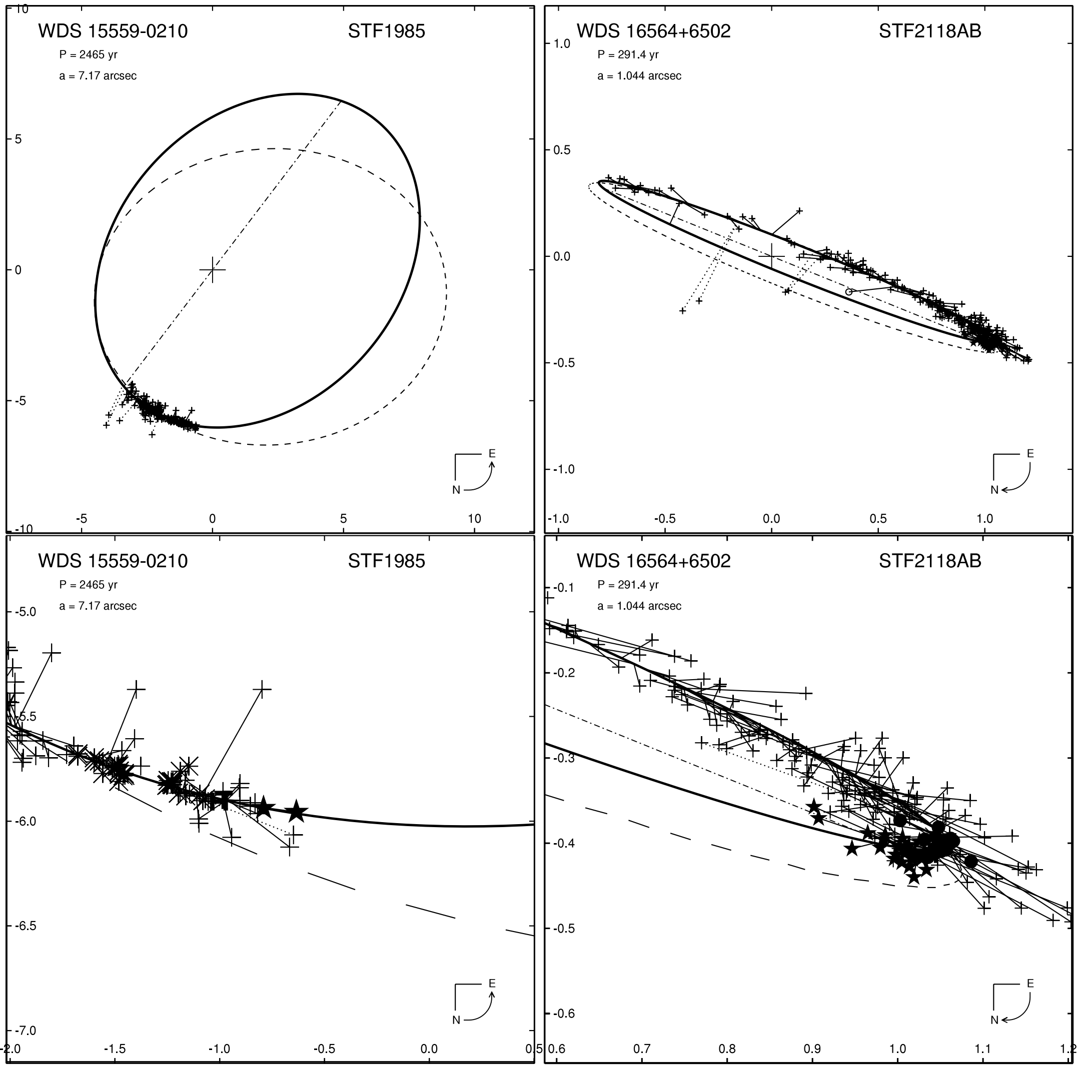

FIG. 2.—*Top*: For each system, the figure shows the relative visual orbit of the system; the *x*- and *y*-scales are in arcseconds. The solid curves represent the newly determined orbital elements, while the dashed curves represent previously published orbital elements. The previous calculations are cited in Hopmann (1973) for 15559−0210 and Scardia et al. (2002b) for 16564+6502. The dot-dashed lines indicate the line of nodes. Interferometric measurements are shown as filled circles (Center for High Angular Resolution Astronomy) or stars (USNO). Visual measurements are denoted with plus signs. Measurements of *Hipparcos* and Tycho are represented by "H" and "T," respectively. All measurements are connected to their predicted positions on the new orbit by "$O - C$" lines, where dotted $O - C$ lines indicate measurements given zero weight in the final solution. The direction of motion is indicated on the north-east orientation in the lower right of the plot. *Bottom*: Blowups of both orbit plots indicating the recent data and how they are systematically running off from the previous orbits.

orbit is not certain; in five cases a new preferable calculation (W. I. Hartkopf et al. 2006a, in preparation) is in process, and in two cases new orbital elements are provided in Table 4.

As mentioned in § 2, absolute calibration is determined by means of a slit mask placed in front of the primary. Since absolute calibration is done in this manner, binaries with well-characterized motion can be used to approximate errors. Binaries on the Calibration Orbit list[5] were again selected. Many of those resolvable are too close to the resolution limit of the 26 inch telescope to be of adequate value. Those with calibration-quality orbits have 42 measures in Table 3. Of those, mean errors are 1°.2 in position angle and 3.0% in separation, although clearly in many cases the quality of the calibration orbit is the reason for the large residual. For many of these orbits it is either time to reconsider which are "calibration" quality or update their elements. Two of the systems in Table 3 are also suitable for linear element calculation. It is likely that these may prove to have smaller errors associated with them. However, nearly all of these will fall outside the typical r_0 window. Further investigation of these systems is certainly advisable.

Finally, Table 4 presents the new, calculated orbits. Both were determined using the method described in Seymour et al. (2002) using the observation-weighting rules of Hartkopf et al. (2001). Indeed, it might be said that the greatest use of the elements from Table 4 is for position prediction for dates not given in Table 5. For these systems, were there not earlier calculations it would probably have been advisable to wait. However, both of these were beginning to show systematic runoff. The orbital elements listed in Table 4 and illustrated in Figure 2 are, while better than the previously published orbits, probably not terribly reliable over the course of a complete orbit. However, the ephemerides in Table 5 should be quite adequate for the next decade. Relative visual orbits of each system are plotted in Figure 2, with the *x*- and *y*-axes indicating the scale in arcseconds. Each solid curve represents the newly determined orbital elements of Table 4, while the dashed curves represent the previously published orbit cited in the figure legend.

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[5] See http://ad.usno.navy.mil/wds/orb6/orb6c.html.

As mentioned in § 2, the continued instrument maintenance by the USNO Instrument Shop, John Pohlman, Tie Siemers, David Smith, and Gary Wieder, makes the operation of a telescope of this vintage a true delight.

APPENDIX

INSTRUMENTAL IMPROVEMENT TO THE 26 INCH TELESCOPE

During 2003 and 2004, the USNO 26 inch refractor underwent a significant upgrade. It was last upgraded back in the early 1960s (Mikesell & Riddle 1969), and many of the components are no longer commercially available. During this recent upgrade, all the motors, electronics, and cables were replaced. The old magnetic right ascension clamp, which often caused problems, was replaced with a mechanical clamp. The purpose of this work was to improve the performance and reliability of the telescope and should not have directly affected the speckle results, except for the removal of the old electronics from the inside of the telescope tube, which was a heat source very near the optical light path. The upgrade was done by one of us (T. J. R.) with the assistance of J. Pohlman, G. Wieder, and other members of the USNO Instrument Shop.

In 2004 September, the old 10× and 20× microscope objectives were replaced in the speckle camera. At the same time, the USNO Instrument Shop machined the microscope objective wheel so that both objectives had the same focus.

Between 2004 September and November one of us (T. J. R.) conducted a study of the focus of the speckle camera on the USNO 26 inch refractor. The focus of the 26 inch refractor is unusual in that it appears insensitive to temperature, although the 1873 lens/lens cell and the 1893 telescope tube were not specially made to be temperature compensating. A four-hole Hartmann screen was used, with each hole 6 inches (15 cm) in diameter. Two holes were 180° apart and 9.5 inches (24 cm) from the center, and the other two holes, 90° from the line of the other pair, were also 180° apart and 6 inches from the center. The difference in separation of the two pairs of holes from the center was to determine likely zonal effects of the lens on the focus. Only one pair of holes was used for each speckle observation, with the other pair covered. The Hartmann screen could be rotated to allow each pair to be aligned east-west and north-south. Due to nonsymmetrical effects of the lens, data were taken with each pair of holes in both the east-west and north-south alignments. The number, size, and separation of the holes in the Hartmann screen were not ideal but were found to yield the best autocorrelations in early tests. A full group of observations, using each pair of holes in both alignments, with each set including four focus settings using the 10× objective and another four focus settings using the 20× objective, yielded a total of 32 observations. Each observation took about 2 minutes (2000 frames per observation). Adding in the time to change the focus, rotate the Hartmann screen, and cover and uncover the two pairs of holes, a full group of observations took 2 hr to complete. Single, 4 mag stars were used for the focus study so data could be taken with all the filters in the speckle camera. The temperature readings used were air temperature measured from the top of the telescope pier. The relationship between the focus settings and separation of the two images formed by the Hartmann screen is linear,

$$y = a + bx,$$

where y is the focus setting, x is the image separation, b is the slope of the function, and a is the true focus.

A least-squares fit of the data gave the slope, the intercept, the uncertainties of both, and the correlation coefficient. There are two formulae given for determining the best focus using a Hartmann screen given in Riddle (1968). The first is from Hartmann (1904):

$$\mathrm{Fo} = \sum \frac{R_i F_i}{R_i},$$

where Fo is the best focus, R_i is the radial distances of the ith hole in the Hartmann screen, and F_i is the focus determined for the ith hole. The other is from Fox (1908):

$$\mathrm{Fo} = \sum \frac{R_i^2 F_i}{R_i^2}.$$

Both formulae gave nearly the same results.

During the 3 month study, focus determinations were made over a range of temperatures from 24.4°C to 10.8°C and over a range of declinations from +63° to $-9\overset{\circ}{.}5$. No significant correlations were found between the focus and time, temperature, declination, filter, or microscope objective.

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