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SPECTROSCOPIC ORBITS OF THREE BINARIES

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ABSTRACT

This paper presents new spectroscopic orbits of three binaries with evolved primaries and periods of the order of a few years, two of them very eccentric. All the orbits were determined primarily from observations made with the DAO 1.2-m telescope and coudé spectrograph. Observations were obtained using the radial velocity spectrometer until it was decommissioned in 2004, and since then using a CCD detector, and cross-correlating the spectra with those of standard stars. It will be evident that the latter procedure leads to smaller observational scatter than the former did.

RESUMEN

Se presentan nuevas órbitas para tres binarias espectroscópicas con primarias evolucionadas y períodos de algunos años, dos de ellas muy excéntricas. Las órbitas se determinaron principalmente a partir de observaciones realizadas con el telescopio de 1.2 m y el espectrógrfo coudé del DAO. Las observaciones se hicieron con el espectrómetro para velocidades radiales hasta que fue descontinuado en 2004. A partir de entonces se utilizó un detector CCD, efectuando una correlación cruzada con espectros de estrellas estándar. Es evidente que este último procedimiento reduce la dispersión observacional.

Key Words: binaries: spectroscopic — stars: individual (6 Persei, HR 8078, HD 212989)

1. INTRODUCTION

The three binary stars discussed in this paper came to the author's attention in different ways. 6 Per was interesting because of its high, and at the time poorly determined, eccentricity. This, coupled with an argument of periastron close to 270°, leads to a rapid increase in radial velocity, most of which is accomplished in only one percent of the orbital period, which is close to 4.3 years. HR 8078 was in a list of stars claimed to be possibly variable in velocity, whose author had been unfortunate enough to miss the short interval, about a year in a period a little over seven years, in which most of the excursion of radial velocity occurs, and this led to the uncertainty. HD 212989 was one of a handful of stars with no published radial velocity in a list used by the author many years ago. Since then an orbit has been published by others, but their regrettable distribution of observations led them to deduce the wrong period. The correct one is a little over five years.

Observations of all three systems have been obtained using the coudé spectrograph of the Dominion Astrophysical Observatory's 1.22-m telescope, at a dispersion of 0.24 nm mm^{-1}. Initially the radial velocities were determined at the telescope with the radial-velocity spectrometer (RVS) (Fletcher et al. 1982). Numerous observations of IAU standard stars have been used to adjust the zero-point of the system to the scale defined by Scarfe (2010). Since 2004, when the spectrometer was decommissioned, observations have been made through the same spectrograph optics, but using a CCD as detector, and reduced with a 'pipeline' program developed by D. Bohlender. Radial velocities were determined by averaging the results from cross-correlation with the standard stars listed in Table 1, where the velocities are on the scale and zero-point of Scarfe (2010), and the binaries for which each was used are indicated.

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TABLE 1

STANDARD STARS USED FOR CROSS-CORRELATION

Standard Star	R.V. km s^{-1}	Binaries 6 Per	HR 8078	HD 212989
α Ari	14.49	x	x	x
α Boo	-5.30	x	x	x
α Cas	-4.25		x	
β Gem	3.28	x	x	x
β Oph	-12.20		x	x
κ Her	-10.31	x	x	x
16 Vir	36.52	x	x	x
31 Aql	-100.28	x		x
35 Peg	54.36	x	x	x
HR 3145	71.71	x	x	x

For all three binaries, solutions were obtained from the RVS and CCD data separately, and weights based upon the standard deviations from those solutions were assigned for a solution from the combined data. The weight for the CCD data was always set to 1.0. In all cases the weight for the RVS data was lower than for the CCD data, being 0.35, 0.20 and 0.25 respectively for 6 Persei, HR 8078 and HD 212989. The orbital elements are presented in Table 10 for all three binaries.

2. 6 PERSEI

The bright star 6 Persei (HR 645, HD 13530, HIP 10366, $\alpha = 2^h\ 13^m\ 36^s$, $\delta = 51°\ 3'\ 57''$ (J2000)) lies very close to the southern edge of its constellation, near the boundary with Andromeda. Its *UBV* magnitude and colours have been determined several times, with results clustering around the values $V = 5.31$, $B{-}V = 0.93$, $U{-}B = 0.62$, consistent with its spectral type of G8 III, given in the *Bright Star Catalog*.

The *Hipparcos* parallax of 6 Per (van Leeuwen 2007) is $\pi = 15.4 \pm 0.5$ mas, which yields $M_v = 1.25 \pm 0.07$, as might be expected from its spectral classification. *Hipparcos* also measured proper motions of 347 mas yr^{-1} in right ascension and -171 mas yr^{-1} in declination. Together with the parallax these yield a velocity of 17.1 km s^{-1} perpendicular to the line of sight, almost as large as the systemic radial velocity.

The first known spectroscopic orbit of 6 Per was published by Christie (1936), based on observations from DAO and Lick Observatory. It gave only rough values of the elements and was graded 'e' (poor) by Batten et al. (1989). But it was not until 1999, when the present observations were well under way, that a much better orbit was published by de Medeiros and Udry (1999). By then, however, the author's observations with the radial velocity spectrometer yielded an orbit of quality comparable to theirs, so observations were pursued in the hope of making further improvements.

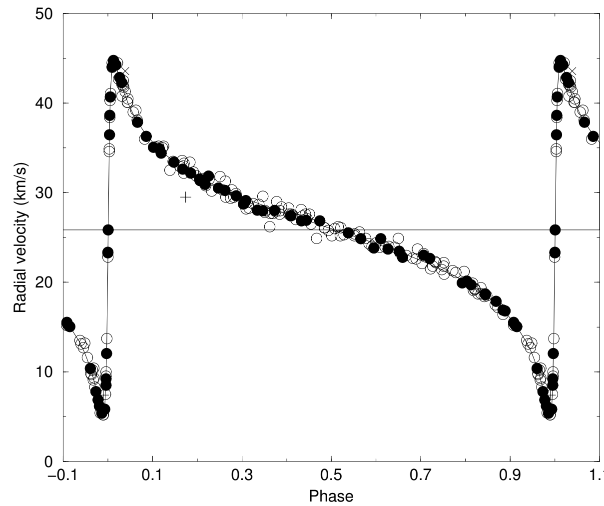

Fig. 1. The observed radial velocities of 6 Persei, with the curve derived from the adopted elements drawn through them. The DAO CCD data are shown as filled circles and the spectrometer data as open circles. A rejected CCD velocity is shown as a plus sign.

For 6 Persei, 155 observations were obtained with the RVS between J.D. 2444257 and 2453040, and 68 with the CCD from J.D. 2453213 to 2457295. The total span is a little more than eight orbital cycles. The RVS and CCD velocities are presented in Tables 2 and 3 respectively.

For 6 Persei, the elements in Table 10 differ only slightly from those obtained by de Medeiros and Udry (1999), and only the period is determined here with much greater precision. The most notable difference is that our values of K, and hence of $a_1 \sin i$ and $f(M)$, are significantly smaller than theirs. The velocity curve derived from the new elemsts is presented in Figure 1.

3. HR 8078

The bright star HR 8078 (HD 200817, HIP 103956, $\alpha = 21^h\,3^m\,48^s$, $\delta = 53°\,17'\,9''$ (2000)) lies in the northern part of Cygnus, about two degrees south of the boundary with Cepheus. Its spectral type is given as K0 III, and its *BV*

TABLE 2

RVS RADIAL VELOCITIES OF 6 PERSEI

Julian Date −2,400,000[a]	Cycle No. & Phase	R.V. km s^{-1}	O−C km s^{-1}	Julian Date −2,400,000	Cycle No. & Phase	R.V. km s^{-1}	O−C km s^{-1}
44257.69	0.1620	32.9	-0.1	49600.98	.5519	25.4	0.3
44264.66	.1664	33.6	0.7	49662.63	.5910	24.0	-0.5
44291.60	.1835	33.4	1.1	49676.74	.6000	24.4	0.1
44492.98	.3112	28.9	-0.4	49914.98	.7511	21.8	0.5
44548.87	.3467	29.6	1.0	50019.86	.8176	19.1	-0.4
44597.68	.3777	29.0	1.0	50024.82	.8208	19.2	-0.2
44614.62	.3884	28.4	0.5	50025.76	.8214	19.2	-0.2
44639.62	.4043	28.3	0.7	50046.79	.8347	19.4	0.5
44814.00	.5149	26.2	0.5	50066.72	.8473	18.5	0.0
44824.02	.5213	26.1	0.5	50124.60	.8841	16.4	-0.5
44871.93	.5517	25.2	0.1	50246.96	.9617	9.8	-0.4
44910.82	.5763	24.9	0.2	50252.98	.9655	10.2	0.6
45218.01	.7712	21.3	0.5	50279.98	.9827	5.4	-0.5
45288.82	.8161	19.9	0.4	50300.90	.9959	9.5	-0.4
45556.01	.9857	5.9	0.6	50301.01	.9960	10.0	-0.0
45611.86	1.0211	44.5	0.9	50314.84	4.0048	40.3	0.9
45756.59	.1129	35.2	0.2	50321.97	.0093	44.0	-0.0
45935.01	.2261	31.5	0.4	50356.76	.0313	42.1	0.2
45994.84	.2641	29.5	-0.8	50362.78	.0352	41.8	0.5
46015.78	.2773	30.3	0.3	50377.71	.0447	40.5	0.5
46280.99	.4456	27.1	0.2	50405.76	.0624	39.2	1.0
46378.82	.5077	26.0	0.1	50436.69	.0821	36.0	-0.7
46465.59	.5627	25.6	0.7	50475.69	.1068	35.1	-0.2
46670.00	.6924	23.7	1.1	50503.61	.1245	35.2	0.8
46732.81	.7322	22.3	0.6	50673.02	.2320	30.2	-0.8
46763.80	.7519	22.2	0.9	50711.92	.2567	30.3	-0.1
46834.68	.7969	21.2	1.1	50739.87	.2744	29.4	-0.6
47017.98	.9132	15.1	-0.1	50794.75	.3092	28.2	-1.1
47055.91	.9372	13.5	0.2	50804.65	.3155	28.3	-0.9
47072.81	.9480	13.2	1.1	50860.60	.3510	27.8	-0.7
47108.63	.9707	8.3	-0.3	51018.00	.4509	27.6	0.8
47138.63	.9897	7.4	2.4[a]	51070.94	.4845	26.1	-0.1
47146.69	.9948	7.5	-0.4	51084.94	.4933	25.8	-0.3
47150.74	.9974	13.7	0.1	51096.91	.5009	25.2	-0.8
47161.60	2.0043	38.4	0.0	51126.79	.5199	25.2	-0.5
47164.60	.0062	41.1	-0.6	51414.99	.7027	22.1	-0.3
47169.65	.0094	44.5	0.5	51444.89	.7217	21.5	-0.5
47180.71	.0164	44.3	-0.0	51452.91	.7268	21.8	-0.1
47215.60	.0385	41.3	0.5	51484.83	.7470	21.4	0.0
47346.98	.1219	35.0	0.4	51492.86	.7521	20.9	-0.4

[a]Rejected observation.

TABLE 2 (CONTINUED)

Julian Date −2,400,000[a]	Cycle No. & Phase	R.V. km s^{-1}	O−C km s^{-1}	Julian Date −2,400,000	Cycle No. & Phase	R.V. km s^{-1}	O−C km s^{-1}
47385.01	.1460	33.5	-0.1	51534.61	.7786	21.1	0.5
47422.94	.1701	33.3	0.6	51623.62	.8351	18.7	-0.2
47499.75	.2188	30.8	-0.5	51634.64	.8421	18.4	-0.3
47726.00	.3623	26.2	-2.1[a]	51737.99	.9077	15.2	-0.4
47745.99	.3750	27.9	-0.2	51788.84	.9399	13.1	0.1
47800.74	.4098	27.6	0.1	51796.85	.9450	12.7	0.3
48075.98	.5844	24.3	-0.3	51810.94	.9539	11.6	0.3
48113.92	.6084	23.9	-0.3	51824.86	.9628	9.7	-0.3
48132.77	.6204	23.9	-0.0	51831.89	.9672	9.1	-0.2
48165.78	.6414	23.9	0.3	51866.71	.9893	5.2	0.3
48184.85	.6535	23.3	-0.0	51936.65	5.0337	42.0	0.5
48448.94	.8210	19.3	-0.1	51937.64	.0343	42.5	1.1
48459.99	.8280	18.7	-0.5	51951.67	.0432	40.1	-0.1
48520.93	.8667	17.5	-0.2	52101.99	.1386	32.5	-1.3
48529.90	.8724	17.2	-0.2	52151.00	.1697	32.2	-0.5
48681.60	.9686	10.4	1.4	52157.82	.1740	29.5	-3.1[a]
48681.67	.9687	9.3	0.3	52184.92	.1912	32.3	0.2
48714.72	.9896	5.2	0.3	52220.68	.2139	31.6	0.1
48730.66	.9997	22.8	0.4	52278.68	.2507	31.8	1.2
48735.66	3.0029	34.9	0.2	52297.56	.2627	31.3	1.0
48735.67	.0029	34.6	-0.1	52334.60	.2862	29.9	0.1
48757.98	.0171	44.3	0.1	52465.98	.3695	27.7	-0.5
48768.97	.0240	42.7	-0.4	52489.02	.3841	27.6	-0.3
48780.96	.0316	40.8	-1.0	52534.91	.4132	27.5	0.1
48800.98	.0443	40.1	0.0	52564.89	.4323	28.1	1.0
48819.95	.0564	39.0	0.2	52579.87	.4417	27.6	0.6
48833.98	.0653	38.1	0.1	52599.73	.4544	26.5	-0.2
48997.65	.1691	33.0	0.2	52619.80	.4671	24.9	-1.6
49041.62	.1970	31.9	-0.0	52647.76	.4848	26.1	-0.1
49174.96	.2816	29.5	-0.4	52716.62	.5285	25.3	-0.2
49262.92	.3374	28.7	-0.1	52873.90	.6283	24.0	0.2
49243.00	.3248	28.8	-0.2	52907.79	.6498	24.9	1.5
49285.77	.3519	28.0	-0.5	52935.86	.6676	23.0	-0.1
49303.81	.3634	27.7	-0.6	52957.83	.6815	22.7	-0.1
49337.73	.3848	28.0	0.1	52970.76	.6898	22.6	-0.0
49369.65	.4051	27.6	0.0	52996.74	.7062	23.2	0.9
49393.60	.4203	27.0	-0.3	53040.58	.7340	22.2	0.5
49417.62	.4356	27.4	0.3				

[a]Rejected observation.

magnitude and colour are $V = 5.92$, $B-V = 1.01$, according to the *Tycho-2 Catalogue*. Its *Hipparcos* parallax (van Leeuwen 2007) is $\pi = 8.05 \pm 0.43$ mas, which yields $M_v = 0.46 \pm 0.12$, consistent with its spectral classification. *Hipparcos* also measured proper motions of 59 mas yr^{-1} in right ascension and 11 mas yr^{-1} in declination. Together with the parallax these yield a velocity of 34.4 km s^{-1}

TABLE 3

CCD RADIAL VELOCITIES OF 6 PERSEI

Julian Date −2,400,000[a]	Cycle No. & Phase	R.V. km s^{-1}	O−C km s^{-1}	Julian Date −2,400,000	Cycle No. & Phase	R.V. km s^{-1}	O−C km s^{-1}
53213.99	5.8441	18.71	0.12	54447.76	6.6268	23.71	-0.12
53251.96	.8682	17.86	0.23	54486.58	.6514	23.48	0.10
53283.88	.8884	16.80	0.14	54498.62	.6591	22.78	-0.46
53314.84	.9080	15.53	0.00	54708.98	.7925	19.93	-0.31
53325.81	.9150	15.05	-0.01	54724.96	.8027	20.12	0.17
53417.60	.9732	7.78	-0.30	54739.93	.8122	19.72	0.06
53424.60	.9777	6.85	-0.25	54790.80	.8444	18.63	0.05
53448.62	.9929	5.83	-0.13	54852.61	.8836	16.89	-0.01
53452.62	.9955	8.50	-0.46	54893.62	.9097	15.34	-0.08
53452.63	.9955	9.22	0.25	55013.97	.9860	5.37	0.12
53454.63	.9967	12.04	0.28	55042.98	7.0044	38.65	-0.04
53459.64	.9999	23.30	0.09	55051.00	.0095	44.05	-0.03
53459.65	.9999	23.35	0.12	55055.99	.0127	44.77	0.20
53460.64	6.0005	25.84	0.06	55063.98	.0177	44.28	0.14
53465.65	.0037	36.46	-0.57	55077.00	.0260	42.86	0.10
53468.65	.0056	40.71	-0.17	55096.96	.0387	43.58	2.77[a]
53594.96	.0858	36.28	-0.19	55139.83	.0659	37.87	-0.05
53619.93	.1016	35.08	-0.46	55426.02	.2474	30.53	-0.10
53640.93	.1149	34.93	0.06	55448.84	.2619	30.25	-0.06
53647.89	.1193	34.42	-0.24	55488.88	.2873	29.67	-0.09
53692.79	.1478	33.41	-0.09	55782.99	.4739	26.87	0.45
53782.59	.2048	31.54	-0.16	56148.99	.7061	23.03	0.72
53784.59	.2061	31.34	-0.33	56171.03	.7201	22.66	0.65
53788.60	.2086	31.32	-0.28	56549.88	.9604	10.38	-0.02
53802.61	.2175	30.93	-0.44	56581.94	.9808	6.17	-0.21
53986.05	.3339	28.06	-0.78	56631.77	.0124	44.69	0.12
54004.95	.3459	27.98	-0.64	56660.71	.0307	42.32	0.34
54047.87	.3731	28.03	-0.10	56876.00	.1673	32.64	-0.18
54104.60	.4091	27.43	-0.07	56903.97	.1851	32.18	-0.09
54159.60	.4440	26.93	0.02	56966.69	.2249	31.87	0.69
54307.99	.5381	25.51	0.15	57089.63	.3029	28.73	-0.71
54351.96	.5660	24.87	-0.02	57098.65	.3086	29.13	-0.20
54397.84	.5951	23.81	-0.58	57256.99	.4090	27.42	-0.08
54421.78	.6103	24.88	0.75	57294.92	.4331	26.86	-0.23

[a]Rejected observation.

perpendicular to the line of sight, comparable to the systemic radial velocity.

HR 8078 came to the author's attention in a list of stars with possibly variable velocity published by Beavers (1985). HR 8078 has only a small variation for nearly six years of its seven-year period, and the author was lucky that the variation in the seventh year occurred very soon after he began observing, while Beavers was unfortunate in missing such a year, and was therefore unable to show variability with certainty. After following the variation for several years the author presented a preliminary orbit

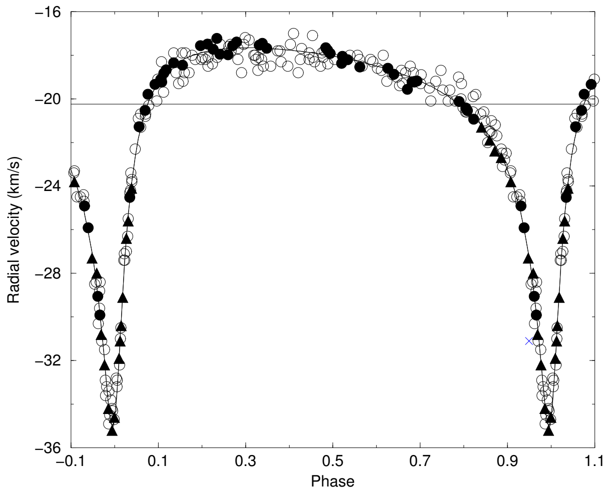

Fig. 2. The observed radial velocities of HR 8078, with the curve derived from the adopted elements drawn through them. The DAO data are shown as in Figure 1. Griffin's data are shown as filled triangles, and a rejected RVS velocity is shown as a cross.

to the Canadian Astronomical Society. In the meantime, however, Prof. R.F. Griffin had also begun to obtain observations through the rapidly variable portion of the cycle. But on seeing the author's abstract in print (Scarfe 2001) he very kindly offered to contribute his data to the determination of a definitive orbit.

For HR 8078, 164 observations were obtained with the RVS between J.D. 2444548 and 2452971, and 43 with the CCD from J.D. 2453144 to 2457295. The total span for HR 8078 is about 4.75 orbital cycles. The RVS and CCD velocities are presented in Tables 4 and 5 respectively. In addition, the 19 observations covering one of the minima near periastron, that were obtained by Griffin and kindly contributed by him to the orbital solution, are given in Table 6. It should be noted that he provided his data to a precision of only 0.1 km s^{-1}, but their very small residuals sugggest that they appear to merit a second decimal digit. They were included in the solution with unit weight, after a small adjustment of their zero poit.

The elements are presented in Table 10 and the velocity curve derived from them is drawn through the data in Figure 2.

4. HD 212989

HD 212989 (HIP 110900, $\alpha = 22^h\ 28^m\ 7^s$, $\delta = 12^\circ\ 14'\ 55''$ (2000)) is to be found in Pegasus, almost on a direct line between ϵ and α Peg, and slightly closer to the latter. Its UBV magnitude and colours are (Argue, 1966) $V = 7.06$, B-$V = 0.90$, U-$B = 0.56$, consistent with its MK type, K0 V. It should be noted that HD 212989 is the primary of a visual binary, known as ADS 15972 or WDS J22281+1215, with a period of 554 years. The secondary is 2.28 magnitudes fainter than the primary, but no doubt contributes a little to the above magnitude and colours, since the current separation is close to one arc second.

The *Hipparcos* parallax of HD 212989 is $\pi = 15.87 \pm 1.18$ mas, which yields an absolute visual magnitude of $M_v = 3.06 \pm 0.16$, more luminous than would be expected from its spectral type, by more than can be accounted for by the light of the secondary, suggesting that the primary star is somewhat evolved from the main sequence. *Hipparcos* also measured proper motions of 196 mas yr^{-1} in right ascension and -9 mas yr^{-1} in declination, which in turn yield a velocity of 57.3 km s^{-1} perpendicular to the line of sight.

HD 212989 first came to the author's attention when he was still a graduate student, when it was one of a small handful of stars on his observing list that had no known radial velocity. He did not try to remedy that lack until after the radial velocity spectrometer became available in the early 1980s. The primary's binary nature was soon discovered and the system has been followed ever since. However in the meantime it also came to the attention of other observers, including Massarotti et al. (2008), who included HD 212989 in a long list of binaries for which they determined orbits. Unfortunately in the case of HD 212989 the distribution of their data led them to determine an incorrect period. The correct value is derived in this paper from the author's observations and shown to be consistent with the data of Massarotti et al. More recently Halbwachs et al. (2014) detected a very faint spectroscopic secondary component and obtained a rather uncertain mass ratio of 0.72 for the system, although they appear not to have redetermined its orbit. They also find that the star's absolute magnitude is 3.0, and suggest that it be reclassified as K0 IV. A more recent value of the parallax obtained by *GAIA*, 11.14 mas, would yield an even brighter absolute magnitude.

For HD 212989, 169 observations were obtained with the RVS between J.D. 2444823 and 2452971, and 51 with the CCD from J.D. 2453180 to 2457295. The total span in this case is over 6.5 orbital cycles. The RVS and CCD data are presented in Tables 7 and 8 respectively. Because a separate solution was also made with the CCD data and the CfA data of

TABLE 4

RVS RADIAL VELOCITIES OF HR 8078

Julian Date −2,400,000	Cycle No. & Phase	R.V. km s^{-1}	O−C km s^{-1}	Julian Date −2,400,000	Cycle No. & Phase	R.V. km s^{-1}	O−C km s^{-1}
44548.67	0.8857	-22.3	0.3	49285.72	.6526	-19.4	-0.6
44791.94	.9765	-31.5	0.5	49303.64	.6593	-19.3	-0.4
44823.92	.9884	-34.5	-0.1	49418.06	.7021	-18.9	0.3
44868.72	1.0051	-33.2	0.2	49508.88	.7358	-19.2	0.4
44910.63	.0207	-27.4	0.7	49628.71	.7805	-20.1	0.0
44934.72	.0297	-26.3	-0.6	49662.60	.7933	-20.0	0.3
44951.54	.0360	-24.2	0.1	49676.62	.7984	-20.4	-0.0
45113.99	.0967	-20.1	-0.7	49691.57	.8040	-20.6	-0.1
45216.78	.1349	-17.9	0.6	49804.04	.8460	-20.6	0.7
45231.72	.1405	-18.8	-0.4	49849.92	.8630	-21.0	0.8
45267.73	.1540	-17.9	0.3	49914.87	.8872	-22.5	0.2
45288.57	.1617	-17.9	0.2	49931.87	.8937	-22.8	0.1
45330.59	.1774	-18.0	0.0	49969.74	.9077	-23.3	0.4
45428.03	.2138	-18.5	-0.7	50024.67	.9282	-24.4	0.7
45443.03	.2193	-17.5	0.3	50125.13	.9657	-28.8	1.0
45454.00	.2238	-18.4	-0.6	50161.05	.9791	-33.6	-1.0
45555.85	.2615	-17.6	0.1	50181.94	.9869	-33.4	0.8
45567.81	.2659	-17.5	0.2	50213.90	.9988	-34.7	0.1
45611.74	.2823	-17.7	-0.0	50232.85	3.0058	-32.9	0.3
45646.74	.2954	-17.5	0.2	50246.92	.0111	-32.2	-0.7
45680.57	.3079	-17.3	0.4	50252.96	.0133	-31.0	-0.3
45716.61	.3214	-18.0	-0.3	50279.87	.0234	-27.4	-0.1
45813.02	.3574	-18.5	-0.8	50300.94	.0312	-25.5	-0.2
45869.96	.3786	-17.8	-0.1	50314.86	.0366	-23.4	0.9
45934.93	.4028	-17.5	0.3	50321.80	.0390	-23.7	0.1
45952.86	.4095	-17.0	0.8	50342.65	.0468	-22.3	0.4
45994.72	.4251	-18.2	-0.4	50362.68	.0544	-20.9	0.9
46049.57	.4456	-17.9	-0.0	50377.59	.0598	-20.7	0.6
46069.55	.4531	-17.1	0.8	50405.56	.0703	-20.8	-0.3
46128.09	.4748	-17.9	0.1	50504.09	.1071	-18.3	0.8
46164.05	.4883	-18.4	-0.4	50518.07	.1122	-19.7	-0.8
46204.99	.5036	-18.2	-0.1	50609.95	.1465	-19.3	-1.0
46299.90	.5389	-18.0	0.2	50636.78	.1566	-19.2	-1.0
46345.79	.5560	-18.0	0.3	50644.91	.1595	-18.8	-0.6
46358.65	.5609	-18.2	0.1	50673.83	.1703	-18.8	-0.7
46616.96	.6572	-18.7	0.2	50711.77	.1846	-18.2	-0.2
46641.86	.6665	-18.8	0.1	50748.69	.1982	-18.2	-0.3
46669.81	.6770	-18.5	0.5	50774.59	.2079	-18.2	-0.4
46700.86	.6885	-19.2	-0.1	50932.01	.2668	-17.8	-0.1
46870.05	.7516	-19.6	0.1	50973.96	.2823	-18.2	-0.5
46902.97	.7639	-20.1	-0.2	50995.96	.2905	-18.8	-1.1

TABLE 4 (CONTINUED)

Julian Date −2,400,000	Cycle No. & Phase	R.V. $\mathrm{km\ s^{-1}}$	O−C $\mathrm{km\ s^{-1}}$	Julian Date −2,400,000[a]	Cycle No. & Phase	R.V. $\mathrm{km\ s^{-1}}$	O−C $\mathrm{km\ s^{-1}}$
46913.02	.7676	-19.6	0.3	51017.88	.2988	-17.2	0.5
46967.92	.7881	-19.0	1.2	51070.77	.3184	-18.0	-0.3
46984.90	.7945	-19.3	1.0	51084.77	.3236	-18.2	-0.5
47017.92	.8067	-20.6	-0.1	51096.68	.3282	-18.7	-1.0
47055.73	.8208	-20.6	0.2	51118.60	.3362	-18.2	-0.5
47072.69	.8272	-19.8	1.1	51126.60	.3392	-17.7	-0.0
47146.64	.8547	-22.0	-0.4	51280.04	.3966	-18.5	-0.7
47161.55	.8603	-21.5	0.3	51344.98	.4207	-18.8	-1.0
47260.00	.8971	-22.5	0.6	51365.95	.4285	-17.7	0.1
47303.95	.9134	-24.5	-0.5	51435.76	.4547	-18.1	-0.2
47324.92	.9212	-24.5	0.0	51444.73	.4579	-18.3	-0.4
47346.94	.9295	-24.7	0.4	51737.91	.5672	-18.5	-0.2
47422.72	.9577	-28.4	-0.0	51788.72	.5863	-18.2	0.2
47443.60	.9655	-29.6	0.1	51831.66	.6022	-18.6	-0.1
47478.63	.9786	-32.9	-0.5	51866.58	.6152	-18.0	0.6
47486.60	.9815	-33.2	-0.1	52051.98	.6845	-18.8	0.3
47499.64	.9864	-34.9	-0.8	52096.96	.7011	-19.3	-0.1
47627.94	2.0343	-24.3	0.4	52150.82	.7212	-19.5	-0.1
47641.02	.0391	-23.8	-0.0	52157.78	.7240	-20.1	-0.7
47694.83	.0593	-21.3	0.1	52220.59	.7472	-18.7	1.0
47725.82	.0708	-20.7	-0.2	52418.94	.8212	-19.9	0.9
47745.87	.0782	-20.3	-0.2	52465.93	.8389	-20.7	0.5
47800.70	.0988	-19.1	0.2	52488.90	.8473	-21.0	0.4
47821.65	.1065	-19.1	-0.0	52516.81	.8577	-21.5	0.2
48075.93	.2014	-18.1	-0.2	52534.88	.8645	-21.6	0.3
48109.84	.2141	-18.1	-0.3	52555.70	.8722	-21.2	0.9
48165.69	.2348	-18.1	-0.4	52564.76	.8756	-21.7	0.6
48184.79	.2420	-17.5	0.2	52599.63	.8886	-23.1	-0.3
48418.94	.3294	-18.1	-0.4	52647.56	.9065	-23.4	0.2
48448.75	.3404	-18.5	-0.8	52762.02	.9493	-31.1	-3.9[a]
48536.80	.3733	-17.8	-0.1	52775.00	.9540	-28.5	-0.7
48557.63	.3811	-18.3	-0.6	52796.97	.9622	-30.3	-1.2
48731.02	.4457	-18.2	-0.3	52808.94	.9667	-28.4	1.5
48800.91	.4718	-18.5	-0.5	52817.98	.9701	-31.1	-0.5
48816.92	.4778	-18.1	-0.1	52873.85	.9909	-33.8	1.0
48822.90	.4800	-17.8	0.2	52880.90	.9935	-34.2	0.8
49121.98	.5915	-18.3	0.2	52885.82	.9954	-34.3	0.7
49174.88	.6113	-18.7	-0.1	52907.72	4.0035	-32.8	1.1
49207.88	.6235	-19.2	-0.6	52935.68	.0140	-30.5	-0.0
49242.80	.6366	-18.9	-0.2	52957.65	.0222	-27.1	0.6
49270.64	.6471	-19.0	-0.2	52970.58	.0270	-27.0	-0.6

[a]Rejected observation.

TABLE 5

CCD RADIAL VELOCITIES OF HR 8078

Julian Date −2,400,000	Cycle No. & Phase	R.V. km s^{-1}	O−C km s^{-1}	Julian Date −2,400,000[a]	Cycle No. & Phase	R.V. km s^{-1}	O−C km s^{-1}
53144.96	4.0920	-19.34	0.17	55393.93	.9308	-24.91	0.38
53180.90	.1054	-19.11	-0.02	55413.87	.9383	-25.91	0.06
53187.93	.1080	-19.23	-0.21	55475.86	.9614	-29.05	-0.06
53213.89	.1177	-18.67	0.12	55488.69	.9662	-29.91	-0.06
53259.81	.1349	-18.35	0.13	55672.00	5.0346	-24.52	0.11
53314.70	.1553	-18.46	-0.24	55728.96	.0558	-21.28	0.39
53525.97	.2341	-17.23	0.52	55765.98	.0696	-20.53	0.06
53544.97	.2412	-17.96	-0.20	55782.96	.0759	-19.79	0.43
53594.88	.2598	-17.98	-0.30	55880.59	.1124	-18.83	0.08
53622.82	.2702	-17.56	0.12	56106.97	.1968	-17.56	0.33
53647.76	.2796	-17.40	0.27	56148.88	.2124	-17.49	0.33
54292.97	.5202	-18.37	-0.25	56184.74	.2258	-17.73	0.04
54328.98	.5336	-18.21	-0.03	56466.90	.3310	-17.54	0.13
54404.69	.5619	-18.54	-0.24	56486.95	.3385	-17.46	0.22
54695.94	.6705	-19.56	-0.60	56513.90	.3486	-17.68	0.01
54724.82	.6813	-19.22	-0.17	56875.91	.4836	-17.66	0.33
54739.75	.6868	-19.23	-0.14	56886.86	.4877	-17.77	0.23
54754.74	.6924	-19.19	-0.05	56903.80	.4940	-17.92	0.10
55013.96	.7891	-20.13	0.12	56978.70	.5219	-18.05	0.08
55055.83	.8047	-20.42	0.09	57256.90	.6257	-18.60	0.05
55064.87	.8081	-20.54	0.03	57294.76	.6398	-18.87	-0.13
55103.77	.8226	-20.93	-0.08				

TABLE 6

R. F. GRIFFIN'S RADIAL VELOCITIES OF HR 8078

Julian Date −2,400,000	Cycle No. & Phase	R.V. km s^{-1}	O−C km s^{-1}	Julian Date −2,400,000[a]	Cycle No. & Phase	R.V. km s^{-1}	O−C km s^{-1}
52470.57	3.8405	-21.3	-0.1	52881.57	.9938	-35.2	-0.2
52519.49	.8587	-21.9	-0.2	52896.47	.9993	-34.6	0.1
52552.41	.8710	-22.4	-0.3	52924.42	4.0098	-31.9	0.0
52591.41	.8856	-22.7	-0.1	52931.43	.0124	-31.1	-0.1
52651.23	.9079	-23.8	-0.1	52937.44	.0146	-30.4	-0.2
52758.65	.9479	-27.3	-0.3	52947.32	.0183	-29.1	-0.2
52788.55	.9591	-28.0	0.6	52970.37	.0269	-26.4	-0.0
52815.56	.9692	-30.8	-0.4	52981.27	.0310	-25.6	-0.2
52835.56	.9766	-32.2	-0.2	53002.30	.0388	-24.1	-0.3
52860.55	.9859	-34.2	-0.2				

TABLE 7

RVS RADIAL VELOCITIES OF HD 212989

Julian Date −2,400,000	Cycle No. & Phase	R.V. km s^{-1}	O−C km s^{-1}	Julian Date −2,400,000	Cycle No. & Phase	R.V. km s^{-1}	O−C km s^{-1}
44823.9450	0.6703	6.4	-0.9	49747.5866	.2827	1.4	0.0
44910.6780	.7168	8.8	0.6	49914.9269	.3714	3.1	0.3
45217.8230	.8793	11.4	1.2	49931.9626	.3804	3.2	0.2
45231.7660	.8867	11.4	1.3	49969.8287	.4005	3.9	0.7
45330.6020	.9391	10.6	1.4	49991.7588	.4122	3.4	0.0
45555.8980	1.0587	0.3	0.1	50019.7456	.4270	3.1	-0.6
45567.8790	.0655	-0.2	-0.1	50024.6762	.4297	4.4	0.7
45575.8180	.0692	-0.0	0.2	50232.9694	.5401	4.3	-1.0
45611.8360	.0883	-0.7	-0.0	50246.9377	.5476	4.6	-0.9
45646.7660	.1069	-0.6	0.2	50262.9676	.5561	4.8	-0.8
45680.6430	.1249	-0.4	0.4	50279.9381	.5651	4.9	-0.9
45716.5710	.1443	0.5	1.2	50300.9262	.5762	5.2	-0.7
45869.9720	.2253	0.4	-0.1	50314.8741	.5836	6.8	0.8
45887.9810	.2349	1.4	0.8	50321.8482	.5873	5.9	-0.1
45934.8600	.2597	1.3	0.3	50342.7957	.5984	5.4	-0.8
45994.7110	.2915	1.1	-0.4	50362.7435	.6090	6.4	-0.0
46045.6200	.3189	3.5	1.6	50377.6916	.6169	6.0	-0.6
46069.6450	.3312	3.7	1.5	50405.6555	.6318	6.7	-0.0
46238.9500	.4211	4.1	0.6	50609.9699	.7402	8.4	-0.0
46264.9560	.4349	4.2	0.4	50672.9380	.7736	8.0	-0.9
46273.9730	.4397	5.0	1.2	50711.7828	.7942	9.0	-0.3
46280.9340	.4437	4.8	0.9	50739.7690	.8090	9.0	-0.5
46299.9150	.4534	4.6	0.6	50774.6409	.8275	9.5	-0.3
46345.8030	.4778	5.2	0.8	50794.5989	.8381	8.7	-1.2
46616.9760	.6216	8.2	1.6	50804.5674	.8434	9.2	-0.7
46641.9320	.6349	7.3	0.5	50973.9700	.9333	9.3	-0.1
46669.8700	.6500	7.7	0.6	51017.9478	.9566	7.6	-0.7
46700.8650	.6661	7.6	0.3	51070.8479	.9847	5.2	-0.8
46732.7450	.6831	8.3	0.8	51084.7842	.9921	5.0	-0.4
46987.9038	.8184	10.4	0.8	51096.7384	.9984	3.8	-1.0
47017.9251	.8344	10.1	0.3	51104.7283	4.0027	4.5	0.2
47055.8070	.8548	10.3	0.3	51126.6860	.0142	2.4	-0.8
47108.6186	.8825	10.0	-0.1	51153.6808	.0286	1.7	-0.3
47146.6255	.9026	9.8	-0.2	51165.5722	.0349	1.1	-0.4
47161.5570	.9106	10.7	0.8	51309.9924	.1116	-2.0	-1.1
47324.9611	.9973	5.1	0.3	51325.9787	.1201	-2.4	-1.6
47346.9512	2.0092	4.2	0.5	51344.9580	.1300	-2.2	-1.4
47367.9293	.0201	3.2	0.5	51365.9580	.1413	-0.9	-0.2
47384.8836	.0291	2.2	0.2	51374.9610	.1460	-1.5	-0.8
47422.7953	.0492	0.8	0.2	51414.8650	.1672	-1.2	-0.8
47443.7666	.0603	0.1	0.0	51435.8225	.1783	-1.1	-0.8
47499.6503	.0902	-1.2	-0.5	51444.7755	.1830	-1.1	-0.9
47694.9736	.1936	0.2	0.3	51452.8244	.1873	-1.1	-1.0

TABLE 7 (CONTINUED)

Julian Date −2,400,000	Cycle No. & Phase	R.V. km s^{-1}	O−C km s^{-1}	Julian Date −2,400,000	Cycle No. & Phase	R.V. km s^{-1}	O−C km s^{-1}
47499.6503	.0902	-1.2	-0.5	51444.7755	.1830	-1.1	-0.9
47694.9736	.1936	0.2	0.3	51452.8244	.1873	-1.1	-1.0
47725.9248	.2100	-0.6	-0.7	51464.6950	.1936	-0.7	-0.6
47745.9113	.2206	0.2	-0.2	51484.7367	.2043	-0.8	-0.9
47800.8056	.2497	0.9	0.1	51534.5825	.2307	0.5	-0.0
48075.9130	.3959	2.7	-0.4	51711.9709	.3247	2.3	0.2
48109.9291	.4137	3.4	0.0	51785.9237	.3641	2.8	0.1
48165.7557	.4434	3.5	-0.4	51788.7770	.3656	3.1	0.4
48184.7600	.4534	3.6	-0.4	51796.8018	.3699	2.9	0.2
48418.9670	.5777	4.7	-1.2	51810.7897	.3773	3.0	0.1
48448.8345	.5937	5.2	-0.9	51824.7739	.3845	3.3	0.3
48459.9031	.5994	5.4	-0.8	51831.7639	.3884	2.8	-0.2
48520.7706	.6317	6.5	-0.3	51866.6362	.4069	3.2	-0.1
48529.7689	.6365	6.8	-0.0	51936.5844	.4440	4.6	0.7
48557.6834	.6513	6.8	-0.2	51937.5796	.4445	4.7	0.8
48757.9716	.7577	9.0	0.2	52052.9794	.5056	5.0	0.2
48768.9631	.7634	8.6	-0.3	52073.9694	.5169	5.0	-0.0
48780.9738	.7698	9.2	0.3	52096.9782	.5291	6.0	0.8
48800.9651	.7804	9.0	-0.1	52150.9223	.5577	5.7	0.1
48816.9241	.7888	9.3	0.1	52163.8354	.5646	5.1	-0.6
48827.9263	.7948	9.8	0.5	52171.7932	.5686	6.0	0.2
48833.9026	.7979	9.7	0.3	52184.7969	.5757	6.2	0.3
48997.6181	.8847	10.7	0.6	52297.5801	.6355	8.1	1.3
49174.9253	.9788	7.0	0.4	52418.9850	.7000	9.7	1.9
49183.9248	.9836	6.1	-0.1	52460.9678	.7222	8.9	0.7
49207.8844	.9964	5.1	0.2	52465.9794	.7247	9.3	1.1
49242.8377	3.0148	3.5	0.3	52488.9514	.7371	8.4	0.0
49262.7455	.0254	2.1	-0.1	52534.8593	.7614	9.5	0.7
49270.7531	.0296	1.8	-0.1	52544.8153	.7667	7.8	-1.1
49285.6724	.0375	0.8	-0.6	52564.7953	.7773	9.3	0.2
49303.6637	.0472	0.4	-0.3	52579.7688	.7850	9.3	0.1
49337.5972	.0651	0.1	0.2	52599.6763	.7958	8.7	-0.6
49369.5881	.0821	-0.5	0.0	52647.5825	.8212	10.3	0.6
49382.5814	.0890	-1.5	-0.8	52796.9670	.9005	9.0	-1.1
49460.0146	.1300	-0.9	-0.1	52817.9582	.9116	10.0	0.0
49490.9800	.1465	-0.7	-0.1	52873.9128	.9411	9.5	0.4
49508.9641	.1560	-0.3	0.2	52880.9527	.9451	9.9	1.0
49541.9573	.1735	-0.5	-0.1	52885.9212	.9477	9.6	0.8
49557.9418	.1820	-0.5	-0.0	52907.8713	.9593	7.6	-0.5
49600.8302	.2048	-0.4	-0.6	52935.7296	.9741	5.9	-1.1
49628.7905	.2196	-0.0	-0.4	52957.7361	.9855	5.6	-0.4
49662.6172	.2375	1.4	0.8	52964.7858	.9895	5.4	-0.2
49676.6171	.2450	0.8	0.0	52970.6423	.9926	5.4	0.0
49691.5942	.2529	1.0	0.1				

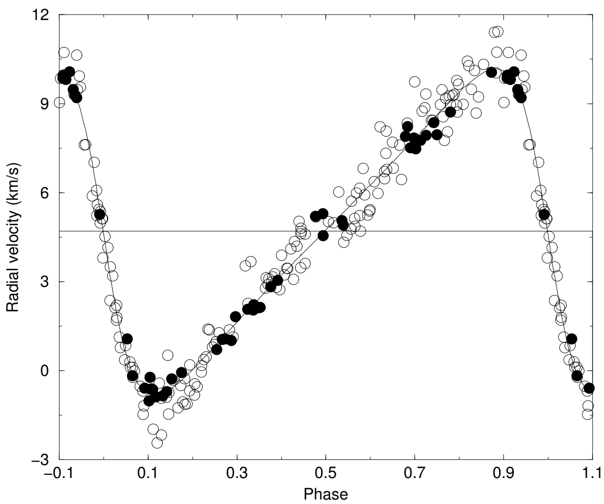

Fig. 3. The observed DAO radial velocities of HR 212989, with the curve derived from the adopted elements drawn through them. The symbols have the same meaning as for Figure 1, except that there are no rejected data.

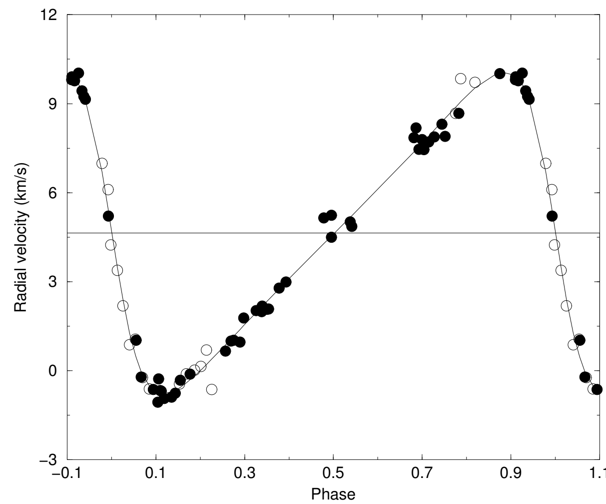

Fig. 4. The observed DAO CCD radial velocities of HR 212989, and those from CfA that were used by Massarotti et al. (2008) with the curve derived from the elements obtained from all those data drawn through them. The DAO data are shown as filled circles, and the CfA data as open circles.

Massarotti et al. (2008), those CfA data are also reproduced in Table 9. In that solution the CfA data were given weight 0.5, but no adjustment of their zero point was necessary.

In all tables the residuals are those from the final solution, except for the CfA data, where they are from the CfA-CCD solution mentioned above and included in Table 10. The velocity curves from the solution from DAO data only, and from the CfA-CCD solution, are drawn through the corresponding data in Figures 3 and 4 respectively. As can be seen the CfA-CCD solution is very similar to that from DAO data only, attesting to the very satisfactory way in which the CfA data conform to the new solution. In fact it is clear that the origin of the erroneous solution presented by Massarotti et al. (2008) is simply that they were unfortunate in placing their final observation on the wrong branch of the velocity curve.

5. DISCUSSION

All three binaries discussed in this paper show no trace of faint companions in our data, and it must be concluded that the companions must be at least 2.5 magnitudes fainter than the primaries, especially if their spectral types are similar. Despite this, it might be possible to detect the companions interferometrically. We estimate below values of the likely angular separation of the stars at apastron, on two different assumptions. For both, we make the plausible assumption that the primary's mass is twice that of the Sun in the cases of 6 Per and HR 8078, and 1.2 solar masses for HD 212989, for want of evidence to the contrary. We make use of the following two equations. The first is the equation of the mass function, in which M_1 is the primary's mass, M_2 is that of the secondary, and $q = M_2/M_1$.

$$\frac{f(M)}{M_1 \sin^3 i} = \frac{q^3}{(1+q)^2} \qquad (1)$$

The second equation is for the projected separation ρ at apastron, in terms of the parallax π, the mass ratio q, and the eccentricity e, the argument of periastron ω, the inclination i, and $a_1 \sin i$.

$$\rho = \pi\,(a_1 \sin i)\,(1+q^{-1})\,(1+e)\sin\omega\cot i \qquad (2)$$

Our first method begins by assuming that despite the luminosity differences between the stars, they are similar in mass, as was found for the components of HR 6046 by Scarfe et al. (2007), where the companion was detected with difficulty. Here, let us assume that $q = 0.9$ for all three binaries. In that case equation (1) gives inclinations of $43^\circ\!.6$, $31^\circ\!.2$, and $26^\circ\!.9$ for 6 Persei, HR 8078 and HD 212989 respectively. These values, the relevant elements, and the *Hipparcos* parallaxes, entered into equation (2), yield angular separations at apastron of 87, 20 and 81 mas for the three binaries.

TABLE 8

CCD RADIAL VELOCITIES OF HD 212989

Julian Date −2,400,000	Cycle No. & Phase	R.V. km s^{-1}	O−C km s^{-1}	Julian Date −2,400,000	Cycle No. & Phase	R.V. km s^{-1}	O−C km s^{-1}
53180.9457	5.1042	-0.23	0.58	54695.9571	.9080	9.86	-0.16
53187.9541	.1079	-0.62	0.21	54708.8515	.9149	9.82	-0.09
53204.9695	.1170	-0.89	-0.06	54724.8892	.9234	10.08	0.36
53251.8758	.1419	-0.71	-0.00	54739.8310	.9313	9.48	-0.01
53272.8604	.1530	-0.28	0.32	54754.7573	.9392	9.20	0.01
53314.7687	.1752	-0.07	0.26	54852.5847	.9911	5.26	-0.20
53542.9589	.2963	1.82	0.24	55042.9717	6.0921	-0.59	0.12
53594.9464	.3239	2.07	0.05	55076.8316	.1101	-0.64	0.19
53618.8871	.3366	2.04	-0.18	55766.9888	.4763	5.20	0.82
53619.8451	.3371	2.16	-0.07	55798.8729	.4932	5.29	0.66
53620.8551	.3376	2.22	-0.02	56148.9217	.6789	7.90	0.42
53640.8079	.3482	2.12	-0.29	56157.9509	.6837	8.23	0.67
53647.8253	.3519	2.13	-0.34	56184.8531	.6980	7.84	0.06
53692.6898	.3757	2.83	-0.01	56513.9475	.8726	10.06	-0.09
53721.6642	.3911	3.04	-0.04	56581.7966	.9086	9.96	-0.05
53914.9421	.4937	4.55	-0.09	56631.6417	.9350	9.30	-0.06
53994.8867	.5361	5.06	-0.22	56853.9864	7.0530	1.07	0.66
54000.8800	.5392	4.91	-0.42	56875.9542	.0647	-0.17	-0.09
54285.9683	.6905	7.51	-0.15	56945.7682	.1017	-1.02	-0.22
54307.9768	.7022	7.48	-0.37	57004.6682	.1329	-0.85	-0.08
54327.9855	.7128	7.76	-0.26	57232.9913	.2541	0.71	-0.18
54351.8404	.7255	7.93	-0.29	57256.9600	.2668	1.05	-0.04
54384.8422	.7430	8.36	-0.14	57267.9632	.2726	1.07	-0.12
54397.6975	.7498	7.95	-0.66	57294.8452	.2869	1.01	-0.41
54455.6695	.7805	8.72	-0.37				

TABLE 9

CFA RADIAL VELOCITIES OF HD 212989

Julian Date −2,400,000	Cycle No. & Phase	R.V. km s^{-1}	O−C km s^{-1}	Julian Date −2,400,000	Cycle No. & Phase	R.V. km s^{-1}	O−C km s^{-1}
48789.8289	2.7754	8.67	-0.21	49344.5245	.0698	-0.24	-0.11
48811.8584	.7871	9.84	0.78	49373.4591	.0852	-0.62	-0.11
48871.6095	.8188	9.72	0.19	49500.8219	.1528	-0.45	0.13
49172.8300	.9787	6.99	0.29	49530.7768	.1687	-0.11	0.30
49198.7784	.9925	6.10	0.65	49564.7900	.1867	0.01	0.19
49237.7163	3.0131	3.38	-0.10	49591.6643	.2010	0.14	0.12
49260.7318	.0253	2.18	-0.22	49615.6679	.2137	0.69	0.49
49289.6171	.0407	0.87	-0.40	49638.6335	.2259	-0.64	-1.03
49313.5625	.0534	1.06	0.53	52978.4776	4.9984	4.24	-0.63

TABLE 10

ORBITAL ELEMENTS

Object Data used	6 Per RVS, CCD	HR 8078 RVS, CCD, RFG	HD 212989 RVS, CCD	HD 212989 CCD, CfA
P (days)	1576.23±0.04	2681.08±0.62	1884.8±1.5	1884.2±1.9
T (J.D. − 2,450,000)	307.31±0.12	2898.3±0.9	1099.7±5.5	2981.4±7.0
K (km s^{-1})	19.82±0.06	8.66±0.05	5.50±0.05	5.44±0.06
e	0.8828±0.0007	0.7350±0.0024	0.436±0.008	0.435±0.010
ω (degrees)	266.4±0.3	197.2±0.4	90.7±1.5	89.4± 1.8
γ (km s^{-1})	25.84±0.04	−20.24±0.03	4.70±0.04	4.64±0.04
S.E. (wt. 1) (km s^{-1})	0.333	0.235	0.328	0.316
a_1 sin i (Gm)	201.8±0.9	216.5±1.6	128.4±1.4	126.9±1.6
$f(M)$ ($M_\odot$)	0.1321±0.0017	0.0564±0.0012	0.0238±0.0008	0.0230±0.0009

The second method is follow the procedure used by Scarfe and Griffin (2012) for HD 23052, namely to assume for all three binaries the average value of $\sin^3 i$, which for a random distribution is 0.589 (Scarfe 1970). This turns equation (1) into a cubic equation in q, which yields mass ratios of 0.68, 0.47 and 0.405 for the three stars in the above order, and then equation (2) yields angular separations at apastron of 63, 12 and 44 mas for each. These results are slightly smaller than those for $q = 0.9$, but similar in order of magnitude.

We can perhaps do a little better in the case of 6 Persei. Pourbaix and Boffin (2003) made use of the *Hipparcos* intermediate astrometric data to find an inclination of 104°, and assuming a primary mass twice that of the Sun, as we have done above, found $q = 0.56$. Using these results in equation (2) yields an apastron separation of 27 mas. This smaller result is primarily due to the high inclination, so despite the very eccentric orbit of 6 Per, the angular separation may be larger at phases other than apastron.

For HD 212989 we can choose to adopt the preliminary mass ratio of 0.72 found by Halbwachs et al. (2014), which yields an inclination of 32°.7 and a separation at apastron of 73 mas.

An alternative, and somewhat different approach is to estimate the angular sizes of the systems' major semiaxes, using Kepler's Third Law and their parallaxes, by means of equation (3), in which a and π are the major semiaxis and parallax, P is the period in years and M is the total mass of the system in solar units.

$$a = \pi P^{2/3} M^{1/3} \quad (3)$$

As it happens all the previously described methods yield cube roots of the total mass close to 1.5 $M_\odot^{1/3}$ for both 6 Per and HR 8078, and 1.25 $M_\odot^{1/3}$ for HD 212989. Those values lead to angular major semiaxes of 61 mas for 6 Per, 46 mas for HR 8078 and 60 mas for HD 212989.

All of these approaches yield angular separations that are amenable to modern interferometry, depending, of course, on the correctness of our underlying assumption that the secondary is a main-sequence star and not a more compact object. That assumption appears to be correct in the case of HD 212989, from the work of Halbwachs et al., but is unproven for the other two systems. Interferometric observations would yield much valuable information on all three. It is to be noted that the above discussion is intended only to give the order of magnitude of the likely separations, since phases other than apastron may give larger values, and better parallaxes from *GAIA* or other sources may alter the details of the results, but not the conclusion that interferometric observation is possible. Ultimately, reliable detection of the secondaries will permit confident determination of masses and other fundamental properties.

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