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THE SPECTROSCOPIC ORBITS OF HD 23052 AND HD 90512

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RESUMEN

Presentamos observaciones de velocidades radiales obtenidas en el DAO y en Cambridge, a partir de las cuales obtenemos elementos orbitales. HD 23052 es un objeto tipo G de secuencia principal, que se ha considerado como análogo al Sol. Su órbita tiene un período de cerca de tres años. HD 90512 es una gigante de tipo G, en una órbita casi circular con un período de poco más de 100 días.

ABSTRACT

We present radial-velocity observations from DAO and Cambridge, from which we derive orbital elements. HD 23052 is a G-type main-sequence object which has been regarded as a solar analogue, in an orbit of period nearly three years. HD 90512 is a G-type giant in a nearly circular orbit with a period just over 100 days.

Key Words: binaries: spectroscopic

1. INTRODUCTION

Each of the authors started to observe the two objects discussed in this paper independently of the other. However, on discovering their mutual interest they agreed to collaborate. It has taken some time for the project to come to fruition, in part because one of them (C. D. S.) was obliged to switch to a new instrument partway along, as a result of the decommissioning of the original one. However, as will be seen, the switch proved advantageous as far as precision was concerned.

2. BACKGROUND INFORMATION

2.1. *HD 23052*

HD 23052 = HIP 17336 [$\alpha = 3^h\ 42^m\ 33^s.9$, $\delta = +17^\circ\ 17'\ 37''$ (J2000)], lies near the western boundary of Taurus. Its UBV magnitudes (Oja 1987) are $V = 7.08$, B–$V = 0.66$, U–$B = 0.18$, so it is just bright enough to be included in the *Supplement to the Bright Star Catalogue* (Hoffleit, Saladyga, & Wlasuk 1983), whose limiting visual magnitude is 7.1. As it happens, Perry (1969) published Strömgren indices for HD 23052, well before Johnson magnitudes were determined.

The *Hipparcos* parallax of HD 23052, 38.75 mas (ESA 1997), was revised to 40.55 ± 1.11 mas by van Leeuwen (2007); that yields a visual absolute magnitude of 5.12 ± 0.06. The star's proper motion, $\mu_\alpha = -125$ mas yr^{-1}, $\mu_\delta = 33$ mas yr^{-1}, places it in the nearby disk population. *Hipparcos* also detected the orbital motion of the system's centre of light about its centre of mass.

The HD spectral type of HD 23052 is G0, but Abt (2004) classified it as G7V, while Gray et al. (2003) regard it as G4V, and thus very similar to the Sun, but slightly cooler, with an effective temperature of 5639 K. Takeda et al. (2010) found that it has slightly lower overall metallicity than the Sun ([Fe/H]=-0.12). They also estimated its age to be about 3.9×10^9 years, largely upon the basis of its low lithium abundance.

The *Supplement to the Bright Star Catalogue* gives no radial velocity for HD 23052. The first radial velocities known to the authors were published by Abt & Willmarth (1994), whose five velocities, taken over a time span of a little over two years, show a range of 16 km s^{-1}. However, they did not continue to follow those variations. Their data are reproduced for reference in Table 1, with phases and residuals relative to the orbital elements to be derived below.

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TABLE 1

ABT & WILLMARTH VELOCITIES OF HD 23052

Julian Date −2,400,000	Cycle No. & Phase	R.V. km s^{-1}	O−C km s^{-1}
47488.89	0.1238	−14.8	+0.7
47489.86	.1248	−14.8	+0.7
47766.97	.3938	−6.0	−0.7
48160.98	.7763	+1.2	+0.5
48226.73	.8401	−2.9	−0.9

2.2. *HD 90512*

HD 90512 = HIP 51179 [α = 10^h 27^m $12^s.2$, δ = +11° 19′ 2″ (J2000)], lies in Leo, about 4°.7 following Regulus. Its *UBV* magnitudes were measured by Rybka (1969, 1979) as $V = 6.70$, B–V = 0.83, U–B = 0.56. In addition, Olsen (1993) published Strömgren indices for the star, and Janes & McClure (1971) obtained DDO photometry in their study of possible CN-rich stars.

The *Hipparcos* parallax (van Leeuwen 2007) of HD 90512 is 8.05 ± 0.56 mas, which leads to an absolute visual magnitude of 1.23 ± 0.15. The star's proper motion, $\mu_\alpha = -39$ mas yr^{-1}, μ_δ = 14 mas yr^{-1}, indicates a modest space velocity, as in the case of HD 23052. Harlan (1969) gave G5III as the spectral type of HD 90512, which is consistent with the above absolute magnitude and colour index.

As in the case of HD 23052, the *Supplement to the Bright Star Catalogue* gives no radial velocity for HD 90512, and the first published radial velocities known to the authors are again those of Abt & Willmarth (1994), who obtained data on 12 nights spread over a little longer than two years. Their data are reproduced in Table 2.

3. NEW OBSERVATIONS AND ORBITS

By chance, one of the authors (C.D.S.) began to observe HD 90512 in the same year as Abt & Willmarth (1994) began to do so, and obtained a single observation of HD 23052 only a year after their first two observations, as part of a programme to obtain radial velocities for stars that lacked them in the *Supplement to the Bright Star Catalogue* (Hoffleit et al. 1983). However, he then left the latter star unobserved for nine years, beginning again in earnest only in the late 1990s. All the early observations were made with the radial-velocity spectrometer (Fletcher et al. 1982) at the coudé focus of the DAO 1.22-m telescope. 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

TABLE 2

ABT & WILLMARTH VELOCITIES OF HD 90512

Julian Date −2,400,000	Cycle. No. & Phase	R.V. km s^{-1}	O−C km s^{-1}
47191.92	0.2169	+9.9	+0.4
47209.77	.3893	+12.1	−0.4
47211.88	.4097	+11.0	−0.3
47254.74	.8237	−27.1	−0.2
47255.77	.8337	−27.4	−0.5
47582.76	3.9922	−17.4	−0.5
47898.03	7.0376	−12.8	−1.3
47899.01	.0470	−10.7	−0.4
47993.79	.9626	−21.3	−1.3
47994.74	.9717	−16.3	+2.8
47995.73	.9813	−16.4	+1.7
47996.74	.9911	−15.4	+1.6

TABLE 3

ADOPTED VELOCITIES OF STANDARD STARS

Star	Velocity (km s^{-1})
α Ari	−14.5
α Boo	−5.3
α Cas	−4.3
β CVn	6.3
β Gem	3.3
β Vir	4.4
κ Her	−10.2
o Aql	0.0
10 Tau	28.0
16 Vir	36.5
31 Aql	−100.3
35 Peg	54.3
HR 3145	71.7
HR 6349	−16.8

TABLE 4

DAO VELOCITIES OF HD 23052

Julian Date −2,400,000[a]	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}
47878.77	0.5023	−1.4	−0.8	53594.98	6.0519	−13.9	+0.3
51165.77	3.6935	+2.2	−0.4	53618.98	.0752	−14.8	0.0
51223.63	.7497	+1.6	−0.3	53620.00	.0762	−14.8	0.0
51435.99	.9558	−9.0	0.0	53620.98	.0771	−14.6	+0.2
51492.89	4.0111	−12.6	−0.2	53640.98	.0966	−14.7	+0.4
51623.63	.1380	−15.4	−0.4	53647.94	.1033	−15.4	−0.3
51634.65	.1487	−15.6	−0.8	53700.85	.1547	−14.9	−0.2
51788.99	.2986	−9.7	−0.4	53721.79	.1750	−14.2	0.0
51810.97	.3199	−9.0	−0.7	53782.63	.2341	−12.4	−0.2
51866.84	.3741	−6.2	−0.4	53784.64	.2360	−12.2	−0.1
51936.70	.4420	−2.4	+0.4	53788.65	.2399	−11.9	+0.1
51950.65	.4555	−2.4	−0.1	53802.65	.2535	−11.6	−0.2
52163.98	.6626	+3.5	+0.9	53995.03	.4403	−2.8	+0.1
52184.96	.6830	+2.9	+0.2	54000.99	.4461	−2.9	−0.2
52220.83	.7178	+3.0	+0.6	54006.94	.4518	−2.5	−0.1
52278.73	.7740	+1.4	+0.2	54012.04	.4568	−2.2	0.0
52297.65	.7924	+2.0	+1.4	54047.89	.4916	−0.8	+0.1
52489.01	.9782	−10.1	+0.4	54104.72	.5468	+0.8	0.0
52516.99	5.0053	−11.4	+0.7	54159.64	.6001	+2.1	+0.1
52528.00	.0160	−12.6	+0.1	54180.64	.6205	+2.1	−0.2
52544.98	.0325	−14.0	−0.6	54352.01	.7869	+0.6	−0.2
52564.93	.0519	−14.1	+0.1	54397.93	.8314	−1.3	−0.2
52579.90	.0664	−14.9	−0.3	54404.94	.8382	−1.2	+0.3
52599.82	.0857	−15.3	−0.4	54447.79	.8798	−3.8	+0.1
52619.82	.1052	−15.6	−0.5	54455.80	.8876	−4.7	−0.3
52647.75	.1323	−14.8	+0.2	54486.69	.9176	−6.4	0.0
52691.72	.1750	−15.1	−0.9	54498.68	.9292	−7.0	+0.2
52716.63	.1992	−14.1	−0.6	54531.63	.9612	−9.2	+0.2
52874.02	.3520	−6.9	−0.1	54714.98	7.1392	−15.1	−0.1
52907.97	.3849	−5.0	+0.3	54725.00	.1490	−14.8	0.0
52935.92	.4120	−4.4	−0.3	54739.96	.1635	−14.9	−0.4
52964.84	.4401	−2.6	+0.3	54754.92	.1780	−13.9	+0.3
52996.73	.4711	−1.9	−0.2	54761.96	.1849	−14.0	0.0
53040.62	.5137	+0.3	+0.5	54790.86	.2129	−12.9	+0.1
53251.99	.7189	+2.4	0.0	54852.68	.2729	−10.6	−0.1
53258.97	.7257	+2.6	+0.3	55063.99	.4781	−1.3	+0.1
53272.98	.7393	+1.9	−0.2	55096.99	.5101	−0.2	+0.1
53283.95	.7499	+1.7	−0.1	55139.91	.5518	+1.9	+1.0[b]
53325.87	.7906	+0.8	+0.1	55236.68	.6457	+2.6	0.0
53417.63	.8797	−4.1	−0.2	55448.87	.8517	−0.8	+1.4[b]
53424.64	.8865	−4.5	−0.2	55475.98	.8781	−3.5	+0.3
53448.64	.9098	−6.1	−0.2	55488.95	.8906	−4.4	+0.2

[a]Before JD 2,453,110 – Spectrometer data, weight 0.25; after J.D. 2,453,110 – CCD data, weight 1.00.
[b]Rejected observation.

same spectrograph optics, but using a CCD as detector, and reduced with a 'pipeline' program developed by D. Bohlender. The optical train yields a dispersion of 0.24 nm mm^{-1} for both the CCD and the spectrometer. Radial velocities were determined by averaging the results from cross-correlation with the standard stars β CVn, β Vir, o Aql, 10 Tau, 31 Aql and HR 6349 for HD 23052, and for HD 90512 with the standards κ Her, α Ari, α Boo, α Cas, β Gem, 35 Peg, 16 Vir, 31 Aql and HR 3145. It should be

TABLE 5

DAO VELOCITIES OF HD 90512

Julian Date −2,400,000[a]	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}
47227.82	0.5637	−4.5	0.0	51632.76	.1131	−1.6	+0.1
47259.76	.8722	−25.9	+0.3	51634.78	.1326	+0.8	+0.1
47263.71	.9104	−24.1	+0.2	51662.73	.4026	+11.0	−0.8
47303.72	1.2969	+13.5	−0.2	51689.70	.6631	−17.2	−0.5
47939.91	7.4421	+8.7	−0.2	51711.72	.8758	−26.4	−0.4
47962.91	.6643	−16.9	−0.1	51867.09	45.3766	+13.8	+0.8
47997.71	8.0004	−16.3	−0.3	51936.93	46.0512	−9.5	+0.2
48290.96	10.8331	−28.1	−1.2	51951.91	.1959	+7.2	−0.4
48325.87	11.1703	+5.2	+0.2	52009.68	.7539	−24.4	+0.2
48340.77	.3142	+14.2	+0.2	52010.75	.7643	−24.4	+0.8
48388.75	.7777	−26.0	−0.2	52026.70	.9183	−23.8	−0.1
48604.03	13.8572	−26.6	0.0	52051.71	47.1599	+3.3	−0.6
48730.74	15.0811	−5.9	−0.1	52073.71	.3724	+13.1	−0.1
48735.75	.1295	+0.6	+0.3	52297.88	49.5378	−0.2	+1.1
48960.10	17.2966	+13.4	−0.3	52334.86	.8950	−23.8	+1.4
48997.96	.6623	−16.7	−0.1	52387.77	50.4061	+11.2	−0.3
49041.89	18.0867	−5.4	−0.3	52417.71	.6953	−18.7	+1.3
49061.88	.2797	+13.0	−0.2	52418.71	.7049	−20.8	+0.1
49084.77	.5009	+2.5	−0.6	52565.06	52.1186	−0.8	+0.2
49103.72	.6839	−19.1	−0.2	52647.98	.9196	−22.6	+1.0
49121.70	.8576	−26.7	−0.1	52702.84	53.4495	+8.1	−0.2
49369.95	21.2555	+12.4	+0.3	52716.82	.5845	−7.2	0.0
49382.90	.3806	+13.2	+0.3	52745.81	.8646	−27.6	−1.2
49417.85	.7182	−21.8	+0.3	52761.75	54.0185	−14.3	−0.5
49418.84	.7278	−23.1	−0.3	52768.70	.0857	−5.4	−0.2
49442.75	.9587	−19.8	+0.6	52774.71	.1437	+2.0	0.0
49451.78	22.0460	−10.5	−0.1	52796.72	.3563	+12.7	−1.0
49459.75	.1230	−0.9	−0.4	52983.07	56.1564	+2.5	−1.0
49490.74	.4223	+10.9	+0.4	53040.90	.7150	−20.7	+1.1
49677.08	24.2223	+9.6	−0.3	53109.69	57.3794	+13.2	+0.3
49803.78	25.4461	+9.1	+0.5	53117.75	.4573	+7.3	−0.3
49813.79	.5428	−1.9	0.0	53144.72	.7178	−21.8	+0.2
49840.69	.8026	−25.8	+0.8	53417.88	60.3564	+13.7	0.0
49849.70	.8897	−25.3	+0.1	53424.90	.4242	+10.4	+0.1
50124.99	28.5488	−2.1	+0.6	53454.78	.7128	−21.4	+0.2
50160.80	.8947	−25.6	−-0.4	53468.73	.8476	−26.6	+0.2
50181.77	29.0973	−3.6	+0.1	53495.72	61.1083	−2.0	+0.3
50187.72	.1548	+3.7	+0.4	53507.70	.2240	+9.6	−0.4
50213.72	.4059	+11.5	−0.1	53515.71	.3014	+13.2	−0.6
50218.70	.4540	+7.4	−0.5	53522.73	.3692	+13.3	0.0
50232.70	.5892	−8.0	−0.2	53722.05	63.2945	+14.0	+0.3
50246.72	.7247	−23.7	−1.1	53782.85	.8818	−25.8	0.0
50252.72	.7826	−26.3	−0.3	53784.87	.9013	−24.9	−0.1
50437.00	31.5627	−4.7	−0.3	53788.95	.9407	−21.7	+0.3
50461.93	.8035	−26.5	+0.1	53823.75	64.2769	+13.1	0.0
50475.95	.9389	−21.7	+0.5	53836.75	.4025	+11.6	−0.2
50503.84	32.2083	+9.4	+0.7	53850.71	.5373	−1.8	−0.6
50531.81	.4785	+5.7	+0.2	53860.69	.6337	−12.7	+0.6
50577.71	.9219	−23.9	−0.4	53871.72	.7402	−23.9	−0.2
50588.70	33.0280	−12.7	0.0	54092.01	66.8681	−26.1	+0.2
50765.09	34.7318	−23.0	+0.2	54120.92	67.1474	+2.0	−0.5
50795.03	35.0211	−13.7	−0.2	54159.84	.5233	+0.1	−0.4
50804.07	.1084	−3.1	−0.8	54180.83	.7261	−22.6	+0.1
50858.82	.6372	−13.1	+0.6	54207.74	.9860	−17.2	+0.4
50917.73	36.2063	+8.1	−0.5	54486.97	70.6832	−18.6	+0.2
50925.69	.2832	+13.0	−0.3	54526.84	71.0684	−7.4	+0.1
50931.70	.3412	+13.9	−0.1	54531.87	.1169	−1.6	−0.4
50946.68	.4859	+4.0	−0.7	54561.73	.4054	+11.5	−0.1
50973.73	.7472	−24.4	−0.2	54567.76	.4636	+6.5	−0.5
51154.07	38.4892	+4.0	−0.4	54586.74	.6470	−14.4	+0.5
51166.04	.6048	−9.3	+0.4	54593.71	.7143	−21.5	+0.2
51202.94	.9612	−20.4	−0.3	54594.71	.7239	−22.1	+0.4
51223.92	39.1639	+4.4	+0.1	54602.70	.8011	−26.8	−0.2
51243.82	.3561	+13.7	0.0	54852.93	74.2182	+9.6	0.0
51284.72	.7512	−25.7	−1.2	54893.83	.6133	−10.6	+0.2
51317.71	40.0699	−8.8	−1.5	54926.77	.9315	−22.4	+0.4
51325.72	.1472	+1.5	−1.0	54957.70	75.2302	+10.5	0.0
51344.73	.3309	+12.7	−1.3	54966.73	.3175	+14.2	+0.2
51485.09	41.6867	−18.4	+0.8	55287.81	78.4189	+10.4	−0.3
51623.81	43.0266	−12.3	+0.5	55302.78	.5635	−4.9	−0.4

[a]Before JD 2,453,110 – Spectrometer data, weight 0.25; after J.D. 2,453,110 – CCD data, weight 1.00.

TABLE 6

CAMBRIDGE VELOCITIES OF HD 23052

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}
51823.61	4.3322	−7.6	+0.2	52881.67	.3594	−6.6	−0.1
51830.58	.3389	−7.7	−0.3	53029.44	.5028	−0.8	−0.3
51834.65	.3429	−7.1	+0.2	53095.31	.5668	+0.9	−0.4
51861.57	.3690	−5.8	+0.2	53249.66	.7166	+2.6	+0.2
51878.52	.3855	−5.2	+0.1	53414.33	.8765	−3.7	0.0
51892.49	.3990	−4.7	0.0	53454.31	.9153	−6.3	−0.1
51906.48	.4126	−4.1	0.0	53641.66	6.0972	−15.1	0.0
51923.37	.4290	−3.2	+0.2	53704.47	.1582	−14.6	0.0
51941.36	.4465	−2.7	−0.1	53740.38	.1931	−13.6	+0.1
51955.33	.4600	−1.9	+0.2	53775.38	.2270	−12.5	0.0
51981.36	.4853	−0.8	+0.3	53792.34	.2435	−12.2	−0.4
52136.57	.6360	+2.4	−0.1	54035.56	.4796	−0.8	+0.6
52182.61	.6807	+3.4	+0.7	54075.60	.5185	−0.4	−0.4
52201.57	.6991	+2.3	−0.3	54102.47	.5446	+0.2	−0.5
52239.57	.7360	+1.5	−0.6	54137.36	.5785	+1.4	−0.2
52258.45	.7543	+1.8	+0.1	54157.28	.5978	+2.0	0.0
52292.38	.7873	+0.9	+0.1	54507.33	.9376	−7.6	+0.2
52320.31	.8144	+0.0	+0.3	54522.32	.9522	−9.0	−0.2
52343.33	.8367	−1.1	+0.3	54555.31	.9842	−11.1	−0.2
52363.31	.8561	−3.2	−0.8	54837.35	7.2580	−11.3	−0.1
52519.66	5.0079	−12.3	0.0	54851.38	.2717	−10.5	+0.1
52551.62	.0390	−13.8	−0.1	54865.34	.2852	−9.5	+0.5
52585.56	.0719	−14.5	+0.2	54883.34	.3027	−8.8	+0.4
52655.43	.1397	−14.6	+0.3	55116.62	.5292	+0.3	0.0
52688.32	.1717	−14.0	+0.3				

noted that wavelength consistency is maintained by frequent observations on every night of a thorium–argon hollow-cathode lamp, and that the standard-star observations used for cross-correlation are a set of heavily exposed high-signal-to-noise spectra which are kept in a 'library' along with the relevant spectra from the hollow-cathode lamp. In a sense this continues the technique of the spectrometer which used a mask, which the standard spectra are replacing. The standards are similar in type to the binaries with which they were used, at least insofar as the formal uncertainty of the velocity derived from cross-correlation is concerned. The ones used were those that gave the lowest formal uncertainty, which was taken as indicating the best match of the spectra. Because the velocities obtained with each standard differ systematically from those with others, several standards were used, to average this effect out, or at least to reduce its size. But because the standards were different for the two stars, the zero points of the CCD velocities are not necessarily the same.

The radial velocities adopted for the standard stars are presented in Table 3. In some cases they differ slightly from those presented by Scarfe (2010); that is because they are weighted means of those velocities and many obtained with the spectrometer, whose zero point was adjusted to that of Scarfe (2010) by the same amount for all stars. The CCD observations have been found to show less scatter than the ones made earlier with the spectrometer. Some 34 spectrometer, and 50 CCD, observations of HD 23052, and 100 spectrometer, and 40 CCD, observations of HD 90512, are available for orbit determination. Those data are presented in Tables 4 and 5.

The interest of R.F.G. in the two objects was aroused by the work of Abt & Willmarth (1994). His observations of them began in 2000, soon after the commissioning of the current Cambridge *Coravel*, which is optically analogous to the *Coravel* spectrometer developed at the Geneva and Marseilles observatories (Baranne, Mayor & Poncet 1979). Tables 6 and 7 present 49 Cambridge observations of HD 23052 and 73 of HD 90512.

Spectroscopic orbital elements have been determined for both stars from all the available data. It

TABLE 7

CAMBRIDGE VELOCITIES OF HD 90512

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}
51861.74	45.3249	+14.3	+0.2	52328.55	.8340	−27.0	−0.1
51868.73	.3924	+12.4	+0.1	52334.55	.8920	−25.4	−0.1
51880.73	.5083	+2.2	0.0	52335.55	.9017	−24.5	+0.3
51887.71	.5758	−6.3	−0.2	52341.53	.9594	−20.8	−0.5
51908.59	.7775	−26.3	−0.5	52343.52	.9786	−18.2	+0.2
51915.65	.8456	−26.6	+0.2	52360.47	50.1424	+2.1	+0.2
51920.65	.8939	−25.0	+0.2	52361.48	.1521	+3.0	−0.0
51923.64	.9228	−23.8	−0.4	52362.46	.1616	+4.2	+0.1
51947.59	46.1542	+3.5	+0.2	52363.54	.1720	+5.3	+0.1
51957.60	.2509	+11.5	−0.3	52368.47	.2196	+10.0	+0.3
51962.57	.2989	+14.0	+0.2	52369.43	.2289	+10.7	+0.3
51970.63	.3767	+13.1	+0.1	52370.45	.2388	+11.3	+0.2
51973.55	.4049	+11.7	+0.1	52371.43	.2482	+12.1	+0.4
51979.55	.4629	+7.6	+0.6	52375.38	.2864	+13.9	+0.5
52028.42	.9349	−22.2	+0.3	52381.41	.3446	+14.2	+0.3
52034.43	.9930	−16.5	+0.3	52384.41	.3736	+13.5	+0.3
52037.42	47.0219	−13.2	+0.2	52388.43	.4125	+11.4	+0.3
52041.40	.0603	−8.3	+0.2	52389.43	.4221	+10.6	+0.1
52214.72	48.7345	−23.5	−0.2	52391.44	.4415	+9.1	+0.1
52218.74	.7733	−26.0	−0.4	52399.42	.5186	+1.3	+0.3
52227.76	.8605	−27.2	−0.7	52644.68	52.8877	−25.8	−0.3
52255.72	49.1305	0.0	−0.5	52666.62	53.0996	−3.3	+0.1
52258.66	.1589	+3.4	−0.4	52688.54	.3114	+14.2	+0.2
52263.65	.2071	+8.8	+0.2	52692.57	.3503	+14.1	+0.3
52273.64	.3036	+13.6	−0.3	52714.52	.5623	−4.4	0.0
52275.66	.3232	+14.0	−0.1	52722.46	.6390	−13.9	0.0
52276.62	.3324	+13.6	−0.4	52745.44	.8610	−26.5	0.0
52277.62	.3421	+14.7	+0.7	52981.73	56.1434	+1.9	−0.1
52278.69	.3524	+13.4	−0.4	53021.69	.5294	−0.6	−0.3
52292.59	.4867	+4.2	−0.4	53044.59	.7506	−24.8	−0.4
52299.61	.5545	−3.5	−0.1	53115.44	57.4350	+9.8	+0.3
52305.64	.6127	−10.5	+0.2	53504.43	61.1924	+7.2	−0.1
52309.62	.6512	−15.3	+0.1	53764.61	63.7056	−21.0	0.0
52312.54	.6794	−18.4	0.0	54221.42	68.1182	−1.2	−0.1
52319.57	.7473	−24.1	+0.1	54929.42	74.9571	−20.4	+0.1
52320.53	.7566	−25.3	−0.5	55248.59	78.0401	−11.1	0.0
52326.63	.8155	−27.1	−0.3				

was found necessary to subtract 1.3 km s^{-1} from the Cambridge observations to bring their zero point into agreement with the DAO data. Weights were derived from the r.m.s. residuals in separate solutions of the data. The Cambridge and DAO CCD data were each weighted 1.0 in the final solutions, and the DAO spectrometer data were given weight 0.25. By trial and error, weights of 0.05 were assigned to the data of Abt & Willmarth (1994). As indicated in Table 4, two CCD observations of HD 23052 were rejected; those observations were obtained on poor nights, and their residuals were respectively 3.3 and 4.5 times the r.m.s. residual of all the data of unit weight in a solution made prior to their rejection. No other residual exceeds three times the r.m.s. value for data of equal weight.

For HD 90512 the eccentricity is very small, and the argument of periastron is consequently uncertain. But since the eccentricity is about four times its own uncertainty, and since separate solutions of each group of data (Cambridge, DAO spectrometer and DAO CCD) yield arguments of periastron of similar uncertainty, that agree with each other within their uncertainties, all of them falling well within the third

TABLE 8

ORBITAL ELEMENTS

Element	HD 23052	HD 90512
P (days)	1030.0±0.6	103.525±0.002
T (J.D. −2,450,000)	3,542±5	2,139±5
T_0 (J.D. −2,450,000)		2,069.07±0.05
γ (km s^{-1})	−5.53±0.02	−6.36±0.03
K (km s^{-1})	8.89±0.04	20.48±0.03
e	0.125±0.004	0.0066±0.0016
ω (degrees)	129±2	242±16
a_1 sin i (Gm)	125.0±0.5	29.15±0.05
$f(M)$ ($M_\odot$)	0.0735±0.0009	0.0923±0.0005
S.E. (wt. 1) (km s^{-1})	0.25	0.29

quadrant, the eccentricity is regarded as real. Further confirmation has been obtained by applying the second test of Bassett (1978), which shows that the eccentricity is statistically significant at the level of 1%. The elements are presented in Table 8. The velocities of HD 23052 and HD 90512 are plotted, together with curves calculated from the elements in Table 8, in Figures 1 and 2, respectively.

4. DISCUSSION

Neither of us has detected in our observations any signature of the secondary star in either of the two binaries. Nevertheless, the mass functions clearly indicate the presence of an object of stellar mass. No observations of eclipses have been reported for either system. That of course means only that the orbits are not seen edge-on, but the range of inclinations thus excluded is very small for HD 23052, where the primary is a main-sequence object and the period is long.

For HD 23052, *Hipparcos* detected evidence of orbital motion. As a first approximation, a circular orbit was fitted to the data, which yielded an inclination $i = 78^\circ \pm 2^\circ$. That inclination should be fairly reliable, since the major semi-axis of the photocentric orbit is about 20 times its formal uncertainty. But at our request, F. van Leeuwen (2012, private communication) has kindly re-analysed the *Hipparcos* astrometry, adopting our orbital period and eccentricity. His results include revised values of the proper motion, $\mu_\alpha = -119.6 \pm 1.4$ mas yr^{-1}, $\mu_\delta = 39.0 \pm 1.7$ mas yr^{-1}, and of the parallax, 39.05 ± 0.64 mas. The latter, in turn, yields an absolute visual magnitude of 5.04 ± 0.04, slightly closer to that of the Sun than the value found above. He also found the orbital inclination to be $72^\circ.2 \pm 3^\circ.1$, which we adopt for the following calculation.

For any value of the inclination, a unique relationship between the component masses is defined. If M_1 is the primary mass, and M_2 is that of the secondary, and $q = M_2/M_1$, then the expression for the mass function $f(M)$ is given by equation (1)

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

This is a cubic equation in q, which can be readily solved by iteration for given values of i and M_1, and the solution gives M_2 at once. Since the mass of the primary of HD 23052 is likely to be between 0.9 $M_\odot$ and 1.0 $M_\odot$, we can use equation (1) to show that the inclination constrains the invisible secondary's mass to lie between 0.56 $M_\odot$ and 0.62 $M_\odot$. The secondary is thus likely to be a dwarf of late K or early M type, at least three magnitudes fainter than the primary in V. It might be directly resolvable by interferometry in the near infrared. It is also possible that it is a white dwarf, in which case it should be detectable by its ultraviolet flux. The major semi-axis of the relative orbit might be expected to subtend an angle on the order of $0''.1$, well within the range of modern interferometers.

For HD 90512 no orbital motion has been detected astrometrically, as might be expected since it is farther away and has a shorter period than HD 23052. But let us naïvely assume that $\sin^3 i$ takes on its average value, which for a random distribution is 0.589 (Scarfe 1970). In that case, a plausible mass of 2.0 $M_\odot$ for the primary, coupled with a mass of 1.15 $M_\odot$ for the secondary, would yield

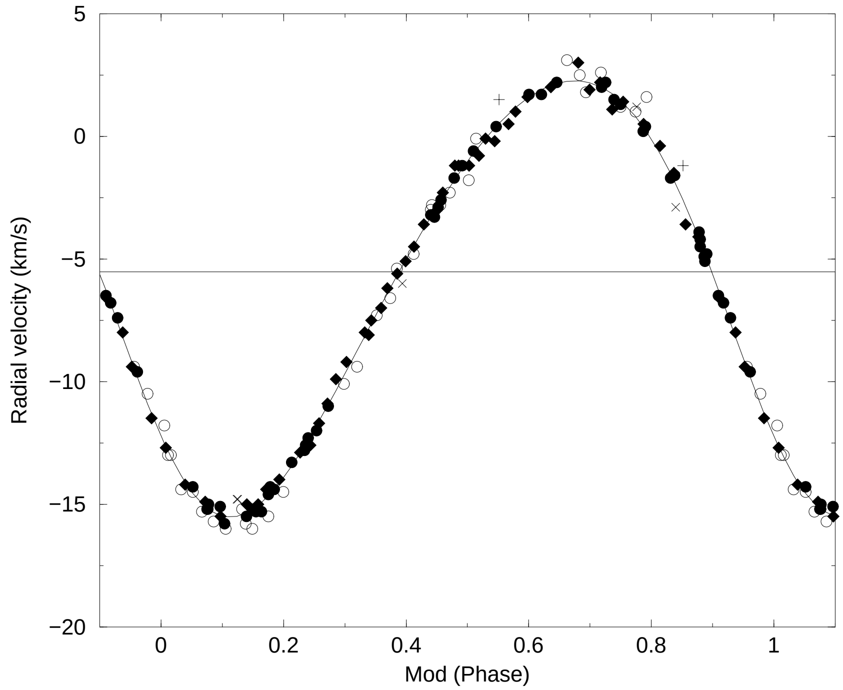

Fig. 1. The observed radial velocities of HD 23052, with the curve derived from the adopted elements drawn through them. The DAO CCD data are shown as filled circles and the spectrometer data as open circles. The Cambridge spectrometer data are filled diamonds, and those of Abt & Willmarth (1994) are crosses. Two rejected CCD velocities are shown as plus signs.

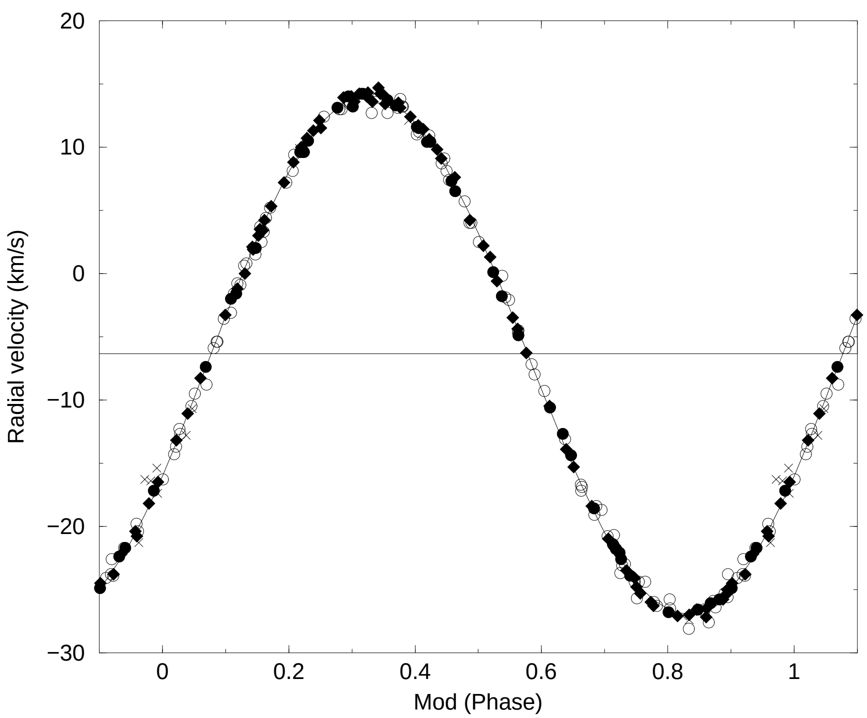

Fig. 2. The observed radial velocities of HD 90512, with the curve derived from the adopted elements drawn through them. The symbols have the same meaning as for Figure 1, except that there are no rejected data.

the observed mass function. The secondary in that case would be similar in spectral type to the primary, and about three magnitudes fainter, and would not be easily detectable. An inclination near the average value cannot therefore be ruled out. And the smaller orbit and greater distance of HD 90512 would lead to an angular major semi-axis of about $0\overset{''}{.}005$. That, and the expected similarity in the components' temperatures, would make HD 90512 much more difficult to resolve interferometrically than HD 23052.

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