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An improved spectroscopic orbit for HD 75767

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Abstract. HD 75767 is a sixth-magnitude solar-type star for which Sanford gave an orbit in 1931 on the basis of 37 low-dispersion Mount Wilson spectrograms. The orbit has a period of 10 days and was attributed a small eccentricity. During the last few years the radial velocity of the object has been measured photoelectrically on 60 occasions, allowing the orbital elements to be considerably refined; the eccentricity is shown to be very close (and quite likely equal) to zero.

Key words : radial velocities—spectroscopic binaries—orbits—stars, individual—HD 75767

1. Introduction

The subject of this paper is a star on the southern border of the constellation Cancer; it forms the northern apex of an almost equilateral triangle, about 2° on a side, whose other vertices are marked by the third-magnitude stars ε and ζ Hya. Its brightness is just below the level that would qualify it for inclusion in the *Bright Star Catalogue* (Hoffleit 1982) but it features in the *Supplement* (Hoffleit, Saladyga & Wlasuk 1983) to that *Catalogue*, as indeed it did in the *Supplement* (Pickering 1908b) to the original edition of the *Bright Star Catalogue*—the *Revised Harvard Photometry* (Pickering 1908a). Its spectrum is of solar type.

2. Proper motion

The characteristic that first drew attention to HD 75767 was its considerable proper motion, amounting to about 0″.30 per annum in position angle 145°. The first accurate measure of the star's position appears to have been made by Lalande (Delalande 1801, Baily 1847); its proper motion was already fully recognized a century ago (Grant 1883, Stumpe 1890, Porter 1892) and led to its inclusion in many lists of proper-motion objects as well as in the general stellar catalogues. Table 1 gives the identifications under which it may be traced in some of the more important catalogues, but it is not by any means exhaustive; there are others, particularly among the older catalogues, which I have been unable to consult, and doubtless there are still others of which I am unaware.

Table 1. Aliases for HD 75767

Catalogue	Number	Reference	Date
Weisse	VIII.1150	Weisse	1846
Lalande	17480	Baily	1847
Bonner Durchmusterung	8°2134	Argelander	1859
Schjellerup	3255	Schjellerup	1864
Glasgow Catalogue	2272	Grant	1883
Second Armagh Catalogue	1035	Robinson & Dreyer	1886
M.P. [Meridian Photometer Cat.]	1179	Pickering & Wendell	1890
Paris Catalogue	10903	Obs. de Paris	1891
Cincinnati 12	489	Porter	1892
Second Glasgow Catalogue	772	Grant	1892
Cincinnati 13	833	Porter	1895
A.G., +5°-+10° zone (Leipzig II)	4850	Bruns & Peter	1899
Romberg II	2033	Seyboth	1909
Cincinnati 18	1042	Porter, Yowell & Smith	1915
Henry Draper Catalogue	75767	Cannon & Pickering	1919
Hamburger Sternverzeichnis	5861	Schorr	1922
Cincinnati 19	1546	Smith & Porter	1922
Parallax Catalogue	718	Schlesinger	1924
Geschichte des Fixsternhimmels	8°2134	Preussischen Akademie. . .	1928
Albany Catalogue	7785	Boss, Roy & Varnum	1931
Allegheny Parallax Catalogue	429	Burns	1932
Parallax Catalogue, second edn.	2813	Schlesinger	1935
Eigenbewegungs-Lexicon	8°2134	Schorr	1923, 1936
General Catalogue	12243	Boss	1937
Toulouse III Appendix II	10718	Paloque	1941
Yale Zone Catalogue	8°4850	Barney	1950
Parallax Catalogue, third edn.	2118	Jenkins	1952
Radial Velocity Catalogue	5842	Wilson	1953
AGK2	8°1194	Schorr & Kohlschutter	1953
LTT ['Luyten Two-Tenths']	12312	Luyten	1961
SAO	117212	Smithsonian. . .	1966
First Greenwich Cat. for 1950.0	II-2247	Astronomer Royal	1969
AGK3	8°1194	Heckmann & Dieckvoss	1975
NLTT ['New Luyten Two-Tenths']	8°2134	Luyten	1979
Carlsberg Meridian Catalogue 2	4358	Carlsberg. . .	1986
Carlsberg Meridian Catalogue 4	204358	Carlsberg. . .	1989
PPM	115114	Roser & Bastian	1991

3. Magnitude and spectral type

Eggen (1969, 1974) appears to be the only person to have obtained photoelectric *UBV* photometry of HD 75767. In his 1969 paper he gave the values $V = 6^{m}.57$, $(B - V) = 0^{m}.63$, $(U - B) = 0^{m}.04$; the text of the paper indicates that the observations were made at one or more of the Cape, Pretoria, Lick, Mount Wilson, Palomar or Siding Spring observatories. He proposed the star as a probable member of the 'Wolf 630 moving group', and on that basis derived a 'group parallax' corresponding to an absolute magnitude of $+4^{m}.0$. The 1974 paper includes the star in a list of Wolf 630 group giants and subgiants, with colour indices (newly measured and with their source distinctly identified as the Siding Spring 40-inch reflector) of $(B - V) = 0^m.635$, $(U - B) = 0^m.06$. A subsequent paper (Eggen 1978) which appears to show HD 75767 having a V magnitude of $8^m.82$ is in that respect misleading. It ought to be mentioned that McDonald & Hearnshaw (1983) have called into question the existence of moving groups in general and of the 'Wolf 630' group in particular.

The large proper motion led (Sanford 1931) to HD 75767's being placed on the Mount Wilson programme of absolute-magnitude determination (Adams *et al.* 1935), on which it was estimated to have $M_V = +4^m.2$. Adams *et al.* made allowance for a hypothetical contribution of the undetected secondary star to the light of the system as a whole, and attributed to the primary star an apparent magnitude of $6^m.9$; from the resulting distance modulus they deduced a spectroscopic parallax of $0''.029$ (it would have been $0''.034$ if they had considered the secondary to be too faint to contribute significantly to the total light). The spectral type was classified as dG1; the Henry Draper type (Cannon & Pickering 1919) is G0.

MK classifications (Morgan, Keenan & Kellman 1943) of HD 75767 seem to be as scarce as photometry: the only one of which the present author is aware is the G5 IV given by Young & Koniges (1977) and estimated from a Kitt Peak coudé spectrogram taken at a dispersion—usually considered inappropriately high for classification purposes—of 13 Å mm^{-1}. Such a type would generally correspond to redder colours than are shown by HD 75767; on the other hand, the subgiant luminosity would be more in keeping with the trigonometrical parallax (*cf.* Section 4 below) than the absolute magnitude determined in the programme undertaken for that specific purpose at Mount Wilson. Marilli & Catalano (1984) listed HD 75767 as being of type G0 V, and Giuricin, Mardirossian & Mezzetti (1984) gave it as G0-G1 V, but neither of those syndicates was concerned with spectral classification and they may simply have combined the HD and/or Mount Wilson type with the likelihood of main-sequence luminosity to produce results that liik look MK types—and probably are close to the truth!

4. Parallax

The trigonometrical parallax of HD 75767 has only been determined once, at the Allegheny Observatory (Burns 1932). Although the work was published only in 1932, the plates had been taken and the result was known long before that, since the parallax is quoted in Schlesinger's (1924) *General Catalogue of Trigonometric Stellar Parallaxes.* The value obtained, of $0''.014 \pm 0''.007$, has been adjusted in later compilations (Schlesinger & Jenkins 1935, Jenkins 1952) to $0''.017$. It is still not in good agreement with the value of about $0''.037$ which would be implied by the distance modulus corresponding to a spectral type of dG1. There is no independent way of deciding whether it is the trigonometrical parallax that is in error or whether the star is actually above the main sequence, but the balance of probability is that the first alternative is the correct one: the main-sequence luminosity is supported by the measurement of Adams *et al.* (1935), and the quoted uncertainty of the trigonometrical parallax is a 'probable error' and not a standard deviation, so the discrepancy between it and the spectroscopic value is less than two standard deviations and therefore not truly significant.

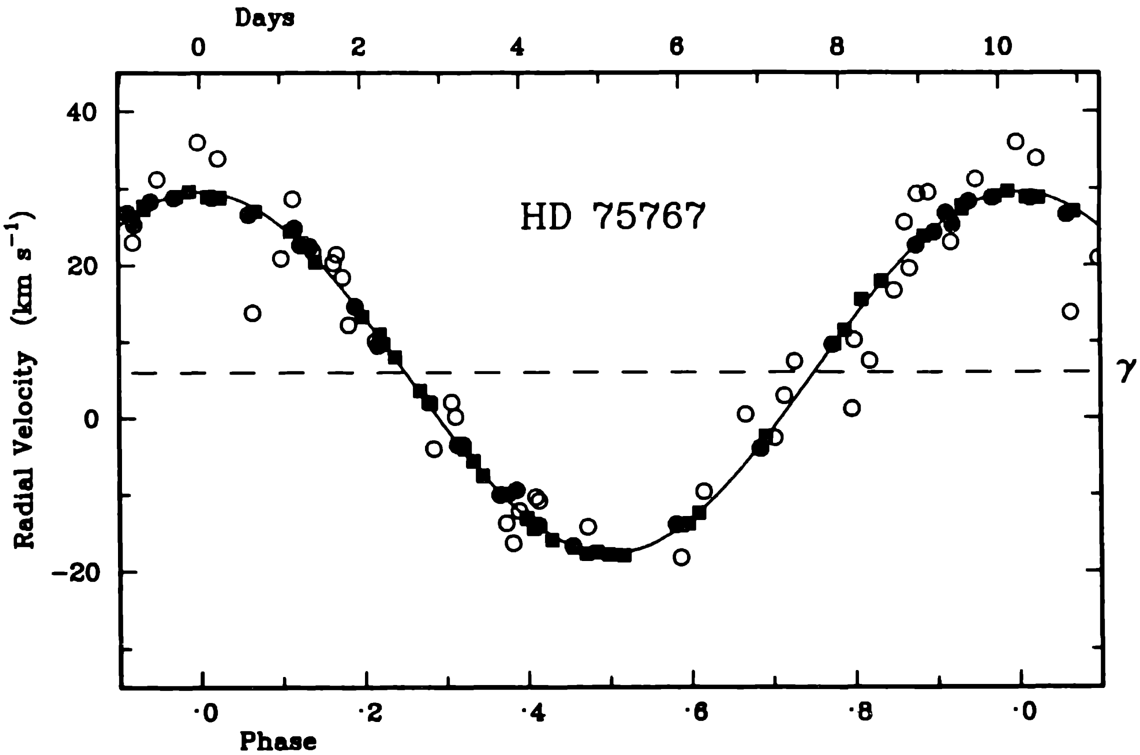

Figure 1. The orbital radial-velocity curve for HD 75767, with the measured radial velocities plotted. Squares: observations made with 'Coravel' or at the Dominion Astrophysical Observatory or Palomar (all weight 1). Filled circles: Cambridge observations (weight 0.3). Open circles: photographic measurements by Sanford (1931) (weight 0.01).

5. Radial velocities and orbit

5.1. *Sanford's*

The plates taken at Mount Wilson for the absolute-magnitude programme (Adams *et al.* 1935) were evidently measured routinely for radial velocity— and promptly too, since the velocity discordances among the first four plates are clearly what must have triggered a concentrated sequence of additional exposures after a lapse of less than a year. The radial-velocity investigation was undertaken by Sanford (1931), who used altogether 37 spectrograms obtained in 1924-1929. They were all taken with Cassegrain prism spectrographs giving reciprocal dispersions of 37 Å mm^{-1}, which were available at both the 60-inch and 100-inch reflectors; all but four of the plates came from the 60-inch. Sanford readily found the period, which is 10.25 days, but his derivation of the orbit from the radial velocities might be styled as adequate rather than rigorous. Of course, in the days before digital computers were available to solve orbits automatically in moments, a rigorous orbital solution was indeed a rigorous undertaking, and an adequate one would often represent a sensible choice. Sanford obtained preliminary elements by Russell's (1914) graphical method. He did try to improve on them by least-squares corrections to 13 'normal places', but encountered a mathematical impasse arising from the smallness of the eccentricity, for which his preliminary value was 0.1; so he simply fell back on the preliminary elements and adopted them as final. As a matter of interest a rigorous solution has now been computed from Sanford's data and is shown, together with the elements given by Sanford himself, in table 3. The computed solution also leads to the conclusion—already recognized by Lucy & Sweeney (1971)—that the apparent eccentricity is not statistically significant and that it would be best to adopt a solution with $e = 0$.

5.2. *New*

HD 75767 was placed on the observing programme of the original photoelectric radial-velocity spectrometer (Griffin 1967) in 1985, with a view to improving the orbital elements. Owing to the shortness of the period it can usefully be observed at relatively frequent intervals—even consecutive nights—and that circumstance has led to an unusually large proportion of the observations being made with other spectrometers, especially 'Coravel' (Baranne, Mayor & Poncet 1979), which the author has been fortunate enough to use on a guest-investigator basis. Observations proceed so quickly on such spectrometers, integrations of one minute's duration being the norm for stars as easy to observe as HD 75767, that nightly measurements of short-period objects are readily accommodated. The total number of photoelectric observations is 60, of which 21 have been made at Cambridge and 31 with the Haute-Provence 'Coravel'; the remainder have been made with the ESO 'Coravel' (3), the Dominion Astrophysical Observatory spectrometer (Fletcher *et al.* 1982) (4), or the Palomar instrument (Griffin & Gunn 1974) (1).

All the radial velocities are set out in table 2. The table includes Sanford's (1931) photographic measures, so that their individual residuals, which were not given (even as an overall r.m.s. figure) in the original paper, can be provided. A systematic zero-point difference is apparent between Sanford's velocities and my own; it amounts to 2 km s^{-1} and has been removed by an ad-hoc adjustment of +2.0 km s^{-1} to all of Sanford's measurements—the adjustment has been applied before those measurements were entered in table 2.

Table 2. Radial-velocity measurements of HD 75767

Date	MJD	Velocity km s^{-1}	Phase	$(O - C)$ km s^{-1}	Source*
1924 Feb 18.40	23833.40	+2.9	$\overline{2200}$.714	+2.3	Sanford
Apr 13.23	888.23	+13.8	$\overline{2194}$.064	−13.9	Sanford
May 20.15	925.15	+0.5	2191.667	+6.3	Sanford
1925 Jan 3.49	24153.49	+31.2	$\overline{2169}$.948	+2.9	Sanford
Dec 30.37	514.37	+20.3	$\overline{2133}$.162	+2.0	Sanford
1926 Jan 26.36	24541.36	+1.2	$\overline{2131}$.796	−11.5	Sanford
27.32	542.32	+29.5	.890	+5.4	Sanford
28.43	543.43	+36.0	.998	+6.5	Sanford
Feb 5.37	551.37	+9.6	$\overline{2130}$.773	+0.3	Sanford
6.33	552.33	+19.6	.867	−2.1	Sanford
24.25	570.25	−9.6	$\overline{2128}$.615	+2.1	Sanford
25.39	571.39	+7.4	.726	+4.9	Sanford
27.35	573.35	+23.0	.918	−3.5	Sanford
Mar 1.21	575.21	+20.9	$\overline{2127}$.099	−4.2	Sanford
Dec 20.52	869.52	+7.5	$\overline{2099}$.818	−8.2	Sanford

Table 2. Continued

Date	MJD	Velocity km s^{-1}	Phase	$(O-C)$ km s^{-1}	Source*
1927 Jan 10.46	24890.46	+25.6	$\overline{2097}$.861	+4.5	Sanford
13.30	893.30	+21.8	$\overline{2096}$.138	+0.6	Sanford
Mar 17.29	956.29	−4.0	$\overline{2090}$.285	−4.9	Sanford
18.20	957.20	−13.7	.373	−3.1	Sanford
18.36	957.36	−12.1	.389	0.0	Sanford
Nov 3.52	25187.52	+16.7	$\overline{2068}$.848	−2.9	Sanford
Dec 7.53	221.53	+21.4	$\overline{2064}$.167	+3.6	Sanford
1928 Jan 1.33	25246.33	−18.2	$\overline{2062}$.587	−4.0	Sanford
3.51	248.51	+10.2	.799	−3.0	Sanford
7.42	252.42	+12.2	$\overline{2061}$.181	−3.7	Sanford
10.41	255.41	−14.2	.473	+3.1	Sanford
Feb 9.22	285.22	−16.3	$\overline{2058}$.381	−4.9	Sanford
Dec 29.48	609.48	+33.9	$\overline{2026}$.023	+4.6	Sanford
30.41	610.41	+28.6	.113	+4.8	Sanford
31.44	611.44	+10.1	.214	−1.2	Sanford
1929 Jan 1.39	25612.39	+2.1	$\overline{2026}$.307	+4.3	Sanford
2.44	613.44	−10.3	.409	+3.6	Sanford
Mar 30.21	700.21	+29.3	$\overline{2018}$.876	+6.6	Sanford
Apr 2.26	703.26	+18.4	$\overline{2017}$.174	+1.5	Sanford
24.17	725.17	+0.2	$\overline{2015}$.312	+3.1	Sanford
25.21	726.21	−10.8	.413	+3.4	Sanford
28.17	729.17	−2.6	.702	−1.5	Sanford
1985 Nov 12.24	46381.24	+25.3	0.919	−1.3	Cambridge
Dec 23.15	422.15	+26.8	4.911	+0.8	Cambridge
1986 Jan 4.44	46434.44	+24.4	6.111	+0.3	Palomar
25.06	455.06	+22.6	8.123	−0.3	Cambridge
26.03	456.03	+9.5	.217	−1.3	Cambridge
27.02	457.02	−3.5	.314	−0.2	Cambridge
Feb 13.91	474.91	+26.6	10.060	−1.3	Cambridge
Mar 5.95	494.95	+28.8	12.015	−0.6	Cambridge
6.98	495.98	+24.8	.116	+1.2	Cambridge
Apr 4.84	524.84	+27.3	14.932	−0.1	Coravel
10.83	530.83	−17.9	15.516	−0.4	Coravel
Oct 26.22	729.22	+22.6	34.875	0.0	Cambridge
Dec 7.17	771.17	+28.8	38.968	−0.3	Cambridge
12.15	776.15	−16.7	39.454	0.0	Cambridge
1987 Jan 31.02	46826.02	−3.5	44.321	+0.7	Cambridge
31.96	826.96	−14.0	.412	+0.1	Cambridge
Feb 20.98	846.98	−10.0	46.366	−0.3	Cambridge
28.92	854.92	+20.4	47.141	−0.5	Coravel
Mar 1.91	855.91	+8.0	.237	+0.2	Coravel
2.89	856.89	−5.6	.333	+0.2	Coravel
3.87	857.87	−15.9	.429	−0.6	Coravel
18.92	872.92	+24.3	48.897	−0.5	Cambridge
21.91	875.91	+14.6	49.189	−0.2	Cambridge
25.93	879.93	−13.9	.581	+0.7	Cambridge
Oct 13.18	47081.18	+11.0	69.219	+0.5	Coravel
19.22	087.22	+15.5	.808	+1.1	Coravel
Nov 8.37	107.37	+9.7	71.775	+0.1	ESO
Dec 8.19	137.19	−4.0	74.684	−0.5	Cambridge

Table 2. Continued

Date	MJD	Velocity km s^{-1}	Phase	$O-C$ km s^{-1}	Source*
1988 Jan 26.37	47186.37	−17.5	79.483	0.0	DAO
31.37	191.37	+29.0	.971	−0.2	DAO
Feb 1.36	192.36	+27.0	80.068	−0.4	DAO
Mar 10.94	230.94	+17.9	83.833	+0.2	Coravel
11.95	231.95	+27.7	.931	+0.3	Coravel
12.91	232.91	+28.8	84.025	−0.5	Coravel
13.93	233.93	+22.9	.124	+0.2	Coravel
14.95	234.95	+9.7	.224	−0.1	Coravel
Nov 3.23	468.23	+29.6	106.987	+0.1	Coravel
6.24	471.24	+1.9	107.281	+0.5	Coravel
7.20	472.20	−9.9	.375	+0.8	Coravel
1989 Jan 18.05	47544.05	−9.4	114.386	+2.4	Cambridge
Feb 24.19	581.19	+28.9	118.010	−0.6	ESO
Mar 17.96	602.96	+22.4	120.134	+0.7	Cambridge
28.86	613.86	+13.3	121.198	−0.3	Coravel
30.92	615.92	−13.1	.399	−0.1	Coravel
Apr 29.88	645.88	−4.0	124.322	+0.4	Coravel
May 2.82	648.82	−12.4	.609	−0.1	Coravel
Nov 1.21	831.21	−14.4	142.407	−0.7	Coravel
1990 Jan 31.02	47922.02	+3.6	151.268	+0.3	Coravel
Feb 12.19	934.19	−16.9	152.455	−0.2	ESO
Mar 16.29	966.29	−14.0	155.588	+0.1	DAO
Apr 29.89	48010.89	+28.3	159.940	+0.4	Cambridge
1991 Jan 26.04	48282.04	−13.0	186.398	0.0	Coravel
27.06	283.06	−17.8	.498	−0.2	Coravel
28.07	284.07	−13.8	.596	−0.4	Coravel
29.04	285.04	−2.4	.691	+0.2	Coravel
30.03	286.03	+11.5	.788	0.0	Coravel
31.02	287.02	+23.8	.884	+0.2	Coravel
Feb 4.06	291.06	+2.1	187.278	+0.3	Coravel
6.03	293.03	−17.7	.471	−0.5	Coravel
Oct 29.19	558.19	−7.5	213.345	−0.2	Coravel

*Sources of measurements:
Sanford : published photographic observations (Sanford 1931)
All others : photoelectric observations by the author:
Cambridge : 36-inch telescope (Griffin 1967)
Palomar : 200-inch telescope (Griffin & Gunn 1974)
Coravel : 1-m Geneva telescope and Coravel at Haute-Provence (Baranne, Mayor & Poncet 1979)
ESO : Coravel on Danish 1.54-m telescope at ESO
DAO : Dominion Astrophysical Observatory 48-inch telescope (Fletcher *et al.* 1982)

The solution of the orbit from the ensemble of data in table 2 was straightforward. The period is sufficiently well determined by the photoelectric observations alone (though not by Sanford's alone) that there is no ambiguity in the cycle count during the 56 years (more than 2000 cycles) that intervened while the star was unobserved. To obtain approximate equality in the weighted variances of the different data sources, it has been necessary to weight Cambridge velocities 0.3 and the photographic ones 0.01, observations with the other four spectrometers being taken as unity. The r m.s. residuals from the orbital solution are found to be about 0.4 km s^{-1} for the four spectrometers other than the Cambridge one (their integration of the trace offers a higher precision than the repeated scans drawn by the Cambridge instrument), 0.8 km s^{-1} for Cambridge, and 4.8 km s^{-1} for the photographic work.

It may be remarked that 4.8 km s^{-1} represents a linear distance of about 2 microns on plates of the dispersion (37 Å mm^{-1}) used by Sanford, so the achievement of such a standard error is quite satisfactory; the improvement in the variance by a factor of about 30 at Cambridge (with a much smaller telescope, and on an urban site, too), and by a further factor of three or four with the newer spectrometers, is entirely attributable to technological advances.

The sum of the weighted squares of the deviations for the 97 observations is 17.57 (km $s^{-1})^2$ when the eccentricity is included as a free parameter in the orbital calculation, and rises to 19.25 (km $s^{-1})^2$ when zero eccentricity is forced upon the solution. With e free, there are six orbital elements fitted, so the number of degrees of freedom is 90 (one extra degree was lost when we cavalierly adjusted Sanford's zero-point), and the variance per degree is 17.57/90, or 0.195 (km $s^{-1})^2$. The two degrees of freedom gained by fixing the eccentricity (and implicitly the longitude of periastron) at zero cost an extra (19.25-17.57) or 1.68 (km $s^{-1})^2$ in the total variance, or 0.84 (km $s^{-1})^2$ per degree. Comparing the two estimates of the variance per degree of freedom allows us (Bassett 1978) to determine the significance or otherwise of the small eccentricity given by the solution with e free. We do that by comparing the variance ratio, F, with values of F having 2 and (by interpolation) 90 degrees of freedom, in tables (*e.g.* Lindley & Miller 1953) for different degrees of significance. The observed ratio, $F \sim 4.31$, is significant at the 2½% level ($F \sim 3.84$) but not at the 1% level ($F \sim 4.86$). We are therefore left with the rather unsatisfactory situation that we still do not know whether the eccentricity is significantly different from zero or not. We *do* know that it is much smaller than Sanford (1931) supposed, and from the fact that many orbits with periods around 10 days are known to be tidally circularized, it is tempting to suppose that this one is too, and that the very small eccentricity of 0.012 ± 0.004 (with $\omega = 205° \pm 20°$) given by the solution with e free is just a statistical fluke. It may seem a trifle perverse, when the statistics have just shown that there is a chance of between 40 : 1 and 100 : 1 that the orbit is *not* circular, to deduce from that that it probably *is*, but the point is that a very small but non-zero

Table 3. Orbital elements for HD 75767

	Observer :	Sanford		Sanford + R.F.G.
	Computer :	Sanford	R.F.G.	R.F.G.
Element				
P (days)		10.2504	10.2515 ± 0.0014	10.24806 ± 0.00003
T (MJD)		24890.518	24892.0 ± 0.9	
T_0 (MJD)				47212.160 ± 0.007
γ (km s^{-1})*		+5.5	+5.6 ± 0.9	+5.96 ± 0.07
K (km s^{-1})		24.5	23.8 ± 1.3	23.59 ± 0.09
e		0.1	0.09 ± 0.06	0
ω (degrees)		314	5 ± 32	–
$a_1 \sin i$ (Gm)		–	3.34 ± 0.19	3.324 ± 0.013
$f(m)$ ($M_\odot$)		–	0.0142 ± 0.0024	0.01396 ± 0.00017

*After adjustment of all Sanford's velocities by +2.0 km s^{-1} (see text) eccentricity is thought to be unlikely, and an appearance of such an eccentricity might arise from some lack of normality (in the technical sense) of the error distribution of the observations, so if the statistics show that there is even a small chance that the orbit could be circular we seize on that chance to consider it so. We therefore adopt here the circular solution, whose elements are given in the last column of table 3; the table includes Sanford's elements for comparison.

6. Summary and discussion

This paper has confirmed for HD 75767 the orbit given by Sanford (1931), on the basis of modern radial velocities that have provided a 'weight' more than 100 times greater than that of Sanford's velocities—an improvement reflected in the reduction of the variances of the orbital elements by a similar factor. The orbit is shown to differ scarcely, if at all, from a circle, a fact that was already recognized in the rediscussion of Sanford's observation by Lucy & Sweeney (1971); but the eccentricity that would now constitute a significant departure from a circle is ten times smaller now than it was then.

There is still no detection of the secondary star in the system; it must be much fainter than the primary, and is most likely a late-main-sequence star.

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