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Spectroscopic Binaries near the North Galactic Pole
Paper 16: HD 116093

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Abstract. Photoelectric radial-velocity measurements show that HD 116093 is a double-lined spectroscopic binary in a very eccentric 53-day orbit. Very little else is known about the system, but circumstantial evidence is consistent with the hypothesis that the components' types are near to F3 V and F8 V. If that is so, the orbit must be seen very nearly edge-on; a search for eclipses is warranted and an ephemeris for them is given.

Key words: radial velocities—spectroscopic binaries—stars, individual

1. Introduction

The last two papers in this series have dealt with spectroscopic binaries having periods of 59 days. The object treated in the present paper, HD 116093, has a very similar period, and (like the subject of Paper 15) is double-lined. It is situated in the eastern part of Coma Berenices in a region lacking conspicuous stars, and is hitherto totally undistinguished in the literature. Apart from positional data, and the approximate magnitude given in the *Henry Draper Catalogue* (Cannon & Pickering 1920), the only information (*mis*information, as will be shown below to be probable) that we have on it is its *HD* spectral type of G5.

2. Observations

Some of the fainter stars of the earliest *HD* type (G5) included in the Cambridge Galactic-Pole observing programme were not observed until rather late in the project, and so it came about that the first observation of HD 116093 was not made until 1980. The object proved to give such a weak and elusive dip on the trace made with the original radial-velocity spectrometer at Cambridge that it was noted for observation at Palomar, where it was at once discovered to be double-lined. A subsequent observation at the Dominion Astrophysical Observatory revealed the two dips to be separated by as much as 120 km s^{-1}, and led to the expectation that the period would be much shorter than it actually proved to be. Although the system was then observed frequently at Cambridge it is right at the limit of the capability of the original instrument, so every opportunity has been taken to observe it with newer spectrometers, and when in 1986 the period became apparent the Cambridge efforts were discontinued altogether. Fortunate timing of a recent observing run on the Geneva Observatory's 'Coravel' at Haute-Provence at last permitted good coverage of the abrupt periastron passage in the very eccentric orbit ($e \simeq 0.7$). Altogether, measurements have been made on 62 occasions; they are set out in Table 1. Several additional traces were made at Cambridge during the long intervals when the components have a velocity separation such as to produce a broad blend, but they had to be discarded because it proved impossible to read them. One other Cambridge observation was

Table 1. Photoelectric radial-velocity measurements of HD 116093.

Date		MJD	Velocity Prim. km s⁻¹	Velocity Sec. km s⁻¹	Phase	(O−C) Prim. km s⁻¹	(O−C) Sec. km s⁻¹
1980 May	14.91	44373.91	+16.4		0.262	+1.4	
1981 May	17.40*	44741.40	+25.1	−42.8	7.171	+0.4	+1.4
1982 Nov	23.57*	45296.57	−14.5	−1.6	17.609	−0.1	−0.1
	24.58*	297.58	−15.2	+1.4	.628	+0.8	+1.0
	25.56*	298.56	−16.8	+1.4	.647	+0.9	−0.8
1983 Feb	3.53†	45368.53	−67.3	+56.3	18.962	−0.8	+0.7
	4.50†	369.50	−58.5	+49.1	.980	+0.6	+1.6
	23.13	388.13	+12.1	−31.8:	19.331	+3.4	−5.1
	28.12	393.12	−0.3:		.425		
Mar	15.11	408.11	−24.0		.706	−0.3	
1984 Apr	14.03	45804.03	+27.9	−44.2	27.150	+0.7	+2.8
	17.04	807.04	+21.2	−39.0	.207	+0.6	+0.8
	21.01	811.01	+16.3	−28.6:	.282	+3.2	+2.9
	23.97	813.97	+12.5	−22.8:	.337	+4.4	+3.3
	24.97	814.97	+5.5	−30.9::	.356	−1.0	−6.6
	25.90	815.90	+6.6	−27.6:	.373	+1.5	−4.9
May	9.00	829.00	−11.0		.620		
	10.97	830.97	−13.6:		.657		
	12.93	832.93	−20.9		.694		
Nov	29.57*	46033.57	−2.0	−17.4	31.466	+0.5	−2.9
	30.54*	034.54	−4.7	−11.2	.484	−0.8	+1.7
Dec	2.55*	036.55	−8.3	−8.3	.522	−1.3	+1.2
1985 Feb	7.51†	46103.51	−33.5:	+21.8:	32.781	−1.1	+3.5
	8.56†	104.56	−34.9	+21.7	.801	+0.3	+0.4
	16.45†	112.45	−62.8	+54.6:	.949	+2.6	+0.3
	17.40†	113.40	−65.7	+54.5	.967	+0.3	−0.6
	18.35†	114.35	−53.7	+43.1	.985	+0.5	+1.0
Mar	2.08	126.08	+59.5:	−35.2:	33.205	+38.7	+4.7
	6.04	130.04	+7.4	−27.5:	.280	−5.9	+4.2
	17.99	141.99	−6.9		.504		
May	31.96	216.96	−58.0	+45.5	34.914	−1.0	+0.3
June	1.92	217.92	−58.3	+49.4	.932	+3.3	−0.8
1986 Jan	4.54*	46434.54	−14.5	−6.9	39.005	−1.7	−3.7
	17.20	447.20	+17.0	−31.6	.243	+0.1	+4.0
	25.16	455.16	−0.1:		.393		
Mar	6.07	495.07	+29.0	−44.9:	.143	+0.8	+3.1
April	4.98‡	524.98	−24.1	+7.9	.705	−0.6	−0.7
	9.97‡	529.97	−35.3	+21.3	.799	−0.4	+0.3
	11.06‡	531.06	−38.8	+23.7	.820	−0.8	−0.7

Table 1. Continued

Date		MJD	Velocity Prim. km s^{-1}	Velocity Sec. km s^{-1}	Phase	$(O-C)$ Prim. km s^{-1}	$(O-C)$ Sec. km s^{-1}
May	5.98	555.98	+13.8	−31.4	41.288	+1.3	−0.5
	13.96	563.96	−7.4:		.438		
	15.93	565.93	−7.9		.475		
	18.93	568.93	−8.0		.532		
	25.91	575.91	−14.3:		.663		
June	3.93	584.93	−40.2	+31.6	.832	−0.1	+4.9
	10.92	591.92	−60.0		.964	+6.4	
	11.92	592.92	−57.8	+43.6:	.983	−1.0	−1.3
	14.94	595.94	+34.0	−50.4	42.039	+0.8	+3.2
Aug	28.81†	670.81	−8.8		43.447		
Nov	23.55*	757.55	+35.1	−57.9	45.078	−0.9	−1.3
	25.55*	759.55	+31.8	−51.2	.116	+0.1	+0.7
1987 Mar	1.18‡	46855.18	−56.7	+44.7	46.914	+0.2	−0.3
	3.02‡	857.02	−67.9	+52.8	.948	−2.7	−1.4
1988 Jan	23.55‡	47183.55	+35.5	−56.4	53.087	+0.4	−0.8
	31.47‡	191.47	+16.9	−37.0	.236	−0.6	−0.6
Mar	11.15‡	231.15	−57.4	+46.6	.982	−0.3	+1.4
	12.02‡	232.02	−28.2	+10.5	.999	−0.7	−2.4
	12.97‡	232.97	+11.1	−28.4	54.017	−0.7	+1.7
	13.18‡	233.18	+18.4	−37.0	.021	+0.6	−0.3
	13.95‡	233.95	+32.3	−49.8	.035	+1.1	+1.5
	14.98‡	234.98	+35.8	−57.7	.054	−0.7	−0.6

* Observed, in collaboration with Dr J. E. Gunn, with the 200-inch telescope (Griffin & Gunn 1974).

† Observed with the Dominion Astrophysical Observatory 48-inch telescope (Fletcher *et al.* 1982).

‡ Observed with 'Coravel' at Haute-Provence (Baranne, Mayor & Poncet 1979).

rejected: it gave such a wild residual ($\simeq$40 km s^{-1}) that the feature measured on the trace must have been illusory.

3. Orbit

Once the general nature of the orbit was established, the best determination of the elements required the observations to be suitably weighted. By iterative trials it was found that the standard errors of the Palomar, DAO and Coravel measurements were comparable with one another and averaged nearly $2\frac{1}{2}$ times smaller than those of the Cambridge velocities, which were accordingly weighted one-sixth ($\simeq (2\frac{1}{2})^{-2}$) in the final solution. Additionally, observations of the secondary star needed to be weighted 0.6 to obtain a weighted variance similar to that found for the primary. Some unexpectedly bad residuals are given by each of the sources of velocities, and (with one possible exception discussed below) it is probably fruitless to try to identify the cause of each one with a view to finding an excuse to reject the corresponding observation. The fairest thing to do is to leave all the observations in the solution and to allow the

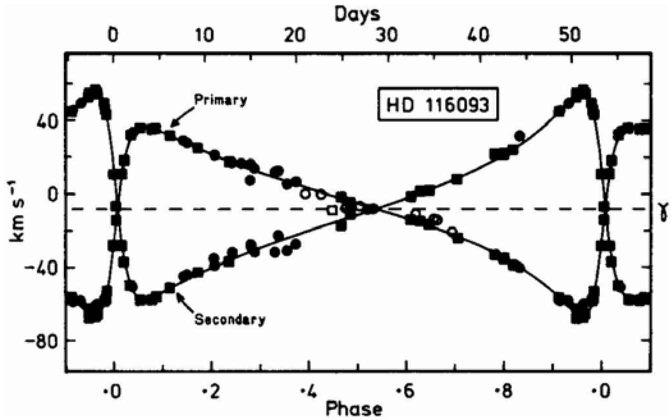

Figure 1. The computed radial-velocity curve for HD 116093, with the measured radial velocities plotted. Palomar, Dominion Astrophysical Observatory and Coravel observations, which were accorded weight 6 in the orbital solution, are plotted as squares; Cambridge observations are represented by circles. Open symbols indicate data which are (or may be) affected by blending between the two components and were not used in the solution.

standard errors of the orbital elements to reflect the real uncertainties of the data. On that basis the orbit plotted in Fig. 1 was determined; its elements are:

$P = 53.1870 \pm 0.0011$ days	$(T)_{37} = \text{MJD } 46327.907 \pm 0.022$
$\gamma = -8.21 + 0.15 \text{ km s}^{-1}$	$a_1 \sin i = 27.35 \pm 0.17$ Gm
$K_1 = 51.7 \pm 0.3 \text{ km s}^{-1}$	$a_2 \sin i = 29.93 \pm 0.31$ Gm
$K_2 = 56.5 \pm 0.6 \text{ km s}^{-1}$	$f(m_1) = 0.289 \pm 0.005\ M_\odot$
$q = 1.094 \pm 0.009\ (= m_1/m_2)$	$f(m_2) = 0.378 \pm 0.012\ M_\odot$
$e = 0.690 \pm 0.002$	$m_1 \sin^3 i = 1.39 \pm 0.03\ M_\odot$
$\omega = 259.2 \pm 0.4$ degrees	$m_2 \sin^3 i = 1.27 \pm 0.03\ M_\odot$

R.m.s. residuals (km s^{-1}):	Primary	Secondary
Palomar, DAO, Coravel	1.0	1.5
Cambridge	2.7	3.2

4. Discussion

An interesting feature of the orbital elements shown above is the size of the minimum masses: the values of 1.39 and 1.27 $M_\odot$ are too large to belong to main-sequence stars of the type (G5) attributed in the *Henry Draper Catalogue* to the system. The dips seen on radial-velocity traces are also incompatible with an origin in normal G5 stars, being much too shallow. In this section, therefore, we shall disregard the *HD* classification and, unfettered by any other published data about the system, explore the cones-quences of supposing that we are dealing with a pair of F-dwarfs.

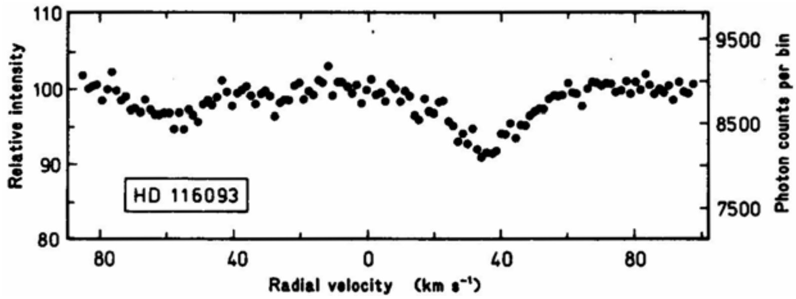

Figure 2. Palomar radial-velocity trace of HD 116093, obtained on 1986 November 23 and illustrating the double-lined nature of the object.

First we present such astrophysical information as may be gleaned from the Palomar radial-velocity traces. It is unfortunate that seven of the ten Palomar traces show closely blended dips, only three being truly double-lined; one of those three is shown in Fig. 2. The sum of the equivalent widths of the two dips is in all cases close to 3.2 km s^{-1} , and the ratio between the two is approximately 1:0.6 in the three cases in which it is independently determinable. The first number can be used to estimate the mean spectral type, and the second indicates the difference in types between the twin components. The three double-lined traces are in fair mutual agreement that the projected rotational velocity of the primary star is 9km s^{-1}; with much more uncertainty the secondary has a mean of 5 km s^{-1}.

Not having any significant experience of observing normal F-dwarf field stars with the Palomar spectrometer, we use the Hyades ((*B* – *V*), equivalent width) relationship to estimate that the observed total equivalent width corresponds to a (*B* – *V)* colour of $0^{m}.42$. From Allen (1973) we find that such a colour belongs to stars of type F5 V. To obtain the desired ratio of dip areas the best types to choose are F3 V and F8 V. The properties of that combination, again according to Allen (1973), are shown in Table 2.

The difference in *B* magnitude is 1.08, corresponding to a ratio of luminosities in the *B* band of 2.7:1 or (expressed in percentage terms) 73:27. The equivalent widths of the dips given by single Hyades stars having the colours of the stars in the model are 2.7 and 4.1 km s^{-1} respectively (the former value represents an extrapolation of the observed relationship). When the two stars are observed simultaneously, each dip area is reduced in the same proportion as the light of the respective component is diluted by the light of the other, so the equivalent widths become73% of 2.7 and 27% of 4.1, or 1.97 and 1.11 km s^{-1} , respectively—close to the observed values.

Table 2. Model for HD 116093.

Spectral Type	Absolute Mag. *V* m	*B* m	Colour (*B*–*V*) m	Mass $M_\odot$
F3 V	3.08	3.44	0.36	1.43
F8 V	4.00	4.52	0.52	1.17
F3 V+F8 V	2.69	3.10	0.41	2.60

The masses of both the stars in the model are close to the minimum masses $m \sin^3 i$ demanded by the orbit; the mass ratio in the model is however rather too high, and a compromise with the ratio of dip areas would warrant a choice of components somewhat closer to one another in spectral type. A significant fact is that the observed *minimum* total mass is marginally greater than the mass of the model system, indicating that $\sin^3 i$ must be close to unity and implying the possibility of eclipses.

One of the times of conjunction in this very eccentric orbit is very close to periastron, when the separation of the stars is $(a_1 + a_2)(1 - e)$, or about 17.7/sin i Gm. The sum of the radii of the model stars is about 1.65 Gm, so there will be an eclipse if $\tan i > 17.7/1.65$ or $i > 84°.7$. The orbital elements allow the time of conjunction to be predicted within about an hour for several years ahead: it occurs 0.212 days after periastron, so the ephemeris for it is $t_{conj} = T + 0.212 + nP$, = MJD 46328.12 + 53.187n, where n is any integer. Favourable dates during the next three observing seasons (though only near appropriate longitudes, of course) are 1989 Jan 25.42, Mar 19.61, May 11.79; 1990 Feb 1.72, Mar 26.91, May 19.10; 1991 Feb 9.03, Apr 3.21. At those conjunctions the eclipse (if any) would be of the secondary star. The relative transverse velocity is about 180 km s^{-1}, so the maximum duration of an eclipse would be $2(R_1 + R_2)/180$ seconds (where the radii are expressed in kilometres), or about 5 hours.

An indication that there may indeed be an eclipse is afforded by the Palomar radial-velocity observation of 1986 Jan 4, which was made one hour after conjunction and therefore possibly during an eclipse. The trace on that occasion shows the dips closely blended together, with the secondary on the positive-velocity side of the blend. Although in Section 3 above we affected to a view all disconcerting residuals with an air of lofty detachment, we did suffer a good deal of private pain at the incredible negative residuals (particularly the secondary's) given by that observation. An eclipse would explain them. If half the secondary star were eclipsed, half of the share of the dip that is attributed to it would really belong to the primary, whose velocity would then be found to be more positive than before. As for the secondary velocity, of course that *would* be found far too negative during egress from eclipse because we would only be seeing the approaching limb of the star.

If the rotational velocities of the stars are pseudo-synchronized (Hut 1981) with the orbit, the rotation periods are about 0.13 times the orbital period or about 7 days, corresponding to $v \sin i \simeq 9$ km s^{-1} for the primary (in exact agreement with the observed value) and 8km s^{-1} for the secondary (in reasonable agreement with the weakly determined observational value).

Although the model developed in this section fits the few known facts rather attractively, it is only fair to recall that such basis as it may have is largely circumstantial and in fact the only previously published datum has in effect been rejected. Even if the model proves to be broadly correct it may still require some adjustment to take account of the inaccuracies of assumptions such as the use of the Hyades relationship between colour and radial-velocity dip areas. The probable direction of the adjustment needed on that particular account is easily assessed: the average field star is likely to have smaller line-strengths in relation to its spectral type and therefore will need to be of later type than we have suggested in order to match the observed dip areas. Since the expected masses will then be smaller, such an adjustment further strengthens the likelihood of eclipses; it also tends to reduce the discrepancy with the *HD* type. Clearly, the next steps that need to be taken concerning HD 116093 are to watch for eclipses at the known times of conjunction and to obtain good spectra for classification purposes,

Acknowledgements

I am most grateful to the Palomar, Dominion Astrophysical and Geneva observatories for the use of their equipment, and to Dr R. E. M. Griffin for her assistance in using it.

Errata in Paper 15. Owing to an elementary arithmetical mistake, for which I apologize, the distance modulus of HD 106947 according to the model given in Table 3 of the paper was quoted as $4^{m}.44$ when it should have been $5^{m}.44$; the correction impairs the correspondence between the properties of the Coma star cluster and HD 106947, whose membership is now much less conclusive than the paper made it appear. The date of the reference to Trumpler in the bibliography should have been 1938.

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