

J. Astrophys. Astr. (1991) 12, 39–48

Spectroscopic Binaries near the North Galactic Pole Paper 19: HR 4693

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Received 1990 October 22; accepted 1990 December 5

Abstract. HR 4693 is a fifth-magnitude K2 III star whose radial-velocity nature has been the subject of conflicting ideas. It is shown here to be a spectroscopic binary of small amplitude, less than 2 km s^{-1} ; the orbit is quite eccentric and has a period of 16 years.

Key words: radial velocities—spectroscopic binaries—orbits—stars, individual—HR 4693

1. Introduction

HR 4693 (HD 107325) is a fifth-magnitude late-type giant star seen projected against the Coma Cluster; indeed, it may well be actually within the cluster but it is not a member of it, since (as Trumpler (1938) was aware when he numbered it no. 71 in his catalogue of stars in the area of the cluster) both its proper motion and its radial velocity are at variance with those of the cluster members.

UBV photometry of HR 4693 has been given by Nekrasova, Nikonov & Rybka (1965) (subsequently corrected by Rybka (1969, 1979)), and by Helfer & Sturch (1970), Schild (1973) and Fernie (1976), all of whom give values close to $V = 5^{\text{m}}.54$ and $(B - V) = 1^{\text{m}}.09$, and not so tightly bunched around $(U - B) = 1^{\text{m}}.07$. Eggen (1989), who considers HR 4693 to be a member of the “HR 1614 group”, gives a discordant V magnitude of $5^{\text{m}}.49$. The star features in the *New Catalogue of Suspected Variable Stars* (Kukarkin *et al.* 1982) as NSV 05559, on the authority of Stock (1952), but Stock seems only to refer to its supposed *radial-velocity* variability.

The first two-dimensional spectral classification of HR 4693 was probably that of Adams *et al.* (1935), who gave its type as K2 and its absolute magnitude as $+0^{\text{m}}.6$. Trumpler (1938), in his investigation of the Coma Cluster, called it gK1. Several efforts have been made to mimic MK classifications by means of objective-prism spectra. Thus Duflo & Fehrenbach (1956) found a type of K1 IV; Yoss (1961) gave K2 III–IV; and Upgren (1962), who also re-designated the object 27°87 in his catalogue of North Galactic Pole stars, found a type of K1 III. MK classifications from slit spectra have been made by Schild (1973), who used the Cassegrain spectrograph of the McDonald 82-inch reflector, and by Bolton *et al.* (1975), from the 74-inch Cassegrain of the David Dunlap Observatory; they derived types of K2 III–IV and K2 III respectively. Bolton *et al.* also interpreted the width of the K line as implying an absolute magnitude of $+1^{\text{m}}.4$. Altogether, a consistent picture emerges of a star of type K2 or slightly earlier, with a luminosity possibly slightly on the low side in comparison with a normal giant.

Janes & McClure (1971) included HR 4693 in a paper on strong-cyanogen stars, but their figures show that its CN enhancement is at most marginal.

2. Radial-velocity history

HR 4693 has had a very chequered career in the world of radial velocities. It sprang into prominence in 1948 when Fehrenbach (1948), on the basis of early measurements with his objective-prism technique of estimating radial velocities, assigned it a large-amplitude orbit with a period close to half a day. The salient elements were $P = 0.49116$ day, $K = 36.6 \text{ km s}^{-1}$, and $e = 0.3$. As a matter of fact the list of measurements simply reveals a gross hour-angle effect, a fact that was admitted by Fehrenbach many years later (Bolton *et al.* 1975). Hardly had Fehrenbach's paper been published when Wellmann (1949), recognizing the improbability of such a star having such an orbit—the period is less than that corresponding to an object in a circular orbit grazing the surface of the star—re-investigated the matter for himself. Eight spectrograms that he took at 65 Å mm^{-1} with the Cassegrain spectrograph of the Hamburg 1-m reflector showed the velocity to be constant at -20 km s^{-1} , with a scatter of only 2 km s^{-1} . There had long existed in the literature a record by Adams *et al.* (1929) of three Mount Wilson Cassegrain spectrograms which yielded an apparently constant mean velocity of $-9.7 \pm 1.3 \text{ km s}^{-1}$. However, since the dates of the individual measurements were not published—as they have been subsequently, by Abt (1973)—it could not be said categorically that those measurements refuted Fehrenbach's orbit, as Wellmann's clearly *did*. On the other hand the discrepancy between the mean velocities found by Adams *et al.* (1929) and by Wellmann (1949) was about seven times their joint standard deviation, so it looked as if *some* velocity variation did take place. The *Radial Velocity Catalogue* (Wilson 1953) does not address the question of variability, recording only the three Mount Wilson plates and ignoring Fehrenbach and Wellmann equally. The *Catalogue* entry shows the mean velocity (presumably after a trivial correction was applied) to be -9.8 km s^{-1} , with quality *b*.

The next radial-velocity contribution concerning HR 4693 was another series of objective-prism measures by Duflo & Fehrenbach (1956), from which they deduced a constant mean velocity of -23 km s^{-1} . They misquoted the *Radial Velocity Catalogue* as giving the mean velocity as -17 km s^{-1} and with quality *c*. They listed previous measures of the stars they observed, referring in the case of HR 4693 to Adams *et al.* (1929) and also to three unpublished Haute-Provence slit spectra that they reported as giving a mean velocity of -24.9 km s^{-1} , but rather surprisingly they said nothing about their own earlier measures of HR 4693.

Despite all the evidence that had accumulated that Fehrenbach's orbit for HR 4693 was erroneous, even to the extent that its author had appeared tacitly to repudiate it, Batten (1967) gave it renewed currency by including it in his *Sixth Catalogue of the Orbital Elements of Spectroscopic Binary Systems*. He added a note, "While the velocity variation seems to be established, the combination of a high eccentricity with a short period is unusual, and should be checked".

The entry in the *Sixth Catalogue* (Batten 1967) apparently galvanized a number of observers into action. A brief report in the *IAU Transactions* for 1973 (Bouigue 1973) mentions that HR 4693 had been observed by Bolton and found to have a constant velocity. Subsequently, Bolton and three collaborators (1975) wrote a whole paper

concerning the radial velocity of the star and referring to slit spectrograms taken at three different observatories, unfortunately in time intervals that scarcely overlapped. First there were 23 plates at a reciprocal dispersion of $33 \text{ \AA mm}^{-1}$ from the Lindheimer 1-m telescope, all but one of them being obtained in the 1970 observing season; they led to the conclusion that the radial velocity was constant, with a mean value of $-16.2 \pm 0.5 \text{ km s}^{-1}$. Then there were 41 plates at $12 \text{ \AA mm}^{-1}$ from the David Dunlap 74-inch Cassegrain between early 1971 and early 1973; they too suggested a constant velocity, of $-16.6 \pm 0.2 \text{ km s}^{-1}$, but there was a hint of a trend towards more positive velocities. Lastly, there were nine plates from the Kitt Peak 84-inch coude at $13 \text{ \AA mm}^{-1}$; four were taken in the spring of 1973 and five in the spring of 1974, and there appeared to have been a change in velocity between the two seasons—the mean for 1973 was $-12.6 \pm 0.3 \text{ km s}^{-1}$, and that for 1974 was -10.5 ± 0.3 . The authors concluded that there was a small-amplitude long-period variation, but they were unable to decide upon the actual nature of the variation. One of the alternative possibilities that they described, however, was indeed the correct one, *viz.* that HR 4693 “is a very long-period binary, and the last of the DDO observations, as well as all of the KPNO observations, were the first of this series to occur on the ascending branch of the velocity curve”.

The literature contains additional velocities of HR 4693, not taken in the course of specific efforts to prove or disprove variability. There are two by Chériguene (1971), from Haute-Provence slit spectrograms taken on consecutive nights in 1968; they are -16.4 and -14.5 km s^{-1} . Beavers *et al.* (1979) included HR 4693 in a table of stars tentatively proposed as radial-velocity standards—objects which had not appeared to exhibit significant velocity changes over the duration of those authors’ observations; they found a mean of $-13.0 \pm 0.7 \text{ km s}^{-1}$ from 15 measurements (not given separately) made with the photoelectric radial-velocity spectrometer (Beavers & Eitter 1977) of the Erwin W. Fick Observatory of Iowa State University at Ames. A complete list of the radial velocities determined with the Fick spectrometer was later published by two of the same authors (Beavers & Eitter 1986): the number of measures of HR 4693 had by then risen to 25, and although the authors did not seem to notice it there appears to be a significant downward trend. One other measurement, an undated one of -13.3 km s^{-1} , has been published from the McDonald spectrometer (Barnes, Moffett & Slovak 1986). Bolton *et al.* (1975) referred also to velocities determined at Haute-Provence by Pédoussaut which were to be published “shortly” but seem not to be in print yet.

3. New radial velocities and orbit

The present writer’s interest in HR 4693 arose merely from its presence in the North Galactic Pole field rather than in connection with its troubled radial-velocity history. The first photoelectric observation was made—with very fortunate timing, as is apparent in retrospect—with the Palomar 200-inch reflector early in 1972, in the course of a survey of K giants in the Uggren (1962) zones. A second measurement, noticeably discordant from the first, was made by G. A. Radford with the Cambridge instrument in 1973. After the publication by Bolton *et al.* (1975) had drawn my attention to the interest in HR 4693, and in view of the definite change that had occurred between the first two photoelectric measures, the object was put on the

regular spectroscopic-binary programme in Cambridge. It was several years before any further change could be detected, but, since the velocity had changed before, it could be only a matter of time before it had to change again, and in due course the observer was rewarded by witnessing a slow decline in the star's velocity. Finally, in 1988 the same relatively rapid rise took place as had been sketchily observed by Bolton *et al.* and by us in 1972/3, and—always provided that one is prepared to take on trust that what has been seen is one cycle of an orbital motion and that the same thing will be repeated as often as one cares to watch it—the nature of the velocity variation had been completely elucidated. To verify the above proviso by watching a second and/or subsequent cycle(s) of the variation before publishing the orbit would rather try the author's patience and hardly seems warranted.

It remains, therefore, only to derive the best orbit possible from the available radial velocities. To use isolated observations, or even batches of observations, that cover only very small ranges of phase is not usually very helpful, and proves not to be so in this case. The only measures that add anything to the orbit determined from my own velocities are those from the Fick Observatory; they are listed along with my own results in Table 1. The Fick data are routinely graded for quality at the time of measurement, and their authors (Beavers & Eitter 1986) have shown that the standard error of a velocity of their quality A is about 1.0 km s^{-1} while that of quality B is 1.6 km s^{-1} . In comparison with my own measures, whose r.m.s. error in this case proves to be 0.6 km s^{-1} , Fick quality A merits a weight of about 0.4 and B about 0.15; those weights have been used in the orbit solution and have indeed proved realistic.

There are 96 new photoelectric measurements in Table 1 in addition to those of Beavers & Eitter. All the other data are listed in Table 1 simply as means, the dates as well as the velocities being averaged for each set; they have not been used in the derivation of the orbit, although those that fall within the boundaries of the diagram have been plotted in Fig. 1, which shows the finally derived radial-velocity curve. All velocities taken from the literature have been increased by 0.8 km s^{-1} before being entered in Table 1, in an effort to take account of the discrepancy (Griffin & Herbig 1981) between the photoelectric zero point and the Lick zero-point to which the zero-point of the other data ought to be traceable; that adjustment has, as usual, brought the Fick measurements into systematic agreement with my own within their statistical errors. The finally derived orbital elements are:

$P = 5792 \pm 85 \text{ days}$	$(T)_2 = \text{MJD } 47256 \pm 52$
$\gamma = -13.70 \pm 0.07 \text{ km s}^{-1}$	$a_1 \sin i = 126 \pm 8 \text{ Gm}$
$K = 1.90 \pm 0.11 \text{ km s}^{-1}$	$f(m) = 0.0024 \pm 0.0005 M_{\odot}$
$e = 0.55 \pm 0.04$	
$\omega = 252 \pm 6 \text{ degrees}$	R.m.s. residual = 0.6 km s^{-1}

4. Discussion

HR 4693 is shown to have an orbit of considerable eccentricity, small amplitude, and a period of about 16 years. The orbit is quite securely determined, although of course it could always be improved by further observations, which would naturally offer a constantly increasing time base and nowadays could well be of higher accuracy. A review, in the light of the orbit that is now known, of all the previously published radial

Table 1. Radial-velocity measurements of HR 4693. (See end of Table for the key to the Notes)

Date			MJD	Velocity km s ⁻¹	Phase	(O—C) km s ⁻¹	Note
1926	Apr	5	24610	—8.0	̄.090	+4.2	A
1948	Dec	19	32904	—19.2	̄.522	—5.7	W
1968	Dec	30	40220	—14.7	0.785	+0.1	C
1970	May	10	40716	—15.4	0.871	+0.1	L
1971	Aug	24	41187	—15.8	0.952	+0.1	D
1972	Jan	6.52	41322.52	—15.9	0.976	—0.4	1
1973	Apr	4	41776	—11.8	1.054	+0.8	K
		27.94	799.94	—11.4	.058	+1.1	G
1974	May	12	42179	—9.7	1.123	+2.4	K
1975	Feb	25.02	42468.02	—12.5	1.173	—0.3	
	June	21.92	584.92	—12.7	.193	—0.4	
1976	Jan	24.17	42801.17	—12.8	1.231	—0.4	
	Mar	1.08	838.08	—13.2	.237	—0.8	
		25.24	862.24	—11.3	.241	+1.2	B
		28.14	865.14	—12.8	.242	—0.3	B
	Apr	2.25	870.25	—11.1	.243	+1.4	B
	May	4.01	902.01	—12.5	.248	0.0	
	June	7.92	936.92	—13.9	.254	—1.4	
	July	9.14	968.14	—13.4	.260	—0.9	1
	Nov	29.22	43111.22	—12.8	.284	—0.2	
1977	Jan	30.14	43173.14	—11.6	1.295	+1.1	1
	Mar	30.01	232.01	—13.2	.305	—0.5	
	Apr	24.98	257.98	—13.9	.310	—1.2	
	May	24.88	287.88	—12.7	.315	0.0	
	June	10.91	304.91	—12.1	.318	+0.6	
	July	5.89	329.89	—11.8	.322	+1.0	
		15.89	339.89	11.8	.324	+1.0	
1978	Jan	23.13	43531.13	—13.7	1.357	—0.8	
	Feb	21.35	560.35	—10.9	.362	+2.0	B
	Mar	9.33	576.33	—11.3	.365	+1.6	B
		13.08	580.08	—13.8	.365	—0.9	
	Apr	1.29	599.29	—14.2	.369	—1.3	B
		13.20	611.20	—13.7	.371	—0.8	B
	May	9.94	637.94	—10.9	.375	+2.1	
		15.18	643.18	—14.0	.376	—1.0	B
		23.21	651.21	—12.9	.378	+0.1	1
	June	18.91	677.91	—11.5	.382	+1.5	
	Nov	20.28	832.28	—13.3	.409	—0.2	
1979	Jan	13.16	43886.16	—12.9	1.418	+0.2	
	Feb	25.11	929.11	—12.8	.426	+0.4	
	Mar	8.08	940.08	—13.1	.427	+0.1	
	Apr	25.02	988.02	—13.3	.436	—0.1	
	May	9.95	44002.95	—13.5	.438	—0.3	
	Nov	28.27	205.27	—13.6	.473	—0.3	
	Dec	25.20	232.20	—13.6	.478	—0.2	

Table 1. Continued.

	Date	MJD	Velocity km s ⁻¹	Phase	(O - C) km s ⁻¹	Note
1980	Feb 12.14	44281.14	-12.4	1.486	+1.0	
	May 5.96	364.96	-13.2	.501	+0.2	
1981	Feb 24.30	44659.30	-15.4	1.552	-1.7	B
	Mar 19.29	682.29	-14.2	.556	-0.5	B
	Apr 14.99	708.99	-14.3	.560	-0.6	
	May 2.96	726.96	-13.5	.563	+0.2	
1982	Jan 11.12	44980.12	-14.1	1.607	-0.2	
	Mar 4.06	45032.06	-13.2	.616	+0.7	
		6.29	034.29	.616	-0.5	B
		28.20	056.20	.620	-0.2	B
	Apr 14.19	073.19	-13.3	.623	+0.7	B
		14.95	073.95	.623	+0.4	
	May 11.91	100.91	-15.5	.628	-1.5	
	July 3.91	153.91	-13.2	.637	+0.8	
1983	Feb 4.52	45369.52	-14.9	1.674	-0.7	2
	Mar 7.07	400.07	-14.5	.680	-0.3	
		25.26	418.26	.683	+1.9	B
	Apr 20.20	444.20	-13.3	.687	+1.0	B
		26.18	450.18	.688	-0.7	B
	May 9.91	463.91	-14.1	.691	+0.2	
	June 6.93	491.93	-14.2	.695	+0.1	
	July 2.92	517.92	-14.2	.700	+0.1	
	Dec 11.20	679.20	-14.3	.728	+0.2	
1984	Jan 2.23	45701.23	-14.1	1.732	+0.4	
	Feb 1.41	731.41	-15.6	.737	-1.1	B
		21.34	751.34	.740	-0.5	B
	Apr 3.02	793.02	-14.4	.747	+0.2	
		13.96	803.96	.749	+0.8	
	May 10.94	830.94	-14.4	.754	+0.2	
	June 8.90	859.90	-14.2	.759	+0.5	
	Dec 21.19	46055.19	-14.7	.793	+0.2	
1985	Jan 12.25	46077.25	-14.9	1.796	0.0	
	Feb 8.47	104.47	-15.6	.801	-0.7	2
	Mar 15.01	139.01	-16.2	.807	-1.2	
	May 29.95	214.95	-16.2	.820	-1.1	
	July 6.90	252.90	-14.2	.827	+0.9	
1986	Jan 17.15	46447.15	-15.4	1.860	0.0	
		22.15	452.15	.861	-0.8	
	Feb 27.09	488.09	-16.1	.867	-0.7	
	Mar 7.02	496.02	-14.6	.869	+0.9	
	Apr 5.05	525.05	-15.3	.874	+0.2	3
	May 5.90	555.90	-15.8	.879	-0.3	
	June 4.89	585.89	-15.4	.884	+0.2	
	Aug 23.81	665.81	-15.4	.898	+0.3	3
	Nov 24.54	758.54	-16.1	.914	-0.3	1
1987	Jan 6.17	46801.17	-15.5	1.921	+0.4	
	Feb 21.07	847.07	-15.7	.929	+0.2	
	Mar 3.08	857.08	-16.3	.931	-0.4	3
	Apr 27.86	912.86	-15.7	.941	+0.2	

Table 1. Continued.

	Date	MJD	Velocity km s ⁻¹	Phase	(O - C) km s ⁻¹	Note
1987	May 24.92	46939.92	-15.8	1.945	+0.1	
	June 22.91	968.91	-15.7	.950	+0.2	
	Dec 8.24	47137.24	-15.5	.979	-0.1	
1988	Jan 8.19	47168.19	-15.1	1.985	+0.1	
	23.47	183.47	-15.2	.987	-0.1	2
	Mar 11.04	231.04	-14.6	.996	+0.2	3
	Apr 9.93	260.93	-14.3	2.001	+0.2	
	May 6.88	287.88	-14.4	.006	-0.1	
	June 5.93	317.93	-14.4	.011	-0.3	
	Nov 5.20	470.20	-13.1	.037	-0.1	3
	Dec 20.14	515.14	-12.3	.045	+0.5	
1989	Jan 18.17	47544.17	-12.7	2.050	-0.1	
	Feb 11.11	568.11	-13.0	.054	-0.4	
	23.25	580.25	-12.8	.056	-0.3	4
	Mar 12.06	597.06	-13.5	.059	-1.0	
	30.95	615.95	-12.4	.062	0.0	3
	Apr 28.01	644.01	-11.8	.067	+0.6	3
	May 19.91	665.91	-11.7	.071	+0.6	
	June 18.92	695.92	-11.5	.076	+0.8	
	July 3.92	710.92	-12.7	.079	-0.5	
	Oct 31.21	830.21	-12.1	.099	0.0	3
1990	Jan 14.04	47905.04	-11.9	2.112	+0.2	
	31.06	922.06	-12.0	.115	+0.1	3
	Feb 12.29	934.29	-12.3	.117	-0.2	4
	Mar 13.38	963.38	-12.3	.122	-0.2	2
	Apr 4.98	985.98	-12.6	.126	-0.5	
	May 3.97	48014.97	-12.4	.131	-0.3	

Notes

(Numerical notes refer to the author's observations, alphabetical ones to observations by others.)

A Mean of a series of 3 observations by Adams *et al.* (1926); the mean velocity has been re-calculated from the individual measurements, which have been listed by Abt (1973), and differs slightly from the originally published mean value. Like all the other published velocities reproduced in this table, the re-calculated mean has been adjusted by +0.8 km s⁻¹ to accord with the photoelectric zero-point (Griffin & Herbig 1981).

W Mean of a series of 8 spectrograms by Wellmann (1949).

C Mean of two spectrograms by Chériguene (1971).

L Mean of a series of 23 Lindheimer spectrograms

D Mean of a series of 41 David Dunlap spectrograms

K Means of 4 (1973) and 5 (1974) KPNO spectrograms

Bolton *et al.* (1975)

B Individual photoelectric measurement by Beavers & Eitter (1986), apart from the first one which is a mean of 8 measures all made on the same night. That one has been

arbitrarily accorded unit weight; the others have been weighted 0.4 or 0.15 according as their authors attributed them quality A or B.

None of the published observations apart from those by Beavers & Eitter (1986) has been utilized in the orbital solution.

- 1 Observed with the Palomar spectrometer (Griffin & Gunn 1974).
- 2 Observed with the Dominion Astrophysical Observatory spectrometer (Fletcher *et al.* 1982).
- 3 Observed with 'Coravel' at Haute-Provence (Baranne *et al.* 1979).
- 4 Observed with 'Coravel' at ESO.

All entries without a note were observed by the author with the original radial-velocity spectrometer at Cambridge (Griffin 1967).

G Observed by G. A. Radford with the Cambridge spectrometer.

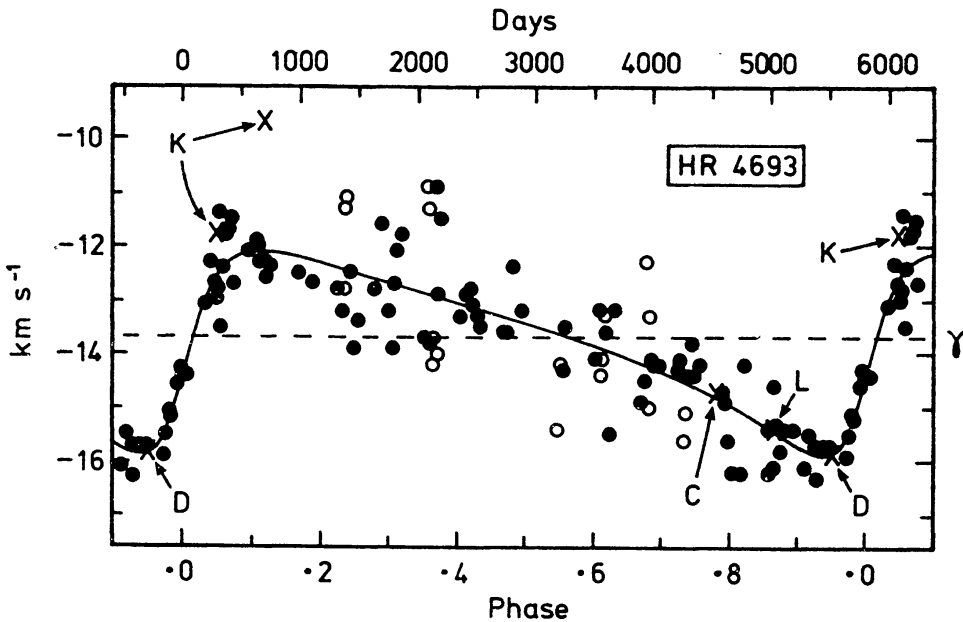


Figure 1. The computed radial-velocity curve of HR 4693, with the measured radial velocities plotted. The filled circles represent the author's photoelectric measurements; their apparently bad scatter arises merely because the very small amplitude of the star's velocity variation necessitates a very open scale of ordinates—the r.m.s. deviation of the points from the curve is actually only 0.6 km s^{-1} . Open circles represent the published photoelectric velocities of Beavers & Eitter (1986) from Iowa State University. The labelled crosses indicate the mean velocities obtained in a number of brief campaigns undertaken photographically; the key to the labels will be found in the footnotes to Table 1. None of the photographic measurements was taken into account in the solution of the orbit. In so far as they are plotted, the photographic data appear to offer the photoelectrically determined orbit some support; however, there are three other sets of velocities (Adams *et al.* 1929, Wellmann 1949, Fehrenbach & Duflot 1956), determined photographically from slit spectra, whose means would unfortunately fall outside the boundaries of the Figure. Additionally, there are two series of objective-prism velocities which equally cannot be plotted. The earlier set (Fehrenbach 1948), which led to an orbit with a half-day period (now repudiated), has a range about eight times the whole height of the diagram; the other (Fehrenbach & Duflot 1956) has a mean that is below the bottom edge of the Figure.

velocities shows that only the original Fehrenbach (1948) series was altogether mistaken. The three earliest series of slit spectra—those by Adams *et al.* (1929), Wellmann (1949), and those reported without any details by Fehrenbach & Duflot (1956)—were correct in showing no significant velocity changes over the time intervals they covered (*probably* covered, as regards the last set); but they exhibited rather serious errors of standardization, leading to appreciable systematic discrepancies from what are believed to have been the true velocities at the relevant times. The more recent series fit the velocity curve shown in Fig. 1 as well as could be desired, with perhaps the slight exception of the 1974 Kitt peak measures. It may be seen as somewhat ironic that the small inter-season difference that was noticed in that series by Bolton *et al.* (1975) and was partly responsible for their correct conclusion about the long-term variability of the velocity now appears to have been spurious!

In view of the small amplitude of velocity variation and the correspondingly small mass function, it is far from surprising that no evidence has been seen of the secondary star. There is, however, no reason to suspect it of being anything more modern and topical than a late main-sequence star: if the primary has a mass of two or three solar masses, the mass function actually *requires* the secondary to be at least of the order of a quarter of a solar mass, and it could easily be considerably more than that without the need to postulate that the system is viewed at an improbable angle.

Acknowledgement

Dr K.-P. Schröder kindly provided a copy of the article by Wellmann (1949).

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