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THE SPECTROGRAPHIC ORBIT OF BIDELMAN'S PECULIAR STAR H.D. 30353

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THE SPECTROGRAPHIC ORBIT OF BIDELMAN'S PECULIAR STAR H.D. 30353

By John F. Heard

Abstract

Orbital elements of this single-lined, hydrogen-poor spectrographic binary were published in abstract form by Heard and Boshko (1955). Since then additional observations have been obtained, and a more rigorous solution of the orbit has been made by the present writer. Velocity observations from other observatories are discussed as possible evidence of variations of the orbital elements. Photometric observations are presented which indicate that the system is not eclipsing, although a high orbital inclination might have been expected from the very large mass function. Indirect evidence that the system is very massive is adduced from the elements.

Introduction

The star H.D. 30353, $\alpha(1900)$ 4^h $41^m.8$, $\delta(1900)+43°06'$, m_{pg} 8.3, sp. Ape, has been studied by Bidelman (1950) who discussed its very peculiar spectrum and who discovered its binary character.

On the basis of the lines of ionized metals the star's spectrum resembles that of an A5 supergiant, but it shows extremely weak hydrogen lines and, at the same time, strong helium lines and numerous lines which do not appear in normal stellar spectra. Bidelman concluded that the star is truly deficient in hydrogen, and attributed the richness of the spectrum to the low opacity resulting from the hydrogen deficiency. He compared the star to several others which exhibit similar spectral peculiarities.

Bidelman's 18 published radial-velocity measures from spectrograms extending from October 1946 to April 1949 suggested a period of about one year. The range of velocities, namely about 100 km./sec., combined with the one-year period indicated a large mass function—at least 3 solar masses.

From an extensive analysis of the very rich spectrum Bidelman was able to select only eight lines which he believed were sufficiently free of blending to be trustworthy for velocity measures at moderate dispersions. These were λλ 3951.97 (V II), 4028.33 (Ti II), 4067.05 Ni II, 4101.74 (Hδ), 4122.64 (Fe II), 4233.20 (Fe II + Cr II), 4246.83 (Sc II) and 4481.23 (Mg II). He found no evidence of lines which could be attributed to the companion star.

Observations and Orbital Elements

The star was placed on the observing programme here in 1951 in the hope that the determination of definitive orbital elements would shed more light on the nature of the system and the component stars. Between 1951 and 1956 61 one-prism spectrograms of measurable quality were obtained—17 with a dispersion of 33 A./mm. at Hγ, the rest with a dispersion of 66 A./mm. The measurements for velocity were made with the use only of the lines chosen by Bidelman as listed above. On most of the plates either seven or all eight of the lines were measured, and the internal probable error of the mean velocity from a spectrogram was about 3 km./sec. on the average. In weighting the velocities for the least-squares solution for the orbital elements, weight 4 was assigned to the 33 A./mm. observations compared with weight 1 for the 66 A./mm. observations.

It is these 61 Dunlap observations of 1951–56 which form the basis of the orbital solution reported here. The period turned out to be so close to a year that there was an interval of about eighty days in the velocity curve without observations. However, in 1962 two new observations were made which fall in the middle of this gap. These observations were not incorporated in the solution, but are shown in the velocity curve of figure 1 along with the earlier Dunlap observations.

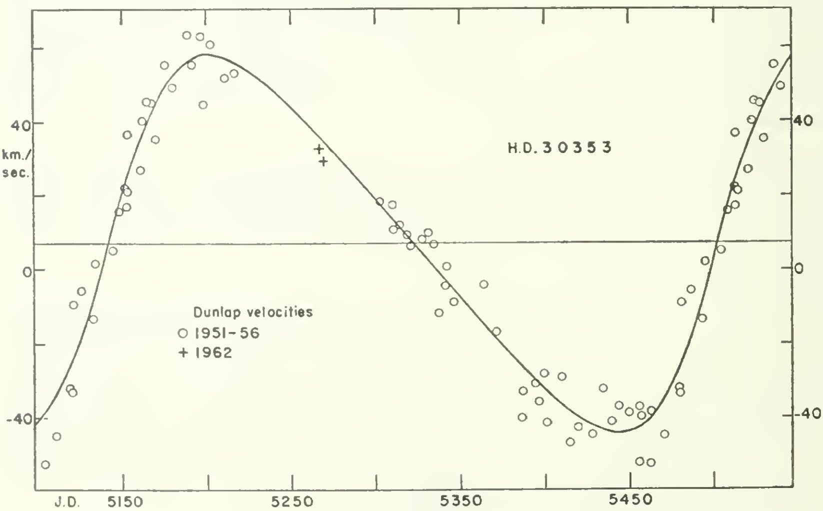

Figure 1

A preliminary orbit was derived by the use of R. K. Young's pre-computed curves, and then a least-squares solution was carried out by the digital computer method reported by Heard and MacRae (1956). The period was included in the solution, and there was no grouping of the observations. Table I gives the preliminary and final elements so derived, and Table II gives the Dunlap observations from which the solution was made plus the two 1962 observations not used in the solution.

TABLE I

ORBITAL ELEMENTS FOR H.D. 30353

Element		Preliminary	Final	m.e.
Period	P	360.00 days	360.47 days	±1.07
Eccentricity	e	0.30	0.28	±0.03
Angle of periastron	ω	270°.0	268°.4	±4.8
Periastron passage	T	J.D.2435142.80	J.D.2435141.74	±5.06
Velocity of the system	γ	+6.0 km./sec.	+7.0 km./sec.	±1.0
Semi-amplitude	K	50.0 km./sec.	51.4 km./sec.	±1.6
$a \sin i$			2.43×10^8 km.	$\pm 0.08 \times 10^8$
Mass function	$f(m)$		4.41 ⊙	±0.44

TABLE II

DUNLAP RADIAL VELOCITY OBSERVATIONS OF H.D. 30353

J.D.	Disp. A./mm.	V_o km./sec.	Phase from final T	V_c km./sec.	$V_o - V_c$ km./sec.
2433945.787	66	−40.1	245.922	−26.1	−14.0
955.825	"	−36.0	255.960	−30.7	− 5.3
960.754	"	−41.3	260.889	−33.2	− 8.1
2434086.541	"	+44.6	26.206	+42.7	+ 1.9
260.806	33	+ 0.8	200.471	− 2.6	+ 3.4
347.597	"	−44.5	287.262	−42.3	− 2.2
375.557	"	−52.0	315.222	−43.2	− 8.8
398.538	"	−32.1	338.203	−27.3	− 4.8
412.610	66	−13.5	352.275	− 8.1	− 5.4
426.506	"	+15.9	5.701	+14.6	+ 1.3
432.596	"	+21.0	11.791	+23.3	− 2.3
443.591	"	+45.2	22.786	+38.9	+ 6.3
454.522	"	+55.1	33.716	+49.3	+ 5.8
467.567	"	+63.3	46.762	+56.0	+ 7.3
470.562	"	+55.2	49.757	+56.9	− 1.7
475.556	"	+63.1	54.751	+57.7	+ 5.4
482.565	"	+60.4	61.760	+58.0	+ 2.4
489.566	"	+51.1	68.761	+57.3	− 6.2
589.862	"	+11.0	169.057	+13.9	− 2.9
592.888	"	+12.3	172.083	+12.3	0.0

TABLE II (*continued*)

J.D.	Disp. A./mm.	V_o km./sec.	Phase from final T	V_c km./sec.	$V_o - V_c$ km./sec.
2434600.894	66	+ 6.3	180.089	+ 8.1	− 1.8
606.899	"	+ 8.1	186.094	+ 5.0	+ 3.1
613.893	"	+ 6.9	193.088	+ 1.3	+ 5.6
620.891	"	− 4.4	200.086	− 2.8	− 1.6
626.899	33	− 8.9	206.904	− 5.5	− 3.4
642.913	66	− 4.1	222.108	−13.9	+ 9.8
666.907	33	−33.1	246.102	−26.0	− 7.1
699.709	66	−43.0	278.904	−41.6	− 1.4
713.688	"	−32.3	292.883	−43.8	+11.5
735.657	"	−37.1	314.852	−43.3	+ 6.2
742.590	"	−52.3	321.785	−40.6	−11.7
750.579	"	−44.6	329.774	−35.1	− 9.5
791.490	"	+17.0	10.215	+21.8	− 4.8
793.502	"	+36.2	12.227	+24.5	+11.7
800.506	"	+25.0	19.231	+34.6	− 9.6
810.505	"	+34.7	29.230	+45.6	−10.9
819.566	"	+48.9	38.291	+52.2	− 3.3
838.540	"	+44.4	57.265	+57.9	−13.5
856.565	"	+52.7	75.290	+56.1	− 3.4
942.852	"	+18.4	161.577	+17.8	+ 0.6
949.853	33	+17.5	168.578	+14.1	+ 3.4
957.875	"	+ 9.4	176.600	+ 9.8	− 0.4
970.868	"	+ 9.8	189.593	+ 3.1	+ 6.7
977.892	66	−11.9	196.617	− 0.6	−11.3
2435009.879	"	−17.1	228.604	−17.2	+ 0.1
033.920	"	−31.0	252.645	−29.1	− 1.9
039.945	"	−28.1	258.670	−31.9	+ 3.8
050.822	"	−28.9	269.547	−36.6	+ 7.7
055.823	"	−46.8	274.548	−38.4	− 8.4
083.785	33	−36.7	302.510	−44.8	+ 8.1
089.717	"	−38.5	308.442	−44.6	+ 6.1
121.578	66	− 8.7	340.303	−24.9	+16.2
126.774	"	− 5.5	345.499	−18.2	+12.7
135.578	"	+ 1.9	354.303	− 4.9	+ 6.8
143.662	"	+ 5.2	1.917	+ 7.2	− 2.0
151.665	33	+22.0	9.920	+21.4	+ 0.6
162.655	"	+40.2	20.910	+36.7	+ 3.5
440.808	"	−41.1	299.063	−44.7	+ 3.6
457.686	"	−39.7	315.941	−43.0	+ 3.3
463.565	"	−38.5	321.820	−40.4	+ 1.9
480.676	"	−33.4	338.931	−26.5	− 6.9
2437789.581	66	+32.7	124.551	+37.0	− 4.3
791.594	"	+29.6	126.564	+35.8	− 6.2

Velocity Observations from other Observatories

Bidelman's 18 published velocity observations of 1946–49 cannot be reconciled with the Dunlap observations as well as might be expected. The question is: can the discordances be construed as evidence of changes in the orbit?

The velocities published by Bidelman (1950) were obtained from McDonald spectrograms of the years 1946 to 1949; they include one prism spectrogram ($f/2$) with dispersion 76 A./mm., three prism spectrograms (CG) with dispersion 27 A./mm. and 14 prism spectrograms (CQ) with dispersion 55 A./mm. (all dispersions at $H\gamma$). The manner in which they disagree with the Dunlap velocity curve is seen in figure 2 where they are plotted, along with eleven unpublished velocities, kindly supplied by Bidelman, derived from McDonald CQ spectrograms taken in 1949 and 1950 in the season immediately following his published series. It will be observed that Bidelman's 1946–50 velocities, regardless of dispersion, have this pattern relative to the Dunlap velocity curve: they are systematically more negative by about 20 km./sec. over the greater part of the velocity curve, but agree with the Dunlap curve (in fact tend to be a little above it) in the middle of the steep rising branch.

It is apparent that no adjustment of the period will reconcile the two sets of observations; neither will a steady change of any of the orbital elements. Rather, it would appear that either there was a seasonal effect in the McDonald or the Dunlap velocity system (the period being so close to one year), or there was an abrupt change in the apparent orbital elements between the end of Bidelman's series in February 1950 and our series beginning in October 1951.

A single Mount Wilson Coudé spectrogram of December 22, 1950, taken by Greenstein and measured by Bidelman, falls close to the Dunlap velocity curve. So also do three velocities from McDonald Coudé spectrograms (dispersion 35 A./mm.) of December 1955, kindly taken and measured by A. Blaauw at the writer's request.

All 15 of the unpublished velocities are listed in Table III with the kind permission of the investigators involved. Along with the earlier 18 velocities published by Bidelman they are also shown plotted with reference to the Dunlap velocity curve in figure 2.

In correspondence with the writer, Bidelman has pointed out that, while he would expect his Oct. 31, 1946 velocity (from an $f/2$ spectrogram with dispersion 76 A./mm.) to be poor, a re-examination of his measures of the CG and CQ series and a survey of the velocities of

TABLE III

UNPUBLISHED VELOCITIES OF H.D. 30353

Observatory and Spectrograph		Date (U.T.)	Vel. (km./sec.)
Mt. W. Coudé (4.5 A./mm.)	1950	Dec. 22.244	−48
McD. Coudé	1955	Dec. 4.423	−43.2
(35 A./mm.)		Dec. 7.468	−36.6
		Dec. 8.429	−40.8
McD. CQ	1949	Sept. 12.344	−13.8
(55 A./mm.)		Sept. 12.364	−13.1
		Sept. 12.386	−18.9
		Sept. 12.405	−17.4
		Dec. 4.275	−58.9
		Dec. 11.264	−52.6
		Dec. 19.324	−65.3
		Dec. 22.132	−64.7
	1950	Jan. 5.267	−54.8
		Feb. 2.094	−25.8
		Feb. 24.075	+ 3.5

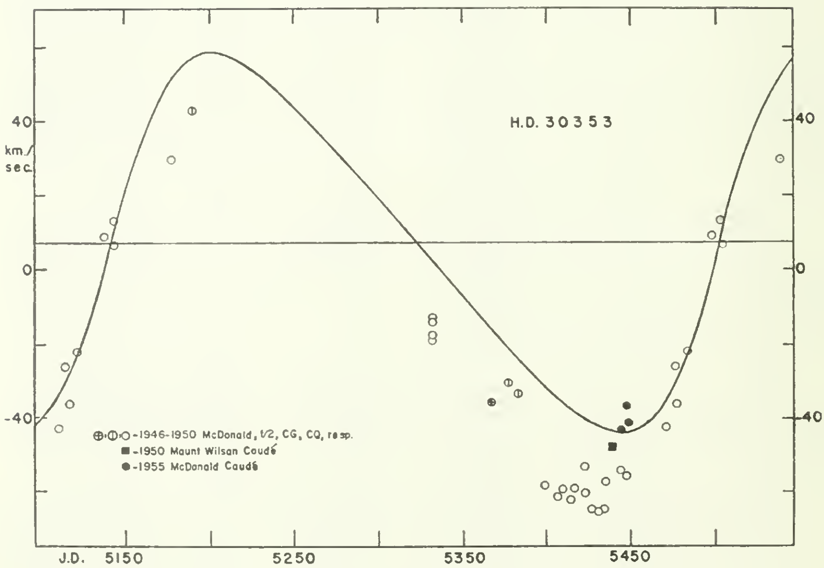

FIGURE 2

standard velocity stars taken during the long "run" of McDonald CQ spectrograms of 1948–49 have convinced him that there are no large systematic or seasonal errors in his velocities. On the other hand, the present writer has a similar conviction regarding the Dunlap velocities, and draws attention again to the agreement of the 1955 McDonald Coudé velocities and the 1950 Mount Wilson Coudé velocity with the Dunlap velocities. Furthermore, each of us, using the same lines, fails to find systematic velocity differences which could be attributed to effects of blending with different dispersions, and, indeed, our dispersions are not dissimilar (McDonald 27 and 55 A./mm., Dunlap 33 and 66 A./mm.).

If, as it would thus appear, we may rule out what might have seemed to be systematic errors of either or both of the McDonald and Dunlap velocity systems, we are left with the conclusion that there occurred between early 1950 and late 1951, if not a change in the elements, at least some effect which mimicked such a change.

Photometric Observations

The large mass function of 4.4⊙ for H.D. 30353 brought up the interesting possibility of this binary being an eclipsing system. In Moore's (1948) *Fifth Catalogue of Spectroscopic Binaries* there are seven binaries with listed mass functions greater than 3⊙; all seven are eclipsing systems. Since there is no evidence whatever of a secondary component of H.D. 30353 in the spectrum, one might expect the eclipse of the primary star, if it occurs, to be deeper than that of the secondary. From the orbital elements the times of superior conjunction of the primary were calculated to be about August 4, 1955 and July 29, 1956, with mean error of about 5 days. Because of the long period the eclipse, if any, might be expected to last for some days. With the possibility of detecting an eclipse, G. A. Bakos, then at this Observatory, undertook to make photoelectric observations of H.D. 30353, using the 19-inch reflecting telescope. The observations at the time of superior conjunction of the primary were made difficult by reason of the large easterly hour angle of the star at dawn; it will be noticed that this difficulty has been aggravated from year to year. It will not be convenient to observe the star again at superior conjunction for some years to come. An inferior conjunction, corresponding to possible eclipse of the secondary, would have occurred about Jan. 31, 1956.

From the observations which Bakos was able to obtain in 1955 and 1956 there is no evidence of an eclipse. His observations near superior conjunctions were on 1955 Aug. 8, 16, and 24, and on 1956 July 28, 29, 31, Aug. 8, 14, 22, and 25; and near inferior conjunction he had observations on 1956 Jan. 17 and Feb. 10. No minima were detected at these times. Also it should be remarked that a study of our spectrograms revealed no evidence of an atmospheric eclipse near the times of conjunctions of the primary.

Although Bakos' observations revealed no eclipses, they did indicate variability of the light. Altogether, between Aug. 8, 1955 and Nov. 8, 1956, he obtained photoelectric observations, mostly in two colours, on 57 nights. Variations amounting to about 0.1 magnitude were detected. There is an indication that the variations may consist of short-lived increases in brightness about every 30 days.

The Masses of the Components

Bidelman (1950) has remarked on one consequence of the large mass function of H.D. 30353, namely that it indicates a fairly massive secondary. Table IV indicates a few possible combinations of the masses of primary and secondary which are consistent with our mass function of 4.4⊙ for inclinations of 90° and of 45°.

TABLE IV

Possible Mass Combinations and Deviations from the Mass-Luminosity Law

	For $i = 90°$		For $i = 45°$	
Mass of observed component	Mass of unobserved component	Mag. dev.	Mass of unobserved component	Mag. dev.
2⊙	7⊙	7^m	15⊙	10^m
10	13	3	25	6
20	19	2	33	4

If the mass-luminosity law is given by $\Delta M = 9.54 \log m_2/m_1$, and if the secondary is at least two magnitudes fainter than the primary (since the secondary's spectrum is not seen), then the figures designated by "Mag. dev." in Table IV are the least number of magnitudes by which the stars would fail to be related by the mass-luminosity law, in the sense of the observed component being over-luminous. It is seen that the departure would be rather spectacular if the primary is a dwarf, and would amount to several magnitudes even if the primary has the mass of a supergiant.

The absolute magnitude of the primary is not known with certainty, but Bidelman (1950) has remarked on the fact that the spectrum resembles that of a supergiant, and he calculated that if the difference between the measured colour index of 0.54 and an assumed normal colour index of 0.10 can be attributed to interstellar reddening, then the primary would be a rather luminous supergiant ($M = -6$, say). If this is the case he would expect the mass of the primary to be of the order of $20\odot$, and we would then be dealing with a very massive pair. Bidelman noted that these are mere speculations, however, since, for all we know, a star with such a peculiar spectrum may be very over-luminous for its mass and it may be intrinsically reddened.

Since Bidelman (1950) wrote the foregoing discussion of the reddening, Hiltner (1956) has published three-colour and polarization observations of H.D. 30353. From Hiltner's data we may compute that the absorption in the visual is at least $0^m.83$, and that $(B-V)_0 \leqslant 0^m.18$, and $(U-B)_0 \leqslant -0^m.37$, and we should note that the weakness of the hydrogen lines will be expected to make the star bright in the ultra-violet because of the smallness of the Balmer jump. To draw further conclusions, however, would require a precise spectral classification—which we do not have.

Acknowledgements

The writer gratefully acknowledges the help of Miss Olga Boshko, formerly an assistant at the Observatory, who did a great part of the plate measuring and made a preliminary orbital solution. He is also indebted to Dr. William P. Bidelman for valuable discussions and for providing unpublished velocity observations with permission to include them in this report. Dr. Adriaan Blaauw also made three velocity observations and permitted them to be included in the report. Dr. Gustav Bakos made the photometric observations which have been referred to.

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