SPECTROSCOPIC ORBITAL ELEMENTS AND PHOTOMETRY OF THE MULTIPLE SYSTEM EPSILON HYDRAE

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ABSTRACT. In combination with older plate material, the recently obtained high-dispersion spectrograms have been used to derive the orbital elements of the AB pair of this multiple system. The new orbital elements have been compared with those already published. In addition, over the period of seven years a two-colour photometry of the system has been conducted and light variations of about 0.1 mag have been observed. The derived period is 72 days.

СПЕКТРОСКОПИЧЕСКИЕ ОРБИТАЛЬНЫЕ ЭЛЕМЕНТЫ И ФОТОМЕТРИЯ КРАТНОЙ СИСТЕМЫ ЕПСИЛОН ГИДРЫ. На основе раньше приобретеных пластинок и недавно полученных высокодисперзных спектрограмм были вычислены орбитальные элементы AB пары этой кратной системы. Новые элементы были сравнены с раньше опубликованными элементами. Кроме того в течении наблюдательного интервала семь лет была осуществлена двухцветная фотометрия и были найдены изменения блеска приблизительно 0.I звездной величины. Был найден период этих изменений 72 дней.

SPEKTROSKOPICKÉ DRÁHOVÉ ELEMENTY A FOTOMETRIA NÁSOBNEJ SÚSTAVY EPSILON HYDRAE. Na základe staršieho pozorovacieho materiálu a nedávno získaných vyso-

kodisperzných spektrogramov odvodili sa dráhové elementy AB páru tejto násobnej sústavy. Nové dráhové elementy sa porovnali s elementami predtým publikovanými. Naviac po dobu 7 rokov sa prevádzala dvojfarebná fotometria sústavy a boli objavené svetelné zmeny približne 0.1 magnitúdy. Perióda týchto svetelných zmien je 72 dní.

1. INTRODUCTION

The bright star epsilon Hya (HD 74874, HR 3482) appears to be at least a quintuple system. The AB pair, having a separation of only 0.2 arcsec, is a visual and spectroscopic binary with a period of about 15 years. Component C (separation 3 arcsec) is a spectroscopic binary with a period of 9.9 days and the fifth component D is a 13 mag star at a distance of 19 arcsec. It is believed to be a member of the system on account of its common proper motion.

There is some discrepancy in the spectral types of the close pair. According to Heintz (1963) the spectral types of AB are F8 and G0 III(we believe they should be listed in reverse order) while Cowley (1976) classified the system as K III: and F0 V. Similarly, there is confusion about the trigonometric parallax of the system. Quoting Heintz, the Yale parallax is given as 0.010 arcsec while the Allegheny values are close to 0.025 arcsec. Heintz himself derived a dynamical parallax of 0.021 arcsec. The apparent magnitude of the pair is V = 3.38, B - V = 0.68 (Nicolet, 1978). There are at least six astrometric and four spectroscopic orbits available (Abrami, 1963; Heintz, 1963). The earlier spectroscopic elements of the AB pair by Adams (1939) have been recalculated by Heintz (1963). He used both the astrometric observations of the last 100 years and the spectroscopic data of Lick, Bonn and Cape observatories in calculation of the orbital elements. At about same time Underhill (1963) published her spectroscopic investigation. She suspected a secondary variation in radial velocities with a period of 70 days.

The C component separated by three arcsec from the brighter pair is also a spectroscopic binary with a period of 9.9047 days. The orbital elements were derived by Sanford (1926). According to Heintz (1963), AB and Cc have an orbital period of 890 years while the D component has an estimated orbital period of 10000 years.

2. OBSERVATIONS

Since 1972 spectroscopic observations of the AB pair have been conducted at the David Dunlap Observatory (DDO) with the 1.9 m reflector. Eighteen spectrograms with a dispersion of 1.2 nm.mm^{-1} have been obtained and measured. These are listed in Table 1. The phase was calculated by means of the period and time of the periastron passage given in Table 2. In addition, the older measurements made at Mount Wilson (Abt, 1970), Lick (Cambell and Moore, 1928) and the Dominion Astrophysical Observatory (DAO) (Underhill, 1963) have been utilized to derive differential corrections to the orbital elements of Adams. The Lick and Mount Wilson low-dispersion spectrograms were given a weight of 0.3 of the DAO and DDO material. Altogether 71 entries have been used in a least-squares solution to derive new orbital elements. Compared with Heintz's 23 entries our data cover another 46 years. The value P = 5478.98 days was derived for the orbital period from four epochs of maximum velocity. The new orbital elements are compiled in Table 2 and the velocity curve is plotted in Fig 1. Since Heintz has not published the mean errors of his elements, no comparison with our results is possible.

T A B L E 1

The DDO Radial Velocities of ε Hya

J.D. hel	Phase	V_r(km.s^{-1})	m.R(km.s^{-1})	No.of meas. lines	O-C(km.s^{-1})
2441331.795	0.7795	+37.97	± 0.68	21	-0.53
1380.629	0.7884	38.14	0.55	22	-0.11
1408.567	0.7935	39.56	0.54	23	+0.96
2739.816	0.0365	42.34	0.65	24	+2.55
2753.890	0.0391	41.30	0.58	23	+2.37
2823.681	0.0518	39.02	0.51	23	+2.36
2837.677	0.0544	36.83	0.34	22	-5.74
3572.689	0.1885	27.41	0.57	24	-1.14
3880.890	0.2448	25.48	0.34	27	-4.88
3943.708	0.2562	26.94	0.42	27	-3.65
3978.624	0.2626	28.32	0.39	26	-2.36
4251.731	0.3124	34.19	0.39	27	+3.26
4692.582	0.3929	33.01	0.52	27	+3.09
4727.615	0.3993	32.78	0.56	26	+1.93
5049.657	0.4581	33.01	0.45	29	+1.30
5378.644	0.5181	33.78	0.39	28	+0.04
5392.668	0.5207	33.30	0.53	28	-0.54
5420.579	0.5258	+34.59	0.42	28	+0.53

Photoelectric observations of epsilon Hya in the B and V passbands have been conducted since 1979. To our knowledge this is the first systematic photometry of this system. The three stars, A, B and C, have been measured in the diaphragm. Component C is about 3.5 mag fainter than the brighter pair. However, its contribution has not been subtracted from that of the pair. Regardless of Underhill's suggestion of a 70 day period in the radial velocities, six epochs of increased brightness of the system have been identified. A period of 72 days has easily been recognized, and the following elements have been calculated by the method of least squares:

$$\mathrm{Max_{hel}} = \mathrm{J.D.}\ 2443953.925 + 71^{d}.71464 \times E$$
$$\pm 1.293 \qquad \pm 44$$

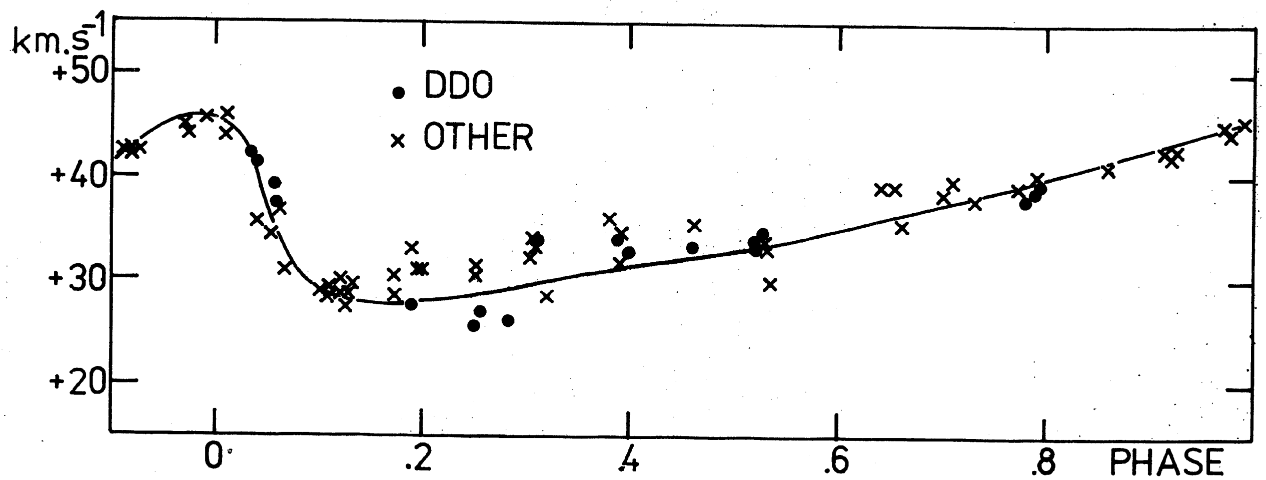

Fig. 1. The spectroscopic orbit of epsilon Hya.

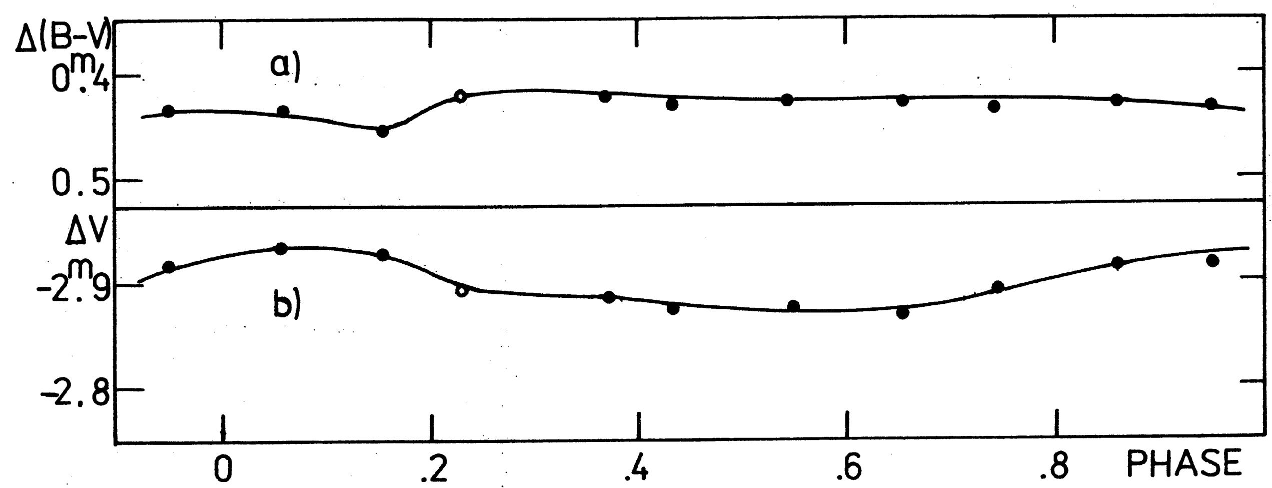

Fig. 2. a) The mean colour index of epsilon Hya. b) The mean light curve of epsilon Hya.

T A B L E 2

Spectroscopic Orbital Elements of ε Hya AB

Element	Value	mean error	Heintz
P (days)	5478.98	± 93.19	5497
T (periastr.)	2437060.85	± 63.85	2437319
K ($km.s^{-1}$)	8.05	± 0.14	8.01
ω (deg)	74.66	± 0.21	84.0
e	0.652	± 0.020	0.67
γ ($km.s^{-1}$)	36.20	± 0.78	36.6
f (m)	0.1294		
a sin i (km)	4.5996 E8		

The Individual photoelectric observations are listed in Table 3, the mean light curve is reproduced in Table 4 and plotted in Fig. 2. The mean error of these points is lower than 0.01 mag. However, the light curve may be affected by seasonal variations of both the variable and the comparison star. The observations were obtained at astronomical observatories Skalnaté Pleso and Waterloo. No instrumental or observational effects which could explain the variations of V and (B-V) have been found. Such effects are improbable as long series of photoelectric observations from both observatories over ten years for several stars were obtained, compiled and interpreted. The brightness of the variable star varies in its minimum by about 0.02 mag. We have also plotted the magnitude difference between the comparison and the check star. With the aid of the period fitting program, a period of 50.49 days and a semi-amplitude of approximately 0.01 mag has been found. A second check star is needed to clarify this situation.

T A B L E 3

Photometric Observations of ε Hya

J.D.	Phase	Δ V	Δ(B-V)	J.D.	Phase	Δ V	Δ(B-V)
2443907.781	0.4907	-2.883	+0.440	4687.707	0.3661	-2.893	+0.426
3910.716	0.5316	-2.862	+0.432	4689.685	0.3937	-2.896	+0.420
3932.824	0.8399	-2.892	+0.436	4691.718	0.4220	-2.878	+0.412
3939.762	0.9366	-2.914	+0.433	4713.633	0.7276	-2.888	+0.424
3949.720	0.0755	-2.914	+0.383	4715.635	0.7555	-2.891	+0.437
3955.708	0.1590	-2.956	+0.446	4720.665	0.8257	-2.890	+0.402
3960.697	0.2286	-2.899	+0.424	4725.605	0.8946	-2.896	+0.423
3973.675	0.4095	-2.880	+0.428	4731.591	0.9780	-2.904	+0.440
3983.632	0.5484	-2.879	+0.415	5044.672	0.3437	-2.876	+0.431
4189.933	0.4251	-2.844	+0.422	5056.600	0.5100	-2.883	+0.441
4242.895	0.1636	-2.911	+0.489	5061.585	0.5795	-2.880	+0.438
4277.760	0.6497	-2.856	+0.430	5073.581	0.7468	-2.893	+0.424
4598.862	0.1272	-2.928	+0.452	5074.588	0.7608	-2.910	+0.432

Table 3 - ontinued

J.D.	Phase	ΔV	Δ(B-V)	J.D.	Phase	ΔV	Δ(B-V)
5078.633	0.8172	-2.893	+0.425	6142.589	0.6532	-2.851	+0.428
5081.565	0.8581	-2.902	+0.450	6143.597	0.6672	-2.868	+0.425
5082.574	0.8722	-2.900	+0.448	6144.608	0.6814	-2.877	+0.437
5084.586	0.9002	-2.913	+0.430	6146.581	0.7089	-2.877	+0.447
5087.585	0.9421	-2.902	+0.429	6158.562	0.8759	-2.901	+0.440
5091.573	0.9977	-2.923	+0.422	6167.557	0.0014	-2.926	+0.432
5098.566	0.0952	-2.937	+0.435	6171.554	0.0571	-2.962	+0.433
5320.844	0.1947	-2.891	+0.440	6174.561	0.0990	-2.962	+0.430
5354.790	0.6680	-2.873	+0.429	6176.556	0.1268	-2.986	+0.492
5383.811	0.0727	-2.925	+0.433	6445.757	0.8806	-2.858	+0.443
5406.643	0.3911	-2.884	+0.418	6483.715	0.4099	-2.895	+0.451
5418.667	0.5587	-2.874	+0.447	6486.357	0.4468	-2.865	+0.450
5423.690	0.6288	-2.873	+0.428	6489.500	0.4906	-2.862	+0.468
5425.649	0.6561	-2.883	+0.413	6490.649	0.5066	-2.879	+0.438
5437.554	0.8221	-2.868	+0.414	6500.348	0.6417	-2.848	+0.442
5441.550	0.8778	-2.891	+0.420	6506.619	0.7293	-2.901	+0.432
5449.562	0.9895	-2.906	+0.456	6511.592	0.7986	-2.889	+0.441
5450.553	0.0033	-2.865	+0.432	6517.422	0.8799	-2.900	+0.453
5452.556	0.0313	-2.909	+0.468	6522.331	0.9483	-2.907	+0.438
5746.694	0.1328	-2.900	+0.454	6523.553	0.9654	-2.935	+0.458
5753.690	0.2303	-2.890	+0.412	6533.564	0.1050	-2.893	+0.437
5763.676	0.3696	-2.876	+0.414	6538.571	0.1748	-2.921	+0.425
6124.651	0.4031	-2.872	+0.431	6556.342	0.4226	-2.868	+0.415
6140.610	0.6256	-2.876	+0.417	2446557.356	0.4368	-2.866	+0.416

TABLE 4

The Mean Light Curve of ε Hya

Phase	ΔV	Δ(B-V)	n
0.0617	-2.934	+0.435	7
0.1541	-2.927	+0.457	7
0.2294	-2.894	+0.418	2
0.3728	-2.885	+0.422	5
0.4369	-2.874	+0.432	9
0.5476	-2.874	+0.427	8
0.6524	-2.868	+0.428	9
0.7468	-2.893	+0.434	7
0.8590	-2.895	+0.431	11
0.9526	-2.914	+0.436	7

3. DISCUSSION

The inclination of the orbital plane, derived from visual observations ($i = 49\overset{\circ}{.}3$), makes it possible to calculate the mass function and compare it

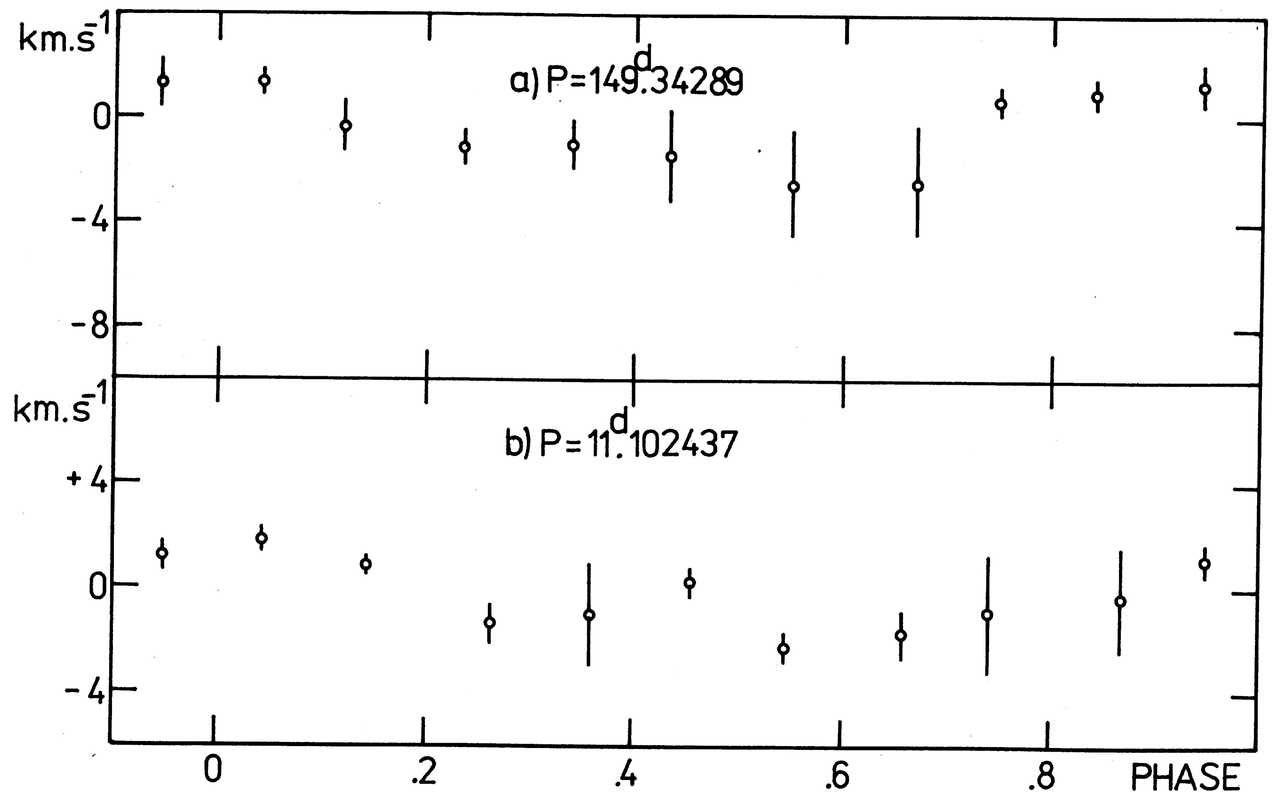

Fig. 3. a) The velocity residuals plotted against the phase of the period of 149.34289 days.
b) Same as above with the period of 11.102437 days. In both cases the vertical bars indicate the mean error of the point

with the mass function resulting from the spectroscopic elements. We have tried a number of combinations of spectral and luminosity types and found that the best fit is achieved with the pair GO III and FO V.

The derived orbital elements differ by about 10 per cent from those published earlier by Heintz (1963) and Adams (1939). The rather large residuals of the calculated values are a disturbing factor, for two of the DDO spectra they have reached the extremes of +3.65 and -5.74 $km.s^{-1}$. We agree with Underhill that this is an unexpectedly large amount of scatter. Therefore, period fitting programs have been applied to all spectroscopic residuals and two possible periods with a high coefficient of confidence have been derived (Fig. 3, where error bars have also been indicated). The periods are 149.34289 and 11.10244 days. The frequency analysis was carried out on an SM 4-20 computer of the Astronomical Institute in Tatranská Lomnica using the programs of Fourier analysis for unequally spaced data and the Stellingwerf approach. The programs were written by Dr. J. Zverko, CSc.. The program structures are based on Deemnig's (1975) and Stellingwerf's (1978) mathematical procedure. The 72-day period has a very small coefficient of confidence, which is rather surprising. Assuming the radial velocities are affected by the presence of a third body of small mass (about one solar mass), the semi-major axes are 0.8 and 0.1 AU for the two periods. It might be possible to assume the existence of a companion at a distance of 180 R_O, while the distance of 30 R_O appears to be uncomfortably close to explain the 11-day period.

The photometric observations plotted in Fig. 2 indicate a small change in brightness of the most likely G spectral type giant with a period of 72 days. If radial pulsations are involved, it would postulate a late-type supergiant as the carrier of such pulsations. Unfortunately, the colour index varies very little with phase and there is a weak indication of the colour index becoming redder at the time of maximum brightness. To reconcile these discrepancies we assume that these changes are associated with the rotation of the giant star. This period of rotation is acceptable for a giant star of this spectral type. There may be some kind of a "blue spot" on the surface of this star rotating with a period of 72 days.

In conclusion, an improvement in spectroscopic orbital elements has been achieved. However, there is no indication of a short periodic effect in the residuals of the velocity curve as suspected by Underhill. On the other hand, a longer period of 149 days or a much shorter period of 11 days has been found to fit the distribution of the residuals.

The photoelectric photometry of the system has shown the variability of the GO III star.

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