SPECTROSCOPIC ORBIT AND TIDAL CIRCULARIZATION OF HD 8634

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Two formally incompatible spectroscopic orbits with eccentricities 0.38 and 0.28 have been published for the 5.4-day single-lined binary HD 8634. We re-observed this system and derive a new orbit from our velocities. Moreover, all available data fit a common orbital solution with $e = 0.27$. Although most binaries of spectral type F5 have circular orbits at such short periods, the non-zero eccentricity is normal for HD 8634 because the primary is not yet convective. If this system were in the process of rapid circularization (as one could naively infer from the decreasing eccentricity), its period would be decreasing, and such small period changes would be actually detectable with a long time span of the data available for HD 8634. We argue that if a suitable candidate binary in the stage of rapid circularization is found, the rate of tidal dissipation can be measured by accurately monitoring its period over several decades.

Introduction

Radial velocities of stars of spectral types later than F5 can be measured with a good precision, hence their spectroscopic orbits are usually well determined. Essentially all such binaries with periods shorter than 10 days are circularized by tides (e.g. Fig. 5 in Duquennoy & Mayor [1]). The 5.4-day spectroscopic binary HD 8634 with eccentric orbit and F5 III primary contradicts this trend, hinting that circularization may still go on in this system. Two good-quality orbits of HD 8634 with very different eccentricities $e = 0.378 \pm 0.02$ and $e = 0.28 \pm 0.03$ are published. We re-observed this binary in attempt to find the reason for this contradiction.

Data overview

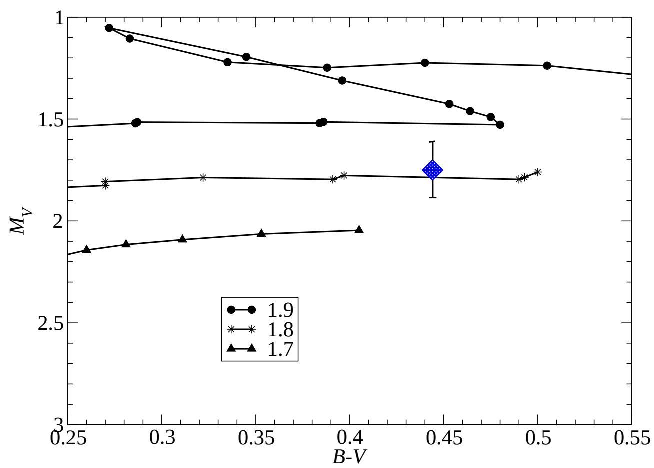

Figure 1: Evolutionary tracks from Girardii et al. [3] for stars of 1.7, 1.8, and 1.9 $M_\odot$ up to the age of 1.6 Gy. The primary component of HD 8634 is marked by a large diamond at ($B - V = 0.444$, $M_V = 1.75$). Its estimated age is 1.3 Gyr, mass 1.82 $M_\odot$.

HD 8634 = HR 407 = HIP 6669 (2000: 1^h 25^m 35.7^s, $+23^\circ$ $30'$ $42''$) is a 6-th magnitude star of spectral type F5 III. The Hipparcos parallax is 13.0 ± 0.8 mas (distance modulus 4.43 ± 0.14), the proper motion is $(+34, -22)$ mas/yr. The $WBVR$ ptotometry from Kornilov et al. [2] is $(V, W{-}B, B{-}V, V{-}R) = (6.182, -0.086,\ 0.444,\ 0.385)$. The photometry from 2MASS [4] is $(J, H, K) = (5.32,\ 5.13,\ 5.03)$. The star is located in the Main Sequence (MS) band in the $B{-}V, W{-}B$ two-color diagram and has $B{-}V$ and $V{-}K$ colors appropriate for the F5 spectral type. The primary component is a sub-giant (Fig. 1), it was a late-A type star on the MS. Böhm-Vitense [5] gives basic parameters of this star: $\log T_e = 3.813$, $V \sin i = 34$ km/s, [Li/Fe]=2.65. The presence of lithium confirms the sub-giant status of the primary which has not yet developed an outer convective envelope and is still burning hydrogen.

The variability of the radial velocity has been established by Plaskett [6] with 4 observations in 1918. Wright & Pugh [7] (WP54) observed this object in 1938–1952 and determined the first spectroscopic orbit with a period of 5.42906^d and the eccentricity $e = 0.378 \pm 0.023$, unusually high for such a short period. Assuming the primary mass 1.82 $M_\odot$ (Fig. 1), the minimum mass of the secondary is 0.19 $M_\odot$.

The spectroscopic orbit was re-determined by Mayor & Mazeh [8] (MM87) in search of precession caused by a tertiary companion, with a negative result. Curiously, a significantly lower eccentricity $e = 0.28 \pm 0.03$ was found by MM87. They claim that their data are "inconsistent" with the period determined by WP54, although in fact they are (see below).

Melo & de Medeiros [9] measured the rotation velocity of the primary $V \sin i =$ 31.5 km/s and noted that the axial and orbital rotations are not synchronized. They studied the ratio of X-ray to visible fluxes as an indicator of coronal activity and noted that HD 8634 is less active compared to other giants in close binary systems. de Medeiros et al. [10] give $V \sin i = 30.8$ km/s and draw attention to the non-circularity of the orbit.

The radius of the primary is $3.0 R_\odot$ from isochrone fitting, hence the average equatorial velocity corresponding to synchroization is 28.0 km/s. The synchronous velocity at periastron is $(1-e^2)^{1/2}(1-e)^{-2} = 1.8$ times larger or 51 km/s ($e = 0.27$). The inclination is not known, so the measured $V \sin i = 31$ km/s can correspond to pseudo-synchronous rotation.

The system HD 8634 is in fact triple. A faint physical tertiary component with a separation $1.''47$ and position angle $70°$ was discovered in 2004 with adaptive optics by Tokovinin et al. [11]. The magnitude difference with the spectroscopic binary is $\Delta(J,H,K) = (6.3,\ 5.8,\ 5.5)$, hence the tertiary component has $(J,H,K) = (11.6,\ 11.0,\ 10.5)$. These magnitudes correspond to a MS dwarf of $\sim$0.3 $M_\odot$ at the distance of HD 8634. The orbital period is of the order of 900 yr.

In order to check whether the change of the spectroscopic orbit is real, a new set of 19 observations has been secured in September 2006 by N.A.G. using the correlation radial-velocity-meter (RVM) on the 1-m telescope in Crimea. The radial velocities (RV) are measured with RVM with an accuracy of 0.3 km/s [12]. However, in case of HD 8634 rapid axial rotation and shallow contrast of the correlation profile lead to the reduced RV precision. Moreover, a systematic offset of instrumental nature may appear, despite reference to the RV standards. The RVs and residuals to the orbit E3 are listed in Table I. The internal measurement errors are determined in the process of fitting a Gaussian curve to the correlation profiles. The new data set is designated as TG06 and will be analyzed below jointly with two other data sets, WP54 and MM87.

Orbital solutions

Table II lists the elements of the spectroscopic orbits published by WP54 and MM87, in common notation. The 7-th column contains the number of RVs and the weighted rms residuals. For consistency, we re-computed these orbits from the same data by using two different codes and obtained concordant results, also quoted in Table II as E1 and E2. We excluded the first 4 points by Plaskett from the WP54 data set (thus designated WP54*) and imposed a fixed period $P = 5.42923^d$ for all re-computed orbits. The period is determined by fitting all data simultaneously.

We also combined all three data sets in a common solution (Fig. 2). In doing so, we added offsets of +1.2 and −2.0 km/s to the WP54* and TG06 data, to bring into

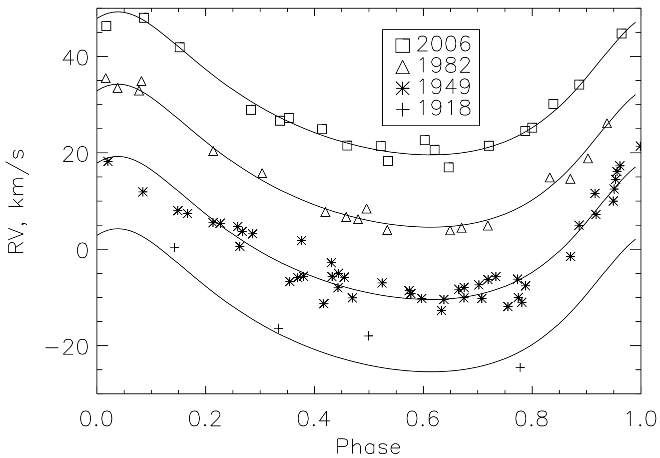

Figure 2: New combined spectroscopic orbit of HD 8634 is compared to the individual data sets, labeled by their average epochs and displaced vertically by 15 km/s for clarity.

agreement the center-of-mass velocities (Table III). The relative weights of the data sets were adjusted in order to reach $\chi^2/(N-M) \sim 1$ for each set separately. The WP54* data are assigned errors $\sigma_V = 4.0/\sqrt{W}$, where W are the published weights (typically $W=3$, $\sigma_V = 2.3\,\mathrm{km/s}$). The true errors are not known, this estimate follows from the residuals to the E1 orbit. By similar argument, the errors given by MM87 are multipled by 2.0 and the TG06 errors are left unmodified. The weights in the combined solution are inversely proportional to the square of errors. The weighted rms residuals of three data sets to the individual orbital fits, σ, and the residuals to the orbits E1 and E4 are compared in Table III. In calculating the residuals to different orbits, the elements T_0 and γ are fitted, thus allowing for the shifts in time and velocity zero point for each set.

The data sets MM87 and TG06 are formally incompatible with the orbit E1: the probabilities of getting χ^2 larger than the observed ones, $P(\chi^2)$, are estimated as 10^{-4} and $2\,10^{-6}$, respectively. All three sets are compatible with the orbit E4, $P(\chi^2) = (0.17, 0.27, 0.22)$ (this conclusion depends, of course, on the adopted errors). The point here is that no strong evidence of any significant orbit change is furnished by the data.

In search of possible period changes, the fitting program was modified to include the linear period drift A as an additional parameter. The formal fit gives $A = (\mathrm{d}P/\mathrm{d}t)/P =$

$-1/\tau_P = (-2.0 \pm 3.8) \cdot 10^{-10}$ d^{-1}. The period decreases with $\tau_P = 13$ Myr, but this number is not statistically significant. The 1σ lower limit is $\tau_P > 4.7$ Myr.

Discussion

Our study shows that great care is needed in the interpretation of old data. Even a formally significant change of some orbital element may be spurious. However, apparent changes of e can be also caused by a *real distortion of the RV curve* due to such effects as spots, blending with lines of a tertiary companion, gas streams. We could demonstrate that all these effects are insignificant in case of HD 8634. On the other hand, a real ecentricity modulation in the close triple system HD 109648 was detected by Jha et al. [13].

One could naively interpret the eccentricity changes in HD 8634 as being caused by tidal orbit circularization, but this process is too slow to be observable. The time scale of orbit circularization $\tau_e = -1/(\mathrm{d}\ln e/\mathrm{d}t)$ is a strong function of the ratio of semi-major axis a to component radius R, $\tau_e \propto (a/R)^8$ (see Eggleton [14] for the theory). Even in most favorable cases (binaries with short periods and/or large radii), τ_e is longer than 1 Myr, leaving no hope to measure this parameter directly.

However, if a circularizing binary evolves with *constant orbital angular momentum* proportional to $P^{1/3}(1-e^2)^{1/2}$, its period P and eccentricity e are related by the condition

$$P(1 - e^2)^{3/2} = \mathrm{const.} \tag{1}$$

As e becomes smaller due to tides, P decreases as well. The period can be measured with a very high accuracy, so its small change caused by tidal evolution may be actually detectable. It can be inferred from Eq. 1 that $\tau_P = -P/(\mathrm{dP}/\mathrm{d}t) = 2(1 - e^2)/(3e^2)\ \tau_e$. In eccentric binaries with $e > \sqrt{2/5}$, the period evolves even faster than the eccentricity, $\tau_P < \tau_e$. Tidal evolution of (P, e) also implies an exchange between orbital and rotational angular momenta, therefore Eq. 1 is approximately valid only for binaries where the rotational angular momentum is much smaller than the orbital one. Careful modeling will be needed to relate period changes of tidally interacting binaries with the tidal dissipation rate, while Eq. 1 is useful for preliminary estimates.

HD 8634 appeared to be an interesting case to test this idea. By adding a new data set to the two existing orbits, we could hope to detect a period change or at least to place a limit. Indeed, the data presented above indicate that $\tau_P > 4.7\,\mathrm{Myr}$. It turns out that HD 8634 is not expected yet to circularize its eccentric orbit. Nevertheless, our project shows a feasibility of measuring ongoing circularization in some other, more suitable binaries with time scales below few Myr, given the data of similar or better quality. This work is a “training excercise” that might stimulate further attempts to measure the tidal dissipation rate directly.

Binaries with rapid (i.e. detectable) tidal circularization must be rare – either very young or with components expanding into giants ($\tau_e \propto R^{-8}$). If such a binary is found, its observation over a sufficiently long time will lead to the measurement of τ_P and hence to the measurement of the tidal dissipation.

Acknowledgements

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Table I: *New observations of HD 8634 and residuals*

JD - 2400000	RV	Err	O−C
	km s^{-1}	km s^{-1}	km s^{-1}
53969.562	−18.10	1.46	1.44
53970.588	−20.38	2.56	3.06
53971.592	−18.48	1.68	−0.40
53972.553	1.76	0.83	0.94
53973.572	−1.10	0.92	0.18
53974.573	−16.33	1.05	−0.55
53975.578	−21.62	1.08	1.07
53977.560	−8.83	0.86	−0.12
53981.545	−22.38	1.33	1.02
53982.520	−17.77	0.83	−0.60
53985.519	−15.76	1.04	0.92
53986.510	−24.72	1.84	−1.80
53987.516	−21.52	1.03	−0.03
53989.502	5.02	0.95	1.08
53990.571	−14.08	1.11	−1.72
53991.533	−21.48	0.82	−0.28
53992.544	−26.02	1.80	−2.82
53993.589	−12.86	1.26	1.03
53994.557	3.29	0.89	−1.59

Table II: *Spectroscopic orbits of HD 8634*

P	T	e	w	K_1	γ	N	Author, orbit
days	JD		$\circ$	km s^{-1}	km s^{-1}	σ	
5.42908	2433243.762	0.378	322.5	14.50	-15.86	53	WP54 original
-	±0.043	±0.023	±3.8	±0.46	±0.24	-	
5.42923	2433243.72	0.352	319.6	14.28	-15.72	49	WP54* (E1)
-	±0.09	±0.043	±7.6	±0.88	±0.44	2.44	
5.4264	2449998.46	0.28	351	15.2	-14.8	18	MM87 original
±0.0009	±0.12	±0.03	±9	±0.4	±0.4	1.3	
5.42923	2444998.25	0.290	335.2	15.52	-14.32	18	MM87 (E2)
-	±0.10	±0.033	±7.9	±0.50	±0.39	1.25	
5.42923	2453972.77	0.246	337.5	14.39	-12.32	19	TG06 (E3)
-	±0.08	±0.026	±5.9	±0.40	±0.25	1.04	
5.42923	2433243.93	0.274	334.3	14.78	-14.26	86	Combined (E4)
±0.00001	±0.05	±0.017	±3.6	±0.27	±0.17	1.62	

Table III: *Analysis of the data sets*

Data	N	Error	Offset	σ	σ(E1)	σ(E4)
set			km s^{-1}	km s^{-1}	km s^{-1}	km s^{-1}
WP54*	49	$4.0/W$	$+1.2$	2.44	2.44	2.65
MM87	18	$\times2.0$	0	1.25	2.12	1.37
TG06	19	$\times1.0$	-2.0	1.04	1.87	1.13