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Synchronization in early-type spectroscopic binary stars

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Summary. Extending a recent study on the rotation in eclipsing binaries, we have rediscussed the synchronism between rotation and revolution in close binaries by an inspection of the published rotation velocities of ~80 early-type non-eclipsing double-lined spectroscopic binary components.

Basically, we have found that a considerably tendency to synchronization (or pseudosynchronization) extends up to wider binaries than previously believed (i.e., nearly up to estimated fractional radii $r \sim 0.05$), whilst only for $r \lesssim 0.05$ do pronounced deviations from synchronism (or pseudosynchronism) become the rule. Remarkably, current theoretical views (Zahn, 1977) on synchronization time scales appear to be inadequate to account for such a strong tendency.

Key words: spectroscopic binaries – rotation velocities

Introduction

A pronounced tendency towards synchronization between the axial rotation and orbital revolution is observed in close binary systems (e.g., Levato, 1974, 1976, and references cited therein). According to Levato (1976) synchronism appears to be the rule, for orbital periods shorter than about 4–8 d in the early B spectral range, ~3 d in the early A spectral interval, ~2 d at mid A-type, and ~10–14 d at mid F-type. Tidal friction is invoked to explain this tendency. Time scales to reach synchronization mainly depend on the stellar masses, the fractional radius of the binary component (ratio of the stellar radius to the orbital semimajor axis), and on the rate of the energy dissipation processes.

Tidal interaction is expected to be very efficient in cool stars having convective envelopes, where turbulent viscosity retarding the equilibrium tide has been identified as the main dissipative mechanism (Zahn, 1977). But it seems to be difficult to devise efficient dissipative mechanisms (capable of accounting for the observed high degree of synchronism) for the early-type binary components (having radiative envelopes), where the dominant dissipative process is believed to be radiative damping on the dynamical tide (Zahn, 1977). In fact, Zahn (1977) realized that early-type binaries appear to be synchronized up to orbital periods (or separations) somewhat greater than predicted by current theoretical views based on standard models of interior stellar structure. But he thought that refined models including overshooting from stellar convective cores could remove this marginal discrepancy.

The question of whether observational data are quantitatively consistent with theory has been recently more extensively tackled by Giuricin et al. (1984) through a survey of the rotational properties of about 140 eclipsing binary members. Discussing the degree of synchronism as a function of the stellar fractional radius r, the authors found that almost all members of detached systems are synchronized up to fractional radii $r \sim 0.15$, whereas, below this r-value, both synchronized and asynchronized rotators are encountered with roughly comparable frequency up to $r \sim 0.10$. They noted that the corresponding high fraction of synchronized rotators with $r < 0.15$ is incompatible with current theoretical predictions on synchronization time scales, even if stellar models including a plausible amount of overshooting are considered.

In order to give a further check on the existence of such a basic discrepancy between theory and observations, in the present paper we have deemed it useful to rediscuss the rotational properties of an extensive sample of non-eclipsing double-lined spectroscopic binaries (hereafter referred to as SB2), which have not been considered in Giuricin et al.'s (1984) paper. We shall limit ourselves to the early-type spectroscopic pairs (spectral types OB, A0–4) whose components have fully radiative envelopes.

Available data

We have considered the SB2s earlier than A5 with known projected rotational velocities, and known spectroscopic orbits. Table 1 lists the orbital period, spectral types, and projected rotation velocities $V \sin i$ for the binaries considered. The values of $V \sin i$ are generally taken from Uesugi and Fukuda's (1982) catalogue, except for HD126983 (see Kaufmann and Klippel, 1973), for HD208095 (Popper, 1982), for HD165052 and HD167771 (Morrison and Conti, 1978), for the primary of HD4727 and for HD140008, HD193536, HD199081, HD218440 (Wolf et al., 1982). The elements of the spectroscopic orbits are generally taken from Batten et al.'s (1978) catalogue, except for HD35411 (see Zizka and Beardsley, 1981), HD177624 (Hill and Fisher, 1980), HD208095 (Popper, 1982), HD165052, and HD167771 (Morrison and Conti, 1978).

From the known magnitude difference or mass ratio between the two members, we have evaluated the secondary's spectral type in a few cases (when it is not available). For the Am stars we give the spectral types corresponding to the hydrogen lines. We have corrected the $V \sin i$ – values for the aspect effect, estimating the

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Table 1. Rotational properties of double-lined spectrum binaries

HD number	Period (days)	Sp. types	$V\sin i$ (km/s)
4727	4.2828	B5V+B6.5	35;10
5408	4.2424	B8–9Vp	225
6118	81.12	B9.5V	50
12534	2.67	B9V+B9V	75;70
22203	6.2236	B8V+B8V	55;50
23180	4.4192	B1III	80
23277	15.5132	A2m+A3	25;25
23625	1.9406	B2.5V	150
26591	3.6587	A3m+A3m	45;45
27376	5.0105	B8.5V	15
29376	2.2075	B3V	240
32964	5.5227	B9.5V+B9.5V	≤ 30;≤30
34790	2.1517	A1 2V+A2V	50;50
35411	7.9893	B1V+B3V	40
37043	29.1351	O9III	125
37756	27.1546	B3III	75
39357	5.969	B9.5V	45
39698	7.9969	B2V	120
41357	28.28	A4m	30
57103	2.2596	B8V	80
66824	18.722	A1V	45
75759	33.311	O9V+O9V	80;80
79763	15.986	A1V	50
89822	11.5791	A0p	15
93205	6.0810	O3V	150
93403	15.093	O6f	195
98088	5.9051	A3Vp	25
104337	2.9631	B1.5V	130
107259	71.9	A2IV	25
110854	7.904	A0V	25
112014	3.2866	A0V+A2V	15;15
116656	20.5386	A1Vp+A1V	35;35
121263	8.024	B2.5IV	225
126983	11.82	A2V+A2V	< 15;<15
136504	4.5598	B3IV	120
139892	12.5843	B7V+B7V	100:;100:
140008	12.26	B5V	20
143018	1.5701	B1V	100
144208	108.075	A2V	20
144217	6.8281	B0.5V	100
147971	3.2617	B3V	180
149632	10.56	A1Vp	80
152218	5.40	O9.5III	155
152248	5.97	O7f	< 130:
153808	4.0235	A0V	85
165052	6.140	O6.5V+O6.5V	65;69

Table 1 (continued)

HD number	Period (days)	Sp. types	$V\sin i$ (km/s)
167771	3.9735	O7.5IIIf+O9III	92;62
171978	14.674	A2V	25
173524	9.8107	A0p+A0p	≤5;≤5
175286	4.1175	A1V	55
175544	1.9858	B3V	165
177624	2.3741	B3V+B6V	120;110
178322	12.47	B5V+B6V	110;50
182490	7.390	A2III–IVm	55
191201	8.3343	B0III+B0III	115;95
191692	17.1243	B9.5III	65
191747	9.316	A3IV	45
193536	2.9847	B2V	70
199081	2.8548	B5V	40
203439	20.30	A2V	45
206267	3.7098	O6.5	155
206644	1.7290	A0V	70
207650	5.3047	A0V	70
208095	9.4792	B7V	60
208947	2.9899	B2V	250
212120	2.6164	B6IV	60
216494	3.4298	B9p	10
218440	7.2511	B2V	30

value of the orbital inclination angle i from the primary's minimum mass $M_1 \sin^3 i$ on the assumption that its mass follows Straižys and Kuriliene's (1981) mass-spectrum relations for different luminosity classes. We have adopted the absolute radii of the components in accordance with Straižys and Kuriliene's (1981) radius-spectrum relations for different luminosity classes (for dwarfs we have used their relation for average main sequence stars). By using our estimates of the radii, for each component we have evaluated the synchronized velocity V_k (corresponding to the mean orbital angular velocity) and the pseudosynchronized velocity V_e, given by the formula

$$V_e = V_k(1+e)^{1/2}/(1-e)^{3/2} \quad (1)$$

which corresponds to a synchronization with the instantaneous orbital angular velocity at the periastron of an orbit of eccentricity e (pseudosynchronization). We recall that in close binaries with appreciably eccentric orbits synchronization is attained with V/V_k larger than unity; according to Hut (1981), it is probably quickly reached at periastron (i.e., with the maximum angular velocity).

The extension of our sample of data regarding components of SB2s is comparable to Levato's (1976) subsample relative to the early-type binaries. But his subsample contains a large fraction of non-eclipsing single-lined spectroscopic binaries (SB1), whose aspect effects cannot be reliably estimated. Moreover, in his study no distinction between substantially unevolved (nearly main sequence) prior-to-mass-exchange systems and post-mass

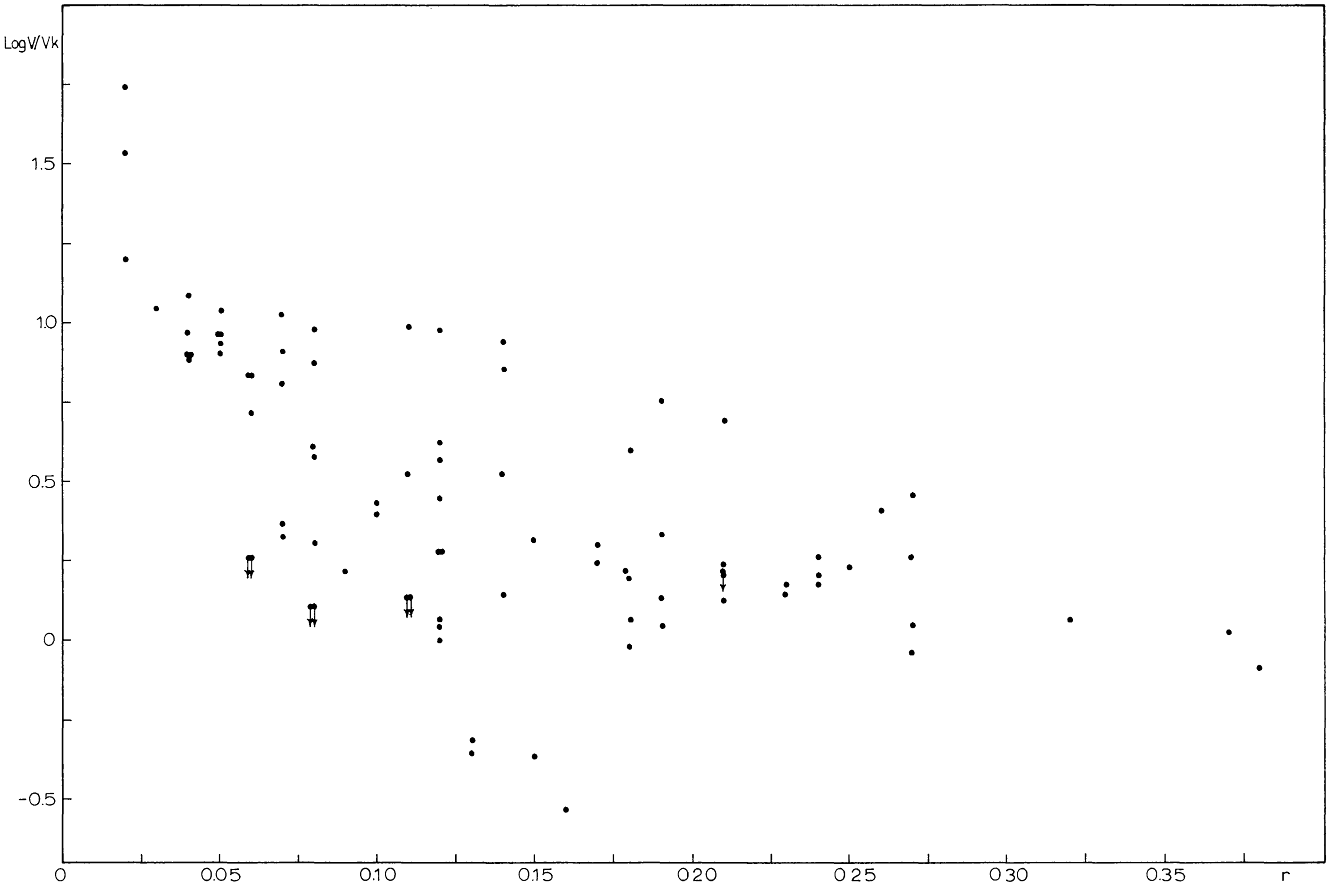

Fig. 1. Plot of Log V/V_k (decimal logarithm of the ratio between the measured rotation velocity and the estimated synchronous one) versus the fractional radius r of the spectroscopic binary components considered

exchange binaries (e.g., Algols) is attempted; we observe that an appreciable fraction of the binaries he considered (i.e., several eclipsing binaries and a lot of SB1s having a low mass function) are probably post-mass exchange pairs, for the mass-gaining components of which very fast (asynchronous) rotation can be brought about by mass exchange (e.g., Plavec, 1970). On the other hand, it is conceivable that our sample of SB2s suffers much less contamination by post-mass exchange systems than his sample; by far the majority of our SB2s are very likely to be in a prior-to-mass exchange phase of evolution, since, owing to observational selection effects, they have, in general, mass ratios near unity, which are quite unusual among the systems which have undergone mass transfer.

Discussion

In previous relevant studies the degree of synchronism was generally illustrated by means of graphs of the ratios V/V_k versus the orbital period P. However, the fractional radius r of a binary member (rather than the period) is the physically most appropriate basic parameter for discussing the degree of synchronism. For our non-eclipsing systems r cannot be determined directly; for each binary member we have estimated this quantity from the above-mentioned estimates of the absolute radius and from evaluations of the binary separation, which results – via Kepler's law – from the total mass of the system (estimated according to the above precepts). Plots of the ratios Log V/V_k and Log V/V_e versus the fractional radius r of our binary components (see Figs. 1 and 2) are suitable illustrations for an inspection of the degree of synchronism. In view of the errors involved in the evaluation of V, V_k, V_e we will consider a star in a synchronous (or pseudosynchronous) rotation if V/V_k (or V/V_e) <2.

We observe that our SB2s are more scattered in our Figs. 1 and 2 than are the eclipsing binary members in Giuricin et al.'s (1984), analogous plots, simply because eclipsing pairs are a more reliable source of relevant data than are non-eclipsing binaries. In this respect, we observe that in the large-r range ($r \geqq 0.15$), where synchronization was found to be practically the rule for eclipsing binary members (Giuricin et al., 1984), the percentage of our SB2 rotators having $V/V_k \geqq 2$ or $V/V_e \geqq 2$ is not entirely negligible (24% and 18%, respectively). It is thus conceivable that spurious fast rotation, related to extrabroadening of lines due to contamination of secondary spectra, is assigned to some primaries of SB2s.

However, in accordance with the view that tidal forces are larger for large r, a correlation between the degree of synchronism and the parameter r emerges from our plots: the fraction of stars showing pronounced deviations from synchronism ($V/V_k \geqq 2$) or pseudosynchronism ($V/V_e \geqq 2$) tends to increase as we go to smaller r. In fact, the percentage of rotators having $V/V_k \geqq 2$ increases up to 62% in the range $0.15 < r < 0.05$. But, reasoning in terms of pseudosynchronization, we point out that the frequency of cases of marked deviation from it ($V/V_e \geqq 2$) increases much less in the region $0.15 < r < 0.05$ (it reaches 31%). An abrupt jump in the

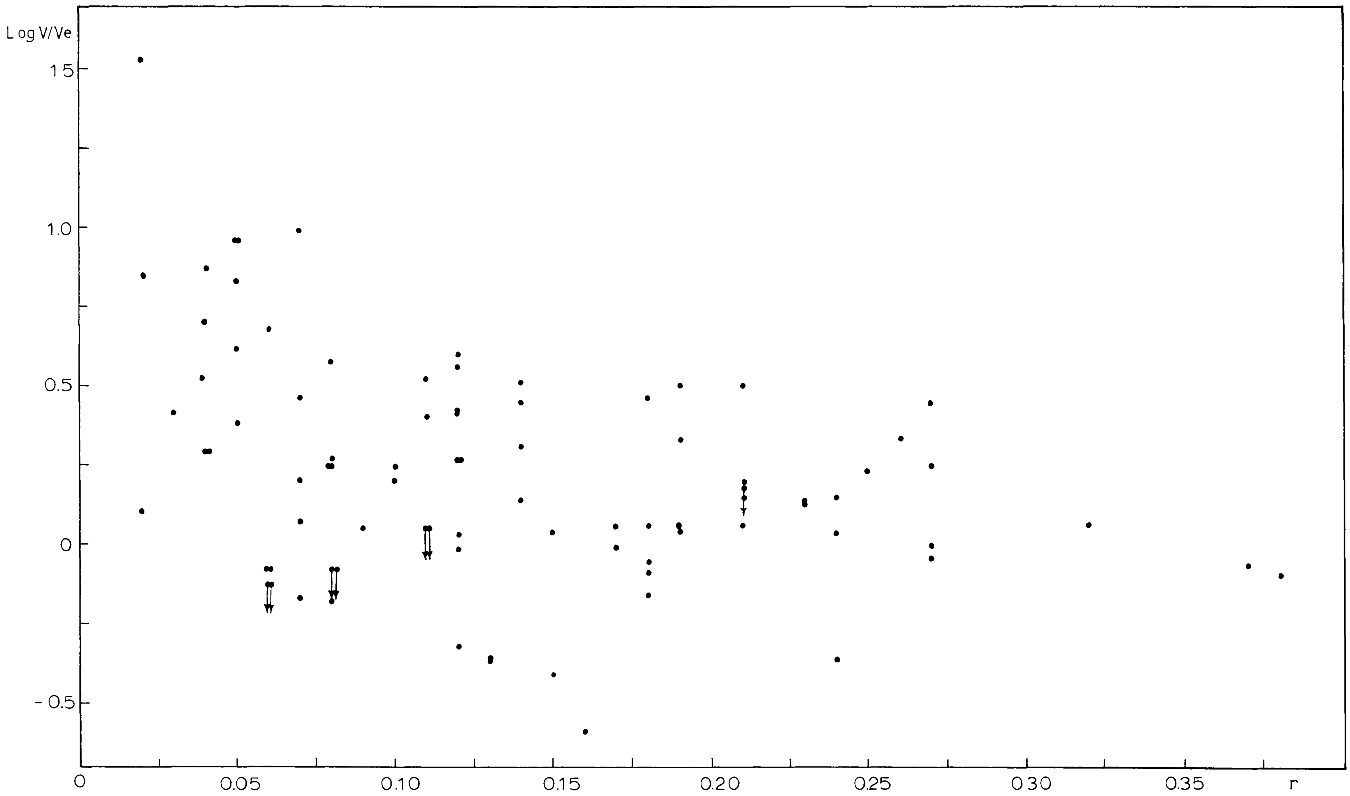

Fig. 2. Plot of Log V/V_e (decimal logarithm of the ratio between the measured rotation velocity and the estimated pseudosynchronous one) versus the fractional radius r of the spectroscopic binary components considered

average location of stars in our plots is observed at $r \sim 0.05$: for $r \lesssim 0.05$ marked supersynchronous or superpseudosynchronous rotation becomes essentially the rule. This we can state that a strong tendency to synchronization or pseudosynchronization appears to persist up to almost $r \sim 0.05$. We recall that investigations based on eclipsing binary data (Giuricin et al., 1984) were unable to establish this limiting r-value, because of the scarcity of wide eclipsing binaries.

Reasoning in terms of orbital periods (for an easier comparison with several previous studies), we can say that for Straižys and Kuriliene's (1981) relations for main sequence stars and high mass ratio (say $M_2/M_1 = 0.8$), a limiting value of $r \sim 0.05$ would correspond to periods of about 26, 18, and 13 d at spectral types B2, A0, and A5 respectively. Compared with the upper envelope of limiting period intervals for synchronism given by Levato (1976), our results show that in the whole early-spectral range a considerable tendency to synchronism (or pseudosynchronism) extends up to binary separations substantially greater than previously held. More interestingly, it extends up to such small r-values as to be incompatible with current theoretical predictions (Zahn, 1977), according to which the synchronization time of equal mass early-type binaries should be considerably longer than the main sequence lifetime for an initial $r \lesssim 0.10$ (and an initial rotational velocity $V = 3\,V_k$).

To conclude, our survey of the rotation velocities of early-type SB2s, supplementing Giuricin et al.'s (1984) very recent study on eclipsing binaries, has specified that in early-type binaries a strong tendency to synchronization (or pseudosynchronization) extends up to substantially wider binaries than had been previously observationally found or expected from present theoretically views; the basic inadequacy of theory is thus meaningfully confirmed.

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