ON THE ROTATION OF A-TYPE STARS

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Abstract. Based upon the statistics of $V \sin i$ among A-type stars it is shown that (1) no relationship exists between rotational velocity and UBV colours, (2) there might be an influence of rotation upon spectral classification, and (3) spectroscopic binaries are associated with low rotational velocity.

1. Introduction

Recently, Cowley *et al.* (1969) (this paper will be referred to as CCJJ) have published a study of bright *A*-type stars, which fulfil the conditions $m < 6^{\mathrm{m}}.5$ and $\delta > -20°$. The number of stars included in the paper was 1700; for all of them spectral classification in the Morgan-Keenan system was provided. The majority (to be accurate, 67%) has also colour measurements in the Johnson-Morgan *UBV* system.

This large material of homogeneous classifications can be used to discuss certain controversial topics of stellar rotation. For instance it is well known that Boyarchuk and Kopylov (1958) obtained in their discussion of the frequency of $V \sin i$ as a function of spectral types, a pronounced minimum at A0 and a maximum around A3. They believed that these extremes were real because their statistics are based upon a large number of stars. Recently Van den Heuvel showed (1965, 1968) that this is probably due to the omission of the Am and Ap stars from the statistics of the Soviet astronomers.

In a second paper on the bright A-stars, which is being prepared for publication, we have re-examined these and other questions. I will not deal with all of them, but will only quote one result concerning the Boyarchuk-Kopylov hypothesis, because of its connection with problems to be discussed later.

In order to decide if the extremes found by Boyarchuk and Kopylov are real, we have examined the average $V \sin i$ values as a function of the $B-V$ colour. The $V \sin i$

TABLE I

Average rotational velocities for dwarfs, Ap, Am and δ Del stars as a function of colour

$B-V$	Interval	$\langle V \sin i \rangle$ (km/sec)	N	Dwarfs	Ap	Am	δ Del
$-0^{\mathrm{m}}.09$	$-0^{\mathrm{m}}.05$	108	29	23	6		
.04	.00	144	71	70	1		
+ .01	+ .05	131	61	57	4	1	
.06	.10	135	47	39	4	4	
.11	.15	132	35	26	1	8	
.16	.20	122	33	21	–	11	1
.21	.25	111	23	14	1	8	
.26	.30	104	12	4	–	7	1

A. Slettebak (ed.), Stellar Rotation, 219–226.

values were taken from Boyarchuk and Kopylov's (1964) catalogue and the colours from CCJJ. The results are given in Table I.

As can be seen, the extremes have disappeared. This is a confirmation of Van den Heuvel's result and can be interpreted as meaning that from a rotational point of view, A-type dwarfs, Am and Ap stars belong to the same group. It is also shown in Paper II that if we mix the dwarfs, Am and Ap stars, we obtain a very similar distribution function of $V \sin i$ for different colours, so that it is possible to use a single distribution function of $V \sin i$ for the whole group. Although this is probably not strictly true because of the smaller rotation of the A stars of latest type, it simplifies considerably our considerations and we will assume it as being strictly true.

Two points will now be examined in detail, the first being the relation between rotation and colour and the second the relation between rotation and duplicity.

2. Rotation and Colour

Theory predicts the existence of a relation between rotation and colour in the sense that the colour of a normal star undergoes a change if its rotational velocity is changed. The exact amount of this change is difficult to predict, however, because of the several assumptions which go into the theory, and therefore I will examine the question from a purely observational point of view.

Since it is impossible to separate in our observations V from $\sin i$, it is impossible to establish directly the relation between V and the colour change. The answer to the problem can thus only be a statistical one and consequently only the largest possible material can be expected to yield a solution. Since for most of the stars *UBV* photometry is available, the easiest thing to do is to examine a sample of dwarfs, to see if $V \sin i$ correlates with colour. The results are displayed in Table II.

TABLE II

Average $U-B$, $B-V$ indices for groups of dwarfs of different rotation

Spectral class	Mean colour	$V \sin i$ (km/sec)		
		0–99	100–199	200–300
B9	$\langle U-B \rangle$	-0.20 (14)	-0.21 (13)	-0.21 (6)
	$\langle B-V \rangle$	-0.06	-0.05	-0.06
A2	$\langle U-B \rangle$	$+0.04$ (12)	$+0.03$ (19)	$+0.04$ (4)
	$\langle B-V \rangle$	$+0.05$	$+0.03$	$+0.05$
A5–A8	$\langle U-B \rangle$	$+0.11$ (5)	$+0.11$ (13)	$+0.10$ (6)
	$\langle B-V \rangle$	$+0.16$	$+0.19$	$+0.15$

Note: Numbers in parentheses give numbers of objects in each group.

It is obvious that no correlation exists between average colour and rotation. The technique used is probably insufficient to detect small effects in the A stars, although one should remember that among the B stars colour differences do exist between rapidly rotating Be stars and more slowly rotating B stars.

A word of caution should be said regarding the use of spectral types for rotation statistics. It cannot be assumed a priori that spectral types are uninfluenced by rotation. This has to be demonstrated, and quite to the contrary, it is easy to show that some classification systems are in fact very much influenced by rotation. A little consideration suggests that probably classifiers have a tendency to assign sharp line stars to a later type than the broad line stars. This can be seen for instance very clearly on a comparison between the Mt. Wilson spectral types taken from the list of Adams *et al.* (1935) and MK spectral types from CCJJ. In Figure 1 are plotted all the

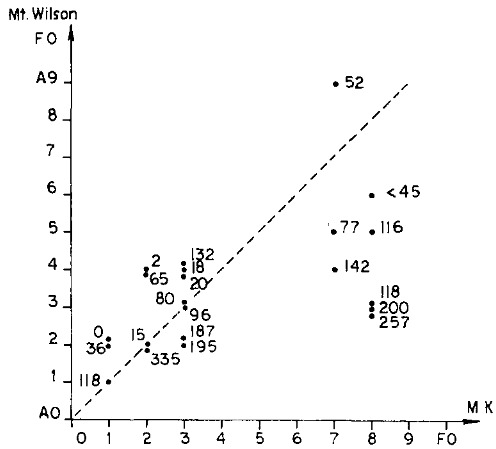

Fig. 1. Mt. Wilson spectral types as given by Adams *et al.* (1935) vs. MK spectral types estimated by CCJJ. Rotational velocities are given in km/sec.

stars common to both catalogues and for which rotational velocities exist. It is very evident that rapid rotators tend to be classified in the Mt. Wilson system as having earlier types than the average, which is what one would expect. The explanation of this lies in the fact that the Mt. Wilson material was obtained at higher dispersion than the MK material. The visibility of the lines is thus much more influenced by rotation in the Mt. Wilson material than it is in the MK material.

One might therefore think that no influence of rotation exists in the MK system. This question can be examined if a parameter exists which substitutes for the spectral types. Assuming that narrow band photometric indices are such a substitute, we have selected samples of stars of a given spectral type for which both Hβ and K indices were measured (Cameron, 1966; Henry, 1969) and for which also $V \sin i$ has been measured. The results are exhibited in Figure 2.

It can be seen that no relation exists between the position of the objects in each plot and the rotational velocity, written at each point. This is what one would expect (Henry, 1969).

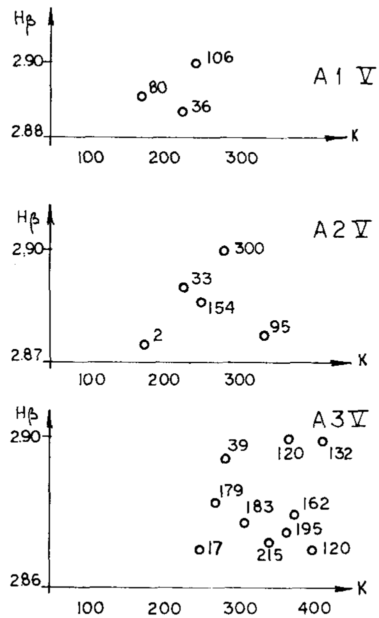

Fig. 2. Correlation between Hβ and K indices, spectral types and rotational velocities. The $V \sin i$ values are given in km/sec.

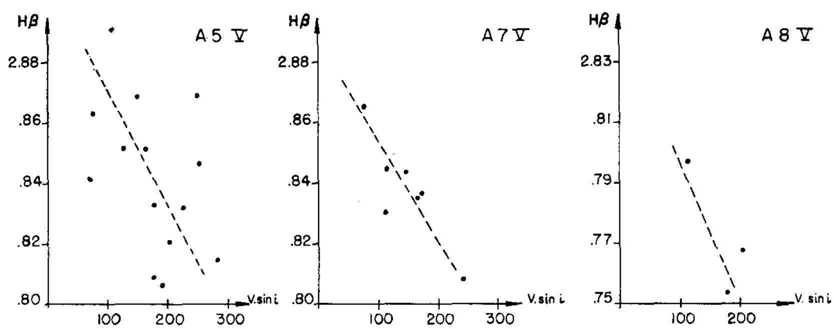

Fig. 3. Correlation between Hβ indices, spectral types and rotational velocities. The $V \sin i$ values are given in km/sec.

One can also examine dwarfs for which only the Hβ index has been observed (Cameron, 1966). If one assumes that Hβ indices are unaffected by rotation – which is likely but undemonstrated – one gets the situation depicted in Figure 3.

Spectral types A0–A4 do not reveal anything, probably because the Hβ index varies very little in this range. For A5–A8 dwarfs one gets the rather unexpected situation that on the average larger rotation implies lower indices, i.e. later spectral types. We have found no convincing explanation for this. Although the result is based upon few stars, and should thus be taken with caution, it must be taken as a warning that spurious effects *may* be present.

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Another word of warning should be said regarding the sharp lined dwarfs. These stars are often called Am, specially when viewed at high dispersion. The southern star π Ara is a good example, and it would be easy to pick out more examples. Probably the best way out of this difficulty would be to set up suitable standard stars for both fast and slow rotators.

3. Rotation and Duplicity

Several years ago Abt and Hunter (1962), on the basis of cluster material pointed out that spectroscopic binaries are slow rotators. Since nobody examined if the same is true for field stars and if so, to what extent, the question will be examined in detail.

Table III gives the relation between $V \sin i$ and $\log P$ for spectroscopic binaries with

TABLE III

Distribution of $V \sin i$ and $\log P$ for spectroscopic binaries

$V \sin i$ (km/sec)	$\log P$ (days)			
	0–1.0	1.0–2.0	2.0–3.0	3.0–4.0
0–50	27	10		
50–100	16	4	5	1
100–150		1	1	1
150–200	1		1	2
Number	44	15	7	4

orbits. The rotational velocities were taken from Boyarchuk and Kopylov (1964), Koch *et al.* (1965) and Olson (1968) and the periods from Batten (1967).

Very clearly the majority of the systems exhibit slow rotation. The first question which might be asked is if this sample is representative of the total number of A-type spectroscopic binaries. This can be tested by examining the distribution of the systems over $\log P$.

TABLE IV

Percentage distribution over $\log P$ of A-type spectroscopic binaries

Sample	Number	$\log P$			
		-1.0–0.0	0.0–1.0	1.0–2.0	2.0–4.0
All A-type SB's	228	0.07	0.61	0.23	0.09
A-type SB from Table III	70	0.00	0.63	0.21	0.16

It follows that the sample in Table III is representative of the whole population. One can compare now the distribution of $V \sin i$ (for $P < 100^d$) with the distribution of $V \sin i$ for all A-type stars. The comparison is made in Table V.

This implies that 98% of the stars have $V \sin i < 100$ km/sec, while only 45% of the

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TABLE V

Distribution of $V \sin i$ for spectroscopic binaries and normal stars with A-type spectra

$V \sin i$ (km/sec)	SB, $P < 100^d$	All
0–50	63%	23%
50–100	34%	22%
100–150	1%	18%
150–200	1%	20%
200–250		9%
250–300		5%
300–350		3%
Number	69	330

TABLE VI

Distribution of $V \sin i$ for spectroscopic binaries and normal stars with B-type spectra

$V \sin i$ (km/sec)	SB	Normal
0–100	53%	31%
100–200	39%	39%
200–300	8%	18%
300–400		8%
400–500		4%
Number	77	277

'normal stars' lie in this range. Something very similar happens among the B-type stars, for which similar statistics were made, which are given in Table VI.

In both tables we have called 'normal stars' all stars regardless of their duplicity status. This implies that in their frequency distribution one also includes spectroscopic binaries. It would evidently be preferable to compare the distribution of the rotation of spectroscopic binaries with the distribution for single stars. This is impossible, however, because many stars are considered to be single simply because we ignore if they are binaries. It is clear from the data of Table V, however, that if the spectroscopic binaries are a sizable fraction of all A-type stars (for instance one-third), it implies that essentially no single stars with low rotation exist. We are therefore led to the conclusion that in field stars also duplicity is closely related to slow rotation.

It must be remarked that this kind of relationship is quite contrary to what one would expect. In the first place one expects short periods to produce rapid rotation because of synchronism. In the second place one would expect that the discovery of spectroscopic binaries is more likely if $\sin i$ is large. If moreover rotational axes are normal to the orbital planes, one would expect spectroscopic binaries to be associated with larger than normal rotation. This is evidently not borne out by Tables III, V and VI.

We can now ask if there are possible selection effects which could explain the distribution found in Table III. The easiest one to visualize is the one implying that fuzzy lines do not permit the detection of small amplitudes. If this is true one would expect to find (1) no spectroscopic binaries with large $V \sin i$ and small amplitudes; (2) spectroscopic binaries with large $V \sin i$ associated with large amplitudes. The data assembled in Table VII show that this is not true and therefore this selection effect

TABLE VII

Distribution of semi-amplitudes as a function of $V \sin i$, for A-type spectroscopic binaries

$V \sin i$ (km/sec)	K (km/sec) 0–49	50–99	100–149	150–199
0–39	18	10	3	2
40–79	13	6	0	
80–119	4	4	0	1

cannot be very important. Besides this, it seems rather unlikely that if spectroscopic binaries with large $V \sin i$ do exist, none was observed until now in a sample of 70.

The conclusion is therefore that selection effects seem incapable of explaining the close association between duplicity and slow rotation. In view of the importance of this point it would be very interesting for someone to examine a sample of rapidly rotating stars for duplicity.

A final word might be added with regard to the 'breaking point' in this correlation. In other words, from which point on do we have rotational independence? We have seen already that for $P > 100^d$ higher rotations are present. One can associate this limit with the minimum distance of two protostars at the stage when rapid collapse stops. At this time the radius of the stars is given by

$$R/R_0 \sim 50(\mathfrak{M}/\mathfrak{M}_0)$$

which in our case, with $\mathfrak{M} \sim 3\mathfrak{M}_0$ gives $P = 150^d$ and with $\mathfrak{M} \sim 2\mathfrak{M}_0$ gives 65^d, thus bracketing nicely the value of $P = 100^d$.

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Discussion

Abt: In your comparison of Mt. Wilson and MK types, the types for broad-lined stars are either too early on the Mt. Wilson system or too late on the MK system. The first possibility seems more likely.

Jaschek: I agree completely and I am sorry that I did not succeed in making my point clear. Certainly the figure implies that the Mt. Wilson types are influenced by rotation in the sense they should be, i.e., faster rotators are classified as being earlier. This is so because the Mt. Wilson observers classified at higher dispersion and are therefore subject to the influence of rotation.

Abt: You point to a lack of spectroscopic binaries with $V \sin i \simeq 400$ km/sec. But such binaries would have synchronous periods of $\frac{1}{4}$ day, which is impossible for A-type stars. Even periods less than one day are rare; I believe that none are known among the stars brighter than $V = 6.0$ mag.

Jaschek: I think there are some stars with $P < 1^d$ which should rotate faster than 100 km/sec. But the main point is that there should be some spectroscopic binaries with P larger than the synchronization limit, which exhibit velocities larger than 100 km/sec, and you simply do not find them.

Collins: It appears from your graph of β vs. $V \sin i$ for given spectral types that β has the expected theoretical dependence which results from changes in β not the MK type. Thus, I would like to suggest that it may not be rotational effects on MK types that you observe, but rather rotational effects on the β index.

Jaschek: This is probably true, but I would also like to emphasize that one should not take these conclusions too seriously, because they are based on too few stars. The important point is that instead of assuming that the MK types are not influenced by rotation, one must try to prove it.

Buscombe: (1) The form of your negative correlation of Hβ line-strength (based on photoelectric indices) with rotational velocity for stars classified A5V, A7V, and A8V on the MK system is in the same sense as my equivalent widths for B stars.

(2) It has come to notice that some early published measures of equivalent width for A stars have not taken sufficient account of the contribution of the wings, which also are not included in the narrower Strömgren Hβ filter.

Steinitz: Dr. Jaschek concludes that the velocities in binaries are independent by looking at the distribution of $v_1 \sin i_1 + v_2 \sin i_2$; however, it can be easily shown that this distribution does not give the relevant information, which can be, however, obtained from the distribution of

$$| V_1 \sin i_1 - V_2 \sin i_2 . |$$

Deutsch: There certainly must be a considerable selection against the discovery of wide-line stars as spectroscopic binaries, especially when the periods are larger than a few days.

Jaschek: Yes, certainly. But in about 80 stars one would expect to observe at least one if there were many; since none is observed it is doubtful whether they really do exist.