Mon. Not. R. astr. Soc. (1978) **182**, 773–776

On the intrinsic rotation of magnetic variables

R. Rajamohan and G. S. D. Babu *Indian Institute of Astrophysics, Koramangala, Bangalore 560034, India*

Received 1977 November 8; in original form 1977 August 1

Summary. The intrinsic rotational velocities of magnetic variables with periods greater than a day are found to be related to their colour index or equivalently to their masses. It is also found that the components of spectroscopic binaries rotate slower than the single stars of similar colours.

The present work favours the associated periods of 4.23 and 2.675 day for HD 140728 and 140160 respectively. The 34 kG star, HD 215441, is most likely a spectroscopic binary seen pole-on.

1 Introduction

Recently Rajamohan (1977) has shown that normal single stars arrive on the main sequence with a small dispersion in their true rotational velocities which depends only on their respective masses. We investigate here the possibility whether the rotational velocities of Ap stars are also uniquely related to their masses.

Preston (1970) has already shown that the available observational material of Ap stars supports the rigid rotator model of Stibbs (1950) and Deutsch (1958) to explain the light, spectrum and magnetic-field variations of these objects. Therefore it becomes possible to derive the true rotational velocities (V) of Ap stars from their known periods (P) and derived radii (R) using the relation

$$V = 50.6(R/P) \qquad (1)$$

where V is in km/s, P in day and R in solar radii. Since Ap stars are found in very young clusters with ages $\leqslant 10^8$ yr, we can assume that they are all close to the main sequence. Further Hartoog (1977) found that there are no significant angular momentum losses for Ap stars on a timescale of 10^7 to 10^9 yr and such losses, if any, should have occurred in the pre-main-sequence stage. Therefore, if V, the intrinsic velocity of rotation in the case of Ap stars, is also a function of mass, then it should be related to any observable parameter which varies continuously in the temperature range in which these stars are found.

2 Results and discussion

Out of the 43 Ap stars with fairly well determined periods listed by Preston (1970), only 28 have radii determined by Babu (1977a, b) and Stift (1974). While Stift derived the radii employing the effective temperatures and bolometric magnitudes, Babu used the ratio of the observed and computed monochromatic fluxes along with their known trigonometric parallaxes. These are given in Table 1 along with their measured $(B-V)_0$, $V \sin i$, radii and periods. Also included in Table 1, are five long-period Ap stars for which no radii measurements are available. The $(B-V)_0$ values were generally taken from Eggen (1968). In the case of β CrB which is heavily blanketed, the $(B-V)_0$ value given by Babu (1977b) is adopted. The $V \sin i$ values are from Preston (1970).

Table 1. Basic data for magnetic variables.

S No.	HD	Name	$(B-V)_0$	R (solar radii)	P (day)	$V \sin i$ (km/s)	R/P
1	8441	—	+0.02	2.8	106.0	⩽5	0.02
2	9996	HR 465	+0.13	—	8400.0	⩽5	0.00
3*	10 783	—	−0.08	3.6	4.16	24	0.87
4*	18 296	21 Per	−0.11	3.1	2.88	22	1.08
5	19 832	56 Ari	−0.15	4.3	0.73	—	5.89
6*	25 354	—	+0.09	2.2	3.90	17	0.56
7	25 823	41 Tau	−0.16	4.2	11.94	21	0.35
8*	34 452	HR 1732	−0.19	3.1	2.47	62	1.26
9*	65 339	53 Cam	+0.15	2.0	8.02	14	0.25
10	68 351	15 Cnc	−0.07	2.3	4.12	38	0.56
11*	71 866	—	−0.02	3.6	6.80	⩽17	0.53
12*	74 521	49 Cnc	−0.12	2.1	5.43	19	0.39
13	98 088	HR 4369	+0.20	2.8	5.90	25	0.47
14	108 662	17 Com A	−0.07	2.2	5.09	20	0.43
15*	112 185	ϵ UMa	−0.01	3.8	5.09	35	0.75
16	112 413	α^2 CVn	−0.12	3.1	5.47	24	0.57
17*	118 022	78 Vir	−0.01	2.4	3.72	10	0.65
18	124 224	HR 5313	−0.11	2.2	0.52	160	4.23
19	125 248	HR 5355	−0.04	3.3	9.30	⩽17	0.35
20*	126 515	—	+0.01	—	130.0	⩽5	0.00
21	137 909	β CrB	+0.03†	2.2	18.50	⩽3	0.12
22	140 160	χ Ser	+0.04	1.9	1.60	66	1.19
23*	140 728	HR 5857	−0.07	3.6	4.23†	75	0.85
24	153 882	HR 6326	0.00	2.9	6.01	26	0.48
25	173 650	HR 7058	−0.09	4.2	10.10	16	0.42
26	187 474	HR 7552	−0.05	—	2500.0	⩽8	0.00
27*	188 041	HR 7575	+0.20	—	224.0	⩽3	0.00
28	196 502	73 Dra	+0.07	2.5	20.30	8	0.12
29*	215 038	—	(−0.14)	3.3	2.04	31	1.62
30*	215 441	—	(−0.18)	4.2	9.49	⩽5	0.44
31*	220 825	κ Psc	−0.02	2.1	0.58	34	3.62
32*	221 568	—	+0.23	—	160.0	⩽5	0.00
33*	224 801	HR 9080	−0.12	3.3	3.74	38	0.88

* Apparently single stars.
† See text for details.

In Figs 1(a), (b) we have plotted $(B-V)_0$ against the computed true rotational velocity V obtained from equation (1). Fig. 1(a) displays the apparently single stars of Table 1, while Fig. 1(b) includes the rest as well. Not plotted in these figures are HD 19832, 124224 and 220825 since the ratio of radii to periods of these stars are much too large.

It is obvious from Fig. 1(a) that there is a definite correlation between the colour index and the computed true rotational velocity in the case of apparently single Ap stars, with

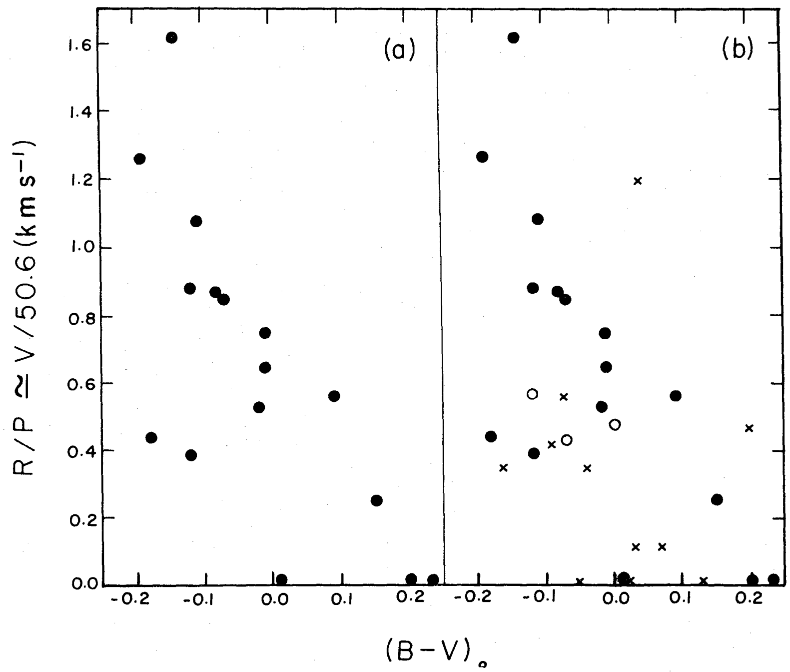

Figure 1. A plot between the colour index $(B-V)_0$ and the intrinsic rotational velocity V of magnetic variables based on the rigid rotator model. Filled circles denote the apparently single stars while the visual and spectroscopic binaries (definite or suspect) are denoted by open circles and crosses respectively.

only three objects, HD 74521, 126515 and 215441 deviating considerably. However, we find from Fig. 1(b), that binaries, in general, fall below the mean relationship defined by the single stars. Though the scatter is large in the case of binaries, they do seem to indicate a relationship similar to that of single stars. Thus, the above mentioned three objects, in all likelihood, could also belong to the class of spectroscopic binaries, which have gone undetected.

One of these three stars, HD 215441, which also happens to possess the largest magnetic field strength yet measured, is possibly seen pole-on in addition to being a spectroscopic binary. This conjecture is based on the fact that the star has a constant radial velocity (Preston 1969) and its projected rotational velocity is very low ($\leqslant$ 5 km/s).

The three short-period Ap stars, HD 19832, 124224 and 220825 ($P < 1$ day), which could not be included in Fig. 1 do not seem to belong to the same class of objects as the other magnetic stars.

There is only one star HD 140160 (χ Ser), a suspected spectroscopic binary (Ledoux & Renson 1966), which is found to lie too much above the general trend shown by the single stars, for its given $(B-V)_0$. It would fit the mean relationship as defined by the single stars better with the associated period of 2.675 day, even though Deutsch (1952) rejected this period in favour of 1.60 day. A similar remark applies to HD 140728 to which we prefer to assign a period of 4.23 day rather than the 1.31 day found by Wehlau (1962). In fact, Wehlau did find that a period of 4.23 day fitted his observations equally well, but he rejected it in favour of the 1.31 day period. Since the larger period brings the star right into the general trend of the diagram we have adopted the same in Table 1.

3 The long-period Ap stars

Amongst the long-period Ap stars (Preston 1970, Table IV) only HD 8441 has a radius estimate (Stift 1974). For the rest, we have assumed the ratios between their radii and corresponding periods to be very close to zero. This assumption is well justified due to the fact that their periods are very large (> 100 day).

Two out of these six stars; HD 126515 and 188041, are at the cool end of the relation for the apparently single stars, while three others (HD 8441, 9996 and 187474), which are reported as spectroscopic binaries by Ledoux & Renson (1966) are at the corresponding cool end of the relation for the binaries.

Thus, it does not seem necessary to invoke a relatively powerful deceleration mechanism any more for cool Ap stars, in light of the present finding that the true rotational velocity is a function of colour and equivalently of the mass as the stars arrive on the main sequence.

4 Conclusion

It is found that most of the Ap stars are rigid rotators with a definite angular momentum which depends purely on the mass of the star. Reasonable deviations from the relation shown in Fig. 1(a) can be explained in terms of multiplicity which affect the derived colours and radii. The spectroscopic binaries in general have lower rotational velocities than their corresponding single Ap stars. The slope of the relationship between intrinsic rotational velocity and colour index found here seems to be the same for both the single stars as well as binaries. Apparently, there is only a zero point shift in case of the spectroscopic binaries. The only exceptions to the general trend found amongst the Ap stars are those with very short periods ($P < 1$ day). The present work favours a period of 4.23 day instead of 1.31 day for HD 140728 and 2.675 day instead of 1.60 day in the case of HD 140160. The 34 kG star HD 215441 is most likely a spectroscopic binary seen pole-on.

References

Babu, G. S. D., 1977a. *Astrophys. Space Sci.*, **50**, 343.
Babu, G. S. D., 1977b. To be published.
Deutsch, A. J., 1952. *Publ. astr. Soc. Pacific*, **64**, 315.
Deutsch, A. J., 1958. *Handbuch der Physik*, **51**, 689.
Eggen, O. J., 1968. *Magnetic and related stars*, p. 141, ed. Cameron, R. C., Mono Book Corporation, Baltimore.
Hartoog, M. R., 1977. *Astrophys. J.*, **212**, 723.
Ledoux, P. & Renson, P., 1966. *A. Rev. Astr. Astrophys.*, **4**, 293.
Preston, G. W., 1969. *Astrophys. J.*, **156**, 967.
Preston, G. W., 1970. *Stellar rotation*, p. 254, ed. Slettebak, A., D. Reidel, Dordrecht, Holland.
Rajamohan, R., 1977. *Mon. Not. R. astr. Soc.*, submitted.
Stibbs, D. W. N., 1950. *Mon. Not. R. astr. Soc.*, **110**, 395.
Stift, M. J., 1974. *Astr. Astrophys.*, **34**, 153.
Wehlau, W., 1962. *Publ. astr. Soc. Pacific*, **74**, 286.