ROTATION OF B-TYPE STARS AS AN INDICATOR OF STAR FORMATION MECHANISMS

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ABSTRACT

Differences in the distributions of v sin i for various samples of B-type stars may reflect different mechanisms of star formation. The overall distribution of v sin i for late B-type stars in clusters at low galactic latitudes is bimodal, but normal class V field stars may have a Maxwellian distribution of v. The spin axes of stars in tightly bound clusters may be preferentially aligned perpendicular to the galactic plane. Early B-type stars in the youngest subgroups of associations may have a Maxwellian distribution of v, but there is a prominent excess of slow rotators among stars in older subgroups and field stars. This excess cannot be entirely accounted for by tidal or magnetic braking during main-sequence evolution.

1. INTRODUCTION

In a previous study of late B-type stars (Guthrie 1982), it was found that cluster and field stars differ markedly with regard to their distribution of projected rotational velocities v sin i. The overall distribution of v sin i for stars in clusters at low galactic latitudes is bimodal with a scarcity of values between 80 and 160 km s^{-1}, and the distribution for the rich cluster NGC 2516 is sharply peaked. Thus there is probably a tendency for the spin axes of stars in tightly bound clusters to be aligned perpendicular to the galactic plane; such stars may have been formed with initial values around 230 km s^{-1} through collapse and fragmentation of gas clouds. The distribution of v sin i for field stars is not bimodal and does not depend on galactic latitude; the data are consistent with their spin axes being randomly orientated and their initial values of v being Maxwellian. Field stars may have been formed in loose clusters and associations through turbulence in gas clouds. For both cluster and field stars the proportion of slow rotators increases with age; this is partly due to tidal braking in binaries and rapid braking of magnetic stars through interaction with interstellar clouds.

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Early B-type stars are now discussed in a similar way. B0 - B5 stars may be unique among O-, B- and A-type stars in having a high proportion of very slow rotators (Wolff, Edwards, and Preston 1982, henceforth WEP), but their short main-sequence lifetimes afford little opportunity for braking. Early B-type stars occur in young associations as well as in the field.

2. B0 - B5 STARS IN ASSOCIATIONS

OB associations often contain a young, compact cluster or subgroup embedded in nebulosity and older, more dispersed subgroups (Blaauw 1964). Such subgroups may be recognized in Ori OB1, Cep OB3, Lac OB1, and Sco OB2, and the NGC 2264 and h and χ Persei clusters constitute young subgroups of Mon OB1 and Per OB1 respectively. Values of v sin i for B0 - B5 stars in these subgroups were found in the references compiled by Uesugi and Fukuda (1982) and in the paper on NGC 2264 by Vogel and Kuhi (1981). Table 1 gives, for each subgroup, the total number N of B0 - B5 stars with known v sin i, the number N_{45} of these stars which have v sin i $\leqslant$ 45 km s^{-1}, and the mean value of v sin i. The overall ratio N_{45}/N is significantly higher for the older subgroups (31/120 as compared with 7/90 for the young subgroups). The overall distribution of v sin i for the 90 stars in the young subgroups is consistent with a Maxwellian distribution of v and random orientations of the spin axes. The distribution of v sin i for the stars in the older subgroups is similar except for the prominent excess of values $\leqslant$ 45 km s^{-1}.

Table 1. Rotation of B0 - B5 stars in associations

Subgroup	Earliest MK type	N	N_{45}	Mean v sin i (km s^{-1})
(a) Young subgroups				
Ori OB1 Nebula	O6	10	1	157
Cep OB3 young	O7	9	0	206
NGC 2264	O7	7	0	146
Per OB2	O8	11	1	133
Lac OB1b	O9	10	2	141
Upper Scorpius	O9.5	27	1	185
h and χ Persei	B0.5	16	2	162
(b) Older subgroups				
Ori OB1c Outer Sword	O9	22	11	70
Ori OB1b Belt	O9.5	16	4	180
Ori OB1a Northwest	B0.5	31	6	171
Cep OB3 old	B0	14	0	145
Lac OB1a	B1.5	13	3	149
Upper Centaurus	B1.5	24	7	127

3. B0 - B5 FIELD STARS

WEP measured v sin i for 70 per cent of the B0 - B5 stars in the Bright Star Catalogue having declinations > -45° and luminosity classes III - V. They published their values of v sin i for the 308 stars included in the uvbyβ photometric catalogue compiled by Philip et al. (1976). Excluding members and possible members of clusters and associations, there are 103 class V stars and 80 stars of classes III and IV. There is a significant bias against Be stars in WEP's published sample, probably due to the exclusion of stars with $\beta \leqslant 0.195(u - b) + 2.5$ from the photometric catalogue. This bias was allowed for by adding 13 class V Be stars and 5 Be stars of classes III and IV with suitable distributions of v sin i. The overall ratio N_{45}/N for the 116 class V field stars is 25/116 and the distribution of v sin i does not differ significantly from that for the 120 stars in the older subgroups of associations (χ^2 = 6.6 for seven degrees of freedom). However, the 85 field stars of classes III and IV have a lower mean value of v sin i (91 km s^{-1}) and a higher N_{45}/N ratio (37/85).

4. DISCUSSION

The B0 - B5 sample studied by WEP, which included both field stars and stars in associations, was magnitude-limited. Thus low-luminosity class V stars were under-represented. By distinguishing stars according to their luminosity classes and association membership, it has been shown that the proportion of slow rotators among class V field stars is high, although not quite as high as for stars of classes III and IV. A high proportion of small values of v sin i is also found for members of the older subgroups of associations, but not for stars in the youngest subgroups. This poses a severe problem, since the older subgroups have ages of only $\sim 10^7$ yr. The stars in the older subgroups may have shed angular momentum rapidly when they left the nebulosity in which they were embedded; alternatively the stars in the older subgroups may have been formed in a different way from those in the youngest subgroups. Unlike late B-type stars in clusters and associations, early B-type stars in associations do not have bimodal distributions of v sin i.

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