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Research Note

On the galactic latitude distribution of rotational velocity for evolved stars*

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Abstract. We study the galactic latitude distribution of rotational velocity of a large sample of about 1 220 evolved stars of luminosity classes IV, III, II and Ib, with spectral types F, G and K. We show that there is a tendency for stars with enhanced rotational velocity to concentrate near the galactic plane. Such a trend is more evident for the more evolved stars.

Key words: stars: fundamental parameters – stars: rotation – stars: statistics – Galaxy: general – Galaxy: stellar content

1. Introduction

The study of the distribution of stellar rotational velocities is relevant to a variety of problems in stellar astrophysics, particularly for the understanding of the star formation process itself. In spite of the conventional view that favors a randomly orientation for stellar rotation axes (e.g.: Struve 1945, 1951; Slettebak 1949; Huang & Struve 1954) one cannot rule out the possibility that axes of rotation for small groups or for some specific class of stars may have a particular orientation. A study of the process of star formation based on the analysis of the behavior of the distribution of rotational velocities was carried out by Burki & Maeder (1977). Specifically, these authors have analyzed the link between $V \sin i$ and galactic longitude for early B-type stars, which are particularly appropriate for this kind of analysis, since they are young enough to be still located near the position in the Galaxy where they were formed. Burki & Maeder (1977) have found that $V \sin i$ depends on the galactic longitude, in the sense that early B-type stars towards the galactic center rotate faster than those located in the anticenter direction. Such a result was confirmed by Wolff et al. (1982). Burki & Maeder (1977) also analyzed the distribution of the rotational velocities of early B-type stars in clusters and associations and concluded that, for these stars, rotation decreases with increasing galactocentric distance. For late B-type stars, Burki & Maeder (1977) have found no sign of dependence of rotation on the position in the Galaxy. Guthrie (1982) has analyzed the distribution of the rotational velocity for late B-type stars in clusters located at low galactic latitudes, concluding that there is a general tendency for the axes of rotation of cluster stars to be roughly aligned perpendicular to the galactic plane.

Concerning the evolved stars, Gray & Toner (1987) have suggested that for Ib supergiants there may exist a preferential alignment of rotation with the galactic poles. These authors suggested that a $\cos b$ law could represent the latitude dependence of rotation for such class of stars.

In the present work, we analyse the link between rotation and galactic position for evolved stars. The analysis is based on a large and homogeneous sample of about 1 220 stars, namely subgiants, giants, bright giants and Ib supergiants, presenting precise rotational velocity $V \sin i$, obtained with the CORAVEL spectrometer.

2. The observational data

For the present study, we have selected all the subgiants, giants and bright giants for which projected rotational velocities $V \sin i$ are available in the Catalogue of rotational and radial velocities for evolved stars by De Medeiros & Mayor (1999). The complete sample presented by these authors is composed by 200 subgiants and 1 100 giants covering the spectral range from F5 to K5, and 425 bright giants with spectral types from F3 to K5 and northern declination of -25 degrees. In addition, we have selected 233 Ib supergiant stars with spectral types ranging from F0 to K5 covering the entire northern and southern declinations from De Medeiros et al. (1996). Nevertheless, to follow completeness criteria, which will be discussed in the next section, the results of the present work are based on a sample of 123 subgiants, 707 giants, 250 bright giants and 147 Ib supergiant stars. The reader is referred to De Medeiros (1990) and De Medeiros & Mayor (1999) for observational procedure and calibration.

The rotational velocities given by De Medeiros & Mayor (1999) and De Medeiros et al. (1996), were determined from observations carried out with the CORAVEL spectrometer (Baranne et al. 1979) and present a precision of about 1.0 km s^{-1}

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* Based on observations collected at the Observatoire de Haute – Provence (France) and at the European Southern Observatory, La Silla (Chile).

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Table 1. Number of stars on the original and selected samples in each luminosity class.

Luminosity Class	Selected	Single	Binary	Total
Ib	147	155	0	155
II	250	295	97	392
III	707	710	241	951
IV	123	124	60	184

for the luminosity classes IV and III, and of about 2.0 km s^{-1} for the luminosity classes II and Ib. The behavior of the distribution of these rotational velocities as a function of color index and spectral types was presented by De Medeiros et al. (1996). The stellar galactic coordinates were taken from the SIMBAD Data Center.

2.1. On the completeness of the sample

The large amount of data presently available in the literature allowed a detailed analysis on the completeness of our sample. As a first step, we have eliminated from the sample all the spectroscopic binary systems with an orbital period lower than about 100 days, as well as all those binaries with no available orbital period but presenting a large radial velocity range. This was done in order to avoid the influence of synchronization on the stellar rotational behavior. As a second step, we have analyzed the source of the spectral types and luminosity classes. In order to assign a MK spectral type and luminosity class to each star, we have searched for information in the Michigan Catalogue of Two- Dimensional Spectral Types for HD stars (Houk & Cowley 1975; Houk 1978, 1982), as well as in the Catalogue of Selected Spectral Types in the MK System (Jaschek 1978). As a third step, we have dereddened the color index $(B-V)$ and, by using the color index - spectral type calibration from Flower (1977), we have eliminated from the sample all those stars presenting a corrected $(B-V)$ value out of the corresponding color index - spectral type range.

Finally, we have checked the completeness of the sample to apparent visual magnitude m_v. In Fig. 1 we show the m_v integral function for all the stars of the present sample. We note that no flattening occurs for m_v lower than about 9, in both luminosity classes Ib and II, indicating that our sample is complete to apparent magnitude $m_v \sim 9.0$. In the case of class III and IV, Fig. 1 shows that the sample is complete to a visual magnitude of about 6.5. Let us recall that all the stars from our sample with m_v lower than about 6.5 come from The Bright Star Catalogue (Hoffleit & Jaschek 1982; Hoffleit et al. 1984). As shown by Bahcall et al. (1987), the Bright Star Catalogue is complete to apparent visual magnitude m_v of about 6.3. With all these criteria of competence in mind, the entire list of stars for our study amounts to those numbers shown in Table 1.

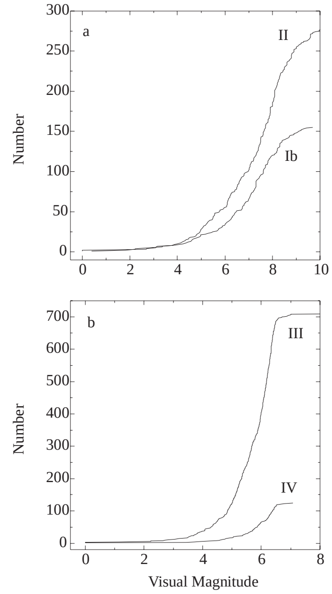

Fig. 1a and b. Visual magnitude integral function. The upper panel is for luminosity classes Ib and II while the lower panel is for classes III and IV.

3. Latitude distribution of rotational velocity

A rotational discontinuity is now well established for evolved stars of luminosity classes IV, III, II and Ib. For subgiants and giant stars such discontinuity is located near F8IV and G0III, respectively (De Medeiros 1990; De Medeiros & Mayor 1990; Gray & Nagar 1985; Gray 1989), whereas for the bright giant and Ib supergiant stars the discontinuity is located near F9II and F9Ib, respectively (De Medeiros 1990; De Medeiros & Mayor 1990). In all these luminosity classes, stars earlier than the rotational discontinuity show a wide range of rotational velocities, whereas stars located later than the discontinuity present essentially low rotation rates. In fact, stars later than the discontinuity and presenting moderate or high rotation rates are typically component of binary systems, for which the abnormal rotational velocities are very likely the result of the synchronization between rotation and orbital motion induced by tidal effects.

In Figs. 2a and 2b we show the distribution of the projected rotational velocity $V \sin i$ for Ib supergiants as a function of galactic latitude $\mid b \mid$ for stars earlier and later than F9Ib, respectively. The span of latitude is small, with most of the stars lying in the range $-30° < b < 30°$. Only three stars have $\mid b \mid > 30°$, namely HD 10303, HD 35949 and HD 198145. It is difficult to define any relationship to determine a possible dependence of $V \sin i$ with b, although there is some tendency for stars with high rotational velocity to concentrate near the galactic plane. This trend is more evident for the stars later than F9, typically G and K stars. In both figures we have also drawn the $\cos b$ curve (dashed line) suggested by Gray & Toner (1987) for Ib and Ib-II stars, representing the latitude dependence for perfect axial alignment of the rotational axes to the galactic poles. The dispersion of the points is quite large at $b = 0$ and it is evident that such a curve does not fit our data. This indicates that the agreement found by Gray & Toner could be a consequence of an artifact resulting from a selection effect due to the limitation of their sample.

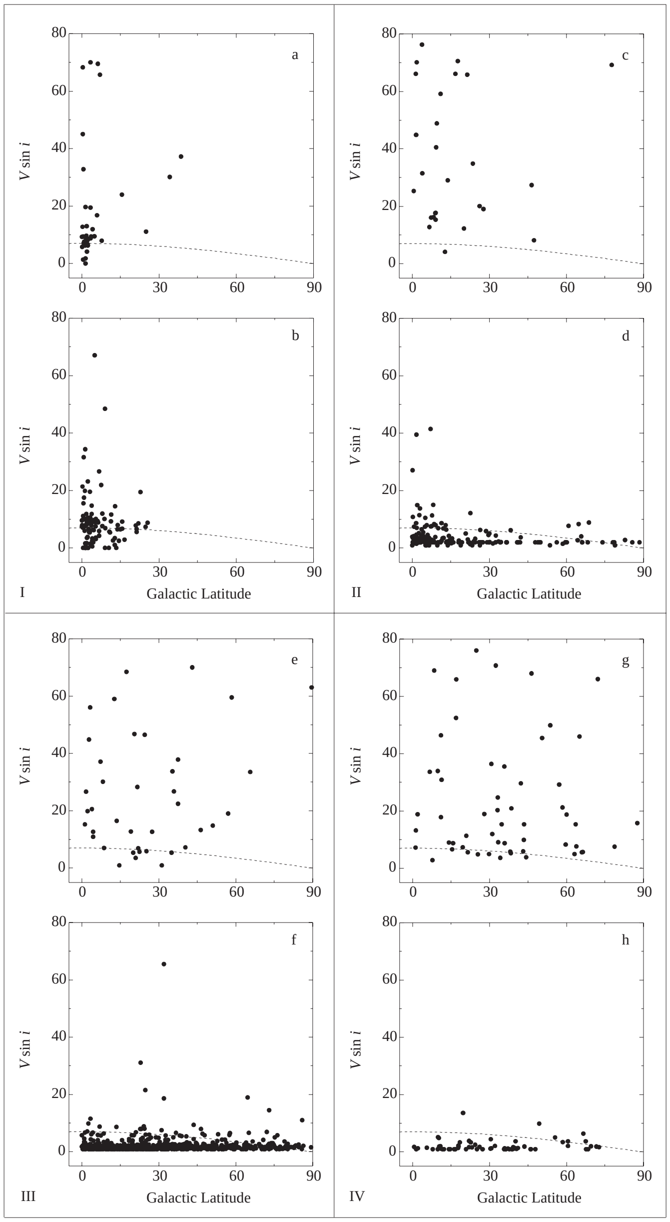

Fig. 2a–f. Latitudinal distribution of rotational velocity for evolved stars of luminosity classes IV, III, II and Ib. The dashed line indicates the $\cos b$ curve.

Figs. 2c and 2d show the distribution of the projected rotational velocity $V \sin i$ for the luminosity class II. Here, the difference between stars earlier and later than the rotational discontinuity near F9II is very clear. Stars earlier than F9II, Fig. 2c, have a broad distribution spanning almost $60°$ in latitude to both sides of the galactic plane. Only one star, HD 104452, lies outside this range with $b = 77.64°$. The distribution of $V \sin i$ values for stars later than the discontinuity, Fig. 2d, shows more clearly that stars with high velocity tend to concentrate near the galactic plane, namely $b < \pm 15°$. Once again, the curve found by Gray & Toner on the hypothesis of perfect axial alignment is shown (dashed line). We see that it does not fit our data.

Table 2. Result of the Kolmogorov-Smirnov test giving the probability P_{b_*} that the two cumulative distribution functions of rotational velocity of stars with $|b| < b_*$ and $|b| > b_*$ be significantly different.

Luminosity Class	earlier than rotational discontinuity	later than rotational discontinuity
Ib	$P_{10°} = 93.7$	$P_{10°} = 86.3$
II	$P_{5°} = 94.4$	$P_{10°} = 97.7$
III	$P_{20°} = 73.0$	$P_{20°} = 97.9$
IV	$P_{20°} = 33.8$	$P_{20°} = 87.2$
Ib + II	$P_{10°} = 95.7$	$P_{10°} = 99.9$
III + IV	$P_{20°} = 83.5$	$P_{20°} = 99.3$
All Classes	$P_{5°} = 92.1$	$P_{5°} = 100.0$

In Figs. 2e and 2f we show the distribution of the projected rotational velociy $V \sin i$ as a function of the galactic latitude $\mid b \mid$ for stars of luminosity class III, earlier and later than the rotational discontinuity at G0III respectively. Fig. 2e represents stars of spectral types from F5III to G0III, whereas Fig. 2f represents stars from G1III to K5III. Figs. 2g and 2h show the distribution of the projected rotational velocity $V \sin i$ as a function of the galactic latitude $\mid b \mid$ for the subgiant stars. Fig. 2g represents stars of spectral types from F5IV to F8IV, namely stars located earlier than the rotational discontinuity at F8IV, whereas Fig. 2h represents subgiants from F9IV to K5IV, that is, stars located later than the rotational discontinuity. For these two luminosity classes, the concentration of high rotational velocity stars near the galactic plane is less evident for stars earlier than the rotational discontinuity and just perceptible for those later than such discontinuity. It is clear that for giant and subgiant stars the distribution of rotation as a function of galactic latitude cannot be described by a $\cos b$. On the other hand, for both luminosity classes III and IV, the behavior of the distribution of rotation as a function of galactic latitude for stars earlier than the rotational discontinuity is clearly different from the one found for stars later than such discontinuity. This is the same trend observed for classes Ib and II.

In order to verify the existence of any dependence of $V \sin i$ with galactic latitude we have performed a Kolmogorov-Smirnov test. We first defined two distributions D1, which contains all stars having latitude $\mid b \mid < b_*$, and D2 containing all stars for which $\mid b \mid > b_*$. We have applied the test and, for a given value of b_*, we calculated the probability P_{b_*} that the cumulative distribution function of D1 and D2 differs significantly one from another.

The test was carried out for different values of b_*. In Table 2 we give the results for that value of b_* presenting the highest probability. In general, the probabilities are high, supporting our suggestion that there is a clear concentration of high $V \sin i$ values near $b = 0$. In particular, we see that, for giants and subgiants, the probabilities are higher for stars located later than the rotational discontinuity, than for those located earlier. For the supergiants the statistics shows a behavior in contrast to the one found for subgiants and giants.

Finally, we have also applied the Kolmogorov-Smirnov test and calculated the probabilities for three combined samples of stars, namelly for classes Ib+II, classes III+IV and for the whole of the luminosity classes. The results are also shown in Table 2. We see that, if we take the cumulative distributions of velocities for stars located near and far from the galactic plane we find that the probabilities that they are different is quite high in all the three cases.

4. Conclusion

We have analyzed the behavior of the projected rotational velocity $V \sin i$ as a function of the galactic latitude, for a large and uniform sample of evolved stars of luminosity classes IV, III, II and Ib. As a main result, the present work shows that the distribution of rotational velocity as a function of the galactic latitude is far from being uniform for all luminosity classes studied. There is a clear tendency for stars with high values of $V \sin i$ to concentrate near the galactic plane as it has been shown by a Kolmogorov-Smirnov test applied to the velocity distributions at $\mid b \mid < b_*$ and $\mid b \mid > b_*$. This fact cannot be explained by supposing that there is an alignment of stars rotation axes with that of the Galaxy. This is the reason why a $\cos b$ law does not fit the data. In addition, this same tendency exists as the luminosity of the stars increases from subgiants to giants to Ib supergiants, or equivalently with increasing mass. This fact is observed for stars located on both sides of the rotational discontinuity.

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References

Bahcall J.N., Casertano S., Ratnatunga K.U., 1987, ApJ 320, 515
Baranne A., Mayor M., Poncet J.L., 1979, Vistas in Astron. 23, 279
Burki G., Maeder A., 1977, A&A 57, 401
De Medeiros J.R., Mayor M., 1999, A&AS 139, 433
De Medeiros J.R., Da Rocha C., Mayor M., 1996, A&A 314, 499
De Medeiros J.R., Mayor M., 1990, In: Wallerstein G. (ed.) PASP Conf. Ser. vol. 9, p. 404
De Medeiros J.R., 1990, Ph.D. Thesis, Geneva Observatory
Flower P.J., 1977, A&A 54, 31
Gray D.F., 1989, ApJ 347, 1021
Gray D.F., Toner C.G., 1987, ApJ 322, 360
Gray D.F., Nagar P., 1985, ApJ 298, 756
Guthrie B.N.G., 1982, MNRAS 198, 795
Huang S.-S., Struve O., 1954, Ann. d'Ap. 17, 85
Hoffleit D., Jaschek C., 1982, The Bright Star Catalogue. 4th. edition, Yale University, New Haven
Hoffleit D., Saladyga M., Wlasuk P., 1984, A Supplement The Bright Star Catalogue. 4th. edition, Yale University, New Haven
Houk N., Cowley A.P., 1975, Michigan Catalogue of Two-Dimensional Spectral Types for HD Stars. Vol. 1, University of Michigan
Houk N., 1978, Michigan Catalogue of Two-Dimensional Spectral Types for HD Stars. Vol. 2, University of Michigan
Houk N., 1982, Michigan Catalogue of Two-Dimensional Spectral Types for HD Stars. Vol. 3, University of Michigan
Jaschek M., 1978, Catalogue of Selected Spectral Types in the MK System. Bull. Inf. CDS 15, 121
Struve O., 1945, Pop. Astr. 53, 259
Struve O., 1951, In: Hynek J. (ed.) Astrophysics. McGraw-Hill, New York, p. 85
Slettebak A., 1949, ApJ 110, 498
Wolff S.C., Edwards S., Preston G.W., 1982, ApJ 252, 322