Rotational velocity distributions of A-type stars

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Abstract

Using an homogeneous sample of $v \sin i$ for A-type Main-Sequence stars (Royer et al. 2002), the equatorial velocity (v) distributions are determined as function of the spectral class, from B9 to F2. The chemically peculiar and binary stars are discarded. These distributions of "normal" stars are discussed in terms of stellar formation and evolution, in particular the remaining bimodality observed for the earliest spectral types of the sample. We show that late B and early A-type main-sequence stars have genuine bimodal distributions of true equatorial rotational velocities due probably to phenomena of angular momentum loss and redistribution the star underwent before reaching the main sequence. A striking lack of slow rotators is noticed among intermediate and late A-type stars. The bimodal-like shape of their true equatorial rotational velocity distributions could be due to evolutionary effects.

Rotational velocities data

This study is based on the catalogue published by Royer et al. (2002), which gathers homogeneous $v \sin i$ data for B8 to F2-type stars. The luminosity class range V to IV is used as synonymous for "dwarfs" representing the first MS evolutionary phases. The first selection in then based on the luminosity class of the stars, and only the main sequence stars (classes V, IV-V and IV) are retained.

In this work, all known "close" binaries and chemical peculiar stars in the studied spectral range have been removed. Binaries were eliminated because of possible tidal braking mechanisms which introduce deviations in the distributions that cannot be ascribed to initial MS conditions related to single stars. In the same line of thoughts, Am stars were taken out of the studied sample, for they are considered to be close binaries (Debernardi 2000).

Moreover, they are found among slow rotators systematically (Abt & Morrell 1995). Evidence exists that the Ap phenomenon shows up when the star has already completed at least the first third of its MS life span (Hubrig et al. 2000a). Ap stars represent then a population which is systematically separated from what it could be meant as the first MS stages, even no clear signs were found for significant magnetic braking in the stellar surface (Hubrig et al. 2000b). Be stars and A-type stars with shell spectra were also removed. A-shell stars seem to be the A-type counterparts of early-type Be stars (Abt & Moyd 1973), where the Be phenomenon is fast rotation and age-dependent (Zorec 2004).

CP stars (chemically peculiar stars): The catalogs of Ap and Am stars from Renson et al. (1991) is used to identify peculiar stars, as well as the spectral classification made by Abt & Morrell (1995) and Abt etal. (2002).

CB stars ("close" binary stars): Tidal effects in a multiple system tend to synchronize the axial rotation period on the orbital period. This category of stars will be selected on criteria based on HIPPARCOS data and spectroscopic data. Except for a few of them, all the selected stars are in the HIPPARCOS catalog (ESA 1997). The binaries detected by the satellite, with $\Delta Hp < 4$ mag are flagged as CB stars. The compilation by Pedoussaut et al. (1985) of spectroscopic binaries is used to complete the identification, together with the Eighth catalog of the orbital elements of Spectroscopic Binaries (Batten et al. 1989). Stars with both CB and CP criteria are classified as CP.

The sample is divided according to the spectral type, chosen so as to warrant in each statistical significance and mass resolution, to allow for detection of possible mass dependencies of velocity distributions. The six resulting subsamples are listed in Table 1. Their respective $v \sin i$ distributions are displayed in Fig. 1.

Table 1: Moments of the $v \sin i$ distributions (yellow in Fig. 1). For each subsample, the number of stars, the median, the mean and the dispersion of the $v \sin i$ distribution are indicated.

Subsample	#	Center ($\mathrm{km\,s^{-1}}$) median	Center ($\mathrm{km\,s^{-1}}$) mean	Disp. ($\mathrm{km\,s^{-1}}$)
B9	125	159 ±11.0	161 ±8.7	98 ±6.2
A0–A1	271	128 ±5.9	131 ±4.7	78 ±3.4
A2–A3	258	128 ±5.2	133 ±4.2	67 ±3.0
A4–A6	137	138 ±6.0	144 ±4.8	56 ±3.4
A7–A9	141	133 ±6.3	134 ±5.0	60 ±3.6
F0–F2	150	110 ±5.9	114 ±4.7	57 ±3.3

Distributions of equatorial rotational velocities

Rectified distributions

The observed $v \sin i$ parameter is the projection of the equatorial velocity v of the star on the line of sight, i being the inclination between the stellar rotation axis and the line of sight. The assumption that stellar rotation axes are randomly oriented is adopted. This hypothesis has been tested many times (Gray 1992; Gaigé 1993) and is still the most valid.

The Probability Density Function (hereafter PDF) of the $v \sin i$ is thus the result of the convolution between the distribution of "true" equatorial velocities v, the distribution of inclination angles i, and the observational error law.

The observed PDF of $v \sin i$ is first deconvolved by the distribution of errors (chosen as lognormal) and then by the distribution of inclinations. Both processes are carried out using the Lucy iterative method (Lucy 1974).

The resulting v distributions are displayed in red for the six subsamples.

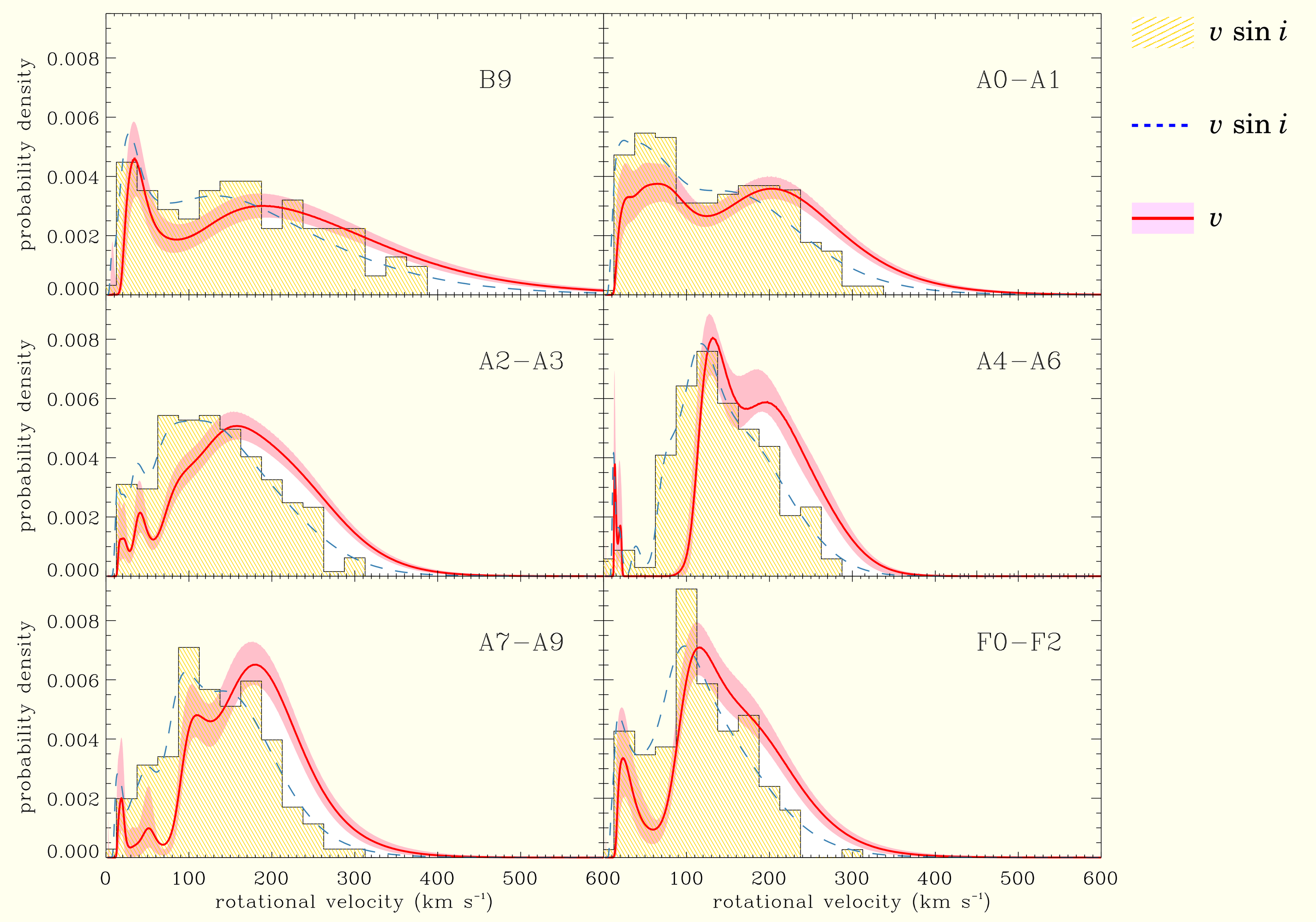

Figure 1: Velocity distributions: observed $v \sin i$ (red\yellow), fitted $v \sin i$ distribution (blue), deconvolved v distributions (red).

Description of the v distributions

The distributions of true equatorial velocities imply the following facts:

- The bimodal character of distributions corresponding to B9 and A0–A1 field dwarf stars is clearly present, even the samples have been cleared from all known Am, Ap and close binaries. For B9-type stars: the mode of slow rotators is ~ 35 $\mathrm{km\,s^{-1}}$, and for fast rotators ~ 190 $\mathrm{km\,s^{-1}}$. For the A0–A1 subsample: they are ~ 60 $\mathrm{km\,s^{-1}}$ and ~ 200 $\mathrm{km\,s^{-1}}$ respectively. The modes of fast rotators ($v \gtrsim 150$ $\mathrm{km\,s^{-1}}$), for B9 and A0–A1 type stars, are fitted by Maxwellian PDFs. The proportion of slow rotators ($v \lesssim 150$ $\mathrm{km\,s^{-1}}$) is taken as the excess compared to the Maxwellian fast rotator distribution. The slow rotator peak corresponds to some 19 stars for B9-type stars, and about 66 stars for A0–A1-type stars.
  The distribution of rotation velocities of B9 to A1-type "normal" field dwarf stars are genuinely bimodal. This finding is contrary to the results obtained by Gutrie (1982), Abt & Morrell (1995) and Abt (2000). The presence of modes around 50 and 200 $\mathrm{km\,s^{-1}}$ may be due to formation processes and phenomena of AM loss and redistribution undergone during PMS phases.
- In the A2 to A9 spectral type groups, the small wiggles of distributions in the velocity interval $0 \lesssim v \lesssim 70$ $\mathrm{km\,s^{-1}}$ concern a negligible fraction of stars. Moreover the variability bands associated to the distributions argue in the sense that the presence of these slow rotators is not significant. These objects are probably unknown synchronized binaries or chemically peculiar stars that pollute the sample of "normal" stars. There is a net lack of rotators with $v \lesssim 70$ $\mathrm{km\,s^{-1}}$. An absolute minimum of this fraction is seen in the A4–A6 group.
- An excess of slow rotators with velocities $0 \lesssim v \lesssim 60$ $\mathrm{km\,s^{-1}}$ appears in the F0–F2 group. This mode of slow rotators, around 20 $\mathrm{km\,s^{-1}}$, in the distribution for early-F stars, is significant. The $B-V$ distribution for all the "normal" F0–F2 stars, ranging from 0.2 to 0.4 mag, shows that all (but one) stars with $v \sin i < 75$ $\mathrm{km\,s^{-1}}$ have color index $B-V \gtrsim 0.3$ mag. It is known that the Böhm-Vitense gap occurs at $0.33 \lesssim B-V \lesssim 0.38$ mag (D'Antonna et al. 2002), and is a signature of the transition from radiative to convective atmospheres. The population of slow rotators for F0–F2 stars is then probably composed of stars that undergone a braking due to their convective atmosphere.
- The high-velocity side of distributions of stars with spectral types ranging from A2 to F2 have a double-like structure. A well defined peak can be noticed at $v \simeq 200$ $\mathrm{km\,s^{-1}}$ in all groups, except for the F0–F2 for which at $v \simeq 200$ $\mathrm{km\,s^{-1}}$ there is only an inflection. The maximum of fast rotators in the B9 and A0–A1 groups is also situated at $v = 200$ $\mathrm{km\,s^{-1}}$, although the corresponding distributions do not show any noticeable double structure.
  The double structure might be ought to an evolution-fast rotation interplay effect.

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