DIFFERENTIAL ROTATION IN B AND Be STARS

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SUMMARY

In this paper we present two kinds of results which show that differential rotation is a highly probable phenomenon in B and Be stars. These results show that angular momentum is an important parameter which must be taken into account for interpreting the observed parameters of B and Be stars and for studying their structure.

I - STATISTICAL STUDY OF V sin i FOR B AND Be STARS

We have studied the modes of true rotational velocities distributions (distributions of V sin i corrected statistically for sin i and corrected also for the dispersion due to observational uncertainties, hereafter DTRV) as a function of spectral type and luminosity class, in order to compare the observations with models of stars evolving with different types of angular momentum distribution. Our results are statistical and give the most probable situation concerning the rotation of B and Be stars. The V sin i data for 1200 B stars and 500 Be stars are mainly from Uesugi & Fukuda's (1982) compilation catalogue,and three methods have been used to derive the DTRV: the exponential distributions(Chandrasekhar and Münch 1950), polynomial representations (Smart 1958, Balona 1975), and the Pearson's curves (C.E.A. 1978).

The observed ratios $(V_o/V_\ell)_{obs}$ (V_o being the DTRV mode corresponding to a given spectral type for stars on the main sequence and V_ℓ the mode for the same stars evolved to another luminosity class) have been compared to theoretical curves $(V_o/V_\ell)_{th}$ obtained from Endal & Sofia's (1979) calculations of models of stars evolving with complete angular momentum redistribution (solid-body rotators) and of stars evolving with no-angular momentum redistribution (equipotential perfect differential rotators). *The relation between the spectra of the same star in two different* evolutionary stages were obtained using the $\lambda_1 D$ diagram of the *BCD classification system (Chalonge & Divan 1973) and the models of stellar* evolution of Becker (1981), Brunish & Truran (1982) and Endal & Sofia (1979).

The comparison of observed surface velocity ratios with the theoretical curves for solid-body rotators and for differential rotators is given in figure 1, where ℓ is a continuous parameter of luminosity class defined in the BCD system. In spite of the observational uncertainties , the position of the points corresponding to the observed B and Be stars between the two theoretical curves of figure 1 is well demonstrated

https://doi.org/10.1017/S025292110001160IX Published online by Cambridge University Press

(probability 97%) and suggests that most B and Be stars have a high probability to be differential rotators. In this interpretation of the observed rotational velocities, some uncertainties may appear because in the case of cylindrical differential rotation which is not considered in Endal and Sofia's models but cannot be excluded (Spruit *et al.*1983) the meaning of the V sin i parameter is different, and also because the relation between the spectral type and the mass of a star may be not unique when differential rotation exists, the quantity of kinetic energy which can be stored being then several times higher than for critical solid-body rotation.

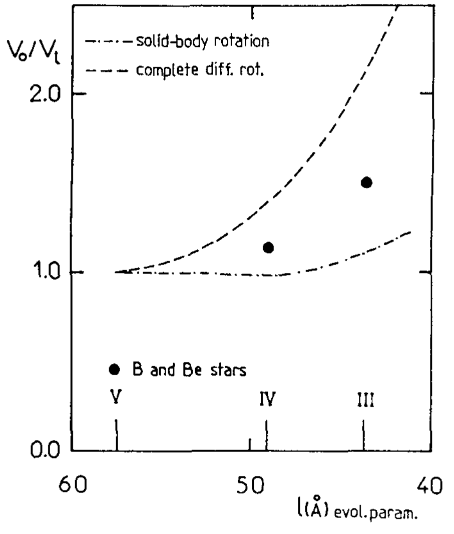

Figure 1.

II - THE ANGULAR MOMENTUM OF MODEL STARS AND OBSERVED PARAMETERS

For stars with differential rotation it is possible to construct secularly stable models having deformation parameters with values up to $\tau \sim 0.10$, where $\tau = K/W$; K : rotational kinetic energy, W : gravitational potential energy (Clement 1979). For such a high value of the kinetic energy the stars behave like objects having a smaller mass and are subject to strong deformations. The relation between spectral type and mass is then not unique, and the same spectrum may correspond to objects with different physical characteristics, different rotation laws and different degrees or kinds of instabilities. This means that each observed parameter of a rotating star must be considered to be a function of at least the following six independent quantities : M (mass), J (total angular momentum), β (angular momentum distribution law), i (inclination of the rotation axis), ℓ (the evolutionary stage parameter) and Q (chemical composition).

Comparing the models of stars with differential rotation calculated by Zorec and Mochkovitch (1986) with the following observed parameters : D (Balmer discontinuity), λ_1 (position of the Balmer discontinuity), L (bolometric luminosity) and V sin i, we estimated the deformation parameter τ for 100 B and Be stars. The evolutionary stage of each star was considered as a free parameter and the chemical composition was that

https://doi.org/10.1017/S025292110011601X Published online by Cambridge University Press

of the solar surroundings.

In spite of uncertainties in the evolutionary stage of stars, the result is that the mean value of τ is the same for the B and Be stars, and equal to about $4\tau_c$, where τ_c corresponds to the critical solid-body rotation. This means that B and Be stars do not rotate as solid bodies. Moreover, the result $\tau(Be) \sim \tau(B)$ together with the fact that the observed velocities of Be stars are larger than those of B stars by a factor of 1.5 or 2 as a mean, indicate that B and Be stars have different rotation laws, the smaller velocities of B stars being explained by a smoother distribution of the angular momentum.

DISCUSSION OF A POSSIBLE STRUCTURE FOR Be STARS

We have shown that solid-body rotation leads easily to higher mean surface angular velocities than the differential one, and involves only small values of τ ($\tau \lesssim 0.015$). To explain the large observed rotational velocities of the Be stars, we can imagine that Be stars have a stellar envelope likely in solid-body rotation leading to high mean surface angular velocities, and a stellar core in which the bulk of their angular momentum is concentrated. The core deformation parameter can then be easily higher than 0.10 or 0.14, which is a condition for secular instability (Clement 1979). On the other hand, the lowering of the surface effective gravity by the high rotation of the stellar envelope and the instabilities in the stellar core, may lead to a more effective mass outflow than in the case of B stars.

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https://doi.org/10.1017/S025292110011601X Published online by Cambridge University Press

DISCUSSION FOLLOWING ZOREC

Collins:

What law of gravity darkening did you use?

Zorec:

We have used only the von Zeipel's theorem.

Underhill:

Your results give just one more example of the point I have made in connection with O stars: stars with the same photosphere may produce different mantles, or expressed in another way, stars with similar mantles (similar emission lines) may possess different photospheres.

Zorec:

In the case where differential rotation exists, the apparent photospheres (deduced from spectra that are integrated over the observed hemisphere of stars) which appear the same, may correspond to stars having different masses and which are subjected to different degrees of deformation. For small deformation parameters (optical depth around 0.03), the same star seen pole-on or equator-on shows different spectra, but they correspond to a global bolometric luminosity reduced by about 20% when it is compared to that of a non-rotating star having the same mass. On the other hand, differences of one spectral type may represent in hot stars are error of 10% in the estimation of masses. This error is smaller when the stars have smaller masses.