THE ROLE OF ROTATION IN THE EVOLUTION OF MASSIVE STARS LOSING MASS

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ABSTRACT

The role of differential and solid body rotation in the evolution of massive stars undergoing mass loss is discussed. The implications for Of, WR, β Cephei stars and shell stars are brought out.

1. INTRODUCTION

In recent years a number of investigations have been reported in which the effect of mass loss on the evolution of massive stars has been assessed (see de Loore in this volume for references) following the discovery that was made possible through ultraviolet observations with rockets and satellites (see Snow in this volume for detailed references). While these studies have clarified to a certain extent the reasons for the presence of overluminous stars, the relative rarity of red supergiants above a certain mass limit and a possible explanation of the origin of Wolf-Rayet stars, there still exist some controversies, e.g.whether WR stars are hydrogen burning objects or helium burning objects, whether they are single or double stars and some discrepancies, e.g. relative number of red versus blue supergiants. There are also many things about these stars that we do not quite understand, e.g. whether there are abundance anomalies amongst yellow supergiants, the nature of the β Cephei phenomenon, and the nature of maa loss in red supergiants.

In this progress report we shall outline briefly the role of rotation (solid body as well as differential rotation) in the evolution of massive stars undergoing mass loss. One of the reasons for this study is an attept to understand phenomenologically the observational results concerning the rotation of OB stars.

P. S. Conti and C. W. H. de Loore (eds.), Mass Loss and Evolution of O-Type Stars, 367–370.

2. EFFECTS OF ROTATION

In a recent paper (Sreenivasan and Wilson, 1978a) we have attempted to assess the effect of a centrifugal force on the amount of mass lost by a massive star due to stellar winds driven by radiation pressure acting on the outer layers due to resonance lines absorption. We concluded that the mass loss rate can be enhanced by about 20-30% over the rate for non-rotating models. We also showed that the surface rotation in these models can be reduced to zero well before hydrogen is exhausted in the core. If mass loss due to an acoustic energy flux driven wind is included it can be shown that a 15 $M_{\odot}$ star ($X = 0.70$; $Z = 0.03$) will have about 70% of its mass left when it enters the stage of being a cepheid. It thus appears possible to understand the mass discrepancy as well as the fact that cepheids are either non-rotating or slowly rotating objects.

3. DIFFERENTIAL ROTATION

The time required for spin-down of the surface layers is different according to whether one discusses only conservation of angular momentum or conservation of angular momentum and energy (including rotational energy of a mass-losing star). Clearly, there are stars which exhibit some rotation (albeit small) in spectral stages later than B. Many supergiants show a small residual rotation of the order of 50 km/sec according to Conti and Ebbets (1977). This is clearly due to differential rotation between the surface and the interior regions as was shown by Sreenivasan and Wilson (1978a).

We have made explicit allowance for the effect of differential rotation in the form of a macro-turbulent pressure in a subsequent study (Sreenivasan and Wilson, 1978b) by including a term:

$$\frac{1}{3}\bar{\rho}\,\frac{(V_b - V_s)^2}{l}$$

to represent the force due to the turbulent pressure gradient in the outer layers. Here V_b is the rotational speed of the boundary of the interior model, V_s is the rotational speed at the surface, and l is the distance between the points at which $V = V_b$ and $V = V_s$ and $\bar{\rho}$ is the mean density of the shell of width l. Estimating the contribution to mass loss in the same fashion as in Sreenivasan and Wilson (1978a), we find that the enhancement in mass loss rate is about a factor of 2-3 over the rate when only a centrifugal force is included. We have shown elsewhere (Sreenivasan and Wilson, 1978c) that one can explain the β Cephei phenomena as a manifestation of the differential rotation in massive stars in the mass range 15-20 $M_{\odot}$ due to Kelvin-Helmholtz instability resulting in observed variations of the order of 0.1 magnitude.

4. SHELL STARS

It is known that β Cephei stars are confined to a narrow range in spectral type B0-B2 (Lesh and Aizenman, 1978) whereas Be stars occur with lower effective te-peratures. The core of an evolving star contracts as it exhausts hydrogen while the surface rotation drops in speed due to mass loss. This results in a faster spinning core coupled to a surface which is braking due to the stellar wind. A dynamical consequence of this could well be the ejection of a shell revealing a rapidly spinning interior. Thus one might understand why β Cephei stars are slow rotators whereas the shell stars are rapid ones. Before any firm conclusions can be drawn on these aspects, more careful quantitative work is required. However, it is clear that differential rotation in a mass losing star holds the key to a number of interesting properties of massive stars.

5. WR STARS

Finally, we should like to remark that the origin of Wolf-Rayet stars is connected to the high mass loss rates that are necessary to understand not only their spectra but the che-ical state of their interior. De Loore et al (1977) believe that WR stars are predominantly hydrogen burning stars, which are members of a binary system. Chiosi et al (1978) on the other hand argue that the WC stars could possibly be helium stars whose outer layers have been depleted by an acoustic energy flux driven wind and that only those stars for which the helium burning lifetime is larger than the time scale needed to remove the hydrogen rich outer layers are possible candidates. The effect of rotation and differential rotation tend to favour their inequality $\tau_{He} > \tau_{\dot{M}}$ and also strengthen it because a higher mass loss rate produces a larger q_{He} value. As also emphasized by them and Giannone earlier, the q_{He} value holds the key to the subsequent evolutionary pattern of stars.

Fuller details of this investigation will be published elsewhere.

6. ACKNOWLEDGEMENT

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DISCUSSION FOLLOWING SREENIVASAN and WILSON

Vanbeveren: To derive the formula for $\dot{\omega}$, did you assume that after a mass layer has left the star, its angular momentum remains constant?

Sreenivasan: Yes, if no subsequent mass loss from star magnetic fields, other mechanisms for transport of angular momentum are not considered.