ON THE STRUCTURE AND EVOLUTION OF THE OB-COMPANIONS IN WOLF-RAYET BINARIES

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1. INTRODUCTION

The treatment of close binary evolution changed from conservative (total mass and angular momentum constant) to non-conservative (a certain fraction of the matter expelled from the mass losing star, the primary, leaves the system, carrying away a fraction of the total angular momentum). Only the evolution of the mass losing star was computed in detail; the evolution of the accreting star was estimated in a very simple way by computing the evolution in the normal way just like for single stars, but taking into account the mass increase.

Investigations of Benson (1970) however revealed that as a consequence of the inflow of matter the accreting star expands, so that contact systems can be formed. We calculated the evolution of massive close binaries simultaneously through detached, semi-detached and contact phases.

2. SIMULTANEOUS EVOLUTIONARY COMPUTATIONS

In order to take into account the effects of accretion and the influence of the changing structure of the secondary on the system parameters the evolution of the two components was calculated simultaneously, i.e. by calculating successive models for both components, alternatively computing the structure of the primary and the secondary in one single evolutionary code.

The physical processes of energy transfer by convection, mixing as a consequence of accretion and mass loss were treated as follows:

i) convection
For the determination of the boundary of the convective core the Schwarzschild criterion is applied. Neither effects of overshooting nor semi-convection are taken into account.

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ii) accretion

As mixing process for the already present matter and accreted material thermohaline mixing is adopted (Ulrich, 1972).

iii) stellar wind mass loss

During the hydrogen burning phase a moderate mass loss rate is applied (N=100, de Loore et al., 1977). For the phase of helium burning, corresponding with the Wolf-Rayet phase a mass loss rate of one magnitude larger was adopted (N=1000).

iv) mass transfer and mass loss during the Roche lobe overflow stage

Mass transfer is treated as conservative ($\beta=1$, Vanbeveren et al., 1979) as long as the secondary is not yet filling its Roche volume. During contact phases, i.e. when the secondary exceeds its own Roche radius, matter has to leave the system ($\beta<1$) and in our treatment it is assumed that this mass loss occurs in a spherically symmetric way (Plavec, 1981). Non spherically symmetric mass outflow will be considered in the near future. As soon as the semi-detached conditions are restored the conservative treatment is reapplied. Computations were performed for two massive close binary systems, 100 $M_\odot$ + 90 $M_\odot$ and for 40 $M_\odot$ + 36 $M_\odot$, from ZAMS to helium ignition of the secondary as test computations for the simultaneous code, and in order to investigate the structure of the accretion stars.

3. RESULTS

Results of the computations for the two given systems are shown in Table 1 for a numer of selected evolutionary moments. During the mass

100 + 90	$t/10^6$yr	$M_1/M_\odot$	$M_2/M_\odot$	log $L/L_\odot$ 2	log T_{eff} 2	$R/R_\odot$ 2	$X_{at,2}$	Code
ZAMS	0	100.	90.0	5.98	4.70	13.1	0.70	A
Start RLOF 1	3.2912	72.1	66.6	6.08	4.50	36.5	0.70	B
End RLOF 1	3.3020	42.4	94.8	6.30	4.66	22.4	0.47	C
End He-burn 1	3.5851	22.9	91.0	6.30	4.68	20.4	0.47	D
Start He-burn 2	3.5947	-	90.8	6.34	4.62	28.5	0.47	E
40 + 36								
ZAMS	0	40.0	36.0	5.22	4.61	8.1	0.70	A
Start RLOF 1	5.2258	31.4	29.2	5.36	4.45	20.2	0.70	B
End RLOF 1	5.2377	13.0	47.4	5.69	4.59	15.7	0.61	C
End He-burn 1	5.7031	9.7	45.9	5.70	4.56	17.9	0.61	D
Start He-burn 2	5.8420	-	45.4	5.75	4.41	38.0	0.61	E

Table 1. Evolution of massive close binaries. The table shows the time, masses of the primary (M_1) and secondary (M_2), the position in the HRD for the secondary (log L, log T_{eff}), its radius and the atmospheric hydrogen abundance X_{at}).

transfer a contact phase occurs, lasting however for a very short time of the order of 1000 years; the more massive system loses during this stage ~ 1.3 $M_\odot$, and β is reduced to 0.84. Evolutionary tracks for both components of both systems are shown in Figure 1.

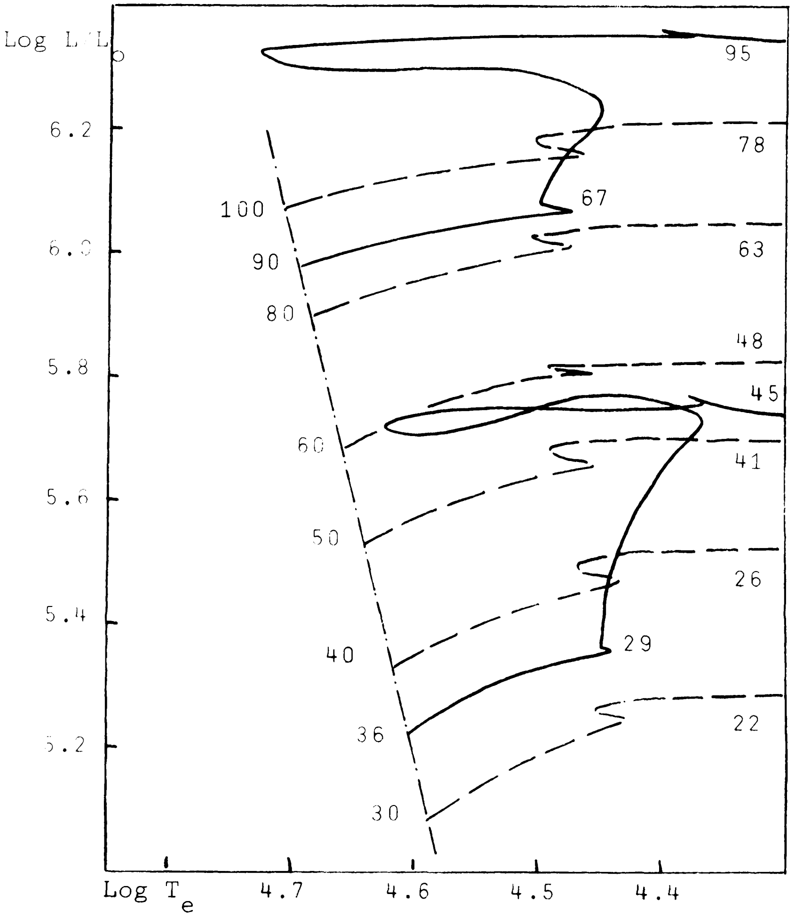

Figure 1. HR-diagram with evolutionary tracks of the secondaries (full line), the stage of WR-companionship (dotted line) and of some massive single stars (dashed line). ZAMS masses and masses at the end of core hydrogen burning are given as well as the masses of the secondaries at the onset of accretion.

As a result of thermohaline mixing the atmospheric structure of the secondary changes, in the sense that the hydrogen abundance X_{at} decreases (see last column of Table 1). The position of these accreting stars in the HRD is normal for their masses, effective temperatures and luminosities; the only difference is that they have different atmospheric composition. The thermohaline mixing affects largely the inner structure. This is depicted in figure 2. The figure shows the hydrogen profiles of the secondary at the beginning and at the end of the mass transfer and at the start of core helium burning. For an evolving single star the atmospheric abundance remains unchanged unless the stellar wind mass loss removes so much material that layers affected by nuclear processes appear at the surface. In the case of accretion however thermohaline mixing causes a decrease of the hydrogen abundance as a consequence of the inflow of helium enriched material.

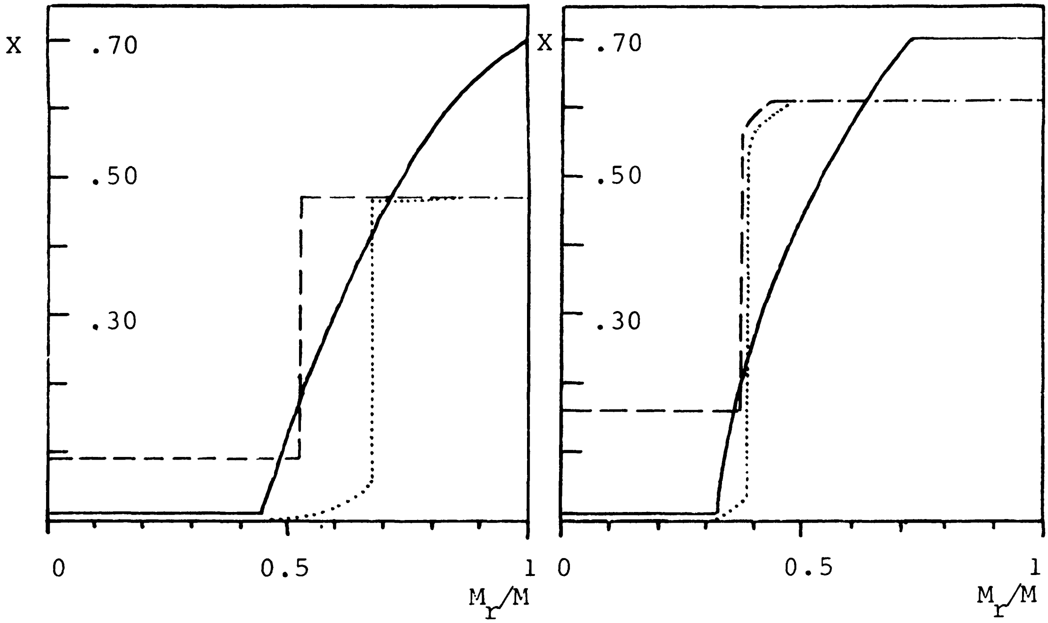

Figure 2. Hydrogen profiles for the secondary at the beginning (full line) and at the end of mass transfer (dashed line), and at the start of core helium burning (dotted line). At the left, the profile of the secondary of the evolving $100M_{\odot}+90M_{\odot}$ binary, at the right the profile of the evolving secondary of the $40M_{\odot}+36M_{\odot}$ system.

4. CONCLUSIONS

The stage following the Roche lobe overflow can account for the Wolf-Rayet stage. Our results predict that the OB companions of the helium remnants are core hydrogen burning stars (see Figure 1).
Our computations reveal that the accretion stars are slightly hydrogen deficient, whereas observations show a normal composition. These differences however cannot be detected by analysis of the stellar spectra.

If we compare our earlier computations (de Loore, De Grève, 1975) for accreting stars with the new ones, it turns out that the thermohaline mixing and the subsequent changed atmospheric composition are the most striking differences. Apart from a loop of the accreting component in the hotter part of the HRD the general trend of the evolutionary tracks is similar: an upward motion (higher luminosities) followed by a rapid expansion, hence a transition to the red supergiant configuration.

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