THE INFLUENCE OF STELLAR WIND MASS LOSS ON THE EVOLUTION OF MASSIVE CLOSE BINARIES.

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1. INTRODUCTION

It is generally accepted that massive (and thus luminous) stars lose mass by stellar wind, driven by radiation force (Lucy and Solomon, 1970; Castor et al. 1975). For the components of massive binary systems, rotational and gravitational effects may act together with the radiation force so as to increase the mass loss rate. Our intention here is to discuss the influence of a stellar wind mass loss on the evolution of massive close binaries. During the Roche lobe overflow phase, mass and angular momentum can leave the system. Possible reasons for mass loss from the system are for example the expansion of the companion due to accretion of the material lost by the mass losing star (Kippenhahn and Meyer-Hofmeister, 1977) or the fact that due to the influence of the radiation force in luminous stars, mass will be lost over the whole surface of the star and not any longer through a possible Lagrangian point as in the case of classical Roche lobe overflow (Vanbeveren, 1978). We have therefore investigated the influence of both processes on binary evolution. Our results are applied to 5 massive X-ray binaries with a possible implication for the existence of massive Wolf Rayet stars with a very close invisible compact companion. A more extended version of this talk is published in Astronomy and Astrophysics (Vanbeveren et al. 1978; Vanbeveren and De Grève, 1978). Their results will be briefly reviewed.

2. THE PHASE OF STELLAR WIND MASS LOSS

Taking into account the similarity in evolution between a single star and a binary component before the Roche lobe overflow phase, it is clear from an observational point of view that components of massive binary systems will lose mass at a rate of 10^{-7} $M_\odot$/yr to 10^{-5} $M_\odot$/yr. In our computations, we have used the equation for the stellar wind mass loss introduced by de Loore (these proceedings). As the parameter N in this formula is assumed to be constant, our results may be considered as average results; our conclusions are independent

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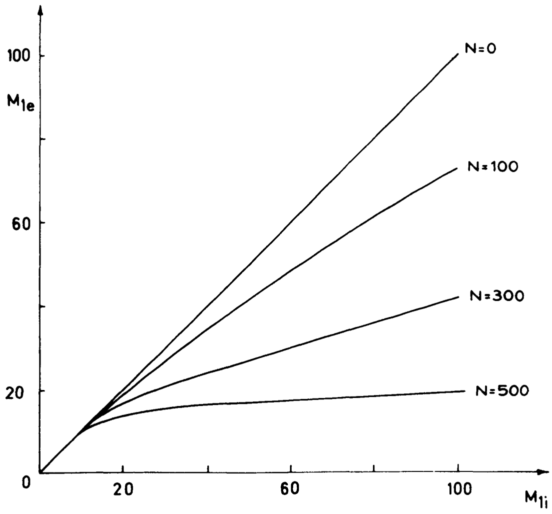
of that assumption. We will return to this in section 4.

a) For a more massive (hence more luminous) primary we may reasonably expect that its mass loss rate is higher than the $\dot{M}$ value of the companion. The mass ratio increases therefore with time and approaches unity.

b) Assuming a spherically symmetric stellar wind, the angular momentum loss can be described by a Jeans like mode (Huang, S.S., 1963). In that case the period of the system increases. For this reason, the probability for the occurrence of a case B (Roche lobe overflow appears during the hydrogen shell burning phase) increases if stellar wind mass loss is included.

3. THE ROCHE LOBE OVERFLOW PHASE

In view of the foregoing remark we considered only case B systems. We computed different cases for the mass and angular momentum loss (Δm and ΔH) from the system during the Roche lobe overflow. It turns out that the final mass and luminosity of the primary are largely independent from the choice of Δm and ΔH. The reason is that the moment of He ignition is almost independent from the behaviour of the expanding envelope. However, as the formation of the He core depends on the total mass loss by stellar wind, we get different results for different stellar wind losses. The relation between initial and final masses can be seen in Figure 1.



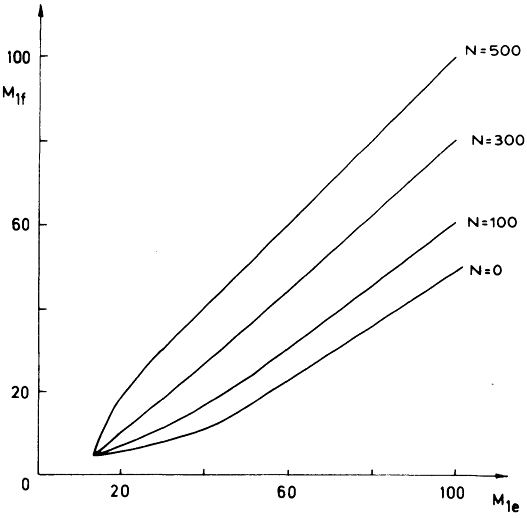


Figure 1a. The mass of the primary at the end of the core H burning phase (M_{1e}) as a function of ZAMS mass (M_{1i}) for different stellar wind cases.

Figure 1b. Remnant primary mass after lobe overflow (M_{1f}) as a function of M_{1e} for various preceding stellar wind cases.

4. APPLICATION TO 5 MASSIVE X-RAY BINARIES

In this section we shall focus our attention to systems consisting of a massive OB primary at the end of the core H burning phase and a compact companion (neutron star or black hole).

More detailed results concerning this application to the massive X-ray binaries Vela X-1, Cyg X-1, 3U 1700-37, SMC X-1 and Cen X-3 will be published in Astronomy and Astrophysics (Vanbeveren and De Grève, 1978). We will recall in this section some of the overall conclusions of this paper.

Assuming the optical components of the massive X-ray binaries to be normal stars at the end of their core hydrogen burning phase, it was shown in the paper of Vanbeveren et al. (1978)(and reviewed in the talk of C. de Loore) that the 5 systems are situated between the N=300 and N=500 tracks in the luminosity-mass diagram. Using the system parameters given by Conti (1978) we have computed the final mass after the Roche lobe overflow phase for both values of N (Table 1). The critical Eddington luminosity for X-rays is reached for accretion rates of the order of 10^{-6} $M_\odot$/yr; the supergiant, when overflowing its Roche lobe loses some 10^{-4} $M_\odot$/yr, hence most of the material leaves the system. On the other hand, a large angular momentum loss may be expected during the Roche lobe overflow if mass is leaving the system (Vanbeveren et al. 1978). Therefore, considering the periods of the X-ray binaries, the final systems will consist of a massive He star (a Wolf Rayet) and a very close compact companion. As the observed mass loss rates during the Wolf Rayet stage are very high, the X-rays are extinguished and the system appears like a single Wolf Rayet star. Comparing the lifetimes of the different evolutionary stages (t_{WR+OB}, $t_{WR+\text{compact star}}$, $t_{X\text{-ray}}$) and taking into account that about 50 % of all well studied WR stars appear in binaries with a massive OB companion (Underhill, 1966) it seems plausible from a statistical point of view, that a large number of the remaining 50 % (seen as single WR stars) are in fact very close binaries with a compact companion.
If the tracks for N=300 and N=500 in the mass-luminosity diagram may be considered as boundary curves for the domain of the X-ray binaries, we can have an indication about the expected N(H)/N(He) ratios for the systems (Figure 2). It seems that for at least 4 of the 5 systems, the N(H)/N(He) ratio is considerably lower than the normal value of 10.7 (assuming an initial composition X=0.70, Z=0.03). It would be interesting to have more observations in order to compare them with the above model.
If N is variable, instead of constant, one finds that :
a) the mass ratio variation, the probability for the occurrence of a case B and the final mass and luminosity of the Roche lobe overflow phase increase compared with the N = constant computations;
b) the H abundance in the surface layers at the end of the hydrogen core burning phase is lower.
Hence a variable N strengthens the conclusions concerning the influence of the stellar wind on binary evolution.

System	$M_{1e}(M_\odot)$	$M_{2e}(M_\odot)$	P_e(days)	$M_{1f}(M_\odot)$ N=300	$M_{1f}(M_\odot)$ N=500	$M_{1f}(M_\odot)$ N=0
Vela X-1	25	2	8.959	13.3	24	7.8
Cyg X-1	25-30	9-14	5.607	13.3-17.5	24-30	7.8-9.9
3U 1700-37	27-35	1.3-2.5	3.412	15-21.7	27-35	8.8-11.2
SMC X-1	~ 30	~ 1.5-4	3.893	~ 17.5	~ 30	~ 9.9
Cen X-3	~ 18	~ 0.7-1.2	2.087	~ 7.4	~ 16	~ 4.5

Table 1. Masses of primaries of massive X-ray binaries after Roche lobe overflow (M_{1f}) for different stellar wind rates. The observed data M_{1e}, M_{2e} and P_e are taken from Conti (1978).

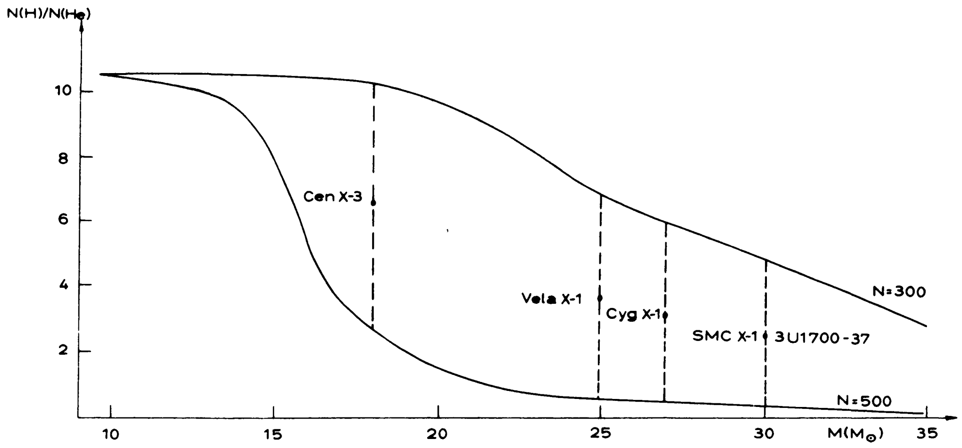


Figure 2.
The N(H)/N(He) ratio as a function of the mass at the end of core Hydrogen burning; the locations of 5 massive X-ray binaries are indicated.

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DISCUSSION FOLLOWING VANBEVEREN, DE GREVE, DE LOORE and VAN DESSEL

Chiosi: I would like to comment on the adoption of large mass loss rate (N=400) during the core H-burning phase of the most massive component before it starts exchanging mass. As a significant fraction of the massive stars appears as single stars, I wonder if by adopting those high rate we will still be able to reproduce the observed properties of the HR diagram nearby the main sequence. It might however be that mass loss by stellar wind is enhanced if the star is in a binary system. Have you any guess about this enhancement? According to your results rather high mass loss rates seem to be necessary for stars in double systems, at least a factor of 5-10 larger than the estimate inferred from the comparison of the occupation area of losing mass stars (near the main sequence) with the theoretical models in core H-burning.

Garmany: I may have missed this in your talk, but can you say something about the time scale for the mass loss and then for the Roche lobe overflow relative to the time spent on the main sequence and post main sequence?

Vanbeveren: Roughly one can say that the hydrogen shell burning stage (the post hydrogen core burning stage) is a factor 10 smaller in time than the core hydrogen burning lifetime while the Roche overflow lifetime is approximately a factor 10 smaller than the lifetime of the hydrogen shell burning phase.

Henrichs: What are the reasons for assuming a constant value of N during the whole evolution? Is it not preferable to infer N as a function of (L, log T_{eff}) from the observed mass loss rates?

Vanbeveren: From the observations it is not clear whether or not N is constant. Following the Barlow and Cohen values, N should be constant. In any case, if we take a constant value of N, this must be considered as an average value over the whole main sequence. On the other hand, using different functions for N will not change the general conclusions of our calculations. Our purpose was to compare our results with the results without a stellar wind and this comparison is independent of the choice of the mass loss rate function.