ON THE EVOLUTIONARY TIME SCALE OF THE ACCRETING COMPONENT IN MASSIVE CLOSE BINARIES : CONSEQUENCES FOR THE SUPERNOVA EVENT

C. Doom and J.P. De Grève
Astrophysical Institute, Vrije Universiteit Brussel

ABSTRACT

The remaining core hydrogen burning lifetime after a case B of mass exchange is computed for the mass gaining component in massive close binaries. Effects of stellar wind mass loss and mass loss during Roche Lobe OverFlow (RLOF) are included. Consequences for the evolutionary scenario are discussed.

1. INTRODUCTION

The remaining lifetime of the secondary after RLOF is calculated using results from evolutionary computations. The remaining time scale is influenced by three elements :

a) The smallest component increases in mass as a result of accretion. The nuclear time scale decreases accordingly.

b) The increase of mass causes the convective core to increase, thus raising the central hydrogen content. This increases the core hydrogen burning time scale.

c) During mass exchange matter with decreasing hydrogen content by mass is deposited on the surface of the gainer. Interaction of the star with the accreting layers may result in a different chemical structure, eventually altering the further evolution.

Stellar wind mass loss related to the individual stars, enters the problem in two ways

a) it increases the lifetime of the star

b) it changes the chemical profile of the outer layers.

The mass loss during RLOF determines the new mass of the gainer and hence, its new lifetime.

A detailed and extended version of this investigation, including the formalism and a description of the input physics, is given in a separate paper, submitted to Astrophysics and Space Science.

C. Chiosi and R. Stalio (eds.), Effects of Mass Loss on Stellar Evolution, 465–468.

2. METHOD

Three parameters govern the mass loss in massive close binary evolution:

a) Stellar wind mass loss during core hydrogen burning (parameter N_H, de Loore et al., 1977)

b) Mass loss from the system during RLOF (parameter β, Vanbeveren et al., 1978)

c) Stellar wind mass loss during the WR-stage (parameter N_{He}, Vanbeveren and Packet, 1979).

The basic assumptions used in the solution are :

a) During core hydrogen burning the lifetime of the star at time t is related to its structure through the implicit relation $f(M(t), M_c(t), X_c(t)) = 0$ with M_c = mass of the convective core, X_c = central hydrogen content by mass;

b) After RLOF, the surface hydrogen content by mass equals 0.2 (Vanbeveren and De Grêve, 1979);

c) The beginning of the case B of mass exchange ($t=t_B$) coincides with the end of core hydrogen burning ($t=t_e$).

In this talk results are presented for one particular choice of the parameters: N_H=300, β=0.5 and N_{He}=3000. The conclusions are consequently related to these values.

We assume that after RLOF equilibrium is established following 3 possible modes :

ACC1 : The accreted matter is simply deposited on the surface of the secondary, without any further interaction. The convective core increases as a result of mass increase.

ACC2 : The outer layers of the gainer are mixed in up to a mass M_m and a homogeneous profile is established in the region M_2-M_m. The net result for the time scale is the same.

ACC3 : The outer layers are mixed in up to the boundary of the new convective core and a homogeneous profile is established throughout the star.

3. RESULTS

The remaining core hydrogen burning lifetimes t_{21} of the secondary are shown in Table 1 for the case ACC1, for masses M_{1i} ranging from 40 $M_\odot$ to 100 $M_\odot$ and mass ratios q_i=0.3, 0.6 and 0.9. For comparison the total core hydrogen burning lifetime t_2 is given for a ZAMS star having the same structure of the mass gaining star at time t_B. As can be seen the remaining hydrogen burning lifetime shortens drastically with increasing mass ratio, and is extremely small (~ 10^5 years) for very massive systems. For high mass ratios and large masses t_{21} is smaller than the core helium burning time scale of the remnant companion.

Table 1. Remaining core hydrogen burning lifetimes t_{21} resulting from mode ACC1 as a function of mass M_{1i} and mass ratio q_i; N=300 and β=0.5 the meaning of t_2 is explained in the text (t in 10^6yr, M in M_o).

M_{1i}	100 M_o			80 M_o			60 M_o			40 M_o		
q	M_{2f}	t_{21}	t_2	M_{2f}	t_{21}	t_2	M_{2f}	t_{21}	t_2	M_{2f}	t_{21}	t_2
0.3	31.7	2.48	4.36	27.3	3.27	5.08	22.7	4.56	6.26	17.7	6.71	8.28
0.6	45.4	0.80	3.08	38.7	0.97	3.42	31.7	1.24	4.01	24.8	2.13	5.09
0.9	54.0	0.17	2.65	45.5	0.20	2.79	37.1	0.29	3.21	28.5	0.47	3.95

4. EVENT DIAGRAM

We simplify the evolution of a massive binary system in defining 4 time events:

1°) t_1 = end of core hydrogen burning of M_1 = t_{B1} = t_{ERLOF} (ERLOF = end of Roche lobe overflow)

2°) t_2 = the same, but for M_2 : $t_2 = t_1 + t_{21} = t_{B2}$

3°) t_3 = end of core helium burning of M_1 = t_{SN1} (t_{SN1} = occurrence of supernova explosion)

4°) t_4 = the same, but for M_2 : $t_4 = t_{SN2}$.

Figure 1 shows the boundary in the M_{1i}-q_i plane where t_3=t_2 (or t_{SN1}=t_{B2}). Below the boundary RLOF of the secondary occurs after the primary has become a compact star. Above the boundary the RLOF occurs while the primary is in the helium core burning (hence while it is a WR-star). The result of this reversed mass exchange may be a system consisting of an old and a young helium star. Such system might be observed as a binary with two WR-components. A possible candidate for such an outcome is the system AS422, spectroscopically consisting of a WN and a WC spectrum, and with a probable period of 22 days.

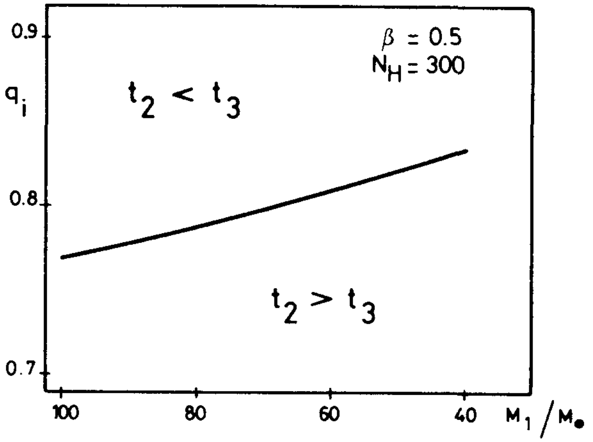

Fig.1. Boundary in the M_{1i}-q_i plane, where t_2=t_3 (SN-explosion of M_1 occurs at the end of core hydrogen burning of M_2).

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https://doi.org/10.1017/S0252921100095129 Published online by Cambridge University Press

DISCUSSION

VANBEVEREN: The results of this talk may include a way to produce single WR stars. Starting from the WN + WC system, the WC star is close to the supernova explosion. From evolutionary theory one may expect that the mass of the WC stars is about the mass of the WN star. So during the SN explosion about half for the system mass is leaving which largely increases the disruption probability, thus leaving behind a single runaway WN star (single now really means without any hidden compact companion).

DE GREVE: I agree that the formation of single WR stars may result from the WN + WC system. However computations should be performed to see if the masses are indeed equal.

CONTI: I do not think that the WN + WC stars in our catalogue have been established as binaries. They need extensive radial velocity study. They may well be single, in transition from WN type to WC type. In any case, an absolute upper limit to such cases is about of 159 WR systems in the galaxy. This number may be useful. On the other hand real WN + WN binaries, if they exist, would be difficult to identify from their spectra alone.

DE GREVE: I agree that the WN + WC stars in the catalogue may be transition stars. I only pointed out that certain massive binaries may readily evolve into a WN + WC binary, which was impossible in the earlier scenarios leading to classical massive X-ray sources.

DE LOORE: The mass ratio distribution of massive stars has, according to Popov, a peak around ~ 1. The fraction of systems with mass ratio q between .9 and 1 is 85%, and only these systems have a "normal life" i.e. they evolve into an "OB - star + neutron star" system, observable as OB - runaway, and later as X-ray source. This confirms the result of Conti & Garmany, where they state that OB stars evolve in tandem, and only a small fraction of OB runaways can be formed.

LORTET: I would like to comment on Dr. Conti's remark on the possibility that you would obtain 2 WN stars rather than WN + WC. It is not easy to distinguish whether you observe one star or a system of two similar ones (before having looked for orbital motions) unless you can tell what the absolute magnitude is. This is possible for stars in the Magellanic Clouds and indeed it may be relevant to remember that WN 7 stars in the 30 Dor region have been claimed to be about 0.7 magnitudes brighter than elsewhere in the Large Magellanic Cloud.

https://doi.org/10.1017/S0252921100095129 Published online by Cambridge University Press