COMMON ENVELOPE BINARIES AND MASS LOSS

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ABSTRACT

In this work we calculate the evolution of a binary system with a common envelope, which consists of a blue supergiant and a neutron star. We consider as a free parameter the effectivity with which the energy liberated at the orbit produces mass loss from the system.

The evolutionary calculations were made, using various values of this parameter, for a system with mass ratio 25:1. As initial state we choose a model in the phase of Hydrogen-shell burning, before and after the begin of Helium-burning in the core.

We found that, under certain conditions, it is possible for the radius of the orbit and the period of the system to increase; the time scale for the "spiral-in" would be of the order of 10^4-10^5 years. Mass loss rates are between 10^{-3} $M_{\odot}/y$ and 10^{-4} $M_{\odot}/y$.

INTRODUCTION

The aim of this work is to investigate the evolution of a massive close binary system, consisting of a blue supergiant and a neutron star, during the phase of a common envelope. Following the normally accepted scenario in the conservative case B (Kippenhahn and Weigert, 1967, van den Heuvel and Heise, 1972), the system has undergone a supernova explosion, before the first X-ray phase, leaving a main sequence O-star and a neutron star, in a very excentrical orbit around it. The orbit is circularised by tidal forces before the O-star envolves away from the main sequence. For mass ratios small enough it becomes unstable and decays to the photosphere of the companion. The occurence of a common envelope stage is made unavoidable (de Grêve et al. 1975). Various authors have considered this problem more or less extensively (Sparks and Stetcher, 1974, Chu et al., 1974, Paczynski, 1976, van den Heuvel, 1976, Thomas, 1977, and, more recently, Taam et al., 1978, Tutukov, 1978) but a good theoretical understanding is still lacking. We present here a simple model which tries to make plausible the possibility of getting a detached system as the end product of the

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common envelope stage. A more detailed treatment is left for future work. In the next section our approach to the problem is described and in section 3 the results are presented and some conclusions are outlined.

FORMULATION OF THE PROBLEM

We have calculated the evolution of a 25 $M_\odot$ star from the main sequence up to a well advanced stage during Helium-burning in the core, using the code described by Kippenhahn et al. (1976). Fig. 1 shows the variation of radius with time in the latter part of the evolution. Our calculations were made with two initial models, taken from this evolutionary sequence; one is in the phase of rapid expansion, corresponding to the shell Hydrogen-burning phase with a neutral core. The other is in the stage just after the beginning of Helium-burning in the core. It should be pointed out that, from this diagramm, and also from observations of binary X-ray sources, the former case is the more probable one. The initial period in this case is of the same order as that given by the observations.

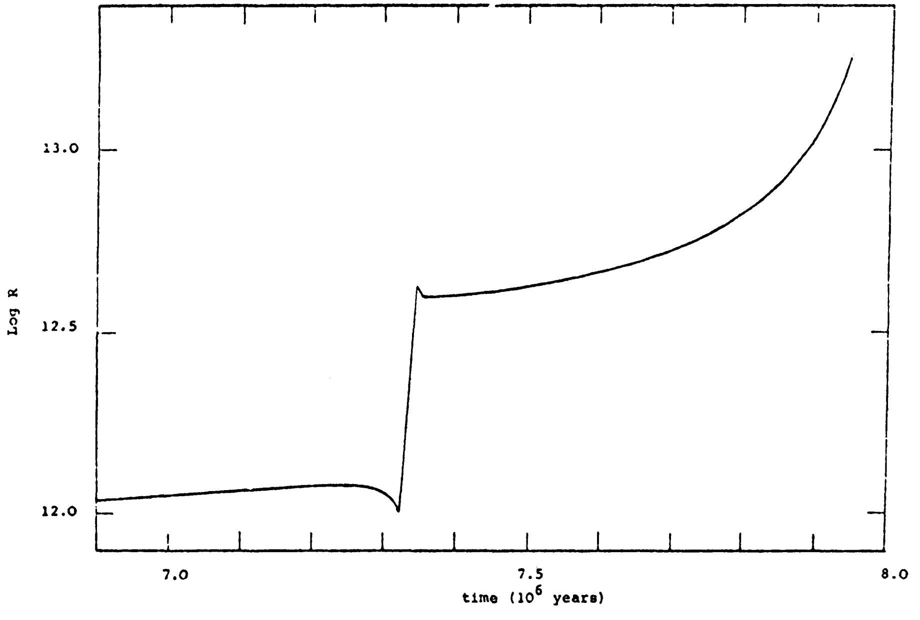

Fig.1: Evolution of the supergiant's radius with time.

We take as the initial state in our calculations the moment when the neutron star penetrates the outer layers of its companion. It was assumed that this star does not rotate, so that velocity of the neutron

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star, relative to the medium, is equal to the orbital velocity. Balance of angular momentum determines the future evolution of the system.

From angular momentum conservation the equation of motion is

$$\frac{dr_B}{r_B} = - \frac{dM_B}{M_B} - \frac{2\dot{M}}{M_{ns}}\, dt \tag{1}$$

where r_B is the radius of the orbit, M_B the mass interior to it, M_{ns} the mass of the neutron star and $\dot{M}$ the rate at which mass is set into move by the neutron star and which is given orbital velocity. Equation (1) was obtained using the assumption that the time-scale of variation of the orbit is larger than the period, so that each orbit can be considered as Keplerian. Further we have assumed that the presence of the neutron star produces only a local perturbation on the companion which, therefore, can assimilate this perturbation without departing sensibly from hydrostatic and thermal equilibrium. This equation was integrated together with the stellar structure equations, using the initial conditions $r_{B_O} = r_{+}$ and $M_{B_O} = M_{+}$ at time $t = 0$, where $+$ denotes the values for the supergiant at this time.

To calculate $\dot{M}$ we used the well-known schema of Bondi (Bondi and Hoyle, 1944). It assumes that a star moves supersonically relative to a homogeneous medium. It is reasonable to approximate the density as homogeneous if its scale hight is greater than about twice the accretion radius, R_A. This condition is well satisfied throughout the whole evolution. R_A and $\dot{M}$ are given by the following expressions

$$R_A = \frac{2GM_{ns}}{v^2} \tag{2}$$

$$\dot{M} = \pi R_A^2 \rho_B v \tag{3}$$

where ρ_B is the density at the position of the orbit and v is the relative velocity.

We take into account the effect of the accretion luminosity from the neutron star's surface by considering it to produce a force acting against the gravitational force of the neutron star. R_A and $\dot{M}$ then become

$$R_A = \frac{2GM_{ns}}{v^2}\left(1 - g\,\frac{L_{AC}}{L_{ED}}\right)$$
$$L_{ED} = \frac{4\pi cGM_{ns}}{\chi_{th}} \tag{4}$$

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$$\dot{M} = 4\pi\ \rho_B \frac{\left(GM_{ns} - g\ \frac{\chi_{th} L_{AC}}{4\pi c}\right)^2}{v^3} \quad . \tag{5}$$

where L_{AC} is the accretion luminosity, L_{ED} the Eddington luminosity and g a factor varing between 0 and 1 which accounts for the possibility that L_{AC} might exceed the Eddington luminosity due to the asymmetry of the accretion flow. χ_{th} denotes the Thompson opacity.

In writing R_A and $\dot{M}$ in this form, it is assumed that the neutron star does not move more material than that which can be accreted, i.e., $\dot{M}$ is equal to the mass accretion rate. This is certainly an extreme assumption, but we only try to get an upper limit for the effect of this correction factor. Writing the accretion luminosity as

$$L_{AC} = \frac{GM_{ns}}{R_{ns}}\ \dot{M} \tag{6}$$

and using the transformations

$$x = \frac{v^3\ \dot{M}}{4\pi\ \rho_B\ G^2 M_{ns}^{\ 2}} \tag{7}$$

$$C = \frac{\chi_{th}\ \rho_B\ G^2 M_{ns}^{\ 2}}{v^2\ c\ R_{ns}} \tag{8}$$

equations (5) and (7) becomes

$$x = (1 - g\ Cx)^2 \tag{9}$$

$$x = \frac{2g\ C+1 - (4g\ C+1)^{1/2}}{2g^2\ C^2} \tag{10}$$

from equations (7) and (10) one obtains the final form for the equation of motion

$$\frac{dr_B}{r_B} = - \frac{dM_B}{M_B} - 8\pi\ \rho_B\ G^{1/2}\ M_{ns} \left[\frac{r_B}{M_B}\right]^{3/2} x\ dt \tag{11}$$

Since $x \sim C^{-1}$ for $C >> 1$ and $C \sim \rho_B$, the density dependence of the second term on the right-hand side of equation (11) is much weaker than in the case of unperturbed accretion radius.

Mass loss from the system is also considered. The energy liberated at the orbit is supposed to be immediately distributed on a spherical shell and transported from there to the photosphere, where it acts as an aditional source of radiation pressure and contributes to the mass loss from the system. The effectiveness of this energy in producing

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mass loss is measured by a factor, f, defined by

$$\frac{GM}{R} \dot{M}_L = f \dot{E}_{orb} \tag{12}$$

where $\dot{E}_{orb}$ is the rate of energy-generation at the orbit and $\dot{M}_L$ the mass-lss rate. f was considered to be a free parameter in the calculations. We have calculated evolutionary sequences for two values of g (1 and 0.2) and f ranging between 10^{-3} and 1.

RESULTS AND DISCUSSION

In table 1 are some relevant data from the evolutionary calculations made with initial models on the phase of rapid expansion. Mass loss rate, energy liberated at the orbit, and mass, bolometric magnitude, and period at the time given in the column on the right.

g	f	$\dot{M}_L(M_\odot/y)$	$\dot{E}_{orb}(L_\odot)$	$M_\tau(M_\odot)$	M_{B_τ}	$P_\tau(d)$	$\tau(y)$
1	10^{-3}	10^{-5}	1.8×10^5	23	- 8.50	1.81	5.2×10^4
1	10^{-2}	10^{-4}	1.8×10^5	14.41	- 8.15	3.91	4.4×10^4
1	10^{-1}	10^{-3}	1.8×10^5	13.76	- 8.00	3.40	1.0×10^4
1	2.3×10^{-1}	2×10^{-3}	1.8×10^5	8.5	- 7.90	8.00	9.5×10^3
1/5	10^{-2}	7×10^{-4}	8.0×10^5	15.34	- 8.01	3.81	1.4×10^4
1/5	5×10^{-2}	2×10^{-3}	8.0×10^5	8.4	- 7.86	7.01	8.5×10^3

Table 1. Parameters for the evolutionary calculations with initial model in the phase of Hydrogen-shell burning with neutral core. The symbols are explained in the text.

Excepting the case with f = 10^{-3}, the supergiant has lost at this time a large part of its envelope and consists of a Helium-burning core, which contains about half of the total mass, and a hydrogen-poor envelope. The chemical composition at the surface is given by X = 0.52, Y = 0.48. At this point we could not calculate any further because of difficulties with the present code; the system should eventually become detached, when the supergiant has lost its whole hydrogen envelope, leaving a Helium star plus neutron star system with a period of the order of several days. Recent observations of the WR star HD 50896 (Firmani, 1978) could be explainable on the basis of a mechanism like that proposed in this paper.

We would like to finish with a remark about this possibility of increasing the period. As one can see from equation (1) two factors influence the variation of the orbit. The drag force (angular momentum loss) tries to bring the neutron star into the interior of the supergiant, whilst the expansion of the latter tries to increase the radius

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of the orbit. With these two processes we can associate two time-scales, $\tau_{orbital}$ and $\tau_{expansion}$. In our case the first time scale is determined by $\dot{M}$. The second one should be the thermal time-scale of the supergiant, since this is its expansion time scale in the evolutionary stage considered. The values $\tau_{orbital} = 10^6$ y and $\tau_{expansion} = 10^4$ y are obtained in the calculations, but, more generally, any factor reducing $\tau_{expansion}$ or increasing $\tau_{orbital}$, for instance, a faster expansion because of the heating at the orbit and, consequently, a decrease of the density at this position, could produce the effect of an increasing period. Calculations including this additional energy source in the energy equation and a more realistic formulation of angular momentum exchange were in the process of calculation at the date of this Symposium and will be presented in a future paper.

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