EVOLUTIONARY COMPUTATIONS FOR INTERMEDIATE MASS CLOSE BINARY SYSTEMS

Th. J. van der Linden

Astronomical Institute, University of Amsterdam.

ABSTRACT. Numerical simulations of the evolution of close binaries with primary mass between 3 and 15 $M_{\odot}$ and mass ratios of ~ 1.5 were carried out. These results show that after mass transfer the system consists of a bright main-sequence star together with a faint He-star in a rather wide orbit ($p > 60^d$) Evolution of this kind predicts isotope anomalies for the CNO-elements with respect to their solar values.

INTRODUCTION:

Theoretical studies of systems with primary mass between three and fifteen solar masses are interesting because there is no direct observational evidence of their endproducts of mass transfer. Systems with primary mass larger than 15 $M_{\odot}$ to 20M lead to Wolf-Rayet systems where the Helium star dominates the system. Systems with a primary mass of less than 3 $M_{\odot}$ evolve into Algol-type systems and further to systems containing a white dwarf.

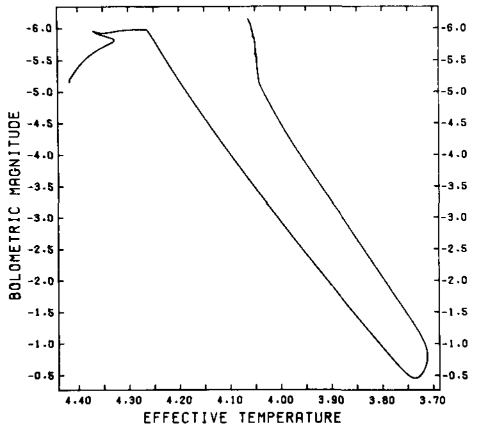
DISCUSSION:

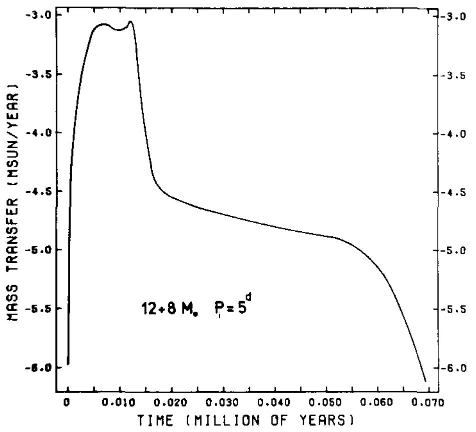
The track in the HR-diagram shows the familiar form for main-sequence stars with a convective core after which the primary expands until this is limited by the critical surface.

Then the luminosity drops sharply due to absorption of energy in the outflowing outer layers. This drop continues until the mass gaining component becomes the most massive star in the system and the critical surface becomes larger when mass is transferred. The mass-losing component can expand again and restore part of the thermal equilibrium, thus less energy is absorbed in the atmosphere and the surface luminosity starts rising until the mass transfer phase is terminated by the onset of core helium burning. The curve of mass transfer vs. time is characterized by a very sharp rise which is due to the fact that mass transfer decreases the critical radius. The mass transfer starts to decrease when the primary can expand again (when the mass-gaining component becomes the most massive star). This decrease is halted temporarily when the luminosity of the star begins to rise again.

C. Chiosi and R. Stalio (eds.), Effects of Mass Loss on Stellar Evolution, 503–506.

https://doi.org/10.1017/S025292110009521X Published online by Cambridge University Press



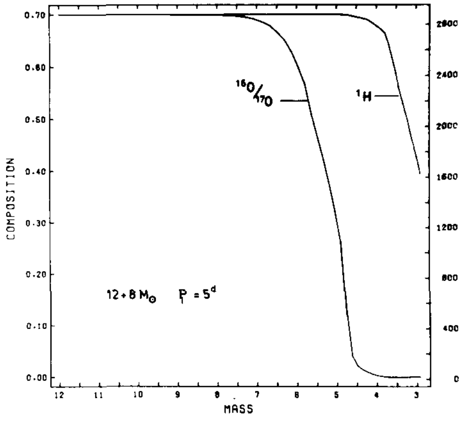


The beginning of the second peak of mass transfer coincides with the minimum luminosity in the HR diagram. This second peak is due to the existence of a small convective zone in the outer parts of the star. The extent of this area is regulated by the luminosity of the star. Due to the fact that a convective zone absorbs almost no energy ($dS/dm \simeq 0$) a higher mass loss rate is necessary to keep the star within its roche lobe. This phase of high mass transfer rate (10^{-3} - 10^{-4} $M_\odot$/yr) is followed by a longer period with a lower mass loss (10^{-5} - 10^{-6} $M_\odot$/yr) during which the mass-losing star loses an amount almost equal to the mass lost in the phase of high transfer rate. The mass transfer is terminated when Helium ignites in the core after which the star relaxes to its thermal equilibrium position on the Helium main-sequence.

ABUNDANCE ANOMALIES

For the 12 + 8 $M_\odot$ system the calculations included all the reactions of the CNO-cycles. The original composition of the star was assumed to the solar (Cameron 1973). During the mass transfer phase layers in which chemical processing has occured reach the surface. This is shown in fig. 3 which shows the O^{16}/O^{17} ratio and the surface hydrogen abundance as a function of the total mass of the mass-losing star. These curves represent the composition profiles which existed at the moment when the mass transfer started. In layers whose mass coordinate exceeded 7.5 $M_\odot$ no chemical processing took place and its composition is unchanged. In layers with mass between 5 - 7.5 $M_\odot$ no nuclear equilibrium can be reached and the composition gradually changes from the original values to the equilibrium values of the core. The maximum extent of the convective core in the ZAMS-model was ~ 5 $M_\odot$ therefore the layers with $M(r) < 5M_\odot$ show the equilibrium

https://doi.org/10.1017/S025292110009521X Published online by Cambridge University Press



abundances of the CNO cycles for log T ∿ 7.4. When these layers reach the surface they will therefore show isotope values very different from the solar values. Predicted values from our models are $C^{12}/C^{13} \sim 3$ $O^{16}/O^{17} \sim 19$ $N^{14}/N^{15} \sim 15000$.

CONCLUSIONS:

The correspondence of the systemparameters before and after mass transfer can be found in table 1. Systems with primary masses between 3 and 15 $M_\odot$ result, after mass transfer, in system with a newly formed early B-star with a small He-star ($q \simeq 12$) companion in a rather wide orbit ($P < 60d$). Due to the fact that the Helium star is rather faint ($\Delta M_{bol} \simeq 2-5$) compared to its companion the binary nature of such an object will probably go unnoticed. As has been suggested (see Kriz and Harmanec 1975 and references therein) these systems might appear as Be-star, because of the UV flux of the He-star, although no direct proof of this exists.

TABLE I System parameters before and after mass transfer.

t = initial, f = final, p = period, A = Orbital distance

Δm = difference in bolometric magnitude of components after mass transfer.

M_1 , M_2	P_t	P_f	A_f	M_{1f}	M_{2f}	Δm
3 + 2	2^d	93	147	.36	4.64	5.0
4 + 3.2	1.78	118	195	.46	6.74	4.0
6 + 4	3	96	191	.82	9.18	3.5
9 + 6	4	78	190	1.48	13.52	2.7
12 + 8	5	65	184	2.30	17.70	1.9

ACKNOWLEDGEMENTS:

This work was supported by the Netherlands Organization for the advancement of pure research, Z.W.O. (ASTRON).

REFERENCES:

CAMERON in Proceedings of the conference on Explosive Nucleo Synthesis, 1973

Kriz, S. and Harmanec P.1975, Bull. Astron. Inst. Czech. 26,65

DISCUSSION

DE GREVE: I just want to get one thing clear. The number of 0.3 you quote for the final hydrogen surface abundance, does it hold for all the computations?

VAN DER LINDEN: No, it ranges from 0.5 for the remnant of the 3 $M_\odot$ to 0.25 for the remnant of the 12 $M_\odot$ star.

DE GREVE: So there is a gradual decrease of H-abundance towards smaller masses?

VAN DER LINDEN: No, it decreases with higher masses.

LAMERS: What are the characteristics which will make the stars look like Be-stars?

VAN DER LINDEN: The presence of a UV source in the form of He-star. The helium star is about a magnitude brighter in the far UV that its companion.