RAPID MASS ACCRETION ON A FULLY CONVECTIVE STAR

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ABSTRACT. We investigated the effects of rapid mass accretion on a fully convective main sequence star of 0.3 $M_\odot$, taking into account the heating of its photosphere by the kinetic energy of the infalling matter. We found that the star develops highly inhomogeneous structure consisting of almost unperturbed initial convective core and a radiative envelope composed of the accreted matter. Both regions are separated by a very stable temperature inversion layer. Due to such structure accreting convective star may significantly increase its radius (contrary to earlier suggestions).

All calculations involving mass accretion on a convective star, published so far, were carried out under the assumption that the entropy of the newly accreted matter is the same as the entropy of the initial convective configuration (Webbink 1977 a,b; Whyte and Eggleton 1985). The results obtained suggested that a convective star should shrink upon accretion even if the accretion rate is very high. This conclusion was not surprising since this is just a behaviour one might expect from a polytrope of index 1.5, which in conserving its entropy but increasing its mass. Taken literally, this would mean that binaries containing low mass main sequence components cannot evolve into contact. On the other hand, we observe many low mass W UMa type binaries with convective components that have somehow reached the state of contact. This does not necessarily mean a contradiction since, in our opinion, the results mentioned above are not relevant for the real evolution of convective stars accreting the matter at high rate. We believe that, in fact, the newly accreted matter should have substantially higher entropy then the original star, since the photosphere of an accreting star is heated by the radiation emitted from the region of a shock wave formed by the infalling matter. The calculations, taking this fact into account, were undertaken by Webbink (1977 a) but he did not carry his investigation far enough to solve the problem of the response of the star (particularly that of stellar radius). Prompted by these considerations we have decided to investigate the rapid mass accretion on a convective main sequence star

Paper presented at the IAU Colloquium No. 93 on 'Cataclysmic Variables. Recent Multi-Frequency Observations and Theoretical Developments', held at Dr. Remeis-Sternwarte Bamberg, F.R.G., 16–19 June, 1986.

Astrophysics and Space Science **131** (1987) 671–674.

of 0.3 $M_\odot$. Our calculations were carried out under the following assumptions:

1) The accretion is spherically symmetric,
2) The effect of so-called accretion luminosity on the surface temperature of an accreting star may be approximated by the formula:

$$L_{total}=4\pi\sigma R^2T_e^4=L_{in}+\alpha L_{accr},\ \text{where } L_{accr}=0.5\dot{M}V_\infty^2 \qquad (1)$$

In the above expression L_{in} is the luminosity coming to the photosphere from the stellar interior and L_{total} is total luminosity radiated from the photosphere. By taking α=0,5 we assume that half of the free-fall energy released in the shock wave above the stellar surface is absorbed

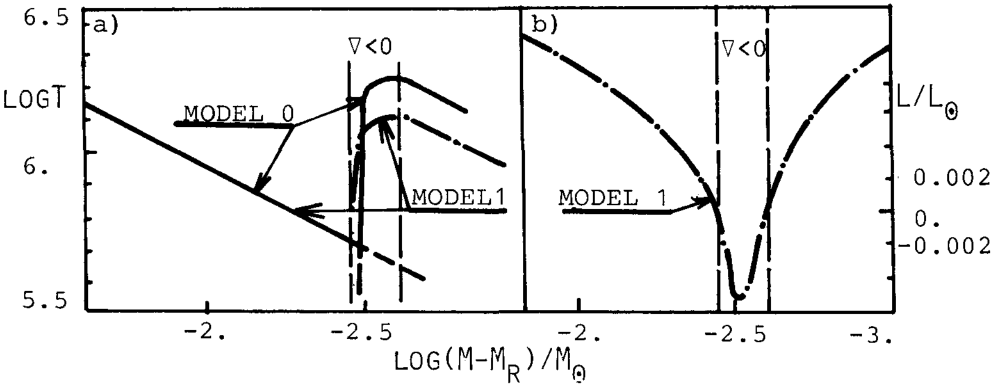

Figure 1. The temperature (a) and the luminosity (b) as functions of mass in the intermediate region between the original convective core and the stationary envelope. The region of temperature inversion (∇< 0) is indicated. See the text for explanation.

by the photosphere. Due to the small size of our computer, we did not try to follow the initial process of the heating of the very outer layers of our star just below the photosphere. However the approximate structure of the outer layers soon after the start of the accretion may be guessed from the following considerations. First, it is reasonable to assume that the entropy of the matter of our original star does not change initially due to large thermal inertia of its convective interior. Second, the structure of the outer layers may be approximated by a stationary solution up to the depth where the local thermal time scale of the envelope $\tau_{th}=GMM_{env}\Delta R/R^2L_{in}$ (where M_{env} is the mass of a newly accreted envelope, ΔR its thickness and M, R and L_{in} are the mass, radius and internal luminosity of our star) is comparable with the accretion time scale defined as $\tau_{accr}=M_{env}/\dot{M}$. For our 0.3 $M_\odot$ star we found that both time scales are comparable for $\dot{M}\sim2\times10^{-8}M_\odot$/yr, which corresponds to $M_{env}\sim3\times10^{-3}M_\odot$. Therefore, our initial model was obtained by a fit of an unperturbed interior of original 0.3 $M_\odot$ star and a thin outer envelope in which the accretion process was approximated by a stationary solution (see MODEL 0 in Fig.1). It is possible to show from analytical considerations that such a fit is

https://doi.org/10.1017/S0252921100105500 Published online by Cambridge University Press

impossible without incorporating a temperature inversion layer as part of the stationary envelope (Sarna and Ziółkowski 1985). The crude structure called MODEL 0 was used as an input for a full Henyey-type program which subsequently produced a consistent model of a convective star accreting matter at a given steady rate (MODEL 1 in Fig.1). This initial model and further evolutionary calculations were made without any assumption about the structure of the star. The only exception was that of a stationary solution for the very thin outer layer of the star. The bottom of this layer was taken at the temperature $T=10^5$ K. Since the mass of this layer was always negligible ($\sim 10^{-5}$ $M_\odot$), the approximation made should not affect the behaviour of the star. We have computed many evolutionary tracks corresponding to the different rates of steady accretion, in the range 2×10^{-8} to max. 5×10^{-6} $M_\odot$ /yr (Sarna and Ziółkowski 1985). For each track the accretion rate was gradually increasing from the initial value ($\sim 2\times10^{-8}$ $M_\odot$ /yr) to a given value and then kept fixed at that value. We found in all our cases that the temperature inversion remained a persistent feature, rather insensitive

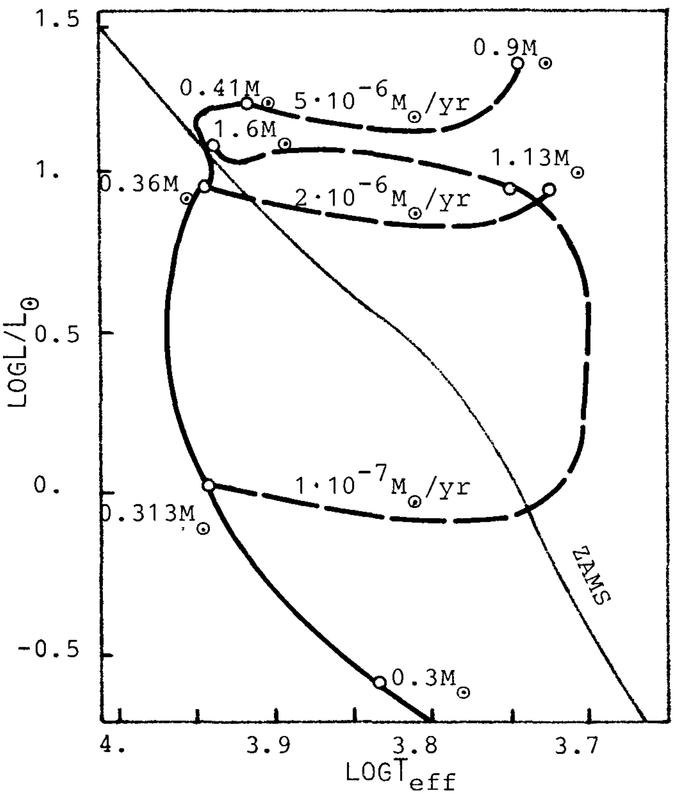

Figure 2. The evolutionary tracks in the H-R diagram for accreting star of initial mass equal 0.3 $M_\odot$. The broken lines correspond to the constant accretion rates and the solid line to the accelerating accretion. The accretion rates and the values of the instantaneous mass of the star are given along the tracks.

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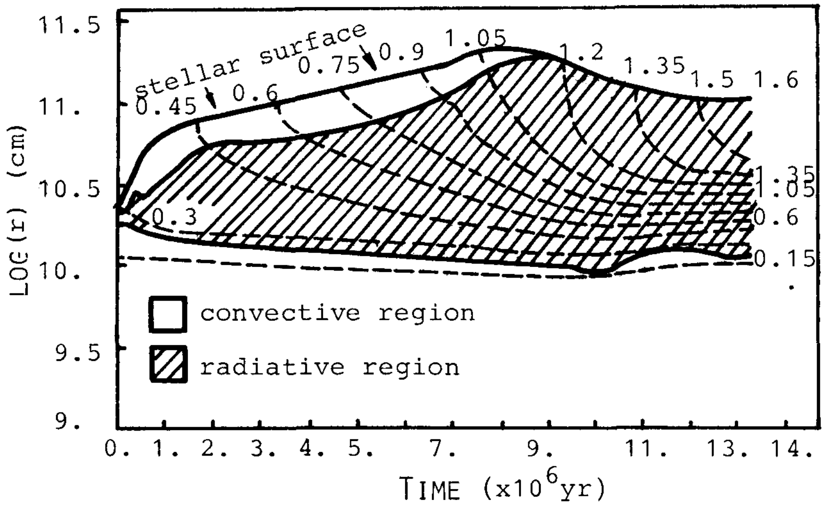

Figure 3. The structural evolution of accreting star with the initial mass equal 0.3 $M_\odot$. Thin broken lines describe the lines of constant mass M_r (the value of M_r is given in solar units).

both to the increasing accretion rate and to the growing accumulation of the accreted material. We found also that almost all material accumulated from the accretion remains in the radiative equilibrium, while the original 0.3 $M_\odot$ convective interior remains practicaly unperturbed. We checked that the evolutionary tracks were not sensitive to the details of our initial "guessed" model. Some results of our calculations are shown in Fig.2 and 3.

The essential result is, of course, that contrary to earlier suggestions, a star with a deep convective envelope may increase its radius very substantially during the accretion process, if the heating of its photosphere is taken into account.

This result may be important for the discusion of the following problems of close binary evolution:

1) formation of the low mass contact binaries (W UMa),
2) final phases of evolution of common envelope binaries,
3) formation of cataclismic variables and related objects like AA Dor or V471 Tau.

Note: After our computations were completed, a paper by Prialnik and Livio (1985) on a similar subject came to our attention. As far as both sets of results could be compared there is a good agreement between them and the essential conclusion is the same in both papers.

REFERENCES

Prialnik,D.,and Livio,M.1985,M.N.R.A.S.,216,37.
Sarna,M.J.,and Ziółkowski,J.1985,(in preparation).
Webbink,R.F.1977a,Ap.J.,211,486.
Webbink,R.F.1977b,Ap.J.,211,881.
Whyte,Ch.A.,and Eggleton,P.P.1985,M.N.R.A.S.,214,357.

https://doi.org/10.1017/S0252921100105500 Published online by Cambridge University Press