RESPONSE OF LOW-MASS MAIN SEQUENCE STARS TO ACCRETION

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I. INTRODUCTION

When the massive component in a close binary system evolves to fill its Roche lobe, mass transfer occurs and gas is accreted onto the companion star. Recently, the response of the unevolved secondary to accretion has been studied by a number of authors, but the emphasis has been on relatively massive stars which have a radiative envelope (Ulrich and Burger 1976; Flannery and Ulrich 1977; Kippenhalm and Meyer-Hofmeister 1977; Neo et al. 1977). The results show that the mass accepting star becomes overluminous and grows in radius until rapid mass transfer ultimately brings the two stars into contact. Such changes in the structure are caused by the steep increase in the specific entropy in the outermost layers and only a small amount of mass (about a tenth of the initial mass of the star) is accreted before contact is made. Thereafter, the expansion of the common envelope will lead to mass loss from the system. It is also found that, for a given accretion rate, the radial increase is much more conspicuous for a smaller mass star. Thus, a characteristic transfer rate which will lead to an increase in radius by, say, a factor of ten is much smaller for a less massive star and becomes as small as $10^{-6}M_{\odot}yr^{-1}$ for a model with an initial mass M_i=$0.75M_{\odot}$, as computed by Neo et al. (1977) assuming a radiative envelope. In such a low mass main sequence star, however, surface convection develops and therefore, response to the accretion is expected to be quite different from that of massive main sequence stars. The evolution of binary systems containing a low mass star is important since such systems may be progenitors of cataclysmic binaries and/or progenitors of Type I supernovae. In this paper, we will focus on the evolution of a low mass main sequence star during accretion.

II. THE DELAY OF EXPANSION OWING TO ENVELOPE CONVECTION

If the specific entropy is assumed to remain unchanged, it is easy to see that the radius of a wholly convective star shrinks as the

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mass M increases in proportion to $M^{-1/3}$. Even when an accreting star possesses a radiative zone below its convective envelope, such a radial shrinkage takes place, provided that the surface convective zone is very deep. This situation was encountered by Webbink (1977) in his study of a binary system containing an accreting star of $M_i=0.5M_\odot$. However, because of the radiative zone, the increase in the stellar mass causes a rise in the specific entropy during the course of evolution which leads to a gradual decrease in the size of the convective zone, and ultimately to its disappearence. In our study, we take as an initial model a zero age main sequence star of mass $M_i=0.75M_\odot$, with a surface convective zone of mass $M_{con}=0.039M_\odot$. The accreted material is assumed to fall at a constant rate softly onto the surface with the same entropy as that in the photosphere. The evolution during accretion is computed for three different accretion rates $dM/dt=3\times10^{-7}$, 10^{-6} and $3\times10^{-6}M_\odot yr^{-1}$, respectively.

The resultant time variations in the surface luminosity L and in the surface radius R are plotted in Figure 1 against the current mass of the star. During the first phase of accretion, the star remains less luminous than a zero age main sequence star of mass equal to the instantaneous mass M of the accreting star and the radius expands very slowly. The depression of L and R lasts until surface convection disappears, as denoted by a dot on each curve in Figure 1. Before this occurs, an appreciable mass has been accreted; since the duration

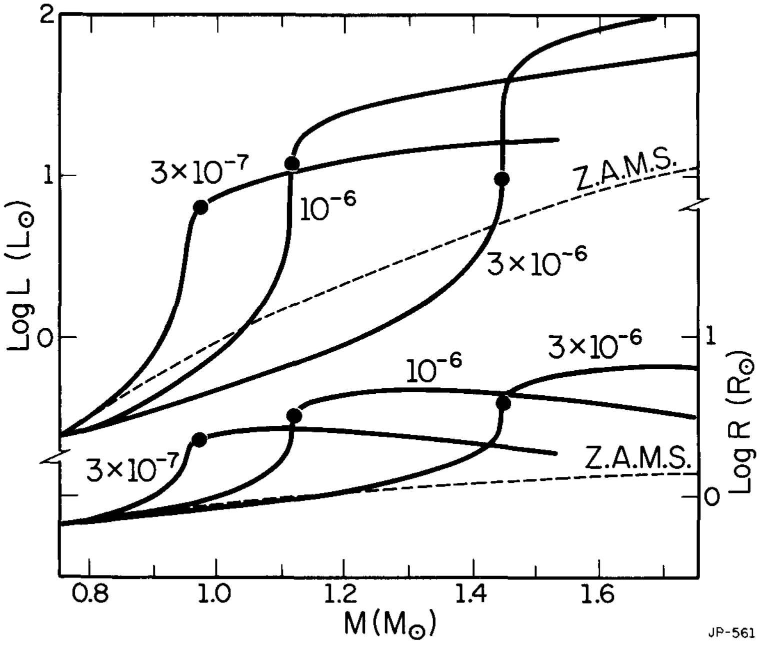

Fig. 1 Variations of the surface luminosity L and radius R during accretion (accretion rates are denoted in units of $M_\odot yr^{-1}$).

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of this phase is about several times 10^5 years and depends only slightly on the accretion rates, the magnitude of this addition is larger for larger accretion rates. The role of convection is as follows: In the convective zone, the compression of material due to accretion no longer releases heat, and yet the convective zone absorbs almost all of the heat liberated by the release of gravitational energy in the radiative zone below it. Therefore, the effect of a rise in the specific entropy in the convective zone takes precedence over the increase in surface luminosity that occurs in the case of a purely radiative envelope, and concomitantly, the convective zone retreats to the surface and eventually dies away. The process takes time comparable to the timescale for heat diffusion in the underlying radiative zone which is about 2×10^5 years. As convection disappears in surface layers, there is a sudden increase in the luminosity and in the radius. However, the extent of this expansion is not so large, since, as a consequence of the increase in mass, the characteristic accretion rate necessary for significant expansion becomes large. In our case of the highest accretion rate, the radius reaches a maximum of only $R=6.68R_\odot$, after which the star begins to contract and returns to the main sequence.

III. DISCUSSION

A low mass main sequence star passes through a brief phase of underluminosity and sub-radius after the onset of accretion. However, because of the short timescale for this phase, there is little possibility for it to be observed. For the accretion rate range that has been discussed here, the accreting star grows in mass without making contact with the companion star. Cataclysmic binaries usually contain a low mass red dwarf, although the white dwarf component may be formed as a result of mass transfer. If Type I supernova explosions in elliptical galaxies are triggered in accreting white dwarfs, their companion star should be less massive than a solar mass. Therefore, such systems are presumably not to be formed through mass transfer at a rate within this range. When the infalling flow is optically thick for a still higher accretion rate, however, the effect of dissipated gravitational energy at the surface will be important (this has been neglected in our computations). In this case, the entropy of the photosphere will grow large and possibly lead to a great expansion before an appreciable mass is accreted. Further investigation including this effect is necessary.

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