W UMa STARS AND ANGULAR MOMENTUM LOSS

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The structure and evolution of W UMa stars is still unsolved although considerable progress has been achieved in recent years. Most theoretical studies are based on the common convective envelope model by Lucy (1968a,b), which almost satisfactorily explains the nearly equal minima of the light curves. All A-type (Wilson, 1978) and some W-type systems (Whelan et al., 1979) may contain an evolved primary. In this case stable models exist (Hazlehurst, 1970; Moss and Whelan, 1970). Computations performed for the subsequent evolution (Moss, 1971; Hazlehurst and Meyer-Hofmeister, 1973; Rahunen and Vilhu, 1977) show nuclear time scale evolution towards more extreme mass ratio, supplemented by possible thermal time scale oscillations.

Many (or most) W-type systems are, however, thought to be unevolved. They have been found in young galactic clusters (Van't Veer, 1975), and usually the system TX Cnc, which is 4 magnitudes below the turn-off point in Praesepe's main sequence, is cited as an unevolved system. However, it is not easy to construct zero-age contact systems in thermal equilibrium without departing significantly from normal abundances or reaction rates (Lucy, 1968a; Whelan, 1972a,b), or without allowing entropy differences between the components (Biermann and Thomas, 1972 and 1973; Vilhu, 1973). Models with entropy differences have been shown (Hazlehurst, 1974) to be secularly unstable, but after the suggestion of the contact discontinuity model (Shu, Lubow and Anderson, 1976; Lubow and Shu, 1977; Shu, 1979) discussion on this interesting possibility continues. This could be noticed also at this symposium. The evolution of the contact discontinuity and the unequal entropy model is probably the same, and this may give the possibility to the scenario W UMa → CV (Vilhu, 1974).

Departing significantly from thermal equilibrium and allowing the mass transfer to be the dominating mechanism, zero-age models with equal entropies can be constructed (Lucy, 1976; Flannery, 1976; Rahunen and Vilhu, 1977; Robertson and Eggleton, 1977). Such models lead in thermal time scale ($\sim 10^7$ y) to break of contact when the inner critical surface is reached. Following Rucinski's idea (1973, 1974), Lucy (1976) and Robertson and Eggleton (1977) suggested that

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after the break of contact the system evolves in reversed direction back into contact and that this continues in a cyclic manner. So far it is not clear how long this process can continue. Without any net mass transfer from the secondary to the primary, the system should rapidly evolve towards unequal entropies (or contact discontinuity). Of course, beside the mass transfer there may be some other mechanism supporting the oscillations.

The break of contact can be avoided if the angular momentum is allowed to decrease. This possibility was discussed already by Robertson and Eggleton. With angular momentum loss the separation between the components decreases, and both stars can more easily fill their Roche lobes. On rather general arguments Struve (1950), Webbink (1976) and Van't Veer (1979) present scenarios where a W UMa star evolves into a single main sequence star. Webbink and Van't Veer find that 70-80 % of the angular momentum should be lost during the process, and Struve thinks that the rest of angular momentum leads to the formation of a planetary system (the solar system has about 10 % of the angular momentum of a typical W UMa star).

According to Van't Veer, solar type magnetic flare activity is the main reason for this angular momentum loss. Great amounts of angular momentum can be lost without significantly changing the total mass of the system. We can speculate that the flare activity increases when the contact becomes shallower and shallower. This would accelerate the angular momentum loss which in turn increases the degree of contact. Then the flare activity diminishes and the whole process will start again. In this way it is possible that a mechanism exists which keeps the system in contact with a suitable loss of angular momentum. The rapid period changes observed can be identified with such an activity, and the extremely strong coronas found by IUE (Dupree, 1979) may also tell about this.

The aim of the present work is, preserving the contact conditions ($\Delta C = \Delta S = 0$) to find out whether it really is possible to obtain more extreme mass ratios, what is the angular momentum loss needed and what is the time scale (The system B from Rahunen and Vilhu, 1977 and total mass = 1.8 $M_\odot$ are used). Preliminary results show that rather extreme mass ratios (at present as far as 0.3) can indeed be reached in a time scale of 10^8 y. The rate of angular momentum loss needed to keep the system in contact was about 10^{43} g cm^2 s^{-1} per year, leading to 20 % loss of the total angular momentum during the process. This loss rate lies well within the general tendency of decreasing angular momentum loss with increasing age, as deduced by Van't Veer (1979) with the help of T Tauri-stars, Pleiades and Hyades dwarfs, and the sun.

We can only speculate what happens when a rather extreme mass ratio has been reached. Because the secondary becomes too radiative (the internal luminosity of the secondary tends to zero with decreasing mass) the contact conditions can no longer be satisfied. This, probably, can be avoided by assuming that a small part of the luminosity transfer takes place below the convective envelope. For extreme mass ratios the concept of a common convective envelope also seems artificial. It is expected that after some critical limit the system catastrophically coalesces into one single star.

Finally, it is interesting to note (following Struve and Van't Veer) that, if a considerable part of all W UMa stars follows the above scenario, then the W UMa state should be a normal state in the life of any solar type dwarf (the ratios of space densities and of life times of G dwarfs and W UMa stars would both be equal to 100). Anyhow, the angular momentum loss should be considered as a serious possibility in addition to the current problems connected with the cyclic and contact discontinuity models.

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COMMENT FOLLOWING VILHU AND RAHUNEN

Sugimoto: How much mass has been transferred from the secondary to the primary before the breakdown of the conservative mass transfer? If it has been an appreciable fraction of the stellar mass, what is the effect of your approximation of the luminosity jump ΔL which was used instead of computing the hydrodynamic flow of specific entropy?

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