DO BLUE STRAGGLERS FORM BY COMMON ENVELOPE EVOLUTION?

F. Meyer and E. Meyer-Hofmeister
Max-Planck-Institut für Physik und Astrophysik,
München, FRG.

COALESCENCE OF CLOSE BINARIES

All proposals to explain the formation of blue stragglers advanced up to now seem to have inherent difficulties. One appealing possibility, the formation by coalescence of close binary stars, appears to be ruled out by the existence of blue stragglers with more than twice the turn-off mass of their cluster. We suggest that this contradiction does not exist, since the binary system on its way to coalescence passes through a phase in which a very extended common envelope with a size of several hundred solar radii forms. In this stage a third companion in the range of this envelope will be captured and finally merge to form a blue straggler that can have more than twice the turn-off mass.

COMMON ENVELOPE EVOLUTION

The processes leading to coalescence of two stars are complicated. Rapid mass transfer in a close binary system where the primary is still in the stage of core hydrogen burning ("case A") induces the secondary to expand until a common envelope around the two stars is formed. It seems plausible that corotation cannot be maintained in the envelope. The tidal interaction between common envelope and interior binary core produces so much frictional heat that the common envelope expands until it reaches an equilibrium "red-giant stage". In this equilibrium the density in the envelope has decreased to such a low value that the generation of frictional heat is just limited to the amount needed to support the envelope. Due to the low pressure in the envelope it is possible that all unprocessed material of the primary will flow into this common envelope and only the He-enriched core remains together with the secondary as the inner binary system. This inner binary shrinks by frictional transfer of angular momentum to the extended envelope. A model for common envelope evolution is developed in Meyer and Meyer-Hofmeister (1979).

M. J. Plavec, D. M. Popper and R. K. Ulrich (eds.), Close Binary Stars: Observations and Interpretation, 145–148.

As an example we have chosen a system with $M_1 = 1.6\ M_\odot$ and $M_2 = 1\ M_\odot$, an initial distance $a_o = 5\ R_\odot$ and a period of $P_o = 0.8^d$. After about $1.3\ 10^9$ years the primary fills its critical Roche lobe and initiates rapid mass transfer. Assuming that synchronism is lost the common envelope formed will expand due to the frictional heat generated. Our computations (chemical composition (X = 0.7, Z = 0.0004) for the common envelope stage show that during this evolution luminosity and radius stay at almost constant high value, $\log L/L_\odot = 4.8$, $R/R_\odot = 570$. Comparison with computations for a population I mixture show that the chemical composition does not essentially influence this result. After a time of about 100 yrs the distance of the inner binary has shrunk that much that the secondary fills its critical Roche lobe initiating the final merging of the stars, possibly via a second mass transfer process. In any case only a finite amount of potential gravitational energy is available due to the finite extent of the internal cores, and this will be exhausted by the high frictional luminosity of the common envelope on a timescale comparable to the shrinkage time of a hundred years. As the interior mass distribution approaches a rotational symmetric configuration the frictional heat generation switches off and the matter in the extended envelope settles on the core. For some time this may keep up the high luminosity. Finally it will relax to a configuration where the He-enriched core of the former primary is surrounded by the rest of the mass.

ANGULAR MOMENTUM

During the common envelope evolution most of the angular momentum was in the outer extended region. This will remain so as the mass in the envelope settles gradually down towards the core while the envelope itself stays fairly extended, since convective "viscous" friction will tend to achieve corotation. This means that most of the mass in the envelope settles down at very low rotational speed. The small remaining fraction containing most of the angular momentum cannot settle in this way and will form a disk as the luminosity decreases. Disk evolution brings down most of this fraction with Keplerian velocity while the angular momentum is removed together with less and less mass towards infinity. We therefore expect a relatively slowly rotating blue straggler that might contain a rapidly rotating core depending on whether or not magnetic or other forms of coupling play a role.

CAPTURE OF A THIRD STAR

During the stage of the extended common envelope any companion directly caught will spiral down in the way discussed in Meyer and Meyer-Hofmeister (1979). This process occurs on a timescale which is at first short compared with the shrinking time of the interior binary. The additional frictional luminosity helps to keep up the extended envelope and will lead to a slight reduction of the interior luminosity and to a reduced shrinking rate in the core. Finally the mass of the three originally separated stars will form one blue straggler. Masses above twice the turn-off mass are indicated for a few observed blue stragglers. In Wheeler's (1979) compilation there are 4 cases out of about 100 blue stragglers.

Besides direct capture the mechanism of tidal interaction between a more distinct companion and the slowly rotating extended envelope can degrade the orbit of a companion so much that it enters the envelope. In this way all those companions are captured for which the tidal interaction time is shorter than the lifetime of a few hundred years for the common envelope stage. Applying a rough formula for the tidal interaction one finds that stars within about twice the radius of the envelope should be captured.

The observations of progenitor systems with a third companion require high resolution spectroscopy. Recently Fekel (1979) employing a solid state spectroscopy technique found a system consisting of G0 dwarf + M0 dwarf binary with a period of $0\overset{d}{.}88$, orbited by a G5 dwarf in highly eliptic orbit with a period of 20 years.

EXOTICA

(a) Wheeler has pointed out that one blue straggler in Hagen's (1970) catalogue in NGC 6940 appears to have a mass about 3.9 times the turn-off mass of the cluster. Masses up to 4 times the turn-off mass could come about if the companion captured is itself a close binary system. Though the incidence of such quadrupole systems is quite high with stellar systems of larger extent (Abt and Levy, 1976) little is known about the occurrence of such systems within separations of a few astronomical units.

(b) Could the occurrence of a blue straggler in a close binary system be understood in a common envelope evolution model? Such a result must occasionally occur when the timescale for capture of a third companion becomes sufficiently large. Though the companion might still enter the common envelope and at first rapidly reduce its separation from the binary core its shrinking time increases about inversely proportional to the separation. If during this time the interior system already coalesces and the interior frictional luminosity is switched off the mass of the envelope might settle while the companion star is still orbiting at some distance and leave a system in which a blue straggler is orbited by the original companion, but at a much decreased separation.

CONCLUSION

The model of an extended common envelope evolution can resolve apparent contradictions in the suggestion that blue stragglers are the result of stellar coalescence. The structure of such common envelopes is relatively well understood, whereas a better quantitative understanding of the processes occurring during the first phase of contact and rapid mass transfer are needed to decide under what circumstances synchronism of a not yet extended common envelope is maintained or lost and the phase of extended envelope supported by frictional heat is initiated.

REFERENCES

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Fekel F., 1980, IAU Symp. No. 88, 53.
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COMMENTS FOLLOWING MEYER AND MEYER-HOFMEISTER

Shaviv: How were the masses of the blue stragglers obtained? Did you assume the blue stragglers to be normal MS stars with normal evolution?

Meyer-Hofmeister: I took the distribution of blue straggler masses from a paper of Craig Wheeler (to appear in Ap. J.)

Shu: I would like to emphasize the distinction between your kind of common envelope binaries and ours. We assume synchronism whereas nonsynchronous motion of the cores through the common envelope is crucial to your model. I have no doubt that there is a regime of parameter space where synchronism cannot be maintained, and your type of model is more appropriate. However, I would hate to think that all close binaries evolve to coalesce into single stars shortly after leaving the main sequence since then we would be in danger of having no interesting close binaries to study like Algols, cataclysmic variables, etc.

Meyer-Hofmeister: I think it is important to note that rapid case A mass transfers as is needed for this kind of common envelope evolution only happens for very close systems. I quite agree that there is a wide range of parameters (for example case B mass transfer) where synchronous evolution could occur.