PROGRESS OF COMMON ENVELOPE EVOLUTION

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ABSTRACT. The current understanding of the common envelope binary phase of evolution is presented. The results obtained from the detailed computations of the hydrodynamical evolution of this phase demonstrate that the deposition of energy by the double core via frictional processes is sufficiently rapid to drive a mass outflow, primarily in the equatorial plane of the binary system. Specifically, recent calculations suggest that large amounts of mass and angular momentum can be lost from the binary system in a such a phase. Since the time scale for mass loss at the final phase of evolution is much shorter than the orbital decay time scale of the companion, the tranformation of binary systems from long orbital periods (> month) to short orbital periods (< day) is likely. The energy efficiency factor for the process is estimated to lie in the range between 0.3 and 0.6.

1. INTRODUCTION

From the existence of short period binary systems containing a compact object one can infer that there were prior evolutionary phases where mass and angular momentum were lost. Examples of such systems are cataclysmic variable binaries (with orbital periods, P, ranging from 2 to 14 hours), binary nuclei of planetary nebulae (with periods ranging from 2.3 to 16 hours), binary X-ray sources (the most extreme example of which is 4U 1820-30 with an orbital period of 11.08 min.; Stella, Priedhorsky, and White 1987), and binary radio pulsars (PSR 1913+16, P = 7.7 hours; PSR 0655+64, P = 1.03 days). The fundamental difficulty in forming such systems is clear when it is recognized that the progenitors of the compact components must have had a radius much larger than the present day orbital separation of these systems. A possible resolution to this difficulty involves the relaxation of the assumption of corotation between the spin and orbital motion (see, for example, Paczynski 1976). The lack of corotation results in processes which can lead to the ejection of substantial amounts of mass and angular momentum via a common envelope or double core stage. For an overview of this evolutionary phase and for references to previous work see the papers by Bodenheimer and Taam (1986) and Taam (1988).

D. McNally (ed.), Highlights of Astronomy, Vol. 8, 155–159.
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https://doi.org/10.1017/S1539299600007681 Published online by Cambridge University Press

A binary system can enter into the common envelope stage by a variety of evolutionary paths. For example, consider a binary system with a red giant companion for which the mass transfer process is unstable. Since matter can be transferred from the red giant to its companion on a time scale much shorter than the thermal time scale of the red giant (see Paczynski and Sienkiewicz 1972), the mass accreting companion will likely expand to fill its own Roche lobe after only a small amount of mass (~ 0.01 $M_\odot$) is accreted. It is likely that the rotation of the giant loses synchronism with the orbital motion because the time scale to achieve solid body rotation is longer than this rapid evolutionary phase. Evolution to the common envelope stage can also result if, at the onset of mass transfer, the red giant is not rotating synchronously with the orbital motion (Counselman 1973). For this case, corotation between spin and orbital motion is lost when the ratio of the spin moment of inertia of the giant is greater than 1/3 the moment of inertia of the binary. This circumstance occurs when the mass ratio of the binary system exceeds about 5 since there is insufficient angular momentum available in the orbit to achieve synchronism. Another evolutionary path to the common envelope stage involves the physical collision of two stars, a possible aftermath of a tidal encounter in a globular cluster stellar system (Verbunt 1987).

2. RESULTS

The detailed hydrodynamical calculations of the common envelope phase have been largely exploratory in nature since the hydrodynamic and thermodynamic processes occur over a wide range of time scales and length scales. Although the complexities of the intrinsic problem hamper rapid progress, a few results can be given based upon general considerations. Specifically, if the entire common envelope is to be ejected before the companion reaches the boundary of the red giant core, then the following conditions must be satisfied (see Taam, Bodenheimer, and Ostriker 1978; Taam 1984): (1) there must be sufficient energy released from the orbit to unbind the envelope, (2) the energy lost from the orbit is directly transferred to the hydrodynamic mode; that is, the time scale for ejection must be shorter than the time scale for the removal of energy by transport mechanisms, and (3) the ejection must be rapid with respect to the orbital decay time scale.

Some recent work describing the mass ejection phase has been reported by Livio and Soker (1988) in the three dimensional approximation and by Taam and Bodenheimer (1989) in the two dimensional approximation. Although the mass ejection process must be described in three dimensions during the early evolutionary stages of the orbital decay (see Livio and Soker 1988), it can be adequately modeled in two dimensions during the later stages (see Bodenheimer and Taam 1984; Taam and Bodenheimer 1989).

The interaction between the star and the envelope of the giant can be described in terms of a Hoyle and Lyttleton (1939) and Bondi and Hoyle (1944) type accretion picture. Within this framework, the kinetic energy of the relative motion between the secondary and common envelope is converted into thermal energy in a shock and a gravitational drag is

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exerted on the secondary forcing the orbit to decay. Because this energy is deposited at such a rapid rate (greater than 10^7 $L_{\odot}$) the energy is not transported efficiently toward the stellar surface by radiative diffusion or by convection, but, instead, is converted into kinetic energy of motion. However, the mass is not ejected uniformly over a spherical volume, but is concentrated to the equatorial plane over a half angle of about 13 degrees (Taam and Bodenheimer 1989). Such an outflow geometry is favored due to the presence of steeper density gradients in that direction. Although the angular momentum lost from the binary orbit is redistributed in the radial direction by the matter outflow leading to only a slight spin up of the common envelope near the vicinity of the secondary, most of this angular momentum is carried out of the system by the ejected matter. Toward the final phase of the hydrodynamical evolution ($P <$ day) the mass outflow is so severe that the density in the vicinity of the companion has declined sufficiently that the drag luminosity drops and, consequently, the orbital decay time scale increases rapidly. At this point the spiral in time scale is more than an order of magnitude longer than the mass loss time scale and more than 75% of the mass of the common envelope has been ejected. If we can extrapolate the results of Taam and Bodenheimer (1989), it appears likely that the entire envelope will be ejected and that the spiral in process will stop.

The general results that can be gleaned from these calculations can be summarized as follows. Multi-dimensional effects are important in the evolution leading to the preferential ejection of matter along the equatorial plane within a greater half angle for larger energy input rates. In addition, the mass ejection process is nearly adiabatic since the time scale on which energy is deposited into the common envelope is much shorter than the energy transport time scale by either radiation or convection. Thus, most of the orbital energy is converted into the kinetic and potential energy of the outflowing matter. However, the energy is not distributed uniformly over the common envelope, but rather in the equatorial plane with the matter accelerated to greater than the escape speed. Thus, the conversion of orbital energy to mass loss is only moderately efficient (~ 30% to 60%).

3. CONCLUSIONS

Within the framework of the double core hypothesis, it has been found that the ejection of the entire common envelope is very likely. The transformation of long period binary systems to short period systems via this evolutionary stage is, thus, confirmed. However, our studies do not predict the relationship between the final orbital period for which the system emerges from the common envelope phase and the initial period just prior to the spiral in process. It is quite possible that this aspect of the problem will depend upon the detailed response of the nuclear burning shells of the red giant to the degree and efficiency of material circulations induced in the inner regions. For example, if hydrogen rich matter is mixed into the helium burning region and carbon nuclei from the helium rich region is mixed into the hydrogen burning shell, the energy generation rates in the nuclear burning shells may be

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enhanced to the extent that the nuclear energy release may significantly aid in the ejection of matter during the terminal stage. On the other hand, if the circulations do not mix combustible fuels into the burning regions, then the extensive mass loss will eventually cause the nuclear burning to be extinguished. In either case, once the mass above the white dwarf core is reduced below some critical value (< 0.001 - 0.01 $M_{\odot}$ the radius of the primary remnant will shrink (in order to maintain hydrostatic equilibrium) and the common envelope phase will terminate.

A second major area of study requiring attention involves the response of the secondary to the conditions within the red giant envelope. Webbink (1988) has inferred from the observations of the cool components of planetary nebulae binary nuclei that the secondary may emerge from the common envelope evolution relatively undisturbed. This suggests that the secondary component accretes or loses very little mass. Along the same lines, the investigation by Kato (1982) indicates that it is likely that there are phases in the evolution where either accretion or evaporation are possible. Clearly, future work in these areas will help clarify our understanding of this important phase of binary evolution.

This research has been supported in part by NSF under grant AST-8608291

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