CASE A EVOLUTION OF MASSIVE CLOSE BINARY SYSTEMS

III. Evolution in and after the Phase of Mode Br Mass-Transfer

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(Received 7 January, 1987)

Abstract. The evolution of three close binary systems of total mass 20.4 $M_\odot$ in and after the phase of mode Br mass-transfer in case A of mass exchange is investigated. In every case a secondary component evolves to interfere with the progress of primary's evolution and the system overflows the outer critical surface before the primary completes its nuclear-burning evolution. This strongly indicates the importance of simultaneous calculation of both components. A summary of evolution of the systems considered in this series of papers up to the stage of $L_2$-overflow is given. The observational aspects of the numerical models are also discussed.

1. Introduction

In the preceding papers of the series (Nakamura and Nakamura, 1984, 1987; hereafter referred to as Papers I and II, respectively), we investigated the case A evolution of twelve close binary systems with total mass 20.4 $M_\odot$ which differ from each other in the initial mass ratio and/or angular momentum. And we found that the evolution of the systems can be classified into seven types as far as early phases of evolution are concerned. In five types out of the seven, a system overflows the outer critical surface when both components are still undergoing central hydrogen burning. On the other hand, in the remaining two types, 1C1Br and 1Nc1Br according to the notation in Paper I, slow phase of mass transfer after mass-ratio reversal comes to an end by the hydrogen exhaustion in the core of the primary component (we always refer to an initially more massive component as the primary). Then the primary detaches from its inner critical surface and makes gravitational contraction. After the completion of switching of energy-generation mode over to hydrogen shell burning, the primary fills its critical lobe again and mass transfer resumes. We shall call the mass transfer which starts at this stage as mode Br mass-transfer according to the notation in Paper I, while it has usually been referred to as case $AB$ mass-transfer.

The evolution in case $AB$ of mass exchange has been studied by several workers (Ziolkowski, 1970; Horn, 1971; Tutukov et al., 1973; Kraitcheva, 1978; etc.). They studied, however, only the evolution of a primary and the effect of its companion was not properly taken into account. According to the results of such studies, the evolution

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in case AB proceeds in a way similar to that in case B. In the latter case of mass exchange a system evolves as follows. After a primary fills its critical lobe, there first comes rapid phase of mass transfer and then slow phase follows. In the slow phase, as the helium core grows, the primary filling its critical lobe expands and its outer layer is stripped off gradually. This phase ends in either of the following two ways. If the primary is so massive that helium burning occurs at the center, the primary begins to contract shortly after a helium ignition and evolves toward the helium Main Sequence in the H–R diagram. But, if the primary is not so massive, it stops filling its critical lobe and begins to contract to a helium white dwarf when the envelope becomes extremely thin and the shell hydrogen burning extincts. In the case AB mass-exchange, however, as the above authors state in their papers, in reality, before the primary reaches these stages, the secondary will consume hydrogen in the core to increase in its radius and fill the critical lobe and a contact system will be formed.

The essential difference between the evolution of case B and that of case AB is in that in the latter case there is enough time for a secondary to evolve before the primary completes its evolution. Two factors contribute to this. (i) At the beginning of slow phase of first mass transfer, mass ratio is reversed to a smaller value than the initial one, then the evolution of the primary is decelerated while that of the secondary is accelerated. And so the evolution of the secondary has already fairly proceeded by the time of onset of mode Br mass-transfer. (ii) The evolution of the primary proceeds more slowly in case AB than in case B, because the primary’s mass at the onset of mode Br mass-transfer is much smaller in the former case for systems with the same total mass and initial mass ratio. This is, of course, due to the preceding mode A mass-transfer in case AB evolution. Therefore, it is essential to understand case AB evolution to follow the evolution of both components simultaneously.

The examples of case AB evolution in which simultaneous evolution is computed are Webbink (1976) for low-mass binaries and Sybesma (1985, 1986) for massive binary systems. In both cases conservative evolution is assumed (apart from stellar wind-type mass loss). Webbink (1976) continued evolutionary calculations even after a system overflows the outer critical lobe. Sybesma (1985) stopped calculations when a primary moves towards the helium Main Sequence (he stated that at this point the primary becomes a Wolf–Rayet star). He also calculated case A of mass exchange of five massive close binary systems (Sybesma, 1986). Of these two systems evolve up to the stage of mode B of mass transfer. He stopped the calculation when helium is ignited in the core of primary. In this paper we follow the further evolution of systems of types 1C1Br and 1Nc1Br in Paper I, and investigate the evolution of close binary system in and after the phase of mode Br mass-transfer of case A evolution. And also the summary of evolution of the systems considered in this series is presented.

2. Model Parameters and Assumptions

The systems calculated in this paper are systems II, V, and VI of Paper I. The initial parameters of the models are as follows: