# Some aspects of evolution and mass transfer in X-ray binaries

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## Introduction and Summary

The progenitor of the compact object (usually a neutron star) in a massive X-ray binary is generally thought to have been a helium star (van den Heuvel and Heise 1972; Sutantyo 1973). This helium star in its turn was the core of the initially more massive component of the binary, left after this star had transferred its hydrogen-rich envelope to its companion during a first stage of Roche-lobe overflow (cf. De Loore and De Greve 1975). The helium star then evolved rapidly towards its final configuration, while its companion remained still relatively unevolved. The final configuration of the helium star depends crtitically on its mass. If the star finally becomes less massive than the Chandrasekhar limiting mass ($\sim 1.4\ M_{\odot}$) it will certainly end as a white dwarf - a configuration which is supported against its own gravity by the pressure of a (not extremely relativistic) degenerate electron gas. Helium stars that finally terminate with a mass larger than the Chandrasekhar limit will go through a supernova event; their cores collapse to neutron stars or black holes. Such a supernova event is thought to be essential for the formation of binary X-ray sources.

Chapter I is devoted to the evolution of helium stars of different masses. If the helium star goes through a stage of intensive envelope expansion, a second stage of Roche-lobe overflow will occur. This is important since the resulting mass transfer could bring the mass of the helium star below the Chandrasekhar limit - thus preventing the formation of an X-ray binary. Since the envelope expansion depends critically on the mass of the contracting helium exhausted carbon-oxygen core, it appeared necessary to develop a physically self-consistent method for the determination of the boundary of an (expanding) helium burning convective core. Such methods did not exist, causing a considerable uncertainty regarding to the extent of the resulting carbon-oxygen cores. The result of these evolutionary calculations is that helium stars with a mass of about 2 $M_{\odot}$ appear to develop carbon-oxygen cores of approximately 1 $M_{\odot}$. This is the limiting mass for non-degenerate ignition of carbon; stars with less massive cores continue their core contraction without the ignition of carbon at the center. This continued core contraction is accompanied by an extensive expansion of the outer layers and will result in further mass transfer. It is likely that the helium star will lose nearly its complete helium-rich envelope during this second stage of Roche-lobe overflow, so that the remnant will be a white dwarf of about

1 $M_{\odot}$. Hence, the limiting mass for which the helium star goes through a supernova stage will be somewhat greater than 2 $M_{\odot}$. In order to study the subsequent evolutionary stages of helium stars, it was necessary to revise much of the physics built in the evolutionary code. Also the effects of mass loss by a strong stellar wind had to be taken into account. The results of this work will be published in a separate paper.

The results of detailed evolutionary calculations of the stage of beginning Roche-lobe overflow towards the collapsed relativistic star (i.e., the stage during which the system is observable as an X-ray binary) are presented in chapter II. It is shown that, contrary to current opinions, the bright massive X-ray binaries may well be powered by mass transfer due to Roche-lobe overflow, instead of by a strong stellar wind. It is highly probable that the rapid X-ray pulsators (P < 10 sec) Her X-1 and Cen X-3 are spinning on the average at their equilibrium rates (cf. Henry and Schreier 1977). In that case it is possible to predict the pulsar spin-up rates from the results of the Roche-lobe overflow calculations presented in chapter II. It is found that the thus obtained spin-up rates of the accreting neutron stars are in good agreement with the observed decrease of the X-ray pulse period of these two sources. This seems to be a strong argument in favour of the occurrence of Roche-lobe overflow in these two binaries.

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In chapter III it is shown that the tidal forces on a rapidly rotating presupernova helium star component of a massive close binary cannot synchronize the rotation of this star with its orbital motion during its lifetime. Hence, the pulsars in these systems are expected to be born in rapid rotation, just like single pulsars. Pulsars are believed to spin down due to emission of magnetic dipole radiation (Ostriker and Gunn 1969). However, pulsars situated in close binary systems can be spun down much more efficiently in the weak stellar winds from their main sequence companions. In this case the electromagnetic interaction of the infalling stellar wind plasma with the pulsar magnetosphere (Kundt 1976) can explain the existence of the so-called slow X-ray pulsators, with pulse periods in the range of $10^2$ - $10^3$ seconds. Afterwards these slow X-ray pulsators may again spin-up rapidly to pulse periods near 1 sec if their companions exceed their Roche lobes.

Chapter IV is a review article describing recent progress in the field of X-ray binary evolution.