Black Holes from Stars to Galaxies – Across the Range of Masses
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Evolution of black-hole intermediate-mass X-ray binaries

Wen-Cong Chen and Xiang-Dong Li

Department of Astronomy, Nanjing University, Nanjing 210093, China
email: chenwc@nju.edu.cn, lixd@nju.edu.cn

Abstract. We propose a plausible mechanism for orbital angular momentum loss in black-hole intermediate-mass X-ray binaries, assuming that a small fraction of the transferred mass form a circumbinary disc. The disc can effectively drain orbital angular momentum from the binary, leading to the formation of compact black-hole low-mass X-ray binaries. This scenario also suggests the possible existence of luminous, persistent black hole low-mass X-ray binaries.

Keywords. Black holes – X-ray binaries – circumstellar matter

1. Introduction

There are currently nine compact black hole low-mass X-ray binaries (BHLMXBs). Their short orbital periods ($\leqslant$ 0.5 d) imply that they must have undergone secular orbital angular momentum loss. If their progenitor systems contain a low-mass secondary initially, it is not clear whether the secondary star has enough energy to eject the envelope of the black hole progenitor during the common envelope evolution phase. Justham, Rappaport & Podsiadlowski (2006) suggested that part of black hole intermediate-mass X-ray binaries (BHIMXBs) may evolve to compact BHLMXBs via magnetic braking. Here we explore an alternative possibility. We suggest that a fraction δ of the transferred matter may form a circumbinary (CB) disc, which can drive BHIMXBs to short period BHLMXBs.

2. Results

We have calculated the evolution of BHIMXBs consisting of an intermediate-mass donor star and a black hole (of mass $10M_{\odot}$). Neglecting the magnetic braking mechanism, we take into account three types of angular momentum loss from the binary system, i.e., gravitational wave radiation, isotropic winds from the donor star, and the tidal torque by the CB disc. Detail description of the model can be found in Chen & Li (2006).

Figure 1 shows the examples of the evolutionary sequence with an initial orbital period of 1 d. The solid and dotted lines correspond to two different values of δ. As can seen in the figure, mass transfer is initially driven by nuclear evolution of the secondary, leading to expansion of the orbits. But this tendency is held up when angular momentum loss via the CB disc becomes sufficiently strong. The mass transfer drops into a "plateau" phase at a rate $\sim 10^{-9}M_{\odot}\mathrm{yr}^{-1}$ for a few 10^8 yr. These features are different from those in Podsiadlowski, Rappaport & Han (2003), in which the orbits always increase secularly. After that the mass transfer rates increase sharply as the secondary ascends the giant branch, but the final orbital evolution depends on the adopted value of δ. With the higher value of δ, a compact BHLMXB will be finally produced after a few 10^8 yr mass transfer.

In Fig. 1 the thick and thin curves correspond to stable and unstable mass transfer during the evolution of BHXBs. It is interesting to see that the model BHLMXBs are

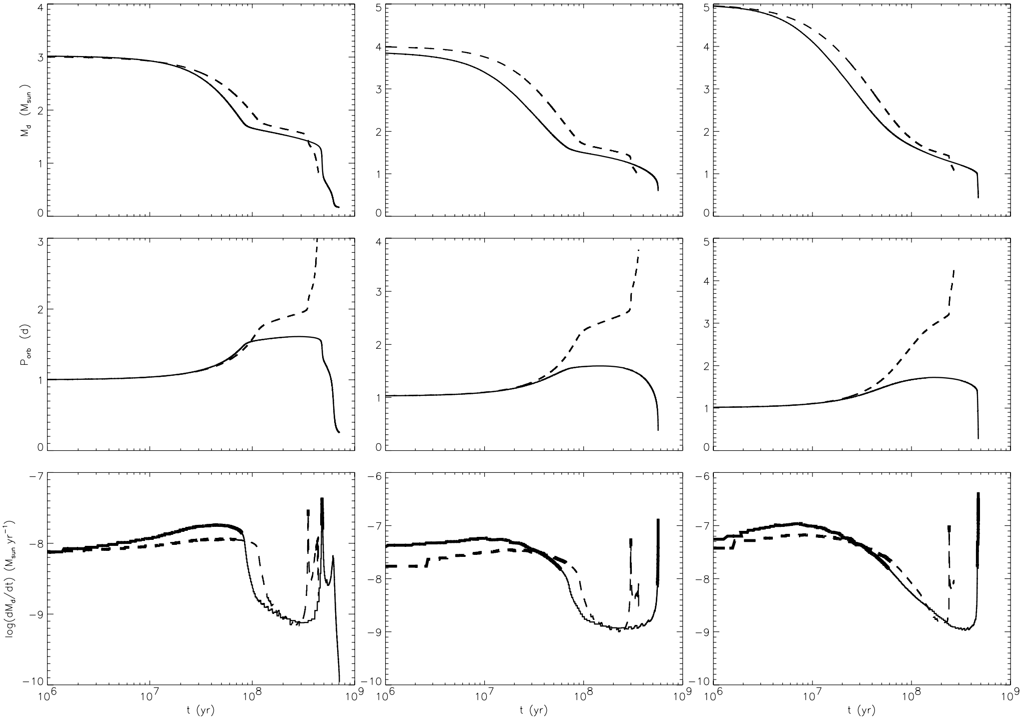

Figure 1. Evolution of the donor masses M_d (top), orbital periods P_orb (middle), and mass transfer rates $\dot{M}_\mathrm{d}$ (bottom) for BHIMXBs with the initial orbital period $P_\mathrm{orb} = 1$ d. The left, middle, and right panels correspond to $M_\mathrm{d} = 3M_\odot$ (solid curve $\delta = 0.0055$, dashed curve $\delta = 0.004$), $4M_\odot$ (solid curve $\delta = 0.007$, dashed curve $\delta = 0.005$), and $5M_\odot$ (solid curve $\delta = 0.007$, dashed curve $\delta = 0.005$), respectively. Stable and unstable mass transfer processes are plotted with thick and thin curves, respectively.

likely to be persistent X-ray sources. This is not compatible with the observations of Galactic BHLMXBs, suggesting that δ does not need to be constant but changes during the evolution. However, *Chandra* observations of the 12.6 hr ultraluminous X-ray source in the elliptical galaxy NGC3379 suggest that the current on phase has lasted ~ 10 yr (Fabbiano *et al.* 2006). This source could be a persistent X-ray source as suggested by our calculations.

Similar as in Justham, Rappaport & Podsiadlowski (2006), our results encounter the difficulty that the calculated effective temperatures are not consistent with those of the observed donor stars in BHLMXBs. If this effective temperature problem can be solved, the CB disc mechanism may provide a plausible solution to the BHLMXB formation problem, without requiring anomalous magnetic fields in the donor stars.

Acknowledgements

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