Creating ultra-compact binaries through stable mass transfer

M.V. van der Sluys*, F. Verbunt* and O.R. Pols*

*Astronomical Institute, Postbox 80.000, 3508 TA Utrecht, the Netherlands

Abstract. A binary in which a slightly evolved star starts mass transfer to a neutron star can evolve towards ultra-short orbital periods under the influence of magnetic braking. This is called magnetic capture. We investigate in detail for which initial orbital periods and initial donor masses binaries evolve to periods less than 30–40 minutes within the Hubble time. We show that only small ranges of initial periods and masses lead to ultra-short periods, and that for those only a small time interval is spent at ultra-short periods. Consequently, only a very small fraction of any population of X-ray binaries is expected to be observed at ultra-short period at any time. If 2 to 6 of the 13 bright X-ray sources in globular clusters have an ultra-short period, as suggested by recent observations, their formation cannot be explained by the magnetic capture model.

Keywords: Globular clusters, X-ray sources
PACS: 98.20.Gm, 97.80.Jp

INTRODUCTION

About half of the bright X-ray sources in the galactic globular clusters possibly are binaries with ultra-short orbital periods (≤ 40 min). Two of the five periods known are 11.4 min (in NGC 6624) and 20.6 min (in NGC 6712). The 11.4 min system has a negative period derivative. This high fraction of ultra-short periods is in marked contrast to bright X-ray sources in the galactic disk, where such periods are less common (See Table 3 of [1]).

One of the scenarios to explain the ultra-short periods starts from a binary with a neutron star and a main-sequence star. For a small range of initial orbital periods, strong magnetic braking can shrink the orbit sufficiently that the system evolves to a minimum period in the ultra-short range. This way, an orbital period shorter than 11 min can be reached [2]. At 11.4 min, the period derivative may be negative or positive, depending on whether the system evolves to the period minimum, or has already rebounded.

We will try to find out which initial systems can reach ultra-short periods within the age of the globular clusters and what the chances are to observe these systems as X-ray sources. This research is published as an article in [3].

THE EVOLUTION CODE

We calculate our models using the STARS binary stellar evolution code, developed by Eggleton [4], but with updated physics [5]. The primary is treated as a point mass with an initial mass of 1.4M⊙. Sources of angular momentum loss are gravitational waves,
FIGURE 1. Time-period (t-P) tracks for $1.1M_\odot$. Initial periods are spaced 0.05 d below 1 d and 0.25 d above that. The symbols show: start of mass transfer $+$; period minimum $\times$; end of mass transfer $\triangle$; the last model $\circ$. The dotted lines are at 11.4 and 20.6 min.

partially conservative mass transfer, and magnetic braking according to [6]:

$$\frac{dJ_{MB}}{dt} = -3.8 \times 10^{-30} M_2 R_2^4 \omega^3 \text{ dyn cm.}$$

(1)

where $M_2$, $R_2$ and $\omega$ are the mass, radius and angular rotational velocity of the secondary respectively. Tidal effects keep the spin synchronised to the orbit and magnetic braking effectively removes angular momentum from the orbit.

RESULTS

We have calculated a grid of models for $Z = 0.01$ (the metallicity of NGC 6624), with initial masses between 0.7 and $1.5M_\odot$ and initial periods between 0.35 and 3 d. The grid is refined in period around the bifurcation period between converging and diverging systems. We consider models that converge after the Hubble time as diverging.

Figure[1] shows that orbits with low initial period converge to about 70 min, and orbits with high orbital period diverge to several days. A small range in between leads to ultra-compact systems. It is clear that an initial period must be picked carefully to find such a short period minimum.

To determine the probability of observing an ultra-compact binary produced this way, we perform statistics on the t-P tracks. We choose a random initial period from a flat distribution in $\log P$ and determine the t-P track of a system with that initial period by
interpolation. Once the track is known, we choose a random moment in time between 10 and 13 Gyr (the dashed lines in Fig. 1) and determine the orbital period at that moment. If a system has passed its period minimum, or has no mass transfer at that moment, we reject it. For 1.1 $M_\odot$, 10.5% of the $10^6$ probes is accepted and shown in Fig. 2a. Of these, 86 systems have an orbital period less than 30 min (the large dots in the figure). Figure 2b shows the corresponding period distribution.

We have calculated similar grids for $Z = 0.002$ and $Z = 0.02$ and performed the same statistics as for $Z = 0.01$. The period distributions for each mass have been added using a flat mass distribution. A Salpeter mass distribution leads to little difference, especially for the ultra-short period regime. We show the results for the two of these metallicities in Fig. 3.

Figure 3 shows firstly that there are no big differences in the expected fraction of observable ultra-compact X-ray binaries. Though the exact numbers are uncertain due to the low number of accepted ultra-compact systems, we expect that of a population of $10^7$ binaries with initial periods between roughly 0.5 and 2.5 d, 1 to 10 systems have a period of 11.4 min and 10 to 100 systems have a 20.6 min orbital period and emit X-rays.
We confirm that magnetic capture can lead to ultra-compact X-ray binaries within a Hubble time. In order to find a binary system that will have its minimum period in the ultra-short period regime, one has to carefully select an initial period, just under the bifurcation period for that system. The systems that reach an ultra-short period remain there for a relatively short time, as can be seen from the steep tracks in Fig. 1. These factors combined make it rather unlikely that such a system can be observed. The metallicity of the stars only has a small influence.

Alternative scenarios to create ultra-compact binaries only allow positive period derivatives for these binaries. For a description and references see Verbunt (these proceedings) and [3].

REFERENCES

1. P. Charles, and M. Coe, “A catalogue of low-mass X-ray binaries,” in Compact stellar X-ray sources, edited by W. Lewin, and M. van der Klis, Cambridge U.P., Cambridge, 2004.
2. P. Podsiadlowski, S. Rappaport, and E. D. Pfahl, ApJ, 565, 1107–1133 (2002).
3. M. Van der Sluys, F. Verbunt, and O. Pols, astro-ph/0411189, A&A, in press (2004).
4. P. P. Eggleton, and L. Kiseleva-Eggleton, ApJ, 575, 461–473 (2002).
5. O. R. Pols, C. A. Tout, P. P. Eggleton, and Z. Han, MNRAS, 274, 964–974 (1995).
6. S. Rappaport, P. C. Joss, and F. Verbunt, ApJ, 275, 713–731 (1983).