Creating ultracompact binaries through stable mass transfer

M.V. van der Sluys, F. Verbunt and O.R. Pols
Astronomical Institute Utrecht, The Netherlands
http://www.astro.uu.nl/∼sluys/

Introduction

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

One of the scenarios to explain the ultrashort periods starts from a binary with a neutron star (NS) 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 ultrashort range. This way, an orbital period shorter than 11 m can be reached [3]. At 11.4 m, 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 ultrashort periods within the age of the globular clusters and what the chances are to observe these systems as X-ray sources.

[a] The discovery of an 18.2 m system was announced recently [5]

The evolution code

We calculate our models using the STARS binary stellar evolution code, developed by Eggleton [1], but with updated physics [2]. The primary (NS) is treated as a $1.4\,M_\odot$ point mass. Sources of angular momentum loss are gravitational waves, partially conservative mass transfer, and magnetic braking according to [4]:

$$\frac{dJ_{\rm MB}}{dt} = -3.8 \times 10^{-30}\, M_2\, R_2^4\, \omega^3\ {\rm dyn\ cm}. \quad (1)$$

where M_2, R_2 and ω are the mass, radius and spin frequency of the secondary respectively. Tidal effects keep the spin synchronised to the orbit and magnetic braking effectively removes angular momentum from the orbit.

The calculated models for Z = 0.01

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

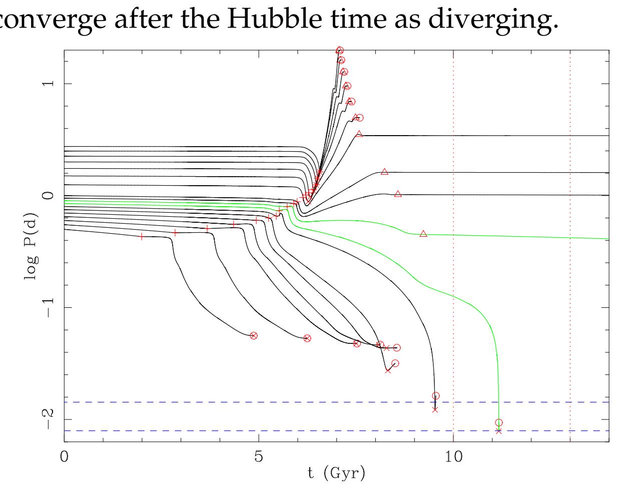

Fig. 1. Time-period (t-P) tracks for $1.1\,M_\odot$. Initial periods are spaced 0.05 d below 1 d and 0.25 d above that. The symbols show: start of mass transfer +; period minimum ×; end of mass transfer △; the the last model ○. The dotted lines are at 11.4 and 20.6 m. The green tracks bracket $P_{\rm bif}$.

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

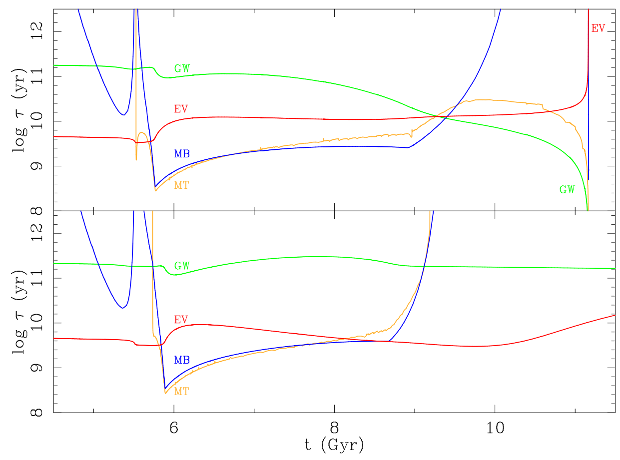

Fig. 2. Time scales of the two green models in Fig. 1. Upper panel: the system with $P_i = 0.85$ d reaches a minimum of 11.3 m after 11.2 Gyr. Lower panel: the system with $P_i = 0.90$ d does not converge within the Hubble time. Colours are timescales of: nuclear evolution (EV), magnetic braking (MB), gravitational waves (GW) and mass transfer (MT).

The models that bracket the bifurcation period for 1.1 $M_\odot$ have initial orbital periods of 0.85 and 0.90 d. A comparison of the various timescales explains the difference between these systems in Fig. 2. The wider system is slightly more evolved when it fills its Roche lobe and its nuclear evolution is a bit faster. When magnetic braking becomes slower than the nuclear evolution, gravitational waves can take over the orbital shrinkage for the closer system, but not for the wider. For the latter, nuclear evolution is faster than the orbital evolution and the donor transfers its envelope and becomes a white dwarf before an ultrashort period is reached.

Statistics for Z = 0.01

To determine the probability of observing an ultracompact 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 its t-P track by interpolation. Once the track is known, we choose a random moment in time between 10 and 13 Gyr (the dotted 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. These are shown in Fig. 3a. Figure 3b shows the corresponding period distribution.

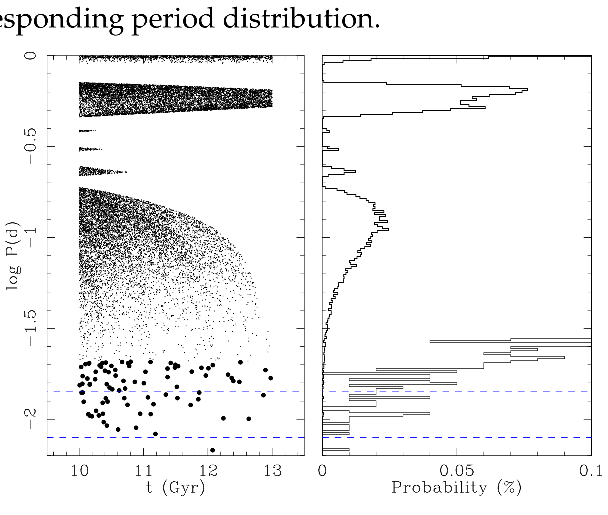

Fig 3. Left panel (a): accepted systems for $1.1 M_\odot$. Each dot represents one system. The spikes at $\log P \approx -0.5$ are artefacts due to the interpolation. Right panel (b): Histogram of the data obtained by summing (a) over the time. The thin line shows the short-period tail, with the probability 100 times enlarged.

Comparison between metallicities

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 ultrashort period regime. We show the results for the three different metallicities in Fig. 4.

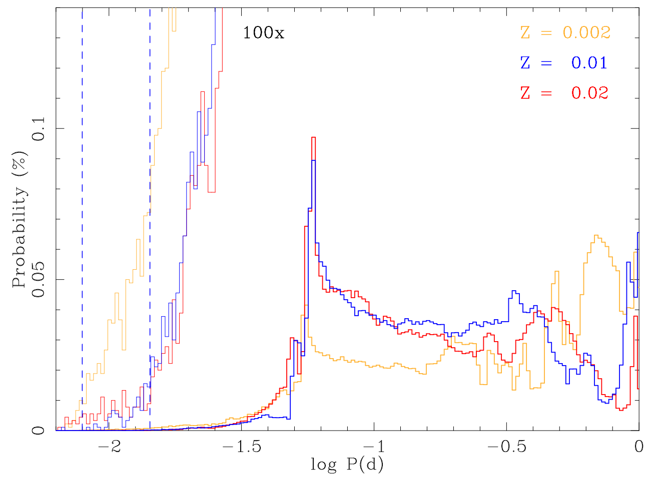

Figure 4. Period distributions for all three metallicities. The thin lines on the left are enlarged 100 times in the vertical direction.

Figure 4 shows firstly that there are no big differences in the expected fraction of observable ultracompact X-ray binaries. Though the exact numbers are uncertain due to the low number of accepted ultracompact 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 m and 10 to 100 systems have a 20.6 m orbital period and emit X-rays.

Discussion

We find that strong magnetic braking can lead to ultracompact X-ray binaries within a Hubble time. In order to find a binary system that will have its minimum period in the ultrashort period regime, one has to carefully select an initial period, just under the bifurcation period for that system. The systems that reach an ultrashort 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.

An alternative scenario to create ultracompact binaries is a spiral-in, possibly initiated by a stellar collision in the dense globular clusters. This scenario only allows positive period derivatives for these binaries, though. The high density in globular clusers can also give rise to the formation of binaries due to tidal capture. If these systems have periods near the bifurcation period, a somewhat larger fraction will evolve to ultracompact binaries.

Marc van der Sluys is a PhD student at the Astronomical Institute in Utrecht, the Netherlands. An article about this study has been submitted to A&A.

References

[1] Eggleton, P. P. & Kiseleva-Eggleton, L., 2002, ApJ, 575, 461
[2] Pols, O. R., Tout, C. A., Eggleton, P. P. & Han, Z., 1995, MNRAS, 274, 964
[3] Podsiadlowski, P., Rappaport, S. & Pfahl, E. D., 2002, ApJ, 565, 1107
[4] Rappaport, S., Joss, P. C. & Verbunt, F., 1983, ApJ, 275, 713
[5] Wang, Z., & Chakrabarty, D., astro-ph 0406465