Stability of Mass Transfer in Eccentric Compact Binaries

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Abstract Compact binaries are important progenitors for gamma-ray bursts. Here we present simulations of the onset of mass transfer in compact binaries, focusing on systems containing a neutron star and a white dwarf. We make use of a modified form of smoothed particle hydrodynamics enabling us to model realistically-low mass transfer rates.

Notation:

- MS – a main-sequence star
- WD – a white dwarf
- NS – a neutron star
- GRB – Gamma-ray burst
- SN – a supernova
- MT – mass transfer

Eccentric WD-NS Binaries: Introduction

Before the mass transfer (see, for example, Davies et al., 2002):

- Birth rate of $10^{-4} - 10^{-5}\mathrm{yr}^{-1}$ per galaxy
- NS is formed second
- There are two observed WD-NS binaries, and two proposed sub-populations
- Merger rate is observationally interesting
- When they come into contact, WD-NS binaries are still interestingly eccentric

During the mass transfer:

- Merger of WD-NS binaries may produce GRBs and SNe (King et al, 2007)
- GRBs possibly originating from these systems have been observed (Gal-Yam et al., 2006; Della Valle et al., 2006; Fynbo et al., 2006)
- Nuclear burning may be important during the merger (Metzger, 2011)
- WD-NS binaries make a promising source for GWs

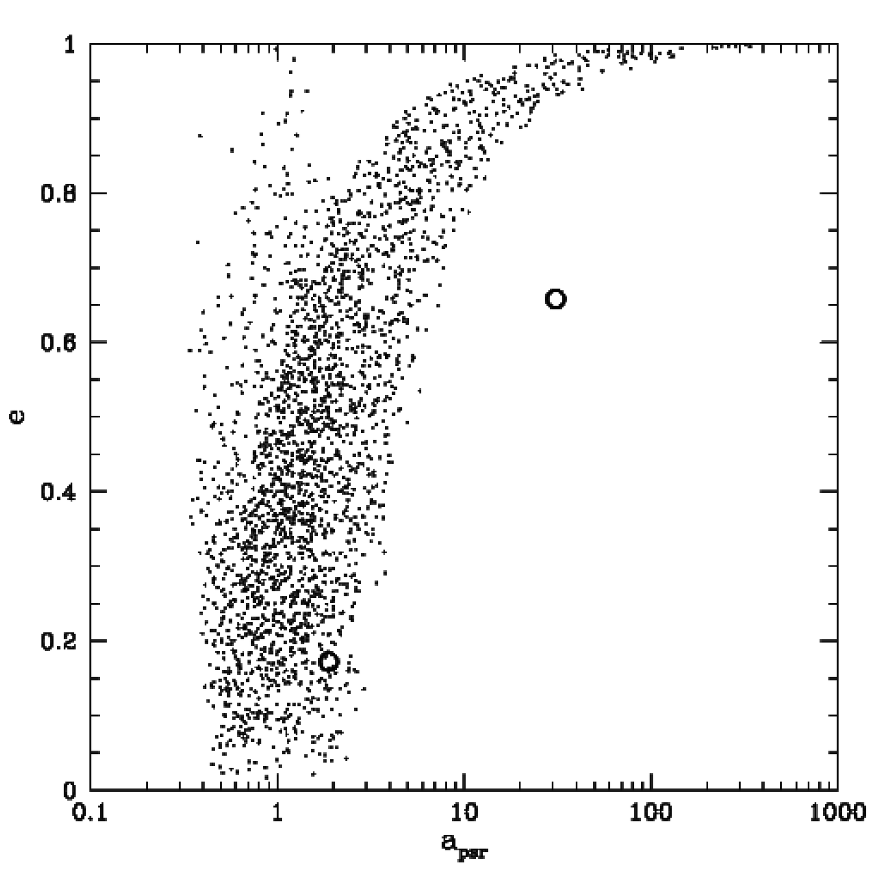
We study the stability of mass transfer in WD-NS binaries

Eccentric WD-NS Binaries Formation

- Primary expands, MT starts
- Only He core left from the primary
- The primary expands and MT starts again
- The primary turns into a WD
- Secondary reaches the red giant phase, and fills its Roche lobe
- Common envelope phase starts, the system gets tight
- He secondary evolves, leading to either MT or mass loss through winds: two populations form
- Secondary explodes as a SN (assuming it has gained enough mass)
- Newborn NS gets a kick – binary becomes eccentric

How Do WD-NS Systems Come Into Contact?

INITIAL POPULATION



Major fraction of WD-NS binaries is formed in tight and eccentric binaries. The observed systems $J1141+6545$ and $B2303+46$ are shown on the figure. The latter binary belongs to the other, more wide population.

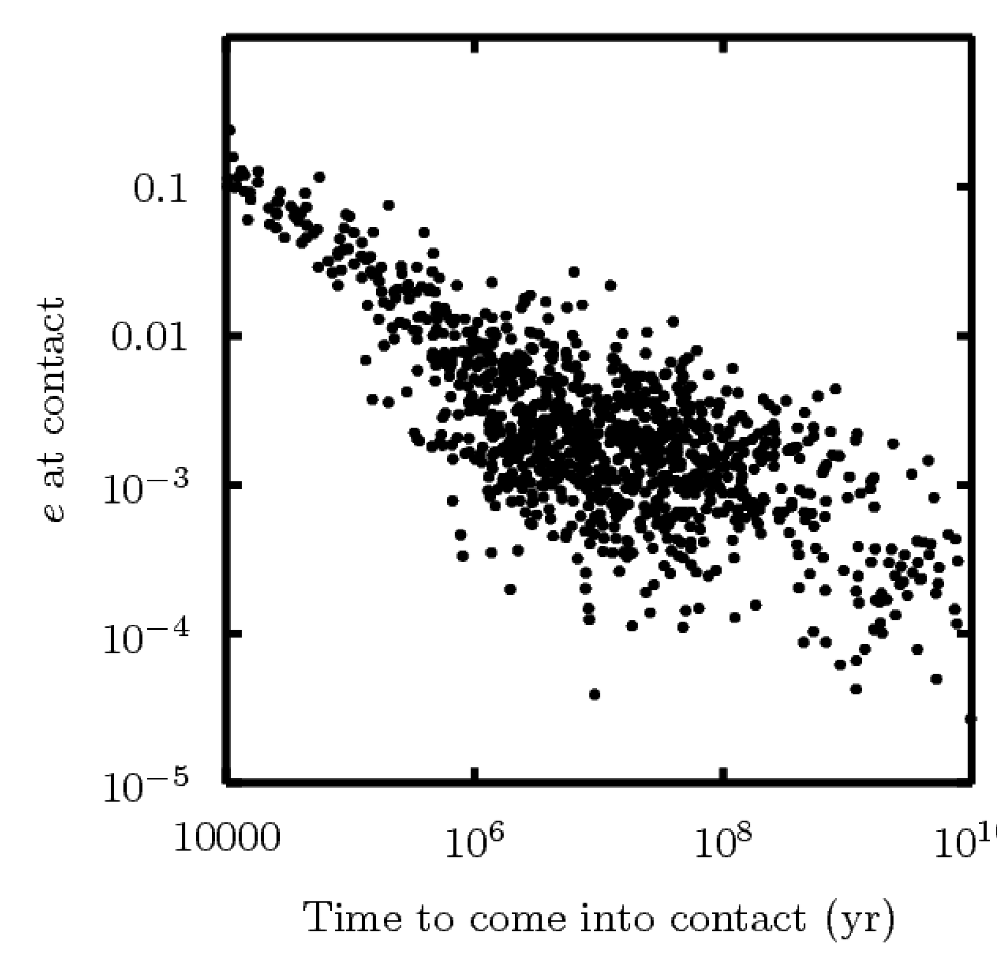
INSPIRAL DUE TO GW EMISSION

$$\frac{\mathrm{d}a}{\mathrm{d}t} = -\frac{64}{5}\frac{G^3 m_1 m_2 (m_1+m_2)}{c^5 a^3 (1-e^2)^{7/2}}\left(1+\frac{73}{24}e^2+\frac{37}{96}e^4\right)$$

$$\frac{\mathrm{d}e}{\mathrm{d}t} = -\frac{304}{15}e\frac{G^3 m_1 m_2 (m_1+m_2)}{c^5 a^4 (1-e^2)^{5/2}}\left(1+\frac{121}{304}e^2\right)$$

GW emission affects both a and e (Peters, 1964). 95 percent of the presented population shall merge in less than a Hubble time.

COMING INTO CONTACT



At the moment of coming into contact the binaries are still interestingly eccentric: variation of the binary separation is of order of scale height of the WD. Consequences: periodic mass transfer, Roche lobe formalism is not applicable.

Modelling the Mass Transfer

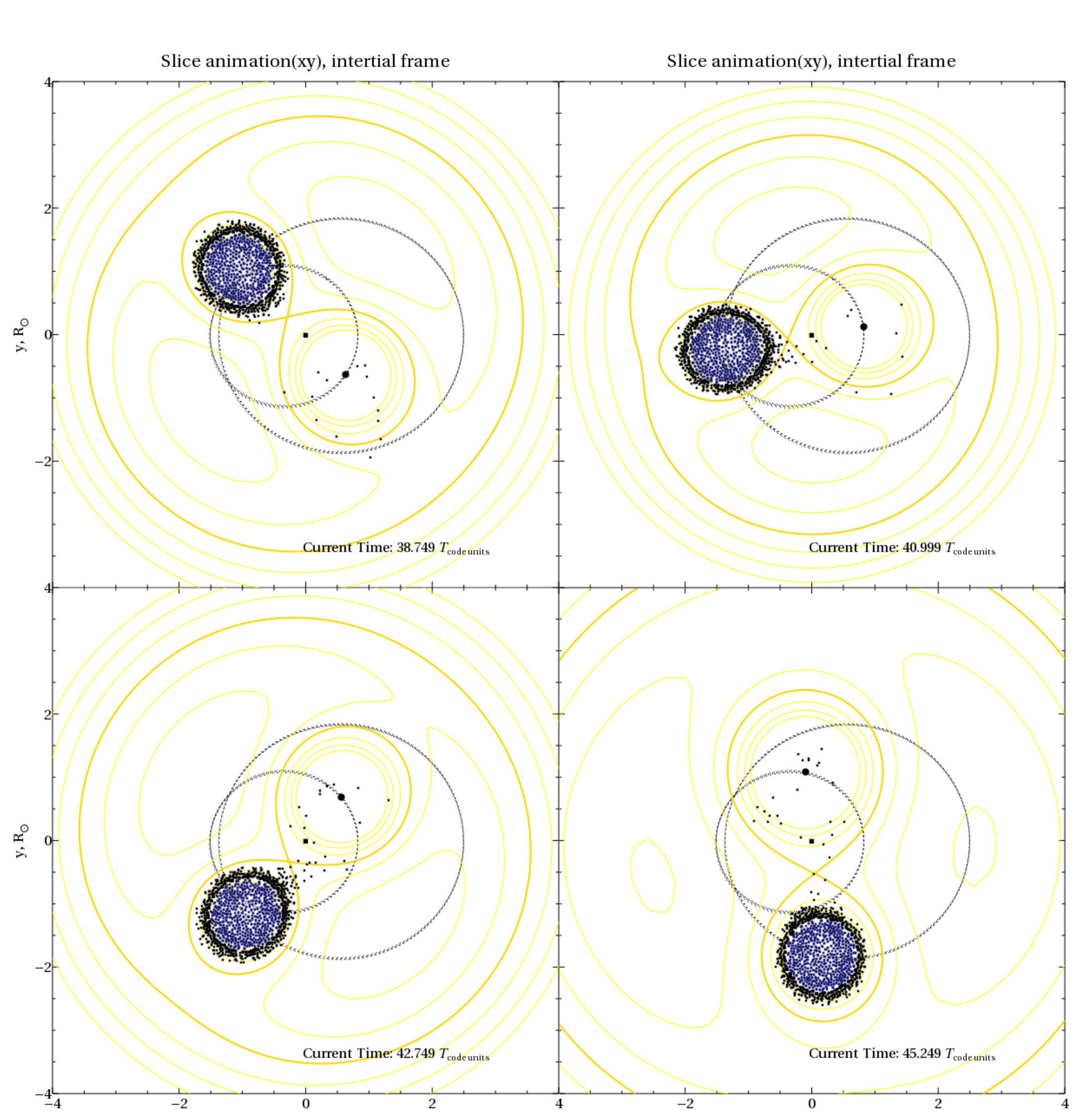
MODIFIED SPH

Motivation:

- SPH method replaces the bodies by sets of particles of comparable masses
- If the binary were circular, the mass transfer rate would be down to of order $10^{-12}M_\odot$ per period (Rosswog & Bruggen, 2003).
- Hence one would need of order 10^{12} SPH particles to resolve the mass transfer

Oil-on-water scheme (Church et al, 2009):

- The main idea is to artificially separate the atmosphere and the body of the star
- This allows one to use two types of SPH particles of very different masses in a single simulation
- Hence one can resolve realistically low mass transfer rates.



SIMULATIONS

A simulation of $\gamma = 5/3$ polytrope $0.6M_\odot$ star orbiting a $1M_\odot$ compact companion, with a resolved phase of episodic mass transfer happening between the stars. We use the units, in which $M_\odot = 1, R_\odot = 1, G = 1$. The binary separation at its minimum is $2.2R_\odot$, the eccentricity is $e = 0.29$.

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