Smoothed Particle Hydrodynamics simulations of white dwarf collisions and close encounters

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Motivation

Physical scenario

Numerical modelling

Results

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4. Results
   - Outcomes
   - Structure of the remnants
   - Observational signatures

Outcomes

Structure of the remnants

Observational signatures

SPH simulations of white dwarf collisions and close encounters
The study of stellar collisions in dense stellar systems has attracted much interest in recent years.

One of the reasons for this is the relatively high frequency of such events expected in these environments (Hills & Day 1976).

It has been predicted that up to 10% of the stars in the core of typical globular clusters have undergone a collision at some point during the lifetime of the cluster.
The collisions of two white dwarfs deserves study for various reasons.

First of all, the collision of two white dwarfs might produce a Type Ia supernova. It has been predicted that the white dwarf merger rate leading to super Chandrasekhar remnants will be increased by an order of magnitude through dynamical interactions (Shara & Hurley 2002).

Consequently, collisions of two white dwarfs could explain supernovae occurring in the nuclei of galaxies.
It has also been recently suggested that such a process could lead to the formation of a magnetar (King, Pringle & Wickramasinghe 2001). This could explain the main characteristics of some soft gamma-ray repeaters and anomalous X-ray pulsars like 1E2259+586.

Also, dynamical interactions in globular clusters can form eccentric double white dwarfs which could be powerful sources of gravitational radiation (Willems et al. 2007).

It has also to be noted that due to the high temperatures achieved during these collisions, we expect that some nuclearly processed material would be ejected, leading to a pollution of the environment.
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A close encounter between two stars might produce several different outcomes.

If stars get close enough, kinetic energy might be dissipated in several ways and an eccentric binary system might be formed.

Typical dispersion velocities in globular clusters are $v_d \approx 10$ km/s, while typical relative velocities in close encounters are $v_c \approx (2G(M_1 + M_2)/d_c)^{1/2} \sim 100$ km/s.
Thus, only $\sim \left(\frac{v_d}{v_c}\right)^2 \lesssim 0.01$ of the kinetic energy available at closest approach needs to be dissipated in order to bound the system (Fabian et al. 1975).

This fraction is small enough to expect a relatively high formation rate of this type of systems (Lee & Ostriker 1986).

If enough kinetic energy is dissipated from the system, mass transfer might begin and an a stellar merger might occur.
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Numerical modelling (1)

- We have simulated a set of close encounters between white dwarfs. As a first step towards a complete understanding of this processes we have decided to focus on the post-capture configuration.

- Our objective is to compute the set of physical parameters leading to the different possible outcomes — that is, eccentric binary systems and stellar mergers.

- To do so we use an SPH code (Guerrero et al. 2004, Lorén–Aguilar et al. 2005), which is very well suited for treating fully three-dimensional hydrodynamical problems.
We have performed 10 simulations of the close encounters of a 0.6 and a 0.8 $M_{\odot}$ CO white dwarfs.

Our free parameters have been the initial relative velocities of the stars, ranging from 50 to 200 km/s, and the impact parameter $b$, ranging from 0.3 to 0.9 $R_{\odot}$. 
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We have found three different types of outcomes: eccentric binary systems, lateral collisions, and direct collisions.

Summary of the main properties:

| Run | \( b \) (\( R_\odot \)) | \( v \) (km/s) | Outcome | \( E \) (\( 10^{49} \) erg) | \( L \) (\( 10^{51} \) erg s) | \( r_{\text{max}} \) (0.1 \( R_\odot \)) | \( r_{\text{min}} \) (0.1 \( R_\odot \)) | \( \varepsilon \) |
|-----|----------------|----------|--------|----------------|----------------|----------------|----------------|-------|
| 1   | 0.8            | 100      | O      | -0.21          | 0.78           | 8.26           | 0.52            | 0.881 |
| 2   | 0.5            | 150      | O      | -0.25          | 0.74           | 6.85           | 0.50            | 0.864 |
| 3   | 0.3            | 200      | LC     | -0.12          | 0.58           | 3.74           | 0.30            | 0.852 |
| 4   | 0.3            | 175      | LC     | -0.46          | 0.50           | 3.70           | 0.22            | 0.886 |
| 5   | 0.3            | 150      | LC     | -0.40          | 0.37           | 4.36           | 0.12            | 0.947 |
| 6   | 0.3            | 100      | DC     | -0.50          | 0.29           | 3.63           | 0.07            | 0.962 |
| 7   | 0.5            | 50       | DC     | -0.27          | 0.25           | 6.72           | 0.05            | 0.984 |
| 8   | 0.1            | 200      | DC     | -0.78          | 0.19           | 2.36           | 0.03            | 0.974 |
| 9   | 0.1            | 150      | DC     | -0.80          | 0.16           | 2.30           | 0.02            | 0.985 |
| 10  | 0.1            | 120      | DC     | -0.21          | 0.06           | 2.28           | 0.01            | 0.989 |
Outcomes (2)

- Some examples of the different types of outcomes
- Movies will be available at the conference program page
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Outcomes (3)

- Using the results of the simulations the different outcomes can be studied. We have found that $r_{\text{min}} \approx 0.030$ and $0.012 \, R_\odot$ separate the regimes.

- In the classical two-body problem the relation between the distance at periastron and the orbital energy and angular momentum is given by $r_{\text{min}} = \frac{k}{2|E|} \left( 1 - \sqrt{1 + \frac{2EL^2}{\mu k}} \right)$.
The structure of the remnant is not very different from the one we found in classical simulations of the merger of a binary white dwarf.

Direct collisions show a spherical mass distribution around the primary star in comparison with the disk-like structure obtained in lateral collisions.
The temperatures are not high enough to ignite representative carbon reactions.

We do not obtain a hot envelope surrounding the primary star. Different long-term evolution of the remnant when compared with a classical merger?
Observational signatures (1)

- We have computed the gravitational wave emission of these systems.

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Emission corresponding to each one of the previously studied outcomes.
It has been argued that the formation of eccentric systems might be a powerful source of gravitational radiation.

The frequency and amplitude of this systems lies out of the range of LISA’s sensitivity curve.

Orbital circularization will move the emission of these systems above the confusion noise, giving us a chance to detect them.
In the case of mergers, a possible observational signature could be its electromagnetic emission.

We followed the model of Rosswog (2007) in order to study which would be the possible signature of a recent merger.
Conclusions

- We have performed a set of simulations of close encounters of white dwarfs in dense stellar systems.

- We have determined the regions in the $E - L$ plane that determine the type of outcome of the close encounter.

- We have shown that the detection of gravitational waves arising from such eccentric systems does not seem to be feasible with LISA. Possibly, after orbital circularization the gravitational wave emission might be detected.
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