Simulating the Evolution of Binary Stars in Stellar Clusters

Astronomical observations show that most stars are not isolated but are usually part of a pair – so-called binary stars or binaries. Being a pair, binary stars have additional properties compared to single stars. Two important such properties are the relative mass of the two stars and the time they need to revolve around each other, which is denoted as period. This period obviously depends on the distance between both stars.

One aim of binary observations is to understand how likely binaries with certain properties are in the total binary population. One surprising observational finding was that the properties in young binaries can differ significantly from those in older populations. In regions were stars just form more binaries with shorter and as well longer periods than in older populations are observed. This is illustrated in Fig. 1, where the young populations is indicated as 'initial' and the older population as 'final' (Refs. [1-3]). This means that over time a large proportion of the very tight and very wide binaries are destroyed by some mechanism.

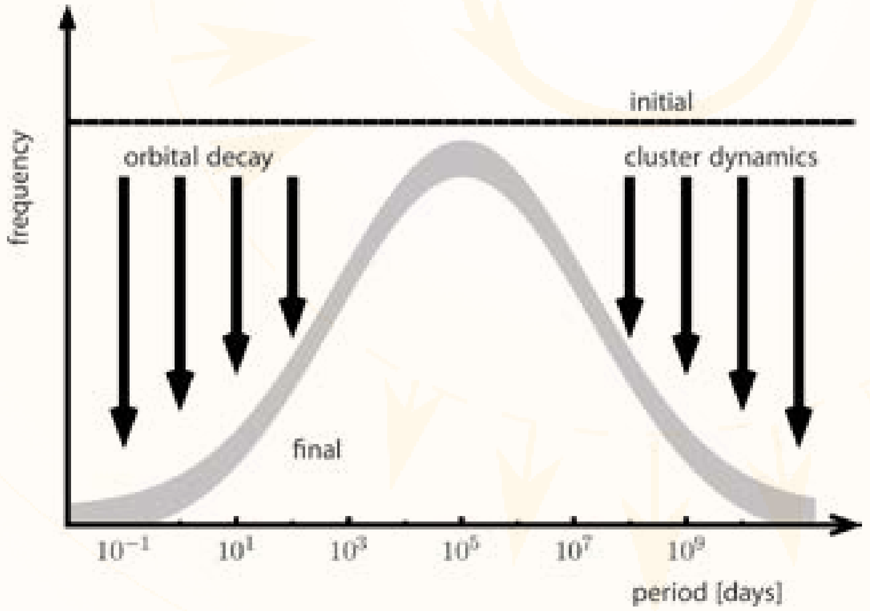

Figure 1: Orbital decay and cluster dynamics convert the initial binary period distribution observed in stellar clusters into the final binary period distribution observed in the field.

The young binary stars are preferentially found in bound groups (clusters) of hundreds to several thousands of stars. After the star formation process has finished these clusters dissolve and become part of the "field" population. Observations of the binary properties in young clusters and the field population give us in some sense the initial and final conditions for our simulations. So ideally the simulations should provide a picture how the binary population is born, changes in the cluster environment and dissolves into a field population.

We use the Orion Nebular Cluster (ONC) as a model star cluster to investigate the evolution of a binary population. The reason is that the ONC is one of the best observed clusters in the solar neighbourhood. So many parameters are well known for the ONC. At an age of one million years it is still relatively young and probably just before it starts to dissolve. It contains approximately 4000 stars which is populous enough to obtain reasonable statistics.

During the first million years of evolution, the cluster population is influenced by two important dynamical processes: First, by gas-induced orbital decay of embedded binary systems, and second, destruction of wide binaries in three-body interactions which will be detailed in the following.

Figure 1 shows the initial period distribution of the binaries and that of the field of a binary population. It can be seen that the gas-induced orbital decay only has an influence on the short-period binaries and that three-body interactions only destruct wide binaries.

The latter processes in stellar clusters have largely been studied (Ref. [4] - [6]) and are relatively well understood. Here the weakly bound wide binaries are separated by the interactions with stars that fly by. By contrast, the process of gas-induced orbital decay has been largely neglected in the past, but will be the focus here.

How does the gas-induced orbital decay work? Stars form from the gas and dust content of large molecular clouds. This natal gas largely stays around until it is expelled from the cluster by various processes. As a result a just formed binary system is still embedded in this natal gas for approximately one million years. The oscillating gravitational potential of the rotating binary system torques the nearby gas. This produces an outgoing wave in the gas, which again leads to a loss of angular momentum (Figure 2) in the binary system. As a consequence the distance between the stars shrinks. In extreme cases it is even possible that the two stars merge.

Steven Stahler (UC Berkeley) was the first to realize that the properties of young binaries might be affected by the surrounding gas. He investigated analytically how an isolated binary system might react to its natal gas (Ref. [8]). Due to the complex nature of the problem he chose a system with special features that are manageable analytically: Two equal-mass stars on a circular orbit with a distance of 100 Astronomical Units (1AU = distance between sun and earth).

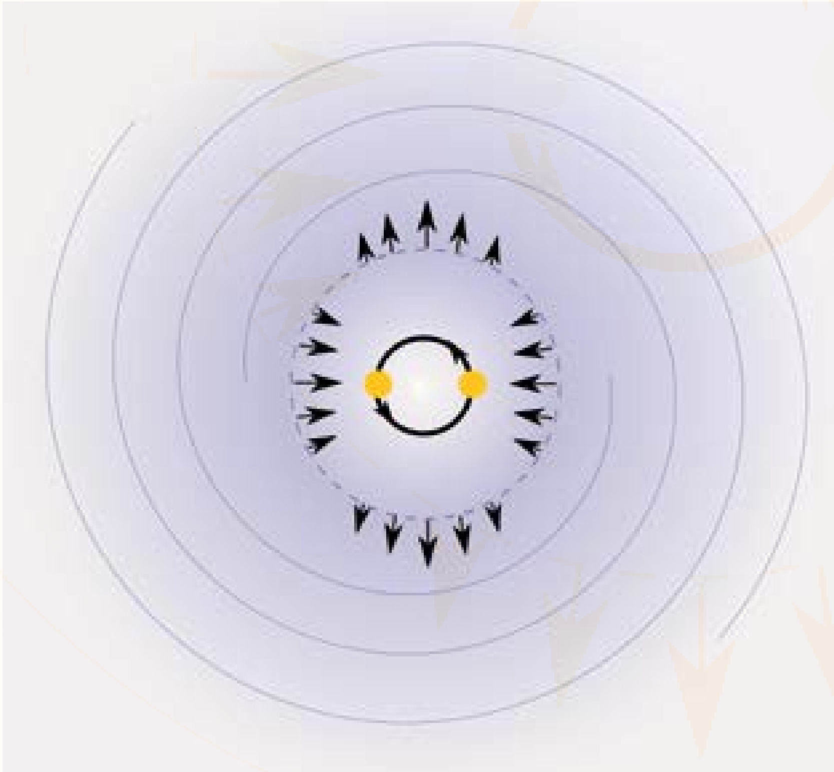

Figure 2: Orbiting binary system embedded in gas. The arrows show the oscillating gravitational quadrupole moment resulting in spiral waves as indicated.

We extended these investigations by simulating a whole binary population on JUROPA at the Jülich Supercomputing Centre. We demonstrated that in combination with dynamical effects this process converts the initial period distribution found in stellar clusters, into the final period distribution, found in the field (Figure 3, Ref [8]).

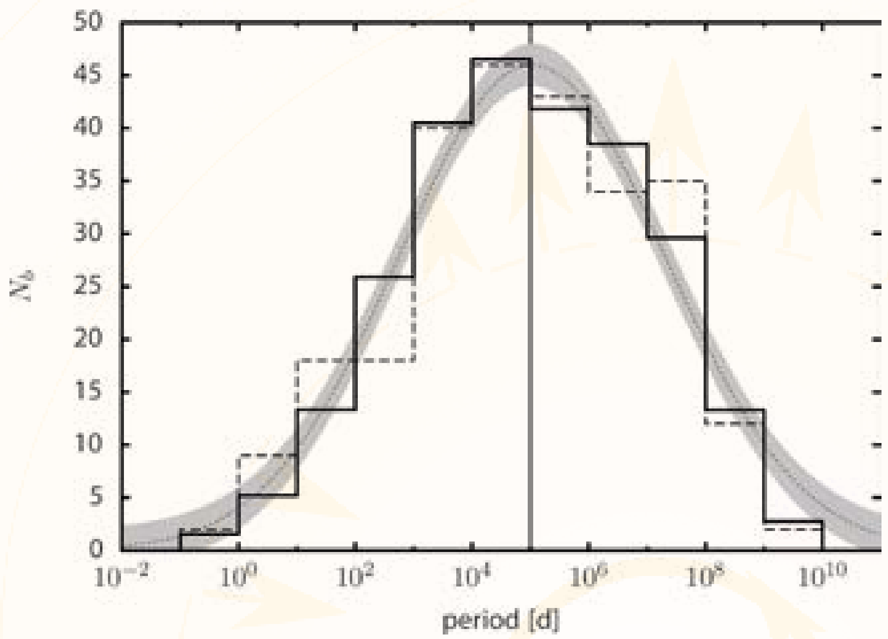

Figure 3: Final period distribution: Observations (solid line), simulation (dashed line), and fit to observations (grey)

As mentioned above, in extreme cases the shrinkage of the binary orbit can even lead to a merger of the two stars. So far it has been largely excluded that massive stars can

merge. The reason was that if one neglects the presence of gas, the only way that two stars merge would be a direct collision. However, that would require much higher stellar densities than usually observed. By contrast, our results suggested that the gas present in young clusters could work as an agent to make the merging of young binaries much more common than previously thought.

We recently developed a hydrodynamic model in order to extend the method from circular orbits to eccentric orbits. In contrast to the analytical calculations, the numerical models have to take special care when simulating the onset of the waves, as this is very sensitive in transporting angular momentum.

The relevant acoustic wave starts only at some distance from the binary [9, 10]. Figure 4 shows our simulations for three different binary systems. In the first row, a circular binary system with equal masses is shown (4.1a). The gravitational interaction with the gas results in waves which form two spiral arms (4.1b). Looking at the density perturbation for two angels separated by 90 degree, we see the expected period shifts by 180 degrees. In the binary system shown in the second row the stars are not of equal mass as before, but one star is twice as heavy as the other one. As a consequence, one of the spiral arms nearly vanishes (4.2b) and the period shifts only by 90 degrees. The binary in Figure 4.3 is on an elliptical orbit (eccentricity = 0.2) which results in an asymmetric acoustic wave, but as the two stars are of equal mass, the period shift remains at 180 degrees.

In the near future we will include the results of the hydrodynamic simulation into an N-body code to model the evolution of the stellar cluster consistently. These simulations will allow us to describe the influence of the cluster of stars and gas on the evolution of the binary population from their initial state to that of the field star population.

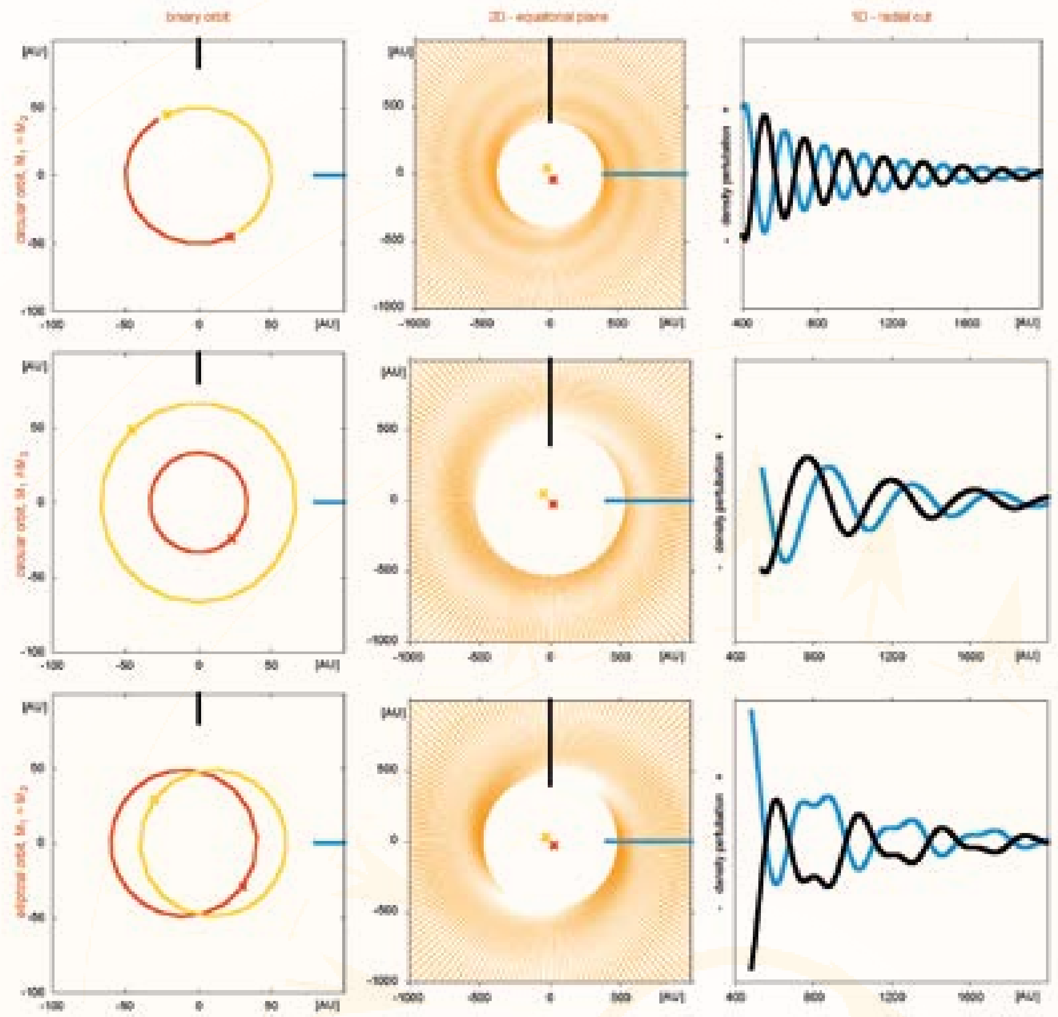

Figure 4: Hydrodynamic simulations of the gas surrounding a stellar binary system.

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