The effects of stellar dynamics on the evolution of young dense stellar systems

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Abstract.
In the present paper we report on first results of a project in Brussels where we study the effects of stellar dynamics on the evolution of young dense stellar systems using the 3 decades expertise in massive star evolution and our population (number and spectral) synthesis code. We highlight an unconventional object scenario (UFO-scenario) for Wolf Rayet binaries and study the effects of a luminous blue variable-type instability wind mass loss formalism on the formation of intermediate mass black holes.

1. Introduction

A population synthesis code calculates the temporal evolution of a population of single stars and of close binaries, in regions where star formation is continuous or in starbursts. Population number synthesis (PNS) predicts the number of stars of a certain type whereas population spectral synthesis (PSS) computes the effects on the integrated spectrum of a population of a certain class of stars. The latter is very useful in the case of young starbursts.

Notice that to make realistic PNS/PSS predictions of massive stars it is essential to use evolutionary tracks calculated with the most up to date wind rates, where we distinguish those during the core hydrogen burning (CHB) phase, the luminous blue variable (LBV) phase, the red supergiant (RSG) phase and the core helium burning (CHeB) phase when the star is classified as a Wolf-Rayet (WR) star. A description of our PNS and PSS code that follows the evolution of young starbursts can be found in Van Bever and Vanbeveren (2000, 2003), and references therein.

The effects of N-body stellar dynamics may be very important in dense stellar systems (Portegies Zwart et al., 2004 and references therein) and we therefore started recently with the implementation of this process in our codes. In the present paper we report first results (more details will be presented by Belkus et al., 2005). In section 2 we describe our model. In section 3 we further discuss the unconventionally formed object scenario (UFO-scenario) introduced by Dany Vanbeveren, these proceedings and section 4 illustrates the effect of an LBV-type instability in the most massive stars on the formation of intermediate mass black holes (IMBHs).
2. The model

Since we are interested in the spectral evolution of young stellar systems, we decided in favor of direct N-body integration. The integrator is written in Brussels and linked to our PSS and/or PNS code. Since we are mainly interested in the evolution during the first few million years, to save computer time we approximate the evolution of our cluster by generating a (large) number of massive (initial mass between 10 and 120 $M_\odot$) objects from a Salpeter initial mass function and a corresponding number of objects with a mass $\leq 10 M_\odot$. The latter objects are fixed in the cluster in space and time but the effect on the trajectories of the massive objects is included in the N-body integration. Each massive object of mass $M$ can be a single star with mass $M$ or a binary with total mass $M$. In case of a binary, the mass ratio is drawn from a flat mass ratio distribution and the period is drawn from a distribution which is constant in the Log (only binary periods smaller than 10 years so that our PNS/PSS code can handle their evolution). The interaction of two objects is treated with the chain regularisation method as explained by Mikkola and Aarseth (1993, and references therein). When at least one of the objects is a binary, the effect of the direction of the impact with respect to the orbital plane and orbital phase is calculated using a Monte-Carlo method.

3. A UFO-scenario for WR+OB binaries

The formation of WR+OB binaries in young dense stellar systems may be quite different from the conventional binary evolutionary scenario as it was proposed by Van den Heuvel and Heise (1972). Mass segregation in dense clusters happens on a timescale of one or a few million years which is comparable to the evolutionary timescale of a massive star. Within the lifetime of a massive star, close encounters may therefore happen very frequently. When we observe a WR+OB binary in a dense cluster of stars, its progenitor evolution may be very hard to predict. Our simulations predict the following unconventionally formed object scenario (a UFO-scenario as introduced by D. Vanbeveren in the present proceedings) of WR+OB binaries. After 4 million years the first WR stars are formed, either single or binary. Due to mass segregation, this happens most likely when the star is in the starburst core. Dynamical interaction with another massive object becomes probable, especially when the other object is a binary. We encountered a situation where an object which started as a 50 $M_\odot$ single star and evolved in 4 Myrs into a single WC-type star with a mass $= 10 M_\odot$, interacts with an object with total mass $= 30 M_\odot$, in our case a 16 $M_\odot + 14 M_\odot$ circularized binary with a period $P = 6$ days. Since we use a Monte-Carlo method in order to calculate the remnant after the interaction, it may be interesting to investigate all possible remnants and their occurrence frequency. The program FEWBODY (Fregeau et al., 2004) is very suited for this purpose. Figure 1 shows the results of 22000 simulations (with different impact parameters). The following objects are possible. (1 and 2): The WC star merges with one of the binary components; the merger forms a binary with the remaining star. (3): the original binary components merge (and forms a 30 Mo rejuvenated and nitrogen enhanced star); the latter forms a binary with the
WC star. (4 and 5): exchange binaries where the WC star replaces one of the original binary components. (6): the preservation of the situation before the interaction, but of course different trajectories and different orbital parameters of the binary. (7): the 3 stars merge and form 1 single star. (8 and 9): one of binary components merges with the WC star; the merger and the remaining binary component become disrupted and further evolve as single stars.

Within the class (3), the following final object is a possibility: the two binary components merge and the $30\,M_{\odot}$ merger forms a binary with the WC star with a period of $\approx 80$ days and an eccentricity $e = 0.3$. This binary resembles very well the WR+OB binary $\gamma^2$-Velorum but it is clear that conventional binary evolution has not played any role in its formation.

In all our simulations, the resulting binaries are eccentric and we therefore conclude that when an eccentric WR+OB binary is observed in a cluster where dynamical interaction may have occurred, predicting its progenitor evolution becomes ambiguous.

![Figure 1. Possible remnants and their occurrence frequency within 22000 simulations after an interaction of a $10\,M_{\odot}$ WC star with a $16\,M_{\odot} + 14\,M_{\odot}$ circularized binary with a period $P = 6$ days.](image)

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4. **The formation of an IMBH**

The formation of massive black holes through collision runaway in dense young star clusters has been studied by Portegies et al. (2004). They applied their results to the cluster MGG-11 in the starburst galaxy M82. To follow the evolution of the massive stars, they use a scenario as explained in Portegies Zwart et al. (1999). However, the stellar wind mass loss rate formalisms deserve some attention, especially the formalism during the LBV phase of a very massive star as discussed by D. Vanbeveren in the present proceedings. In order to investigate the effect on the formation of IMBHs, we generated a cluster with 3000 massive single objects, a King (1966) distribution with parameters so that the simulation may be appropriate for MGG-11. We first made a simulation using evolutionary calculations where the LBV-type mass loss rate is switched off. In
a second simulation, all stars (collision products) with a mass > 120 M⊙ evolve with a stellar wind mass loss rate = 10^{-3} M⊙/yr. When the mass drops below 120 M⊙, we switch back to our normal stellar evolution as it is implemented in our PNS/PSS code (see introduction). Collision products are mixed instantaneously and since we follow the pre-collision stars in detail, we calculate the resulting chemical abundances of the mixed star from first principles. The further evolution of this merger is calculated with our stellar evolutionary code with the appropriate abundances. Figure 3 shows two simulations, one without and one with the LBV-mass loss. In both cases a runaway collision starts after a few 10^5 yrs. However, the simulation with the LBV-type mass loss formalism switched on illustrates that after the runaway process there may be time enough for the merger to lose sufficient mass so that it becomes a normal 120 M⊙ star.

The main conclusion of our calculations is that in order to study the possibility to form IMBHs in young dense stellar systems, a good knowledge of the LBV-type instability in very massive stars and the resulting mass loss rate is essential.

![Graph](image)

Figure 2. The variation of the mass of the most massive star in the cluster. The dashed line shows the runaway mass growth when the LBV mass loss is switched off whereas the full line illustrates the variation of the mass of the same object when the LBV mass loss is included as explained in the text.

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