Dynamical Evolution of Dense Stellar Systems
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The Formation and Evolution of Very Massive Stars in Dense Stellar Systems

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Abstract. The early evolution of dense stellar systems is governed by massive single star and binary evolution. Core collapse of dense massive star clusters can lead to the formation of very massive objects through stellar collisions ($M \geqslant 1000\,M_\odot$). Stellar wind mass loss determines the evolution and final fate of these objects, and determines whether they form black holes (with stellar or intermediate mass) or explode as pair instability supernovae, leaving no remnant. We present a computationally inexpensive evolutionary scheme for very massive stars that can readily be implemented in an N-body code. Using our new N-body code 'Youngbody' which includes a detailed treatment of massive stars as well as this new scheme for very massive stars, we discuss the formation of intermediate mass and stellar mass black holes in young starburst regions. A more detailed account of these results can be found in Belkus, Van Bever & Vanbeveren (2007).

Keywords. stars: evolution, galaxies: starburst, stars: mass loss, stellar dynamics

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Our calculations of the evolution of very massive stars are based on the results of Nadyozhin & Razinkova (2005) who constructed stellar structure models for these objects using the similarity theory of stellar structure. Their models correspond to chemically homogeneous stars, having Thompson scattering as the only opacity source throughout. This provides an accurate treatment, since extremely massive stars are almost completely convective during their evolution, and the opacity differs significantly from the Thompson scattering value only in a thin layer near the surface of the star. Our stellar parameters should therefore be reliable, with the possible exception of the effective temperature.

Kudritzki (2002) studied line-driven stellar winds of very massive stars and calculated mass loss rates of very massive O-type stars as a function of metallicity, in the range $6.3 \leqslant \log(L/L_\odot) \leqslant 7.03$ and $40\,\mathrm{kK} \leqslant \mathrm{T}_{\mathrm{eff}} \leqslant 60\,\mathrm{kK}$. The mass loss rates are smallest for the highest T_{eff}. We use his interpolation formula for the 40 kK models to compute the mass loss rates of our evolutionary models, meaning that we obtain an upper limit to the mass of a model star at all times. Note that for a given luminosity, we ensure that the mass loss rate never exceeds the maximum for line-driven winds, as given by Owocki (2004).

Fig. 1 shows the masses of very massive stars (with initial central hydrogen abundance $X_{\mathrm{c},0} = 0.68$) at the end of the core helium burning stage for 3 different metallicities. It is seen that only very massive stars at sufficiently low metallicities are expected to produce pair-instability supernovae and direct collapse black holes (compared to the limiting masses from Heger *et al.* (2003)). At high Z, the stellar wind mass loss rates

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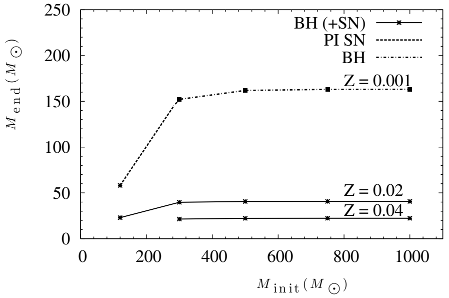

Figure 1. Masses of massive and very massive stars ($X_{\rm c,0} = 0.68$) at the end of the core helium burning stage for 3 different metallicities (see labels). Note the almost constant final mass of very massive stars, which is due to the properties of the $\dot{M} - L$ relationship that is used. Also, the dashed part of the $Z = 0.001$ curve indicates stars that are expected to explode as pair instability supernovae, leaving no remnant.

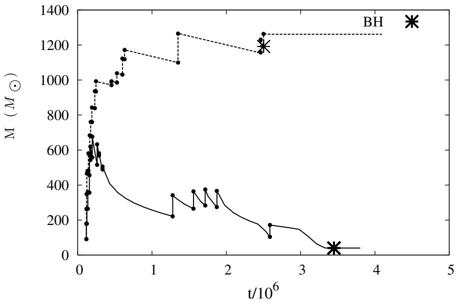

Figure 2. Evolution of the mass of the runaway merger in a King ($W_0 = 9$) N-body model containing 3000 massive single stars ($M \geqslant 10\,M_\odot$) and with a half mass radius of 0.5 pc. The doted line represents a model in which any star more massive than 120 M0 is given a constant mass loss rate of $10^{-4} M_\odot/yr$. The full line represents a model in which those same stars are treated with the mass loss rates of Kudritzki (2002). The star symbols denote the moment at which the runaway merger collapses into a black hole.

reduce the stellar mass to such an extent that only black holes due to accompanying supernova and fallback result.

We implemented this evolution scheme in our direct N-body code 'Youngbody' and computed models of young dense starburst regions showing the creation of so-called runaway mergers. Fig. 2 shows a typical example and indicates that the reduction of mass by stellar wind is able to compete with the growth of the runaway star due to stellar collisions, at least in the later stages. In this model the core collapse stage is over before the merger ends its life and therefore mass loss is able to reduce the stellar mass sufficiently to prevent the formation of an intermediate mass black hole. This suggests that Ultra Luminous X-ray sources (ULXs) may not be IMBH accreting at rates close to the Eddington rate, but could be stellar mass BHs ($\approx 50 - 100\,M_\odot$) accreting at Super Eddington rates (Soria 2007).

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