On the possible formation of IMBHs through runaway merging in dense stellar clusters

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N-body problem: numerical methods and applications

Outline

Outline

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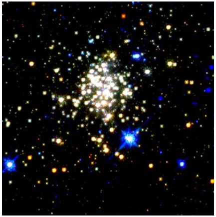
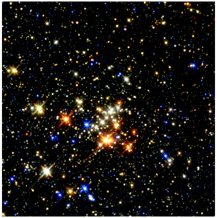
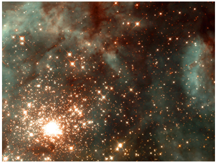
Young Dense Clusters

Arches



Quintuplet





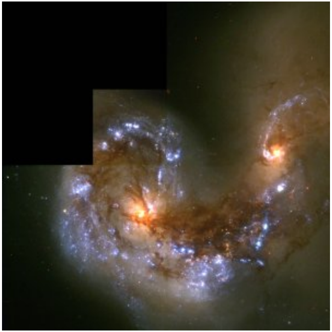
Westerlund 1

R136 (30 Doradus)

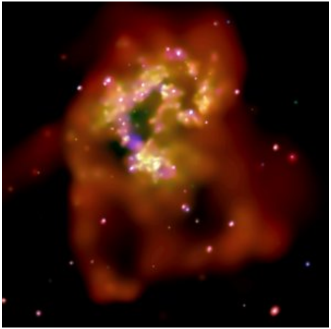
ULXs and IMBHs

Example: Antennae

Optical



X-ray



observed ULX luminosities: assuming compact object as source requires $M \gtrapprox 100\, M_{\odot}$, i.e. IMBH

Runaway Merger Formation

if $t_{cc} < t_{evol}$ and stellar density high enough

$\downarrow$

stellar collisions

$\downarrow$

possibility of runaway merger of upto 1000 $M_{\odot}$

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if $t_{cc} < t_{evol}$ and stellar density high enough

↓

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↓

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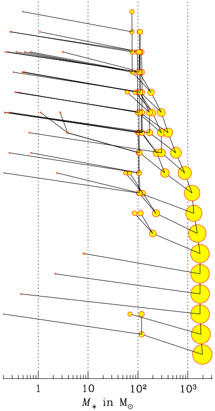


from Gürkan et al. (2006)

Runaway Merger Formation

if $t_{cc} < t_{evol}$ and stellar density high enough

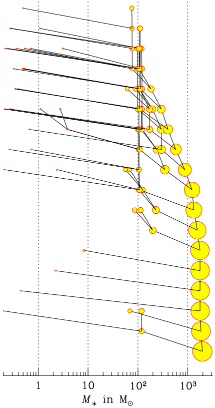
↓

stellar collisions

↓

possibility of runaway merger of upto 1000 $M_{\odot}$

However, very massive stars have huge stellar winds



from Gürkan et al. (2006)

Source Data for Evolution

Similarity theory of stellar structure (Nadyozhin & Razinkova 2005):

Assumptions:

- Chemically homogeneous stars
- Thomson scattering only

Output:

Luminosity	$L = L(\mu^2 M)$
Radius	$R = R(\mu^2 M)$
Convective core mass	$M_{cc} = M_{cc}(\mu^2 M)$

μ = molecular weight of gas

$\longrightarrow$ results for $\mu^2 M \leq 4000\ M_\odot$

Integration Technique

Evolution of central abundances:

- Core Hydrogen burning

$$M_{cc}\frac{dX}{dt} = -\frac{L}{\epsilon_H}$$

- Core Helium burning:

$$M_{cc}\left(\frac{B_Y}{A_Y}\frac{dY}{dt} + \frac{B_C}{A_C}\frac{dC}{dt} + \frac{B_O}{A_O}\frac{dO}{dt}\right) = -L$$

$+$ relations $C = C(Y)$ and $O = O(Y)$ (Langer 1989a, b)

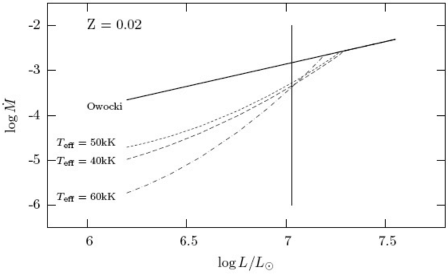
Evolution of stellar mass:

$$\frac{dM}{dt} = \text{any } \dot{M}(M, L, X, Y, \ldots) \text{ formalism}$$

Used Mass Loss Rate Formalisms
Core Hydrogen Burning

Theor. predicted line driven wind rates for very massive O-type stars (Kudritzki 2002)

$\longrightarrow \dot{M} = \dot{M}(L, T_{\mathrm{eff}}, Z)$ through interpolation formulae



See Yungelson et al. (2007) for different formalism.

Used Mass Loss Rate Formalisms

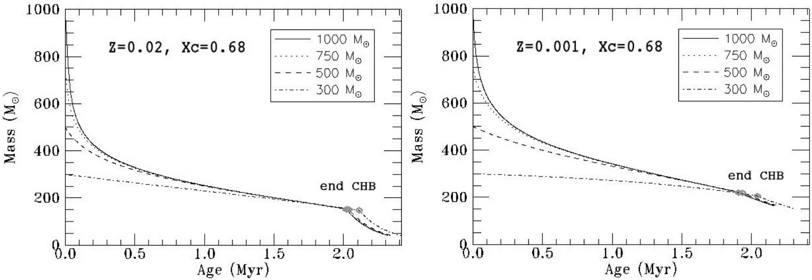
Core Helium Burning

Our preferred formalism:

$$\log \dot{M} = \log L - 10 + 0.5 \log \left(\frac{Z}{Z_\odot} \right) \quad \text{(Vanbeveren 1998)}$$

Note: produces very similar results compared to rates of Nugis & Lamers (2000)

Mass Evolution

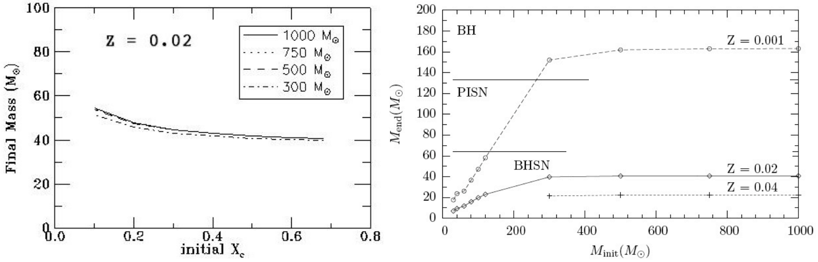


Early tendency towards similar masses

due to high $\frac{d \log \dot{M}}{d \log L}$, i.e. $\frac{d \log \dot{M}}{d \log M}$

Final Masses

Final masses mostly independent of initial mass, but not metallicity



Note: role of eruptive mass loss through LBV-type events?

(Smith & Owocki 2006)

Youngbody

Design

- direct N-body code
- modular OO design (C++)
- population & spectral synthesis module for massive stars: contains Brussels library of binary evolutionary tracks: note: consistent evol. tracks of accretion stars
- (MPI parallellisation for Beowulf type clusters)

Youngbody

Integration Techniques

Single stars and center of masses of complex hierarchies: 4^{th} order Hermite integrator with blockstep scheme.

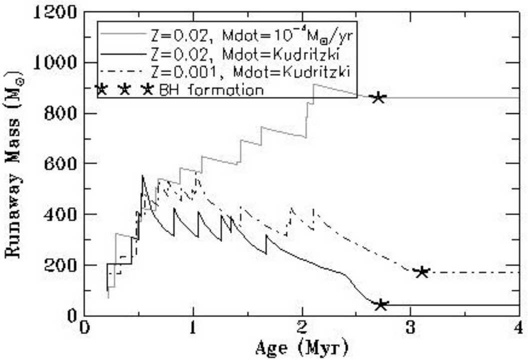
Close encounters:

- two-body encounters: KS regularization with Stumpff functions (Mikkola & Aarseth 1998)
- multi-body encounters: chain regularization (Mikkola & Aarseth 1990, 1993)

Mass Evolution of Runaway Merger

Model:

- 3000 massive stars only ($M > 10\,M_\odot$)
- $\mathrm{R_{hm}} = 0.5$ pc
- King $W = 9$ density profile
- no prim. binaries



Summary

- Very massive stars tend toward very similar final masses if $\frac{d \log \dot{M}}{d \log L}$ is large enough.
- Formation of IMBHs at solar Z through runaway merging is unlikely, but feasible at low Z.