The growth of massive stars via stellar collisions in ensemble star clusters

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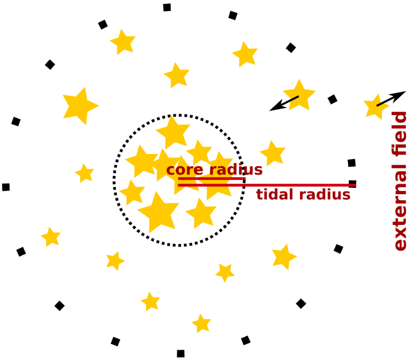
Outline

Relevant star cluster properties

Properties

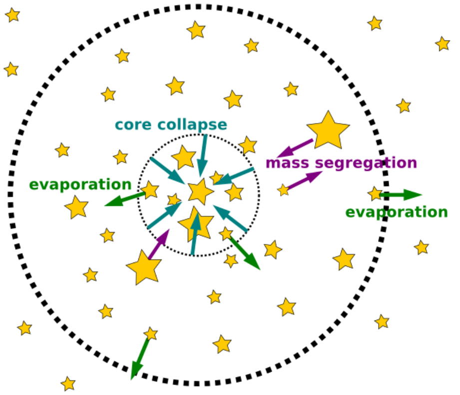
	Young C.	Globular C.
Mass	$10^3 - 10^5$ $\mathrm{M}_\odot$	10^6 $\mathrm{M}_\odot$
Size	1 pc	10 pc
σ_v	10 km/s	10 km/s
t_{relax}	50 Myr	3 Gyr
t_{cc}	7 Myr	1 Gyr



- **Core radius**: where density is $\frac{1}{3}$ of the central one; usually the core is a strongly interacting subsystem
- **Relaxation time**: necessary to lose memory of initial conditions (initial v distrib. $\rightarrow$ Maxwellian one)

Relevant star cluster processes

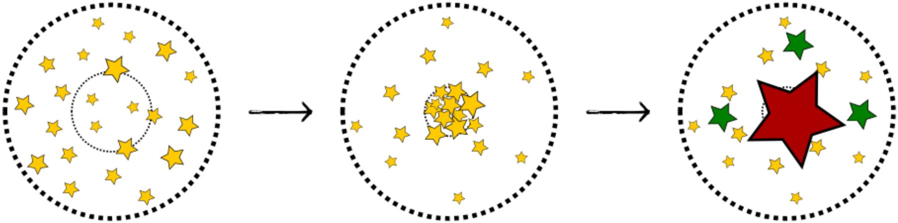
- **Evaporation:** stars with $v_i > 2\sqrt{\langle v^2 \rangle}$ can escape the system $\Rightarrow$ with Maxwellian velocities there are **always stars leaving the system**
- **Core collapse:** stars evaporate $\Rightarrow$ **K does not balance W** $\Rightarrow$ *core contracts* $\Rightarrow$ `density increases` $\Rightarrow$ more evaporation $\Rightarrow$**K does not balance W** $\Rightarrow$ *core contracts* $\Rightarrow$ ...
- **Mass segregation:** IMF + $m_i v_i^2 = m_j v_j^2$ + dynamical friction = **massive stars move to the core** and lighter ones move towards the external regions



* **During the core-collapse the density in the core increases dramatically**
* Mass segregation **enhances** core collapse!

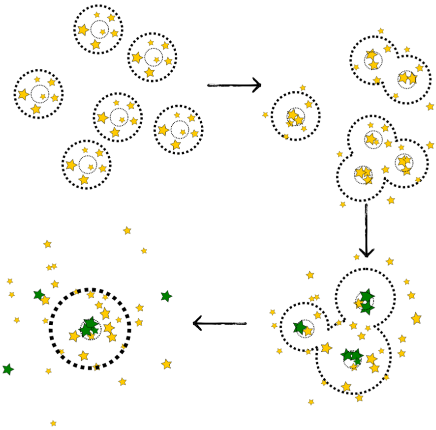
Core-collapse and runaway merger

- Observations found **super-canonical stars** $(150 - 300\,\mathrm{M}_\odot)$ we cannot explain with our stellar evolution models
- Need a mechanism to create them $\Rightarrow$ **runaway merger:** multiple collisions between massive stars
- To obtain it $\Rightarrow$ many stars in a localized dense region $=$ SC core during **core-collapse**
- Core-collapse must occur **before** SN explosion of the most massive stars ($t_{cc} < 3$ Myr)



New in this paper

- First paper studying **runaway merger in an assemblage of sub-clusters**
- Previous studies: (**sub-**)virial and **with**(out) mass segregated ICs **solo**-clusters



Why is an assemblage of sub-clusters **more realistic**?

- Molecular clouds have multiple cores
- better reproduction SCs' **dynamical maturity**
- smaller SCs have **smaller relaxation time hence smaller** t_{cc}

Simulation details

Subclusters:

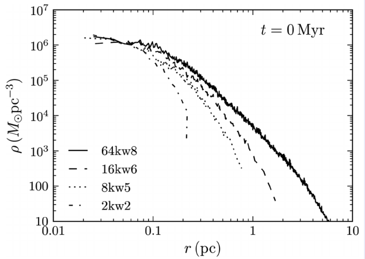
- $\sum m_i = M_{\rm solo}$
- Two different **King** profiles
- Sub-cluster models:
  - **2kw2:** $W_0 = 2$, $M_{\rm tot} = 6300\,\mathrm{M}_\odot$, $r_{\rm hm} = 0.092$ pc, N=2048
  - **8kw5:** $W_0 = 5$, $M_{\rm tot} = 2.5 \times 10^4\,\mathrm{M}_\odot$, $r_{\rm hm} = 0.22$ pc, N=8192

- **Salpeter IMF** with $M \in [1, 100]\,\mathrm{M}_\odot$: $\frac{\mathrm{d}N}{\mathrm{d}M} \propto M^{-\alpha}$, $\alpha \sim 2.35$
- 4 or 8 sub-clusters in a **sphere** or a **filament** (e.g. gas shock in galactic arms)

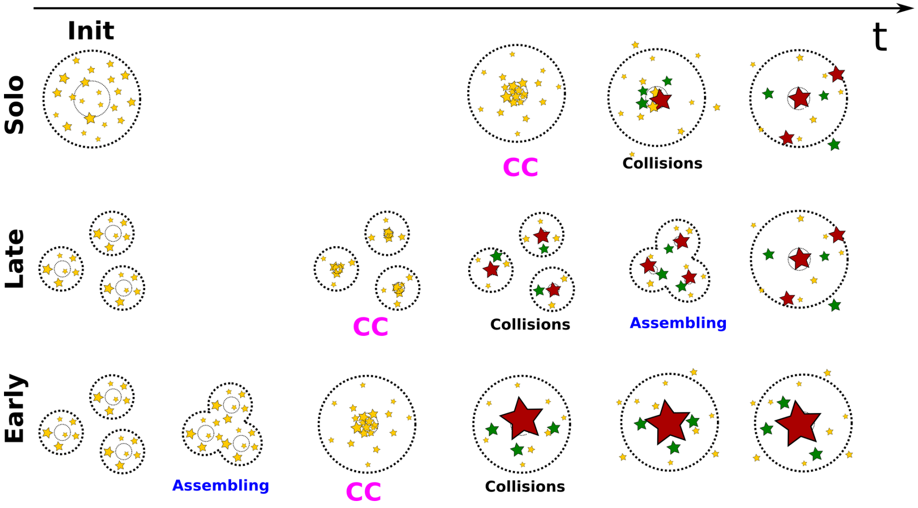
Solo models:

- Two more ICs (**16kw6**, **64kw8**)

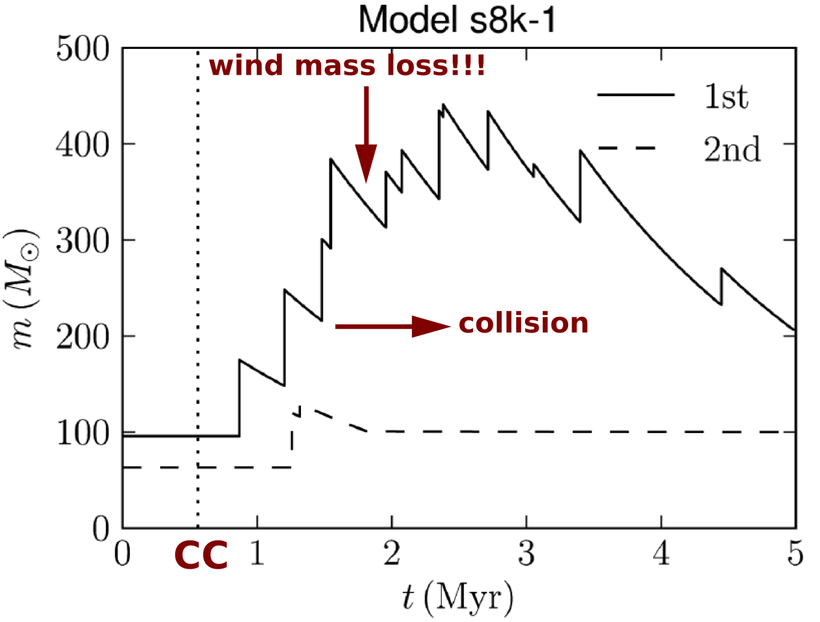
Initial ρ profiles



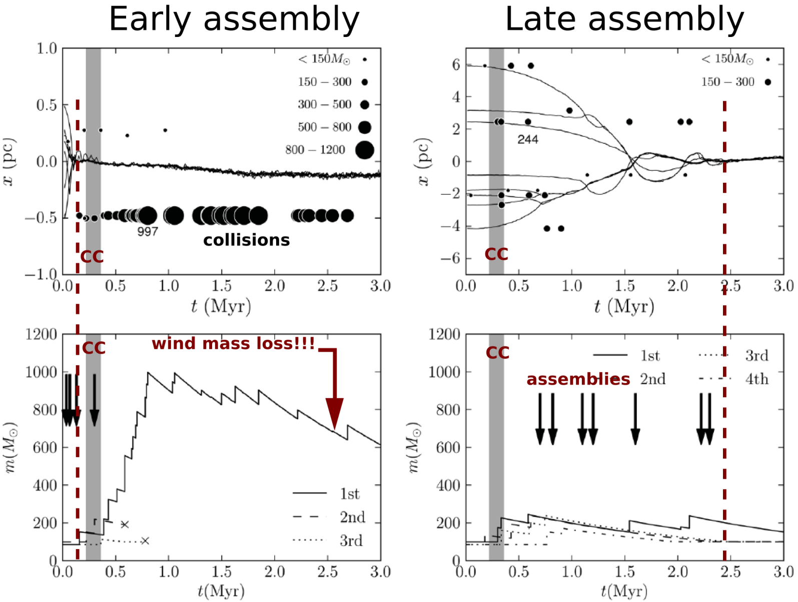
Simulations summary



Solo-cluster collision product mass



Assembly-clusters collision product mass



Conclusions 1

- Authors test the **runaway merger model** to produce massive stars in the sub-cluster **assembly scenario**
- The assembled-cluster evolution result depend upon t_{cc} vs t_{ens}
- **Late assembly ($t_{cc} > t_{ens}$):** dynamics prevents the formation of extremely massive collision products ($m_{\mathrm{MAX}} \lesssim 400\,\mathrm{M}_\odot$)
- **Early assembly ($t_{cc} < t_{ens}$):** the system can form collision products up to $10^3\,\mathrm{M}_\odot$ even if they experience wind mass loss after the collision

Conclusions 2

Strengths

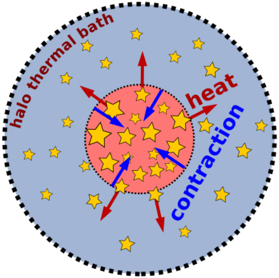
- First time runaway merger studied in assembly of sub-clusters
- Realistic scenario for the cluster formation
- 6-th order Hermite integrator $\rightarrow$ can handle binaries

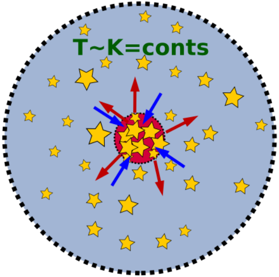
Weaknesses

- Sub-clusters half-mass radii are too small to be realistic (0.092 and 0.22 pc)
- $m_{\text{min}} = 1\,\mathrm{M}_\odot$ is too large
- Stellar winds only for $M > 100\,\mathrm{M}_\odot$ is unphysical $\rightarrow$ here only collision products can experience mass-loss

Gravothermal instability

- Star cluster $\sim$ gas cloud
- Strongly self-interacting systems have **negative heat capacity**
- kinetic energy $\rightarrow$ dynamical temperature: $K = \frac{1}{2}\langle mv^2 \rangle = \frac{3}{2} k_B T$
- From the virial the total internal energy $E = -K = -\frac{3}{2} N k_B \langle T \rangle$
- The **heat capacity** is then defined as $C \equiv \frac{\mathrm{d}E}{\mathrm{d}T} = -\frac{3}{2} N k_B < 0$
- If $K \searrow \equiv T \searrow$ (loss of stars) $\Rightarrow \mathrm{d}E = -\frac{3}{2} N k_B \mathrm{d}T > 0 \Rightarrow$ more stars evaporation and core contraction
- To make it happens the halo must behave like a **thermal bath** thus it must "absorb" the kinetic energy of the evaporating stars





Complete simulation scheme