Dynamical mass segregation on a short timescale

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Mass segregation

(Credit: European Southern Observatory)

- Observational phenomenon
- Basically an 'over-abundance' of massive stars as compared to low mass stars
- Happens on very short timescales ~ 1Myr for ONC
- Understanding MS tells us about cluster and star formation

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Mass segregation

- It has been shown that Plummer spheres can’t two-body relax on short (few Myr) timescales (Bonnell & Davis, 1998)
- How do young clusters mass segregate?
  - Primordial? Dynamical?

Mass segregation

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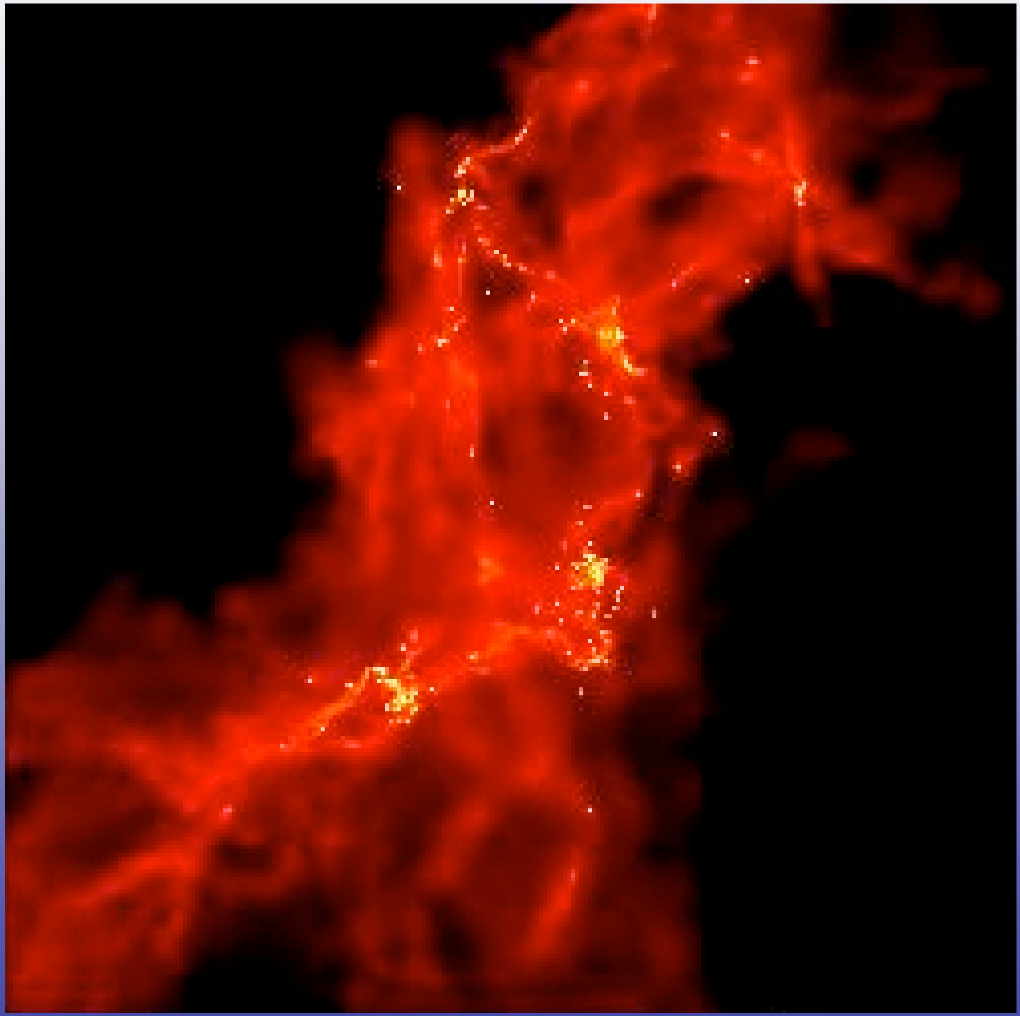
- Do clusters form as Plummer Spheres?

- What are the initial conditions of star clusters?
- How do these conditions affect the evolution of the cluster?

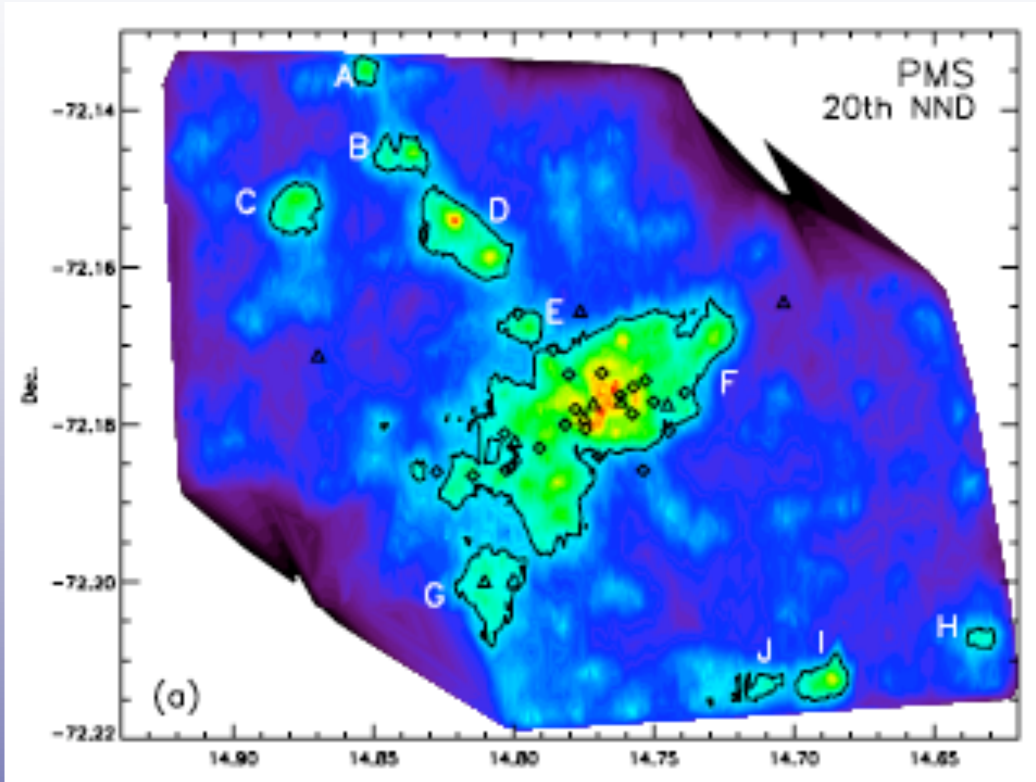
Young clumpy clusters

- Turbulence in molecular clouds causes star formation
- Power input is power-law
- $\Rightarrow$ Hierarchical structure



I. Bonnell

Young clumpy clusters…



NGC 346 (Schmeja, Gouliermis & Klessen, 2009)

- Observations show that young embedded clusters are clumpy

  (Cartwright & Whitworth, 2004; Elmegreen & Elmegreen, 2001)
- They are not spheres with a simple distribution of stars e.g. Plummer sphere

...become 'smooth' clusters

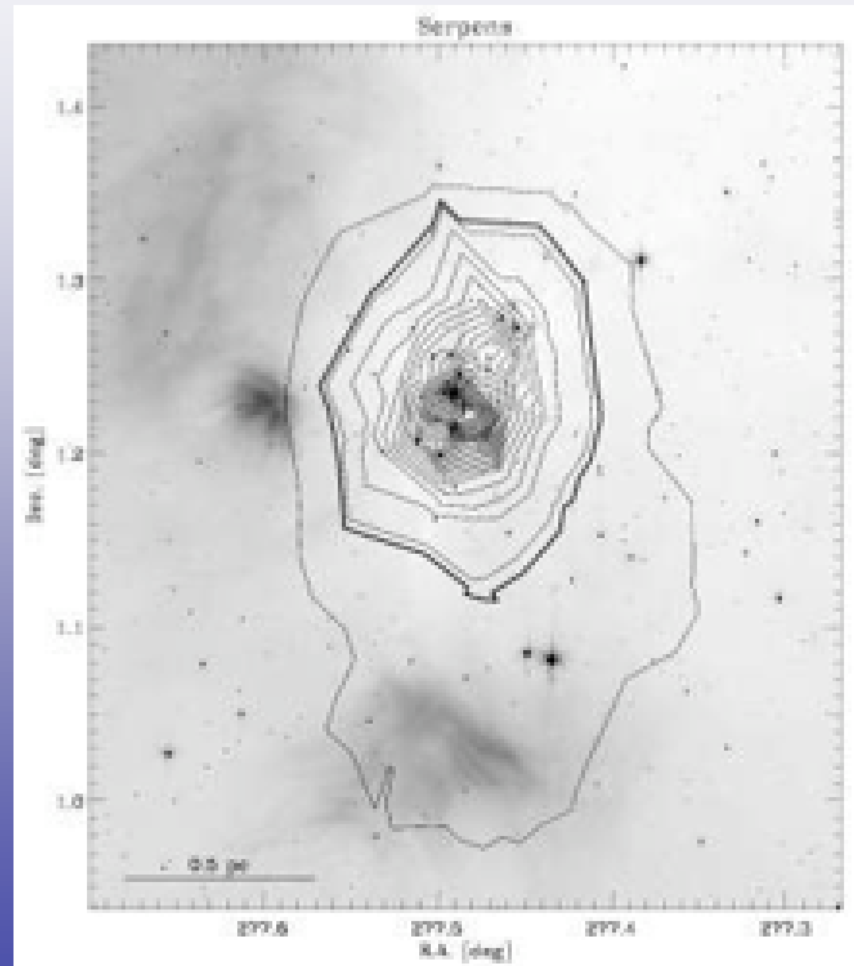
- As clusters age they loose their initial substructure

  (Schmeja et al., 2008)

- To erase substructure in short timescales clusters must initially have a cool virial ratio

  (Goodwin & Whitworth, 2004)

  (see also, Allison et al., 2009, ApJL, 700, 99)



Violent relaxation

- A cool substructured cluster is out of equilibrium
- A cool virial ratio will cause the cluster to collapse

- These conditions allow rapid global changes in the potential field
- This allows the cluster to relax in a crossing time

  → Violent Relaxation

- This leads to:
  - Erasure of substructure
  - Formation of dense core
  - Fast, dynamical Mass Segregation

MS mechanism

- The collapse of the cluster creates a short lived, dense core
- This dense core has a short relaxation time

$$t_{\rm seg} \propto \frac{\langle m \rangle}{M} t_{\rm relax}$$

(Spitzer 1969)

- The segregation time is inversely dependant on mass

$$t_{\rm seg} \propto \frac{\langle m \rangle}{M} \frac{N}{\ln N} \frac{R_{\rm core}}{\sigma_{\rm core}}$$

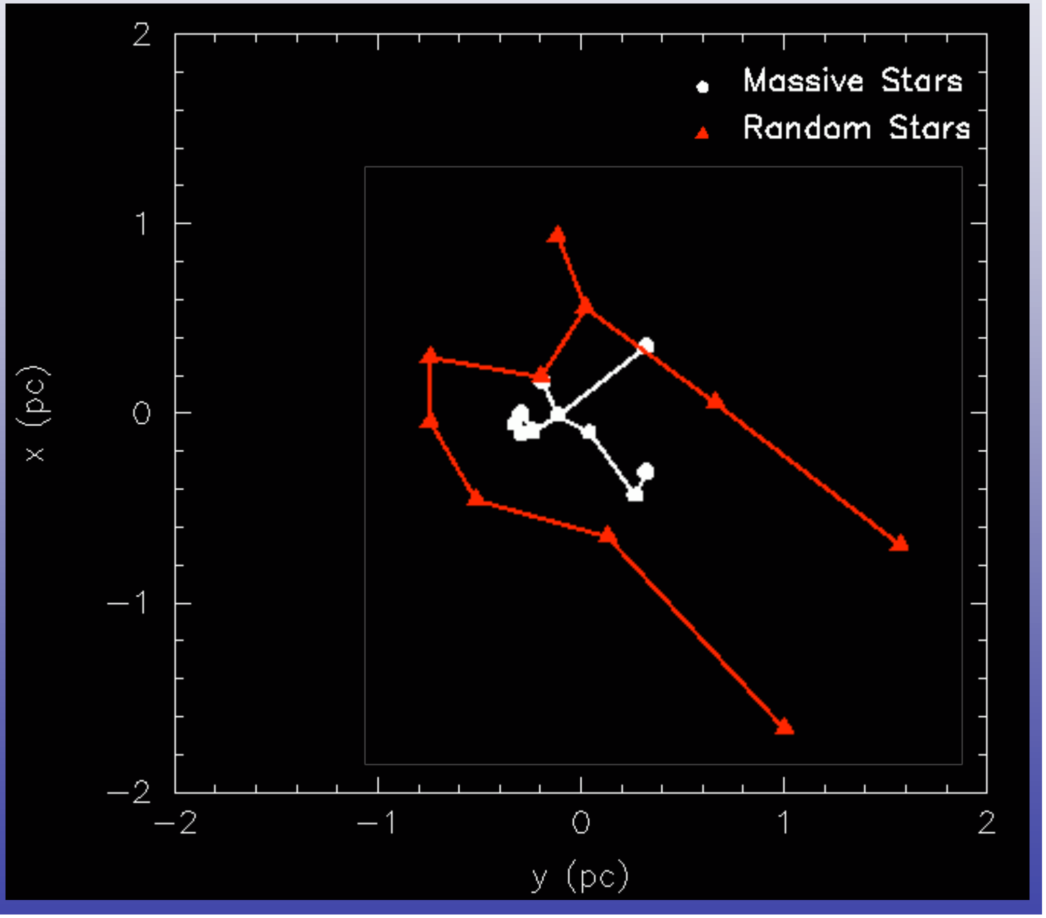
- So the massive stars relax and mass segregate on a short timescale

N-Body simulations

- Fractal stellar distribution (Goodwin & Whitworth, 2004)
- Fractal dimensions of 1.6, 2, 2.6, 3 (Highly fractal to less fractal)
- Virial ratios of 0.5, 0.4, 0.3 → Cool Clusters
- 50 RNS of D=1.6, Q=0.3
- 1000 stars
- Kroupa IMF
- No Initial Binaries
- No Gas
- 4 Myrs
- Used STARLAB's N-body integrator KIRA

Mass Segregation Ratio

- Mass segregation is a difference in the distribution of massive stars to other stars
- Comparing the MST of massive stars to random stars shows the presence of mass segregation

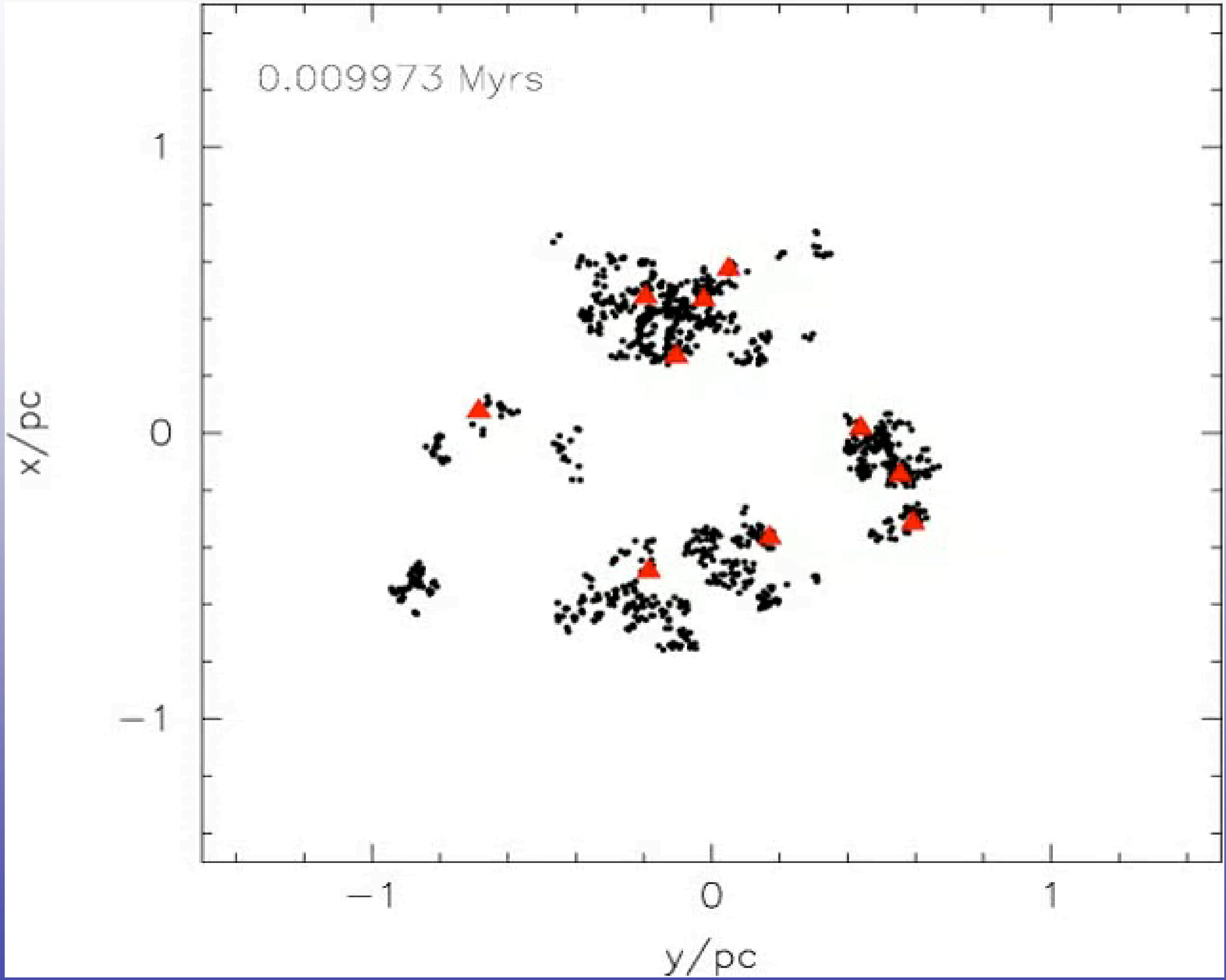


- Ratio gives quantitative measure of mass segregation with sigma

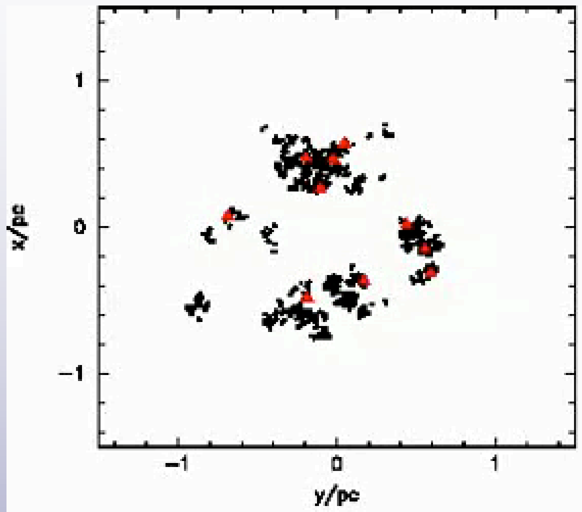
$$\Lambda = \frac{\langle RandomMSTLength \rangle}{MassiveMSTLength}$$

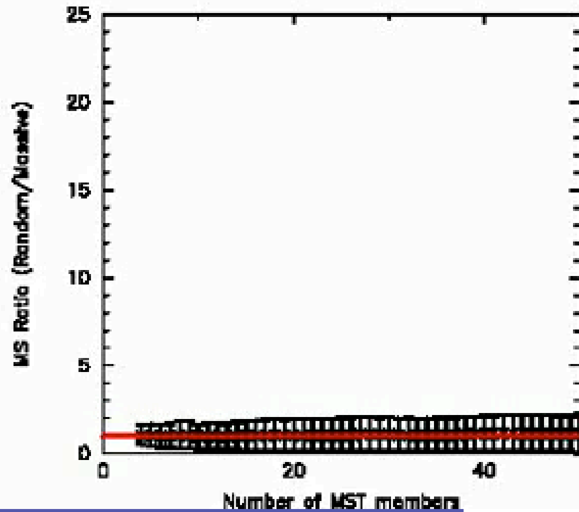
(Allison et al, 2009, MNRAS, 395, 1449)

Evolution of a fractal cluster



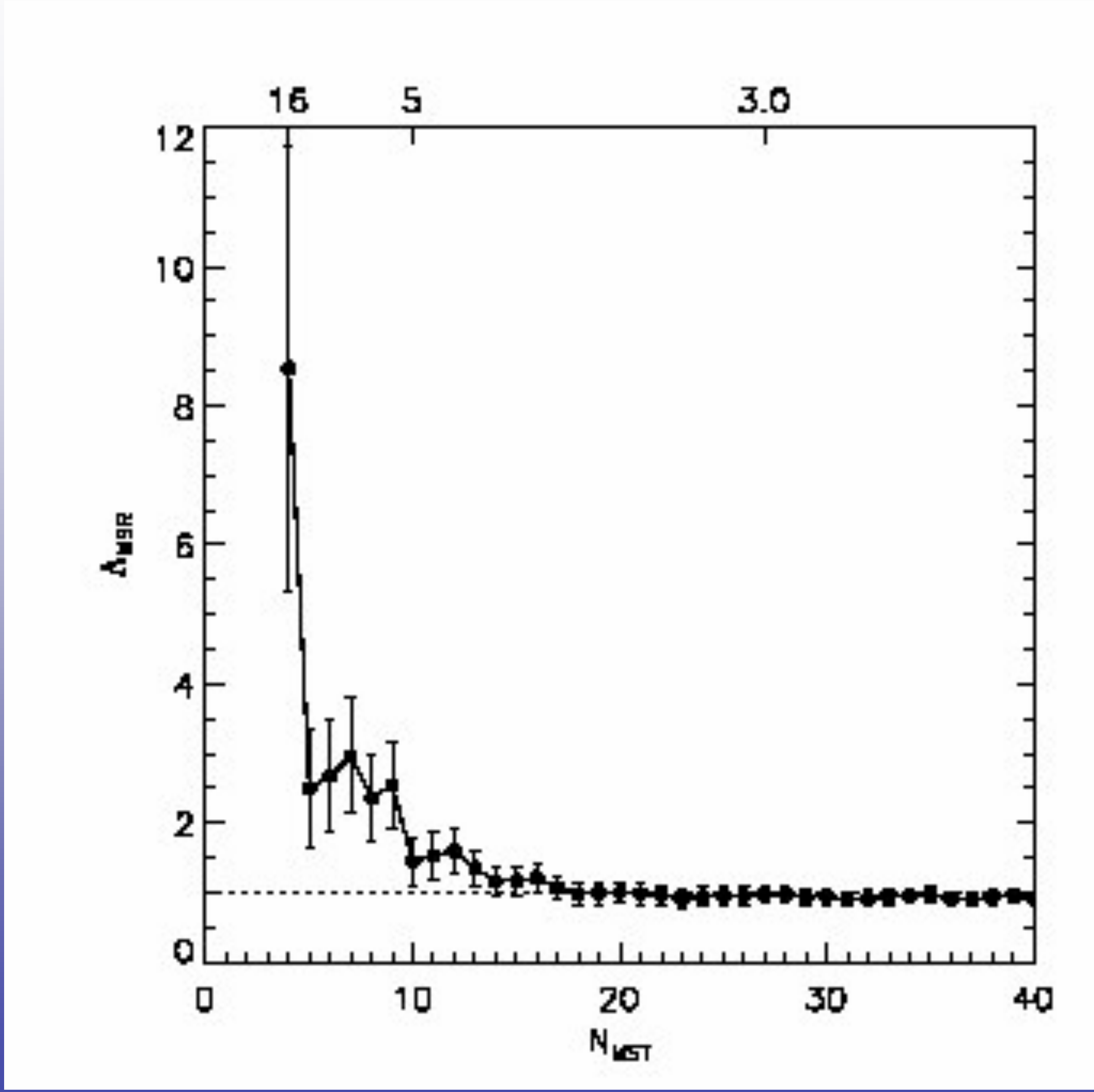
Evolution of a fractal cluster





$$M \propto \langle m \rangle \frac{1}{t_{\rm seg}} \frac{N}{\ln N} \frac{R_{\rm core}}{\sigma}$$

MS in the ONC

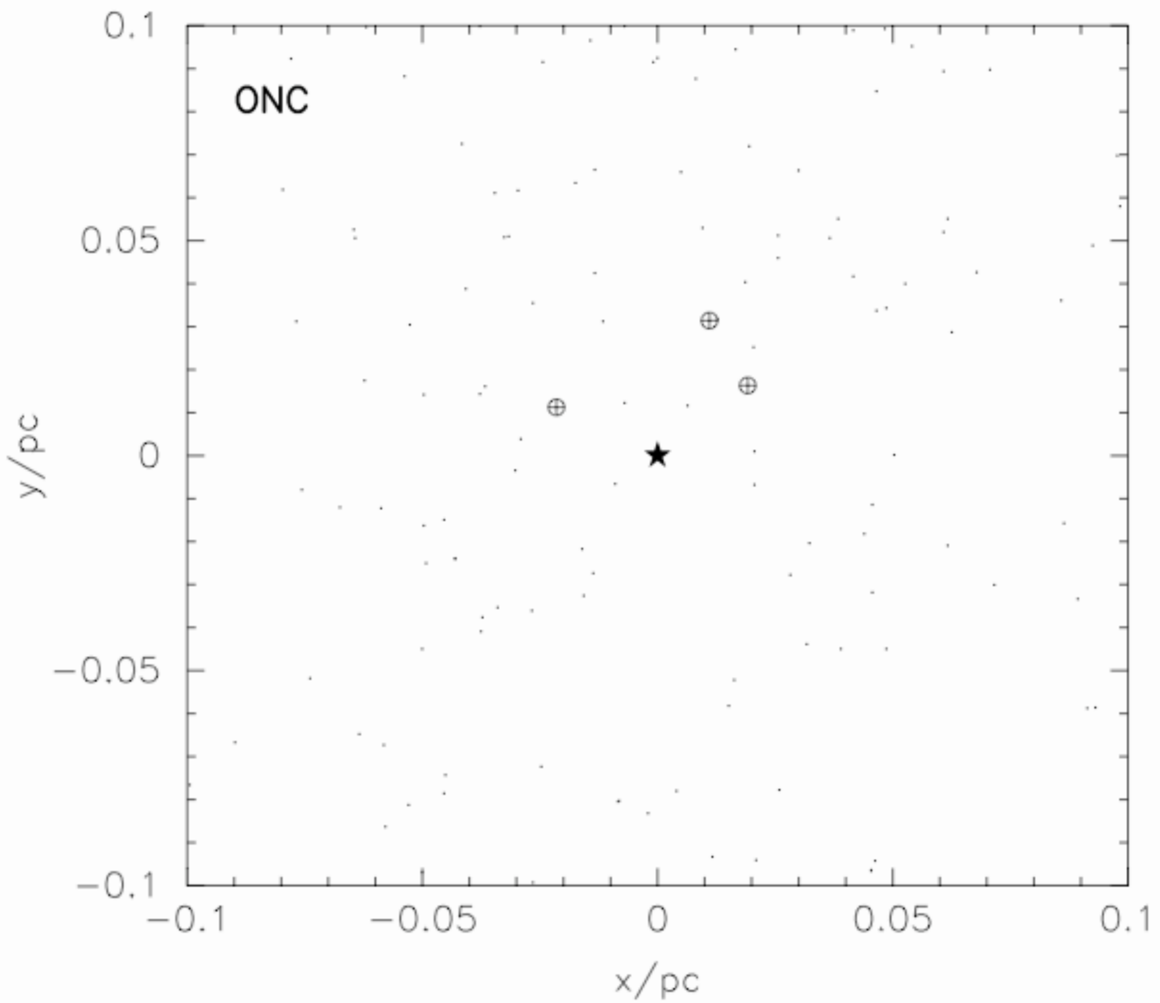


• Dynamical mass segregation?

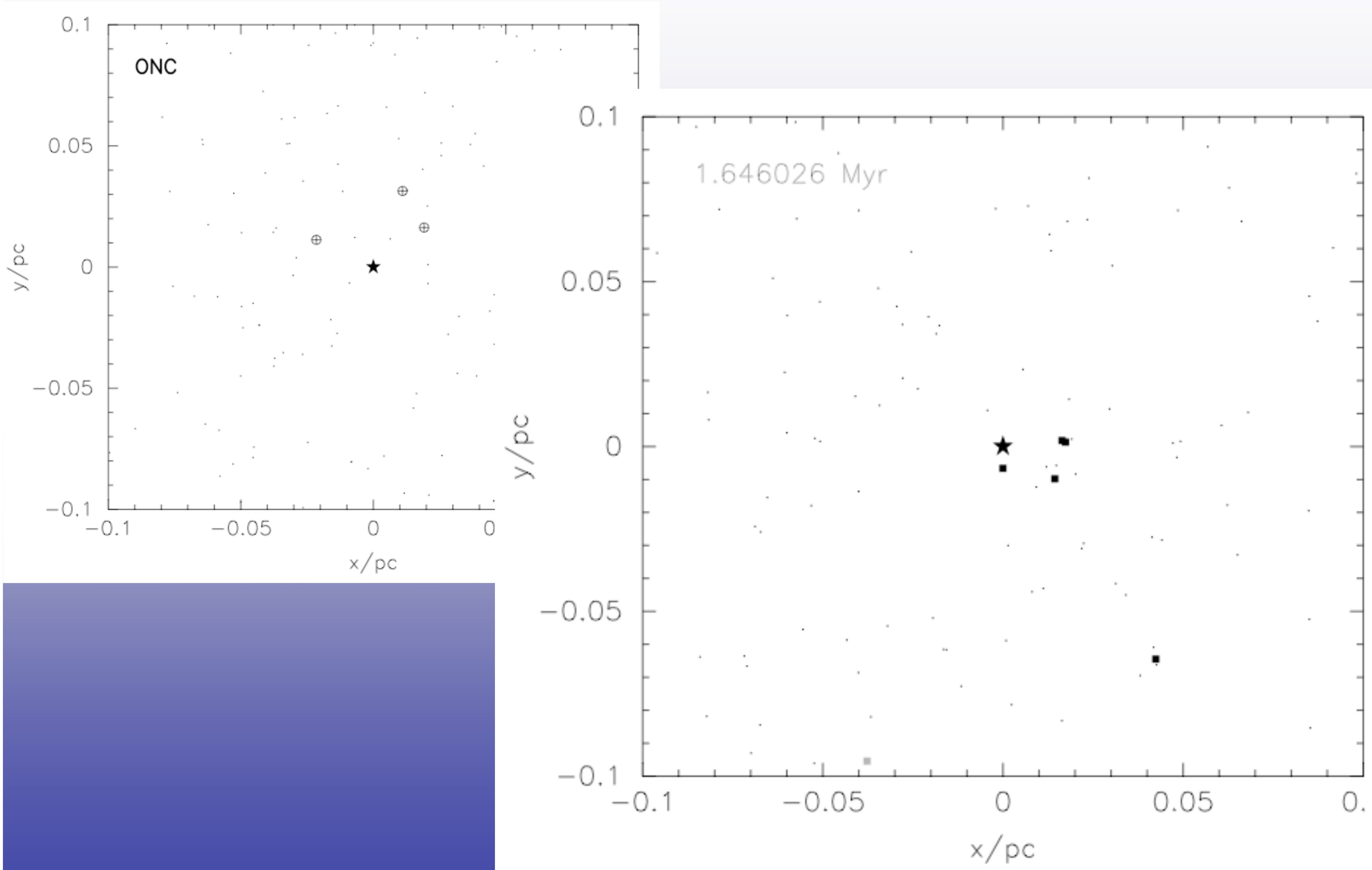
Other phenomena

- Very dynamic evolution leads to other interesting phenomena
  - Dynamical destruction of clusters
  - Rapid ejection of OB stars
  - Formation of 'Trapezium-like' systems

'Trapezium-like' systems



‘Trapezium-like’ systems



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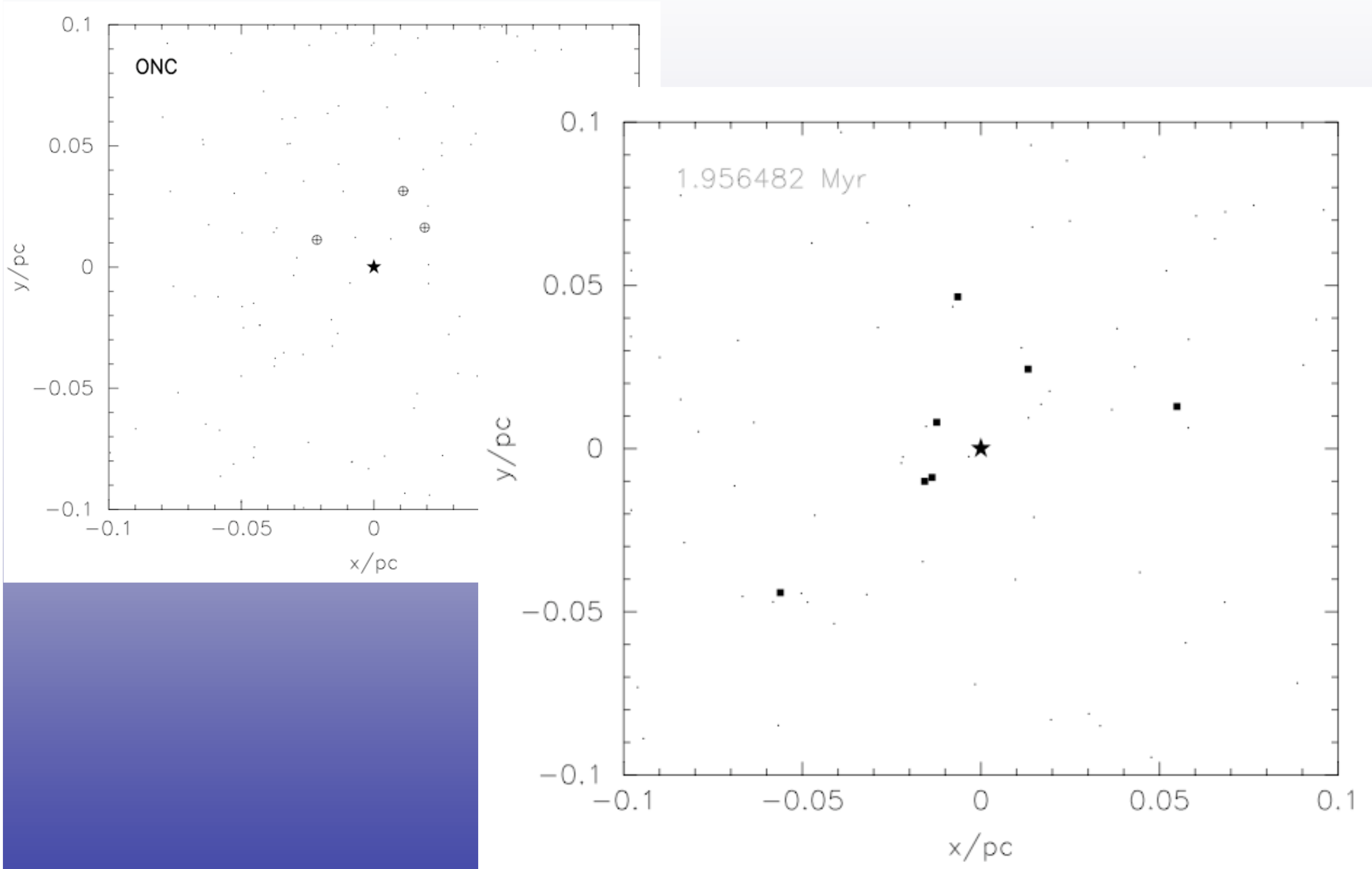

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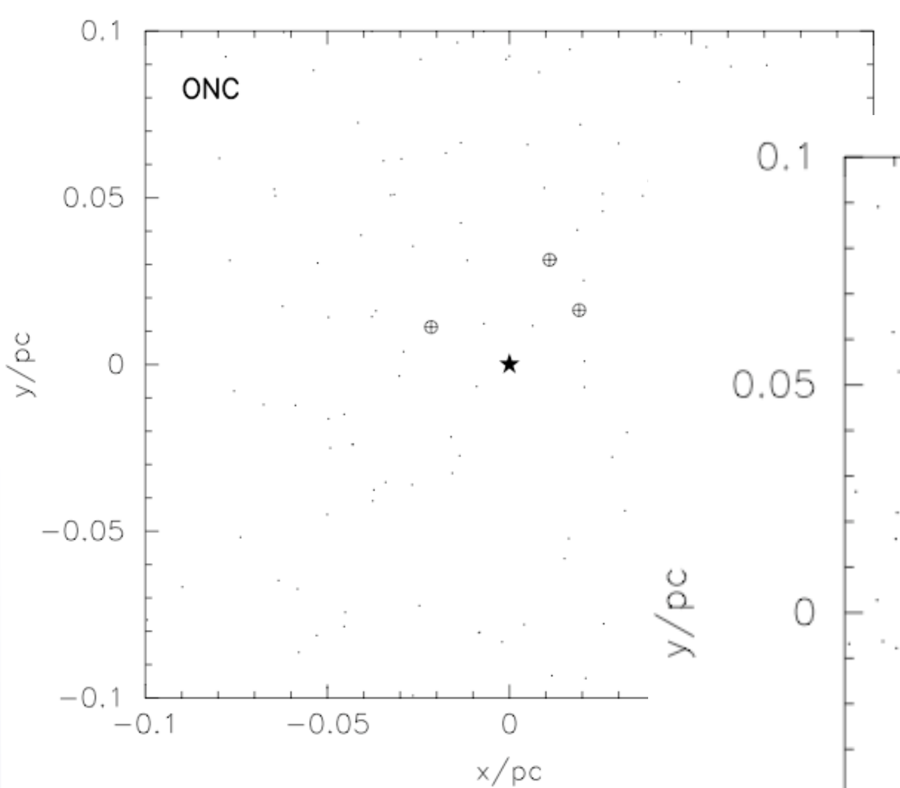

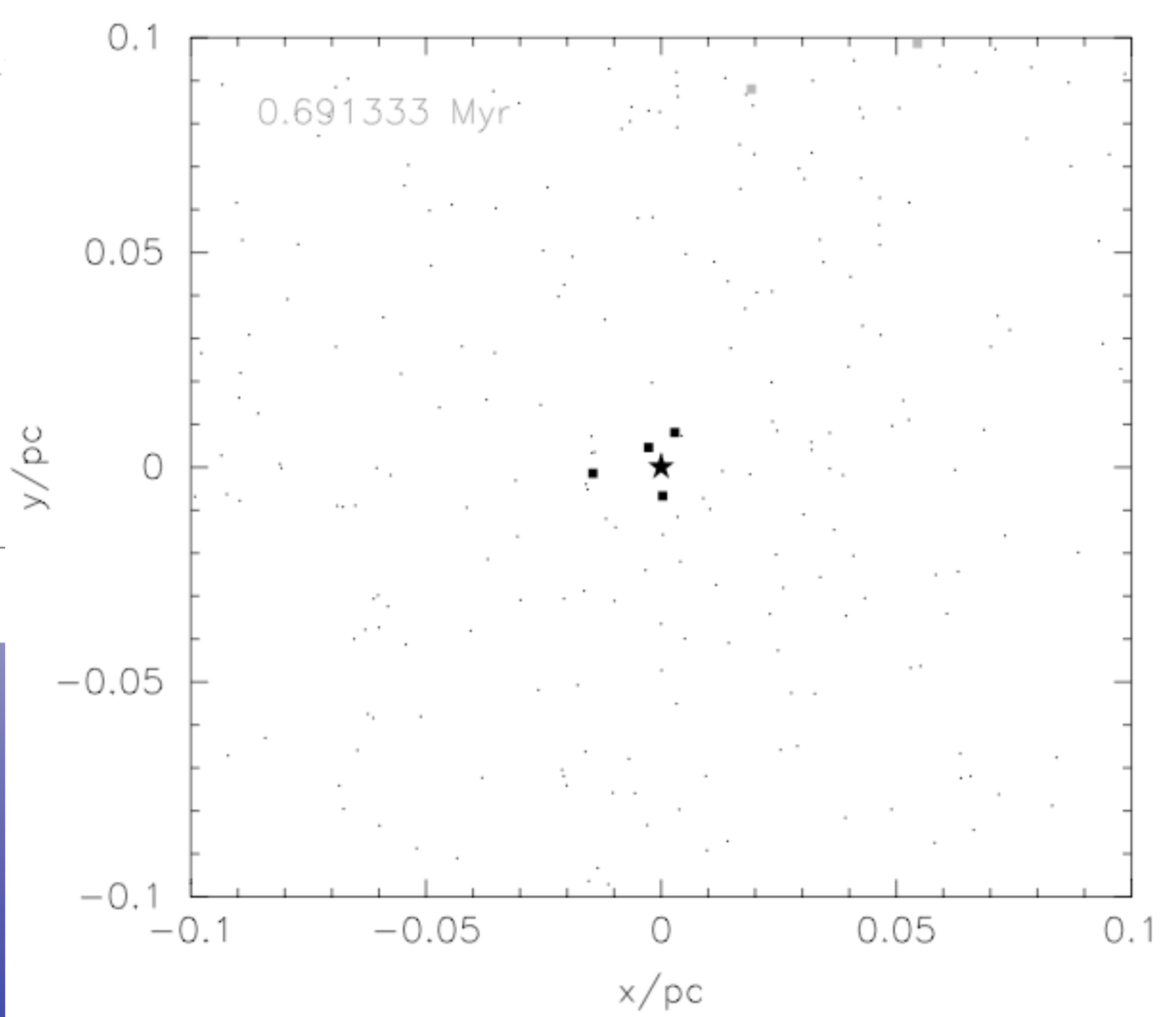

‘Trapezium-like’ systems

- The collapse of an initially clumpy cluster leads to the massive stars in a cluster being closely grouped

- Can it replicate the hierarchy we observe in the Trapezium?

- Currently our simulations cannot
  - could inclusion of primordial binaries solve the problem?

Conclusions

- Use the MST method to look at mass segregation, good for substructured clusters
- The collapse of cool, substructured clusters leads to fast dynamical mass segregation
- The collapse also leads to the formation of high multiplicity systems containing massive stars - Trapezium systems?

‘Trapezium-like’ systems