Hierarchical merged Star clusters – surviving infant mortality

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RERVM COGNOSCERE CAVSAS

Introduction

- Virtually all stars observed today originated in clustered regions
- Star clusters later dissolve to distribute stars throughout a galaxy
- Numerous destruction methods;
  - 2-body encounters
  - Tidal interactions
  - 'First hurdle': *Infant Mortality*
- Infant mortality = gas mass loss

'...it is amazing that any old star clusters exist at all'
S. Goodwin,
IAU270, Barcelona

A double star cluster observed in the Perseus star forming region

Background
'Clumpy star formation'

- Observationally & theoretically agreed – stars form unevenly within clumps of gas.

- Clumps lie along filamentary structures that are well produced by supersonic turbulence

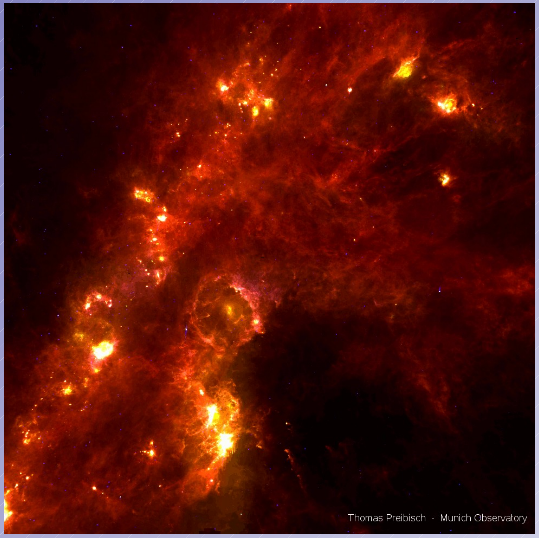
(right) Hydro dynamical simulations of a star-forming region

Key point (1):

Stars form in small *unevenly* distributed sub-clumps containing a few to a few dozen stars

Key point (2):

There is increasing observational & theoretical evidence that these stars may form sub-virially.



(left) IRAS image with the Taurus (upper left), Perseus (upper right), Orion (lower centre) regions

Background
Forming star clusters from sub clumps: Hierarchical merging

- Sub clumps interact within the potential of the surrounding molecular gas
- 2-body encounters, merging & tidal stripping form a central star cluster
- N.b. These star clusters are embedded (they are surrounded by the H_2 gas (and dust) from which they formed.

The trapezium cluster; (left) optical, (right) infrared – revealing numerous embedded stars

Background

Forming star clusters from sub clumps: Hierarchical merging

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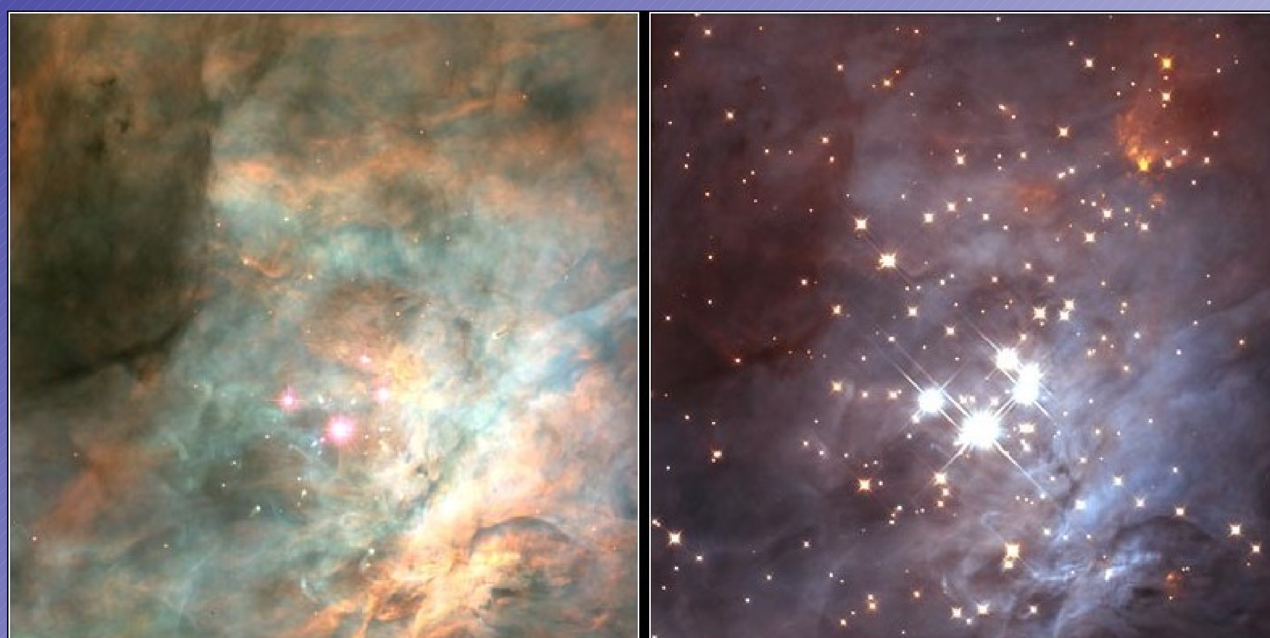
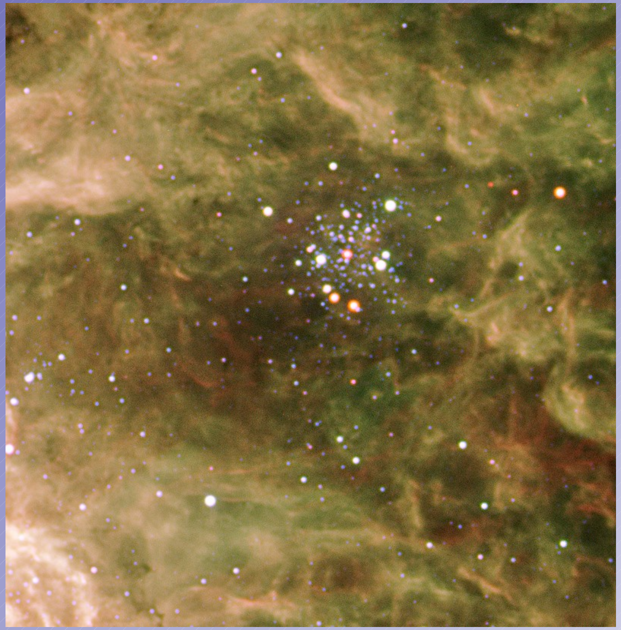


The trapezium cluster; (left) optical, (right) infrared – revealing numerous embedded stars

Background
Feedback & Mass-loss

- Remaining gas does not stay in the cluster for long
- Stellar winds / HII regions / Supernovae feedback drive gas out

Sudden mass loss leaves star clusters out of virial equilibrium
➔ Infant mortality: loss of *significant* fraction of stellar mass from fledgling cluster



Tarantula nebulae clusters:
(left) R136 containing young pre-supernovae stars,
(right) Hodge 301 containing >40 post-supernova stars

Questions

What properties must a star cluster have to survive gas expulsion?

What initial properties must the proto-stellar clumps have to form such a cluster?

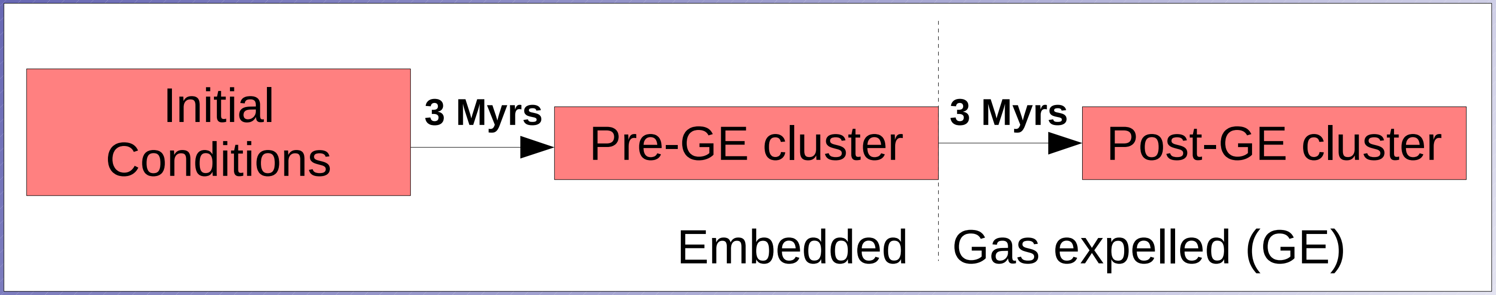
Approach

- Our simulation initial conditions are clumpy & irregular distributions of stars

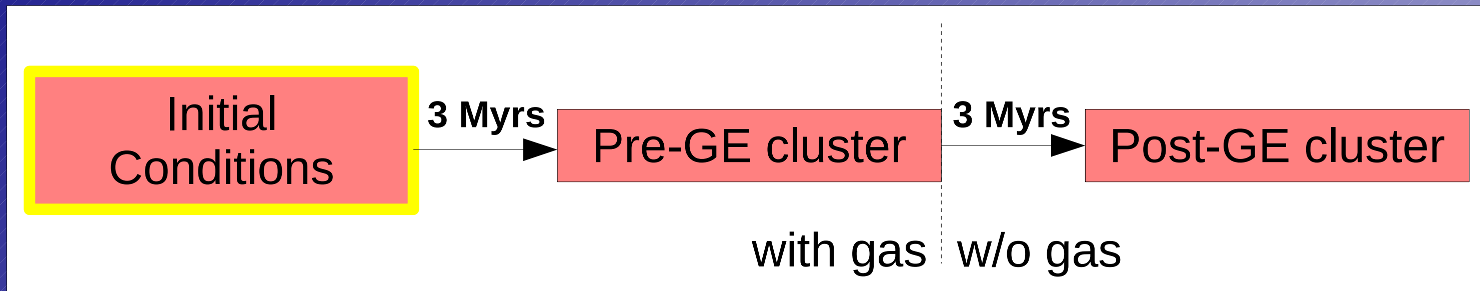
- Conduct accurate & fast, N-body simulations of the stellar component to the time of gas expulsion, and beyond. Code: N-Body2.

- Conduct a parameter study of survivability of star clusters to gas-mass loss.

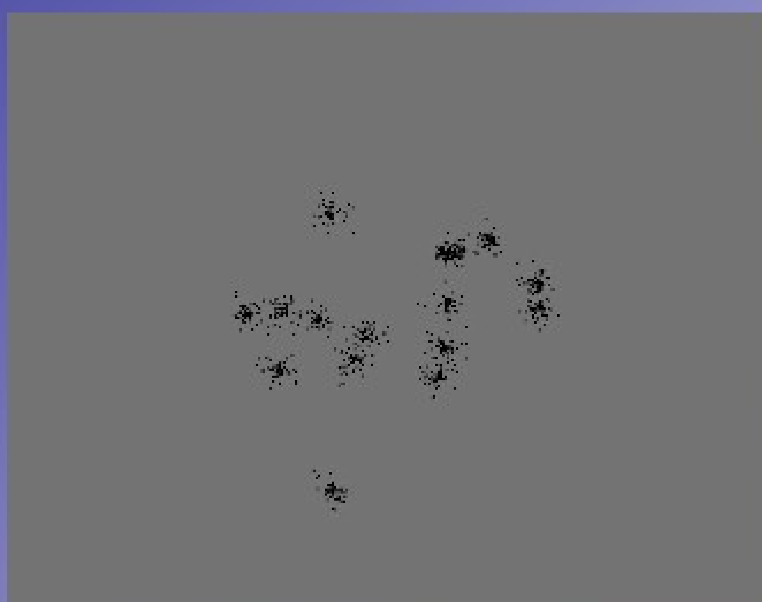
- Gas component modeled as static plummer back-ground potential. Gas expulsion (GE) is modeled by instantaneous removal of the background potential.

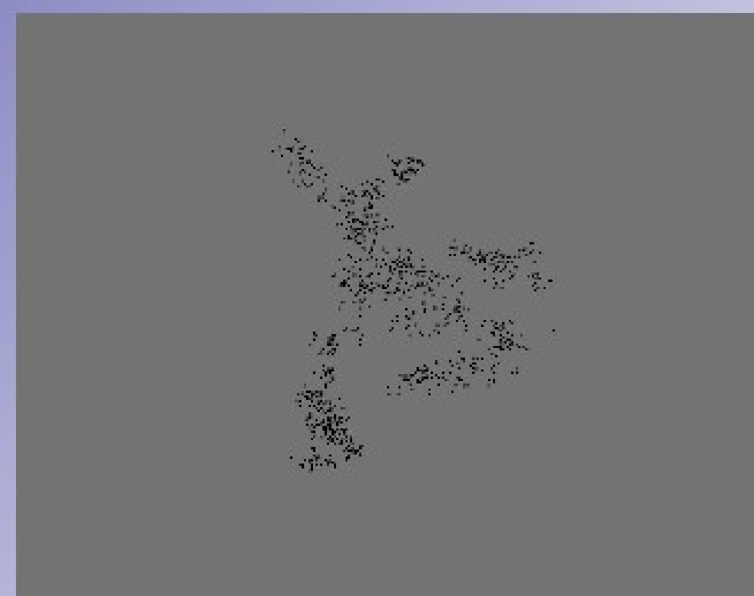


Simulations:
Initial Conditions



- Total mass: 2500 M_sol (r<1.5 pc), SFE=0.2 , N_* = 1000
- Morphology: Plummer or Fractal
- Initial virial ratio: Q=0.0 (icy) – 0.95 (hot)
- Gas potential shape: Shallow (rpl=1.5pc) – Deep (rpl=1.0 pc)

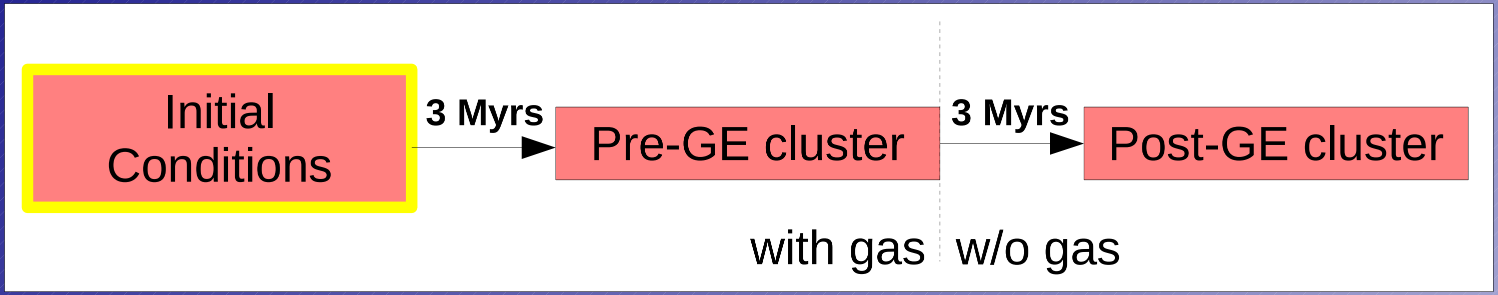




(Left) icy plummer distribution

(Right) hot fractal distribution

Simulations:
Initial Conditions

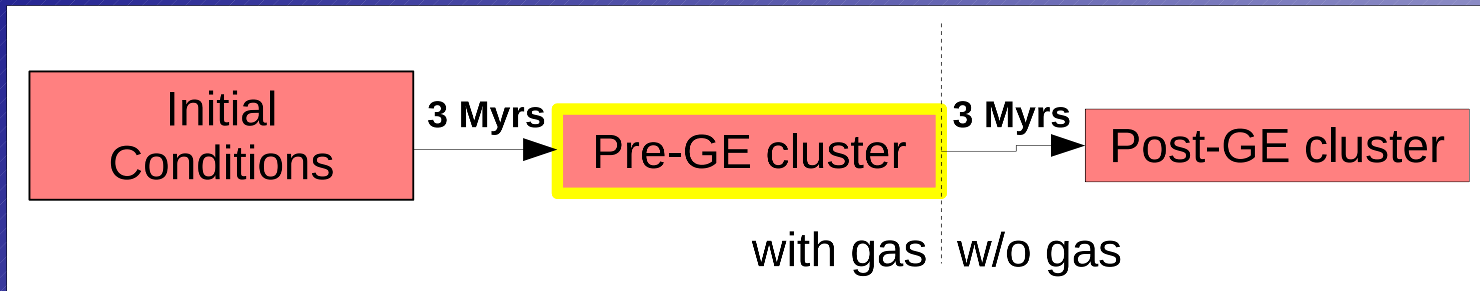


• Embedded phase assumed to last 3 Myrs
(about two crossing-times of the star forming region).

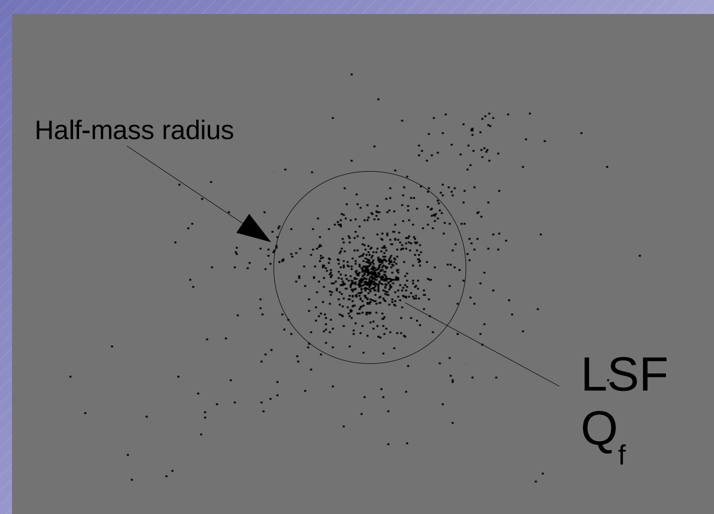
• During this time, the properties of the embedded cluster can change significantly

➔ Clumpy substructure is erased by scattering, clump collisions, tidal interactions
➔ Stars can redistribute themselves within gas potential, settling closer to the cluster centre (especially for cool initial dynamics)

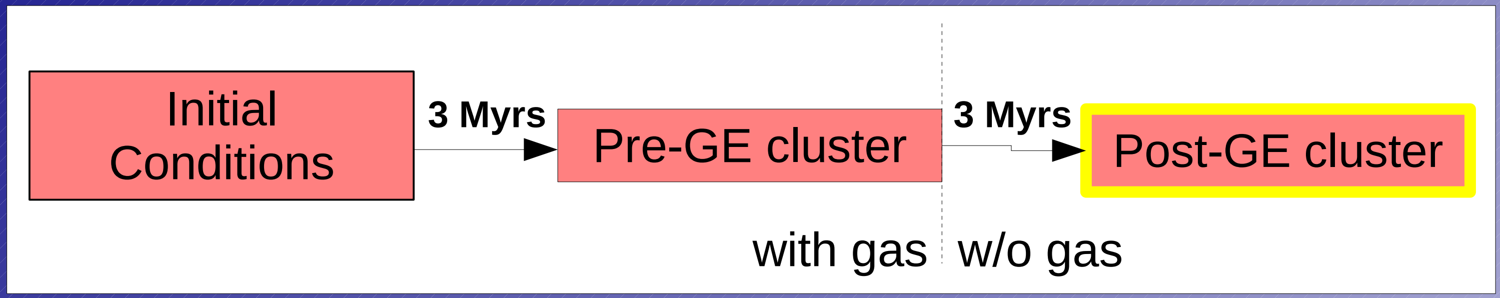
Simulations:
Pre gas-removal cluster properties



- Local Stellar Fraction (LSF) $LSF = \frac{M_{star}}{M_{tot}}$ (measured within half-mass radius of cluster)
- Pre gas-expulsion virial ratio (Q_f)

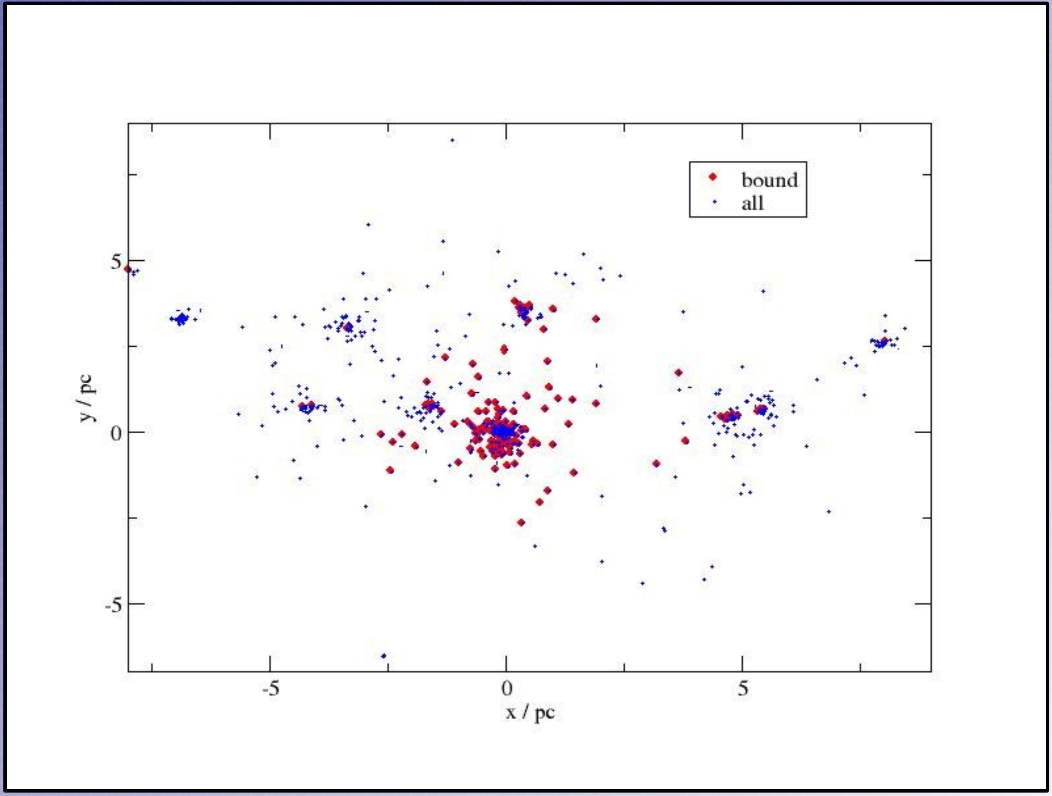


Simulations:
Final star cluster

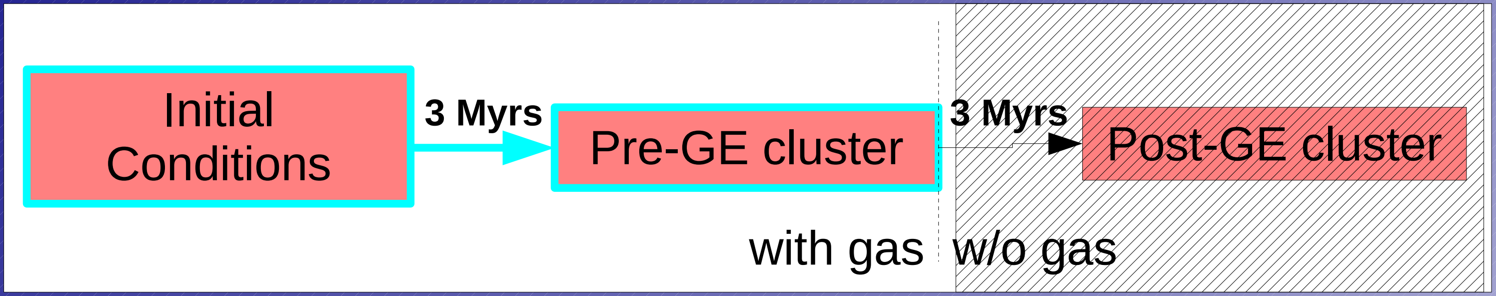


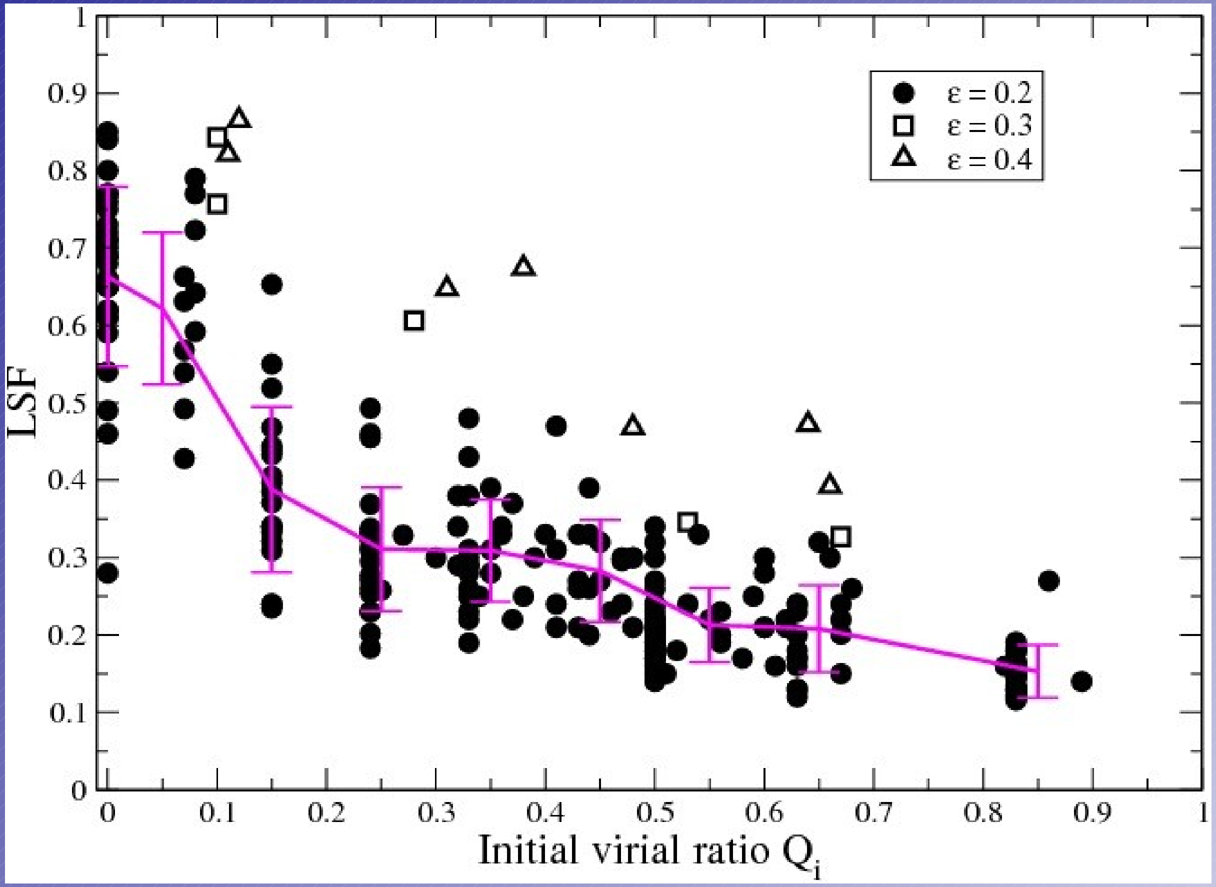
- Final star cluster mass measured:
- Number of stars bound to the cluster
- Measured as the bound fraction:

f_{bound} = bound stars ÷ total stars



Results
Embedded phase

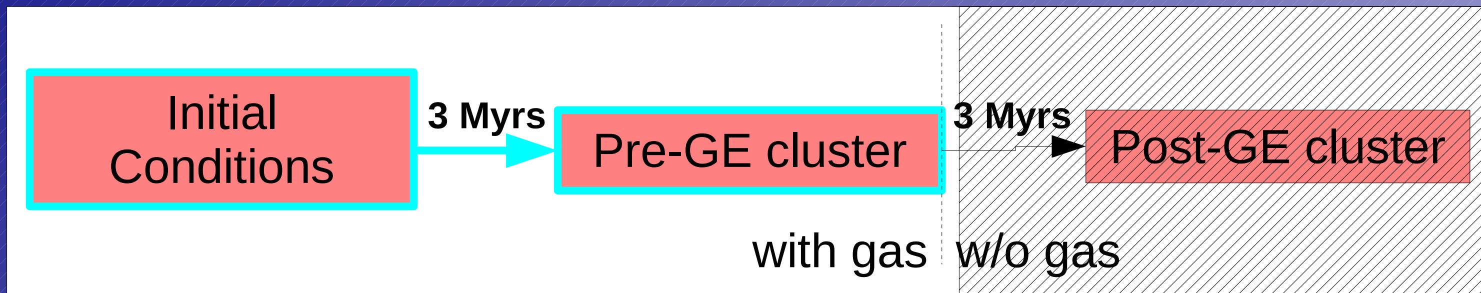


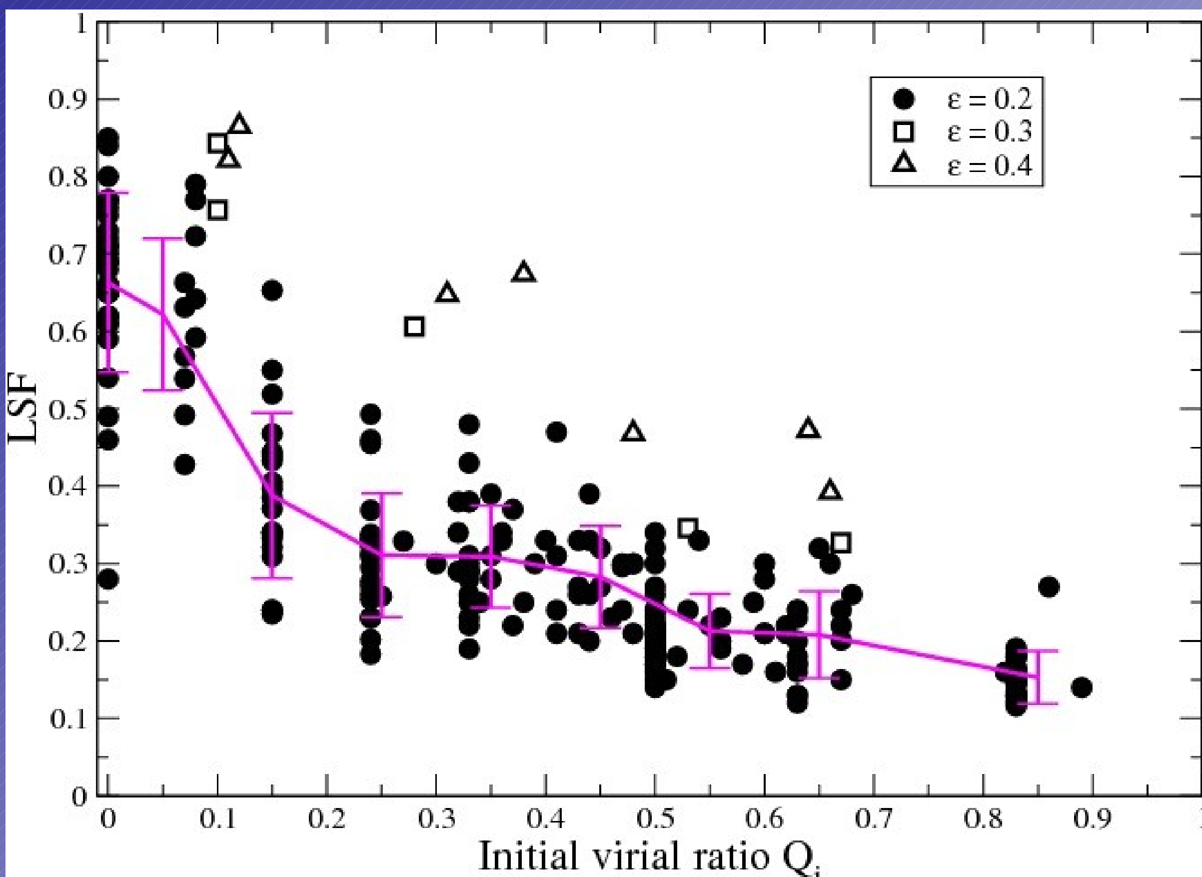


Higher SFE = Higher LSF (as expected – more stars=more stars)

Trend for increasing LSF With decreasing initial virial ratio: cooler=denser

Results
Embedded phase





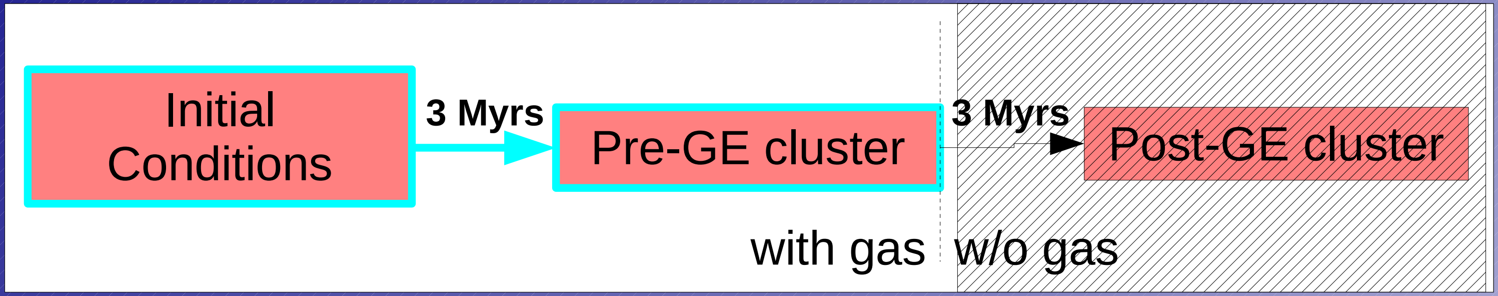
Trend for increasing LSF
With decreasing initial
virial ratio: cooler=denser

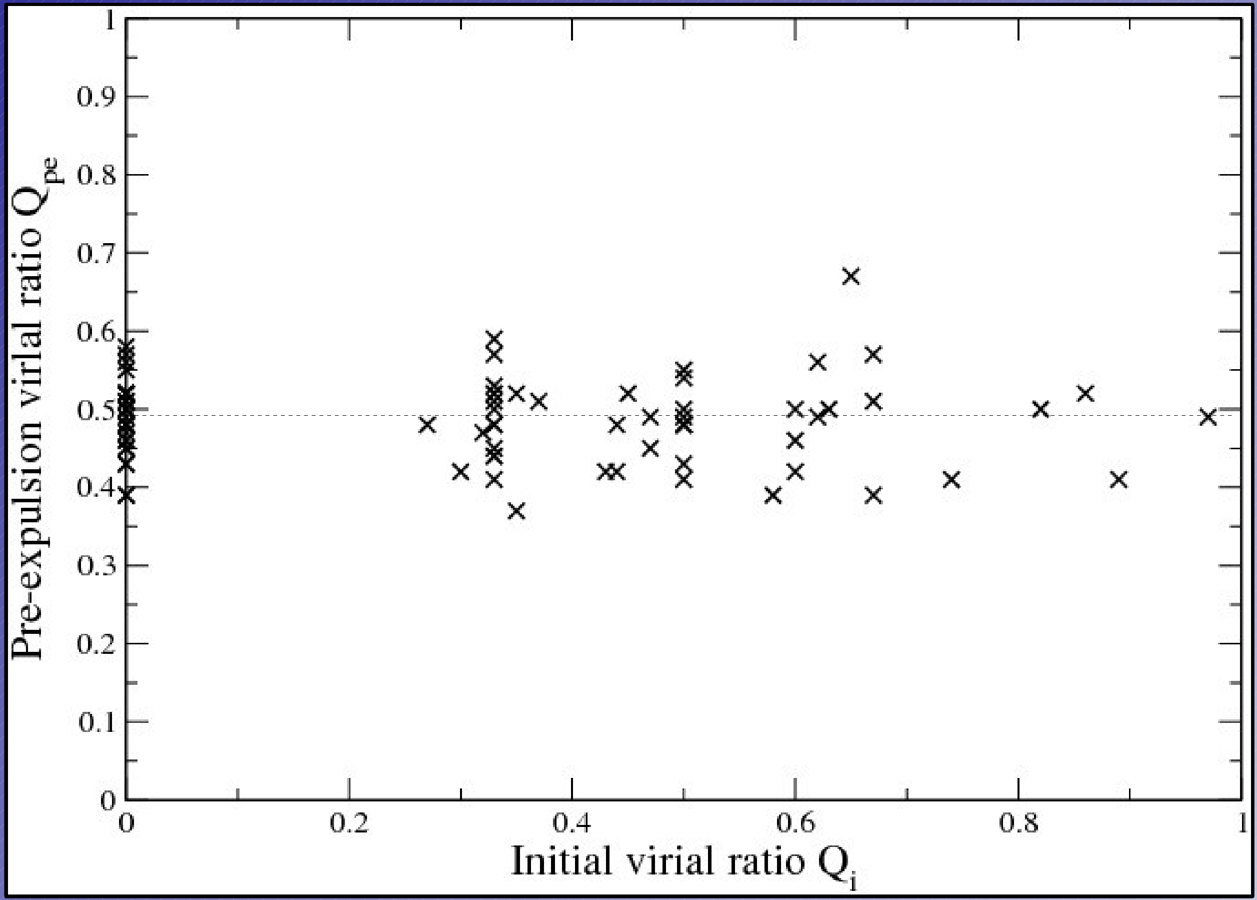
BUT

Lots of stochastic scatter

Results

Evolution of virial ratio in embedded phase

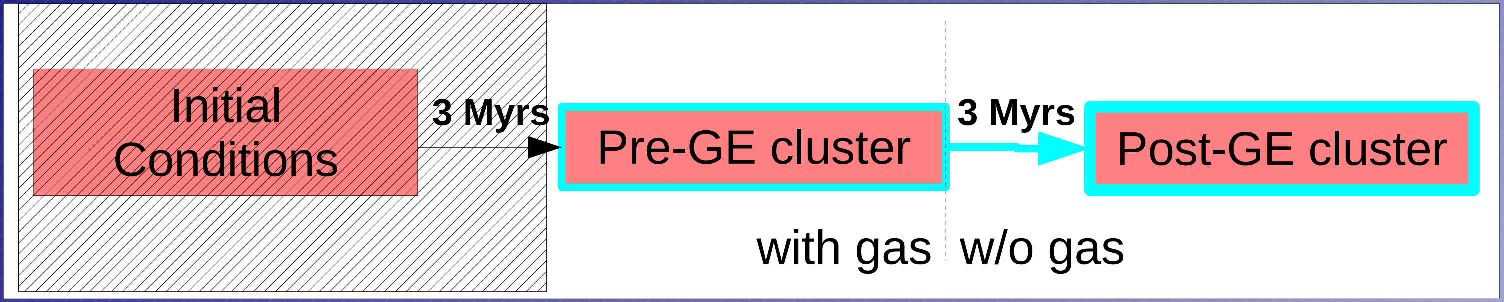


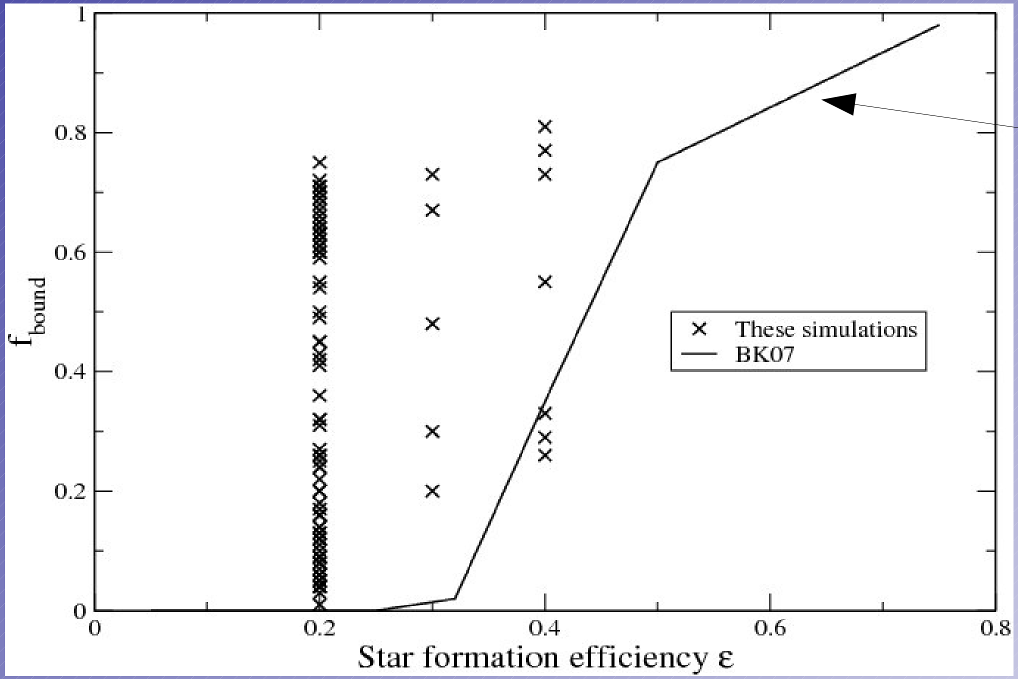


Clusters quickly evolve to *close* to virial equilibrium

Results

Star formation efficiency & cluster survivability

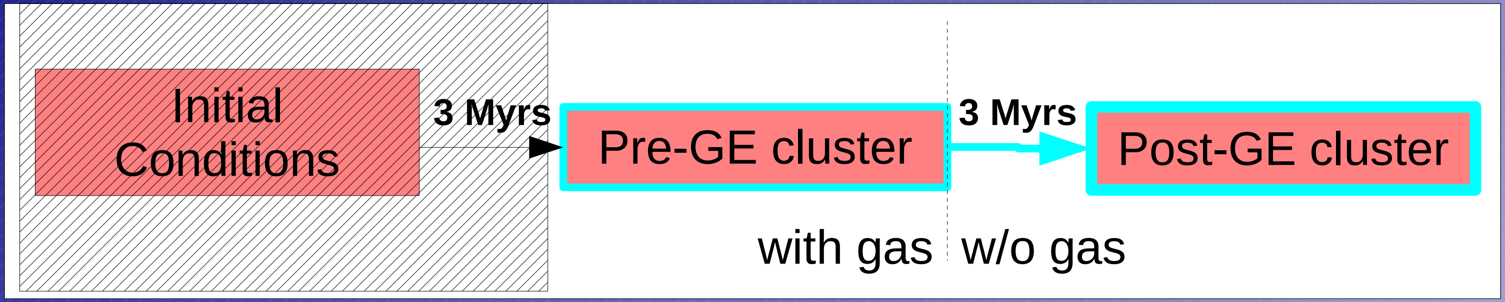


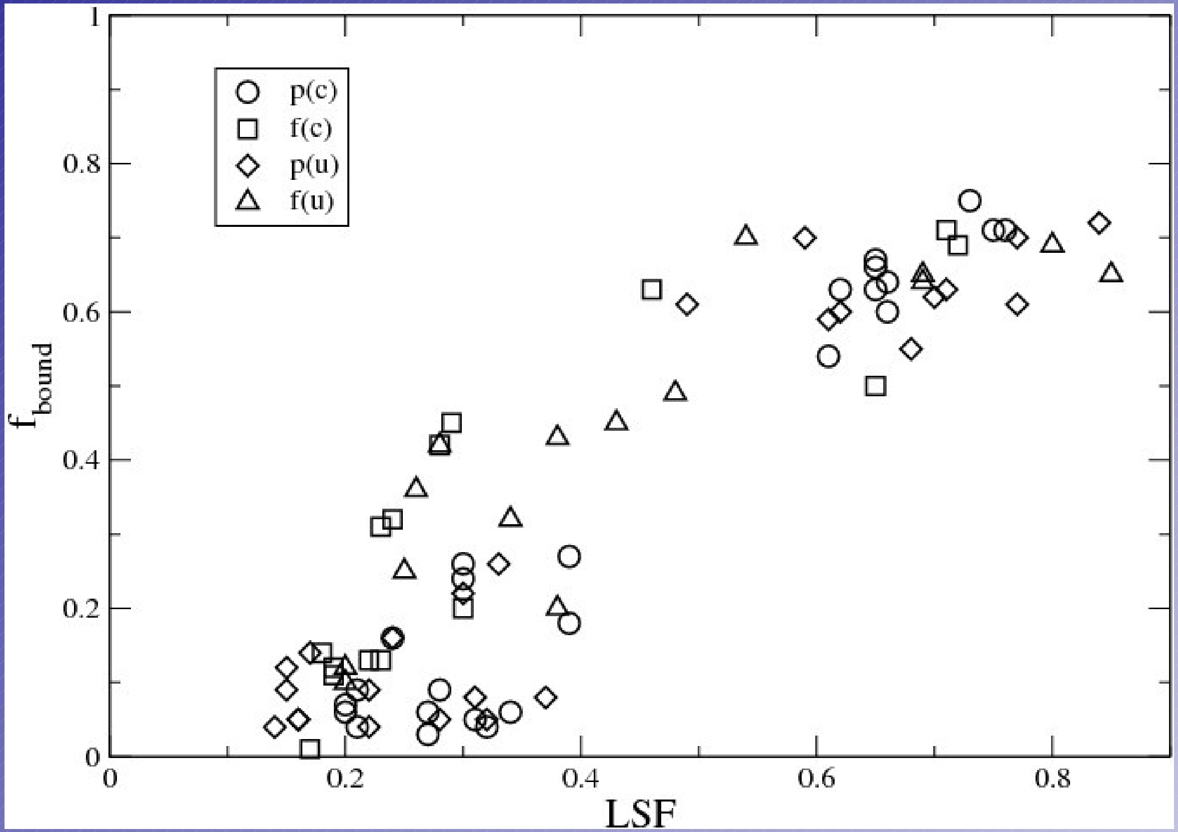


Smooth, spherical, virialised initial-conditions

The Star formation efficiency is a poor indicator of cluster survivability

Results
LSF & cluster survivability

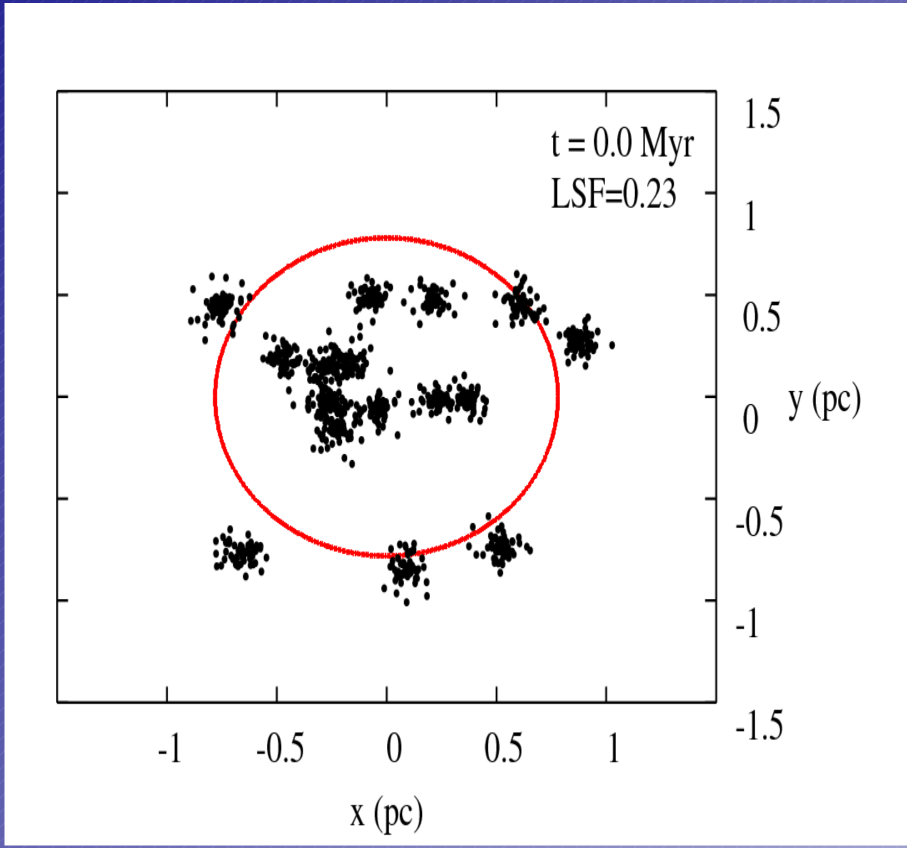


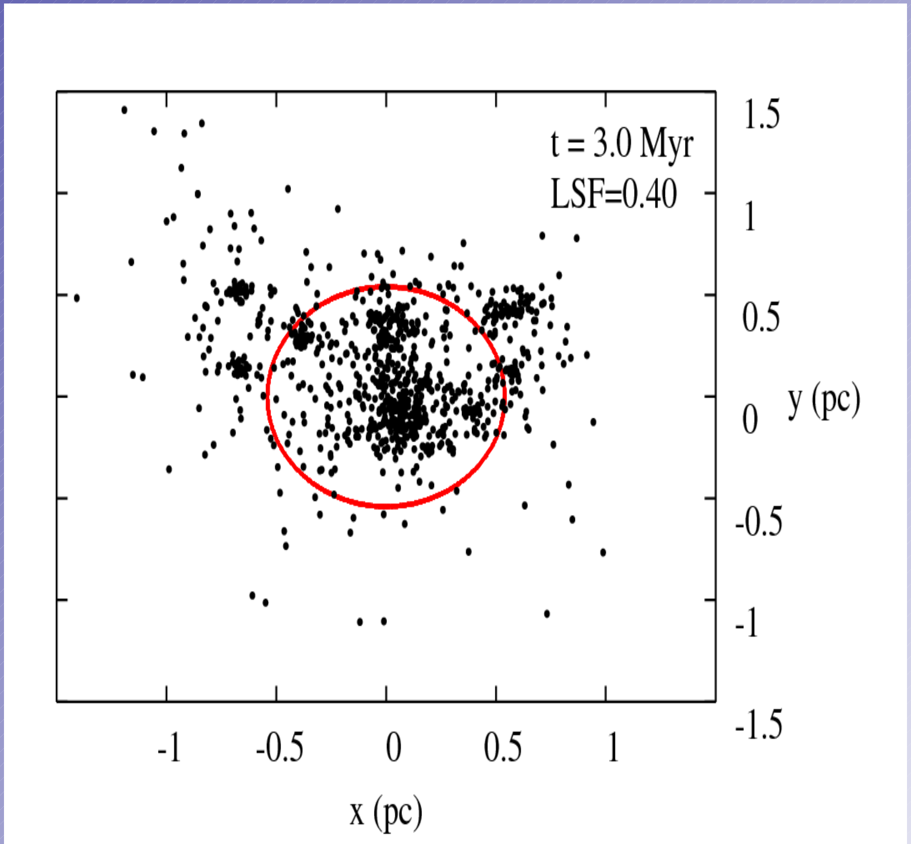


- High LSF
  = High survivability
- Same relationship regardless of;
  cloud mass, SFE, plummer/fractal, or gas potential shape.

Results
Why LSF and SFE?

SFE cannot adapt to changing distribution of stars relative to the gas....

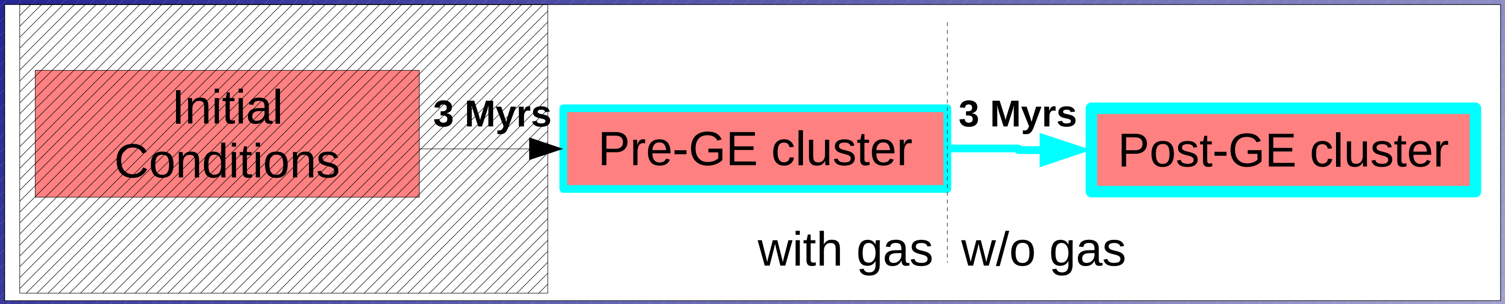


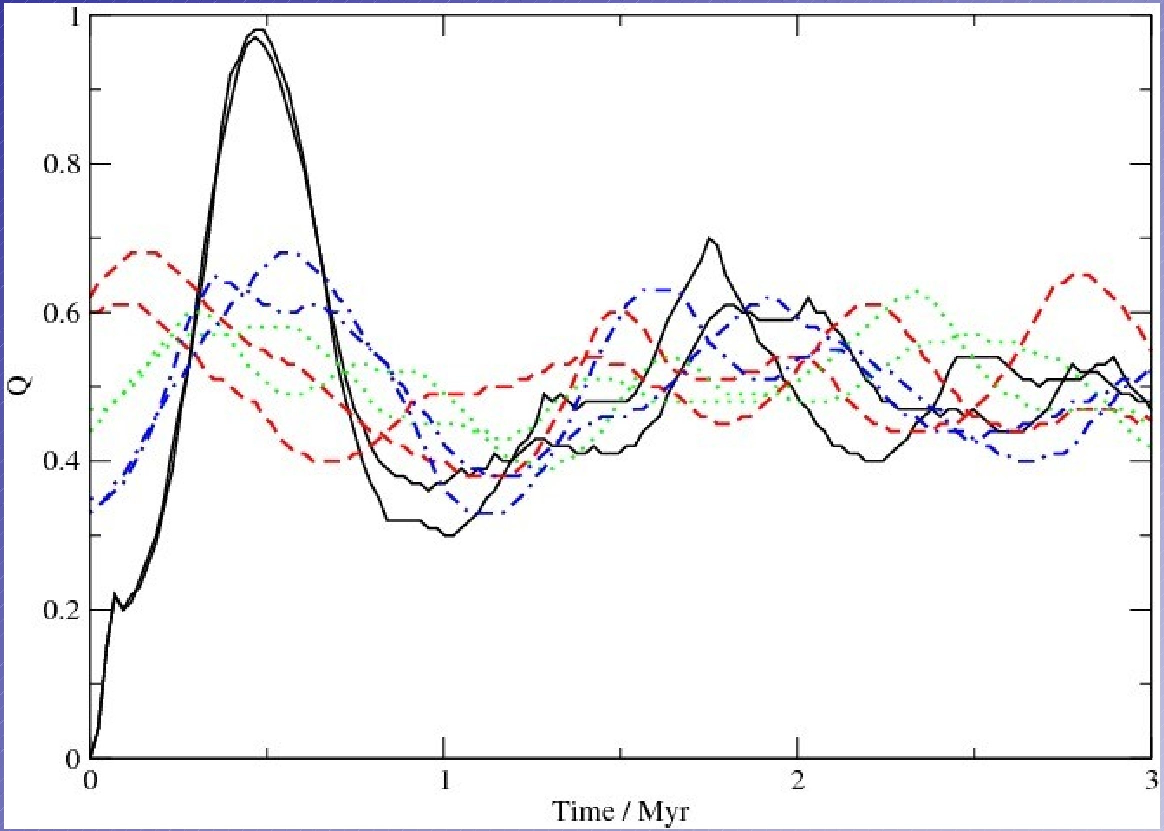


The LSF adapts to account for changing stellar distribution – better measuring the relative importance of the gas potential to that of the stars

Results

The Pre gas-expulsion virial ratio



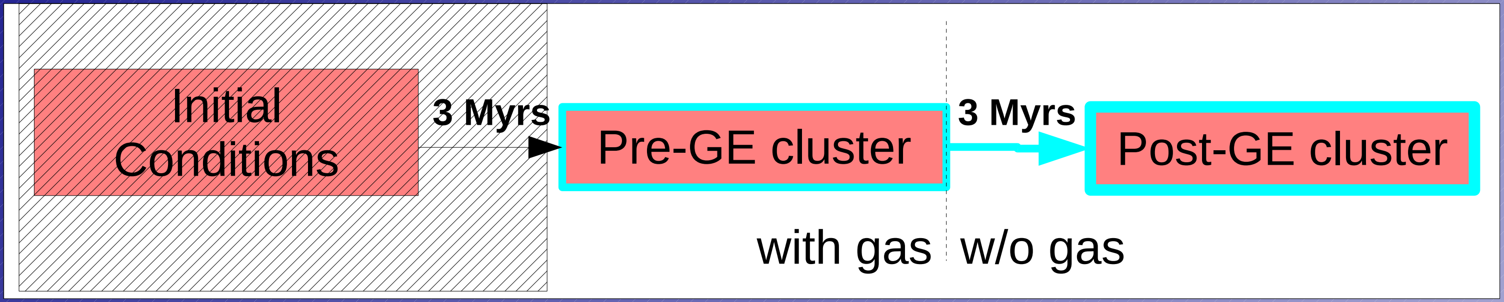


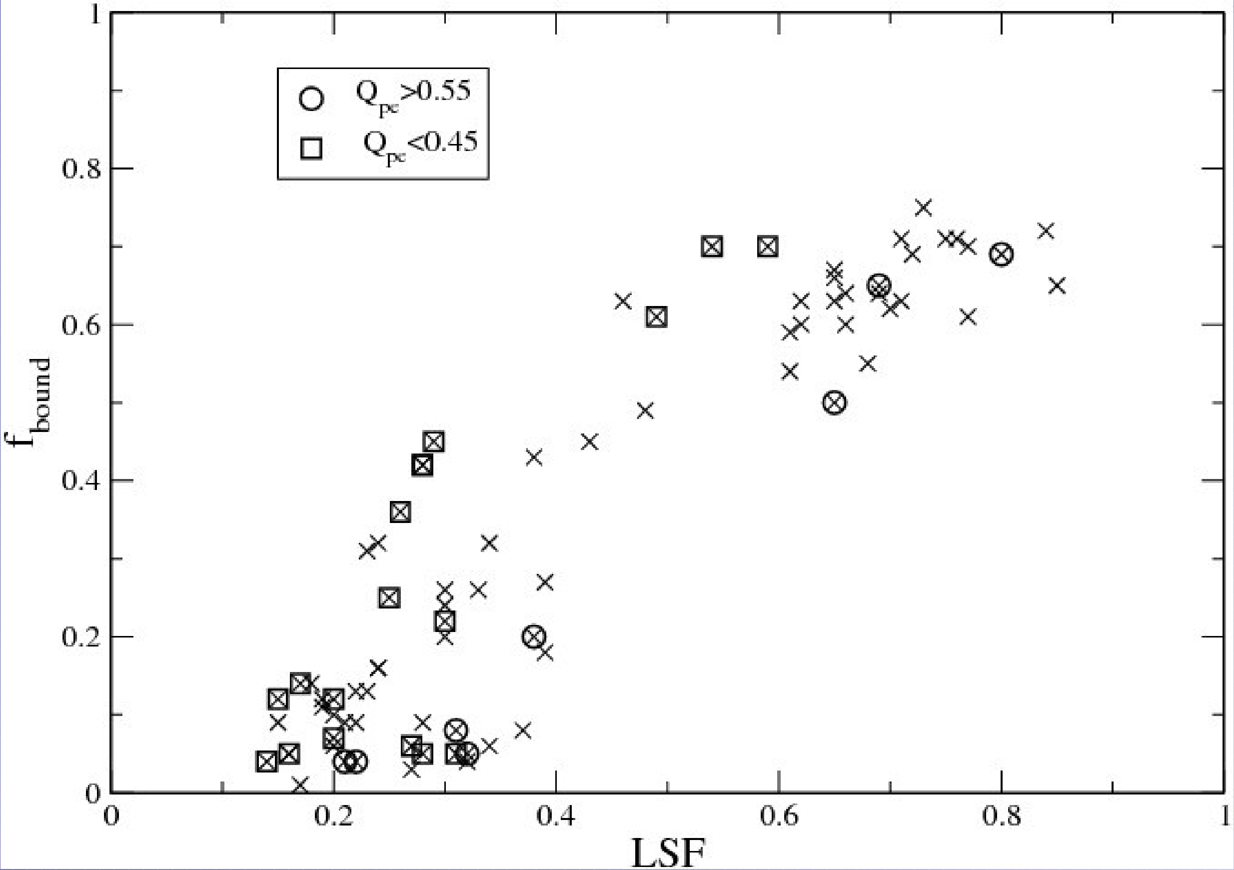
virial ratio quickly relaxes to *close* to virialised....

...but continues to oscillate around virialised for many crossing-times

Results

The Pre gas-expulsion virial ratio





These oscillations can be IMPORTANT

- Collapsing at instant of gas expulsion = better survival
- Expanding at instant of gas expulsion= poorer survival

Summary & Conclusions

- SFE is not a good measure of cluster survivability
- Local stellar fraction (LSF) is a better measure
- A cool initial dynamical state can produce a high LSF
- The cluster's dynamical state at gas expulsion can influence survival

PLEASE SEE: ASTROPH 1102.5360 (accepted in MNRAS)

Watch this space: Smith et al. 2011, 'Formation rates of star clusters in the hierarchical merging scenario' (submitted to MNRAS)

Future considerations

(current model very idealised)

- Binaries
- IMF
- Gas expulsion time-scales
  – when it starts & how long it lasts
- Gas potential is assumed as unvarying in time in this study
- New SPH code in development allowing for changing gas background potential – investigate effect of HII regions on stellar dynamics