Hierarchical merged Star clusters – surviving infant mortality

Rory Smith¹, Mike Fellhauer¹, Simon Goodwin², Paulina Assmann¹

¹ Concepcion University, ² Sheffield University
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

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.
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
Forming star clusters from sub clumps: Hierarchical merging

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- Merging & Tidal stripping may form a central star cluster
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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 background 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)
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) \[ LSF = \frac{M_{\text{star}}}{M_{\text{tot}}} \]
- Pre gas-expulsion virial ratio \( Q_f \)

(measured within half-mass radius of cluster)
Simulations: Final star cluster

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

\[ f_{\text{bound}} = \frac{\text{bound stars}}{\text{total stars}} \]
Results
Embedded phase

Initial Conditions

Pre-GE cluster

Post-GE cluster

with gas

w/o gas

3 Myrs

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

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

Initial Conditions

Pre-GE cluster
3 Myrs
with gas

Post-GE cluster
3 Myrs
w/o gas

The Star formation efficiency is a poor indicator of cluster survivability.
Results
LSF & cluster survivability

Initial Conditions

3 Myrs

Pre-GE cluster

3 Myrs

Post-GE cluster

with gas w/o gas

- 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

- Initial Conditions
- Pre-GE cluster
- Post-GE cluster

Time / Myr

The 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