Abstract

Previously we have shown that we can estimate how well a cluster can survive instantaneous gas expulsion if we know the virial ratio ($Q$) and the Local Stellar Fraction (LSF), both measured at the moment of gas expulsion, using a very simple analytical model. However we use a very simple approach to treat the background gas. Now, we test this analytical model by expelling the gas in highly substructured (gas and stars) embedded star clusters. We perform star formation simulations to achieve such a structure and we induce instantaneous gas expulsion at different stages of gaseous substructure testing how well our analytical treatment works.

Two simple analytic models:

- We estimate how well a cluster survives gas expulsion by developing a very simple analytic model in two flavours: Assuming gas and stars follow the same spatial distribution; and accounting for the independent substructure in the gas and stars.
- We generally assume:
  - Stars follow a Maxwell-Boltzman velocity distribution.
  - The stars to gas mass ratio is given by the LSF.
  - The stars that remain bound are the stars with velocities below the escape velocity after the gas is expelled.

\[
\text{LSF} = \frac{M_r(r<R_h)}{M_r(r<R_h) + M_{\text{gas}}(r<R_h)}
\]

Where $Q_{\exp}$ is the virial ratio measured at the moment of gas expulsion.

Without substructure

\[
\int_{\text{total}} [\text{LSF}, Q_{\exp}] = \text{erf} \left[ \frac{3 \text{LSF}}{2 \text{Q}_{\exp}} \right] - \frac{6 \text{LSF}}{2 \text{Q}_{\exp}} \exp [\frac{-3 \text{LSF}}{2 \text{Q}_{\exp}}]
\]

Where $Q_{\exp}$ is the virial ratio measured at the moment of gas expulsion.

With substructure

\[
\int_{\text{total}} [\eta, Q_{\exp}] = \text{erf} \left[ \frac{3 \eta Q_{\exp}}{2 \eta Q_{\exp}} \right] - \frac{6 \eta Q_{\exp}}{2 \eta Q_{\exp}} \exp [\frac{-3 \eta Q_{\exp}}{2 \eta Q_{\exp}}]
\]

Were $\eta$ is a structure parameter that depends on the spatial distributions of the stars and the gas and on the LSF.

Testing the models:

- We test the analytic models using the results of the star formation simulations.
- Gas expulsion was induced after 0, 1 and 2 Myr of embedded evolution for the SGO and AEOS simulations.

Conclusions:

- The most important parameters that estimate how well a cluster survives are the LSF and $Q_{\exp}$ no matter how complex the embedded star cluster is.
- Using very simple analytic models we can estimate the final bound fractions with an accuracy of ~10% with or without accounting for substructure.
- If gas is dispersed instead of forming clumps (SGO simulations) star clusters can remain with subviral velocities for longer times, increasing their chances to survive gas expulsion no matter the LSF.

Maybe gas expulsion is not the main cause of cluster dissolution...

References: