Simulating Young Massive Clusters

Sarah Jaffa and James Dale

Centre for Astrophysics Research, University of Hertfordshire, Hatfield, UK, AL10 9AA

University of Hertfordshire UH

What is a YMC?

- Young: less than 100 Myr
- Massive: more than 10^4 $M_\odot$
- Clustered: radii less than 5 pc

Why are they important?

- YMCs represent the extreme of clustered star formation - 10^4 $M_\odot$ formed within a few parsec! They therefore serve as a test for our current understanding of the star formation process - from the collapse of turbulent clouds, through the CMF and IMF, to the quenching of star formation by gas exhaustion or expulsion.
- Their high luminosity makes them visible both in our own galaxy and in other galaxies allowing us to link these two scales and test the universality of the star formation process in terms of galactic environment.
- They are the present day equivalent of globular clusters. Studying these closer by and better resolved systems will provide clues to understand the formation of globular clusters at higher redshifts.

Examples

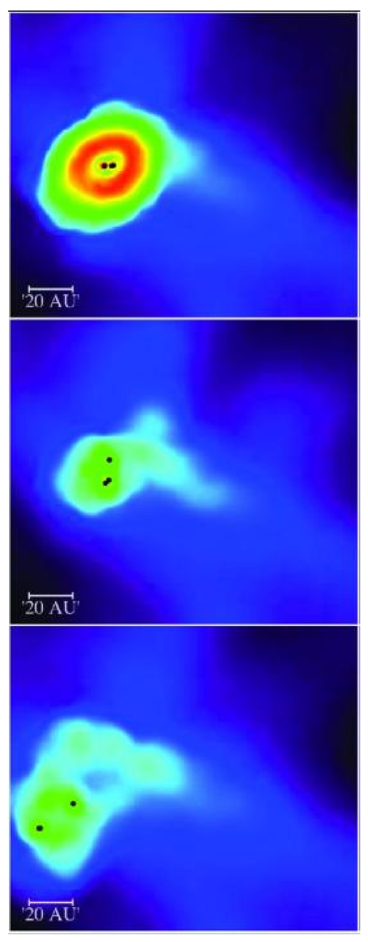
YMCs in our own Galaxy, other galaxies and dwarf galaxies. (a) The 10^5 $M_\odot$ cluster R136 in the LMC. (b) Many young star clusters forming in M83. (c) Westerlund 2, one of the most massive young clusters in the Milky Way. Images adapted from: (a,b) Portegies Zwart et al. 2010, (c) Zeidler et al. 2018

1. Resolving star formation

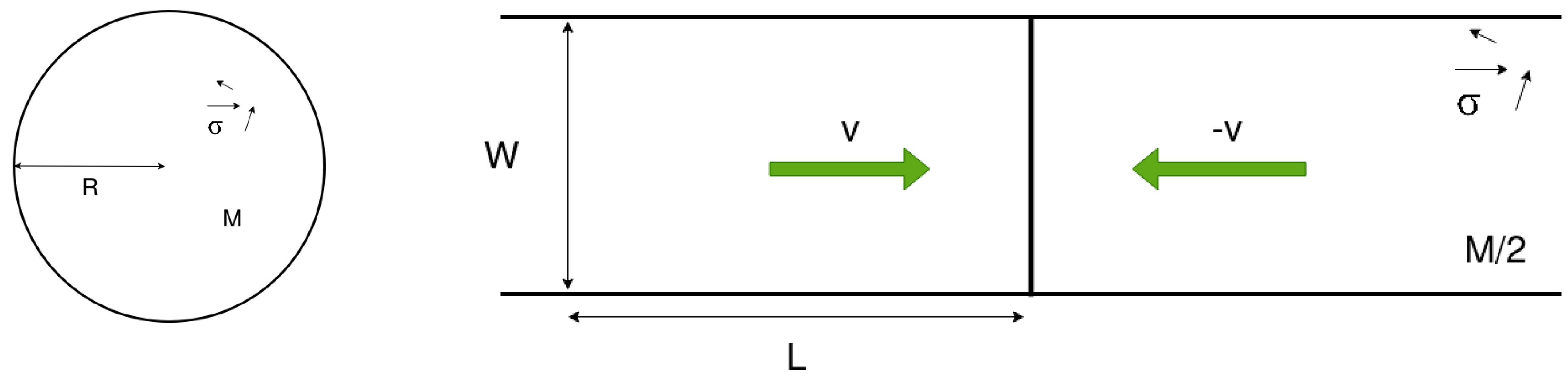
Previous studies (see references below) simulating the formation of YMCs have used sub-grid models of star formation to reduce computation time - inserting sink particles into hydrodynamical simulations when densities reach $\sim 10^{-20}\,\mathrm{g\,cm^{-3}}$, to model the formation of a cluster of stars. These can then evolve by sampling a preset IMF, merge, and give off feedback as a cluster unit.

Using advanced SPH codes with much higher resolution will allow us to track the formation of individual stars.

As Hubber et al. 2013 have shown (see figure, adapted from their Fig.6) that changing the sink density threshold even by one order of magnitude can have a large impact on the structures in the gas surrounding it as well as the formation time and mass of the sinks themselves, even in this relatively simple setup of an isolated turbulent core.



2. Formation mechanisms of YMCs



Simulations of YMC formation often use very simplistic initial conditions: a sphere of turbulent gas, either uniform or with a radial density profile, either isolated or surrounded by an ambient medium (left figure above).

In order to compare our simulations with those of other studies, we begin by simulating an isolated uniform spherical cloud of mass 10^5 $M_\odot$, with a radius of 5 pc and a decaying turbulent velocity field.

However, currently observed massive clouds are not massive enough to form YMCs, so they must gain mass during their evolution. This suggest a scenario analogous to the filament-hub systems seen in smaller cluster formation, where converging flows feed matter into a central dense hub. A simple model of this would be two colliding flows, each with half the mass of the cloud we hope to create (right figure above).

We will experiment with different dimensions of filament and infall speeds to simulate both the '*in-situ*' and '*conveyor belt*' models described in Longmore et al. 2014.

3. Gas exhaustion or expulsion

As noted in Portegies Zwart et al. 2010, the early evolution of massive clusters can be broadly described in two phases: (i) The star forming phase, when the initial GMC is being depleted and stars and gas are interacting, and (ii) the gas-free phase, once the GMC reservoir has been removed and the cluster evolves largely by N-body dynamics. This split is not yet well studied, as the interplay of gas dynamics, stellar evolution, and feedback is a complex problem.

By simulating realistic initial conditions (see formation mechanisms above) for the formation of a GMC and including feedback mechanisms from the individually resolved stars, we can address the question of how and when gas is removed from the system and what effect it has on the boundedness of the resulting star cluster.

References

Hydrodynamic simulations:

- **Li et al. 2019:** AREPO (MM) simulations 10^4 - 10^7 $M_\odot$ clouds with sink particles at $10^{-19}\,\mathrm{g\,cm^{-3}}$, continued as N-body calculations after gas expulsion.
- **Howard et al. 2018:** FLASH (AMR) simulations of 10^7 $M_\odot$ clouds with sink particles at $10^{-20}\,\mathrm{g\,cm^{-3}}$ evolved for 5 Myr.
- **Fujii 2015:** FI (SPH) simulations of a turbulent 10^5 $M_\odot$ clouds with sink particles at $10^{-20}\,\mathrm{g\,cm^{-3}}$ for N-body calculations after 0.9 t_{ff}.

Reviews:

- Portegies Zwart et al. 2010
- Longmore et al. 2014

Other:

- Hubber et al. 2013
- Zeidler et al. 2015

For more info...

A PDF of this poster is available on my website, along with more information about this project and updates on our ongoing simulations.