Formation of young massive clusters via cloud-cloud collisions

Kong You Liow, Clare L. Dobbs & Steven Rieder

University of Exeter, Exeter EX4 4QL, UK

ICYBOB

UNIVERSITY OF EXETER

kl457@exeter.ac.uk

kyliow.github.io

@astro_kyliow

1. Introduction

Young massive star clusters (YMCs), abundant in interacting galaxies, are young (< 100 Myr) yet massive and dense (> 10^4 $M_\odot$ within a few pc). Their unusually high star formation rate is a mystery on their formation mode.

We propose the formation of YMCs via cloud-cloud collisions, as this mechanism agrees with the observed hierarchical formation and reduces their formation timescale. Cloud-cloud collisions are also frequent in highly dynamic galactic environment, e.g. spiral arms. Our aim is to explore the parameter space for the formation of YMCs via colliding clouds. We choose collision speed, initial cloud density, and turbulence as our foremost investigation.

2. Simulation

We perform the colliding clouds simulations using PHANTOM, an SPH code. The collision is head-on and along the elongated axis. We use 5 million particles as resolution and the isothermal equation of state. Sink particles are introduced to replace high density regions, so each of them is a placeholder for small groups of stars.

Our parameter range chosen from observations:

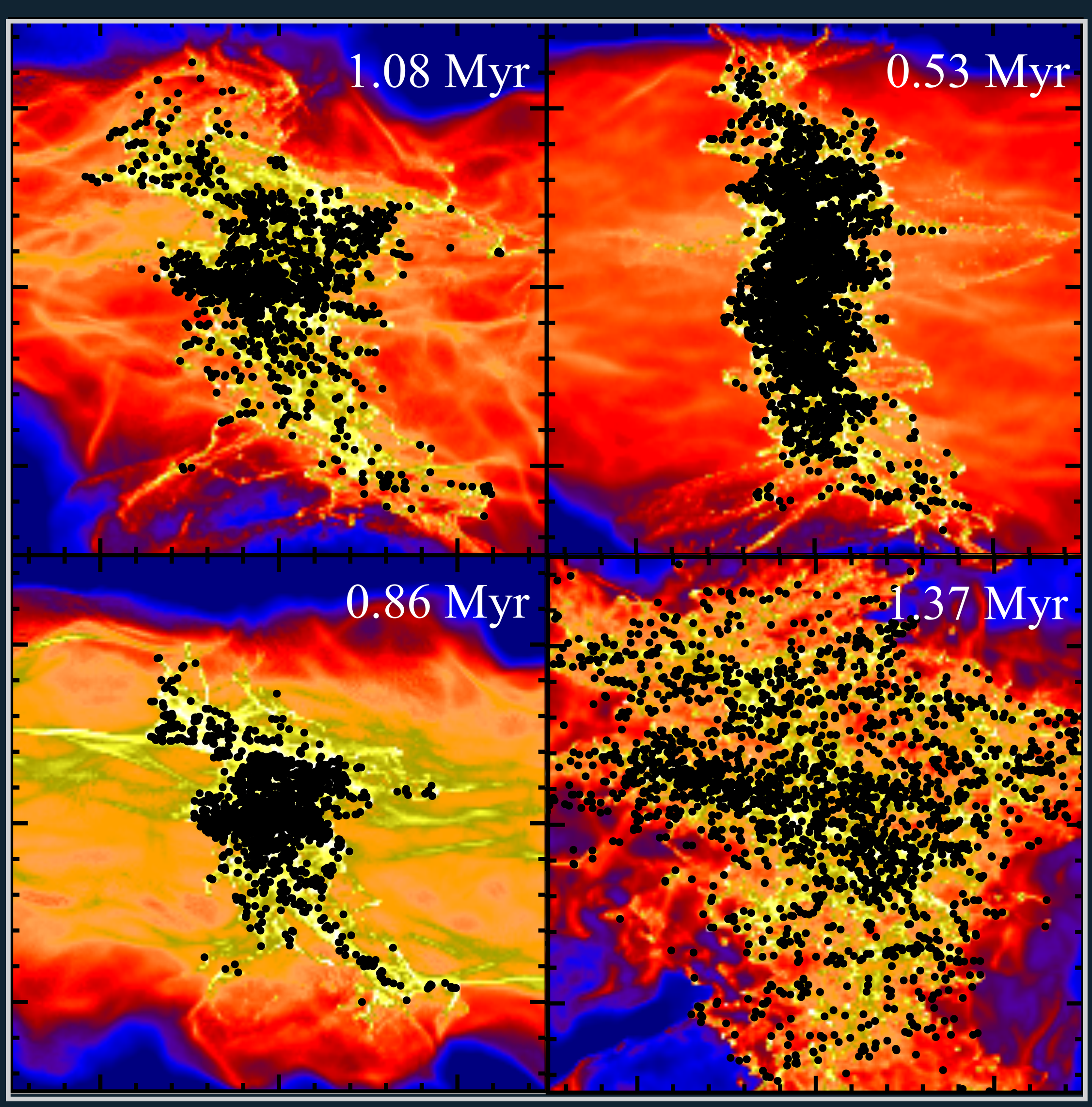
- Relative collision velocity: 0 – 50 km s^{-1}
- Initial cloud density: 130 – 518 cm^{-3}
- Turbulence: 2.5 – 5 km s^{-1}

3. Results

Figure below shows effect of increasing collision speed (plot A then B), increasing cloud density (plot A then C), and increasing turbulence (plot A then D). The box size is 7x7 pc^2 each. In general, greater collision speed and initial cloud density, while lower turbulence create more compact clusters.

Plot A: Fiducial

Plot B: Greater speed



Plot C: Greater density

Plot D: Greater turbulence

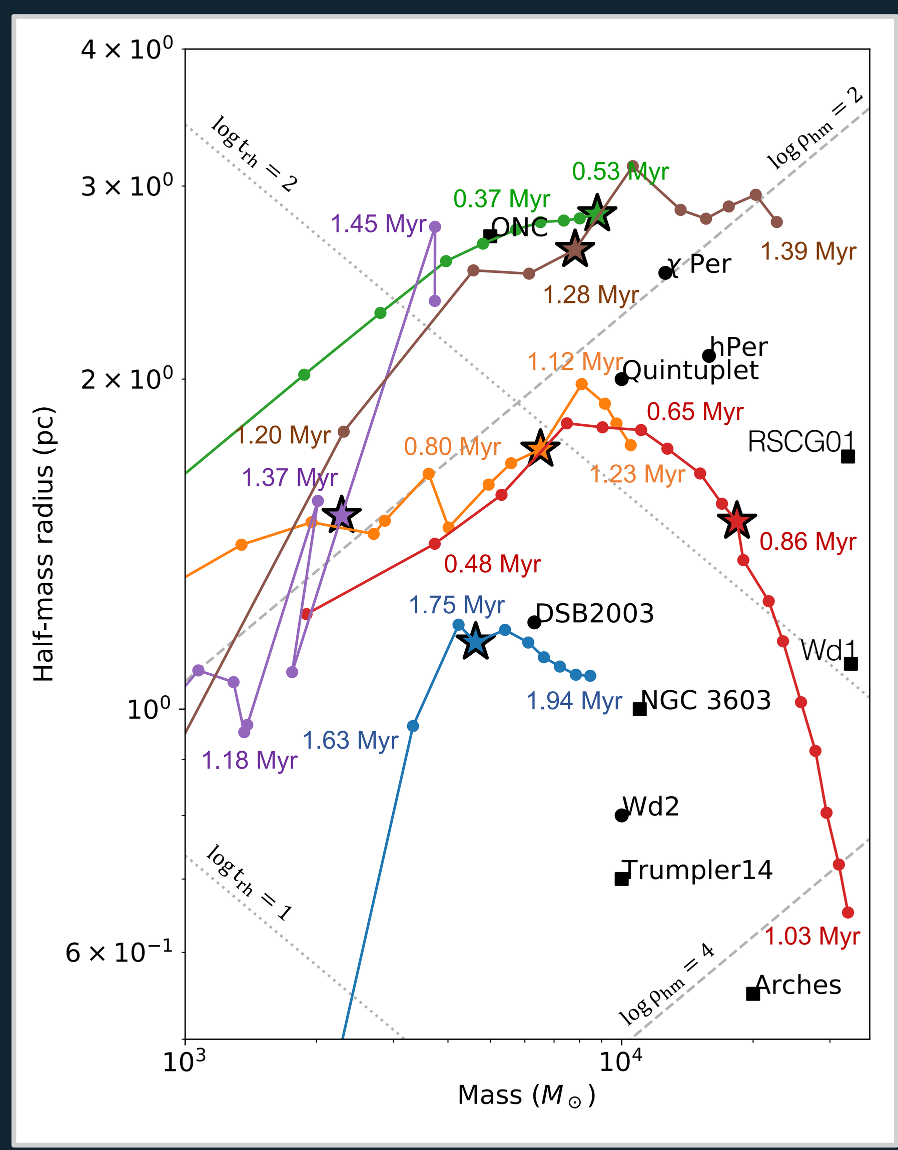
By considering the rate of gas mass accumulated at the collision site, we obtain a simple expression for star formation rate,

$$\dot{M}_* \propto \epsilon n_0 v$$

Gas conversion efficiency (ϵ), Initial cloud density (n_0), Collision speed (v)

Greater turbulence decreases the gas conversion efficiency. Our result is found to be consistent with theory.

We use DBSCAN, a clustering algorithm to identify massive clusters. Figure on the right shows the evolutionary tracks of some of our clusters in the radius-mass plot. Our models are able to form clusters that resemble the YMCs in Milky Way.



4. Additional physics & future work

Collision kinematics

- Star formation rate depends on the amount of gas concentrated at collision site, but the morphology of the clusters may change.

Magnetic field

- Star formation is suppressed strongly when the magnetic field is perpendicular to the collision.

Stellar feedback

- We are developing a star formation prescription that groups the sink particles into larger star-forming regions in order to form individual stars that are sampled from realistic initial mass function.
- Feedback is expected to play a significant role at a later time (> a few Myr) in suppressing/enhancing star formation and thus cluster formation.

References

Main work: **Liow K. Y.**, Dobbs C. L., 2020, MNRAS, 499, 1099

Non-exhaustive list:

- Dobbs C. L., **Liow K. Y.**, Rieder S., 2020, MNRAS, 496, L1
- Dobbs C. L., Wurster J., 2021, MNRAS, 502, 2285
- Longmore S. N. et al., 2014, Protostars and Planets VI. Univ. Arizona Press, Tucson, AZ
- Portegies Zwart S., McMillan S., Gieles M., 2010, ARA&A, 48, 431
- Price D. J. et al., 2018, Publ. Astron. Soc. Aust., 35, 31
- Walker D. L., Longmore S. N., Bastian N., Kruijssen J. M. D., Rathborne J. M., Galván-Madrid R., Liu H. B., 2016, MNRAS, 457, 4536