On the Formation of Young Massive Clusters via Cloud-cloud Collision

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Young Massive Clusters (YMCs)

- Young ($\lesssim 100$ Myr)
- Massive ($\gtrsim 10^4$ $M_\odot$)
- Dense ($\gtrsim 10^4$ $M_\odot$/pc$^3$)
- Small age spread (a few Myr)
Half-mass radius (pc) vs. Mass ($M_\odot$)

Portegeis Zwart et al. (2010)
Key Questions

• What causes the high star formation rate (SFR) in YMCs?
  • E.g. $\sim 3 \times 10^3$ $M_\odot$ Myr$^{-1}$ kpc$^{-2}$ (c.f. SFR in open clusters $\sim 2 \times 10^2$ $M_\odot$ Myr$^{-1}$ kpc$^{-2}$; Portegies Zwart et al. 2010)

• How to form YMCs?
  • Structure of the precursor giant molecular cloud (GMC)
  • Evolution of a GMC or interaction among GMCs?

• Others, e.g. are YMCs ‘baby’ globular clusters?
Formation of YMCs

• YMCs are most likely to be formed from the concurrent collapse of molecular clouds and on-going star formation (Walker et al. 2016)

• Rapid convergence of gas: cloud-cloud collisions (CCC)

• CCC is suggested following observations of star-forming regions
  • Fukui (2015), Dewangan & Ojha (2017), Dobashi et al. (2019) and more
CCC Simulations

• PHANTOM, a smoothed particle hydrodynamics (SPH) code for astrophysics (Price et al. 2018)

• Total resolution: 5 million SPH particles

• Realistic GMC conditions:
  • Mass per cloud: $5 \times 10^4$ $M_\odot$
  • Shape: prolate spheroid with semi-axes (7,7,16) pc
  • Density: $10^{-21}$ g cm$^{-3}$

• Varying collisional speed and level of turbulence
CCC Simulations

• Simulated collisional speed range: Mach 0 – 200
  • Realistic collisional speed range: ~ Mach 10 – 50 (Fukui 2015, etc.)

• Initial supersonic turbulence range: Mach 0 – 40
  • i.e. turbulent KE to cloud GPE ratio range: 0 – 1.2
  • Random Gaussian velocity field with $P(k) \propto k^{-4}$ (Bate et al. 2003)
  • Larson’s scaling relation (Larson 1981): ~ Mach 18
  • Virial equilibrium: ~ Mach 25

• No feedback and B-field
Mach 50 collision with Mach 20 turbulence

Total time
= 1.5 Myr
Star formation rate: theory

- Max $\Sigma_{SFR} \propto \nu$
- Scale time $t = c / \nu$
Accreted mass ($M_\odot$)  

SFR ($M_\odot$/Myr)  

No turbulence  

Mach 10 turbulence  

Mach 20 turbulence  

Mach 40 turbulence  

Time (Myr)  

Collision  

- Mach 0  
- Mach 10  
- Mach 20  
- Mach 50  
- Mach 80  
- Mach 100  

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Maximum SFR vs collisional speed

High-speed collision + low turbulence = high SFR!
Clusters: set up

• Analyse the sink particles at time when 10% of the gas mass is converted into sink particles (Balfour et al. 2015)

• Perform minimum spanning tree (MST) algorithm to obtain clusters
Compare with real YMCs...
Compare with real YMCs...

**Larger markers are clusters formed by collisional speed ≥ Mach 50**

High-speed collision
+ low turbulence
= YMC-like clusters
Q parameter

High-speed collision = greater Q

Cartwright & Whitworth (2004)
Conclusion

• Significance:
  • YMCs as the building blocks of the galaxy & precursor of globular clusters

• Through cloud-cloud collisions, can you:
  • create the high star formation rate of YMCs?
  • create stellar clusters with structure resembling real YMCs?

• Answer: Yes!
  • High collisional speed and low level of turbulence