中性水素ガス衝突による大質量星団形成におけるフィードバック効果の影響

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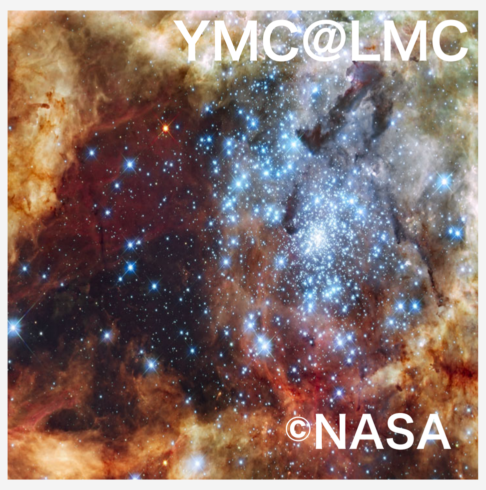
Abstract: Young massive clusters (YMC) are very important objects in terms of their impact on the surrounding interstellar medium in the form of supernova explosions, stellar winds, and ultraviolet radiation. However, the formation mechanism of YMC is still a mystery. YMC are characterized by high stellar densities, and their formation requires the concentration of massive molecular gas, the raw material for stars, in compact regions. How such a region is created has been completely unknown, but recent observations have suggested that fast collisions of HI gas may form the YMC. In this study, we examine this scenario using MHD simulations including the effects of gas self-gravity, heating and cooling by radiation, the chemical evolution from HI gas to molecular gas, and the photoionization feedback to investigate the origin of the YMC. Our simulation results showed that a massive and compact gas clump, which can be a precursor of YMC, can be formed by the global gravitational collapse of molecular clouds formed in the shock wave compression layer produced by the collision. We found that the formed sufficiently compact massive gas clumps have a large escape velocity compared to the sound speed of the HII region, which means that gravity prevents gas evaporation and thus they form stars with a high star formation efficiency and evolve into a YMC. Here, the self-gravity solver using the telegraph equation employed in our simulations has been developed on the Flow computer and is very effective when the time step of the calculation is determined by cooling time or chemical reactions.

Purpose and Background

Purpose: To Answer that fast gas collisions really can form YMCs.

➤Young massive clusters (YMCs)



✓ Dense aggregate of stars

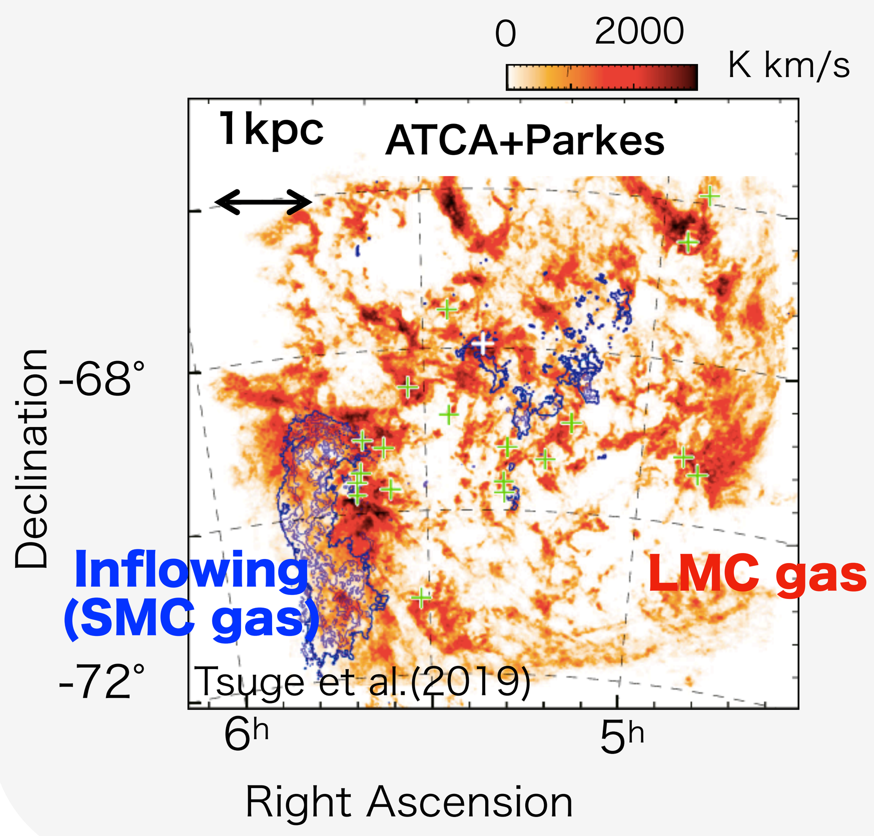
$M \gtrsim 10^4\,\mathrm{M_\odot}$, $R \sim \mathrm{pc}$

$(\rho \sim 10^3\,\mathrm{M_\odot\,pc^{-3}} \gg \rho_{\mathrm{around\ sun}} \sim 0.01\,\mathrm{M_\odot\,pc^{-3}})$

✓ Significant impact on ISM by Supernovas, UV radiation, and Stellar wind.

The mechanism of YMC formation is not yet understood because of the difficulty in creating massive and compact YMC precursor clumps.

➤Observed gas structure at massive star cluster formation region



✓ Small Magellanic Cloud (SMC) gas is falling onto Large Magellanic Cloud (LMC)

Fukui et al. (2017), Tsuge et al. (2019)

Colliding scale: $\sim$ kpc

Colliding speed: ~ 100 km/s $\gg c_{s,\mathrm{HI}} \sim 10$ km/s

✓ Gas infall is due to past galactic interaction between SMC and LMC.

Fujimoto & Noguchi (1990) ,Bekki & Chiba (2007)

✓ Massive star clusters seem to form at fast gas-colliding regions. Fukui et al. (2017), Tsuge et al. (2019)

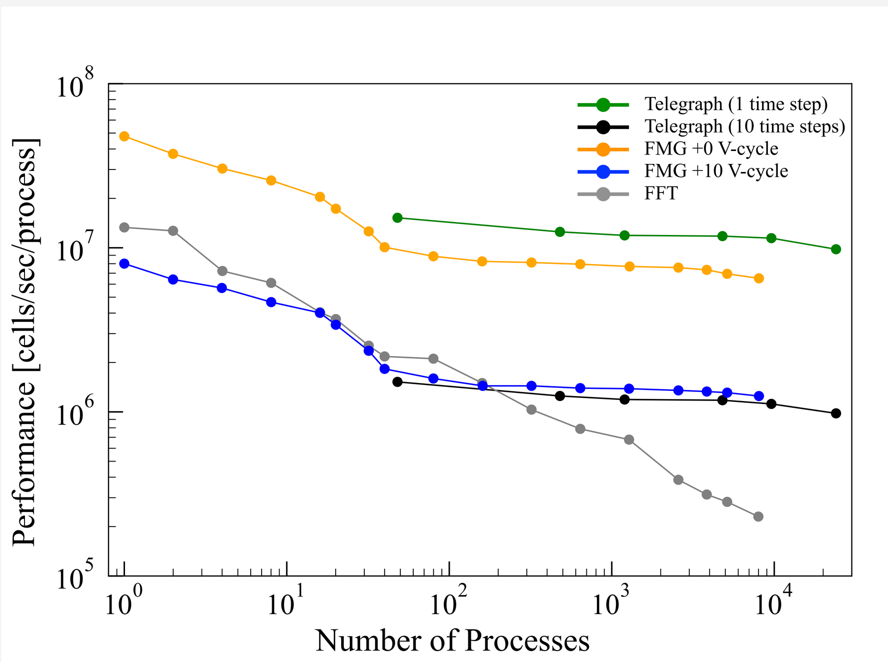
Simulation Methods

➤Basic equations

Ideal MHD＋Heating & Cooling＋Chemistry＋Self-Gravity＋Feedback

c.f. Inoue & Inutsuka (2012), Inoue & Omukai (2015), Maeda et al. (2023) submitted in MNRAS, Maeda et al. (2023) in prep.

✓ Self-gravity solver by telegraph equation is developed using Flow-computer

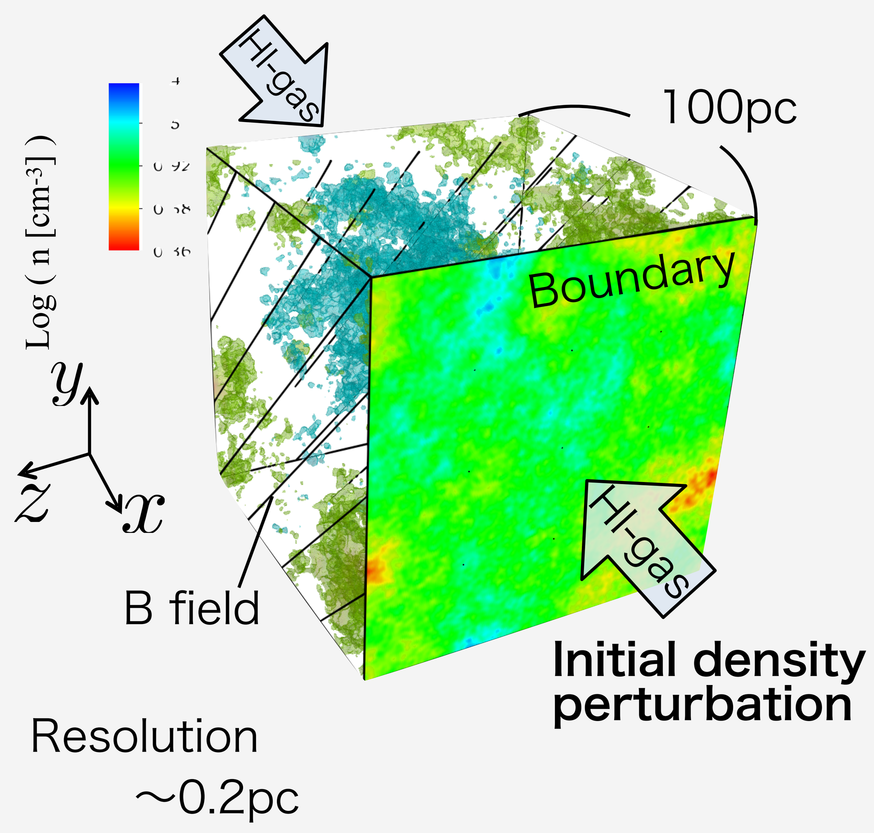


If $\Delta t = \Delta t_{\mathrm{cool}}, \Delta t_{\mathrm{chemical\ reaction}}, \cdots$, is satisfied, then

$$c_g = 0.5\frac{\Delta x}{\Delta t_{cool}} \gg v_f + c_s\,.$$

→ Our method can keep high accuracy without iterative calculations.

➤Initial & boundary conditions



✓ Boundary conditions

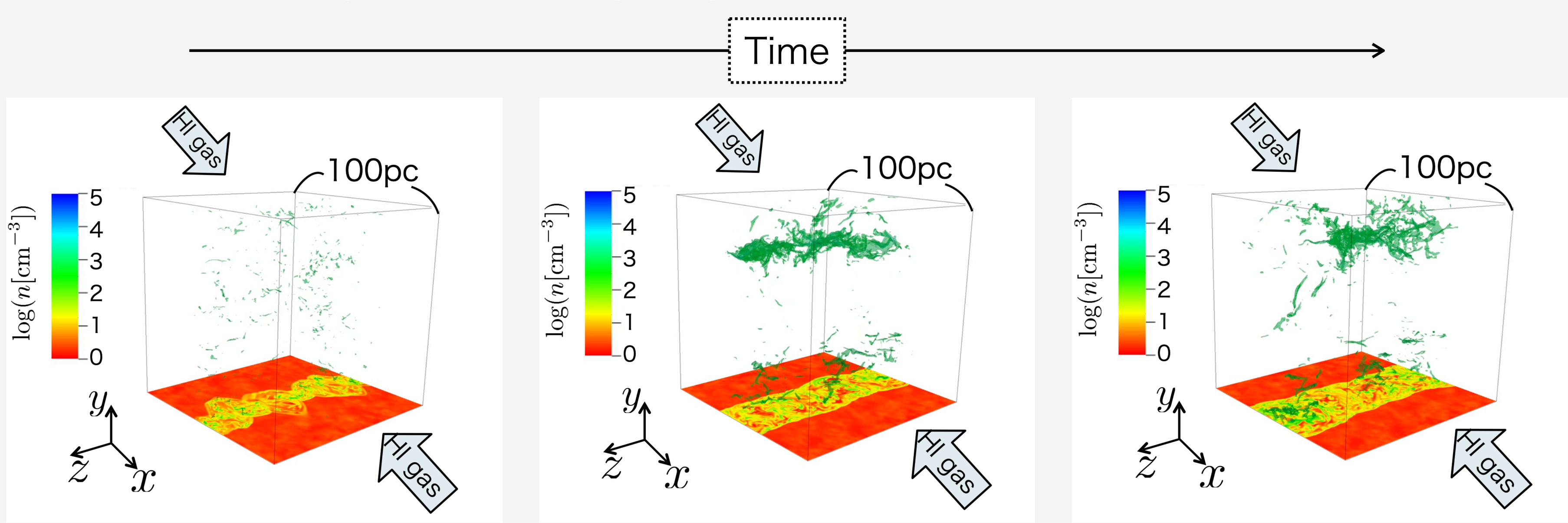
x	Surface	Continuous HI-gas inflow
$y \cdot z$	Surface	Periodic Boundary

✓ Initial conditions

$v_{\mathrm{rel}} = 100$ km/s	: relative velocity
$n_0 \sim 1\ \mathrm{cm^{-3}}$	: number density
$B_0 = 1\ \mu\mathrm{G}$	: magnetic field
$Z_0 = 1\ \mathrm{Z_\odot}$	: metallicity

Results

➤Evolution of gas colliding region



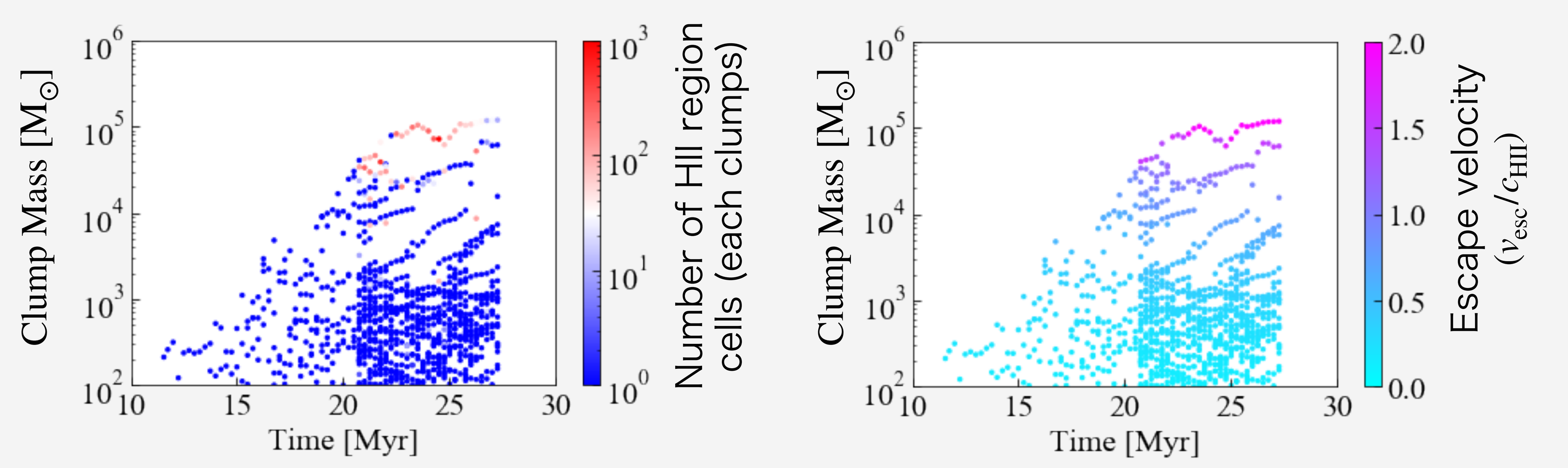
Shock wave go outward. Small clumps are formed at shocked region.

Larger gas clumps formed by self-gravity.

Massive stars formed in massive gas clumps. Gas is evaporated by feedback.

➤Mass evolution of formed gas clumps

We define one connected region ($> 10^4\ \mathrm{cm^{-3}}$) as a clump (each time steps).



Massive($M \sim 10^5\ \mathrm{M_\odot}$) and compact($L \sim 5$ pc) gas clump are formed.

Massive gas clumps have large escape velocities ($v_{\mathrm{esc}} > c_{\mathrm{HII}} \sim 10$ km/s), thus, they can maintain compact structures (by gravity even with feedback).

Summary & Future Work

➤Summary

- **Massive star clusters can be formed by fast HI gas collision due to intergalactic interactions, etc.**
- **The dense clumps that form YMC can maintain the structure for a long time, due to the effect of gravity, even with feedback.**
- **Our self-gravity solver is useful when** $\Delta t = \Delta t_{\mathrm{cool}}, \Delta t_{\mathrm{chemical\ reaction}}, \cdots$.

➤Future Work

- **Star cluster formation in the early universe.**
- **Initial mass function of star clusters.**