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Formation of Massive Star Clusters by Fast HI Gas Collision

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Young massive clusters (YMCs) are dense young star clusters with a typical mass of $M{\sim}10^4\ \mathrm{M_\odot}$ and radius of $R{\sim}1\mathrm{pc}$ (Portegies Zwart et al. 2010). The typical density of YMCs is $>10^3\ \mathrm{M_\odot\ pc^{-3}}$ (Longmore et al. 2014), which is significantly larger than that of field stars in the solar neighborhood $\sim 0.1\ \mathrm{M_\odot\ pc^{-3}}$ (Holmberg & Flynn 2000). Typical YMCs contain tens of massive stars, suggesting that they are crucial for galaxy evolution, owing to their ultraviolet radiation, stellar winds, and supernovae. Despite their importance, the formation mechanism of YMCs is not well understood because a very compact massive cloud should be formed before stellar feedback blows off the cloud. On the other hand, recent observational studies of gas structures around massive star clusters in the Large Magellanic Cloud suggest that the fast HI gas collision triggers YMC formation (Fukui et al. 2017; Tsuge et al. 2019a). The observed HI gas collisions have a spatial scale of $\sim 1\ \mathrm{kpc}$ and the relative velocity of the collision is as high as $\sim 100\ \mathrm{km\ s^{-1}}$, which is ten times faster than the typical collision velocity of interstellar cloud formation sites (e.g., Inutsuka et al. 2015). Such cloud-cloud collisions around the YMCs are observed in the Milky Way (e.g., Furukawa et al. 2009; Ohama et al. 2010; Fukui et al. 2013, 2016) and in the outer galaxies (Tachihara et al. 2018; Tsuge et al. 2019b, 2020).

In this study, we examine whether the fast HI gas collision triggers YMC formation using three dimensional magnetohydrodynamics simulations, which includes the effects of self-gravity, radiative cooling/heating, and chemistry. Results of our simulations show that massive gravitationally bound gas clumps with $M > 10^4\ \mathrm{M_\odot}$ and $L{\sim}4$ pc, are formed in the shock compressed region induced by the fast HI gas collision (Figure 1). These massive gas clumps can evolve into YMCs if star formation efficiency is at least 30%, which is reasonable, given that the escape velocity from these clumps is large. Our results also show that the YMC precursors are formed by the global gravitational collapse of molecular clouds, and YMCs can be formed even in low-metal environments, such as Magellanic clouds. A very massive YMC precursor cloud with $M > 10^5\ \mathrm{M_\odot}$ can be created when we consider the fast collision of HI clouds, which may explain the origin of the very massive stellar cluster R136 system in the Large Magellanic Cloud.

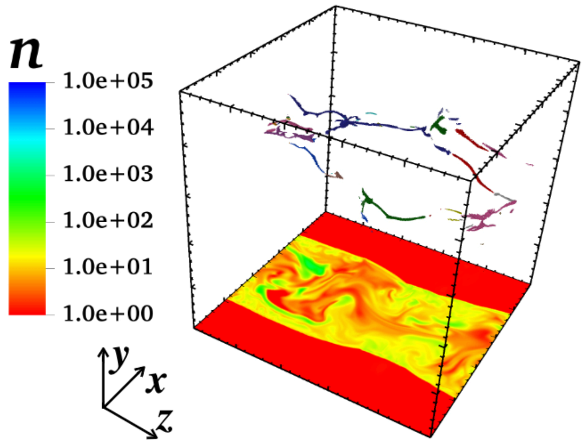

Figure 1: Identified YMC precursor clumps in the result of our fiducial simulation, which are formed owing to the fast HI gas collision suggested by observation. In the box, regions of different color indicate different massive clumps that are identified by the friends-of-friends algorithm. The bottom panel represents the number density map at the y=0 plane.

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