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Time evolution of giant molecular cloud mass functions with cloud-cloud collisions and gas resurrection in various environments

M. I. N. Kobayashi, S. Inutsuka, H. Kobayashi, and K. Hasegawa

Division of Particle and Astrophysical Science, Graduate School of Science, Nagoya University, Aichi, 464-8602, Japan, e-mail: masato.kobayashi@nagoya-u.jp

Abstract. We formulate the evolution equation for the giant molecular cloud (GMC) mass functions including self-growth of GMCs through the thermal instability, self-dispersal due to massive stars born in GMCs, cloud-cloud collisions (CCCs), and gas resurrection that replenishes the minimum-mass GMC population. The computed time evolutions obtained from this formulation suggest that the slope of GMC mass function in the mass range $< 10^{5.5}$ $M_{\odot}$ is governed by the ratio of GMC formation timescale to its dispersal timescale, and that the CCC process modifies only the massive end of the mass function. Our results also suggest that most of the dispersed gas contributes to the mass growth of pre-existing GMCs in arm regions whereas less than 60 per cent contributes in inter-arm regions.

1. Introduction

Recent radio observations suggest that giant molecular cloud (GMC) mass functions noticeably vary across galactic disks. For example, the Plateau de Bure Interferometer (PdBI) Arcsecond Whirlpool Survey (PAWS) program (Schinnerer et al. 2013) demonstrates that GMC mass functions have shallow power-law slope in arm regions whereas they have steep power-law slopes in inter-arm regions. Detailed magnetohydrodynamics simulations (e.g., Inoue & Inutsuka 2008) show that multiple episodes of supersonic compression is presumably essential to override magnetic field pressure and create a molecular cloud from the magnetized interstellar medium.

Inutsuka et al. (2015) formulate an evolution equation for GMC mass function, which includes self-growth due to multiple episodes of supersonic compression, self-dispersal due to massive stars born in GMCs. However, latest radio observations in the Milky Way galaxy (e.g., Fukui et al. 2014) indicate the possible importance of cloud-cloud collision (CCC) process for massive star formation. Therefore, in this study, we reformulate the evolution equation in Inutsuka et al. (2015) by introducing CCC terms. In addition, we evaluate the "gas resurrection" process, which replenishes the minimum-mass GMC population out of the total amount of dispersed gas.

2. Formulation and result

The differential number density of GMCs with mass m, $n_{\rm cl}$, is given as:

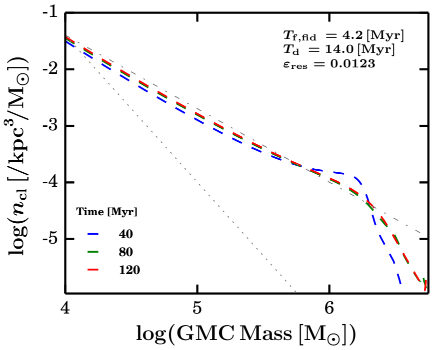

Fig. 1. Computed time evolution of a GMC mass function with $T_{\mathrm{f}} = 4.2$ Myr and $T_{\mathrm{d}} = 14$ Myr. Color scheme corresponds to different timestep. The mass function shows a single power-law slope, which fits the observed shallow slope in arm regions shown in thin gray dot-dashed line.

$$\begin{aligned}
\frac{\partial n_{\mathrm{cl}}}{\partial t} &+ \frac{\partial}{\partial m}\left(n_{\mathrm{cl}}\frac{m}{T_{\mathrm{f}}}\right) \\
&= -\frac{n_{\mathrm{cl}}}{T_{\mathrm{d}}} \\
&+ \frac{1}{2}\int_0^\infty \int_0^\infty K(m_1, m_2) n_{\mathrm{cl},1} n_{\mathrm{cl},2} \\
&\qquad\qquad \times \delta(m - m_1 - m_2)\mathrm{d}m_1\mathrm{d}m_2 \\
&- \int_0^\infty K(m, m_2) n_{\mathrm{cl}} n_{\mathrm{cl},2}\mathrm{d}m_2 \\
&+ \left.\frac{\partial\,(n_{\mathrm{cl}}m)}{\partial t}\right|_{\mathrm{res}}. \qquad (1)
\end{aligned}$$

Here, m/T_{f} represents the mass-growth rate of GMCs averaged over a characteristic GMC growth timescale T_{f}, T_{d} is the self-dispersal timescale of GMCs, $n_{\mathrm{cl},1}$ and $n_{\mathrm{cl},2}$ are the differential number density of GMCs whose masses are m_1 and m_2 respectively, $K(m_1, m_2)$ is the kernel function that determines the CCC rate between GMCs with mass m_1 and m_2, δ is the Dirac delta function, and $\partial\,(n_{\mathrm{cl}}m)\,/\partial t|_{\mathrm{res}}$ is the gas resurrection rate from dispersed gas. We assume that multiple episodes of compression driven by expanding HII regions and supernovae set $T_{\mathrm{f}} \sim 10$ Myr and the dispersal is governed by dissociating photons from massive stars with mass $\gtrsim 20 M_\odot$, which results in $T_{\mathrm{d}} = 14$ Myr.

We perform integration of Equation 1 with various timescales in T_{f} and T_{d}, and Figure 1 shows one of the results with $T_{\mathrm{f}} = 4.2$ Myr and $T_{\mathrm{d}} = 14$ Myr. Our results indicate that CCC affects only the massive end of the mass functions and the single power-law in the mass regime $\lesssim 10^{5.5} M_\odot$ is well fitted by

$$n_{\mathrm{cl}} \propto m^{-1-T_{\mathrm{f}}/T_{\mathrm{d}}}, \qquad (2)$$

which is originally suggested by Inutsuka et al. (2015). Therefore, observational trend can be interpreted that arm regions have much frequent supersonic shock events than inter-arm regions due to active star formation, which results in short T_{f} so that the GMC mass function exhibits shallower slope.

In addition, our results suggest that almost all of the dispersed gas in arm regions accrete onto pre-existing GMCs before regenerating the minimum-mass GMC populations, because arm regions have many massive GMCs whose surface area is large. We refer the readers to Kobayashi et al. (2017) for the detail prescription in our formulation and other results with different parameter sets.

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