The Multi-Messenger Astrophysics of the Galactic Centre
Proceedings IAU Symposium No. 322, 2016
R.M. Crocker, S.N. Longmore & G.V. Bicknell, eds.

doi:10.1017/S1743921316012400

Time Evolution of the Giant Molecular Cloud Mass Functions across Galactic Disks

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Abstract. We formulate and conduct the time-integration of time evolution equation for the giant molecular cloud mass function (GMCMF) including the cloud-cloud collision (CCC) effect. Our results show that the CCC effect is only limited in the massive-end of the GMCMF and indicate that future high resolution and sensitivity radio observations may constrain giant molecular cloud (GMC) timescales by observing the GMCMF slope in the lower mass regime.

Keywords. ISM: clouds, ISM: evolution, ISM: magnetic fields, galaxies: evolution

1. Introduction

Recent radio observations suggest that the GMCMF varies on galactic scales (*e.g.*, Colombo *et al.* 2014). Investigating how and what physical processes cause this variation is central for studying subsequent star formation and galaxy evolution. On the other hand, recent multiphase interstellar medium (ISM) magnetohydrodynamics simulations indicate that multiple episodes of supersonic compression is a key process to form molecular hydrogen in the ISM from the magnetized warm neutral medium, which occupies most of the volume in galactic disks (*e.g.*, Inoue & Fukui 2013). To achieve such multiple episodes of compression, we propose a scenario where a network of expanding shells driven by massive stars and supernovae provides supersonic shocks. As the shocks propagate into the ISM, molecular cloud formation takes place in some specific volume where the ISM has experienced multiple episodes of compression (Inutsuka *et al.* 2015).

2. Formulation

Based on the scenario of the expanding shell network presented in the previous section, we formulate the time-evolution equation for GMCMF including the CCC effect:

$$\begin{aligned}\frac{\partial n_{\rm cl}}{\partial t} + \frac{\partial}{\partial m}\left(n_{\rm cl}\frac{{\rm d}m}{{\rm d}t}\right) = &-\frac{n_{\rm cl}}{T_{\rm d}} - \int_0^\infty K(m,m_2)n_{\rm cl}n_{\rm cl,2}{\rm d}m_2 \\ &+\frac{1}{2}\int_0^\infty\int_0^\infty K(m_1,m_2)n_{\rm cl,1}n_{\rm cl,2}\,\delta(m-m_1-m_2){\rm d}m_1{\rm d}m_2\,.\end{aligned} \tag{2.1}$$

Here, $n_{\rm cl}$ represents the differential number density of GMCs whose masses are m. The second term is a flux term, which is an analogy from the ordinary continuity equation in fluid mechanics. The ordinary continuity equation considers mass conservation in configuration space. Instead we here consider number conservation of GMCs in the GMC mass space, which corresponds to GMC mass-growth through multiple episodes of compression. The mass-growth rate is characterized by the ratio of mass to the characteristic timescale, $m/T_{\rm f}$, for which $T_{\rm f}$ is estimated about 10 Myr for typical gas in the ISM (see

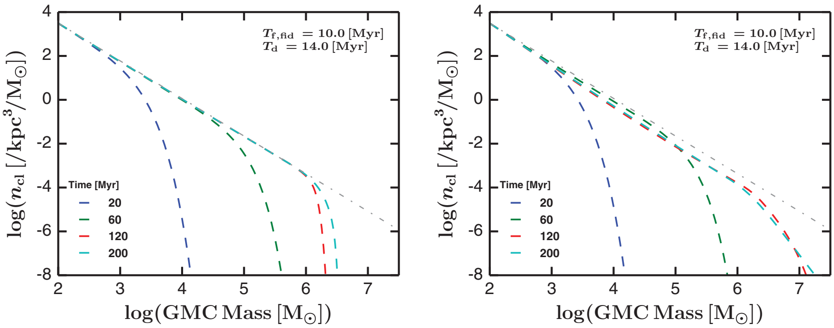

Figure 1. Time evolution of the GMCMF without the CCC effect (left) and with the CCC effect (right) with $T_{\rm f} = 10$ Myr and $T_{\rm d} = 14$ Myr. The dashed lines correspond to the different phases where the GMCMF evolves from the left to the right in GMC mass space. The dot-dashed lines correspond to the power-law of $-1 - T_{\rm f}/T_{\rm d}$ expected from Equation 3.1.

Inutsuka *et al.* 2015). The third term corresponds to GMC self-dispersal, which has a characteristic timescale of 14 Myr based on a recent line-radiation magnetohydrodynamics simulation (see Inutsuka *et al.* 2015). The fourth term means the GMC formation with mass $m+m_2$ due to the CCC between GMCs whose masses are m and m_2. Similarly, the fifth term represents the GMC formation with mass m due to the CCC between GMCs whose masses are m_1 and m_2. Note that we focus on the coagulation due to CCC but not fragmentation or drastic massive star formation induced by CCC.

3. Results, discussions, and conclusions

We conduct the time-integration of Equation 2.1 and calculate the time evolution of GMCMF. Figure 1 compares the time evolution of the GMCMF with and without CCC. This comparison suggests that the GMCMF shows a power-law slope in the lower mass regime ($\lesssim 10^6 {\rm M}_\odot$) irrespective of CCC whereas the massive-end is modified by CCC and maybe by subsequent massive star formation, which we have not modeled yet. If we restrict ourselves to the lower mass regime, our formulation can be rewritten without the CCC terms. Then the equation becomes linear and one can obtain a steady state solution:

$$n_{\rm cl}(m) = \frac{n_0}{{\rm M}_\odot}\left(\frac{m}{{\rm M}_\odot}\right)^{-1-\frac{T_{\rm f}}{T_{\rm d}}} . \tag{3.1}$$

This indicates that the GMCMF has a single power-law exponent characterized as $-1 - T_{\rm f}/T_{\rm d}$, which is originally reported by Inutsuka *et al.* 2015. Indeed, the computed mass functions agree with this exponent even with CCC (i.e., the right panel in Figure 1).

This suggests that observed variations of the GMCMF, especially the slope variation, may originate from the variation of $T_{\rm f}/T_{\rm d}$ on galactic scales. Therefore, future high resolution and sensitivity radio surveys may constrain the ratio of the GMC formation timescale to dispersal timescale by observing the GMCMF slope in the lower-mass regime. We will report more detailed analysis in our forthcoming article, especially the relation between the timescales and gas resurrecting processes (Kobayashi *et al.* 2016 in prep).

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https://doi.org/10.1017/S1743921316012400 Published online by Cambridge University Press