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Comparing the evolution of clouds and clusters in spiral galaxies

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Abstract. We perform numerical simulations to investigate the evolution of GMCs, and stellar clusters. We find that GMCs have lifetimes ranging from $\sim$ 5 to 30 Myr, according to a definition whereby at least half the mass of the chosen cloud must be present. However the formation and disruption of the GMCs takes place over 10's Myr timescales. In particular, precursors to spiral arms GMCs appear to be giant interarm filaments, which also combine with more diffuse gas to form GMCs. The evolution of stellar clusters mimics that of their natal GMCs, so shorter lived clusters occur in short-lived GMCs and vice versa. The disruption of clusters in the simulations appears to be slightly faster compared to observed clusters.

Key words. Galaxies – ISM: molecular clouds

1. Introduction

The lifetime and evolution of molecular clouds is a longstanding problem in astrophysics. Some studies have argued that GMCs are long-lived (e.g. Scoville, Solomon, & Sanders 1979) based on observations of substantial CO gas between spiral arms, whilst others assume that GMCs are in a state of gravitational collapse and are thereby short-lived (e.g. Ballesteros-Paredes et al. 1998). Implications of long-lived GMCs include that they are more likely to undergo collisions during their lifetime. Short-lived clouds are more consistent with observations of local, smaller, clouds, but for example giant molecular complexes may be longer-lived. A further question is how the evolution of clusters corresponds to that of their natal GMCs. In these proceedings, I describe some numerical simulations which investigate cloud and cluster evolution.

2. Numerical models

The models are described in full in Dobbs & Pringle (2013) and Dobbs et al. (2017) so only brief details are given here. The simulations presented study the evolution of a galaxy disc of radius 10 kpc. The simulations are hydrodynamic and include self gravity, ISM heating and cooling, stellar feedback, and those in Section 4 include star particles. An external potential is used to represent the dark matter and stellar component of the galaxy, and also includes a 2 arm spiral component. Stellar feedback is inserted nominally as supernova feedback, following a Sedov solution, with both thermal and kinetic energy added. All simulations use 8 million particles.

3. Results: cloud evolution

We show 3 frames from the simulation of Dobbs & Pringle (2013) in Figure 1. The cen-

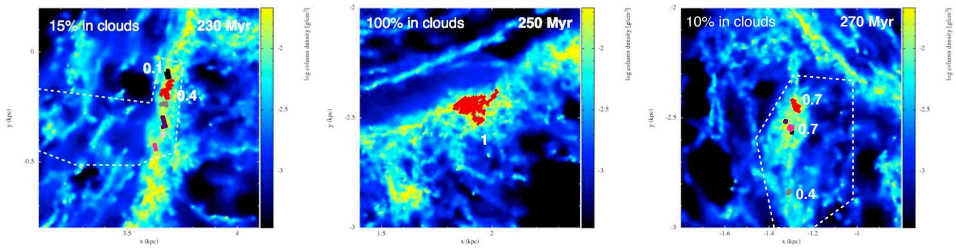

Fig. 1. Cloud evolution shown 20 Myr before (left), when the cloud is selected (centre), and 20 Myr after (right). Coloured regions indicate clouds containing the same material as the cloud selected in the middle panel. The dashed line indicates the locus of material that goes into / emerges from the cloud shown in the middle panel.

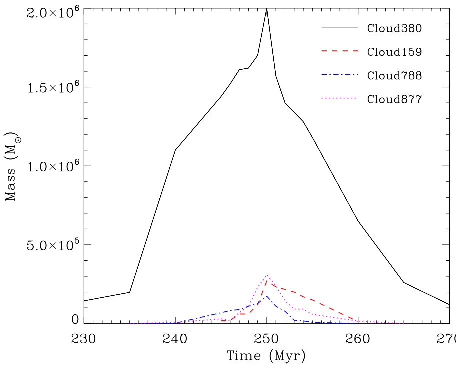

Fig. 2. The mass of gas in 4 clouds, selected at 250 Myr, versus time is shown. The mass is the continuation of each cloud, i.e. the largest mass of the same gas particles at the time of 250 Myr, which is still present in a precursor or successor cloud. Cloud380 is the cloud shown in Figure 1.

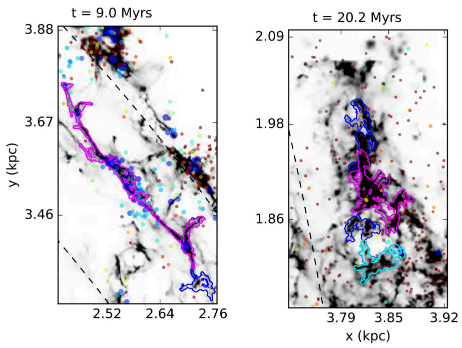

Fig. 3. Evolution of a giant molecular filament. After 10 Myr, the filament (from the left hand panel, purple contours) forms a spiral arm GMC (right hand panel).

tral frame shows a GMC, and the preceding and following frames show the gas and clouds which make up the GMC in the central frame at times of 20 Myr earlier and later. A clumpfinding algorithm used to select the clouds is described in Dobbs & Pringle (2013), which uses a grid based method to select cells above a given (total) density. The GMC appears to be formed from several smaller clouds and diffuse gas, and similarly evolves into several clouds and diffuse gas, via shear and feedback. These frames imply a timescale of 10s Myrs for GMC evolution to occur. A more quantitative approach to determining the lifetime can be made by selecting the timeframe over which there is at least half the mass present in the selected GMC in a precursor or successor cloud. This gives a timescale of around 20 Myrs (see Figure 2).

Applying the same approach to other GMCs in the simulations gives lifetimes of

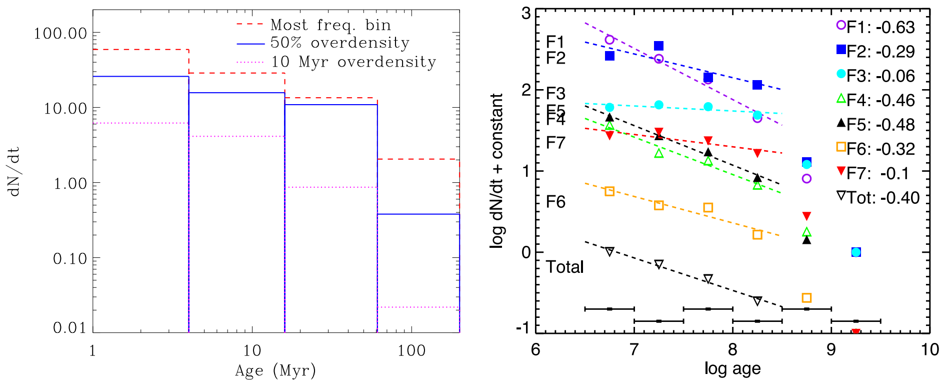

Fig. 4. Age distribution of simulated clusters (left) and observed clusters in M83 (right, from (Silva-Villa et al. 2014)). The slope of the distribution indicates how quickly the clusters disrupt. Although similar, the simulated clusters have a slightly steeper slope indicating they are disrupted a little quicker than observed clusters.

around 5–30 Myr, roughly corresponding to the crossing times of the clouds (Dobbs & Pringle 2013; Elmegreen 2000). Star formation accelerates in the clouds (as observed by Palla & Stahler 2000) until the cloud reaches its peak mass, after which star formation decelerates. Although we find relatively short lifetimes, there are longer timescales seen in Figure 1 to grow the GMCs, and from Dobbs et al. (2012), to accumulate both dense gas and more diffuse gas. We further investigate the formation of spiral arm GMCs by considering the nature of the gas entering the spiral arm. As shown in Dobbs & Bonnell (2006), the gas exhibits inter-arm spurs between the spiral arms, seen in both other simulations and frequently observed in external galaxies. We investigate the evolution of these spurs, or filaments, in Duarte-Cabral & Dobbs (2017). These filaments are comparable to giant molecular filaments, of lengths > 100 pc, seen in our own Galaxy. Long filamentary structures are also clear in images of external galaxies. The filaments appear to be the precursors of spiral arm GMCs, as seen in Figure 3, where the typical evolution of a filament is shown. The filaments enter the spiral arms and become GMCs, although they often combine with other material which is already in the spiral arms as well.

4. Results: cluster evolution

In Dobbs et al. (2017), we also included star particles (we insert one $\sim$ 300 $M_\odot$ star particle per feedback event), so we could follow the evolution of stars as well as gas. The resolution of the simulations is such that large clusters are resolved with groups of star particles, so it is possible to follow the evolution of 'clusters'. We note that these 'clusters' are not necessarily the same as observed clusters. Whilst they will have similar masses to large clusters, the spatial resolution of the simulations is such that the simulated clusters will not be as dense as real clusters. Overall we find that the clusters follow a similar evolution to their natal GMCs. Clusters formed in short-lived, unbound GMCs, tend also to be fairly short-lived. Such clusters are more unbound associations than bound clusters. On the other hand, longer lived clusters tend to be associated with longer lived GMCs, where feedback is less able to disrupt the GMC and stars can continue to form for longer, and in a denser environment. In Figure 4, we compare the frequency of clusters of ages, divided by the time bin (dN/dt), for simulations versus observations. The observations exhibit a power law $dN/dt \propto t^\zeta$ where $\zeta \sim -0.3$ to -0.6. The simulations show a steeper slope (although there is some dependence on how the age bins are defined), with $\zeta \sim -2/3$ indicating that the simulated clusters disperse slightly faster than real clusters. This is likely a consequence of the limited resolution of the simulations, including the ability of the simulations to accurately resolve the effects of stellar feedback on cluster scales.

5. Conclusions

We have perform numerical simulations to investigate the evolution of GMCs, and stellar clusters. GMCs have lifetimes ranging from ∼ 5 to 30 Myr, according to a definition whereby at least half the mass of the chosen cloud must be present. This appears to roughly correspond to their crossing times. However the formation and disruption of the GMCs takes place over 10's Myr timescales. In particular, precursors to spiral arms GMCs appear to be giant interarm filaments. These combine with diffuse gas to form spiral arm GMCs. The evolution of stellar clusters mimics that of their natal GMCs, so shorter lived clusters occur in short-lived GMCs and vice versa. The disruption of clusters in the simulations was found to be slightly faster compared to observed clusters, which may be a consequence of the limited resolution of our simulations.

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