The Formation of GMCs by Agglomeration and Self Gravity in Spiral Galaxies

Clare Dobbs[1]

ABSTRACT

GMC formation in spiral galaxies is investigated by performing 3D MHD numerical simulations. Two scenarios for GMC formation are explored, the agglomeration of gas and smaller clouds into GMCs by spiral shocks, and gravitational instabilities in the spiral arms. Which one dominates depends on the surface density of the disk, and the thermal distribution of the gas. Resulting properties of the GMCs are found to vary according to how they are formed.

Subject headings: galaxies: ISM — infrared: galaxies — infrared: ISM — ISM: dust, extinction — ISM: structure

1. Introduction

Recent hydrodynamical simulations of spiral galaxies have examined the formation of molecular clouds and interarm spurs in the absence of self gravity (Dobbs, Bonnell & Pringle 2006). The formation of GMCs is associated with the agglomeration of the gas into clouds by the spiral shock, similar to previous models of collisional formation of GMCs (e.g. Roberts & Stewart 1987). However, simulations by Shetty & Ostriker (2006) attribute the formation of GMCs to gravitational instabilities. Here we extend previous results by including self gravity and comparing the formation and properties of GMCs for different initial conditions. These proceedings comprise part of a much more comprehensive set of results to be discussed in Dobbs (2008).

[1]School of Physics, University of Exeter, Stocker Road, EX4 4QL

2. Calculations

Calculations were performed using the 3D SPMHD code (Price & Monaghan 2005). Magnetic fields are included using Euler potentials (Price & Bate 2007), and the field is initially toroidal. The gas is initially uniformly distributed, using 4 million particles. The gas is then subject to an external potential containing a 4 armed spiral component. All simulations are isothermal, although some contain a 2 phase medium of cold (100 K) and warm (10^4 K) gas.

3. Results

Figures 1 and 2 show the structure of the disk for surface densities of 4 and 20 $M_\odot$ pc^{-2}, with different thermal distributions. The different outcomes for the low and high surface density cases are described separately.

3.1. Low surface density

For $\Sigma = 4$ $M_\odot$ pc^{-2}, the disk is gravitationally stable for gas at temperatures of $\sim 10^4$ K. If only warm gas is present, there is no substructure in the spiral arms (Dobbs 2008). At these surface densities GMC formation only occurs by agglomeration, where the spiral shock forces material together and increases the chance of clump collisions. This process requires cold clumpy gas but occurs regardless of whether there is self gravity. The structure of the disk for a 2 phase medium is dominated by the cold gas (Figure 1, left), and is very similar in calculations with only cold gas (Figure 1, right). For this mechanism, the length scale between GMCs does not agree with the Jeans length. Instead this length scale (typically 100-150 pc in Dobbs (2008)), and similarly the mass of the GMCs, correlates with the strength of the shock.

GMCs formed in the calculations with low Σ exhibit low angular momentum, and both pro and retrograde rotation. The latter is a consequence of the clumpiness of the gas, with the retrograde motions induced during collisions in the shock. GMCs also tend to be unbound, loose associations of dense clumps, which dissociate when leaving the spiral arm.

3.2. High surface density

With a higher surface density of 20 $M_\odot$ pc^{-2}, the warm gas in the disk is gravitationally unstable. In simulations with only 10^4 K gas, gravitational instabilities give rise to GMCs in the spiral arms (Figure 2, left), as previously demonstrated in global simulations by Shetty & Ostriker (2006). For a two phase model, the structure and evolution of the disk is much more complex (Figure 2, right). However both gravitational instabilities and clump agglomeration appear to be important. Large structures of warm gas are present along the spiral arms, with interiors of cold dense gas. With the same surface density, but only warm or cold gas, such large scale structures are not present at this time. Self gravity induces the structure in the warm gas, with cold clumps effectively 'falling into' the minima associated with the gravitational field of the warm gas. The outcome of cold dense structures within a more extended cloud complex resembles the model of gravitational collapse in a clumpy ISM described in Elmegreen (1989). The properties of the GMCs also change as self gravity becomes more important. The high mass GMCs ($\sim 10^7$ $M_\odot$ pc^{-2}) exhibit larger angular momentum and prograde rotation. The GMCs are marginally bound ($0.7 < \alpha < 2$) and runaway collapse prevents the simulation being continued past the time in Figure 2, right.

If only cold gas is present in the disk, the Jean's mass is much smaller than that of GMCs. Hence GMCs may instead form by agglomeration and gravitational interactions between clumps (Kwan & Valdes 1987). It is difficult to run calculations for longer time periods with such high surface densities. However, it is tempting to postulate that in M51, which contains predominantly cold molecular gas, agglomeration in spiral shocks assembles gas into GMAs rather than gravitational instabilities acting over scales of several 100 pc. Such a mechanism is more likely to produce unbound GMAs in the spiral arms, as has been observed by J. Koda (see these proceedings).

4. Summary

GMC formation by agglomeration occurs when there is a clumpy component of the ISM, i.e. cold HI or molecular gas. If only cold gas is present, GMC formation only occurs by agglomeration, since the Jeans mass of the cold gas is less than that of a GMC (although gravitational interactions between clumps may become much more important at high surface densities). On the other hand, if there is only warm gas, GMCs can only form by gravitational instabilities. Generally, the ISM is presumed to contain both cold and warm components. Then both agglomeration and gravitational instabilities are expected to play a role. Future calculations with consistent heating and cooling, and eventually stellar feedback, will provide more realistic models of the evolution of the ISM and GMC formation.

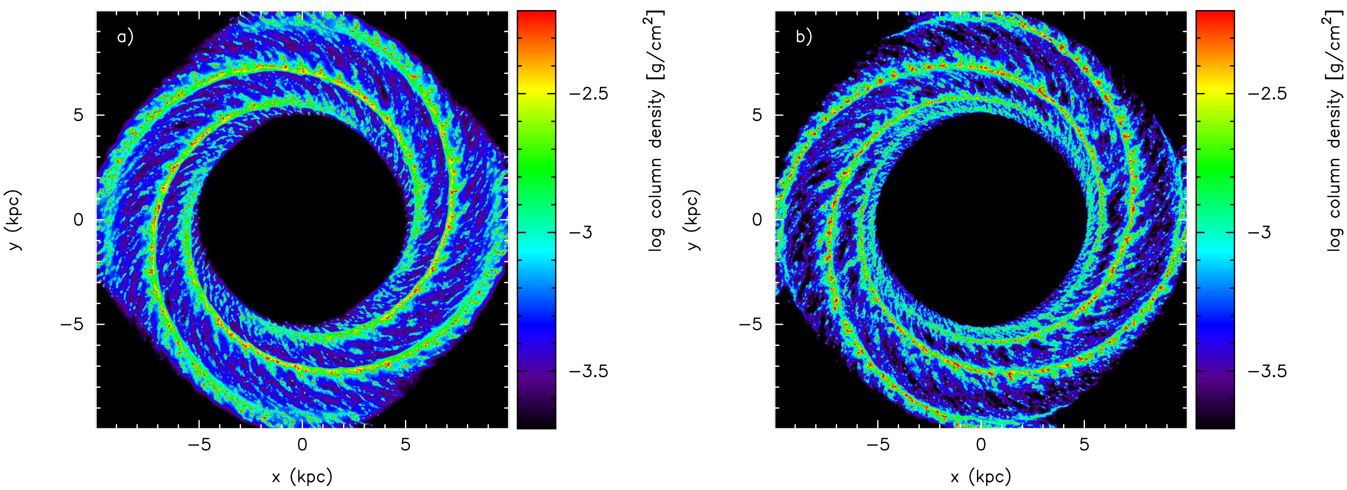

Fig. 1.— The column density for the galactic disk is shown where $\Sigma = 4$ M$_\odot$ pc^{-2}. In a), the ISM is assumed to be a 2 phase medium of 50% cold (100 K) and 50% warm (10^4 K), whilst for b), all the gas is cold. In both cases the structure is dominated by the cold gas, and not dissimilar to calculations without self gravity (see Dobbs 2008). The formation of the largest clumps situated along the spiral arms (of mass $10^5 - 10^6$ M$_\odot$) is due mostly to agglomeration. The corresponding time is 265 Myr for both panels.

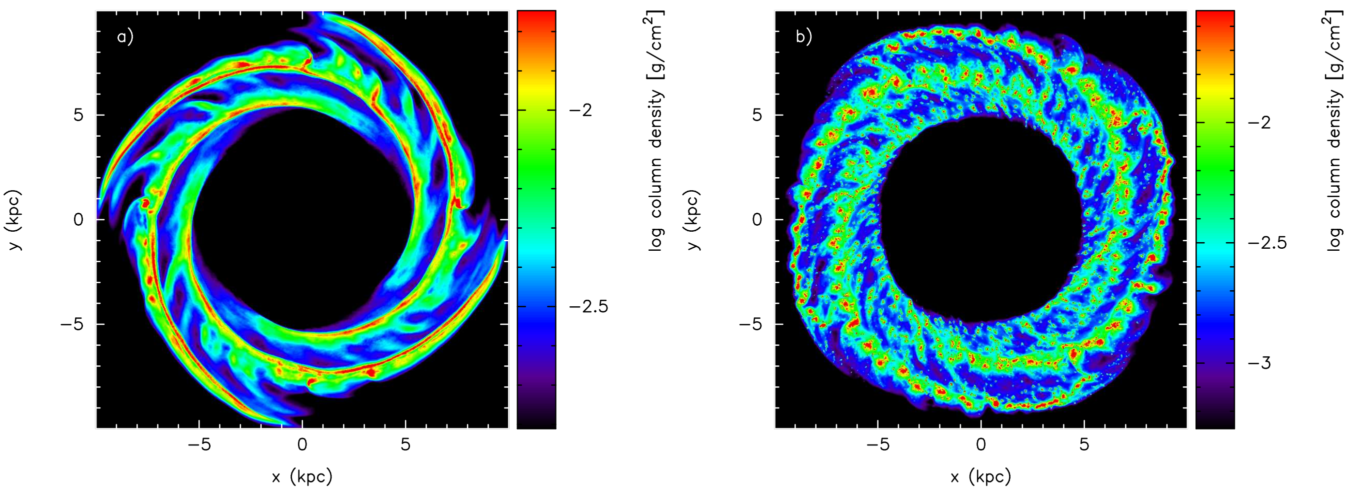

Fig. 2.— The galactic disk is now shown when $\Sigma = 20$ $M_\odot$ pc^{-2}. The ISM is assumed to be all warm in a), and a 2 phase medium in b). For a), the formation of substructure is solely due to self gravity, as the warm gas is completely smooth. With cold and warm gas (b), there is much more structure in the disk, and the clouds themselves that form along the arms. In this case, both self gravity and agglomeration contribute to the formation of GMCs, but the properties are more consistent with self gravity being the dominant process. The time is 265 Myr in a), and 130 Myr in b).

REFERENCES

Dobbs, C. L., Bonnell, I. A., & Pringle, J. E. 2006, MNRAS, 371, 1663

Dobbs, C. L., 2008, MNRAS, submitted

Elmegreen, B. G., 1989, ApJ, 344,306

Kwan, J., & Valdes, F. 1987, ApJ, 315, 92

Price, D. J., & Monaghan, J. J. 2005, MNRAS, 364, 384

Price, D. J., & Bate, M. R. 2007, MNRAS, 377, 77

Roberts, W. W., & Stewart, G. R. 1987, ApJ, 314, 10

Shetty, R., & Ostriker, E. C. 2006, ApJ, 647, 997

This preprint was prepared with the AAS LaTeX macros v5.2.