The Evolution of GMCs in Global Galaxy Simulations

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image from Britton Smith
Simulation properties

We use the AMR code, Enzo, to model a 3D isolated disk galaxy at high resolution (smallest cell size 7.8pc).

The disk is initially smooth and sits in a static background potential that gives a Milky Way-like flat rotation curve.

The gas can radiatively cool down to 300 K during which it becomes gravitationally unstable to form dense knots of gas that we recognise as the giant molecular clouds (GMCs).

We present three runs:

(a) without star formation or feedback

(b) star formation at a constant efficiency per free-fall time of 2%. Star particles are created with 1000 solar masses
Galaxy model

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(a) without star formation or feedback

(b) star formation at a constant efficiency per free-fall time of 2%. Star particles are created with 1000 solar masses

(c) star formation plus photoelectric heating from the absorption of UV photons on dust grains which ejects an electron.

\[ \propto e^{-(R-R_0)/H_R} \]

(Draine, 1978)

(Wolfire, 2003)
Galaxy model
Galaxy model

Star formation

Star formation + PE heat
Star formation and feedback
Cloud identification

Find peaks in the gas density field with \( n_{HI} > 100 \text{cm}^{-3} \)

Recursively search peak neighbours for cells also \( n_{HI} > 100 \text{cm}^{-3} \)

Clouds are tracked through the simulation
ISM structure

Radiative cooling cut-off @ 300K

$t = 250$ Myrs

No star formation

Star formation

Star formation and photoelectric heating

Mass weighted contour plots

Star formation reduces mass of cold dense gas, while further heating reduces cold gas present at lower densities.
No star formation:
Fraction of gas in clouds: 0.6

Incl. star formation:
Fraction of gas in clouds: 0.23

SF + PE heating:
Fraction of gas in clouds: 0.44
Without SF, there is little to stop clouds gaining in mass.

Collisions and agglomerations result in a high mass tail.

Star formation removes gas from the clouds, reducing their maximum size.
The mass function of GMCs in the Milky Way and M33 fits a power law (Rosolowsky et al. 2003):

\[ \frac{dN}{dM} \propto M^\alpha \]

Where \( \alpha = -1.6 \) for Milky way (scaled distribution) \( \alpha = -1.8 \) for Milky Way (more low mass clouds) \( \alpha = -2.6 \) for M33
Observed clouds (including atomic envelopes) have max masses $< 1.2 \times 10^7 M_\odot$

(Williams & McKee, 1997)

This is in good agreement with the runs that include SF, despite the lack of SNe feedback.
Star formation

Initial fragmentation of disk

Simulation without photoelectric heating has a greater SFR over the first 200 Myr of the simulation

In the last 100 Myr, the run with only star formation starts to suffer from gas depletion and it’s SFR drops
The Kennicutt-Schmidt relation finds that the star formation rate in disk galaxies is proportional to the gas surface density:

$$\Sigma_{\text{SFR}} \propto \Sigma_{\text{gas}}^{1.5}$$

Local relations:

Properties averaged over 200 annuli between $r = 2.5 - 8.5$

The gradient is steep, but there is evidence of a fall off at low surface densities.

Diagonal lines show constant SFE, indicating level of SFR needed to consume 1%, 10% and 100% of gas in 100 Myr.
The Kennicutt-Schmidt relation finds that the star formation rate in disk galaxies is proportional to the gas surface density:

\[ \Sigma_{\text{SFR}} \propto \Sigma_{\text{gas}}^{1.5} \]

cloud relations:

Properties calculated for each cloud, projected on the X-Y plane.

For the clouds ("molecular gas") the K-S relation is extremely well reproduced.

PE heating produces lower cloud densities.
The Kennicutt-Schmidt relation finds that the star formation rate in disk galaxies is proportional to the gas surface density:

\[ \Sigma_{\text{SFR}} \propto \Sigma_{\text{gas}}^{1.5} \]

Observations:

Good agreement with results from THINGS, Bigiel, 2008
Cloud collisions may also act as a trigger for star formation.

Tan (2000) showed that if the average cloud collision time is a fraction of the orbital period, and these events trigger star formation, then this can produce the observed Kennicutt-Schmidt relation.

For the run in the absence of star formation:

Merger rate ~ 0.15 - 0.3 over most of the simulation.
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With the inclusion of star formation (and therefore the destruction of clouds):

Merger rate ~ 0.2–0.3 over most of the simulation
Cloud collisions may also act as a trigger for star formation.

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For the run with photoelectric heating:

Merger rate \(\sim 0.2-0.3\)

With late times in the inner disk being most affected due to the region \(< 4 \text{ kpc}\) being warmer.
Do cloud collisions trigger star formation?

The average specific star formation rate of a cloud increases with the number of mergers it has undergone.

This is most noticeable for small (\(< 15\)) mergers.

Clouds undergoing more mergers are rare, and are likely to be large, making their internal dynamics less susceptible to collisions.
Conclusions

We modeled a Milky Way-type galaxy at 10s-parsec resolution in 3D with a fully multiphase ISM, including star formation and feedback from photoelectric heating.

- We identified and tracked GMCs through the galactic disk
- Cloud properties are in good agreement with observed galaxies
- Cloud merger rate is a fraction of the orbital period and appears to be strongly correlated with the star formation rate in the cloud
- This was all in the absence of feedback from supernovae