STAR FORMATION IN A DENSITY-WAVE-DOMINATED, CLOUDY INTERSTELLAR MEDIUM

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We present a model of the interstellar medium in spiral galaxies. The ISM is simulated by a system of particles, representing gas clouds. It is a probabilistic N-body system in which "cloud" particles orbit ballistically, undergo dissipative collisions with other clouds, and experience velocity-boosting interactions with expanding supernova remnants (SNRs). Associations of protostars may form in clouds following collisions or SNR interactions (thus allowing sequential star formation); these associations take finite times before becoming active and undergoing their own SN events (Roberts and Hausman, 1983; Hausman and Roberts, 1983).

In the presence of a spiral-perturbed galactic gravitational field, the cloud distribution responds with a strong global density wave (galactic shock), with clouds concentrated in spiral arms. The appearance of large cloud-particle clumps in the spiral arms of the computations, due in part to the self-gravitation-mimicking effect of inelastic collisions, suggests how easily real clouds can agglomerate into giant complexes in spiral arms.

Our results are found to be remarkably independent of the cloud system's collisional mean free path. Figure 1 shows the cloud distributions at steady state in two cases whose mean free paths differ by a factor of five. The global coherencies of the two cases are not that dissimilar, although case E (longer mean free path) exhibits a somewhat weaker, more ragged spiral pattern.

The young star population in our model exhibits a coherent spiral pattern in all cases for which cloud collisions are an important star-formation mechanism. In contrast, a case, for which sequential (SSPSF) star formation dominates, is unsteady and shows only transient spiral structure. All cases, except this last one, reach steady state within 200 Myr and remain stable through the duration of the computations - 10^9 years in some cases. At the shock, the region of peak cloud velocity dispersion leads the locus of peak cloud density. Although continuum and "cloud-fluid" models can also approximately reproduce the global structure
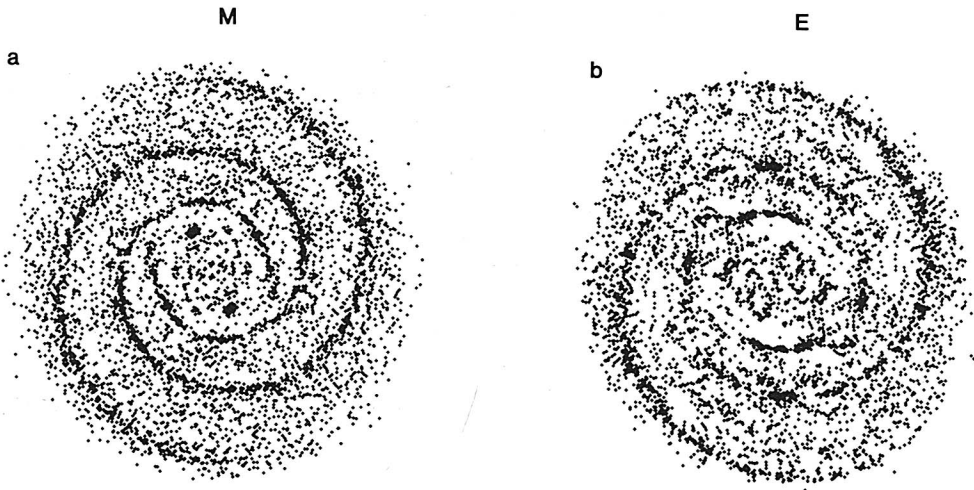
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M   E

a   b

Figure 1. Global spiral structure exhibited by the gas–cloud distribu-
tions in two cases of greatly different collisional mean free path λ.
Left panel – case M, λ = 200 pc. Right panel – case E, λ = 1000 pc.

of a cloudy ISM, they do not represent local effects (scales of a few
hundred pc) as well.

An analytical theory based on fluid–dynamical equations is developed
and compared to our N–body model of the ISM in spiral galaxies. When
steady-state is assumed, the equations may be spatially averaged to give
a mean galaxy-wide star-formation rate. The poorly-known physics of
real star–formation processes is incorporated into two parameters which
measure the relative importance of the cloud–collision and supernovae-
sparking mechanisms. Despite the small-scale stochastic variations and
the large-scale density inhomogeneities of the particulate, numerical
model, its star formation rate is well described by the fluid-dynamical
theory.

ACKNOWLEDGEMENTS

REFERENCES

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Roberts, W. W., and Hausman, M. A., 1983, Ap. J. (submitted for publica-
tion).

DISCUSSION

J.P. Ostriker: Your clouds will lose their velocities on the time-scale for cloud-cloud collisions, unless you have a mechanism for accelerating them, and you lose all your small clouds by making big clouds on the same time-scale. Since the cloud-cloud collision time scale is very short compared with the duration of your simulation, the exact way you put in more energy and more clouds must be important to the final results.

Roberts: That is a very good observation. In fact we have energy coming in through supernova explosions; so the clouds are dissipating, but an energy balance is maintained by the interaction of the supernovae with the clouds. New clouds are not made; we keep the same number of clouds in a given run throughout.

B.G. Elmegreen: How does the size of the clumps produced in your calculation depend on the number of clouds in the simulation? If you had a very large number of clouds, comparable to the expected number in a galaxy, would the resultant clump size be smaller than it is in the present calculations?

Roberts: If we had made our calculations with a much larger number of clouds than the 20000 adopted, and with a correspondingly smaller cloud cross-section (to still preserve the collisional frequency and collisional mean free path estimated for real clouds in the interstellar medium), then clumps on much smaller scales might well have resulted in the simulations. Future simulations with greater numbers of clouds should be able to address this question more adequately.

Heading for reception by President of Groningen University, right to
left: Lyngå, Wramdemark, Roberts, Mrs. Oort, Oort and G.D. van Albada
(hidden), Milogradov-Turin, Mrs. Schwarz, Hu, Twarog   CFD