HOW DOES STAR FORMATION AFFECT THE LARGE SCALE STRUCTURE OF THE ISM?

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1. Introduction

Nearly all the star formation in the Milky Way and nearby spiral galaxies occurs in the giant molecular clouds (GMC). Inside the GMC's the units of star formation are the high density ($\geq 10^3 cm^{-3}$) and high mass ($\geq 10^3 M_\odot$) clumps (Blitz, 1991). Once a GMC is "infected" by star formation many clumps form stars producing a star forming region. The formation of massive stars induces destructive processes, such as H_2 dissociation, HI ionization, stellar winds and supernova explosions, thus self-limiting the lifetime of GMC to $\sim 3\ 10^7$ years.

Here, the star formation is discussed as a collective process happening in GMC. We describe how it influences the ambient interstellar medium and how it propagates in the Galaxy. The large scale means the size comparable to the galactic diameter.

2. Anomalous HI Features, Worms, Chimneys and Supershells

The galactic supershells, discovered by Heiles (1979), are the HI structures up to $\sim 2\ kpc$ in diameter expanding at velocities $\sim 20\ km\ s^{-1}$. They are associated with the HI holes or voids in the HI distribution. Special supershells are the galactic worms, or interstellar HI structures that lie roughly perpendicular to the galactic plane with the median width of some ~ 100 pc and the median height some ~ 180 pc. They were listed by Koo et al. (1992). Another specific version of a supershell is a "chimney": if the released energy is high enough and if the gaseous disk does not have too much of a z-extent, then a supershell blows out of the disk, forming a chimney leading the hot gas from inside the bubble into the galactic halo (Heiles, 1992).

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The supershell appearance, their shape, expansion velocities, and whether it blows out to the galactic halo and becomes a chimney, depends on the energy inserted and on the distribution of the ambient medium. The energy source can be the young and massive stars of a star forming region (Tenorio-Tagle & Bodenheimer, 1988) or the collision of a cloud with the galactic HI plane (Tenorio-Tagle, 1980, 1981). The distribution of the ambient medium influences the superbubble evolution: the low-density and sufficiently thick HI disk can suppress its blowout preventing the transport of the hot and heavy elements enriched gas from the supershell interior far out of the galactic plane. The blowouts are possible when the HI disc has a small scale height, then also the formation of chimneys may be expected (Palouš, 1990).

The local Lindblad's expanding ring of molecular clouds and the O, B stars of the Gould's belt may be the relics left after the supershell expansion (Palouš, 1987). Their motion, which distinctly deviates from the galactic differential rotation (Westin, 1985), should reflect the velocities at earlier times when the expansion has been initiated. Unfortunately, the pure expansion or the influence of the density wave give velocity fields differing from observations (Lindblad, 1980). Other scenarios, such as the collision of a high velocity cloud with the galactic plane or the expansion from a rotating cloud are also discussed (Comeron & Torra, 1992; 1994; Comeron, Torra & Gómez, 1994; Lindblad & Palouš, 1995).

New 21 cm Leiden-Dwingeloo survey by Burton and Hartmann (Burton, 1994; Hartmann, 1994) shows many anomalous-velocity HI structures (Burton et al. 1992). We compare the supershells detected in this survey with simulations: an example is given by Ehlerová et al. (1994). Comparison of the observed galactic supershells with simulations may give constrains on the z-distribution of the interstellar medium and on the energies required.

However, the interstellar medium is not just a collection of clouds and supershells expanding in smooth ambient gas and in isolation. The observations show an interconnected network of filaments with embedded amorphous density concentrations (Scalo, 1990; Elmegreen, 1993). The evolution of clumpy gas in galaxies is analyzed by Yorke et al. (1992). The expansion of superbubbles in the cloudy medium is discussed by Silich et al. (1994a, b).

3. Dissipative Cloud Collisions

The Galaxy involves diffuse, self-gravitating and unbound clouds of sizes from 1 pc to 1000 pc and masses up to $10^7 M_\odot$ (Elmegreen, 1993). About 85% of H_2 mass is contained in $\sim$ 6000 GMC larger than 22 pc in diameter with masses $> 10^5 M_\odot$ each. The cloud-to-cloud velocity dispersion is nearly independent of mass ranging between $4-7\ km\ s^{-1}$ (Stark, 1984). With this velocity dispersion the mean free path of a GMC is $\sim 1.7\ kpc$ (Sanders, Scoville, 1987).

GMC are composed of high density clumps and interclump medium of much lower density. They do collide and we may ask if their formation can be ascribed to collisional agglomeration, or if the star formation and subsequent GMC disruption is the more ultimate result of a collision. It may depend on the relative velocity with the low velocity collision leading to agglomeration and the high velocity collision to star formation and cloud disruption.

A fraction of the energy of relative motion is dissipated in both cases. Such dissipative collisions reduce the velocity dispersion circularizing the cloud orbits. The collisional cooling is counterbalanced with heating, or increasing the noncircularity of motions, from star formation, large scale nonaxisymmetric density perturbations such as spiral arms and bars, or tidal encounters with other galaxies.

Resonances between the galactic orbital frequency and the large scale perturbation are places of increased momentum exchange between the perturbation and individual clouds. There, the orbital heating enhances higher collisional frequency and higher collisional cooling. This is why the rings of molecular clouds appear at resonances (Palouš et al. 1993; Palouš & Jungwiert 1995). Depending on the strength of perturbation, the collisions may happen at sufficiently high relative velocities inducing the ring like star formation burst (Elmegreen, 1994).

4. Propagating Star Formation

The idea that star formation at one place may initiate the star formation at another place was first proposed by Öpik (1953) and Oort (1954). An early theoretical model was developed by Mueller and Arnett (1976). The observational evidence of the sequential star formation within 1.5 kpc was reviewed by Blaauw (1991).

Here we describe two types of models: stochastic, when the propagation is given with a certain probability, and deterministic, when the propagation results from a chain of events (star formation – supershell expansion – accumulation of the ambient medium – formation of clouds) connecting the places of subsequent star formation.

4.1. STOCHASTIC MODELS

First stochastic self-propagating star formation model was developed by Seiden and Gerola (1982), Schulman & Seiden (1986) and Seiden and Schulman (1990). They introduced a finite and isotropic probability that the star formation in one region induces star formation in a neighboring region. Another parameter is the recovery time during which the probability is lower for cells that were active recently. The galactic rotation curve and the relative size of a star forming region are other parameters of their model. Resulting patterns resemble flocculent spirals. This model particularly applies to dwarf irregular galaxies, where the star formation has the burst like nature. The galaxy has to wait until the stars begin to form, then the star formation propagates to all the disk, which is heated and the star formation turns off until the gas cools down again (Elmegreen, 1994).

The model with anisotropic probability distribution was developed by Jungwiert and Palouš (1994). The propagation probability, which depends on the direction in the galaxy, is given with an ellipse: its inclination and eccentricity are related to the galactic rotation curve, resulting in the long and well organized spiral arms. The Hubble sequence Sa - Sb - Sc - Sd - Sm - Irr may be the sequence of decreasing eccentricity and inclination of the major axis of the propagation probability ellipse, which is quite likely if this ellipse reflects the decreasing sheer along the Hubble sequence.

4.2. DETERMINISTIC MODELS

The star formation is propagating when it is able to overjump from one location in the galaxy to another. The star forming clouds can be composed from material accumulated in supershells expanding from the star forming centers. As soon as the massive stars appear they ionize the ambient medium disrupting the parental cloud. The energy from the new stellar cluster generates an expanding supershell. As it reaches large size, the mass accumulated due to the galactic sheer at the tips of elliptical supershells gets opaque to dissociating photons. The gravitational fragmentation can initiate the formation of new molecular clouds and trigger the star formation (Elmegreen, 1994). It is a self-regulating process determining the galactic star formation rate, the number of superbubbles, and the relative fraction of the disc space occupied by the hot medium (Palouš, 1989, 1993; Tenorio-Tagle, 1994).

The cloud formation in expanding supershells is the principle used in a deterministic model of propagating star formation developed by Palouš et al. (1994). It is a coherent process producing at any time of the disc evolution the non-axisymmetric large scale structures sometimes of spiral shape (Fig. 1. and 2.). The propagation organizes the star forming regions to spiral like sequences with the characteristic appearance of 'pearls on a necklace' resembling the situation noted first in observed galaxies by Walter Baade.

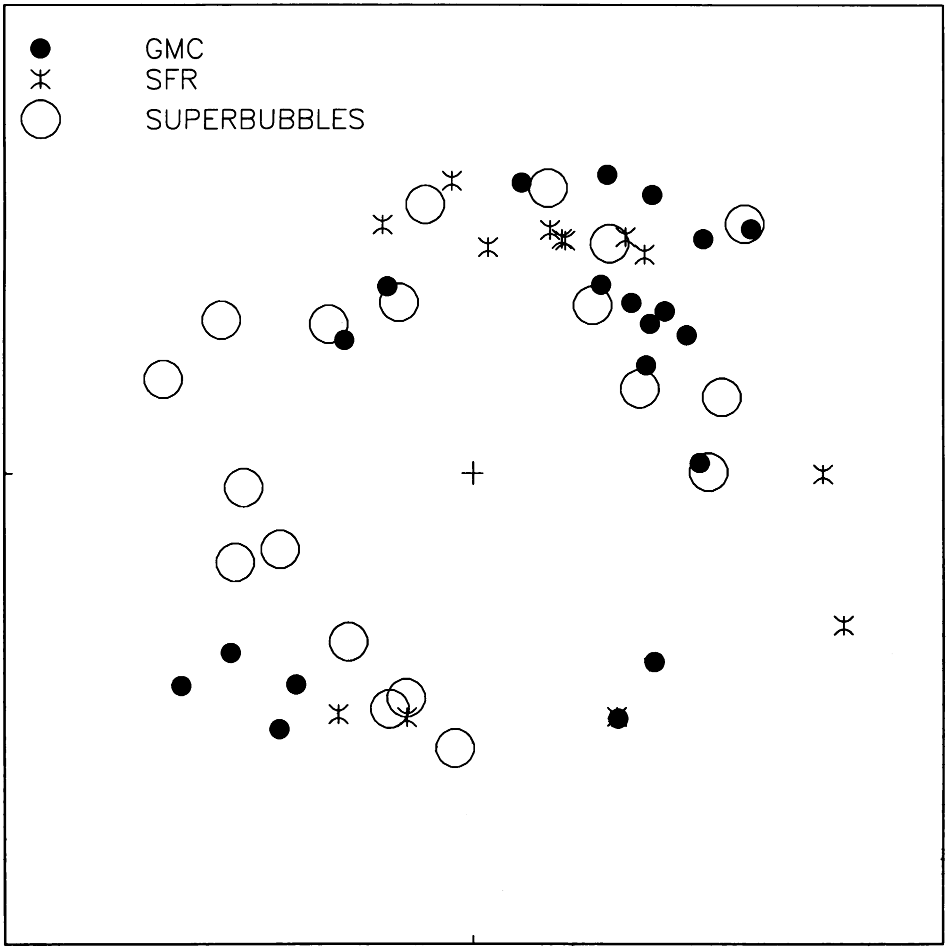

Figure 1. The self-propagating star formation model (Palouš et al., 1994). The plane distribution of massive molecular clouds (> $10^6 M_\odot$), star forming regions (SFR) and superbubbles 1 Gyr after the first star formation was triggered in the galactic disc. The galactic center is marked with the + sign.

5. Principles of Self-Regulation

The two self-regulating mechanism should be distinguished in spiral galaxies:

1) The gravitational mechanism, which is due to the influence of the large scale non-axisymmetric features such as spiral arms and bars on the motions of individual stars. This large scale features, which form in the low velocity dispersion disc, increase the velocity dispersion of both, stars and gaseous clouds. The increase in the velocity dispersion reduces the growth

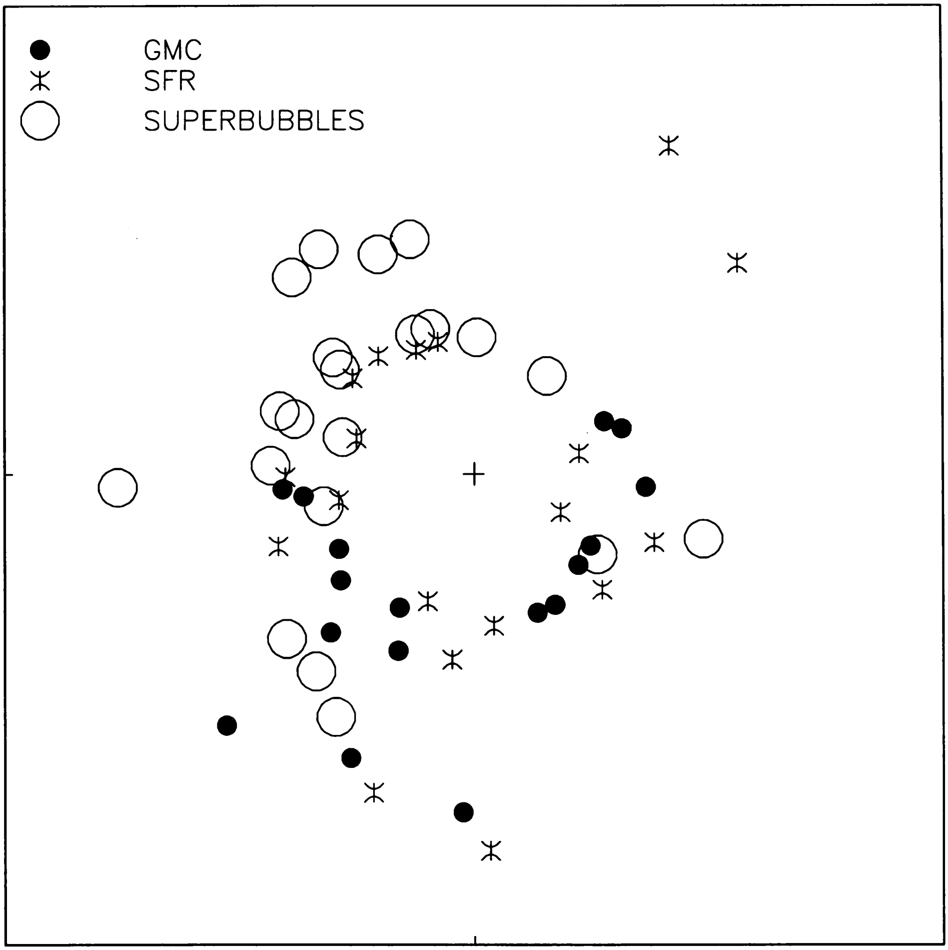

Figure 2. **The self-propagating star formation model. The same as Fig. 1. 10 Gyr after the star formation was triggered in the galactic disc.**

rate of non-axisymmetrical features. Without dissipation the system would rapidly become hot, stable and axisymmetric. Fortunately, the growing velocity dispersion also enhances the energy dissipation in the gaseous component decreasing its value to a critical level of marginal stability. Thus, the presence of the dissipative component keeps this mechanism in operation.

2) The mechanism related to the star formation inside the molecular clouds. The star formation heats the ambient medium prohibiting formation of further stars inside the same interstellar cloud. However, it also propagates to other places in the galaxy initiating further star formation there. This self-propagating star formation mechanism determines the galactic

star formation rate and it predicts its relation to the galactic rotation curve. This prediction should be compared with observations.

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