SUPERSHELLS WITH INDUCED LARGE-SCALE SUPERNOVAE FORMATION

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Abstract: We propose a model of expanding supershells regulated by star formation which is induced in HI superclouds by similar shells from a previous evolutionary stage. Compression of pre-existing cloudlets by such shells triggers the formation of massive stars which then explode at the end of their evolution as supernovae. Efficiency of induced supernovae formation must be less than 1% to fit the observational properties of supershells.

Introduction: Recent observations of our own and nearby galaxies have revealed three types of large-scale structures with a characteristic spatial scale of about 1 kpc and mass ~10 $M_\odot$. These are: neutral hydrogen superclouds[6], star complexes[5], HI "holes" and expanding supershells of neutral and ionized hydrogen[2 7 11]. Several mechanisms for the origin of these structures have been proposed[1 3 13 15]. The coincidence of the typical sizes and masses of all of the above objects suggests that superclouds, star complexes, HI "holes" and expanding supershells are just different evolutionary stages of an overall process of the formation and evolution of huge self-gravitating galactic structures. Our main attention is directed to the dynamics of supershells driven by the collective interaction of supernovae with HI superclouds.

The Model: An initial supercloud (Figure 1a), a two-phase gravitationally-bound system, is likely to be composed of cold dense cloudlets embedded in a substrate of low-density warm interstellar gas. Conditions are created in the central parts of superclouds for the formation of giant molecular clouds. Thus giant molecular clouds appear to be only the cores of these larger fundamental structures. Star formation starts in these cores of superclouds. The combined pressure of stellar winds and supernova explosions in an initial OB-association will generate a shell expanding with a velocity[8 15] $u_{sh} \propto R^{-2/3}$. Unusual OB-associations containing more than 10^3 stars are required to produce the largest expanding shells according to the theory of Kafatos and McCray[8]. However, OB-associations usually contain no more than 100 massive stars. The expansion velocities of shells vary within a narrow velocity range as their sizes change from ~0.1 kpc up to ~1.5 kpc[7]. Similarly there is a clear tendency for HI "holes" to be larger for greater expansion velocities[2]. Thus, in studying the dependence of expansion velocities on the radii of supershells, one gains the impression that additional volume sources of energy input must appear during the evolution of a shell. We suggest that collisions of a supershell with the cloudlets randomly

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distributed in the supercloud will trigger first the formation of massive stars and then a wave of supernova explosions moving after the shell (Figure 1b, 1c).

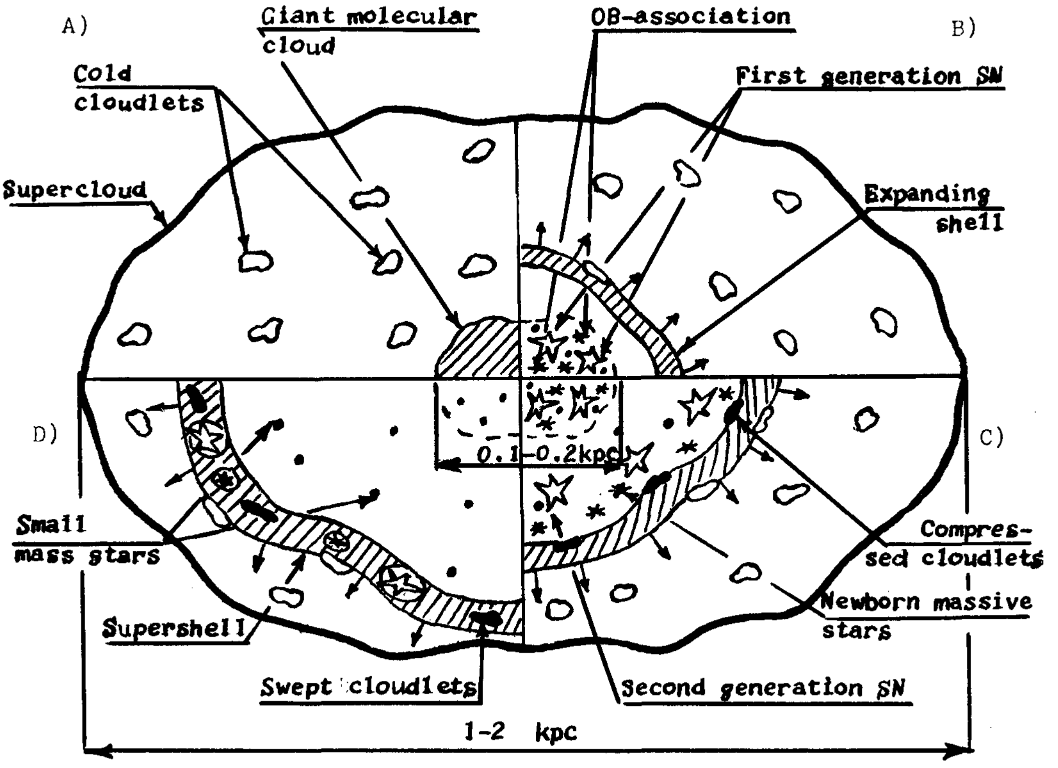

Fig. 1. A scenario of the evolution of a supershell.

Dynamics of the Supershells: Three evolutionary stages are evident for the different dominant mechanisms of energy input into the cavity.

1. The energy input into the cavity is dominated by the supernova explosions in the initial OB-association. Evolution of the shell is described by the models of Kafatos and McCray[8], and Tomisaka et al.[15].
2. The energy input into the cavity is dominated by newborn supernova explosions. This starts immediately after the first newborn supernova explosion and ends when the supershell mass increases enough to sweep the small cold cloudlets out of the cavity.
3. All massive stars inside the supershell have exploded as supernovae. Energy pumping into the cavity stops (Figure 1d). The equation of shell motion[10] is:

$$\frac{d^2u}{dt^2}+(7+3\gamma)\frac{u}{R}\frac{du}{dt}+\frac{9\gamma u^3}{R^2}+\frac{2(2+3\gamma)\pi G\rho_0}{3}=\frac{9(\gamma-1)\mathcal{E}_0(t)}{4\pi\rho_0 R^4}, \qquad (1)$$

where u and R are the shell velocity and radius, ρ_0 is the gas density in the supercloud corona, and G is the gravitational constant.

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Numerical solutions of equation (1) for the expansion of the supershell are given in Figure 2.

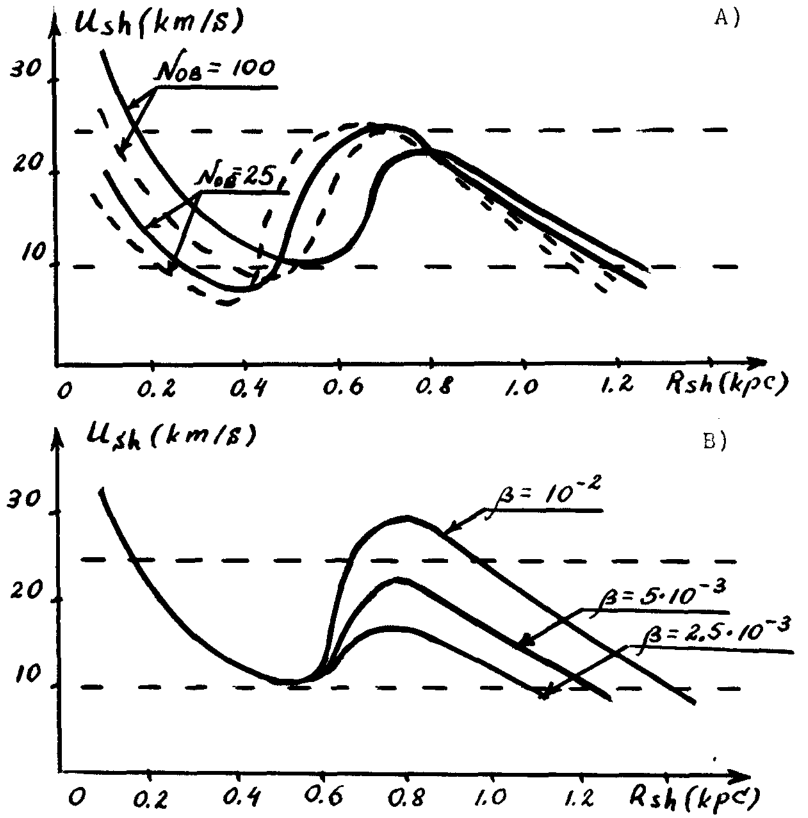

Figure 2. Dependence of the expansion velocity on the supershell radius A) for different numbers of stars in the initial OB-association, N_{OB}, and gas number density, n_0, in the supercloud corona. Solid curves correspond to n_0=0.5 cm^{-3}, dashed lines to n_0=1 cm^{-3} B) for different efficiencies of induced star formation β.

Conclusions:

1. Supershell structures are the natural by-products of the sweeping up of neutral gas from the central parts of superclouds by supernova explosions at a late stage in the evolution of star complexes. To understand the dynamics of the largest supershells it is necessary to take into account the fact that expanding shells can induce star formation in pre-existing cold dense cloudlets formed as a result of thermal instabilities. Explosions of massive short-lived (~10^7 yr.) newborn stars then give an additional volume energy supply to the expansion of the supershell.
2. Gas pressure inside the cavity increases after the second generation supernova explosions begin, so that a sufficiently large (R ~ 0.3-0.5 kpc) shell can expand at ever-increasing speed.

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3. The efficiency of induced star formation has to be less than one percent to produce supershells with radii ~1 kpc and expansion velocities 10-25 km/s throughout the evolution. This value is in good agreement with the data of the efficiency of OB star formation in the Galaxy.
4. Starting at the centre of a supercloud, star formation spreads like an infection through a hundred parsecs in a time of 10^7-10^8 yr. Therefore for the largest supershells young stars and associations will be distributed along their rims and a gradient of age in the stellar population will exist from the center to the edge of the supershell.

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