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TRIGGERED STAR FORMATION

J. Palouš and S. Ehlerová

Astronomical Institute, Academy of Sciences of the Czech Republic, Prague

RESUMEN

Se discute la formación de estrellas en las paredes de cascarones en expansión. Se estudia el proceso de fragmentación con teoría de perturbaciones lineales y no-lineales. Se obtiene la condición para fragmentación gravitacional: los cascarones son inestables cuando la densidad superficial del disco es mayor a un cierto valor crítico, que depende de la energía del cascarón y la velocidad del sonido del gas. Como ejemplo, se discute la formación de asociaciones OB en la vecindad del Sol. Los progenitores de las asociaciones OB de Orión y Scorpius-Centaurus estuvieron juntos hace de 10 a 12 millones de años, en una regón plana y elongada en la dirección $l = 20°$–$200°$, mostrando que pudieron haber sido formados como fragmentos de una superburbuja.

ABSTRACT

The star formation triggered in dense walls of expanding shells is discussed. The fragmentation process is studied using the linear and non-linear perturbation theory. The influence of the energy input, the ISM distribution, and the speed of sound is examined analytically and by numerical simulations. We formulate the condition for the gravitational fragmentation of expanding shells: if the total surface density of the disc is higher than a certain critical value, shells are unstable. This value depends on the energy of the shell and the sound speed in the ISM. As an example the formation of OB associations near the Sun is discussed. We trace their orbits in the Milky Way to see where they have been born: 10–12 Myr ago progenitors of the Scorpius-Centaurus OB associations and the Orion OB association resided together within a sheet-like region elongated in the $l = 20°$–$200°$ direction, showing that the local OB associations may be formed as fragments of an expanding supershell.

Key Words: **GALAXIES: EVOLUTION — HYDRODYNAMICS — ISM: STRUCTURE — STARS: FORMATION — SUPERNOVA REMNANTS**

1. INTRODUCTION

The gravitational instability in the ISM may develop spontaneously, or it may be triggered by an external push (Elmegreen 1998): (i) a compression of pre-existing clouds, (ii) an accumulation of gas into a shell that may be unstable, and (iii) cloud collisions. Shell collisions, as considered by Chernin et al. (1995), can also influence the star formation. Here we focus on the mechanism (ii). The growth of perturbations on the surface of expanding spherical thin shell was analyzed in the linear approximation by Elmegreen (1994) and Vishniac (1994). The instantaneous maximum growth rate is

$$\omega = -\frac{3v_{\rm exp}}{R} + \sqrt{\frac{v_{\rm exp}^2}{R^2} + \left(\frac{\pi G \Sigma_{\rm sh}}{c_{\rm sh}}\right)^2}, \qquad (1)$$

where R is the radius of the shell, $v_{\rm exp}$ is its expansion speed, $\Sigma_{\rm sh}$ is its column density and $c_{\rm sh}$ is the speed of sound within the shell. The perturbation grows only if $\omega > 0$.

The linear analysis is extended to quadratic terms by Wünsch & Palouš (2001). Quadratic terms give the possibility to follow the evolution of fragments after the time when the gravitational instability starts. Masses of individual fragments and their mass spectrum can be evaluated.

Probably both the spontaneous and triggered star formation operate in galaxies and it is difficult to decide, which mechanism is more important. To discuss the star formation triggered in expanding shells without an a priori assumption on their shapes, we use 3-dimensional simulations. In a numerical code, the condition of equation (1) is used and we quantify when and where the expanding shell starts to be unstable. This approach was first used in Ehlerová et al. (1997), here we extend parameter ranges and generalize results. We also propose a model of the local system of young stars, Gould's belt, which may be the result of triggered of star formation event in the local ISM.

2. CRITICAL SURFACE DENSITY

To study the influence of the total energy input $E_{\rm tot}$, of the speed of sound in the ISM $c_{\rm ext}$, of the disk thickness H and of the maximum disk density ρ_0 on the gravitational instability of shell, we use the 3 dimensional numerical model. We fix the speed of sound in the shell $c_{\rm sh}$ and evaluate if the condition for the gravitational instability of the shell (1) is fulfilled at some region during the shell evolution.

In the parameter space ρ_0 versus H the gravitationally unstable and stable regions are separated by surfaces of constant surface density $\Sigma_{\rm crit}$. Simulations with different disc profiles (Gaussian, exponential, multicomponent) show, that $\Sigma_{\rm crit}$ does not depend on it. There are two types of deviations to this rule:

The blow-out effect. For thin disks a higher density ρ_0 than corresponding to $\Sigma_{\rm crit}$ is needed for the instability. The blow-out enables the leakage of the energy to the galactic halo, leading to the decrease of the effective energy and pressure pushing the densest parts of the shell.

The small shell in the thick disk. The low energy shell is generally small, and in thick disks they evolve in an almost homogeneous medium never reaching dimensions comparable to the thickness of the disk. Consequently, the value of the gas surface density of the disk is irrelevant in this case. For the instability, the value of ρ_0 has to be higher than predicted by $\Sigma_{\rm crit}$ criterion, since a substantial fraction of the ISM in the disk remains untouched by the shell.

$\Sigma_{\rm crit}$ depends strongly on $c_{\rm ext}$: for larger values of $c_{\rm ext}$ the fragmentation starts at larger values of $\Sigma_{\rm crit}$. From simulations with different $c_{\rm ext}$, $E_{\rm tot}$ we derive the fit:

$$\Sigma_{\rm crit} = 0.27 \times 10^{20}\, E_{51}^{-1.1} c_{\rm ext}^{4.1}\ {\rm cm}^{-2}, \qquad (2)$$

where $E_{51} = E_{\rm tot}/10^{51}$ erg and $c_{\rm ext}$ is measured in km s^{-1}. With this criterion we can estimate where in the Galactic disk the triggered star formation operates.

3. GOULD'S BELT AS A TRIGGERED STAR FORMATION EVENT

We compute orbits of individual OB stars from Gould's belt in the vicinity of the Sun backwards in time and analyze their positions and velocities at different epochs. The volume taken by members of Scorpius-Centaurus OB association gets smaller going from now to the past. The smallest volume, from which the present OB associations Lower Centaurus-Crux, Upper Centaurus-Lupus and Upper Scorpius are coming, is reached between 10–12 Myr ago, when its diameter is less than 100 pc. At that time the distance of the center of this region was about 100 pc from the Sun and all this region was in the first Galactic quadrant between Galactic longitudes $10° < l < 45°$. Before that time, even deeper in the past, the orbits of the future members of Scorpius-Centaurus OB associations deviate again and the volume taken by the corresponding test particles restarts to grow.

10 Myr ago the OB associations which form today the Gould's belt, particularly the associations in Orion and Scorpius-Centaurus, would have been closer to each other, forming a sheet-like pattern about 500 pc long and less than 100 pc wide, with the main axis in the direction $l = 20°$–$200°$. The formation of stars in such a region may be the result of the gravitational instability, fragmentation and subsequent star formation in an expanding shell, which is deformed by the galactic differential rotation. The motion of stars formed in a triggered star formation event in the expanding shell should be evaluated and compared to the observed kinematical parameters of Gould's belt.

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J. Palouš and S. Ehlerová: Astronomical Institute, Academy of Sciences of the Czech Republic, Boční II 1401, 141 31 Prague 4 Spořilov, Czech Republic (palous,sona@ig.cas.cz).