DETONATION WAVES IN INTERSTELLAR GAS

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In astronomy there is a large amount of observational data on the phenomenon of sequential star formation from a single molecular cloud. In this process, a cluster of stars of the same generation creates favorable conditions for the formation of stars of the next generation. A star-forming wave whose velocity is estimated to be $10^{-30}$ km/sec travels over a molecular cloud of interstellar gas. In the present paper, the self-sustained star-formation phenomenon is claimed to have all features of a detonation process and the star-forming wave is treated as a detonation one. The velocities of the detonation and star-forming waves are estimated to be ($\sim 27$ km/sec) and ($\sim 13$ km/sec), respectively.

In the Galaxy, regions of intense star formation are known in which massive hot O and B stars form. These regions are usually associated with molecular clouds and are located at their edges (constellations Orion, W3, etc.). A typical star-formation region is schematically depicted in Fig. 1. The old 1 and young 2 subgroups of hot O and B stars are massive blue giants, whose surface temperature ranges from $4 \times 10^4$ to $10^4$ K. A considerable portion of radiation from OB stars falls on the ultraviolet spectral range with a quanta energy sufficient to ionize hydrogen atoms. Around stars 2 immersed into a gas cloud, an extended region 3 of almost completely ionized hydrogen (HII) forms, with the same particle density as that of the original molecular cloud. Despite the fact that there is no thermodynamic equilibrium between radiation and material in HII regions, the Maxwellian velocity distribution of particles with temperature $T \approx 10^4$ K is established for the ion and electron gases. In the HII region, the gas-kinetic pressure is approximately two orders of magnitude larger than that in the neighboring nonionized, cold-gas regions.

The youngest objects of the star-forming region — powerful sources of infrared radiation — and compact HII regions 4 are located next to the HII region, in the direction of observation. These are stars that are not observed in the visible spectral range and are at the initial stage of evolution. The radiation from them is absorbed by dust shells. The dust will scatter with time, and a new cluster of stars (similar to region 3) surrounded by a cloud of ionized hydrogen will originate at this place.

Position 5 in Fig. 3 indicates schematically the boundary of disturbance which is caused by compression from the side of the expanding HII region spreading over an original cloud 6 in which hydrogen is in a molecular state at temperatures of 10–100 K.

The ordered arrangement of variously aged objects relative to the cloud and the repeatedness of a similar picture in many cases have led to the hypothesis according to which stars are formed in a regular process that begins at one edge of the cloud and ends at the other. The following qualitative mechanism of the phenomenon was proposed: hot OB stars that born deep in the cloud heat and ionize the ambient gas, thereby creating extended HII regions; expanding, these regions compress the cold gas in the molecular cloud and, hence, create conditions for the formation of a new generation of stars; the hot gas in the HII regions scatters in space with time, and the stars which are immersed in it become one generation older. The process is of a wave-like character, and no external sources of energy are needed for its occurrence. This process is...
Fig. 1. Schematic view of a typical star-formation region: 1, 2) the old and young subgroups of hot O and B stars; 3) the region of almost completely ionized hydrogen (HII region); 4) IF sources and compact HII zones; 5) the boundary of disturbance caused by compression from the extending HII zone; 6) the original cloud.

Fig. 2. Gas-flow diagram (the notation is the same as in Fig. 1).

called "self-sustained star formation" (SSF). Observational data on the difference in ages of the clusters of stars and also the known distance between them allow one to estimate the velocity of the star-forming wave to be $v \approx 10^{-30}$ km/sec [1-7].

The related theoretical studies are mainly concerned with the possibility of initiating the SSF by a compact source of energy (explosion of a supernova, a cluster of young stars, etc.) [1, 8], i.e., they basically deal with the kinetics of the phenomenon. No general characteristics of the SSF, such as the velocity of the star-forming wave and the required energy release, have been revealed.

From the scheme in Fig. 1, one can see a similarity between the structures of a detonation wave (DW) and the star-forming region. Each contains a compression region of the original gas. The energy-release area in the DW chemical-reaction zone corresponds to the next-generation star-formation zone, and the detonation-product expansion zone corresponds to the expanding HII zone and the stars.

In this paper, based on the above similarity between the two phenomena, we set up the hypothesis that the star-forming wave is a detonation one and apply conservation laws to SSF description just as they are used in the classical detonation theory.

Following from the simplest prerequisites and assuming that only a small portion of the compressed-gas mass is transformed into stars (0.1-0.2, according to observational data) and the gas state that corresponds to the Jouguet condition is attained in the HII regions, Zel'dovich and Kompaneets [9] obtained average DW parameters of the standard form. In addition, the specific energy of the explosive transformation of the process was found to be $\sim 1$ eV per particle.

In what follows, we shall consider the problem of a star-forming wave in a one-dimensional approximation.

A wave with velocity $D$ propagates over a gas with initial density $\rho_0$ and pressure $P_0$. Behind the wave front there is a gas flow with average density $\rho$ and temperature $T$ and also a stellar flow with mass per unit volume $\rho_*$. In the general case, the velocities of these flows do not coincide, because after condensing the stars have no mechanical link with the surrounding gas. Figure 2 illustrates the gas-flow diagram in a reference system that moves with the wave velocity.

In this reference system, the laws of conservation of mass, momentum, and energy are of the form

$$\rho_0 D = \rho u + \rho_* u_*,$$  \hspace{1cm} (1)