

Shock waves evolution modeling in orion bar PDR

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Background. A photodissociation region (PDR) is a region of the interstellar medium where the chemical and physical properties of the gas are determined by far-ultraviolet (FUV) photons [1]. According to the study [2], the properties of Orion Bar PDR meet the conditions for isentropic instability. It appears when a positive feedback is established between acoustic waves and nonequilibrium heat release [3]. As a result, disturbances evolve into a series of shockwave pulses [4]. The structure that the isentropic instability produces is consistent with the observational data demonstrating the filamentary structure of the medium [5, 6]. The shockwave pulse parameters have already been analytically predicted in [1, 4, 7], but these works do not answer the question of how quickly these structures can emerge. This issue is of significance because the unstable region where wave growth occurs is restricted.

Aim: Numerical modeling of the shockwave pulse evolution and estimation of pulse growth time.

Methods. The parameters of a shockwave pulse depend only on the temperature and density of the medium. The dynamics of acoustic perturbations in a medium can be described by a system of gasdynamic equations:

$$\begin{cases} \frac{\partial \rho}{\partial t} + \operatorname{div}(\rho v) = 0; \\ \rho \frac{dv}{dt} + \nabla p = 0; \\ C_v \frac{dT}{dt} - \frac{k_B T}{m \rho} \frac{d\rho}{dt} = -\mathfrak{T}(\rho, T); \\ p = \frac{k_B}{m} \rho T. \end{cases}$$

In this work, we have used the model of heat-releasing processes $\mathfrak{T}(\rho, T)$ proposed in [2]. Observations show that the temperature in the Orion Bar can reach 1000K [5]. Using a stationary condition with $\mathfrak{T}(\rho_0, T_0) = 0$ and temperature $T_0 = 1000$ K, one can calculate equilibrium number density in the Orion Bar, which is

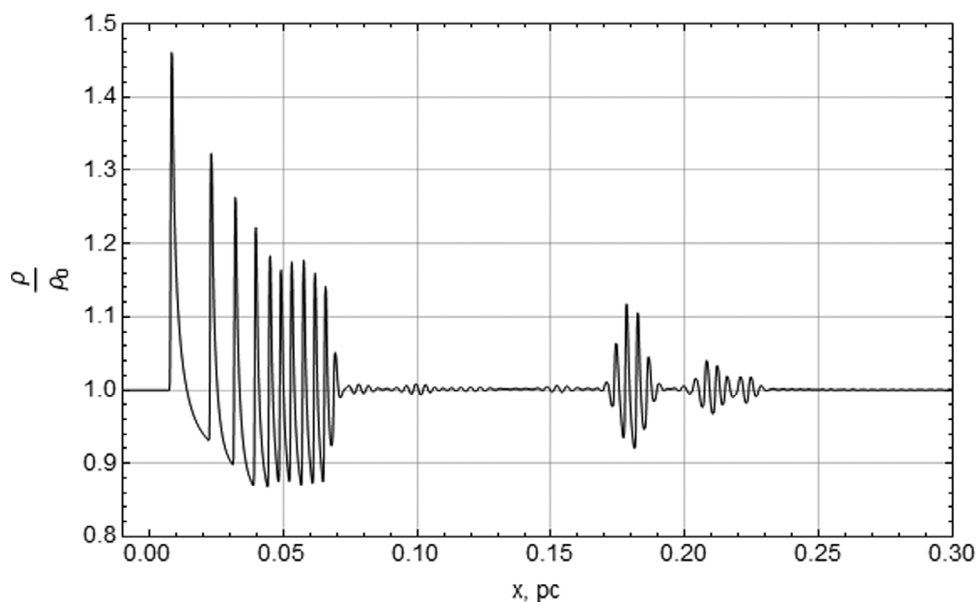


Fig. 1. Numerical simulation of shockwave pulse formation

$n_0 = 2.26 \times 10^5 \text{ cm}^{-3}$. The initial disturbance for numerical simulations is a Gaussian perturbation in the form:

$$\rho = \rho_0 \left(1 + a e^{-\frac{x^2}{2\sigma^2}} \right), \quad p = p_0 \left(1 + \gamma a e^{-\frac{x^2}{2\sigma^2}} \right).$$

To model shockwave evolution, we used the Athena MHD code [8].

Results. The modeling shows that the initial disturbance splits into a periodic structure. The wave on the front forms the shockwave pulse, which amplitude we use in the growth time estimation (fig. 1).

During numerical modeling, the system indicates that the numerical diffusion is considerably higher than it actually is. The diffusion reduces the pulse amplitude. The described effect can be diminished by adjusting the coordinate step (fig. 2, a). We have also described how the characteristic size σ of the initial disturbance influences the pulse growth time (fig 2, b).

Conclusions. The growth time of shockwave pulses in PDR with parameters corresponding to Orion Bar has been estimated. Their evolution can be divided into three stages. During the first stage, the perturbations grow at a low rate. At the second stage, there is an explosive growth of the wave amplitude. During the last stage, the growth of pulses slows down until the maximum amplitude is reached. The whole process takes around 50 thousand years.

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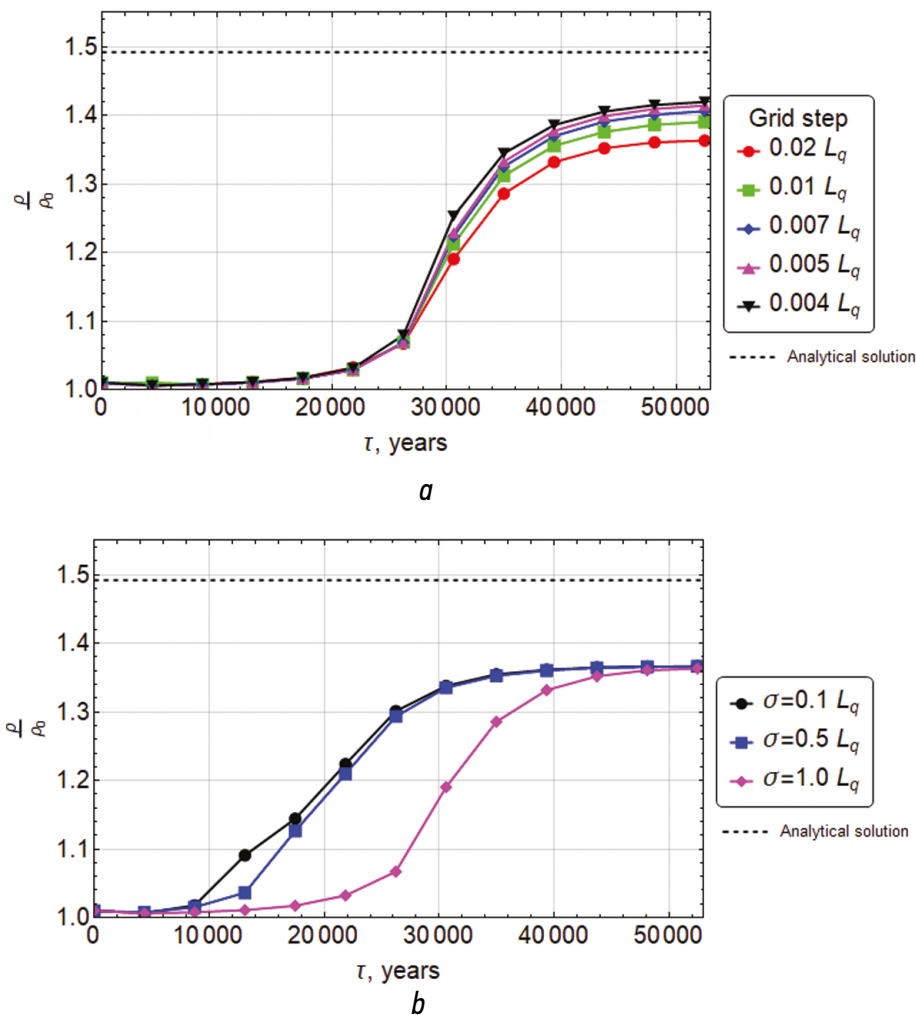


Fig. 2. Dependency of shockwave amplitude on time: a) with different grid step and constant characteristic size σ ; b) with different characteristic sizes and constant grid step Δx

Keywords: isentropic instability; interstellar medium; shock waves; photodissociation regions; molecular clouds; unstable medium.

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