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Hydrodynamic Model of a Self-Gravitating Optically Thick Gas and Dust Cloud

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Abstract—We propose an original mechanism of sustained turbulence generation in gas and dust clouds, the essence of which is the consistent provision of conditions for the emergence and maintenance of convective instability in the cloud. We considered a quasi-stationary one-dimensional model of a self-gravitating flat cloud with stellar radiation sources in its center. The material of the cloud is considered a two-component two-speed continuous medium, the first component of which, gas, is transparent for stellar radiation and is supposed to rest being in hydrostatic equilibrium, and the second one, dust, is optically dense and is swept out by the pressure of stellar radiation to the periphery of the cloud. The dust is specified as a set of spherical grains of a similar size (we made calculations for dust particles with radii of 0.05, 0.1, and 0.15 μm). The processes of scattering and absorption of UV radiation by dust particles followed by IR reradiation, with respect to which the medium is considered to be transparent, are taken into account. Dust-driven stellar wind sweeps gas outwards from the center of the cloud, forming a cocoon-like structure in the gas and dust. For the radiation flux corresponding to a concentration of one star with a luminosity of about $5 \times 10^4\, L_\odot$ per square parsec on the plane of sources, sizes of the gas cocoon are equal to 0.2–0.4 pc, and for the dust one they vary from tenths of a parsec to six parsecs. Gas and dust in the center of the cavity are heated to temperatures of about 50–60 K in the model with graphite particles and up to 40 K in the model with silicate dust, while the background equilibrium temperature outside the cavity is set equal to 10 K. The characteristic dust expansion velocity is about 1–7 $\mathrm{km\,s^{-1}}$. Three structural elements define the hierarchy of scales in the dust cocoon. The sizes of the central rarefied cavity, the dense shell surrounding the cavity, and the thin layer inside the shell in which dust is settling provide the proportions $1 : \{1–30\} : \{10^{-7}–10^{-6}\}$. The density differentials in the dust cocoon (cavity–shell) are much steeper than in the gas one, dust forms multiple flows in the shell so that the dust caustics in the turning points and in the accumulation layer have infinite dust concentration. We give arguments in favor of unstable character of the inverse gas density distribution in the settled dust flow that can power turbulence constantly sustained in the cloud. If this hypothesis is true, the proposed mechanism can explain turbulence in gas and dust clouds on a scale of parsecs and subparsecs.

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1. INTRODUCTION

Star formation in protostellar clouds is governed by a set of physical processes, and the key one among them is turbulence [1, 2]. In order to prevent effectively the gravitational contraction of a cloud, turbulence should have energy exceeding the thermal energy of the cloud material and this means that the turbulence should be near- or supersonic [3–5].

Observations show that gas in interstellar clouds is actually turbulized, with the velocity of turbulent flows being comparable to the sonic one [3, 6].

To maintain both near and supersonic turbulence, permanent powerful energy sources are necessary. Actually, supersonic turbulence is accompanied by the formation of shock waves, beyond the fronts of which the cloud hot matter is quickly cooled down by de-excitation. The characteristic times of cooling the cloud's gas usually are much shorter than the characteristic dynamical time of the process, the time of free contraction of the cloud [1], therefore turbulent motions should quickly attenuate without consistent energy supply.

In the vast majority of papers, different mechanisms are viewed as possible sources of turbulence: both inner for the physical systems studied (various hydrodynamic or magnetic rotation instabilities, self-gravitation and accretion of contracting gas filaments) and those of external influence (ionization

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