SHAPE MORPHING IN MOLECULAR CLOUD-CLOUD COLLISION AFFECTED BY COHERENT INSTABILITIES

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Summary This report is performed to results of numerical simulation of cloud-cloud-collision between two molecular clouds in head-on and glancing impact. The aim was a study of matter compression in formed clumps and generation of vortex coherent structures in the molecular cloud formations disbalanced after collision, with analysis of influence of emergent instabilities to clouds shape morphing.

1 INTRODUCTION

Cloud-cloud collisions (CCC) between molecular clouds in the interstellar medium (ISM) and interplay strong shock wave of remnant front after supernova explosion with molecular clouds are proposed as key mechanisms for triggering protostars originated from dense molecular clouds in ISM. We performed computations in similar situations to study consequences of MCs matter turbulization and instabilities influence onto emergent dense clumps and filament structures. Analysis of consequences of CCC simulated shows a spatial intermittency of outer layers of clouds and their lens-like clump (core) deformation. This process is accompanied by Kelvin-Helmholtz (KH) instability and disturbance of gas density over perturbed superficial layers of clouds.

2 STUDY DEFINITION AND NUMERICAL SIMULATION

We modeled numerically different cases of MCs collision: a head-on concussion with mutual penetration of two molecular clouds of initially spherical form moving in opposite direction with different velocities and a glancing collision in reverse off-center moving.

Key physical parameters and initial suppositions for simulation CCC were given from [1]. Objective setting of study, numerical approach used and code developed are given in [2]. The problems being solved consider impact coupling of compressible gas flows in nonsteady definition. The system of conservation laws of mass, momentum, and energy in 3D rectangular coordinate system is solved within in-house software framework based on multiprocessor computers. Eulerian equations are solved on regular mesh with adaptive Roe solver using the schemes of TVD type. To study the sensing mechanisms of formation of filament structures in MC systems, calculations with a high resolution mesh are required. In serial solutions number of mesh nodes attain to 2048x1024x1024. An application programming interface OpenMP for parallelization is employed. This is tuned by using Intel VTune Amplifier XE. Tuning is carried out for Xeon E2630 and Xeon E5 2650 Ivy Bridge processors. For visualization and graphic postprocessing authors HDVIS code is used.

The simulation was performed according to different impact scenarios between two clouds. In numerical experiments non-identical oppositely directed clouds (of different mass, size and density radial distribution) collide with each other at the velocities of 3 – 30 km s^{-1}. Colliding velocities of each MC are assigned as: 2.943, 5.885, 11.770 km$\cdot s^{-1}$. In the case of the glancing strike centers of MCs are displaced with shift equal $0.2 \cdot R_{c1}$. Initial density contrast χ, equal ratio ρ_{cl} / ρ_{ism} , for density between the MCs centers and the interstellar medium accordingly to each cloud assigned as: 25, 100, and 500. Oncoming velocity U_{cl} and density contrast χ of molecular clouds are varied in simulation. MCs have masses (on high level) in range 0.32 - 1.05 $M_{\odot}$ respectively.

3 RESULTS

We investigated the influence of initial mass and MCs oncoming velocities in collision process on the level of pressure in formed core and clumps cumulative mass distribution during process of the MCs fragmentation, ablation and perturbation distorsion.

Numerical experiment shows that MCs morphing, formation of clumps and filaments, and their subsequent destruction in time evolution, are in a good accordance with the recent studies of molecular clouds and filamentary structures in space. Data are based on recent astrophysical nebulae radiation and stellar observations and produced in numerical modeling, including SPH approach and advanced AMR codes.

In general outline the evolution of CCC contains three stages: mutual penetration of MCs with initial growth of local pressure in contact zone, generation of lens-like core with time-depended transient form, accompanied by stochastic clumps fragmentation in the center of gas strong compression and filaments origination here, tangling of filament and stretch morphing with vortex turbulization inside and on outer surface of formed object with divergence of ablated clumps in outer ISM. One of stage (second, above mentioned) of MCs deformation morphing is shown on Fig. 1. The vortex ripples (pale blue color) on outer cloud surface and isosurfaces of divergent flow of clumps (yellow) are shown here. Analysis of consequences of modeling cloud-cloud collision shows a spatial intermittency of density layers of clouds and their lens-like clump (core) deformation. This process is accompanied by Kelvin-Helmholtz instability and disturbance of gas density over superficial layers of new cloud formation.

In last serial CCC simulations, at the first stage of collision, was observed abrupt change in redistribution of cloud density, that conduce to local grow of density in outer layers of MCs.

Clouds shape a bubble structure that leads to unnoticed interaction of clouds and outside space. Coherent increasing oscillations initiated by extremely strong contractions of lens-like clouds core become clearly observable time pulsations in penetration process of bullet cloud into target cloud. All of cloud matter density fractions enter into self-oscillation regime that can be fixed clearly at second stage of evolution. This observed effects lead to appearance of acoustic density perturbations into neighbor ISM. The fields of density fluctuation are shown on Fig. 2, 3.

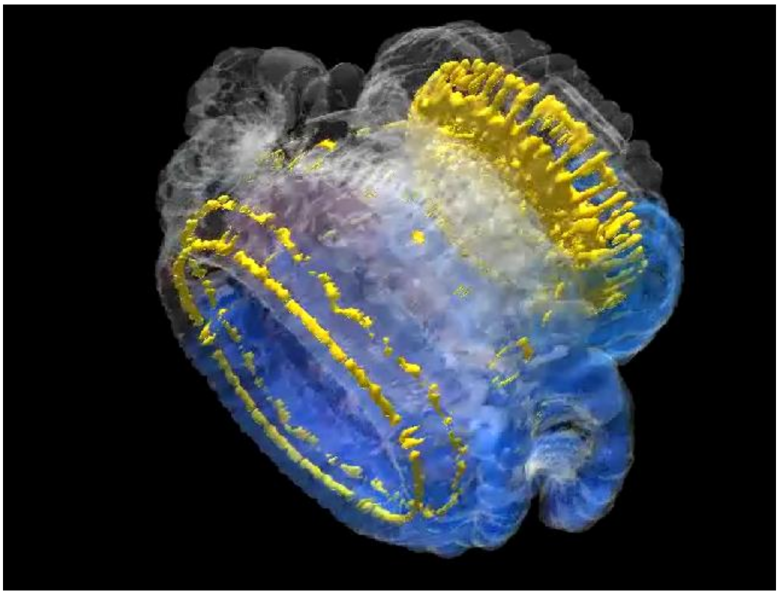

Figure 1: MCs morphing at the second stage of incoming cloud penetration into target cloud.

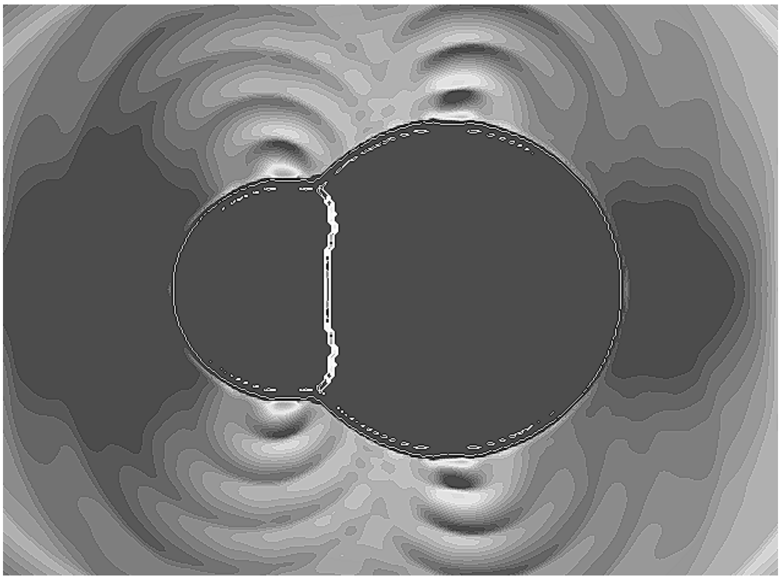

Figure 2: Shadowgraph of a radiated density fluctuations in ISM.

Density perturbation in ISM, shown on Fig. 3 correspons to solution with initial conditions of modeling: χ & U_{cl} : 500 & 5.885 km·s^{-1} – 100 & 5.885 km·s^{-1}. Density contrast waves with χ over 0.5 - 1.0 - 10 conform (in simulation) to time epoch 140000 year.

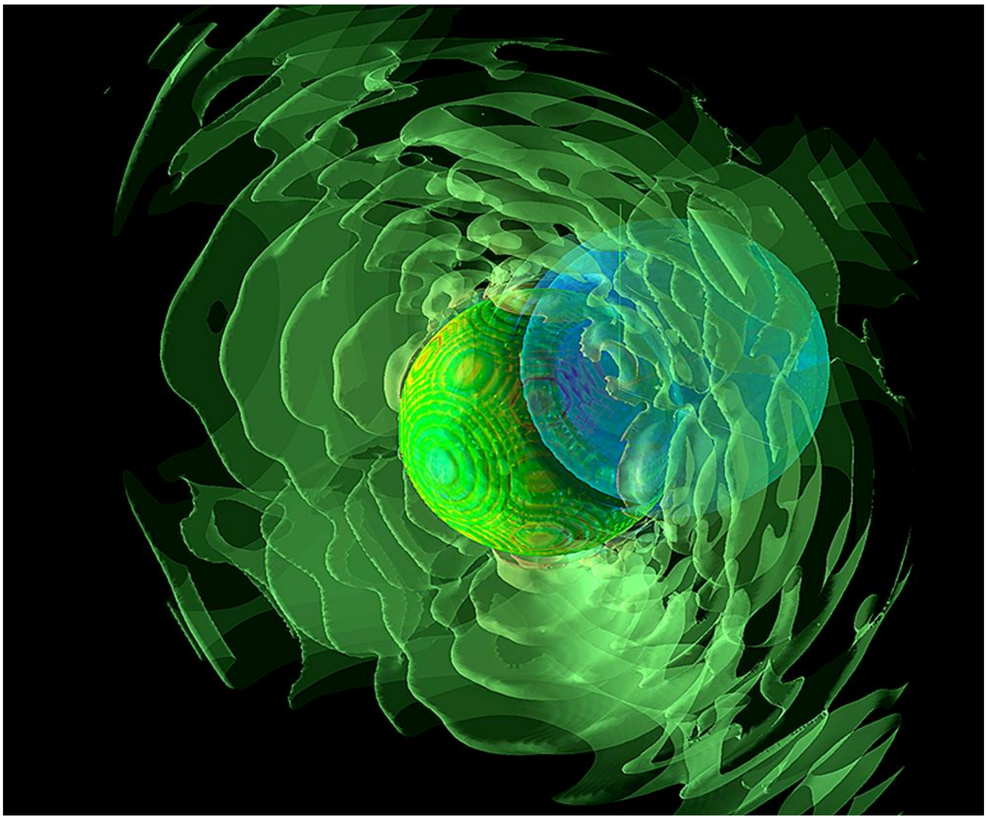

Figure 3: Acoustic perturbations in interstellar medium over MCs shaping during of head-on collision.

Possibly this process is generated by means of energy interchange in high-gradient outer layers and clumpy membrane wave deformation. Non Linear Thin Shell Instability (NTSI) plays crucial role of triggering this process. KH instability and NTSI lead to formation of bubble-like structure and deformation of MCs at distortion phase of their shaping. Observed effect is considered in report.

REFERENCES

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