THE FORMATION AND DYNAMICS OF SELF-GRAVITATING HIGH-DENSITY AREAS IN MASSIVE CIRCUMSTELLAR DISCS

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INTRODUCTION

Planetesimal and large body formation – why massive disc is worthy to consideration?

1. Chemical composition of the gas-dust medium that forms the disc and the star. In such composition after hydrogen, helium and water the organic compounds form the large portion. Presence of the organic compounds drastically changes collisional dynamics of the solids in the discs and their upper size defined by aggregation

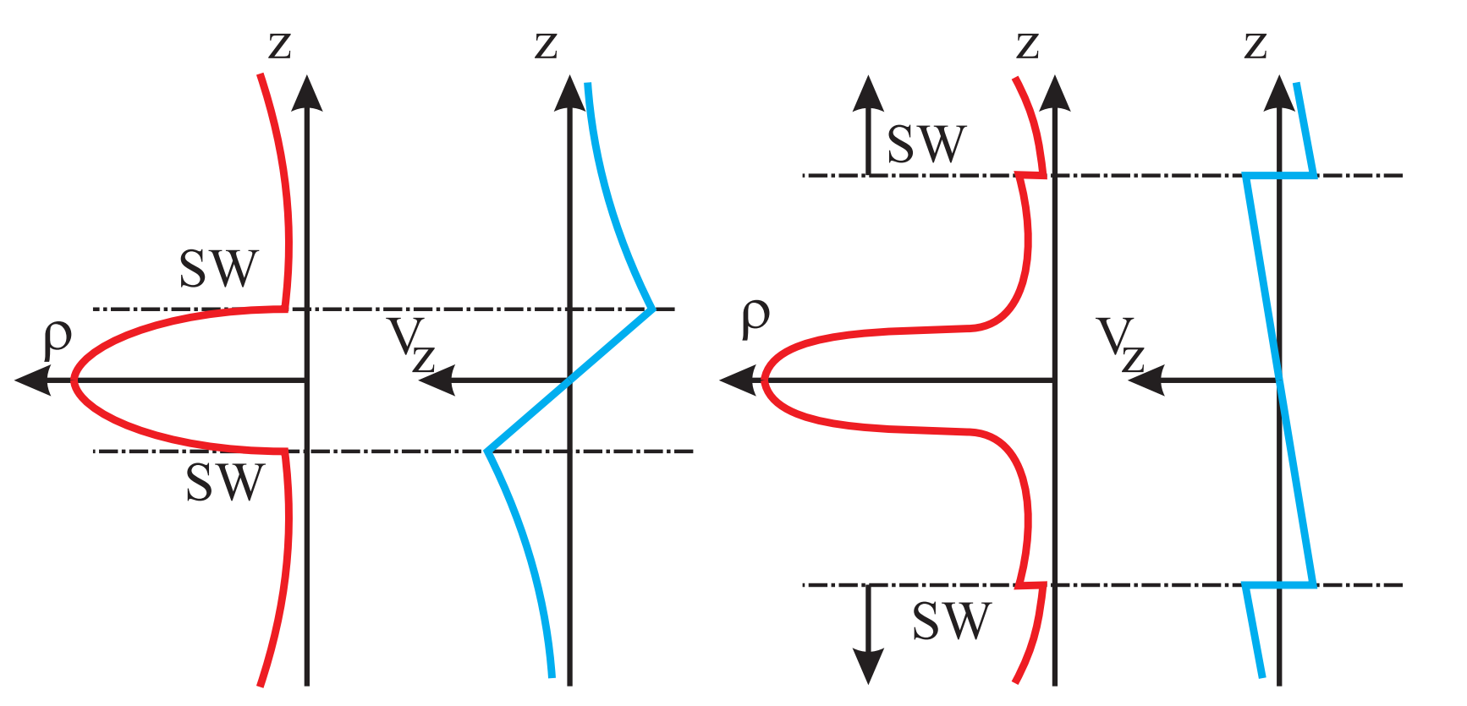
2. The inorganic compounds of the solids are active in chemical reactions of Fisher-Tropsh synthesis $CO + H_2 \rightarrow C_xH_y + H_2O$, which decreases under favorable conditions the concentration of CO. Therefore the ratio $CO/H_2 \sim 10^{-4}$ true for the molecular clouds can be decreased for the circumstellar discs. So when the mass of the disc is estimated by means of CO concentration measuring, it can be underestimated

3. Massive self-gravitating disc where gravitational instability development could take place can be formed as a result of molecular cloud collapse.

- During the solid subdisc formation the part of the gas can leave the disc, abandoning the solids sedimentation in the equatorial plane. As a result of such gas outflow **the ratio of dust to gas surface density** in the subdisc can be significantly larger than 0.01.
- **The temperature** of the gas in the disc can be decreased on the later stages of collapse that forms the disc and the protostar. After first 500 thousand of years the gas changes the direction of their motion and moves mainly from the star, providing the conditions for adiabatic cooling.
- **The effective adiabatic exponent** for the disc medium (mixture of hydrogen and helium) tends to 1 due to (1) contribution of oscillatory degrees of freedom for molecular hydrogen heat capacity under the temperature higher then 600 K, (2) dissociation of molecular hydrogen into two atoms under the temperature higher than 1000 K.

DISC FORMATION

How massive disc can be formed?

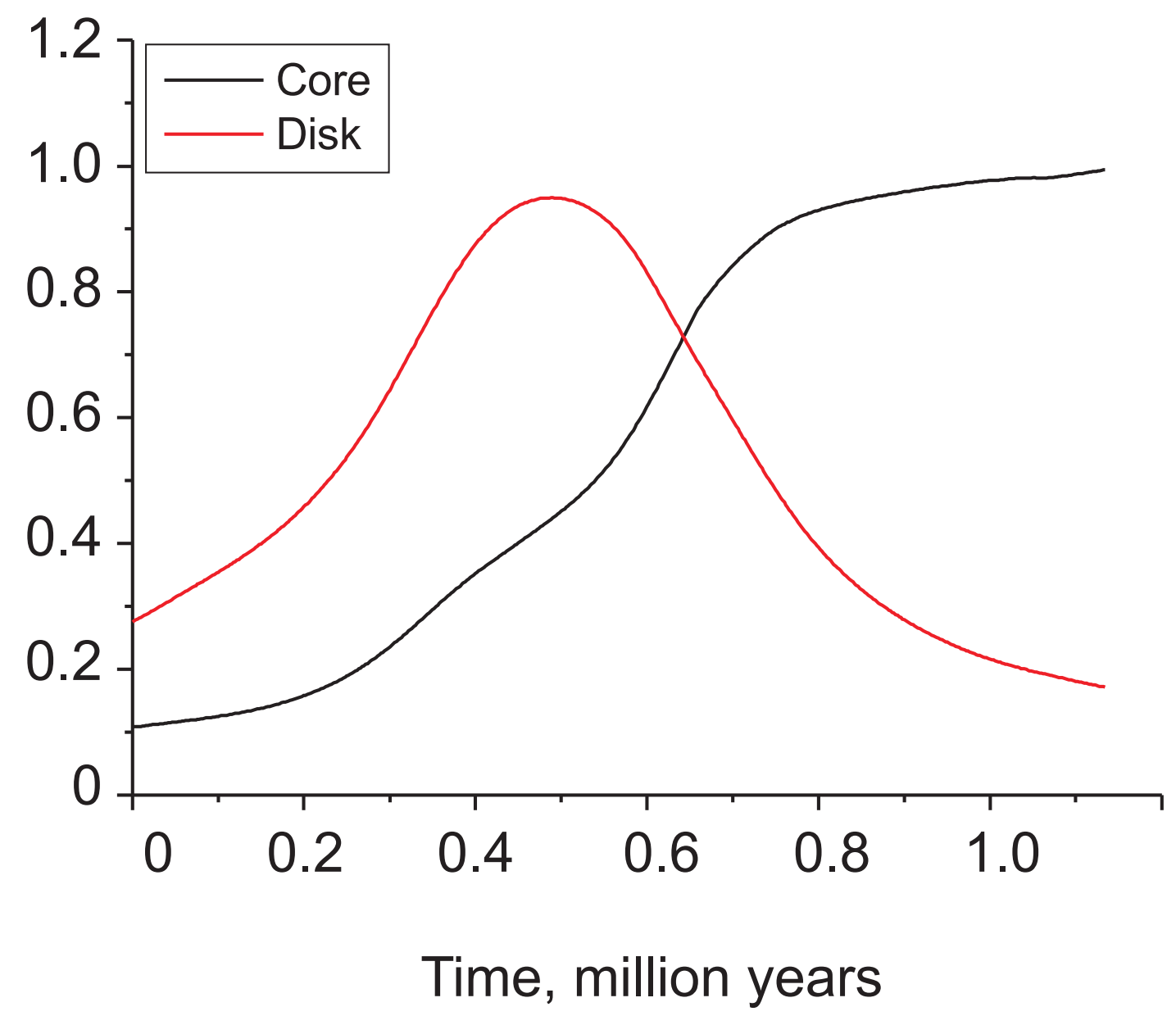


The disc forms simultaneously with a protostar, following the gravitational collapse of gas in the molecular cloud.

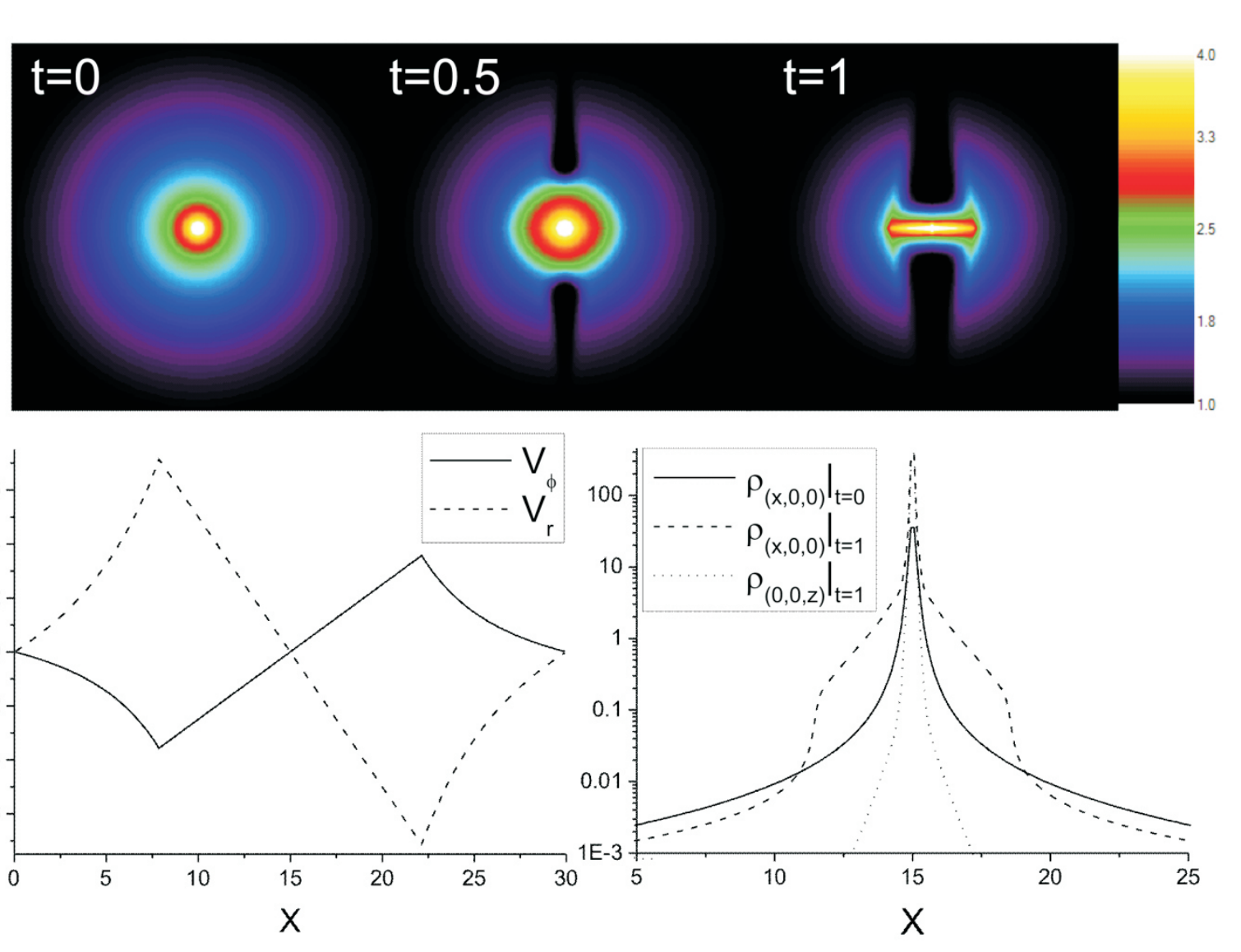
The massive gas-dust subdisc is formed by the collision of the opposing gas streams. The gas streaming during the molecular cloud collapse is supersonic. The infalling gas streams collide and produce the diverging shock waves that decelerate the gas streams velocity. Between a pair of shock waves the gas density is higher than its extreme value for a single shock wave. When the flow rate of collapsing gas decreases in the end of the star formation stage, the shock waves diverge from the disc plane. Now the gas can leave the disc. Fast diminution of its flow provides conditions for the fast gas expansion which is followed up with its cooling.

The molecular cloud dust moves together with the gas. During the gas compression behind the shock waves the dust grains grow in size as a result of heavy molecular absorption and coagulation. The molecules are adsorbed according to their sublimation temperature. The dust grains can grow in size in accretion disc, settle on the disc plane and form their own subdisc. Due to the subdisc gas expansion in outside flow the relation of solid density to gas density increases in contrast to the molecular clouds, where dust constitutes 1-2 per cent of the mass.

Alteration of the disc mass is defined by the flows: (1) falling to the disc from the cloud, (2) accreting from the disc to the protostar, (3) leaving the disc, e.g. in jets. By the time discs become observable (1-3 million years), their masses have decreased to 1 per cent of the host star mass. Inside the period between protostar and young star a stage of massive disc exists, when the mass of the disc and the mass of the central body are comparable. Over the course of the next 60-100 million years, the circumsolar disc evolves to a state similar to that currently present in our own Solar System.



The mass of the disc and the protostar formed as a result of molecular cloud collapse. The unit is the mass of the Sun

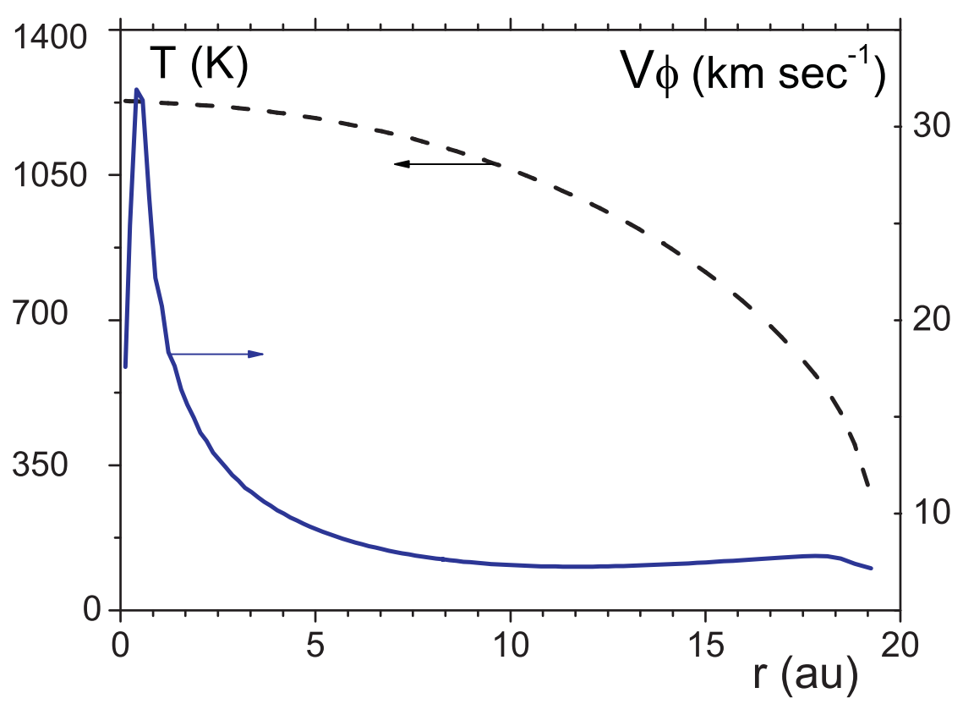


The calculation of collapse of the Bonnore-Ebert sphere with initial solid-body rotation was performed for isothermal model by Snytnikov and Stadnichenko.

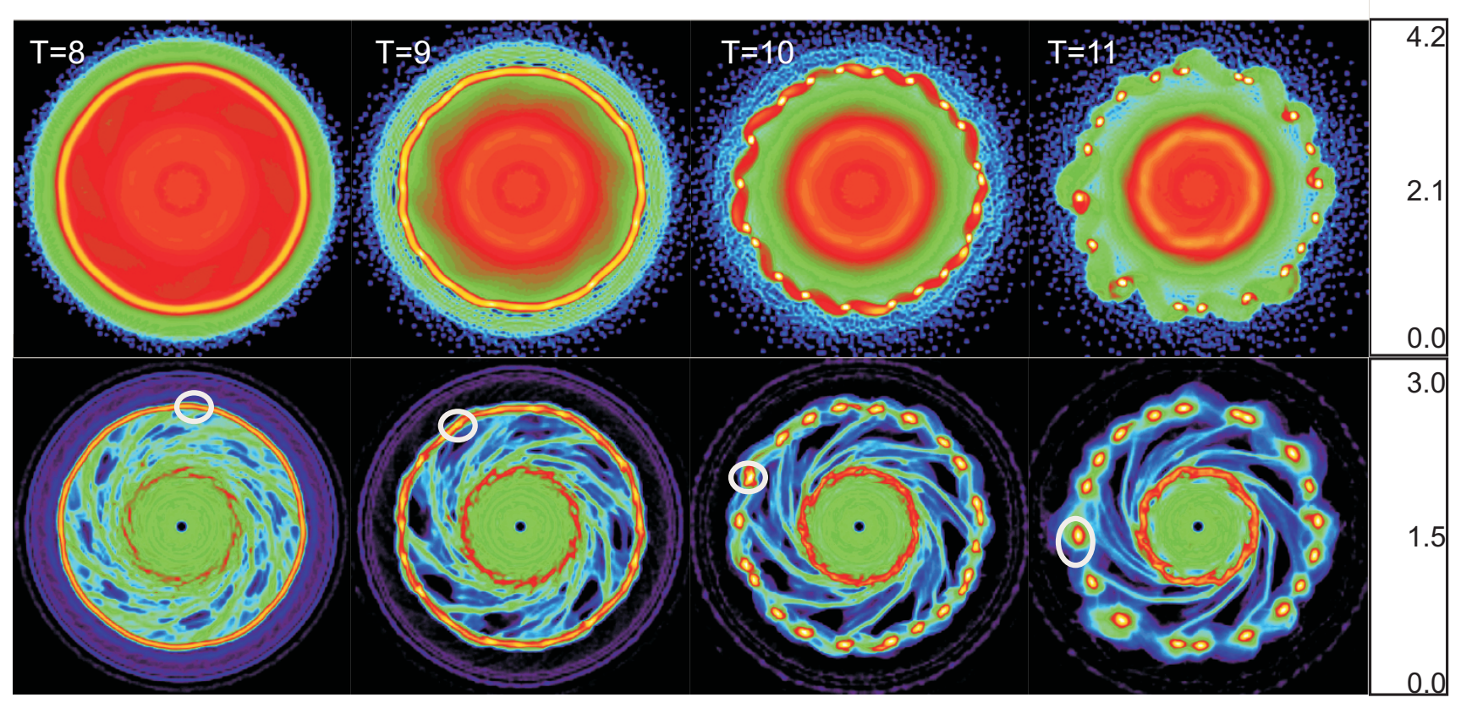
GRAVITATIONAL INSTABILITY

We have simulated the dynamics of a massive disc using two the effective adiabatic exponent $\gamma=1.1 < 4/3$ in gas. The disc had a radius of 20AU, the central body had the mass $M_C = 0.45\ M_0$, the disc was represented by the gas component with the mass $M_{gas} = 0.52M_0$ and subdisc of primary solids (boulders of 1-10 metre in size)with $M_{par} = 0.03M_0$.

The gas disc was represented by *640000* SPH particles. At that, mass of the particles within the smoothing length did not exceed locally the corresponding Jeans mass. Subdisc of primary solids was represented by *40000000* PIC particles. In the disc plane, the grid size was $[r,\varphi]=400 \times 512$ with 200 x 512 cells corresponding to the disc at zero time.



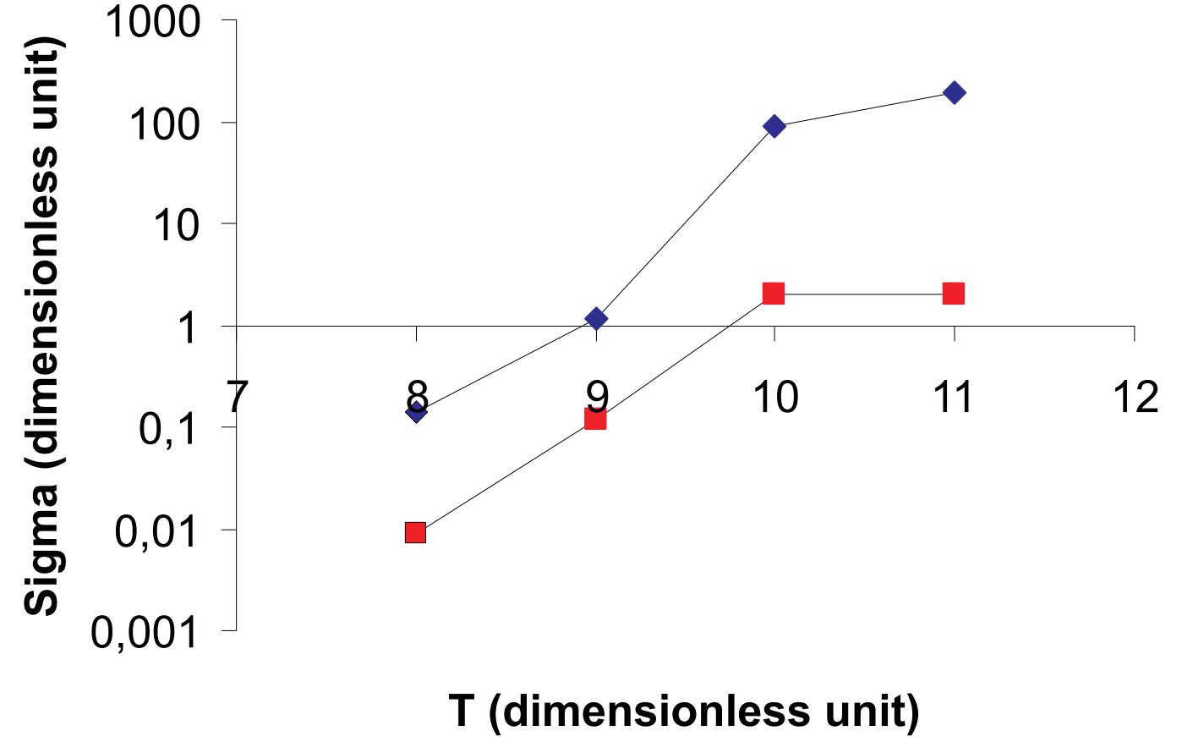
Gas temperature and angular velocity versus radius at initial time



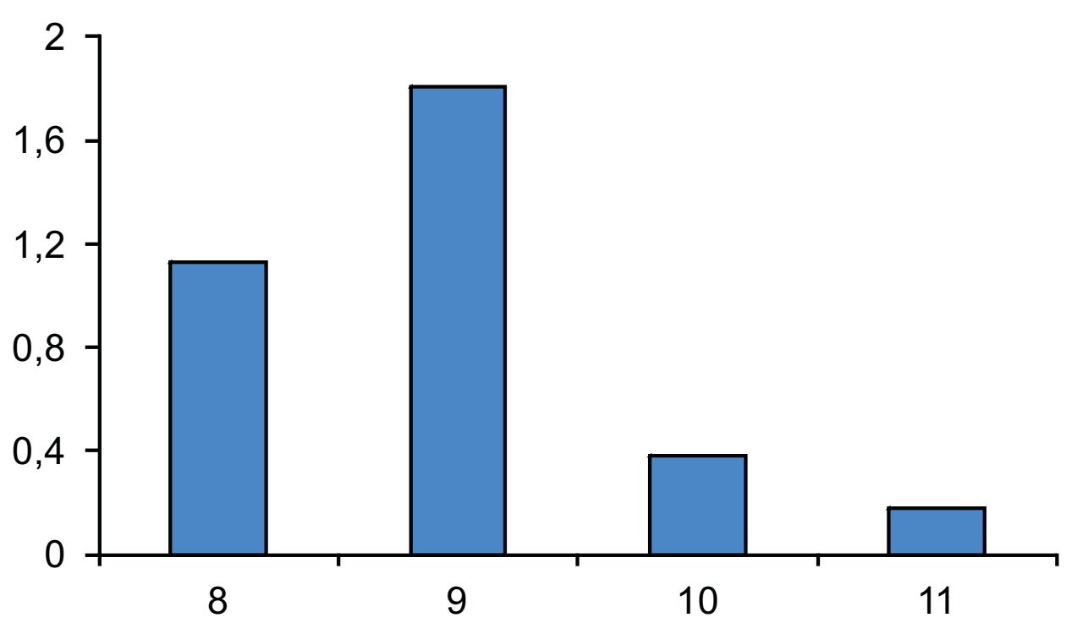
The formation of global rings and their fragmentation due to the development of gravitational instability. Logarithm of the gas (top line) and primary solids subdisc (bottom line) surface density for time points T = 8, 9, 10, 11 is the rotation time of the outer part of the disc

LOCAL GRAVITATIONAL COLLAPSES

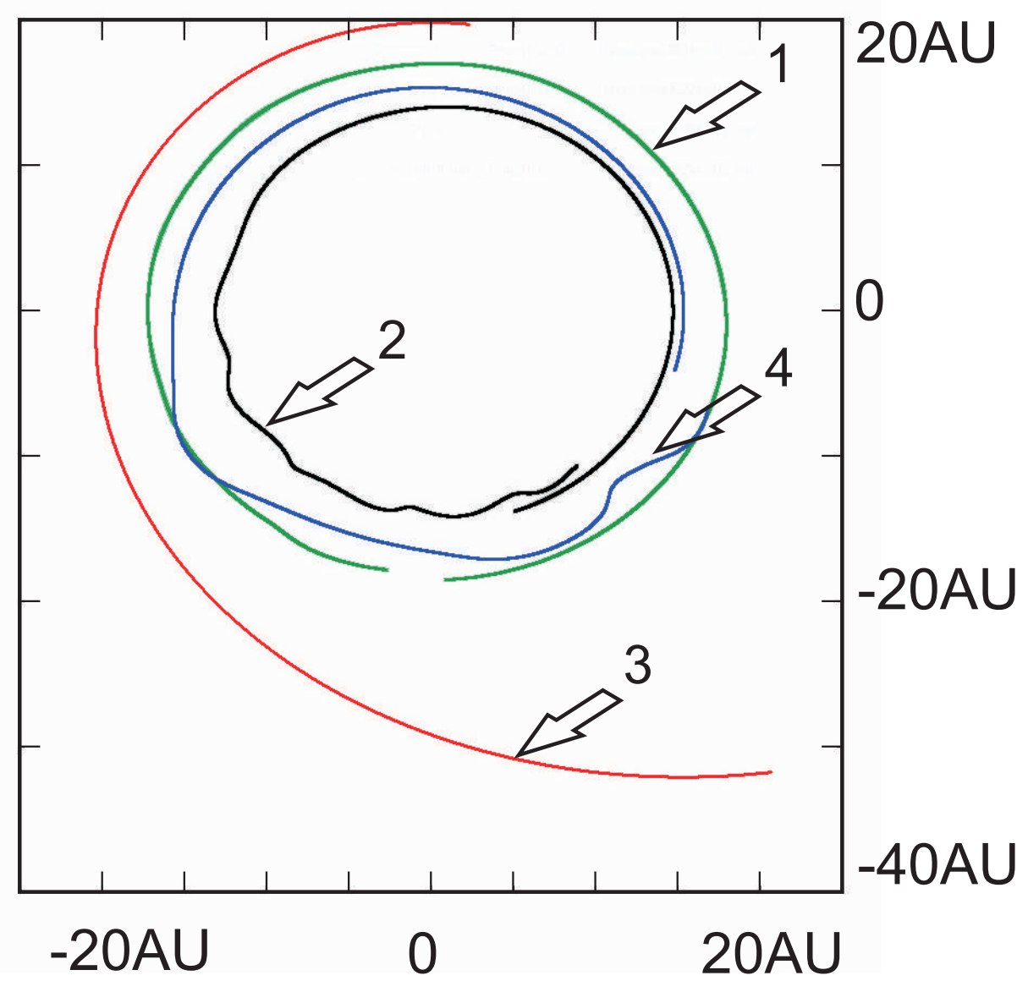
Solids dynamics in rotating gaseous clumps

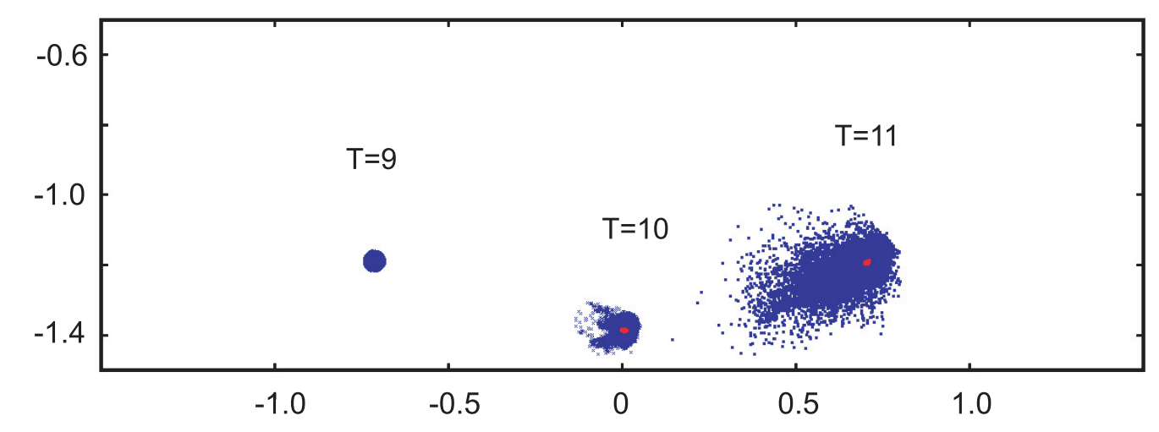


The surface density in the marked individual high-density area of gas (blue) and solids (red).



Ratio $\sigma_{par}/\sigma_{gas}$ in the marked individual high-density area devided into initial ratio $\sigma_{par}/\sigma_{gas}$ for the disc.





The dynamics of gaseous (red) and solid (blue) model particles fixed in the moment T=9 in the marked individual high-density area. The collapsing clump of gas moves as a volume of fixed compound, while the solids are scattered around due to the gradient of gravitational potential.

The trajectories of individual solids. (1) is a closed trajectory, existed although the peaks of potential are formed, (2) is an epicyclic trajectory, when the particle is captured by a gas density peak, (3) is a scattering trajectory, (4) is a trajectory of particle moving around a peak of potential during some part of rotation, then ejected by one high-density area and captured by the other.

CONCLUSION

Generation of self-similar rotating chopping structures, where $\sigma_{par}/\sigma_{gas}$ increases coherently, can exist in a massive multiphase disc. It may facilitate streaming instability development, which demands $\sigma_{par}/\sigma_{gas} > 0.1$, and lead to formation of bodies 10 m - 1 km in size. Moreover, the effective Jeans length in these clumps, determined as $\Lambda = \frac{2\Lambda_{par}\Lambda_{gas}}{\Lambda_{par} + \Lambda_{gas}}$, can be lowered considerably due to the presence of solid phase in the clump, so local gravitational collapse in such two-phase medium could be triggered over a much wider range of conditions. Although these two scenarios of further stages of planet formation are possible only when effective mechanism decreasing v_d in such structures exists that compensates the thermalization of bodies related to the presence of global asymmetric structures in the disc. For boulders inelastic pair collisions of gravitationally-bound clusters of solids can be suggested as such a mechanism.

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