CAN YSO CLASS I-II KEEP DETECTABLE CHEMICAL SIGNATURES OF HIGH PRESSURE CLUMP EXISTENCE?

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INTRODUCTION

There are two main competitive scenarios of earth-like and giant planets formation – core accretion and disc instability. Both of them have evolutional stages that constructive physical mechanism is poorly understood and stages that already can be reproduced in simulations.

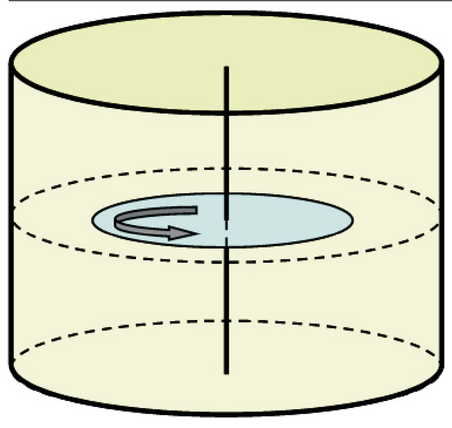
Based on the simulation results for these stages it is becoming possible to develop signatures of planetary formation processes whose observational detection can be interpreted as arguments in favor to one scenario.

The disc instability scenario suggest that most probably on the stage of YSO class O-I (when the disc is dense enough), the gravitational instability develops and forms solitary clumps of high density. We suggest that such self-gravitation clumps existence can leave chemical signatures in the disc atmosphere that could be detectable for later stages. Clump chemistry is different from the disc chemistry, as clumps have high pressure gas and increased solids concentration. Such conditions facilitate chemical reaction of CO, ammonia, formaldehyde, cyanide hydrogen and other species. So if we manage to specify the set of products of homogeneous or heterogeneous (gas-phase catalytic) reactions for clumps condition, the observational detection of the set can be argument in favor of the instability of the disc.

To specify this set we have to (1) estimate the range of physical condition of clumps: temperature, pressure, solid phase concentration and surface area; (2) to study the yield of products of catalytic synthesis for clump and more moderate condition, trying to find out distinguishing products potentially detectable in the YSO of different classes; (3) to suggest the mechanism of species transport from clump to disc atmosphere.

In this study we investigate the dynamics of wandering boulders that can go through high density areas of several clumps, providing adsobtion-desorbtion mechanism for product transport.

RAZOR-THIN MODEL OF THE DISC



Gas dynamics

$$\frac{\partial \sigma}{\partial t} + div(\sigma \vec{v}) = 0, \qquad \sigma_{par,gas} = \int_{-\infty}^{+\infty} \rho_{par,gas} dz; \quad p^* = \int_{-\infty}^{+\infty} p dz.$$

$$\sigma \frac{\partial \vec{v}}{\partial t} + \sigma(\vec{v}, \nabla)\vec{v} = -\nabla p^* - \sigma \nabla \Phi, \quad \frac{\partial S^*}{\partial t} + (\vec{v}, \nabla) S^* = 0, \quad p^* = T^* \sigma.$$

$$\gamma^* = 3 - \frac{2}{\gamma}. \quad T^* = \frac{p^*}{\sigma}, \; S^* = \ln \frac{T^*}{\sigma^{\gamma^* - 1}}$$

Solid dynamics

$$\frac{\partial f}{\partial t} + \vec{u} \frac{\partial f}{\partial \vec{r}} + \vec{a} \frac{\partial f}{\partial \vec{u}} = 0,$$

$$\vec{a} = -\nabla \Phi, \quad \sigma_{par} = \int f d\vec{u} dz.$$

Gravitational field

$$\Phi = \Phi_1 + \Phi_2, \Phi_1 = -\frac{M_c}{r},$$

$$\Delta \Phi_2 = 0, \quad \Phi_2 \longrightarrow_{r \to \infty} 0, \qquad \frac{\partial \Phi_2}{\partial z}|_{z=0} = 2\pi(\sigma_{par} + \sigma_{gas}).$$

Initial conditions

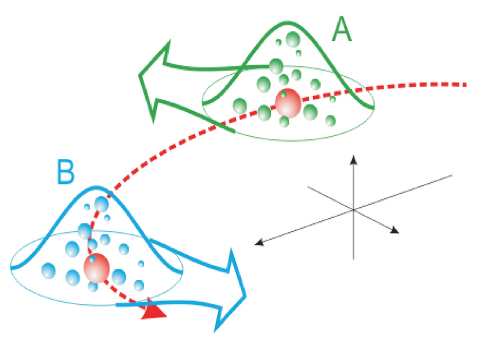
$$\sigma_{par,gas}(r) = \frac{3M_{par,gas}}{2\pi R^2} \sqrt{1 - (\frac{r}{R})^2}.$$

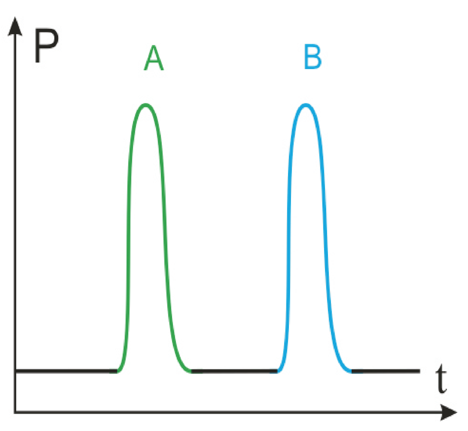
$$T^*(r) \sim \sigma(r)$$

$$\vec{u} = \vec{u'} + \vec{u''}, \qquad v_r = 0, \, u'_r = 0.$$

$$\frac{v_\phi^2}{r} = \frac{1}{\sigma}\frac{\partial p^*}{\partial r} + \frac{\partial \Phi}{\partial r}, \quad \frac{u'^2_\phi}{r} = \frac{\partial \Phi}{\partial r},$$

WANDERING BOULDERS





Wandering boulders are boulders that passed through high pressure area of more than one clump (first captured by one clump and then ejected and captured by another one). In our calculation wandering boulders were specified 'in situ'. The algorithm of specification was based on analysis of pressure extremums.

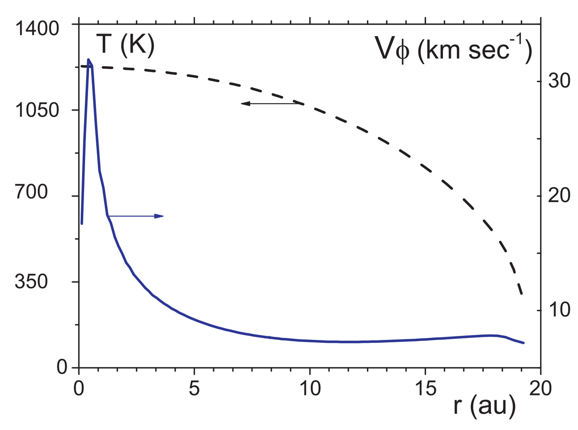
The population of wandering boulders appeared during 1 orbital period had a mass more than 0.01% of total mass of the disc solids. During this short time few amount of boulders went through pressure maximum 5-10 times. When initial dispersion of solids was increased from 100 m/sec to 2000 m/sec the amount of appeared wandering boulders was increased 5 times.

GRAVITATIONAL INSTABILITY

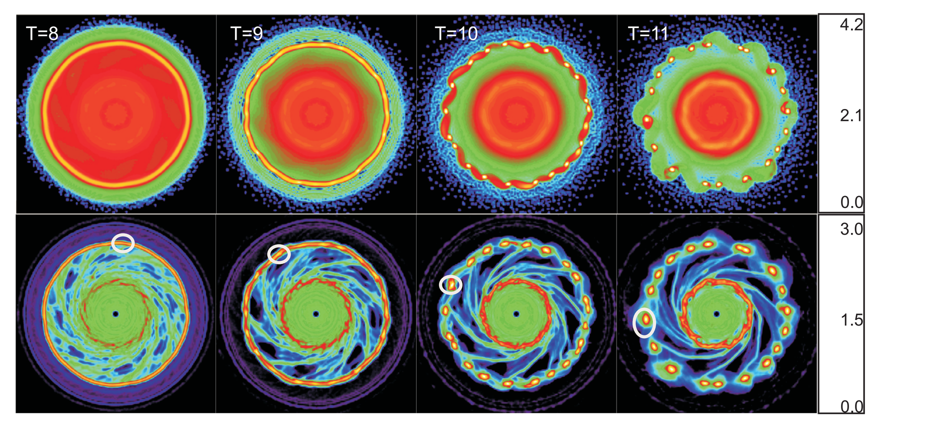
In medium-mass discs with intense cooling, clumps are formed in spiral arms; the clump first appears at a maximum radius, and then the formed clump affects a gas flow in the disc and creates the possibility of clump formation at a smaller radius. For a cold massive disc, the isolated high-density regions are formed by fragmentation of a dense ring emerging due to development of the global Toomre instability. Unlike the case of medium disc, the formation of several rings in a massive disc allows the fragmentation to start not at a maximum radius.

We have simulated the dynamics of a massive disc using two the effective adiabatic exponent γ=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,φ]=400 x 512 with 200 x 512 cells corresponding to the disc at zero time.

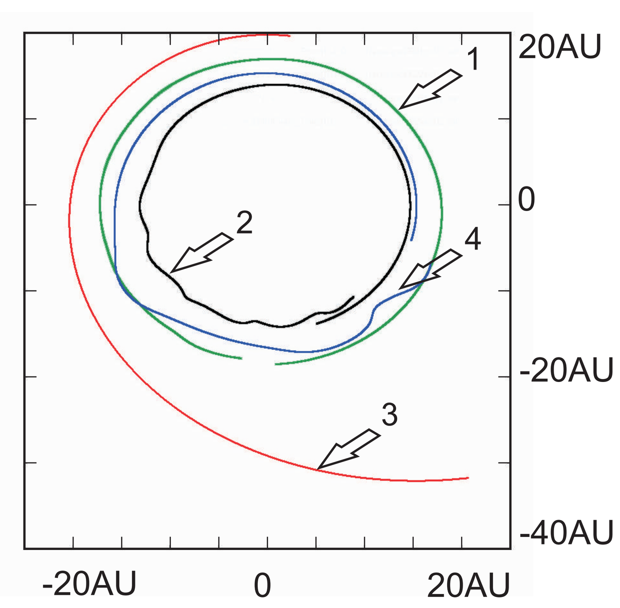


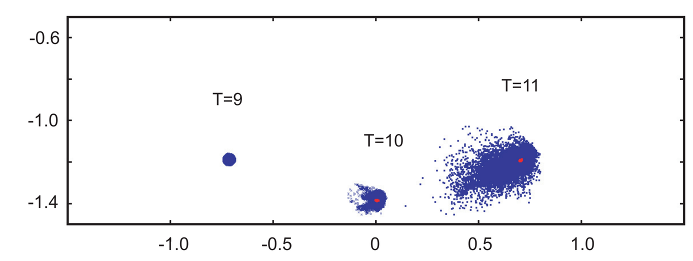
Gas temperature and angular velocity versus radius at initial time



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

DYNAMICS OF BOLDERS INSIDE THE GASEOUS CLUMP





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

Our computer simulations demonstrated that numerous solitary clumps of gas and boulders can be formed in the massive disc. Some metre-sized clusters was found to be wandering, it means that they were captured by one clump, than ejected and captured by the next clump. Such wandering boulders can provide efficient species transport between clumps and from clump to disc atmosphere as well as periodically changing physical conditions for the species adsorbed by the boulder. We found the correlation between initial velocity dispersion of metre-sized solids and the total mass of wandering boulders in the disc.

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