COMPUTER SIMULATION OF DUST GROWTH IN MASSIVE CIRCUMSTELLAR DISKS

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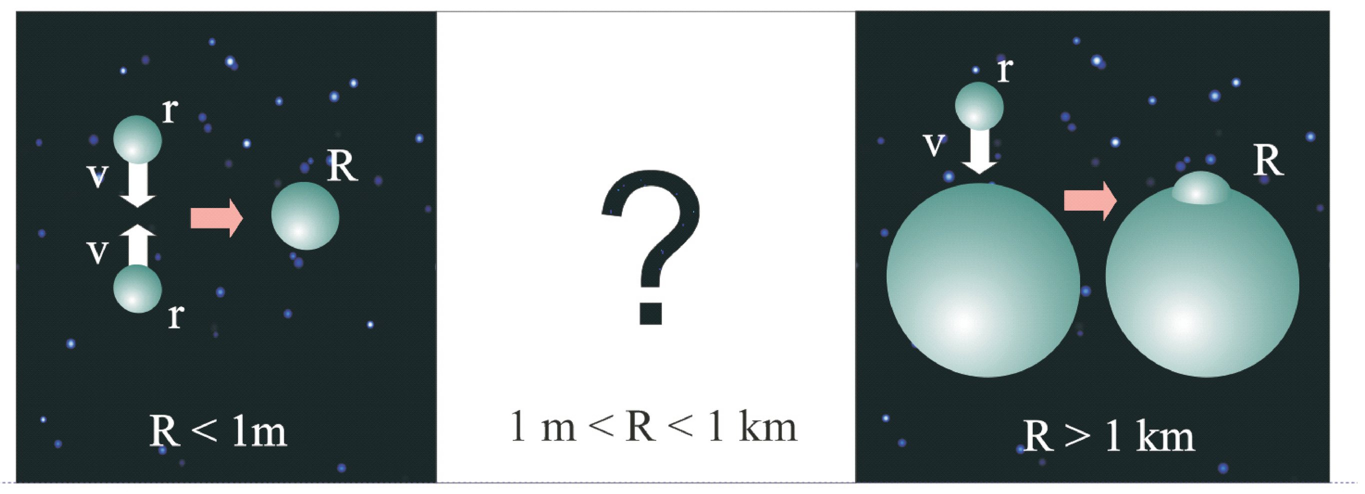
INTRODUCTION

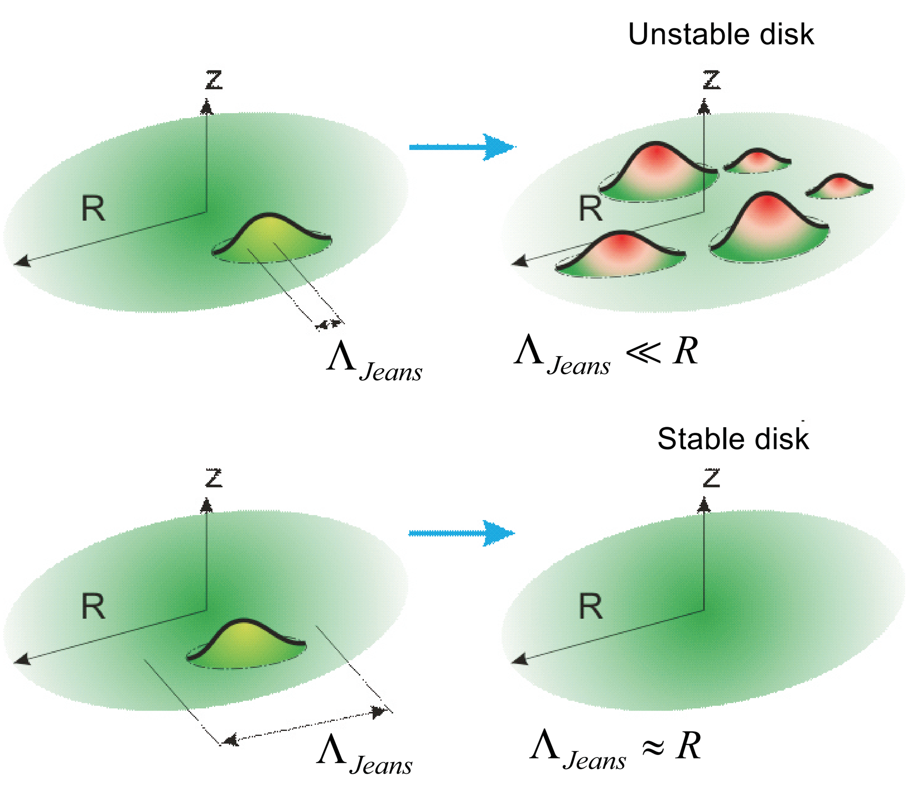
In the frame of solving problem of abiogenous synthesis matter in solar system, on of the most important problems is forming of bodies with radii longer 100 km. According to the astrocatalysis hypothesis carbohydrates are synthesized on the surface of the dust particles in the circumsolar protoplanetary disk? which provide coagulation of these particles, and therefore bodies with radii 1-10 m appear. There is problem of principle mechanism of forming of 100-km-sized bodies, as meter-sized bodies are destroyed due to collisions when they are moving with orbital velocities.

There is a collisionless mechanism fo solving this problem. The main point of it lies in possibility of appearance of gravitational instability in two-phase gas-dust environment. The probability depends on average particles mass/ Thus it is necessary to study the influence of particles growth on increasing of the gravitational instability.



GRAVITATIONAL INSTABILITY

Gravitational instability of the Jeans type. Analytical estimation for two-phase medium.



Jeans length of the gas and the primary bodies in the approximation of a flat layer

$$\Lambda_{gas} = \frac{c_s^2}{G\sigma_{gas}}$$

$$\Lambda_{par} = \frac{v_d^2}{G\sigma_{par}}$$

Jeans length for hybrid systems - non-linear combination

$$\frac{1}{\Lambda} = \frac{1}{\Lambda_{gas}} + \frac{1}{\Lambda_{par}}$$

MATHEMATICAL MODEL

Gas dynamic:

$$\frac{\partial \sigma}{\partial t} + div(\sigma \vec{v}) = 0,$$

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

$$p^* = C\sigma_{gas}^{\gamma}, \quad \sigma_{gas} = \int_{-\infty}^{+\infty} \rho_{gas} dz;$$

Gravitational field:

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

$$\Delta\Phi_2 = 0, \Phi_2 \xrightarrow[r\to\infty]{} 0,$$

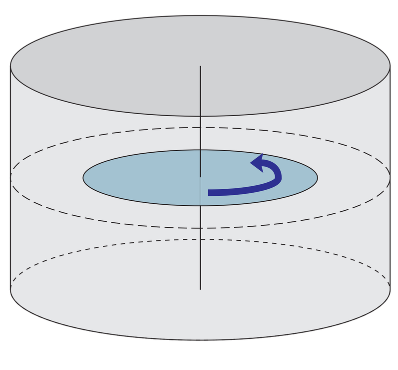
Particles motion:

$$\frac{\partial f}{\partial t} + \vec{u}\frac{\partial f}{\partial \vec{x}} + \vec{a}\frac{\partial f}{\partial \vec{v}} = St(f),$$

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

The initial density:

$$\sigma_{par,gas}(r) = \begin{cases} \frac{3M_{par,gas}}{2\pi R^2}\sqrt{1-\left(\frac{r}{R}\right)^2}, r < R, \\ 0, \quad r \geq R. \end{cases}$$



Smoluchowski equation:

$$\frac{\partial f(m_1,t)}{\partial t} = \frac{1}{2}\int_0^{m_1} K(m_1 - m, m) f(m_1 - m, t) dm - f(m_1, t)\int_0^{\infty} K(m_1, m) f(m, t) dm,$$

Model of inelastic collisions of particles:

$$\begin{cases} m = m_1 + m_2 \\ \vec{r} = \frac{m_1}{m}\vec{r}_1 + \frac{m_2}{m}\vec{r}_2 \\ \vec{u} = \frac{m_1}{m}\vec{u}_1 + \frac{m_2}{m}\vec{u}_2 \\ \frac{m_1 |u_1|^2}{2} + \frac{m_2 |u_2|^2}{2} = \frac{m|u|^2}{2} + Q \end{cases}$$

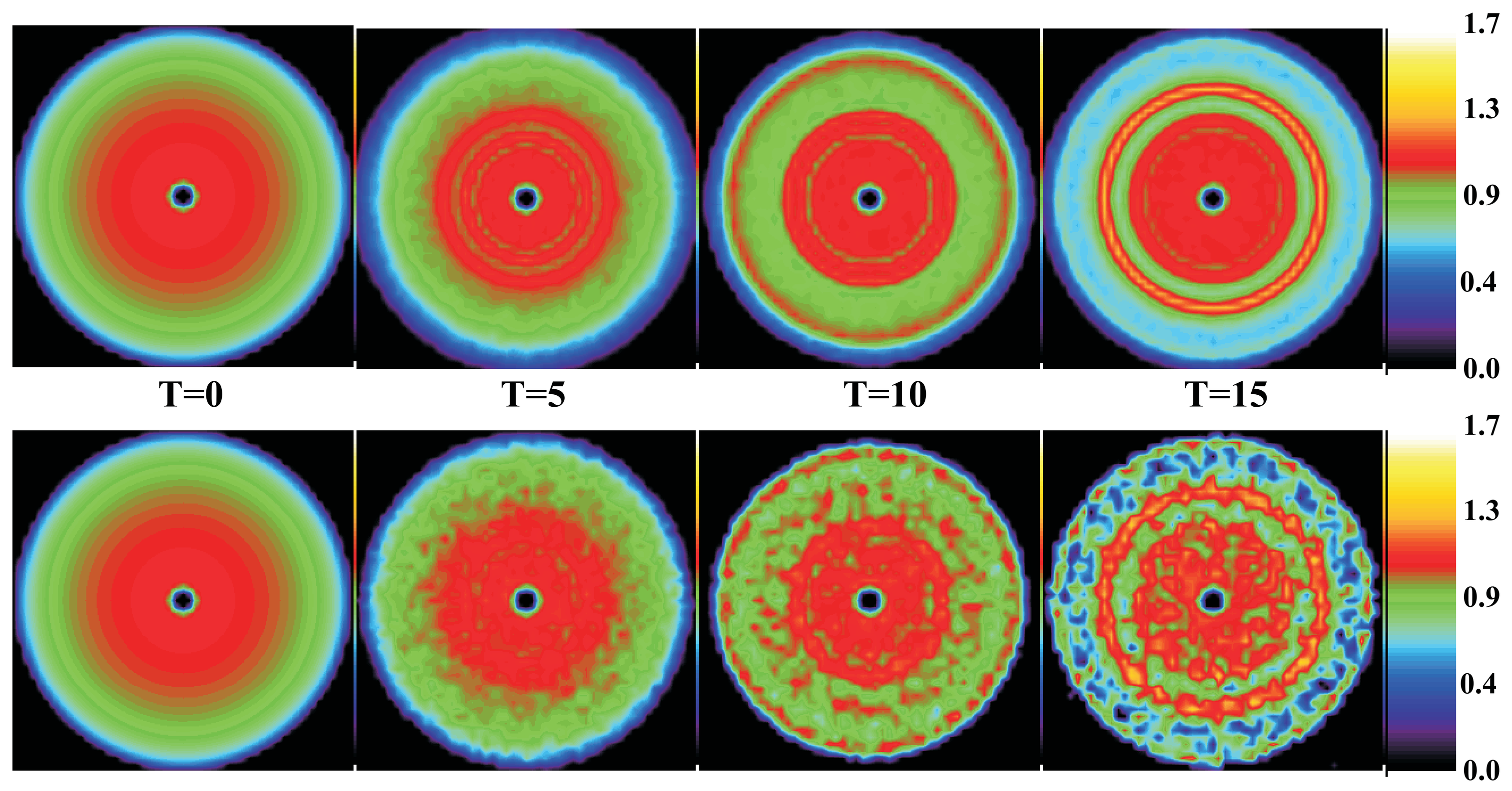
Numerical methods:

method of splitting into physical processes, and then

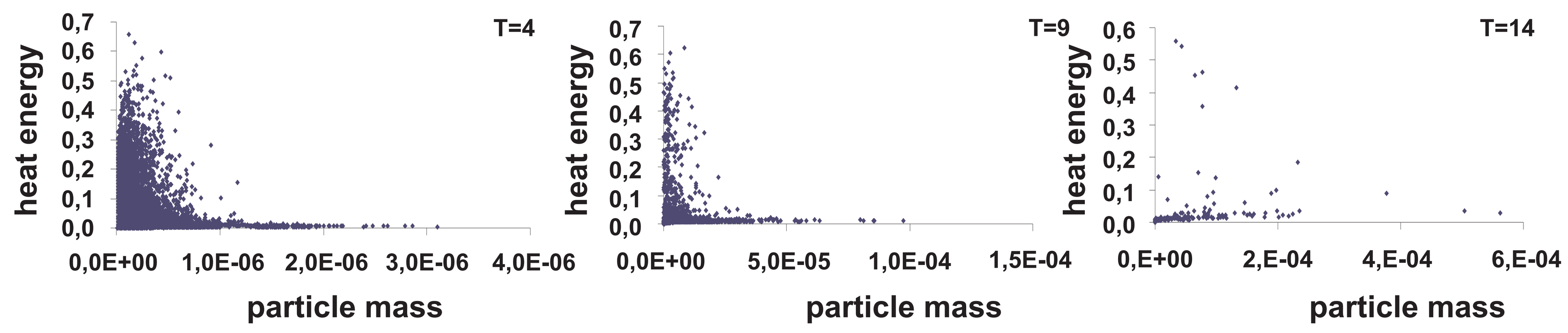
- FLIC (fluid in cell) method for gas
- PIC (particle in cell) method for particle
- method of direct modeling for coagulation

COMPUTER SIMULATION

We have simulated the dynamics of a massive disc using two the effective adiabatic exponent γ= 5/3 in gas. The disc had a radius of 20AU, the central body had the mass M_C = 0.66 M_0, the disc was represented by the gas component with the mass M_{gas}= 0.33M_0 and subdisc of primary solids (boulders of 1-10 metre in size)with M_{par}= 0.01M_0. Subdisc of primary solids was represented by 1*0000000* PIC particles. In the disc plane, the grid size was [r,φ]=512 x 512 .

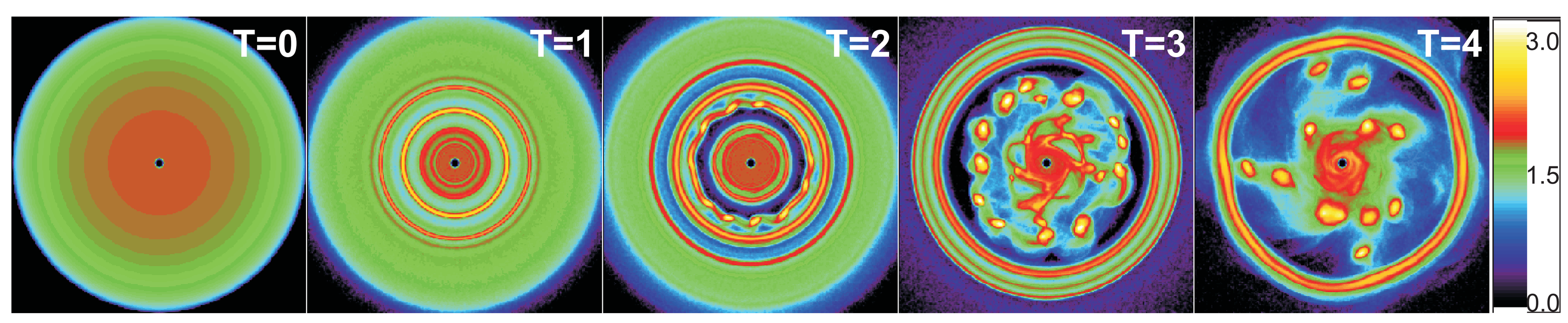


The formation of radial waves of density. Logarithm of the dust surface density without inelastic collisions (top line), and with inelastic collisions (bottom line) fort four time points.



The graph shows the dependence of the thermal energy of the particles on their mass at different points in time. As can be seen, the large particles are not heated by the relatively small and fast particles. So not necessarily protoplanets were melted, as studied asteroids and comets.

If the change ratio of the initial gas, the central body and the particle mass, and effective adiabatic exponent, we can calculate the other gravitational effects, such as clots of dust



The formation of conglomeration. Logarithm of the dust surface density for five time points T = 0, 1, 2, 3, 4 is the rotatin time of the outer part of the disc.

CONCLUSION

One of the most suitable instruments of studying evolution of the protoplanetary disc is mathematical modeling with numerical supercomputer experiments. Numerical model was developed with primary particles motion in the equatorial plane of the disc. The model describes gas dynamics and particles motion including coagulation process. Since the numerical algorithm is based on splitting method. It was made investigation of the influence of the coagulation rate on dynamics of gas-dust system for the initial conditions which gravitational instability appeared. It was found that coagulation rate can increase the instability rate. For some parameters it can significantly influence on the structure of the disc.

Publication:

1. V.N. Snytnikov, O.P. Stoyanovskaya 2013 MNRAS 428, 2-12
2. V.N. Snytnikov, O.P. Stoyanovskaya, O.A. Stadnichenko 2013 EPJ Web of Conferences 46, 07004
3. V.N. Snytnikov, O.P. Stoyanovskaya 2013 EPJ Web of Conferences 46, 07005

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