Initial of Formation of the Bodies in the proto-planetary disks

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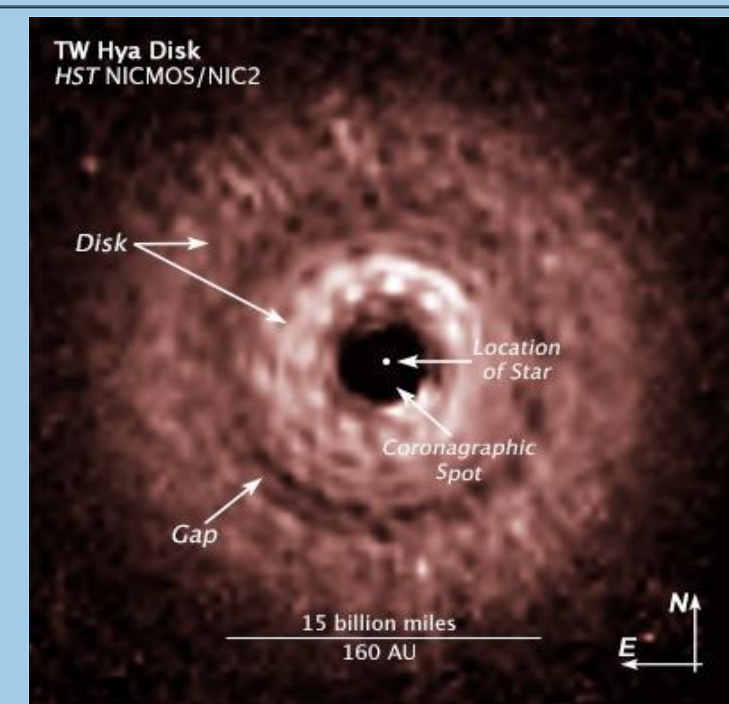
ABSTRACT. In this paper the initial stage of formation of bodies in the proto-planetary disks is considered. It is shown that the redistribution of gas and dust particles in proto-planetary disks could be the cause of disks inside the singular points of the gravitational interaction of the whole disk with dust particles. At these points could be the primary accumulation and the formation of bodies. Growth in the size and mass of the bodies could be due to the influx of new dust particles in the singular points of the neighborhoods of these points.

Dust disk of the TW Hydra. Age star TW Hydra - just only 8 million years. Weight - 0.7 +0.1 solar masses. Refers to a type of T Tauri. In 2008, a group of German astronomers from the Max Planck Institute of Astronomy have discovered a planet on the star TW Hydra b. By weight is a little more of our Jupiter. Revolves around the parent star at a distance of 0.041 AU. In 2013, 80 a. AU from the parent star was discovered planet-forming mass from 6 to 28 Earth masses. (Hubble Space Telescope, John H. Debes.)



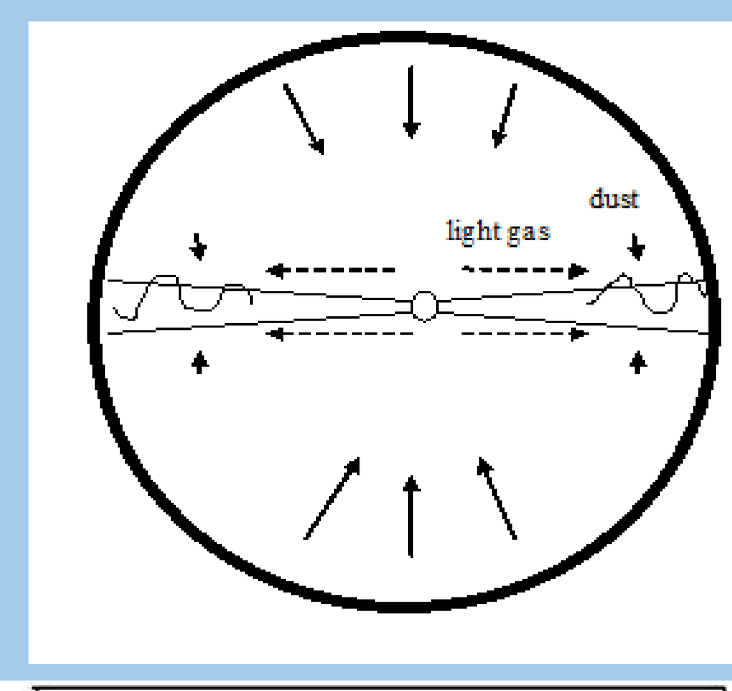
The model of the rings formation. The most intensive movement of the waves could be even in the early stages of the proto-planetary disk. Wave motion of gas and dust particles are formed mainly by the action of two forces [1]: by the gravitational force $\delta Fg = 4\pi\mu\rho 0u$, related to *a* change $\delta\rho$ density $\rho = \rho 0 + \delta\rho$ and by the gas pressure $\delta FP=\rho(\partial P/\partial x + \partial P/\partial y) \approx (cs)^2 \Delta u$, where *u(x, y)* – the displacement of gas and dust particles as a result of the forces δFg and δFP, *cs* – the speed of sound. The condition of gravitational instability in this case will be the following:

$$c_s^2 \Delta u < -4\pi\mu\rho_0 u,\ \Delta = \partial^2/\partial x^2 + \partial^2 y^2$$

, where μ – is the shear modulus.

Then the acceleration of particles in the polar coordinates (*r, φ*) can be determined from the following equation:

$$u_{tt} = c_s^2 \Delta u + 4\pi\mu\rho_0 u$$



To solve the equation will apply the Fourier method. As a result we obtain the function *u(r, φ, t):*

$$u(r,\varphi,t) = \sum_{\nu=0}^{\infty}\Phi_\nu(\varphi)\sum_{k=0}^{\infty}T_{k\nu}(t)R_{k\nu}(r),$$
$$\Phi_\nu(\varphi) = \cos(\nu\varphi + \varphi_0),\ R_{k\nu}(r) = J_\nu(\lambda_{k\nu} r/R_0)$$

$$T_{k\nu}(t) = \begin{cases} a_{k\nu}\exp(c_s\sqrt{\lambda}t) + b_{k\nu}\exp(-c_s\sqrt{\lambda}t), \lambda > 0 \\ a_{k\nu}\cos(c_s\sqrt{-\lambda}t) + b_{k\nu}\sin(-c_s\sqrt{-\lambda}t), \lambda \le 0 \end{cases}$$

where *Jv* – the Bessel functions of order ν, λ*kv* – zeros of the Bessel functions *Jv; R0* – rad proto-planetary disk, *φ0* – the arbitrary constant *,* λ = [4πμρ0 – (λ*kv /R0)2*],

$$a_{k\nu} = 2\beta R_0/\lambda_{k\nu} \approx H\cdot k,\ H = \max_{k,\nu}\{2\beta R_0/(k\lambda_{k\nu})\}, b_{k\nu} = 0.$$

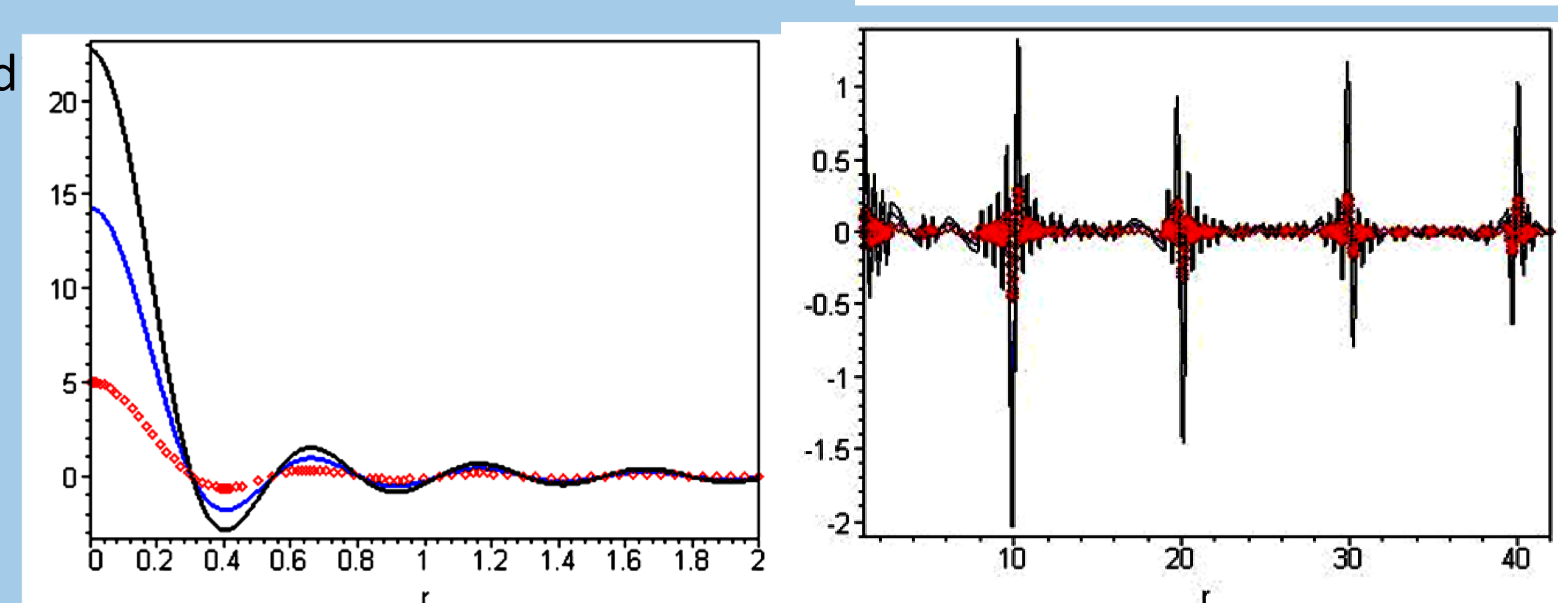


Fig. 1. **The location of the singularities of *u*(*r*) for a given value of the parameters H, R_0: H = 0.108; 0.067; 0.024, a) R_0 = 5(AU); 0 ≤ *r* ≤ 2 (AU). b) R_0 = 5; 2 ≤ *r* ≤ 40 (AU).**

The initial conditions of the problem. The initial moments of formation of proto-planetary rings in the Solar system. According to the model of wave disturbances of the proto-planetary disk of proto-planetary rings before anyone begins to form proto-planetary ring of Neptune, having a maximum value of the wavelength D_0 = 10.876 AU. Proto-planetary ring of Neptune d since the birth of the sun to the beginning of the formation of the asteroid belt will be equal to (10.876 - 1.243) / δ = 12.33 million years. At the lower estimate of the ratio *dD/dr* beginning of formation equals 17.7 million years. According to the estimates of the age of meteorites, the age of the asteroid belt is about 4 million years after the start of the stage thermonuclear reactions in the sun (4.57 billion years ago). Consequently, the lower estimate of the ratio *dD/dr*, stage Hayashi began 4.583 billion years ago. The median estimate is 4.5783 billion years ago. That is, the estimate of the start of the stage for the Sun Hayashi 4.59 billion years old, resulting in work (Bonanno, 2002), according to the model is too high.

Start of formation of the proto-planetary rings

	Distances (AU)	Range difference (AU)	Start building rings (Ma)
Mercury	0.39	0.39	19.64 (4563.36)
Venus	0.72	0.33	19.74 (4563.26)
Earth	1.00	0.28	19.83 (4563.17)
Mars	1.52	0.52	19.37 (4563.63)
Ceres	2.77	1.25	18.10 (4564.9)
Jupiter	5.20	2.43	14.33 (4568.67)
Saturn	9.54	4.34	12.25 (4570.75)
Uranus	19.18	9.64	2.49 (4580.51)
Neptune	30.06	10.88	0.0(4583mill. years)
Pluto	39.44	9.38	2.073 (4580.92)

Libration of small bodies according to the model of an ideal resonance

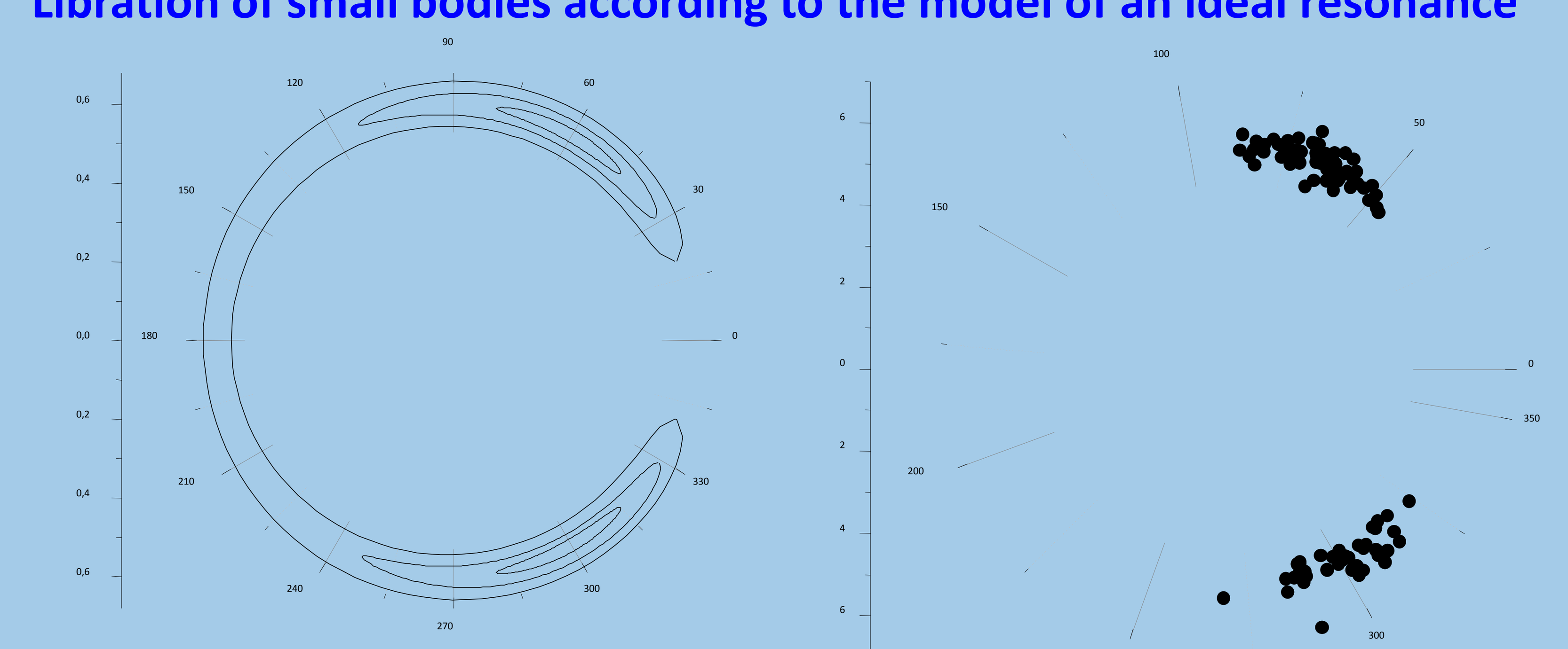


Fig. 2 a) Libration orbit of small bodies near resonance 1/1 for the values of the resonant parameter α = 0.6; one; 2. b) Distribution of polar coordinates (r, λ *) numbered asteroids of the Trojan Group.

Potential of the material lines: $U(x_1,y_1,z_1) = G\int_{(L)}\frac{dm}{\Delta} = G\int_{(L)}\frac{\rho dl}{\Delta}.$

Kepler's second law: $\frac{dS}{S} = \frac{dt}{T}.$

Gauss assumptions: $\frac{dm}{m} = \frac{dt}{T},\quad \frac{dm}{m} = \frac{dS}{S},$

Redistribution of gas and dust particles in the proto-planetary rings. Gauss ring.

Density and potential of the Gauss rings:

$$a)\ dm = \frac{m}{S}dS = \frac{m}{\pi ab}\frac{r^2}{2}d\theta = \rho dl = \rho\sqrt{r^2 + (dr/d\theta)^2}d\theta,\ \rho = \frac{mr^2}{2\pi ab\sqrt{r^2 + (dr/d\theta)^2}},$$

$$U(r_1,\theta_1,z_1) = \frac{Gm}{2\pi ab}\int_0^{2\pi}\frac{r^2 d\theta}{\sqrt{r^2 + r_1^2 + z_1^2 - 2rr_1\cos(\theta - \theta_1)}}.$$

Comparison with the Hamiltonian of the Restricted Three-Body Problem:

$$H = \frac{1}{2(G+\Gamma)^2} + \frac{p+q}{p}n_1 G + mR,$$

$$R = \frac{m}{\sqrt{1 + r^2 - 2r\cos(\tau - \lambda_1)}} - m\cdot r\cdot\cos(\tau - \lambda_1),\quad \bar{f}_0(\lambda^*) = \frac{(p+q)n_1}{2\pi p}\int_0^{2\pi p/[(p+q)n_1]}\left(\frac{1}{\sqrt{1 + r_0^2 - 2r_0\cos(\lambda - \lambda_1)}} - r_0\cdot\cos(\lambda - \lambda_1)\right)dt,$$

$$b)\ dm = \frac{m}{S}dS = \frac{m}{\pi ab}\frac{r^2}{2}d\theta = \rho dl = \rho^* dl^* = \frac{m}{T}dt = \frac{m}{n_1 T}d(n_1 t) = \frac{m}{2\pi}dM_1 = \frac{m}{2\pi}d\lambda_1,\quad \lambda^* = \lambda - \frac{p+q}{p}\lambda_1,\quad \lambda - \lambda_1 = \lambda^* - \lambda_1 + \frac{p+q}{p}\lambda_1.$$