Generation of the Moon and Some Other Celestial Bodies due to Explosion in Planet Interiors

D.V.VORONIN, V.F.ANISICHKIN
Lavrentyev Institute of Hydrodynamics of the Siberian Branch of the Russian Academy of Science,
Lavrentyev str., 15, 630090, Novosibirsk,
RUSSIA
voron@hydro.nsc.ru

Abstract: The structure and composition of planets, small bodies of the Solar system is essentially different. Therefore it is difficult to explain an origin of all celestial bodies of the Solar system due to smooth evolution of the protoplanet cloud. An alternative to the evolutionary one is the hypothesis of the explosive origin of some celestial bodies. It is supposed, that on the solid inner core of a planet the active layer is formed from particles of uranium and thorium oxides (or carbides), weighed in liquid iron of the outer core of the planet. The explosion in such a layer might take place at fast and deep transition of the system in a supercritical condition, for example as a result of collision of a planet with an asteroid. Collision of the protoplanet with an asteroid, the subsequent explosion in an active layer and partial or full fragmentation of the planet in conditions of gravitation is numerically simulated. Modeling was conducted within the framework of hydrodynamical approach for two-dimensional non-stationary motion of the compressible medium on the basis of laws of conservation of mass, pulse and energy in cases of plane and axial symmetry.

The hypothesis that some bodies of the Solar system might be formed as a result of nuclear explosions in the protoplanet core, including large enough fragments mainly iron-nickel, stone-silicate or dust-ice structure is numerically confirmed in the paper. It explains distinctions in structure and characteristics of satellites of some planets, asteroids and comets. Formation of small celestial bodies due to the explosion is possible at preservation of the initial protoplanet as well. If the initial velocity of protoplanet rotation is small enough, the structure and composition of fragments may be determined by the cumulative jet going from a planetary core to its surface. The origin of Io (the nearest satellite of Jupiter, consisting basically from the heated iron) may be explained, for example.

For the great enough velocity of rotation of the initial planet the cumulative jet has not determining influence on the process of destruction. In this case the nuclear explosion in the planet interiors breaks the balance between the centrifugal forces and the gravitation. That results in the separation of the great mass of the stone-silicate shell of the planet and the generation of satellites like the Moon.

Key-Words: numerical simulations, active layer, celestial bodies, explosion, cumulative jet, planet rotation

1 Introduction

One of the most complicated and debatable problem of cosmogony is the question on a genesis of the Earth, the Moon and some other celestial bodies of the Solar system. Existing notions about an origin of planets and their satellites are reduced to five basic groups of hypotheses:

1. The first meteoritic hypothesis [1].
2. The second meteoritic hypothesis [2, 3].
3. Comet one [4, 5].
4. Hypotheses of mega-impact and macro-impacts [6, 7].
5. Hypotheses of explosion [8-10].

Within the framework of meteoritic hypotheses, planets are supposed to be formed due to accretion of planetesimales, similar to meteorites (chondrites), which are considered as initial condensates of a proto-solar nebula. For the first hypothesis, a planet and their satellites are formed in vacuum, when gases of the proto-solar nebula have been drawn to the Sun. According to the second hypothesis, planets accretion occurred in the dense proto-solar nebula and the process was accompanied by formation of a powerful gas shell around the growing planets, preventing their losses of the accretion heat. These hypotheses are strongly criticized recently. According to the petrography data, chondrites represent the magmatic formations connected to long evolution of planets, and may not be considered as initial condensates, some of them (carbonic chondrites) are changed by the processes of hydration and oxidation and contain adjournment of secondary carbon substances.

This disadvantage is eliminated in the third hypothesis where masses of firm comet-like substance consisting of ice with distributed dust iron-silicate particles are considered as initial planetesimales, which planets were formed of. In the processes of planet accretion and gravitational compression there was a fusion of substance in their interiors and the subsequent internal stratifying of planets into iron-stony core and powerful fluid shell around it. This hypothesis is well satisfied with common nebular theory of the origin of the Solar system and explains some fundamental features of its structure, when all planets are disposed in one and the same ecliptic plane, going through the equatorial plane of the Sun, they move around the Sun in the same direction, which the Sun rotates in. Besides, the composition of fluid shells of some planets (Jupiter, Saturn) does not differ significantly from the Sun composition (hydrogen planets). Peripheral fluid planets (Uranus, Neptune) have the shells with essentially water structure; the phenomenon is possible to explain by their remoteness from the Sun. It is considered that planets of a terrestrial group (the Earth, Mars and Venus) have lost their fluid shells in the process of evolution under influence of the Sun; their geochemical structure is close to one of cores of the giant planets. All this confirms generality of the origin of bodies of the Solar system and it is a strong point of the comet hypothesis (as well as meteoritic ones).

However not all features of the structure of bodies of the Solar system may be explained by three hypotheses mentioned above. For example, axes of rotation of planets occupy various positions and are not perpendicular to the ecliptic plane. The axis of Uranus lies in the ecliptic plane, and Venus rotates in the opposite direction in comparison with other planets. Mass concentration of iron inside the Sun and planets of the terrestrial group is approximately identical and varies within the limits of 0,3-0,4. However, concentration of iron in Mercury exceeds 0,6. On the contrary, the Moon does not have massive iron core, its average density is close to one of silicates. Along with that, the chemical composition of the Moon is very close to one of the stone shell of the Earth [10]. The chemical compound of satellites of Jupiter is essentially various and also differs from the structure of an external shell of the planet core. The closer to Jupiter, the concentration of iron in the interiors of its satellites is greater, increasing from the minimal values for satellite Callisto (having average density about 1,5 g/cm^3) up to maximal ones for satellite Io, the latter ones are close to the concentration for Mercury. The available data about the satellites of Uranus and its rings shows comparative youth of these formations [11] (not more, than one billion years that is approximately 1/5 of the age of the Solar system), for example. All the facts point out that evolution of originally similar planets had essentially various modes in the subsequent period and may not be explained only within the frameworks of the hypotheses mentioned above.

The fourth hypothesis (mega-impact) became rather popular recently. According to it, an oblique impact of the Proto-earth and Mars-like body took place. The subsequent accretion of substances from a cloud of stone particles, thrown out by the impact from silicate Proto-earth shell and from the body material, has resulted in formation of the Moon in a circumterraneous orbit. In this way it is possible to explain the similarity of the Moon composition and the one of the Earth stone shell. The numerical modeling of the process [6] confirms an opportunity of such a mechanism of satellite formation, though the probability of this phenomenon is very small, and apparently not all the satellites of planets might be formed in a similar way. Jupiter, Saturn and other giant planets have some massive satellites and it is necessary to assume the existence of many planets chaotically moving in the Solar system, colliding with other planets and forming satellites. That seems quite improbable. Jupiter has rather small but very massive and dense enough iron-stone core because of very high pressure in the fluid hydrogen shell. Therefore, iron-stony substance beating out from the center of Jupiter (for the construction of its satellites Io and Europa) and, simultaneously, throwing off mixes of ice and stones (Ganymede, Callisto) are difficult to explain similarly like for the Earth, practically deprived of liquid-gas shell. Collisions should result in significant eccentricities of the orbits of planet parents. The mega-impact does not explain also the anomalies in characteristics of some other celestial bodies. The small probability of such an event is eliminated within the framework of the theory of macro-impacts (closely related with the mega-impact hypothesis) [7]. The critical analysis of the mega-impact is combined there with its developing, and the model of much smaller sizes of an impact body is offered. Though consequences of such interaction do not generate massive enough bodies with abnormal characteristics any more.

The existence of a belt of asteroids between the orbits of Mars and Jupiter is usually attributed to the full destruction of the Proto-planet (Phaeton), existing earlier in the area. The destruction had a character of an accident [10], finding an explanation within the framework of the fifth group of hypotheses (explosive ones). The differentiation of substance in planets during evolution (sedimentation of heavy elements to the center of a planet and an exit of light fractions to its surface) should result in the acceleration of a planet rotation. Infringement of a balance between forces of gravitation and centrifugal forces may lead to a gravitational explosion [10] and subsequent loss of an essential part of the mass by the planet. Existence of the belt of asteroids and such celestial bodies as Io and Mercury points out that the explosion should be accompanied by the output of substance from the layers close to a planetary core into interplanetary space. However at acceleration of the rotation, superficial layers of the planet begin to destroy earlier than other layers, it should slow down the rotation and prevent the planet from the further destruction. Therefore, the disadvantages of such an explosive hypothesis are (1) too great necessary speed of rotation (one rotation for less than hour) and (2) impossibility of full destruction of a planet.

The other group of explosive hypotheses [8, 9] explains an origin of some celestial bodies by a nuclear explosion inside some Proto-planets which fragments became germs of celestial bodies with unusual characteristics and abnormal chemical composition. Obvious traces of natural chain nuclear reactions, taking place more than 2 billion years ago are found out in the Western Africa [12], but the character and consequences of such explosions for the Solar system have not been considered yet.

Let's analyze conditions at which a nuclear explosion in planet interiors is possible. Two basic models of condensation of substance in a planet are known: homogeneous and heterogeneous ones. For the second model, as against the first one, magnetic and refractory particles are the first to condensate. Therefore in the process of substance cooling, iron-nickel core of a planet is formed first. And then the accretion of not magnetic stone particles occurs on massive iron-nickel core, including ones with addition of uranium, thorium. Dioxides and carbides of uranium are not practically dissolvable and consequently are superseded from silicates hardening at a planet surface in a general process of the planet cooling [13]. Then they filter through a hardening silicate matrix further in the interiors of the planet together with fused iron (as having higher specific density). Crystals of uranium dioxide have density of more than 10 g/cm^3 and very high temperature of fusion, the latter one is about $3{\cdot}10^3$K. Therefore at the beginning of the iron core fusion, the process of sedimentation from a surface proceeded through the fused iron-nickel layer on not-heated internal core of the planet remaining firm because of a high pressure. Thus, the active layer is formed in the planet interiors. An opportunity of concentration of uranium in layers close to the center of the Earth is underlined also in paper [14], though it is supposed there, that it occurs directly in the core of the planet.

The explosion in such a layer might take place at fast and deep transition of the system in a supercritical state. Namely, when fast relative packing of the layer of the uranium dioxide particles and other fissile isotopes, distributed in a liquid iron, takes place. Such compulsory sedimentation of the particles might take place at an exit of a shock wave from a firm core of the planet (as on a "piston") or at falling of a shock wave on an active layer from above. Such a process is explained by inertia of heavy particles located in less dense environment. The shock wave, having sufficient capacity for this purpose, might arise at a collision of the planet with a big asteroid [15]. So, for example, at collision with an asteroid having the diameter of 100km (in the Solar system there are also larger asteroids) at relative velocities of tens km/s, the amplitude of a shock wave in the core of the Earth might achieve meaning of several GPa. Relative packing of active particles could be about ten and more percents [16]. Relative packing of active particles in falling (on a firm core) and reflecting shock wave is less and it also occurs in some distance from the core surface, lifting all particles from the surface. It is also shown in [16]. The explosion is less probable here, than behind the core, but starting intensive heat release mixes a layer of particles with iron environment. Shock wave, coming from the layer (in some minutes) which has blown up on the opposite side of the core, returns active particles closer to the surface of the core and packs the layer, but it is insufficient for the explosion since the particles are not on the "piston" any more. On the other hand, the intensity of the shock wave from an asteroid is higher at the entrance in the core, than at the exit. Thus, explosion might take place simultaneously at two sides, or, asymmetrically, only at one side of a planetary core. Unilateral explosion is modeled below.

At the development of chain nuclear reaction the plane reacting layer begins to extend. But, since there is no increase of a specific surface through which outflow of fission neutrons occurs (as against a spherical geometry of a charge), a failure of chain reaction will not take place. Thus capacity of explosion might be equivalent to explosion of trinitrotoluene in the quantity comparable to the mass of all the Earth, if there is a reaction of the essential part of uranium contained in interiors of the Earth (~10^{-6} part of its mass). However more probable significantly smaller capacities of explosions are considered below.

Mathematical modeling of process of a planet fragmentation at explosion of an active layer inside it in conditions of gravitation is an object of this research.

2 Formulation of mathematical problem

Passage of falling shock wave (SW) through a two-phase layer of the heavy particles dispersed in less dense medium reduces mass concentration of particles at the initial stages of the process. But condensation of particles occurs then in a wave reflected from a rigid wall (a firm planetary core), or at the exit of a wave from the core into the two-phase mixture ("piston" [16, 17]). Therefore, according to the assumption of asymmetrical explosion of an active layer (either in the area laying directly under the place of the impact with an asteroid, or in the area located on the opposite side of a planetary core) made above, the explosion only at one local area of an active layer is modeled below. At the regions, where SW, initiating explosion, goes along a surface of the core, no essential packing of particles and growth of their mass concentration occur.

In Fig.1a the scheme of the modeled process is submitted. A body (1) is a spherical asteroid having initial density ρ_{01} = 5,5g/cm^3, initial longitudinal velocity u_{01} = 30km/s and radius R_{01} = 100km. Transversal velocity of the asteroid v_{01} = 0. The Proto-planet represents the sphere of radius R_0 = 7400km having a firm iron-nickel core with radius R_{02} = 3500km (body (2) in Fig.1). Initial density of the core ρ_{02} = 12,14g/cm^3. A segment (3) in Fig.1 is an exploding part of the active layer (may be located on the opposite side of the core as well). The remaining firm part of the planet is a stone medium (body (4) in Fig.1) with initial density ρ_{04} = 5,5g/cm^3 (water (ice) layer was also added in some variants of calculations). The z-axis is a horizontal line, coming through the center of the planet; the r-axis is normal to the z-axis. The origin of the coordinate system is located on the z-axis at the left end of the figure.

According to [15], four billion years ago full energy of uranium fission in planet interiors might reach the values:

$$W_0 = 120 k_0 M \text{ MJ/kg},$$

where k_0 is a part of reacted U-235, and M is a mass of a planet (in kilograms). We assume in the paper, that only part of the active layer explodes and the value of the liberated nuclear energy is significantly less.

The research was carried out within the framework of hydrodynamic approximation. The equations describing two-dimensional non-stationary motion of inviscid compressible medium at $t > 0$, are based on laws of conservation of mass, pulse and energy. In dimensionless variables they look like:

$$\frac{d\rho}{dt} + \rho\left(\frac{\partial u}{\partial z} + \frac{\partial v}{\partial r} + S\frac{v}{r}\right) = 0,$$

$$\rho\frac{du}{dt} + \frac{\partial p}{\partial z} = \rho g_z, \qquad (1)$$

$$\rho\frac{dv}{dt} + \frac{\partial p}{\partial r} = \rho g_r.$$

$$\frac{dE}{dt} + \frac{p}{\rho}\left(\frac{\partial u}{\partial z} + \frac{\partial v}{\partial r} + S\frac{v}{r}\right) = 0.$$

Here u, v are the velocity vector components in the z and r directions, respectively; p, ρ are the pressure and the density; E is the internal energy of the substance; S=0 for the plane symmetry case, S=1 for the axial symmetry one; g_z , g_r are the components of the vector of gravitation forces $\vec{g}$, affecting the particle of the flow in the z and r directions, respectively.

$$\vec{g} = \sum_{i=1}^{n} \gamma \frac{M_i}{r_i^{S+1}} \vec{l}_i .$$

Here n is the total number of the particles in the system, M_i is the mass of the i-particle, r_i is the distance between i-particle and chosen one, $\vec{l}_i$ is the unit radius-vector connecting the centers of mass of i-particle and chosen one, γ is the gravitational constant,

$$\gamma = 6{,}67\cdot 10^{-8}\,\frac{cm^3}{g\cdot s^2}.$$

To complete the system (1), the equation of state for solid bodies (Osborn [18]) were used for bodies (1,2,4):

$$p = \frac{1}{e+\varphi_0}\left[\zeta(a_1 + a_2\zeta) + e(b_0 + \zeta(b_1 + b_2\zeta) + E(c_0 + c_1\zeta))\right],$$

$$e = \rho_0 E, \quad \zeta = \frac{\rho}{\rho_0} - 1. \qquad (2)$$

where a_1, a_2, b_0, b_1, b_2, c_0, c_1, φ_0 are the constants for the substance. The equations of state in such a simple form are chosen because the main researched processes are the propagation of SW from the place of the collision with the asteroid and the SW propagation from the exploded active layer. Here and further the index "zero" concerns the initial state before collision of the planet and the asteroid.

We assume that products of the nuclear explosion (a body (5) in fig.1) represent the plasma satisfying the equation of state of ideal gas:

$$E = \frac{p}{(k-1)\rho}, \quad (3)$$

where k is the parameter of an adiabatic curve.

3 Boundary conditions and method of calculations

We suggest, that borders between bodies represent contact discontinuity surfaces. At each surface the following boundary conditions are valid:

$$\sigma_{n1} = \sigma_{n2} \ , \ U_{n1} = U_{n2}. \quad (4)$$

Here σ_{n1}, σ_{n1} are the projections of the tension tensor on the direction of the normal to the surface, and U_{n1}, U_{n2} are values of the component of the velocity vector $U = (u, v)$, that is normal to the surface and taken on the different sides from the contact surface. The influence of a magnetic field, phase transitions, a superficial tension and the phenomena of viscosity, heat conductivity and diffusion of substance are not taken into account in the model. Therefore first of conditions (4) is reduced to equality of pressure on the different sides of the contact surface. The lower border of the computational region is the axis of symmetry (in case of axial symmetry). It is considered closed here and the condition of substance non-penetrating is valid (the velocity of the flow $v=0$); the top, right and left borders are open. Boundary conditions on them meet the conditions on a free boundary. In case of plane symmetry all borders are open.

The system of the equations (1) - (3) with the boundary conditions was solved numerically with the help of the method of individual particles, which is updating of Harlow method of particles in cells [19]. The sizes of computed area are as follows: 10^5 km in direction of z-axis and $6{\cdot}10^4$ km in direction of r-axis. The non-uniform computational grid with a growth of number of cells at the axis of symmetry was used. Far from the axis the density of the grid was 0,01cells per kilometer. The computational algorithm provided a growth of the grid density in the areas with the large gradients of the flow parameters (inside a planet, in particular). Therefore the average density of cells here was 0,02. Number of particles in cells is a variable. The numerical algorithm provides an opportunity of association and splitting of the individual particles belonging to the same body, depending on the flow parameters. The maximal number of particles in a cell is equal to seven.

4 Results of calculations

We assume that before the impact of the planet with the asteroid its substance is in a condition of a dynamic balance. Initial distribution of pressure in the planet interiors satisfies an equilibrium condition in case of gravitation. The calculations have been performed at the values of characteristic constants according to the data [18].

As we can see from the results of numerical modeling, the process of a planet fragmentation is mainly determined by parameter λ:

$$\lambda = \frac{Q+K}{G} = \frac{W + 2(\pi R_0 \omega)^2}{\left|\vec{g}\right| R_0}.$$

Here Q – particle energy due to nuclear explosion, K – kinetic energy due to planet rotation, G – energy of gravitation forces, W – specific energy of nuclear explosion per kg of a planet mass, ω - initial velocity of a planet rotation, $\vec{g}$ - total vector of gravitation applied to a particle of planet substance. Values of λ belong to (0; 2,917). Maximal value of λ corresponds to energy W_0. Analysis of the numerical results shows that planet total destruction occurs when $\lambda > 1$ (even without the nuclear explosion). We assume that the value of allocated energy is equal to $6{\cdot}10^{22}$ MJ that is $W = 10^{-2}$ MJ/kg ($W \ll W_0$). The case corresponds to partial planet fragmentation, $\lambda < 1$.

Let's assume at first, that the velocity of the planet rotation is so small, that it may be neglected, $\lambda \in (1{,}7{\cdot}10^{-4}; 3{,}21{\cdot}10^{-4})$. In Fig.1 the initial stage of the process development is submitted: the impact of the planet with the asteroid and the subsequent explosion of the active layer inside it. Instant t=0 in figure corresponds to the moment when the distance between the planet and the asteroid is equal to 15000km. The arrow specifies a direction of the asteroid movement in Fig.1a. At the instant t=700s the impact occurs. The extending cavity is formed on the planet surface. The asteroid is deformed; its velocity falls (Fig.1a – 1d). A spherical SW propagates from the cavity into the planet, it reaches the planet center by the instant t=1280s (Fig.1c). At t=1560s SW comes into the active layer from the core, packs it, and there is a nuclear explosion. The area (5) in Fig.1d is an extending cavity inside the planet, filled with gaseous products of explosion (plasma).

As it is noted above, the explosion of the active layer may take place at the reflection of initiating SW from the planetary core as well. Fig.2 and the subsequent ones correspond to this case. Here the asteroid approached the planet with the same velocity from the right hand side from the planet. The displacement of the regions and their numbering (Fig.2, 3) are similar to Fig.1. The instant t=0 corresponds here to the moment of the celestial bodies impact. Fig.2b represents a transversal profile of pressure (along r-axis) in the cross section z=57800km. In Fig.2c the pressure profile along z-axis is represented at r=0 (an axis of symmetry). The value of pressure in the figure meets the point with coordinates (57800, 0). It is visible that the products of explosion extend, generating powerful SW, which deforms the planetary core. We assume, that initial parameters of the active layer are those, that its part which has not yet exploded by this instant, does not react further, since mass concentration of iron in the active layer is increased at $t > 300$s [16].

By instant t=600s (Fig.3) near to the crater a gas-dust cloud (a plume) is formed from substances of the asteroid and the planet, which is thrown out in the space (region (1) in Fig.2-4). The products of the explosion go on to extend, increasing deformation of the iron core. Interaction of process of expansion and forces of gravitation results in formation of the area of increased pressure inside the planet, that it is well visible in Fig.3. Fig.3b corresponds hear to the transverse profile of pressure along r-axis at z=52800km, and Fig.3c meets one along z-axis at r=0. The pressure p=2156GPa at the point (52800; 0) considerably exceeds initial value.

The dynamics of process at the subsequent instants is submitted in Fig.4. At the expansion, the density of substance and the pressure in the plume quickly fall, and by the instant, corresponding to Fig.4d, this cloud poorly influences all the process already. It is visible from Fig.3, 4 that the cavity in the planetary core begins to shrink at the action of gravitation forces at $t > 600$s. Eventually this process becomes more intensive, since in the nearby less dense cavities (5), consisting of gaseous products of the explosion, the pressure quickly falls down. As a result, the powerful cumulative jet (6) is formed from the substance of the planetary core. It produces the emission of part of the core into the interplanetary space. It is visible in Fig.4d, that gaseous products of the nuclear explosion (5) break off a planet stony shell at t>1500s. It is necessary to note here one more essential role of the asteroid. At half of considered cases emission of the planer substance occurs in the direction of the asteroid crater. Therefore the crater from the impact may facilitate the process of carrying out of the substance to the planet surface and further into the space. Consequently modeling of the explosion was carried out along with the previous impact of the asteroid.

The further stages of the planet fragmentation are submitted in Fig.5. The ratio of the gravitational forces and the velocities of the planet fragments at explosion determine the process. Gaseous products quickly extend in the interplanetary space, the pressure and the density inside them fall, and by instant t=4000s they also practically do not influence the process. At $t > 2300$s the great bulk of the substance in the cumulative jet loses its velocity under the action of gravitation and begins to be involved back into the planet. However some fragments of the jet are pulled out into the interplanetary space. As a result, a great amount of stone and iron-nickel, massive enough celestial bodies is formed, which have sufficient kinetic energy to leave vicinities of the Proto-planet, especially, if to take into account gravitational influence of other planets and own rotation of the planet. The part of the splinters comes into the closed orbit around the common center of mass even without taking into account both of these factors. It is interesting to note also, that at the partial planet fragmentation by the cumulative jet, less dense stony-silicate splinters with density about 3 g/cm^3 are on a periphery of the cloud of particles (a body (7) in Fig.5). When approaching the planet, the density of stone particles grows up to 6g/cm^3 (a body (8)), heavy iron-nickel particles (bodies (9)), representing fragments of the jet, are located on the most close orbits to the planet. This distribution of splinters according to their densities corresponds to one for satellites of Jupiter depending on the distance from the planet. The densest of large ones (with the great contents of iron), satellite Io is the most close to the planet, and then less dense Europa is situated. Ganymede and Callisto are mainly a mixes of a stone and ice. They are located in the greatest distances from Jupiter.

In Fig.6 we can see the process of stabilization and formation of a new planet from the splinters, which have not received sufficient velocity to leave the vicinity of the center of mass. It is visible, that the part of fragments with smaller kinetic energy gradually settles on the planet. The latter one gets the spherical form. The core of the Proto-planet has broken up to parts at the formation of the cumulative jet and its retraction. At the subsequent stages, heavier fragments inside the new planet move to the center of mass and form its core. At the moment t=8000s the volume of a formed planet is about 0,766 of the initial volume. Thus, if to assume that change of the average planet density is insignificant then the planet loses more than 20% of initial mass during the fragmentation. Formation of satellites such as the Moon from splinters occurs in the distances exceeding the sizes of computational region. Therefore this process was not modeled in this case.

The generation of a cumulative jet at nuclear explosion near to a planetary core occurs at the smaller sizes of an active layer as well. In this case it may not come to the planet surface, though it promotes planet partial fragmentation. This can be seen in Fig.7, where the value of the energy of explosion is equal to $3{\cdot}10^{21}$ MJ. The instant t=0 meets here the moment of the impact of the planet with the asteroid also. The profiles of velocity u along r-axis (Fig.7b, z=17500km) and z-axis (Fig7c, r=0) at the moment t=1327s show, that the flow velocity in the jet is much higher than in other regions of the planet. It achieves 7km/s. It is not enough for the emission of substance from the core into the interplanetary space. By instant t=2302s the velocity u in the jet falls up to zero, and it begins to be involved back in the core. Nevertheless, here again the products of the nuclear explosion break off the shell of the planet, and part of its substance comes off the planet, that it is visible in Fig.7.

The variation of parameters of a computational grid, energy of explosion, type of symmetry confirms that at an incomplete planet fragmentation, the cumulative jet may be formed near to the planet core owing to gravitation. In many respects it determines the character of the planet disintegration.

Now we consider the influence of the planet rotation on the character of its destruction at explosion. As calculations show, at small velocities of rotation the character and dynamics of the fragmentation differ little from ones shown above. At the further increase of the velocity, the shape of the explosive cavity on the core surface is deformed and loses the symmetry. That process weakens radial speed of the cumulative jet and reduces a bulk of the substance in it. On the other hand, in this case it is easier for the splinters that have been beaten out into the interplanetary space, to be kept in the orbit, since they have initial angular velocity, which may increase at the explosion. When $\lambda \in (3{,}21{\cdot}10^{-4};4{\cdot}10^{-2})$ the cumulative jet becomes weak and doesn't come through a planet stony core. Nevertheless during the process of planet destruction, a multitude of a stone fragments (quite little in comparison to R_0) come into an orbit round the planet similarly to the previous case. At values of λ close to the upper bound of the interval the jet practically does not influence the process of the destruction.

At further growth of λ (λ >0,04) the process of fragmentation becomes essentially different from one described above. The results of calculations when the period of the rotation is 3 hours are given below. The other initial data correspond to the case considered above. We shall note that at the absence of explosion such a planet keeps the stability. In Fig.8 the initial stage of the destruction at explosion is shown, when the planet rotates in a positive direction (counter-clockwise). Numbering of regions (1) - (5) meets here the previous case. The darker colors of the areas in figure correspond to the higher values of the density. As well as at the absence of rotation, the gas-dust plume (1) is formed from the substance of the asteroid (though it is irregular-shaped here). The density and pressure in it fall down quickly. By the moment t=1600s it ceases to influence the process of the fragmentation. When t=2040s, the jets of plasma (bodies (6)) begin to break off the stone shell of the planet, starting the process of its fragmentation. It is visible from the figure that the cavity on the core surface is insignificant, and the cumulative jet is not generated. The pressure in the products of the nuclear explosion (5) quickly falls down, and at t > 1500s in the vicinity of the core the great bulks of the planet stone shell (the regions (7) and (8)) begins to move towards each other through the region (5), owing to the processes of the gravitation and the rotation. After the impact at t > 3100s these bulks begin to move in the opposite directions. Owing to the planet rotation, the region (7) practically stops, the area (8) gets additional great kinetic energy and begins to go away from the center of mass of the system, keeping the angular velocity of rotation as a whole.

In Fig.9 the subsequent stages of the fragmentation are submitted. The velocity and tension flow-fields are unsteady in the generated splinters. Therefore the process of the splinters crushing proceeds. This is visible from the evolution of bodies (9) and (12) in Fig.8, 9, which go away from the planet. Part of the fragments does not receive sufficient kinetic energy at the explosion and comes back to the planet due to the forces of gravitation, as the splinter (10), for example. The region (8) rotates with the planet; its centrifugal forces exceed the influence of the gravitation. So it gradually comes off the center of mass. The evolution of the body (11) seems to be interesting. It goes along the orbit in a direction opposite to the planet rotation. At t > 7000s there is an impact (practically on a tangent) of this splinter with the region (8) of the planet. The velocity of their mutual approaching exceeds 12 km/s. Arising from the sliding bodies and also due to the gravitation, essentially non-equilibrium field of the pressure in the splinter (11) and in the superficial layers of the region (8) results in the full fragmentation of the body (11) and some parts of the area (8) and the generation of the cloud of small splinters (13). Part of splinters (13) subsequently drops on the planet. This phenomenon is known in cosmogony. At the approaching to the planet in distance less than critical one, some satellites break out to the small fragments (the criterion of Rosh). If the velocity of the satellite was great enough, the most part of the fragments remains in the orbit, generating the rings similar to ones of the giant planets: Saturn, Jupiter and Uranus.

The final stage of the planet destruction is submitted in Fig.10. Here the arrows show the value and the direction of the vector of the fragment average velocity. By the instant t=12450s the speed of substance in the region (8) exceeds 10 km/s, and the separation of a large stone-silicate fragment occurs. Average diameter of the generated splinter is about 0,273 of the initial diameter of the planet (the ratio of the diameters of the Moon and the Earth is equal to 0,272). It comes to the strongly extended eccentric orbit. It is interesting, that at the exit into the circular orbit, the splinter would be turned to the planet by the one and the same side, since up to the moment of the separation linear speeds of substance in it and superficial layers of the planet coincide. Owing to the gravitational influence of the Sun and other planets curvature of a trajectory may vary further. The composition of the fragment is identical to one of the stone shell of the Proto-planet, and the direction of its movement coincides with one of the planet rotation. Thus, the fragment has some properties similar to ones of the Moon. So it is quite probable, that generation of the Moon occurred similarly. At the separation, the plenty of small splinters is formed (the body (14)) as well, which move along the trajectories more close to the planet. Except the large satellite (8), more small fragments come into the orbit also (for example, bodies (15) and (16) in Fig.10). They move around the planet in a counter direction. The same property is also valid for the groups of splinters (17) and (18) which are located closer to the planet. If the bodies (15) and (16) are capable to be kept in the orbit then the bodies (14), (17) and (18) should be destroyed at the interaction and due to the gravitational influence of the planet also (if they approach the planet closer than the limit of Rosh), generating the formations similar to the rings of the giant planets. The difference in the character of the satellites manipulation takes place in the Solar system as well. For example, if Nereida and some other satellites move around Neptune in the direction of its rotation, then the satellite Triton goes in the opposite direction [10].

5 Conclusions

The hypothesis that some bodies of the Solar system might be formed as a result of nuclear explosions in the interiors of some Proto-planet is confirmed in the paper. Modeling has shown that at explosion large enough fragments are formed. They may have mainly iron-nickel or stone-silicate compositions that explains anomaly in the compound and the structure of some planets, satellites and asteroids. The formation of small celestial bodies at the explosion may occur at the preservation of big Proto-planets. Thus the cumulative jet going from the planetary core to its surface may determine the character of the splinters and their compositions. So the origin of Io (the nearest satellite to Jupiter), consisting basically from iron, may be explained, for example. Other explanations are failed. If the velocity of rotation of the initial planet is great enough, the cumulative jet has not determining influence on the process of destruction. In this case the nuclear explosion in the planet interiors breaks the balance between the centrifugal forces and the gravitation. That results in the separation of the great mass of the stone-silicate shell of the planet and the generation of satellites like the Moon.

The study is executed within the framework of the Integration project N 24 "Studying of the opportunity of explosive energy release in a planet interior" at the financial support of Presidium of the Siberian Branch of the Russian Academy of Science.

References:

[1] Shmidt O.J. *On the genesis of the Earth and planets.* M.: Nauka, 1962. 132 p.

[2] Hayashi C., Nakazawa K., Nakagawa Y. Formation of the Solar system // *Protostars and planets.* Tucson. 1985. Pt. 2. P. 1100-1151.

[3] Ozima M. Geohystory. B.-Heidelberg, 1987.-165 p.

[4] Marakushev A.A. *Petrology*. M.: Moscow State University Publ., 1988. 307 p.

[5] Marakushev A.A. *Petrogenesis.* M.: Nedra, 1988. 292 p.

[6] Cameron A.G.W., Benz W. The origin of the Moon and the Single Impact Hypothesis IV // *Icarus.* 1991. V.92. P. 204-216.

[7] Vityazev A.V., Pechernikova G.V. Early differentiation of the Earth and the problem of the Moon composition // *Physics of the Earth*. 1996. N 6. P. 3-16.

[8] Driscoll R.B. Nuclear Disruption of a Planet // *Bulletin of the American Physical Society*. 1988. Series II. Vol. 33. N 1. P. 73.

[9] Anisichkin V.F. Whether planets blow up? // *Combustion, Explosion and Shock waves.* 1997. V. 33. N 1. P. 138-142.

[10] Marakushev A.A. *An origin and evolution of the Earth and other planets of the Solar system* // M.: Nauka. 1992. 208 p.

[11] Cousi J. H., Espozito L.U. Rings of Uranus // *In the world of a science*. 1987. N 9.-P. 26-33.

[12] Shukoljukov J.A. *Fission products of heavy elements of the Earth* // M.: Energoisdat, 1982. 126 P.

[13] Beattie P. The generation of uranium series disequilibria by partial melting of spinel peridotite: constraints from partitioning studies // *Earth and Planetary Science Letters*. 1993. V. 117. P. 397-391.

[14] Marvin Herndon J. Composition of the deep interior of the Earth: divergent geophysical development with fundamentally different geophysical implications // *Physics of the Earth and planetary interiors.* 1998. N 105. P. 1-4.

[15] Mitrofanov V.V., Anisichkin V.F., Voronin D.V. etc. About an opportunity of explosive nuclear energy release in interiors of planets // *Int. Conf. V Zababachin scientific readings. Labors.* Snezhinsk.-1999. - P. 67-76.

[16] Voronin D.V., Anisichkin V.F. Modelling of behaviour of suspensions of heavy particles behind front of a shock wave // *Combustion, Explosion and Shock waves* . 2001. V. 37. N 4. P. 116-121.

[17] Anisichkin V.F., Voronin D.V. A fragmentation of planets at explosion.// *8-th Russia Congress on the theoretical and applied mechanics.* Perm. 2001. P. 48-49.

[18] *High – velocity impact phenomena*. – Ed. Ray Kinslow. Academic Press. New York. London. 1970. 534 p.

[19] Agurejkin V.A., Kryukov B.P. A method of individual particles for calculation of flows of multi-component media with the great deformations // *Numerical methods of the mechanics of the continuous media.* 1986. V. 17. N 1. P. 17-31.

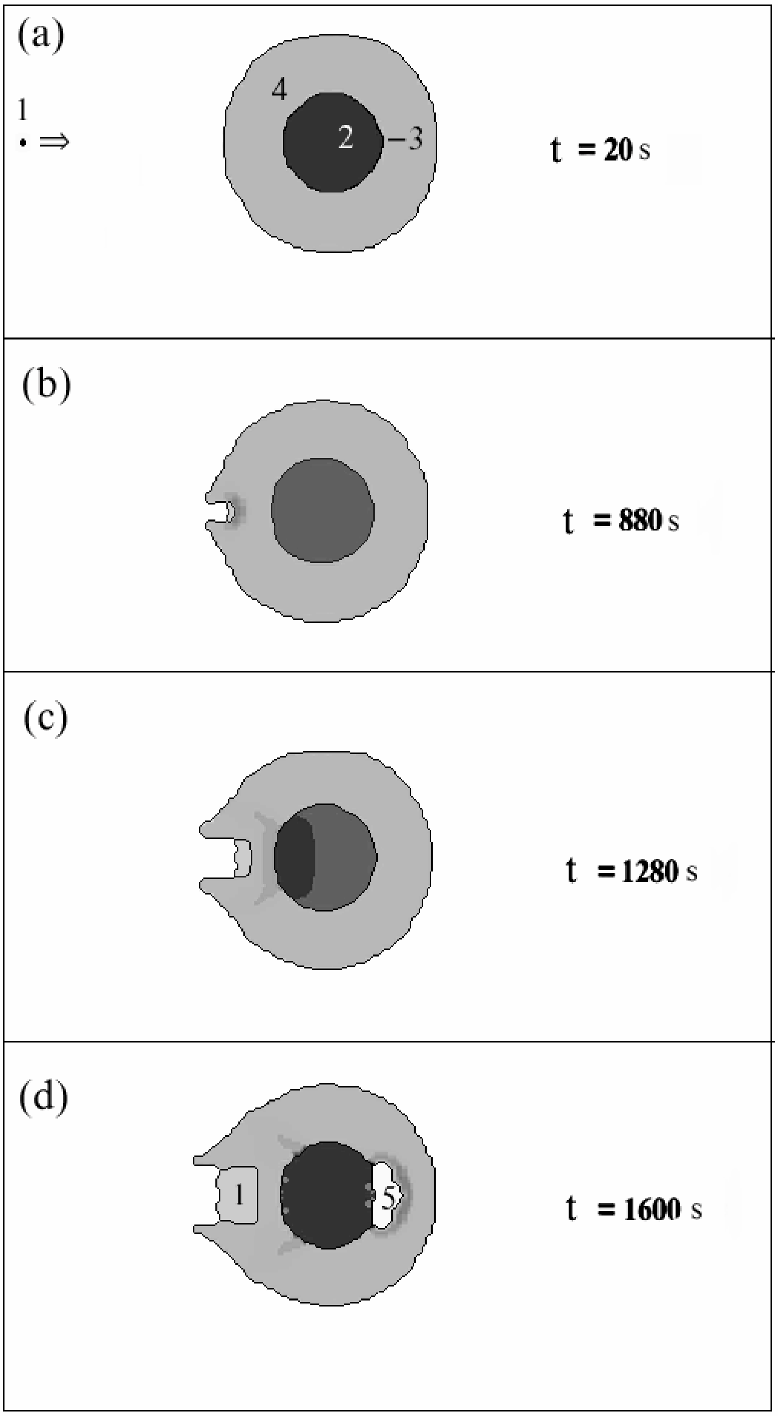


Fig.1.

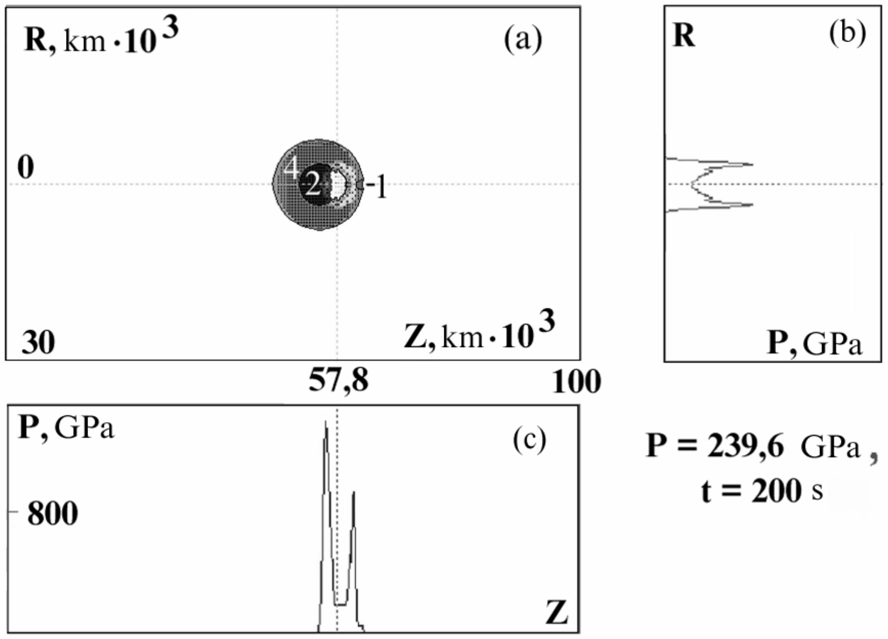

R, km·10^3
(a)
0
4
2
1
30
Z, km·10^3
57,8
100
R
(b)
P, GPa
P, GPa
(c)
800
Z
P = 239,6 GPa ,
t = 200 s

Fig .2.

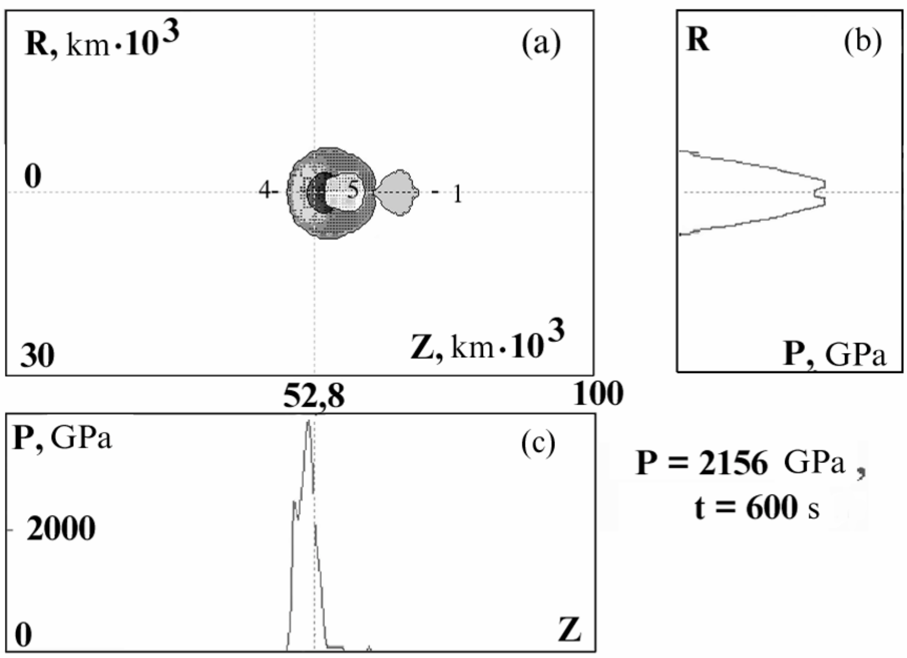

R, km·10^3
(a)
0
4
5
1
30
Z, km·10^3
52,8
100
R
(b)
P, GPa
P, GPa
(c)
2000
0
Z
P = 2156 GPa ,
t = 600 s

Fig .3.

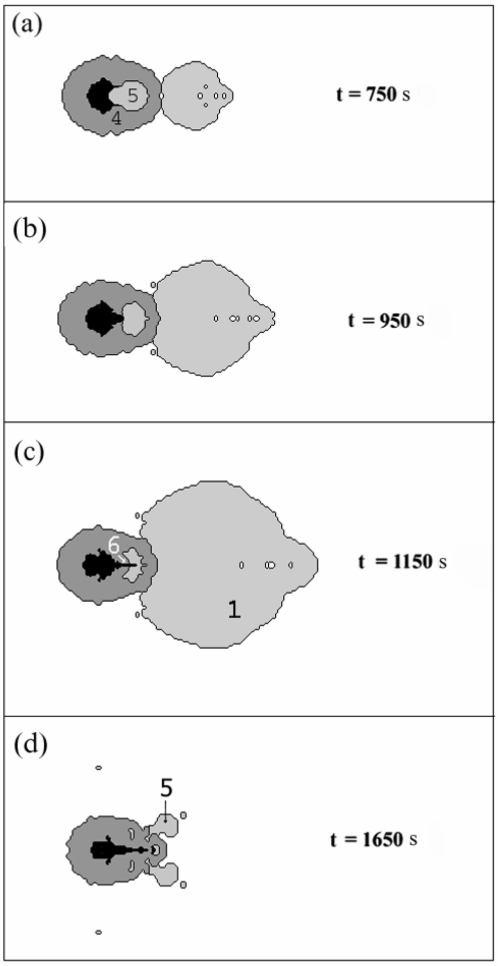


Fig.4.

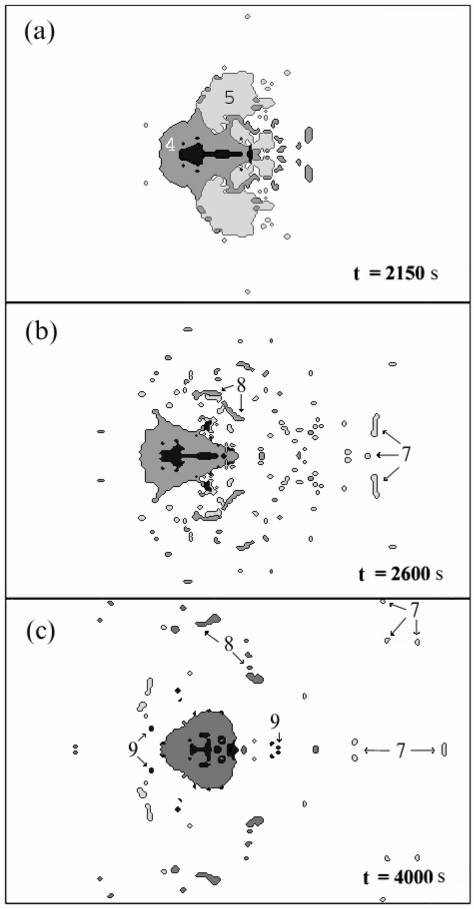


Fig.5.

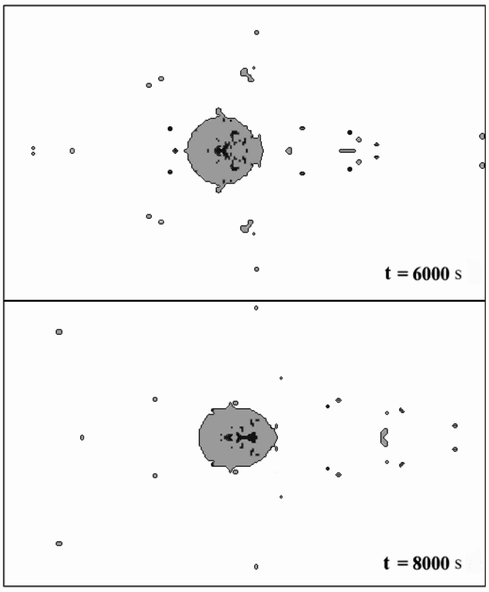


Fig.6.

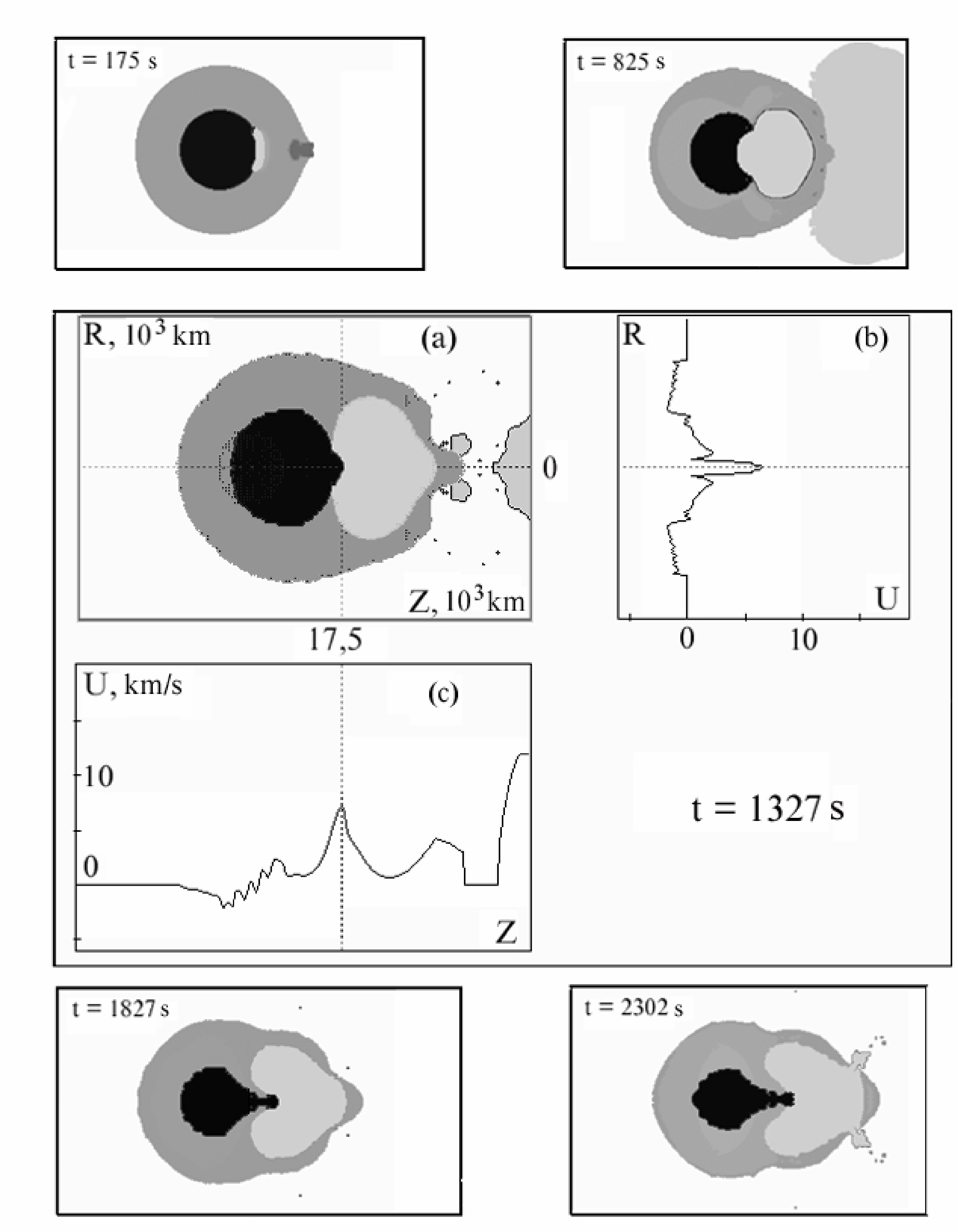

t = 175 s
t = 825 s
R, 10^3 km
(a)
0
Z, 10^3 km
17,5
R
(b)
U
0
10
U, km/s
(c)
10
0
Z
t = 1327 s
t = 1827 s
t = 2302 s

Fig . 7.

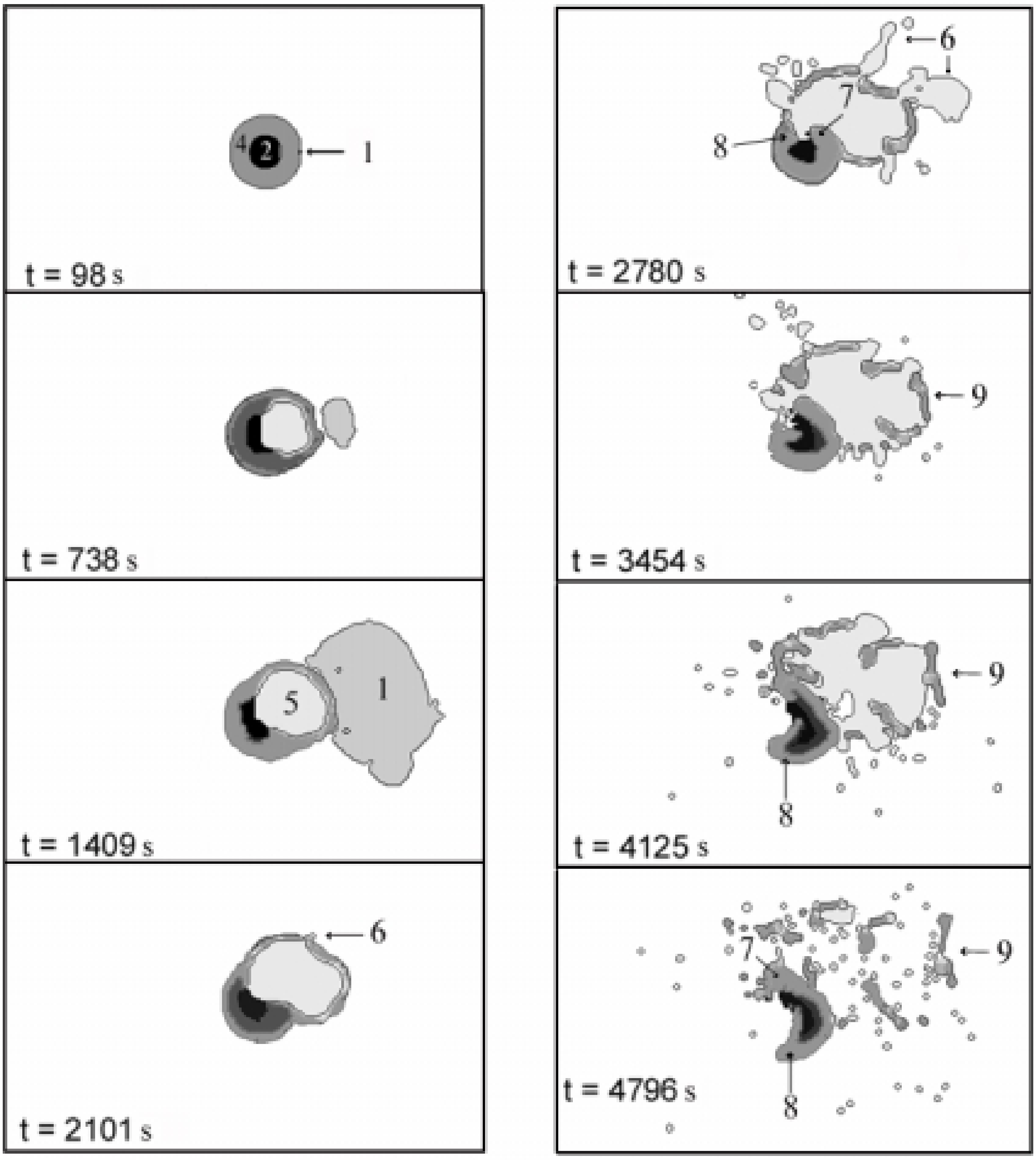
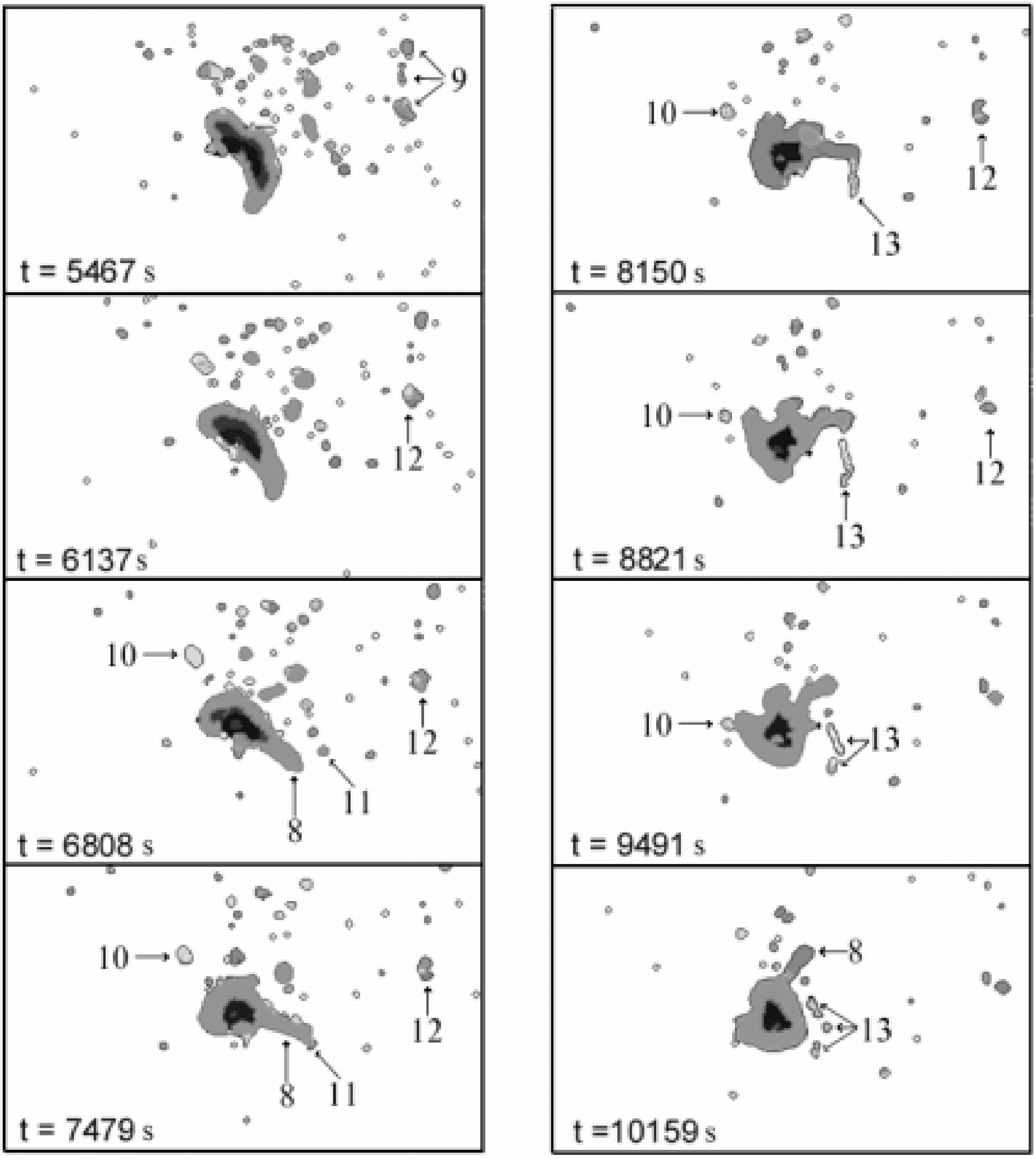

4
2
1
t = 98 s
t = 738 s
5
1
t = 1409 s
6
t = 2101 s
6
7
8
t = 2780 s
9
t = 3454 s
9
8
t = 4125 s
7
9
t = 4796 s
8

Fig . 8.



t = 5467 s
9
t = 6137 s
12
t = 6808 s
10
12
11
8
t = 7479 s
10
12
8
11
t = 8150 s
10
12
13
t = 8821 s
10
12
13
t = 9491 s
10
13
t =10159 s
8
13

Fig . 9.

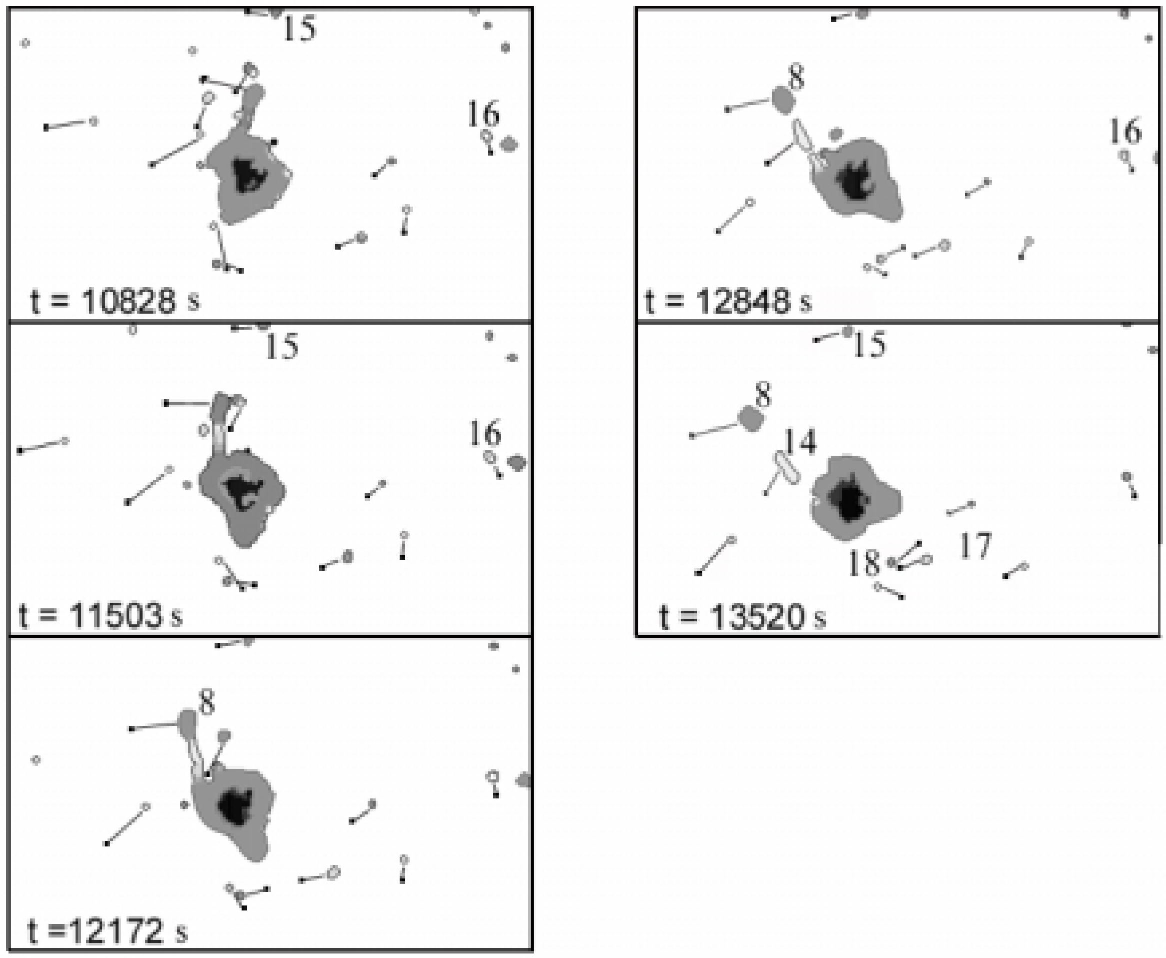

15
16
t = 10828 s
15
16
t = 11503 s
8
t =12172 s
8
16
t = 12848 s
15
8
14
18
17
t = 13520 s

Fig . 10.

Signatures to the figures.

Fig. 1. Impact of the planet with an asteroid and explosion of an active layer in its interiors.
Fig. 2. Distribution of the pressure in the planet interiors at instant t=200s after its impact with the asteroid.
Fig. 3. Distribution of the pressure in the planet interiors at instant t=600s after its impact with the asteroid.
Fig. 4. An initial stage of the planet fragmentation after the explosion of an active layer.
Fig. 5. Fragmentation of the planet under the influence of the extending products of explosion and the cumulative jet from its core.
Fig. 6. Stabilization and formation of the new planet from fragments.
Fig. 7. Dynamics of formation of the cumulative jet in interiors of the planet and its influence on the process of the fragmentation.
Fig. 8. An initial stage of the destruction of the rotating planet.
Fig. 9. Generation and evolution of the fragments of the rotating planet.
Fig. 10. Separation of the large Moon-like splinter from the planet.