FORMATION OF BINARIES AT A STAGE OF RAREFIED PREPLANETESIMALS.
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Introduction: Last years, new arguments in favor of the model of rarefied preplanetesimals - clumps were found (e.g., [1-3]). Even before new arguments in favor of formation of planetesimals from rarefied preplanetesimals have been found, Ipatov [4-5] considered that some trans-Neptunian objects (TNOs), planetesimals, and asteroids with diameter d>100 km could be formed directly by the compression of large rarefied preplanetesimals, but not by the accretion of smaller solid planetesimals. Some smaller objects (TNOs, planetesimals, asteroids) could be debris of larger objects, and other smaller objects could be formed directly by compression of preplanetesimals. There are several hypotheses of formation of binaries for a model of solid objects (see e.g., [6-9]). Ipatov [5] supposed that a considerable fraction of trans-Neptunian binaries could be formed at the stage of compression of rarefied preplanetesimals moved in almost circular orbits. For circular heliocentric orbits, two objects that entered inside the Hill sphere could move there for a longer time than those entered the sphere from eccentric heliocentric orbits. The diameters of preplanetesimals were greater than the diameters of solid planetesimals of the same masses. Therefore the models of binary formation due to the gravitational interactions or collisions of future binary components with an object (or objects) that were inside their Hill sphere, which were considered by several authors for solid objects, are more effective for rarefied preplanetesimals.

Angular momentum of two collided rarefied preplanetesimals: Most of the papers devoted to the formation of spins of forming objects considered a model of solid-body accumulation. Besides such model, Ipatov [10-11] also studied formation of spins for a model of rarefied condensations. Formulas for the angular momentum of two collided rarefied preplanetesimals - Hill spheres (with radii r_1 and r_2 and masses m_1 and m_2), moved in circular heliocentric orbits are presented in [11-12]. At a difference in their semimajor axes a equaled to $\Theta\cdot(r_1+r_2)$, the tangential velocity of collision is $v_\tau=k_\Theta\cdot(G\cdot M_S)^{1/2}\cdot(r_1+r_2)\cdot a^{-3/2}$ and the angular momentum $K_s=k_\Theta\cdot(G\cdot M_S)^{1/2}\cdot(r_1+r_2)^2\cdot m_1\cdot m_2\cdot(m_1+m_2)^{-1}\cdot a^{-3/2}$, where G is the gravitational constant, and M_S is the mass of the Sun. At $r_a=(r_1+r_2)/a<<\Theta$ and $r_a<<1$, one can obtain $k_\Theta\approx(1-1.5\cdot\Theta^2)$. The mean value of $|k_\Theta|$ equals to 0.6. It is equal to 2/3 for mean positive values of k_Θ and to 0.24 for mean negative values of k_Θ. The resulting momentum is positive at $0<\Theta<(2/3)^{1/2}\approx0.8165$ and is negative at $0.8165<\Theta<1$. The minimum value of k_Θ equals -0.5. In the case of uniform distribution of Θ, the probability to get a reverse rotation is about 1/5.

For homogeneous spheres at k_Θ=0.6, a=1 AU, and $m_1=m_2$, the period of axial rotation $T_s\approx9\cdot10^3$ hours for the rarefied preplanetesimal formed as a result of a collision of two preplanetesimals - Hill spheres, and $T_s\approx0.5^h$ for a planetesimal of density ρ=1 g cm^{-3}. For greater a, the values of T_s are smaller (are proportional to $a^{-1/2}$). Such small periods of axial rotations cannot exist, especially if we consider bodies obtained by contraction of rotating rarefied preplanetesimals, which can lose material easier than solid bodies. The value of $v_s=2\pi\cdot r_f/T_s$ (the velocity of a particle on a surface of a rotating spherical object of radius r_f at the equator) is equal to $v_{cf}=(G\cdot m_f/r_f)^{1/2}$ (the minimum velocity at which a particle can leave the surface) at period $T_{sc}=T_s=(3\pi)^{1/2}\cdot(\rho G)^{-1/2}$. The value of v_s is equal to the escape velocity at $T_{se}=T_s=(3\pi)^{1/2}\cdot(2\rho G)^{-1/2}$. For ρ=1 g cm^{-3}, $T_{sc}\approx3.3^h$ and $T_{se}\approx2.33^h$. The form of present small bodies can differ much from their primordial form, and their rotation could change due to collisions with solid small bodies.

We suppose that formation of some binaries could be caused by that the angular momentum that they obtained at the stage of rarefied preplanetesimals was greater than that could exist for solid bodies. During contraction of a rotating rarefied preplanetesimal, some material with $v_s>v_{cf}$ could form a cloud (that transformed into a disk) of material moving around the contracting primary. One or several satellites of the primary could be formed from this cloud. Some material could leave the Hill sphere of a rotating contracting planetesimal, and the mass of an initial rotating preplanetesimal could exceed the mass of a corresponding present binary system. Due to tidal interactions, the distance between binary components could increase with time and their spin rotation could become slower. For the discussed model of formation of binaries, the vector of the original spin momentum of the primary was approximately perpendicular to the plane where the secondary component (and all other satellites of the primary) moved. It is not necessary that this plane is close to the ecliptic because the difference between the distances from centers of masses of collided preplanetesimals to the middle plane of the disk of preplanetesimals could be comparable with sizes of preplanetesimals. Eccentricities of orbits of satellites of the primary formed in such a way will be mainly small.

Some collided rarefied preplanetesimals had a greater density at distances closer to their centers. Therefore it might be also possible that sometimes there were two centers of contraction inside the rotating preplanetesimal formed as a result of a collision of two rarefied preplanetesimals. Such formation of binaries could result in binaries with close masses separated by a large distance. In such cases, the values of the eccentricity of the orbit of the secondary component can be different. It could be also possible that the primary had partly contracted when a smaller object (objects) got into the Hill sphere, and then the object was captured due to collisions with the material of the outer part of the contracted primary. In this case, a satellite can be formed at any distance (inside the Hill sphere) from the primary, and its eccentricity can be different.

We showed [12] that for an object of density ρ, T_s is proportional to $a^{-1/2}\cdot\rho^{-2/3}$. Therefore for greater a, more material of a contacting rotating preplanetesimal was not able to contract into a primary and could get into a cloud surrounding the primary (or there were more chances that there were two centers of contraction). It can explain why binaries are more frequent among TNOs than among large main-belt asteroids, and why the typical mass ratio of the secondary to the primary is greater for TNOs than for asteroids. Longer time of contraction of rotating preplanetesimals at greater a (for dust condensations, it was shown by several authors, e.g. by Safronov) could also testify in favor of the above conclusion. Most of rarefied preasteroids could turn into solid asteroids before they collided with other preasteroids. Spin and form of a small object could change during evolution of the solar system due to collisions with other solid small bodies.

Comparison of angular momenta of present binaries with model angular momenta: For five binaries, the angular momentum K_{scm} of the present primary and secondary components (with diameters d_p and d_s), the momentum K_{s06ps} of two collided preplanetesimals with masses of the binary components moved in circular heliocentric orbits at k_Θ=0.6, and the momentum K_{s06eq} of two identical collided preplanetesimals with masses equal to a half of the total mass of the binary components at k_Θ=0.6 are presented in the Table. All these three momenta are considered relative to the center of mass of the system. K_{spin} is the spin momentum of the primary. L is the distance between the primary and the secondary, and T_{sp} is the period of spin rotation of the primary. The used data were taken from Wikipedia. For the binaries presented in the Table, the ratio $r_K=(K_{scm}+K_{spin})/K_{s06eq}$ is smaller than 1. For most of observed binaries, this ratio is smaller than for the trans-Neptunian binaries considered. Small values of r_K for most discovered binaries can be due to that preplanetesimals had already partly compressed at the moment of collision (could be smaller than their Hill spheres and/or could be denser for distances closer to the center of a preplanetesimal).

The axial tilt of Pluto is 119.6°. Reverse rotation does not contradict to a collision of two objects (see the previous section). Present rotation of Sylvia around its short axis is not in favor of our model, and it could be obtained at a stage of solid bodies.

Solid bodies could get critical angular momenta (corresponding to T_s<3.3 h) at collisions in the case of eccentric heliocentric orbits. Ipatov [11] showed that $T_s \approx 6.33\cdot r_f/v_\tau$ at a collision of two identical bodies (T_s is proportional to m_1/m_2 at $m_1 >> m_2$) and homogeneous spheres. At v_τ=3.5 km·s^{-1}, the equality $6.33\cdot r_f/v_\tau=3.3^h$ is fulfilled at $r_f \approx$6600 km. Therefore, a critical angular momentum could be got at a collision of two identical asteroids of any sizes. At the same eccentricities of heliocentric orbits and m_1/m_2=const, the probability to get the critical momentum at a collision is greater for smaller values of m_1 and a. Some collided solid bodies with the critical momentum could be disrupted due to collision.

Table. Angular momenta (in kg·km^2·s^{-1})

binary	Pluto	(90842) Orcus	2000 CF105	2001 QW_{322}	(87) Sylvia
a, AU	39.48	39.3	43.8	43.94	3.490
d_p, km	1195	950	170	86	286
d_s, km	604	260	150	86	18
L, km	19,570	8700	23,000	130000	1356
T_{sp}, h	153.3	13.19			5.18
K_{scm}	$6\cdot10^{24}$	$9\cdot10^{21}$	$2.4\cdot10^{20}$	$1.3\cdot10^{19}$	10^{17}
K_{spin}	10^{23}	$9\cdot10^{21}$	small	small	$4\cdot10^{19}$
K_{s06ps}	$8.4\cdot10^{25}$	$1.3\cdot10^{24}$	$1.19\cdot10^{21}$	$1.7\cdot10^{19}$	$3\cdot10^{17}$
K_{s06eq}	$2.8\cdot10^{26}$	$4\cdot10^{25}$	$1.24\cdot10^{21}$	$1.7\cdot10^{19}$	$8\cdot10^{20}$

Conclusions: Some TNOs and asteroids could get their axial rotation and/or satellites at the stage when they were rarefied preplanetesimals. The momentum of two collided identical rarefied Hill spheres moved in circular orbits exceeded the momentum of a corresponding present binary of the same total mass.

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