Formation of binaries at the stage of rarefied preplanetesimals

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Last years, new arguments in favor of the model of rarefied preplanetesimals - clumps have been found. There are several hypotheses of formation of binaries for a model of solid objects (see references in [1]). Ipatov [2] 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.

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 [3]. At a difference in their semimajor axes $a$ equaled to $\Theta (r_1 + r_2)$, the tangential velocity of collision is $v_r = k_\Theta \sqrt{(G \cdot M_\odot)^{1/2} (r_1 + r_2)^{a^{-3/2}}}$ and the angular momentum $K = k_\Theta \sqrt{(G \cdot M_\odot)^{1/2} (r_1 + r_2)^{2} m_1 m_2 (m_1 + m_2)^{-1} a^{-3/2}}$, where $G$ is the gravitational constant, and $M_\odot$ is the mass of the Sun. At $r_a = (r_1 + r_2)/a \Theta$ and $r_a < 1$, one can obtain $k_\Theta \approx (1.5 \Theta^2)$. The mean value of $|k_\Theta|$ equals to 0.6. It is equal to 2/3 for mean positive values of $k_\Theta$ and to 0.24 for mean negative values of $k_\Theta$. The resulting momentum is positive at $0 < \Theta < (2/3)^{1/2} \approx 0.8165$ and is negative at $0.8165 < \Theta < 1$.

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 $v_s > v_{cf}$ (where $v_s$ is the velocity of a particle on a surface of a rotating object at the equator and $v_{cf}$ is the minimum velocity at which a particle can leave the surface) 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 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. Most of rarefied preasteroids could turn into solid asteroids before they collided with other preasteroids.

For several observed trans-Neptunian binaries, we calculated the angular momentum $K_{scm}$ of the present primary and secondary components (with observed masses and radii), the momentum $K_{scm}$ of two collided preplanetesimals with masses of the binary components moved in circular heliocentric orbits at $k_\Theta = 0.6$, and the momentum $K_{scm}$ of two identical collided preplanetesimals with masses equal to a half of the total mass of the binary components at $k_\Theta = 0.6$. All these three momenta are considered relative to the center of mass of the system. $K_{spin}$ is the spin momentum of the primary. For the binaries considered [1], the ratio $r_K = (K_{scm} + K_{spin})/K_{scm}$ is smaller than 1. For most of observed binaries, this ratio is smaller than that for the trans-Neptunian binaries considered (Pluto, (90842) Orcus, 2000 CF105, and 2001 QW322). 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).

Conclusions: Some trans-Neptunian objects 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.