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Angular momenta of collided rarefied preplanetesimals

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Abstract

The angular momenta of rarefied preplanetesimals needed for formation of discovered trans-Neptunian binaries from contracting preplanetesimals can be obtained at collisions of preplanetesimals.

1. Introduction

In recent years, new arguments in favor of the formation of rarefied preplanetesimals - clumps have been found. Ipatov [1] and Nesvorny et al. [2] supposed that trans-Neptunian binaries were formed from rarefied preplanetesimals (RPPs). Nesvorny et al. [2] calculated contraction of RPPs and formation of binaries and supposed that RPPs got their angular momenta when they formed from the protoplanet cloud. In my opinion, a considerable fraction of discovered trans-Neptunian binaries could acquire most of their angular momenta at collisions of RPPs. Ipatov [1] obtained that the angular momenta acquired at collisions of RPPs moving in circular heliocentric orbits could have the same values as the angular momenta of discovered trans-Neptunian and asteroid binaries. Below I show that the angular momenta used by Nesvorny et al. [2] as initial data could be obtained at collisions of two RPPs moving in circular heliocentric orbits. The frequency of collisions of RPPs and the formation of trans-Neptunian binaries are also discussed.

2. Angular momentum of two colliding preplanetesimals

Ipatov [1] obtained that the angular momentum of two colliding RPPs (with radii r_1 and r_2 and masses m_1 and m_2) moved before the collision in circular heliocentric orbits equals $K_s=k_\Theta\cdot(G\cdot M_S)^{1/2}\cdot(r_1+r_2)^2\cdot m_1\cdot m_2\cdot(m_1+m_2)^{-1}\cdot a^{-3/2}$, where G is the gravitational constant, M_S is the mass of the Sun, and the difference in semimajor axes a of RPPs equals $\Theta\cdot(r_1+r_2)$. 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 0.6. The values of K_s are positive at $0<\Theta<0.8165$ and are negative at $0.8165<\Theta<1$. In the case of uniform distribution of Θ, the probability to get a reverse rotation at a single collision is ≈0.2. The angular velocity ω of the RPP of radius $r=(r_1^3+r_2^3)^{1/3}$ and mass $m=m_1+m_2$ formed as a result of the collision equals K_s/J_s, where $J_s=0.4\cdot\chi\cdot m\cdot r^2$ is the moment of inertia of the RPP, $\chi=1$ is for a uniform sphere considered by Nesvorny et al. [2]. I obtained that $\omega=2.5\cdot k_\Theta\cdot\chi^{-1}\cdot(r_1+r_2)^2\cdot r^{-2}\cdot m_1\cdot m_2\cdot(m_1+m_2)^{-2}\Omega$, where $\Omega=(G\cdot M_S)^{1/2}a^{-3/2}$ is the angular velocity of the motion of the RPP around the Sun. Computer simulations of the contraction of preplanetesimals in the trans-Neptunian region were made by Nesvorny et al. [2] for initial angular velocities of preplanetesimals equal to $\omega_o=k_\omega\Omega_o$, where $\Omega_o=(G\cdot m)^{1/2}r^{-3/2}$. The values of k_ω were considered to be equal to 0.5, 0.75, 1, and 1.25. In most of their runs, $r=0.6r_H$, where r_H is the Hill radius of a RPP of mass m. Note that $\Omega_o/\Omega=3^{1/2}(r_H/r)^{3/2}$, e.g., $\Omega_o\approx1.73\Omega$ at $r=r_H$.

Below I consider $r_1=r_2$, $r^3=2r_1^3$, $m_1=m_2=m/2$, and $\chi=1$. In this case, the angular velocity is $\omega\approx1.575k_\Theta\cdot\Omega$, e.g., $\omega\approx0.945\Omega$ at $k_\Theta=0.6$. Considering $\omega=\omega_o$, in the case of a collision of Hill spheres, we have $k_\omega\approx0.909k_\Theta\cdot\chi^{-1}$. As k_Θ can be up to 1, then this relationship shows that it is possible to obtain the values of $\omega=\omega_o$ corresponding to k_ω up to 0.909 at collisions of homogenious ($\chi=1$) RPPs. In the case of a collision of Hill spheres and the subsequent contraction of the formed RPP to radius r_c, the obtained angular velocity is $\omega_{rc}=\omega_H(r_H/r_c)^2$, where $\omega_H\approx1.575k_\Theta\Omega$. For the contracted RPP with $r=r_c$, we have $\omega_o=k_\omega(r_H/r_c)^{3/2}\Omega_{oH}$ (where Ω_{oH} is the value of Ω_o for the Hill radius), and therefore ω_{rc}/ω_o is proportional to $(r_H/r_c)^{1/2}$. If we consider the collision of RPPs with Hill radii, then the angular velocity of the contracted RPP with radius $r_c=0.6r_H$ corresponds to k_ω up to 1.17. In their calculations, Nesvorny et al.

[2] obtained binaries or triples only at k_ω equal to 0.5 or 0.75. Therefore, one can coclude that the initial angular velocities of RPPs at which binaries could form at calculations made by Nesvorny et al. [2] could be obtained at collisions of RPPs.

Below I consider the planar disk consisted of N identical RPPs with radii equal to their Hill radii $r_{\rm Ho}$ and masses $m_{\rm o}$=6·10^{17} kg. It is supposed that the ratio of the distances from the Sun to the edges of the disk equals $a_{\rm rat}$=1.67 (e.g., for a disk from 30 to 50 AU), N=10^7, and $M_\Sigma=m_{\rm o}N=M_E$, where M_E is the mass of the Earth. Heliocentric orbits of RPPs are considered to be circular. The mean number $N_{\rm c}$ of collisions of the RPPs in the disk during $n_{\rm r}$ revolutions around the Sun was estimated as $N_{\rm c}\approx 0.2n_{\rm r}$. At compression time of a RPP equaled to 0.6 of the orbital period at a=30 AU obtained by Nesvorny et al. [2], the fraction of collided RPPs for our above model is about 0.3, which is in accordance with the fraction of classical trans-Neptunian objects (TNOs) with satellites among discovered classical TNOs. Some collisions were tangent and did not result in a merger. RPPs contracted with time. Therefore, the real number of mergers can be smaller than that for the above estimates.

Given a primary of mass $m_{\rm p}$ and a much smaller secondary, both in circular heliocentric orbits, one can obtain that the ratio of tangential velocity of an encounter up to the Hill sphere to the escape velocity on the edge of the sphere is proportional to $m_{\rm p}^{-1/3}\cdot a^{-1}$. Therefore, RPPs are more likely to merge when the primary is more massive and located farther from the Sun. The period T_{sp} of rotation of the planetesimal of density ρ formed from the RPP that got its angular momentum at a collision of two RPPs is proportional to $a^{-1/2}\cdot\rho^{-2/3}$. Therefore, for a greater a, the fraction of material of a contracting rotating RPP that could get into a cloud surrounding the dense primary was greater (or there were more chances that there were two centers of contraction). In the case of the collision of RPPs – Hill spheres with masses m_1 and m_2 (at $m_1>m_2$) resulted in the formation of a new RPP, the period of axial rotation of the object formed after contraction of the new RPP to the fixed radius $r_{\rm c}$ is proportional to $(m_1/m_2)\cdot a^{-1/2}$. So, at a greater a for the same $r_{\rm c}$, the critical value of the period of axial rotation of a contracting object (when the velocity of a particle on the edge of the contracting object is greater than the escape velocity) can be reached at a greater mass ratio m_1/m_2 of collided RPPs. Therefore, in a disk of RPPs of different masses, more collisions could result in formation of binaries at a greater a. The above factors could explain why a larger fraction of binaries originated at greater distances from the Sun. The binary fraction in the minor planet population is estimated to be about 0.3 for cold classical TNOs and is 0.1 for all other TNOs. Note that TNOs moving in eccentric orbits (mentioned above as “other TNOs”) are thought to have been formed near the giant planets, closer to the Sun than classical TNOs. Most of rarefied preasteroids could turn into solid asteroids before they collided with other preasteroids. Some present asteroids can be debris of larger solid bodies, and the formation of many binaries with primaries with diameter d<100 km can be explained by other models (not by contraction of RPPs).

Nesvorny et al. [2] supposed that the angular velocities they used were produced during the formation of RPPs without collisions. They noted that simulations by Johansen et al. seem to generally indicated prograde rotation. Angular momenta of some observed trans-Neptunian binaries are negative. The model of collisions of RPPs explains negative angular momenta of some observed binaries, as about 20% of collisions of RPPs moving in almost circular heliocentric orbits lead to retrograde rotation. Note that if all RPPs got their angular momenta at their formation without mutual collisions, then the angular momenta of minor bodies without satellites and those with satellites could be similar (but actually they differ considerably). In my opinion, those RPPs that formed TNOs with satellites acquired most of their angular momenta at collisions.

3. Conclusions

The angular momenta of rarefied preplanetesimals needed for formation of trans-Neptunian binaries can be obtained at collisions of preplanetesimals. The fraction of preplanetesimals collided with other preplanetesimals during their contraction can be about the fraction of small bodies of diameter d>100 km with satellites (among all such small bodies), i.e., it can be about 0.3 in the trans-Neptunian belt.

References

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