EPSC Abstracts
Vol. 13, EPSC-DPS2019-2034, 2019
EPSC-DPS Joint Meeting 2019

EPSC
EPSC-DPS Joint Meeting 2019
15–20 September 2019 | Geneva, Switzerland

Angular momenta of colliding rarefied condensations

Sergei I. Ipatov
Vernadsky Institute of Geochemistry and Analytical Chemistry of Russian Academy of Sciences, Moscow, Russia
(siipatov@hotmail.com)

Abstract

The angular momenta of collided rarefied condensations that are needed for formation of satellite systems as a result of contraction of the condensations could be acquired at collisions of condensations. The angular momentum could be greater for eccentric than for circular heliocentric orbits of condensations. The time between formation of two colliding condensations and their collision that produce the condensation which was parental for the embryos of the Earth-Moon system could be of the order of 100 years.

1. Introduction

Ipatov studied formation of trans-Neptunian satellite systems [1-3] and embryos of the Earth-Moon system [4] at the stage of rarefied condensations. It was considered that the angular momenta of condensations needed for formation of such satellite systems were acquired at collisions of condensations (initial angular momenta were not enough for such formation). Those studies were based on the model of collisions of condensations moved in circular heliocentric orbits. Below I consider eccentric orbits of collided condensations and discuss the times elapsed before collisions of condensations.

2. Angular momentum acquired at a collision of two condensations

In [1-2] I considered the angular momentum at the collision of two condensations moved in circular heliocentric orbits at the moment of the collision. For such orbits let us consider a collision of two condensations with masses $k_m \cdot m$ and $(1-k_m) \cdot m$ (where $0<k_m<1$), with initial angular velocity equal to 0.2Ω [5], and with the same χ and initial density ρ. $\Omega=(G \cdot M_S)^{1/2}a^{-3/2}$ is the angular velocity of the motion of the condensation around the Sun in an orbit with a semi-major axis equal to a, G is the gravitational constant, M_S is the mass of the Sun. $J_s=0.4 \cdot \chi \cdot m \cdot r^2$ is the momentum of inertia of the condensation. In this case, the component of the angular momentum K_s of the formed condensation caused by initial rotation equals to $K_{si}=0.2\Omega(0.4\chi \cdot m \cdot r_{in}^2)[(1-k_m)^{5/3}+k_m^{5/3}]$, where r_{in} is the radius of a condensation of mass m and initial density ρ. The component of K_s of the formed planetesimal with a radius r_{col} which is caused by the collision equals $K_{sc}=k_\Theta \cdot \Omega \cdot m \cdot r_{col}^2 \cdot k_m(1-k_m) \cdot [(1-k_m)^{1/3}+k_m^{1/3}]^2$, where $k_\Theta \approx (1-1.5 \cdot \Theta^2)$ at $r_a=(r_1+r_2)/a<<\Theta$ and $r_a<<1$, with the difference in semi-major axes a of condensations equaled to $\Theta \cdot (r_1+r_2)$ [1]. If condensations compressed before the collision, then $r_{col}<r_{in}$. $K_{si}>K_{sc}$ at $r_{in}/r_{col}>2.7$, $\chi=1$ and $k_\Theta=0.6$. This suggests that collisions produced the dominant contribution to angular momentum only when the sizes of homogeneous preplanetesimals did not differ significantly (by not more than a factor of 3) from the initial sizes.

Actually even for initially circular heliocentric orbits, eccentricities could be not zero at the moment of collision of two condensations. If an aphelion distance of an orbit of a "first" condensation is $a+a \cdot k_a=a+r_H \cdot k_{Ha}$ and this condensation collides with a "second" condensation, which has a semi-major axis a and circular velocity v_c, then its eccentricity e can be about $k_a=k_{Ha} \cdot (r_H/a)$. At a collision of the condensations, the tangential component v_{te} of the collision velocity can be about $e \cdot v_c$, e.g. about $k_{Ha} \cdot v_c \cdot r_H/a$. Note that, at a collision of two condensations that moved before the collision in circular heliocentric orbits, the tangential velocity of the collision equals to $v_{tc}=k_\Theta \cdot v_c \cdot (r_1+r_2)/a$. At $k_\Theta=0.6$ and $r_1=r_2$, we have $v_{tc}=1.2 \cdot v_c \cdot r_H/a$. At $k_{Ha}=2.4$ [6] the above value of $v_{te}=k_{Ha} \cdot v_c \cdot r_H/a$ is greater by a factor 2 than the above value of v_{tc}. So the angular momentum of such collided condensations could be greater by a factor of 2 than that for circular orbits. Due to gravitational influence of other objects in the forming Solar System, the eccentricities of condensations could be greater than those for the model considered above. The angular momentum at the collision is proportional to the tangential velocity of the collision. For a greater tangential velocity, the formation of a satellite system can take place at a greater difference in masses of collided condensations and/or at smaller sizes of condensations. However, the greater is the velocity of a collision of condensations, the less material can be left in the condensation formed as a result of collision, and more material can left the forming condensation.

3. Times elapsed before collisions of condensations

In [4] the masses of condensations that produced the embryos of the Earth and the Moon could be about or greater than $0.01m_E$ (where m_E is the mass of the Earth). Let us consider two identical condensations with masses equaled to $0.01m_E$. At a=1 AU the Hill radius r_H of such condensation is about 0.002 AU. Below I suppose that a condensation moved under the gravitational influence of the Sun and another condensation. For initially circular heliocentric orbits of condensations and not large time elapsed before the collision, two condensations with radii r_H of Hill spheres could collide if the difference $d_a=a\cdot k_a$ between initial values of semi-major axes a of their orbits is less than about $3.5r_H$ [6]. If the initial angle with a vertex in the Sun between directions to two condensations is greater than 60^o, then condensations with $d_a<r_H$ will not collide. If there were two condensations with masses of $0.01m_E$ which could collide, then the mean initial angular distance φ between two condensations is about π rad. As the period of a revolution around the Sun is proportional to $a^{3/2}$, then during one revolution around the Sun, the angle φ decreases by about $2\pi(3k_a/2)=3\pi k_a$. So about $\pi/(3\pi k_a)=(3k_a)^{-1}$ revolutions are needed for the condensations to meet each other and reach φ=0. At $a\cdot k_a=2r_H$ and $r_H=0.002a$, we have $k_a=0.004$ and the condensations could collide after about 100 revolutions. As discussed above, the diameters of the condensations that produce the parental condensation must not change considerably during this time.

Note that in a disk of condensations in initially circular orbits only a few other condensations could collide with the considered condensation. As one of the model implementations, a disk with a width of 0.4 AU was considered, consisting of 100 condensations with masses equaled to $0.01m_E$. For such a model, if the difference in semi-major axes $a\approx1$ AU of close orbits is about $0.004a$, then each condensation has about $5\times0.002/0.004\approx2$ candidates for collisions (with greater and smaller a). So such estimate of the time elapsed before a collision would be similar to that for consideration of only two condensations. Actually all condensations did not form at the same time and could be smaller than r_H.

Conclusions

The angular momentum K_s of collided rarefied condensations could be greater for eccentric than for circular heliocentric orbits of condensations. At a greater K_s, collided condensations, that produce the condensation parental for a satellite system, could be smaller in sizes and differ more in masses. A time between formation of two condensations and their collision that produce the condensation which was parental for the embryos of the Earth-Moon system could be of the order of 100 years.

Acknowledgements

The work was supported in part by the grant of Russian Foundation for Basic Research № 17-02-00507 A.

References

[1] Ipatov, S.I.: The angular momentum of two collided rarefied preplanetesimals and the formation of binaries, Mon. Not. R. Astron. Soc., Vol. 403, pp. 405-414, 2010, http://arxiv.org/abs/0904.3529.

[2] Ipatov, S.I.: Formation of trans-Neptunian satellite systems at the stage of condensations, Solar System Research, Vol. 51, pp. 294-314, 2017, https://arxiv.org/abs/1801.05217 .

[3] Ipatov, S.I.: Origin of orbits of secondaries in the discovered trans-Neptunian binaries, Solar System Research, Vol. 51, pp. 409-416, 2017, https://arxiv.org/abs/1801.05254 .

[4] Ipatov, S.I.: Formation of embryos of the Earth and the Moon from the common rarefied condensation and their subsequent growth, Solar System Research, Vol. 52, pp. 401-416, 2018.

[5] Safronov, V.S.: Evolution of the protoplanetary cloud and formation of the Earth and the planets. NASA TTF-677. 1972. 212 p.

[6] Ipatov, S.I.: Gravitational interaction of two planetesimals moving in close orbits, Solar System Research, Vol. 28, N 6, pp. 494-512, 1994.