EPSC Abstracts
Vol. 11, EPSC2017-225, 2017
European Planetary Science Congress 2017

Formation of trans-Neptunian satellite systems at the stage of rarefied condensations

S. I. Ipatov (1,2)
(1) Vernadsky Institute of Geochemistry and Analytical Chemistry of Russian Academy of Sciences, Moscow, Russia (siipatov@hotmail.com, http://siipatov.webnode.ru/); (2) Space Research Institute of Russian Academy of Sciences, Moscow, Russia

Abstract

Formation of satellite systems of trans-Neptunian objects at the stage of rarefied condensations (consisted of dust and objects with diameter less than 1 m) is studied. It is considered that the main fraction of the angular momentum of a parental condensation needed for such formation was acquired at a collision of two condensations. Orbits of secondaries around primaries in discovered trans-Neptunian binary objects can be explained with the use of the considered model of formation of satellite systems.

1. Introduction

It is considered by many scientists that solid planetesimals were formed by contraction of rarefied condensations, which consisted of dust and/or boulders with diameter up to 1 m [1]. Ipatov [2] and Nesvorny et al. [3] supposed that trans-Neptunian binaries have been formed as a result of contraction of some such rarefied condensations. The angular momenta acquired at collisions of condensations that were moving in circular heliocentric orbits could have the same values as the angular momenta of discovered trans-Neptunian and asteroid binaries with masses equal to the sum of masses of two collided condensations [2].

2. Angular momenta of condensations needed for formation of binaries

The angular momenta used by Nesvorny et al. [3] as initial data in their calculations of contraction of condensations leading to formation of binaries could be obtained at collisions of two condensations that were moving before collisions in circular heliocentric orbits [4-5]. Initial angular momenta of condensations [6] were not enough for formation of binaries [5]. The typical angular momentum obtained at a collision of two identical uniform condensations can be greater by an order of magnitude than the sum of initial angular momenta of the collided condensations. If radii of two uniform condensations decreased before their collision from their initial radii by a factor of more than 3, then the angular momentum due to a typical collision is smaller than that due to initial rotation of condensations. For condensations more dense to their centers this factor is greater. At the ratio of radii of collided uniform condensations of different masses greater than 3, the role of initial rotation in the angular momentum of the formed condensation is greater than that of the collision. For the considered model at which the parental condensation that formed at a collision contracted to form a solid binary system, more chances to form a binary were for greater distances from the Sun.

The parental condensation with radius close to its Hill radius that grew by accumulation of small objects could get the angular momentum at which a satellite system of a trans-Neptunian object could form. However, in this case the angular momentum of all satellite systems (e.g., binaries) would be positive. Actually about 40% of observed trans-Neptunian binaries have negative angular momentum. Depending on heliocentric orbits of two colliding condensations, the angular momentum at their collision can be positive or negative. Therefore in most cases the greater fraction of the angular momentum of a parental condensation that contracted to form a trans-Neptunian binary was acquired at a collision of condensations, but not by accumulation of small objects. However, some fraction of the angular momentum of parental condensations could be delivered by small objects. I suppose that the fraction of condensations collided with other condensations during their contraction can be about the initial fraction of small bodies of diameter d>100 km with satellites (among all such small bodies), i.e., it can be about 0.45 in the trans-Neptunian belt. The results presented in this section are discussed in details in [5].

3. Origin of orbits of secondaries in discovered trans-Neptunian binaries

Based on the data presented in http://www.johnstonsarchive.net/astro/astmoons/, I studied [7-8] prograde and retrograde rotation of discovered trans-Neptunian binaries, the inclinations of orbits of secondaries at different ratios of diameters of the secondary to the primary, the inclinations of orbits of secondaries at different orbital elements of heliocentric orbits of binaries, the separation distances at different heliocentric orbits, the orbits of binaries at different separation distances. It was shown that all these dependences can be explained for our model of formation of binaries at the stage of rarefied condensations. A few of such dependencies are discussed below.

The fraction of trans-Neptunian objects with inclinations i_s of orbits of secondaries (or of orbits of the largest satellites) greater than 90^o is about 0.4. For all four satellite systems with eccentricity of the heliocentric orbit $e>0.3$, $i_s<90^o$. The values of i_s are in a wide range, almost from 0 to 180^o. The absence of binaries with $i_s>130^o$ at the ratio of diameters of the secondary to the primary $d_s/d_p<0.7$ may be caused by that the contribution of initial positive angular momentum of the collided condensations to the final angular momentum of the parental condensation was greater at $d_s/d_p<0.7$ than at $d_s/d_p>0.7$. It could be caused by that masses of collided condensations differed more at smaller d_s/d_p.

For $e>0.3$ the ratio a_s/r_H of the separation a_s between the primary and the secondary to the Hill radius r_H of the binary was smaller than 0.024, while a_s/r_H can exceed 0.225 at $e<0.3$. Note that the trans-Neptunian objects with $e>0.3$ could form in the feeding zone of the giant planets (see, e.g., [9]), i.e., closer to the Sun than the objects with $e<0.3$. Maximum values of a_s/r_H (and also of a_s) are greater for greater semi-major axis a of a heliocentric orbit of an object at $38<a<46$ AU. In our opinion, for smaller distances a from the Sun, the mean sizes of collided condensations could be smaller, and so the mean values of a_s for the formed binaries could be smaller. The smaller sizes of the collided condensations at smaller distances from the Sun could be due to their smaller Hill radii (which are proportional to a) at the collisions and, may be, also due to faster contraction of condensations.

For $a_s/r_H<0.008$, except one object, the values of i_s are between 60^o and 105^o, i.e., are in some vicinity of 90^o. Probably, the origin of such i_s was caused by that for smaller sizes of collided condensations (that produce binaries with smaller a_s/r_H), the ratio of their sizes to the height of the disk where condensations moved was smaller, and collided condensations often moved one above another, but not in almost the same plane as in the case when the sizes of condensations were about the height.

Acknowledgements

The work was supported in part by the grant of Russian Foundation for Basic Research № 17-02-00507 A and by the Program of the Fundamental Studies of the Presidium of the Russian Academy of Sciences N 9.

References

[1] Johansen, A., Mac Low, M.-M., Lacerda, P., Bizzarro M.: Science Advances, Vol. 1, N 3, id. 1500109, 2015 (http://arxiv.org/abs/1503.07347).

[2] Ipatov, S.I.: Mon. Not. R. Astron. Soc., Vol. 403, pp. 405-414, 2010.

[3] Nesvorny, D., Youdin, A.N., Richardson, D.C.: Astron. J., Vol. 140, pp. 785-793, 2010.

[4] Ipatov, S.I.: Proc. IAU Symp. No. 293 "Formation, detection, and characterization of extrasolar habitable planets", pp. 285-288, 2014 (http://arxiv.org/abs/1412.8445).

[5] Ipatov, S.I.: Solar System Research, Vol. 51, N 4, in press, 2017.

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

[7] Ipatov, S.I. Abstracts of 46th LPSC, #1512, 2015.

[8] Ipatov, S.I.: Solar System Research, Vol. 51, N 5, in press, 2017.

[9] Ipatov, S.I.: Earth, Moon, & Planets, Vol. 39, pp. 101-128, 1987.