MIXING OF PLANETESIMALS IN THE TRAPPIST-1 EXOPLANETARY SYSTEM

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The model and initial data: Mixing of planetesimals in the TRAPPIST-1 exoplanetary system is studied at the late gas-free stage of formation of almost formed planets. The previous formation of embryos of planets could include their migration from greater distances and pebble accretion when gas presented in the protoplanetary disk. The TRAPPIST-1 system consists of a star with a mass equal to 0.0898 of the mass of the Sun and 7 planets. The motion of planetesimals under the gravitational influence of the star and seven planets (from *b* to *h*) was calculated with the use of the symplectic code from [1]. In different variants, the step t_s of integration equaled to 0.1 day or 0.01 day. Planetesimals that collided with planets or the star or reached 50 AU from the star were excluded from integration. In each variant of the calculations, a disk of planetesimals was located near the orbit of one of the planets and is marked by the same letter as the planet. The initial values of semi-major axes of orbits of 250 planetesimals varied from a_{min} to a_{max}, their initial eccentricities were equal to e_o=0.02 or e_o=0.15, and the initial inclinations equaled to e_o/2 rad. The orbital elements and masses of the planets and the values of a_{min} and a_{max} are presented in Table 1.

Table 1. Semi-major axes *a* (in AU), eccentricities *e*, and masses *m* (in Earth masses m_E) of exoplanets in the TRAPPIST-1 system, and the values of a_{min} and a_{max} for the considered disks near orbits of planets *b*, *c*, *d*, *e*, *f*, *g*, *h*. $T_{0.02}$ and $T_{0.15}$ are the times of evolution of disks at e_o equaled to 0.02 or 0.15, respectively. $f_{0.02}$ and $f_{0.15}$ are the fractions of planetesimals collided with the 'host' planet during evolution at e_o=0.02 and e_o=0.15, respectively. The left and right values in the colums are for integrations with the step t_s of integration equaled to 0.1 day or 0.01 day, respectively.

	m/m_E	*a*, AU	*e*	a_{min}, AU	a_{max}, AU	$T_{0.02}$, Kyr	$T_{0.15}$, Kyr	$f_{0.02}$	$f_{0.15}$
b	1.37	0.0115	0.0062	0.0094	0.0137	1504, >4000	20, 41	0.80, 0.74	0.75, 0.72
c	1.31	0.0158	0.0065	0.0137	0.0190	12, 52	25, 14	0.61, 0.59	0.56, 0.56
d	0.39	0.0223	0.0084	0.0190	0.0258	32, 11	355, 282	0.48, 0.51	0.27, 0.24
e	0.69	0.0292	0.0051	0.0258	0.0339	6446, 368	437, 394	0.44, 0.42	0.28, 0.29
f	1.04	0.0385	0.0101	0.0339	0.0427	6282, 1816	128, 230	0.39, 0.43	0.24, 0.23
g	1.32	0.0468	0.0021	0.0427	0.0544	212, 1106	119, 468	0.44, 0.46	0.38, 0.38
h	0.33	0.0619	0.0057	0.0544	0.0694	>61000, 1133	3391, 933	0.36, 0.42	0.26, 0.22

Results of calculations: The results of calculations showed that several planets in the TRAPPIST-1 system accumulated planetesimals initially located at the same distance. The below conclusions are the same for calculations with the step t_s of integration equaled to 0.1 day and 0.01 day. There were no collisions of planetesimals with the host star. Not more than 3.2% of planetesimals were ejected into hyperbolic orbits. Often there was no ejection for disks *b* - *d*. More than a half of planetesimals from disks *b* - *g* collided with planets in less than 1000 yr, and for disks *b* - *d* even in 250 yr. Times of evolution of disks *b* - *h* varied from 12 Kyr to more than 60 Myr (see Table 1). In variants with large time of evolution of a disk, most of the time could be due to the last planetesimal, which often was ejected into a hyperbolic orbit. For disk *h* at e_o=0.02 and t_s=0.1^d, the last planetesimal moved for tens of millions of years at a distance R≈0.09 AU from the star (at the resonance 4/7 with planet *h*). The fraction of planetesimals collided with the 'host' planet was 0.36-0.8 at e_o=0.02 and 0.22-0.75 at e_o=0.15 (see Table 1). The fraction of collisions of planetesimals with the 'host' planet was usually smaller for disks located farther from the star. In each calculation variant, there was at least one planet for which the number of collided planetesimals was greater than 25% of the number of collisions of planetesimals with the 'host' planet. For planetesimals initially located at R>0.7 AU for e_o=0.15, the ratio of planetesimals collided with planets *h* and *g* equaled to 1.7. For disk *h*, this ratio was 0.6-0.8 at e_o=0.15 and 1.1-1.5 at e_o=0.02. Planetesimals could collide with all planets for disks *d* - *h* and at least with planets *b* - *e* for disks *b* - *c*. Therefore, outer layers of neighbouring planets in the TRAPPIST-1 system can include similar material, if there was a lot of planetesimals near their orbits at the late stages of the accumulation of the planets. For comparison, it was concluded in [2-3] that each terrestrial planet incorporated planetesimals from the feeding zone of all terrestrial planets. The amounts of material from different parts of the zone from 0.7 to 1.5 AU from the Sun, which entered into almost formed the Earth and Venus, differed, probably, by no more than 2 or 3 times [3].

Acknowledgements: The studies of fractions of planetesimals collided with TRAPPIST-1 planets were supported by the Ministry of Science and Higher Education of the Russian Federation under the grant 075-15-2020-780. Computer simulations of formation of the TRAPPIST-1 system were partly supported by the Vernadsky Institute.

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