

MOTION OF PLANETESIMALS IN THE PROXIMA CENTAURI, TRAPPIST-1 AND GLIESE 581 PLANETARY SYSTEMS. S. I. Ipatov, Vernadsky Institute of Geochemistry and Analytical Chemistry of RAS, Moscow, Russia (siipatov@hotmail.com, <https://siipatov.webnode.ru/>)

Introduction: I studied the motion of planetesimals in the Proxima Centauri [1-3], TRAPPIST-1 [4] and Gliese 581 [5] planetary systems. Such studies were compared in [6] with the studies with the motion of bodies in our Solar System. Migration of dust from the orbit of planet Proxima Centauri *c* was studied in [7]. The late gas-less stage of formation of planets with present masses of the planets was considered. Initial eccentricities e_0 of orbits of planetesimals equaled to 0.02 or 0.15. Initial inclinations of orbits of the planetesimals were equal to $e_0/2$ rad. The gravitational influence of the star and planets was taken into account. The planetesimals or particles were excluded from integration when they collided with the star or the planets or reached some distance from the star (1200 AU for Proxima Centauri).

Motion of planetesimals in the Proxima Centauri planetary system: In the calculations of the motion of planetesimals in the Proxima Centauri planetary system, the gravitational influence of the star (with a mass equal to 0.122 of the solar mass) and two planets: *b* ($a_b=0.04857$ AU, $e_b=0.11$, $m_b=1.17m_E$, m_E is the mass of the Earth) and *c* ($a_c=1.489$ AU, $e_c=0.04$, $m_c=7m_E$) was taken into account. The considered time interval was between 100 Myr and 1000 Myr. Migration of planetesimals from the feeding zone of planet *c* was calculated. The size of the feeding zone of Proxima Centauri *c* is discussed in [2]. After hundreds of millions of years (after accumulation of planet *c*), some planetesimals could still move in elliptical resonant orbits (e.g. at the resonances 1:1, 5:4, and 3:4) inside the feeding zone of planet *c* that had been mainly cleared from planetesimals. The number of such left planetesimals was greater at small eccentricities.

The total mass of planetesimals ejected into hyperbolic orbits was estimated to be about $(3.5-7)m_E$ [1]. The total mass of planetesimals in the feeding zone of planet *c* could exceed $10m_E$ and $15m_E$ at $e_0=0.2$ and $e_0=0.15$, respectively. Based on the amount of planetesimals ejected into hyperbolic orbits, it was concluded [1] that the semi-major axis of the orbit of planet *c* could decrease by a factor not less than 1.5 during accumulation of this planet. Planet *d* was not included in integrations, but the probability of collisions of planetesimals with planet *d* was calculated based on the arrays of orbital elements of migrated planetesimals. The probability of a collision of a planetesimal initially located in the feeding zone of planet *c* with planet *b* was about $2 \cdot 10^{-4}$ and 10^{-3} at e_0 equal to 0.02 or 0.15,

respectively. The above values of the probabilities were greater than the probability of a collision with the Earth of a planetesimal migrated from the zone of the giant planets in the Solar System. The latter probability (per one planetesimal) was typically less than 10^{-5} [6]. A lot of icy material and volatiles could be delivered to planets *b* and *d*. The amount of material delivered from the feeding zone of planet *c* to planet *d* could be about twice less than that delivered to planet *b*.

About 90% of the planetesimals that first reached 500 AU from the star, for the first time reached 1200 AU from the star in less than 1 Myr [3]. The inclinations of orbits of 80% of the planetesimals that moved between 500 or 1200 AU from the star did not exceed 10° . The strongly inclined orbits of bodies in the outer part of the Hill's sphere of the star Proxima Centauri can only be mainly due to the bodies that came into the Hill's sphere from outside. The radius of the Hill's sphere of the star Proxima Centauri is by an order of magnitude smaller than the radius of the outer boundary of the Hills cloud in the Solar System and is two orders of magnitude smaller than the Hill radius of the Sun. Therefore, it is difficult to expect the existence of such a massive analogue of the Oort cloud near this star as near the Sun.

Motion of planetesimals in the TRAPPIST-1 planetary system: The TRAPPIST-1 system consists of a star with a mass equal to 0.0898 of the mass of the Sun and 7 planets *b - h*. Mixing of planetesimals in the TRAPPIST-1 exoplanetary system is studied. The results of calculations showed that several planets in the TRAPPIST-1 system accumulated planetesimals initially located at the same distance. 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. 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 $e_0=0.02$, the last planetesimal moved for tens of millions of years at a distance $R \approx 0.09$ 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 $e_0=0.02$ and 0.22-0.75 at $e_0=0.15$. 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 $e_0 = 0.15$, 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 $e_0 = 0.15$ and 1.1-1.5 at $e_0 = 0.02$. 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

Motion of planetesimals in the Gliese 581 planetary system: Earlier it was considered that the extrasolar system Gliese 581 contains the star with a mass equal to 0.307 of the solar mass and five planets (b , c , d , e , and g). Now only planets b , c , and e are considered. In my calculations with 5 planets, eccentricities and inclinations of orbits of planets were considered to be equal to 0. The semi-major axes of initial orbits of planetesimals were near the semi-major axis of one of the planets. It was obtained [5] that at the late stages of accumulation of planets in the Gliese 581 system, planetesimals from the feeding zone of each planet could fall onto other planets. The fraction of planetesimals ejected into hyperbolic orbits did not exceed 0.05 and 0.15 at initial eccentricities of planetesimals equal to 0.02 and 0.15, respectively. For planetesimals from the feeding zones of planets located close to the star most of collisions of planetesimals with planets were during the first 1 Kyr.

Motion of dust in the Proxima Centauri planetary system: I calculated the migration of dust particles in the Proxima Centauri planetary system. The gravitational influence of the star (with a mass equal to 0.122 of the solar mass) and two planets: b ($a_b = 0.04857$ AU, $e_b = 0.11$, $m_b = 1.17m_E$) and c ($a_c = 1.489$ AU, $e_c = 0.04$, $m_c = 7m_E$) was taken into account. The Bulirsh-Stoer code was used for integrations. The relative error per integration step was taken to be less than 10^{-8} . The Poynting-Robertson drag, radiation pressure, and star wind drag were taken into account. The ratio of star wind drag to Poynting-Robertson drag was considered to be 0.35. The ratio β between the radiation pressure force and the gravitational force varied from 0.0002 to 1. For the silicate particles in the Solar System, such values of β correspond to particle diameters d between 2500 and 0.5 microns; d is proportional to $1/\beta$. Initial orbits of dust particles were located near the orbit of planet c .

It was obtained that the times T of evolution of disks, the number N_b of particles that collided with planet b ,

and the number N_c of particles that collided with planet c are mainly smaller for greater β . At $0.004 \leq \beta \leq 0.1$, more particles collided with inner planet b than with a greater planet c . At such values of β , dust particles are effective for delivery of matter to planet b . In the Solar System, silicate particles with $0.004 \leq \beta \leq 0.1$ correspond to diameters from 3 to 120 microns. At $\beta \geq 0.4$ the fraction of particles collided with planets was small or zero, and most of particles were ejected into hyperbolic orbits. At $0.004 \leq \beta \leq 0.1$, most of particles collided with the star, with maximum at $\beta = 0.04$.

During the first million years at $0.0002 \leq \beta \leq 0.002$, the fraction of ejected particles was less than 0.1, and the fraction of particles collided with planet c was less than 0.04. For $T = 1$ Myr, the fraction of particles collided with planet b was about 0.02 at $0.001 \leq \beta \leq 0.002$. It was zero in other variants of calculations at $0.0002 \leq \beta \leq 0.002$. At $T = 1$ Myr the fraction of ejected particles was about 0.03-0.05.

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