MOTION OF PLANETESIMALS FROM THE FEEDING ZONE OF PROXIMA CENTAURI C. S. I. Ipatov, V.I. Vernadsky Institute of Geochemistry and Analytical Chemistry of RAS, Moscow, Russia (siipatov@hotmail.com, https://siipatov.webnode.ru/)

Introduction: Proxima Centauri with a mass equal to 0.122 of the solar mass is located at 1.3 pc from the Sun. It has three planets: *b* (a_b=0.04857 AU, e_b=0.11, m_b=1.17m_E, m_E is the mass of the Earth), *c* (a_c=1.489 AU, e_c=0.04, m_c=7m_E), and *d* (a_d=0.02895 AU, m_d=0.29m_E, e_d=i_d=0). The motion of planetesimals initially located in the feeding zone of planet *c* was calculated under the gravitational influence of the star and planets *b* and *c* with the use of the symplectic code from [1]. In most calculations, the integration time step t_s equaled to 1 day. The integrations with t_s equaled to 0.5 day and 0.2 day have been also made. The obtained results were about the same for different considered t_s. The considered time interval usually exceeded 100 Myr, and sometimes reached 1000 Myr. However, most of planetesimals were ejected into hyperbolic orbits or collided with planets in less than 10 Myr. Planetesimals collided with planets or the star or ejected into hyperbolic orbits were excluded from integration. In [2] another series of calculations was made. In those calculations, planets and planetesimals were considered as material points, and probabilities of collisions of planetesimals with planets were calculated based on the arrays of orbital elements of planetesimals. For the model considered below, the probability of collisions of planetesimals with planet *b* was smaller by a factor two than that for the [2] model, but the probability of collisions with planet *c* was greater by a factor of two.

In each calculation variant, initial semi-major axes a_o of orbits of 250 planetesimals were in the range from a_{min} to a_{min}+0.1 AU. The number of planetesimals with a_o was proportional to $a_o^{1/2}$. In different variants, the values of a_{min} were in the range from 0.9 to 2.2 AU. Initial eccentricities e_o of orbits of planetesimals equaled to 0.02 or 0.15. Initial inclinations of the planetesimals were equal to e_o/2 rad. For the models [3-6] that considered the mutual gravitational influence of planetesimals, the mean eccentricity of planetesimals in the feeding zone of the terrestrial planets could exceed 0.2 during evolution and reach 0.4 at the late stages. Therefore, for the Proxima Centauri system calculations with e_o=0.15 were also made.

Estimates of the total initial mass of planetesimals in the feeding zone of Proxima Centauri *c*: Based on the results of calculations, it is possible to conclude that the ratio p_{cej}=p_c/p_{ej} of the probability of a collision of a planetesimal with planet *c* to the probability p_{ej} of its ejection into a hyperbolic orbit was about 0.8-1.3 and 0.4-0.6 at e_o=0.02 and e_o=0.15, respectively. Such ratio was about 1.3-1.5 and 0.5-0.6 at calculations with a mass of planet *c* equal to a half of its present mass. The mass planet *c* is 7m_E. Therefore, the total mass of planetesimals ejected into hyperbolic orbits could be about (3.5-7)m_E. The total mass m_{fzc} of planetesimals in the feeding zone of planet *c* could exceed 10m_E and 15m_E at e_o=0.2 and e_o=0.15, respectively. Based on the values of p_{ej} and on the integral of energy, it is possible to conclude 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.

Migration of planetesimals from the feeding zone of planet *c* to planets *b* and *d*: Planet *d* was not included in integrations. However, 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 $2\cdot10^{-4}$ and 10^{-3} at e_o equal to 0.02 or 0.15, respectively. Only one of several hundred planetesimals, which migrated from the feeding zone of Proxima Centauri *c*, reached the orbits of Proxima Centauri *b* and *d*, but its probability of collisions with these planets was high. The obtained probability of collisions of planetesimals from the feeding zone of planet *c* with planet Proxima Centauri *b* was 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} [7]. A lot of icy material and volatiles could be delivered to planets *b* and *d*. Using the estimates of the total mass of planetesimals in the feeding zone of planet *c*, it is possible to conclude that the total mass $m_{c\text{-}b}$ of material delivered from the feeding zone of planet *c* to planet *b* was in the range from $2\cdot10^{-3}m_E$ to $2\cdot10^{-2}m_E$, depending on initial eccentricities of planetesimals. The feeding zone of planet *c* was located farther from the star than the snow line. At fraction k_{ice} of ice in the planetesimals between 0.05 and 0.5, the values m_{ice}=$k_{ice}\cdot m_{c\text{-}b}$ of the amount of water delivered to Proxima Centauri *b* were between $10^{-4}m_E$ to $10^{-2}m_E$. Probably, these values exceeded the mass of water in Earth's oceans, which is $2\times10^{-4}m_E$. The amount of material delivered from the feeding zone of planet *c* to Proxima Centauri *d* could be about twice less than that delivered to planet *b*.

For the present mass of Proxima Centauri *c*, about 90% of ejected planetesimals moved from 500 to 1200

AU (the Hill radius of Proxima Centauri) in less than 1 Myr, and not more than 1% moved in such region for more than 10 Myr (but during less than a few tens of millions of years). The fraction of planetesimals moved from 500 to 1200 AU in less than 1 Myr was about 70-80% for the mass of the planet embryo equal to a half of the mass of planet *c*. Proxima Centauri is a member of a triple star system. However, the consideration of the gravitational influence of other two stars (Alpha Centauri AB) would not change the above conclusions, because the motion of planetesimals was considered inside (mainly deep inside) the Hill sphere of Proxima Centaury and ejected planetesimals have very small chances to return to the Hill sphere of Proxima Centauri.

The feeding zone of Proxima Centauri *c*: The size of the feeding zone of Proxima Centauri *c* was studied [8]. It was obtained that

a_c-a_{min002}=0.04a_c+0.02a_{min002}+2.54$a_c\cdot\mu^{1/3}$,
a_{max002}-a_c=0.04a_c+0.02a_{max002}+2.40$a_c\cdot\mu^{1/3}$,
a_c-a_{min015}=0.04a_c+0.15a_{min015}+2.23$a_c\cdot\mu^{1/3}$, and
a_{max015}-a_c=0.04a_c+0.15a_{max015}+4.3$a_c\cdot\mu^{1/3}$,

where a_c and e_c=0.04 are the semi-major axis and eccentricity of the orbit of planet *c*, μ is the ratio of the mass of planet *c* to the star mass, a_{min002}, a_{max002}, a_{min015}, and a_{max015} are the minimum and maximum initial values of semi-major axes of considered orbits of planetesimals for the feeding zone of planet *c* at initial eccentricities e_o of orbits of planetesimals equal to 0.02 and 0.15, respectively. The first two terms in the above formulas (e.g., $e_c\cdot a_c$ and $e_o\cdot a_{min002}$) are initial values of the product of two factors $a\cdot e$, which characterizes the variation of distances from the star for moving planet Proxima Centauri *c* and a planetesimal. Coefficients before $a_c\cdot\mu^{1/3}$ in the three above formulas are about 2.2–2.5, i.e. are close to the coefficients for initial circular orbits.

The results of calculations showed that after hundreds of millions of years (after accumulation of planet *c*), some planetesimals could still move in elliptical orbits inside the feeding zone of planet *c* that had been mainly cleared from planetesimals. Often such planetesimals could move in some resonances with the planet, e.g. in the resonances 1:1 (as Jupiter trojans), 5:4, and 3:4. The number of such left planetesimals was greater at small eccentricities. For some (typically resonant) subregions of a_o located outside the main feeding zone of planet *c*, planetesimals could be ejected into hyperbolic orbits or could collide with planets.

A few planetesimals that moved for a long time (1-2 Myr) in chaotic orbits then got into the resonances 5:2 and 3:10 with planet *c* and moved in them for at least tens of millions years.

There can be more analogues of the asteroid and trans-Neptunian belts in the planetary system near Proxima Centauri than in the Solar System. The smaller ratio of the mass of planet Proxima Centauri *c* to the mass of the star than that for Jupiter, the larger ratio of the semi-major axes of the orbits of the planets *c* and *b* than that for Jupiter and Mars, and only one large planet in the Proxima Centauri system can be the reasons for such possible differences in the belts and the possible existence of a planet(s) between the orbits of the planets Proxima Centauri *b* and *c*.

Conclusions: During the growth of the mass of planet *c*, the semi-major axis of its orbit could decrease by at least a factor of 1.5. The amount of water delivered to Proxima Centauri *b* probably exceeded the mass of water in Earth's oceans. After hundreds of millions of years, some planetesimals could still move in elliptical orbits inside the feeding zone of planet *c* that had been mainly cleared from planetesimals.

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