CAPTURE OF BODIES INTO THE CIRCUMPLANETARY DISKS OF YOUNG JUPITER AND SATURN. **V. A. Kronrod[1], A. B. Makalkin[2],** [1]Vernadsky Institute of Geochemistry and Analytical Chemistry, Russian Academy of Sciences (RAS), Kosygina St., 19, Moscow, 119991 Russia, va_kronrod@mail.ru; [2]Schmidt Institute of Physics of the Earth RAS, Bol'shaya Gruzinskaya ul. 10, Moscow, 123995 Russia, makalkin@ifz.ru

Introduction. According to the model of a low mass (gas-starved) circumplanetary accretion disk, dust particles and small bodies at any given time contain only ~10^{-3}–10^{-2} of the total mass of regular satellites [1-4]. Thus the formation of satellites in such a disk requires the continuous influx of solids into the disk, in particular through the capture of bodies by gas drag. There is a good reason to believe that the degree of differentiation of the icy moons depends on the specific features of their formation: the accretion rate and masses of bodies falling on the moons, the mass distribution and composition of the bodies. Here we discuss the capture of bodies into the gaseous disks around young Jupiter and Saturn due to gas drag in the disks. We consider the deceleration of bodies accompanied by their ablation and fragmentation, which greatly affect the capture. These processes were recently modeled numerically [5]. In the present research we use the approach adopted in the meteor physics [6-8].

The circumplanetary disk parameters. We consider disks of Jupiter and Saturn at a late stage of planet accretion. We use the model of low-mass gas-starved disk, which satisfies the cosmochemical and physical constraints [1-4]. We assume the isothermal vertical temperature distribution in the disk, which leads to the exponential vertical density distribution. The dependence of the disk surface density Σ_g on the radial coordinate r is determined on the basis of the models of accretion circumplanetary disks [4]. Based on numerical models [4] we have determined an approximate temperature dependence in the middle plane of disk as $T_m(r)= T_{m10}\, r^{-1}$. Taking into account the relations for Σ_g from [4] we adopted the approximate expression $\rho_g=\rho_{20}(r/(20R_p))^{-7/4}$ g/cm^3, where $\rho_{20} =6\times10^{-9}$ g/cm^3 and 2×10^{-9} g/cm^3 are the gas densities in the midplane of disks of Jupiter and Saturn at distance r=20R_p, where R_p is radius of Jupiter or Saturn.

Capture of bodies in the disks. The mean velocity of infall of the body onto the circumplanetary disk V_1 in planetocentric two-body problem (within the Hill sphere of the planet) is determined from the equation $V_1^2=V_e^2+V_m^2$, where V_e is the escape velocity from the Hill sphere of the planet at distance r from the center of the planet, V_m – the RMS velocity relative to the circular Keplerian velocity in the solar nebula in the zone of the selected planet, but outside the planet Hill sphere. Due to deceleration by gas drag the bodies leave the disk with velocity $V_2<V_1$; the body is captured if $V_2<V_E$.

The motion and loss of mass of the bodies in the disk. As the radius of Hill sphere for Jupiter and Saturn is much lower than the half-thickness of the circumsolar protoplanetary disk of planetesimals, the velocity distribution of bodies incoming to the planet's Hill sphere is nearly isotropic. In this case the body's velocity relative to the gas in the circumplanetary disk (V_{rel}) and the velocity of the body in the planetocentric inertial system (V) are related as $V_{rel}^2=KV^2$. Parameter K weakly depends on the radial coordinate r and is estimated to be about K = 1.45 in both Jovian and Saturn's disks at distances of major moons. When crossing the disk the body is exposed to the forces of gas drag and gravitation of the central planet. It is shown that the latter force may be neglected if the following condition is fulfilled: $R<<R_{lim}=(2\rho_g r/\rho_m)$, where R, r, ρ_g, ρ_m are the radius of the body, the distance from the centre of the planet, gas density, and body's mean density. For the bodies' density of 0.5 g cm^{-3} the limiting radius R_{lim} reaches the values 250 m and 160 m at the distances of Ganymede and Callisto in the Jovian disk and 60 m at the Titan distance in the disk of Saturn. Thus when considering the motion in the circumplanetary disks of bodies with $R<R_{lim}$ one may adapt the well developed models of meteor physics [6-8]. In these models the solution of the gas dynamics problem of the body's motion with very high speed is defined by two dimensionless parameters which characterize the deceleration and ablation of the body in the gas medium. A lot of experimental data accumulated in the meter physics allow to set these parameters as a function of the body's velocity, material, ablation coefficient and gas density.

Fragmentation of the bodies. We assume the start of mechanical fragmentation process at the moment when the magnitude of the dynamical pressure $\rho_g V^2$ becomes of the order of the body strength σ. The value of σ depends on body size, according to the statistical theory of strength [9, 10]: $\sigma=\sigma^*(m^*/M)^{\lambda}$, where σ^* и m* are the strength and mass of the tested specimen, σ is the effective strength of the body of the same material, but with mass M. We use the scale factor λ=0.2 adopted for material of the comet [11].

Results and discussion: We simulated passing bodies (small planetesimals) through the circumplanetary disks of Jupiter and Saturn and capture of their material into the disks with consideration of combined processes of aerodynamic braking, fragmentation, and ablation of the bodies in the disk's gas medium. Below are the results of simulation for the cometary material of the bodies. We estimated maximum body size (radius R_1) which the body should have at the entrance to the disk in order to stay in the disk after loosing mass and velocity due to gas drag and ablation. Ablation coefficient (σ_{abl} =10^{-13} c^2cm^{-2}) is taken from [12].

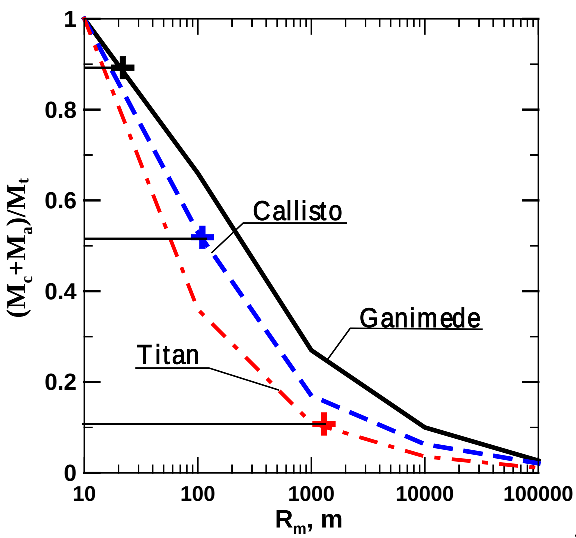

Fig.1. The ratio of the captured mass (consisting of the mass of small bodies captured in the disk (M_c) plus the mass of material lost through ablation (M_a) to the total mass of the infalling bodies (M_t) with radii $R<R_m$ at radial distances of Callisto, Ganymede and Titan as a function of maximum radius of planetesimal in the adopted distribution, R_m. Calculations are based on the fragmentation of the bodies in accretion disks. Crosses denote the minimum radii of a planetesimals, fragmented in the circumplanetary disk. In the disk of Jupiter at distances Ganymede ~90% of the mass of falling bodies in the adopted mass range are captured, at distances Callisto the number is ~50%. In the disk of Saturn at a distance of Titan only ~10% of the mass of planetesimals are captured.

We assume a power-law distribution of body masses with the exponent $q \approx 1.8$ [13]: $n(M)dM = cM^{-q}dM$, where $n(M)dM$ is the number of bodies (in the unit volume) with masses in the span (M, $M+dM$). We have identified the following values: M_c is the mass of solid small bodies captured by the disk, M_a is the mass of solid material, lost by the falling bodies through ablation and thus captured by the disk. M_f is the total mass of the falling bodies with radii in the range $R_m > R > R_1$, where R_m is the radius of the largest body in the adopted distribution (with mass M_M). M_t is the total mass of all infalling bodies (in unit volume) with $R_m > R > 0$.

The ratio $M^o_a = M_a/M_f$ is very small in disks of both Jupiter and Saturn (0.003-0.008) due to small mass loss by ablation M_a (at adopted value of ablation coefficient). At the same time, the parameter $M^o_{ca} = (M_c+M_a)/M_t$ for R_m=1000 m reaches the value 0.27 at the distances of Ganymede and 0.17 in the region of Callisto. For Titan the value of M^o_{ca} is about 0.11. Note that the presented calculations of values M^o_a and M^o_{ca} do not take into account the possible fragmentation of planetesimals. The inclusion of fragmentation would increase the captured masses. The Fig.1 shows the results of calculations with consideration of fragmentation of the bodies in circumplanetary disks.

Conclusion: Our research shows that a significant masses of protosatellite material falling on the circumplanetary disks of Jupiter and Saturn are captured in the disks. The masses captured in the formation region of different moons are very different. Our results also show that in the disk of Jupiter at distances Ganymede about 90% of the mass of falling bodies in the adopted mass range are captured, at distances Callisto the number is 50%, which could lead to greater differentiation of Callisto. In the disk of Saturn at a distance of Titan only 10% of the mass of planetesimals are captured. This could assist in significant elongation of accretion of Titan and formation of non-differentiated rock–ice mantle [14].

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