Vestnik Otdelenia nauk o Zemle RAN, VOL. 3, NZ6085, doi:10.2205/2011NZ000215, 2011

On the origin of the Saturn's belts matter

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Key words: ice rings of Saturn, the tidal disruption of the bodies.

Citation: Roussol A.V.[1], V. A. Dorofeeeva[1] , E. L. Ruskol (2011), On the origin of the Saturn's belts matter, *Vestn. Otd. nauk Zemle, 3*, NZ6085, doi:10.2205/2011NZ000215.

The gas-giant planet Saturn has the biggest ring system among the planets orbiting the Sun. The most massive are the A ring (mass 0.5–0.7×10^{22} g) and the B ring (the mass 4–7×10^{22} g) [*Robbins et al.,* 2010]. The data by space mission "Cassini" show that rings are composed from particles of almost pure (95-98%) crystal water ice with dimensions 10 cm–10 m [*Nicholson et al*., 2008]. The problem of the origin of rings' matter has been investigated since long time. In most cases the models have usedthe idea of the disruption of a body (a comet or a satellite) that approached to Saturn inside the Roche limit, and there was disintegrated by an impact or by tidal forces of the planet. So the models [*Pollack et al*., 1973; *Pollack,* 1975; *Harris,* 1984] are based on disruption of a satellite orbiting on Roche limit distance by an impact of a comet. In the models [*Dones*, 1991; *Dones et al.,* 2007] as the source of the rings matter a massive comet is considered which passed by Saturn on eccentric orbit and was disrupted by tidal forces. The recent model [*Canup,* 2010] suggested that a very massive Titan-like satellite was tidally disrupted. This body is supposed to be already differentiated. Its approach to Saturn is ascribed to the interaction with the spiral density waves in the gas-dust accretion disc of Saturn.

The analysis of all these models with the account of modern evidence shows that the hypothesis that comets may be main source of rings' material is very doubtful. First, cometary masses are too low for providing the mass of the Saturnian rings. Second, the comets' material is known as a fluffy (the dence 0.2–0.5 g/cm^3) mixture of the amorphous ice, the silicate dust and solid organic compounds. But the rings contain the almost pure crystal ice, and therefore, on our opinion, the more realistic would be the fragmentation of a differentiated rock-ice body in which the water ice was melted and crystallized. With the account of loss of the matter in the process of evolution, the initial mass of the ice in the body had to be at least on order of magnitude more than the mass of the rings. However the suggestion [*Canup,* 2010] that the primary body was a large Titan-like differentiated satellite seems to be too extremal (3 orders of magnitude of mass excess), the model by [*Canup,* 2010] also is related to the earliest epoch of the solar nebula (may be < 5 million yr) and that may be in contradiction with the contemporary views on the origin of the Saturnian system [*Dorofeeva, Ruskol*, 2010].

We present here a model, in which the source of icy material of rings is the icy mantle of an ice-rock body of mass 10^{23}- 10^{24} g and radius ~ 600 km which approached Saturn after the gas was already dissipated from the Solar system (including accretion disks). The body could come from the periphery of the Solar system, where even at present time exist many large bodies of Kuiper belt. The possibility of an early differentiation of similar bodies, with the separation of the silicates (~ 30% mass) was considered in [*Busarev et al.,* 2003]. There is much evidence of multiple impacts of different bodies (including large ones) which penetrated into Saturnian system and left millions of craters on satellites from Mimas ($r \sim 3R_{Sat}$) to Iapetus ($r \sim 59R_{Sat}$). Many small satellites of Saturn presumably are fragments of disintegrated large bodies (Telesto, Helena etc.).

We consider as a mechanism of disruption of the body the tidal force of Saturn, acting at Roche limit distance 1.5–2.0R_{Sat} (depending on the density of approaching body). The mantle of the body undergoes a deformation and fragments as it is shown on fig. 1. To follow further behaviour of fragments we used a numerical method of penetratable particals [*Marov, Roussol,* 2011].

Fig. 1. Several stages of tidal disruption of a body inside the Roche limit

At realization of numerical experiments the following cases of an entrance inside the Roche limit were considered: velocity of an entrance less circular for a point of an entrance (fig. 2); velocity of an entrance is close to circular (fig. 3); velocity of an entrance more circular, but less parabolic (fig. 4); velocity of an entrance is close to parabolic (fig. 5).

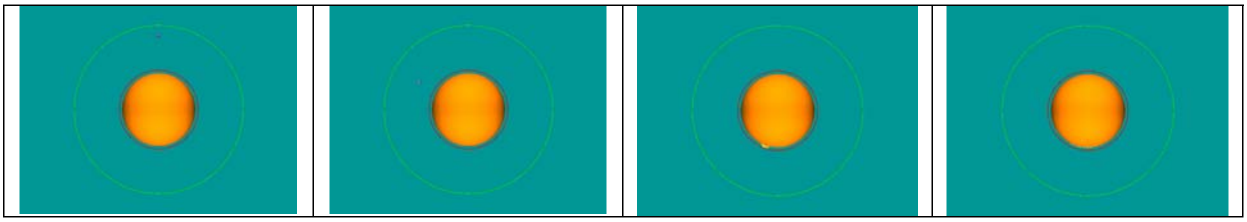

Fig. 2. Velocity of an entrance less circular for a point of an entrance

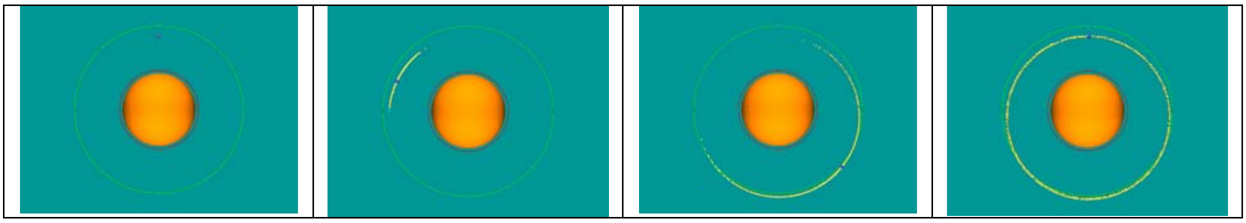

Fig. 3. Velocity of an entrance is close to circular

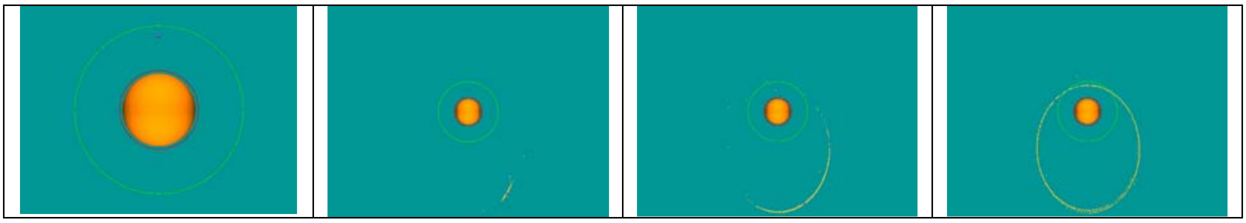

Fig. 4. Velocity of an entrance more circular, but less parabolic

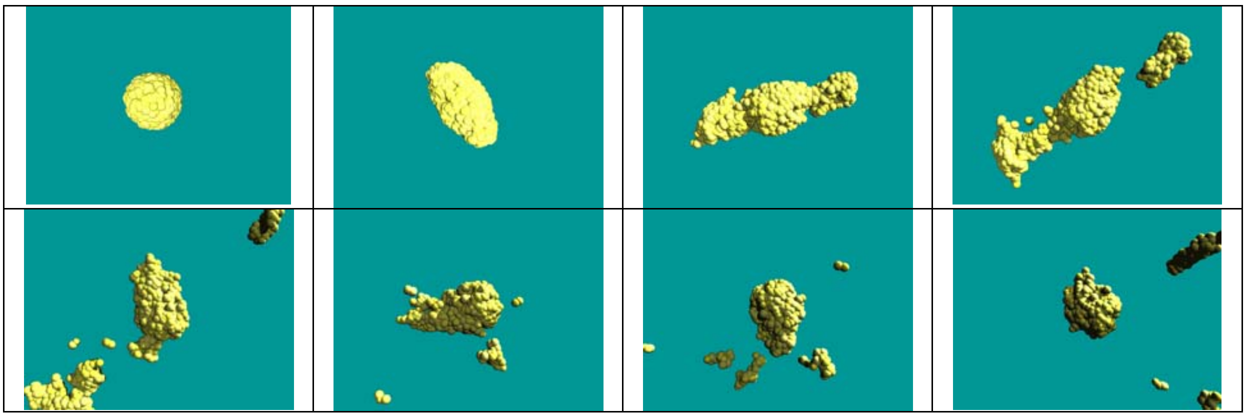

Fig. 5. Velocity of an entrance is close to parabolic

Conclusions

1. The source of the icy particles of Saturn's rings could be represented a rock-ice body with radius ~ 600 km and a mass of 10^{23}- 10^{24} g, which came into zone of tidal disruption of Saturn after the dissipation of gas from Saturnian subnebula (or gas-dust accretion disk).

2. It is shown that the fragments remain on elliptic orbits around the planet if the body enters into Roche zone at the velocity between circular and parabolic ones.
3. The presents of a layer of the liquid water in the rock-ice body is favorite for its disruption, but nevertheless is not necessary in this process.
4. The fate of the rocky core of the body is not yet determined but it is possible that the fragments of the core could be transformed into shepherding satellites.

This work was supported partly by the Russian Foundation for Basic Research, Grants 08-02-00275-a and 11-05-01137.

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