ON THE ORIGIN OF MOLECULAR NITROGEN ON THE REGULAR SATURN'S SATELLITES (TITAN AND ENCELADUS)

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The gaseous molecular nitrogen was experimentally detected on two Saturn's regular satellites as Titan and Enceladus. It was found that N_2 on Titan is a predominant atmospheric component (~95 mol %) but on Enceladus it in one of water plume components (~4 mol %) [1]. It is assumed that nitrogen accumulation on both satellites could be presented by the solid ammonium clathrate (NH_4OH_s). The latter compound could be originated within the Saturn's protoplanetary disk and was not destructed in contrast to nitrogen clathrate. The hypothesis is based on the fact that Kr and Xe were not detected in the Titan's atmosphere [2], the latter being formed clathrates at temperatures above the temperatures of molecular nitrogen clathrate formation [3].

The formation of molecular nitrogen in the Titanium atmosphere as well as its isotopic fractionation ($^{15}N/^{14}N$ rati is on 2.5 magnitude hither than in the Jovian atmosphere) could be a result of the photochemical destruction of NH_3 according the opinion of many authors. But this conclusion is considered to be in controversy with the absence of NH_3 in Enceladus water plumes [1] as well as with current theoretical estimates of nitrogen isotopic fractionation in the photochemical NH_3 destruction [4]. This circumstance stimulates the detailed study of the thermal transformation of NH_3 to N_2. This report deals with the possibility of the molecular nitrogen formation on Titan an Enceladus by the impact heating of the protosatellite matter.

The impact events were evidently realized during the formation and evolution of Jovian and Saturn's protoplanetary disks as the surfaces of their regular satellites are covered with many craters, some of those having diameters near to dimensions of the satellites. But could the impact processes be considered as factor controlling their composition? Let us compare the dependence of mean density values of regular satellites (d) on their radial distance from central planet (r) for the Jovian (fig. 1) and Saturn's (fig. 2) planetary systems.

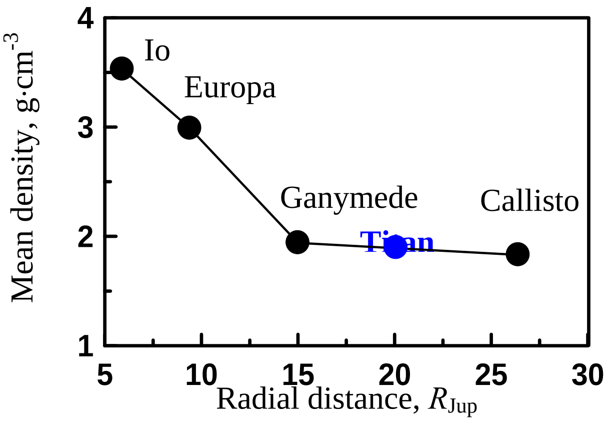

Fig.1. Mean densities and radial distances of Jovian regular satellites and Titan

It is seen (fig. 1) that the increase of r-value is accompanied with the monotonous decrease of d-value reflecting the increase of their ice fraction and correspondent increase of x_{ice}/x_{rock} ratio. Such type of d/r function indicates that the ice/rock ratio could have been controlled by some regular factor. Perhaps such factor is presented with the temperature gradient existed in the Jovian subnebula [5].

The d/r function of the Saturn's regular satellites (fig. 2) was found to be more sophisticated and it is evident that their composition was resulted not only by the influence of the temperature gradient in the subnebula [6] but another factor mainly by the impact processes. If to divide all Saturn's satellites in three conventional groups according their diameters we find out that the minor group (with diameter D = 50 – 200 km) is characterized by two distinctive properties: 1) all satellites are located near the central planet ($r \leq 6.5\ R_{Saturn}$); 2) their density is lower than that of water ice. The latter phenomenon is in accord with the images obtained by the Cassini-Huygens mission which demonstrated the high porosity of those small Saturn's regular satellites. The origin of such objects could be interpreted in terms of impact processes determined the multistage destruction and subsequent accumulation of the satellites. The impact destruction could have been the dominant factor of rock/ice differentiation accompanied by accumulation of the significant was not incorporated by protosatellites. This conclusion is supported by x_{ice}/x_{rock} ratios of all other Saturn's regular satellites (except Titan). These values are higher in relation to x_{ice}/x_{rock} ratios corresponding to the solar abundance of chemical elements [7]. Thus, we conclude that the structure and composition of small Saturn's satellites could have been determined by the intensity of impact recycling of their protomatter. In smaller extent the analogous processes could be responsible of the Mimas and Hyperon 2-d conventional group (D = 200 - 400 km).

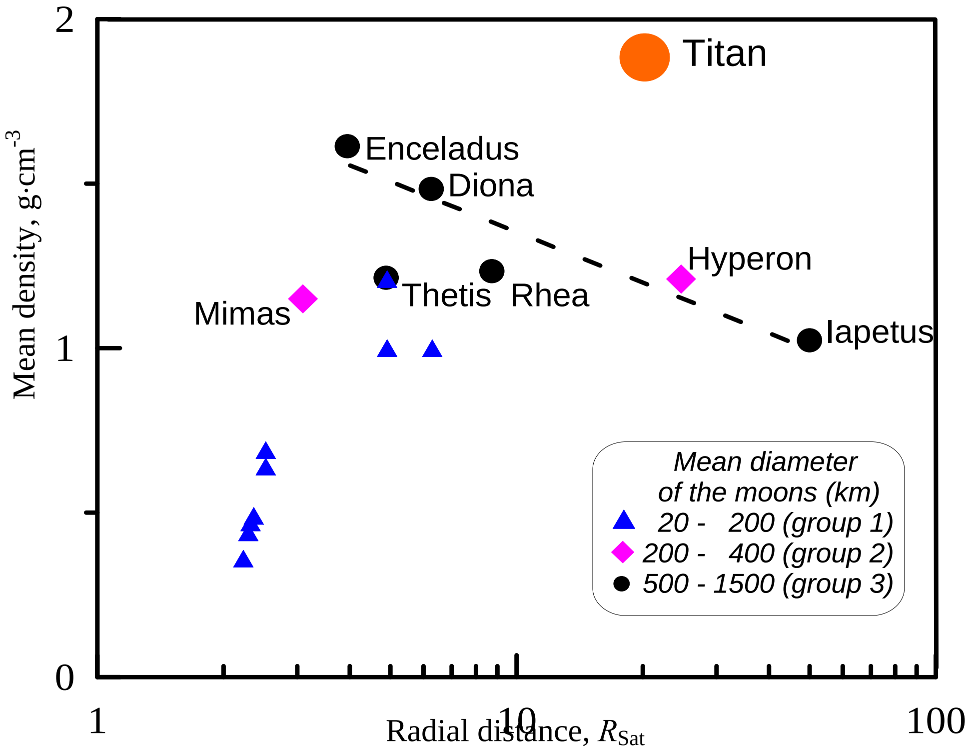

Fig.2. Mean densities and radial distances of Saturn's regular satellites

The 3-d conventional group comprises of 5 relatively large satellites (D = 500 - 1500 km): Enceladus, Thetis, Diona, Rhea and Japetus. Four of them are found to be satisfactory coincidence with the Jovian satellite d/r functional dependence: the increase of radial distance is accompanied by the increase of relative ice component. The deviation of Thetis value is probably a result of not accurate determination of its density taking in mind its structural and composition similarity to Diona and Rhea. It is to be point out that even those relatively large satellites have mean density values below their theoretical values corresponding to chemical differentiation of the solar composition (only Callisto has d = 1.83 being rather similar to its "solar composition" value). Thus, we assume that the satellite composition could be largely controlled by the impact processes.

Titan having the mass and volume parameters of hundreds of times above any other Saturn's satellites is to be discussed separately. Its mean density is much higher in relation to that of Rhea and Hyperon and markedly is out of the aforementioned functional dependence. But it is just in accord with d/r function on the diagram plotted for the Jovian satellites (Jovian and Saturn's radii are rather similar) where it is located between Ganymede and Callisto points (fig. 1). This could be considered as supporting the idea of the protosatellite disk temperature conditions as one of predominant factors controlling the composition of Titan as well as Jovian regular satellites. It could be supposed that such conclusion is based on the large dimension of protoTitan and all Galilean protosatellites. Being involved within the subdisk the rate accumulation of large Saturn's satellites was well above that of all other Saturn's protosatellites. Thus the gravitational attraction was enough for the situation where the running velocity bad become higher than dissipation rate could remain on the satellite surface. High temperatures and pressures generated within the explosion cloud could substantially change the chemical composition of the satellite. We performed the thermodynamic modeling of this event using the maximal values of T (800-2000K) and P (10-30 kbar) in the explosion cloud [8] and taking into account the impact velocities of Saturn's subdisk bodies being in the rage of 2-4 km·s^{-1}. The minimal temperature values were taking as $T \leq 600$K being estimated as a temperature low limit for the action of kinetic constraints. The initial bulk chemical composition in a system in question is also not unequivocal as a ratio of water ice and ammonium clathrate is not known.

The chemical form of carbon source on Titan is also an abject of hypotheses: it to be carbon oxide (as we assumed in [9]) or the organic compound of CHON type (as was supposed in [10]). Thus the bulk chemical composition of the system was taken as corresponding to Enceladus water plumes [1] with three variants of carbon source.

1. All carbon on Titan was accreted in a form of CO_2 ice (Model 3).
2. All carbon on Titan was accreted in a form of CHON (Model 2).
3. Intermediate case – of 50% CO_2 and 50% CHON (Model 1).

The results of modeling are shown on fig. 3.

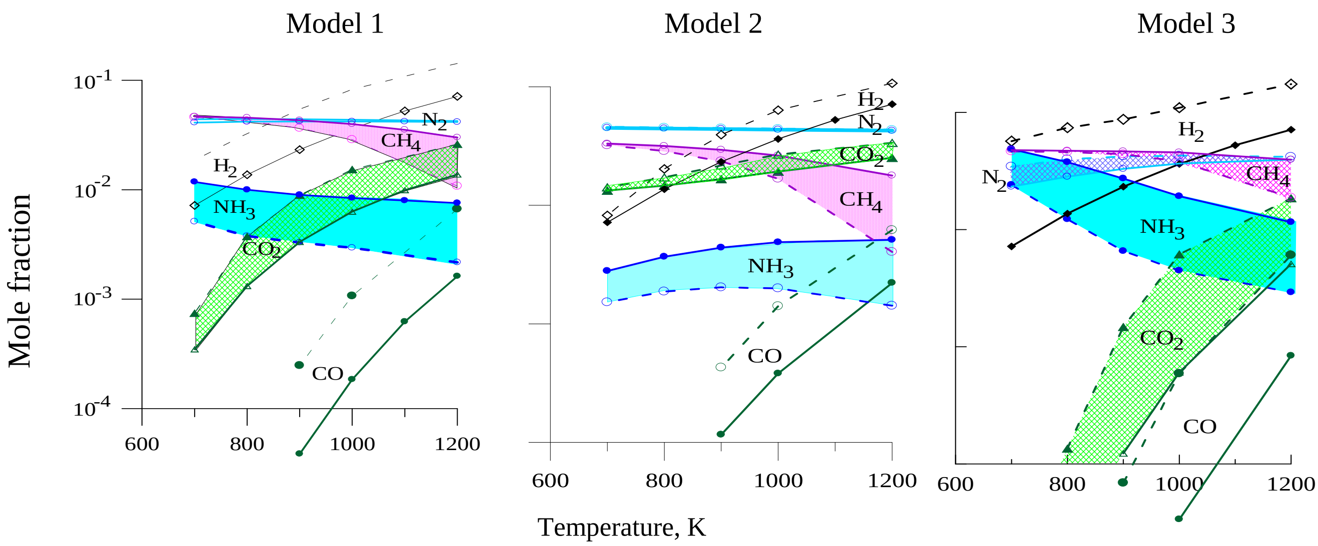

Fig.3. Gas phase composition forming in the collision of rock-ice bodies as a function of temperature within the pressure range of 1 – 10 kbar (dashed and full line correspondingly). The ice component composition: 1) H_2O:C:N is similar to Enceladus water plumes; 2) nitrogen is only in NH_3 forms; 3) variations of carbon chemical form: Model 1: 50%CO_2 + 50% CHON, Model 2: 100% CHON, Model 3: 100% CO_2.

The reduced data and results of modeling lead to a following conclusions:

- The impact processes are assumed to be predominantly controlling the Saturn's small satellite composition as well as influenced on the satellite composition with D = 500 - 1500 km and gas composition on Titan.

- All carbon on Titan could be accreted in CO_2 form according to thermodynamic modeling results (Model 3).

- The composition of CHON up to 30% is also probable (Model 1).

CHON accretion hypothesis is resulting in such atmospheric gas composition which differs from the obtained determinations: NH_3>N_2 and substantially distinct CO_2 and CH_4 values.

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References

1. *Waite J.H., Combi M.R., Ip W.-H. et al.* Cassini ion and neutral mass spectrometer: Enceladus plume composition and structure // Science. 2006. V. 311. P. 1419-1422.

2. *Niemann H.B., Atreya S.K., Bauer S.J. et al.* The abundances of constituents of Titan's atmosphere from the GCMS instrument on the Huygens probe // Nature. 2005. V. 438. P. 779-784.

3. *Lunine J.I., Stevenson D.J.* Thermodynamics of clathrate hydrate at low and high pressures with application to the outer solar system // Astrophys. J. 1985. Suppl. Ser. V. 58. P. 493-531.

4. *Berezhnoy A.A.* Nitrogen on early Titan // 40th Lunar and Planetary Science Conference. 2009. 1077.pdf.

5. *Makalkin A.B., Dorofeeva V.A., Ruskol E.L.* Modeling the protosatellite circum-Jovian accretion disk: an estimate of the basic parameters // Sol. Syst. Res. 1999. V. 6. P. 456-463.

6. *Makalkin A.B., Dorofeeva V.A.* Models of the protosatellite disk of Saturn: conditions for Titan's formation // Sol. Syst. Res. 2006. V. 40. P. 441-455.

7. *Lodders K.* Solar system abundances and condensation temperatures of the elements // Astrophys. J. 2003. V. 591. P. 1220-1247.

8. *Ahrens T.J.; Okeefe J.D.* Shock vaporization and the accretion of the icy satellites of Jupiter and Saturn. In: Ices in the solar system // Dordrecht. D. Reidel Publishing Co., 1985. P. 631-654.

9. *Dorofeeva V.A.* Possible methane sources on the Saturnian's moons-Titan and Enceladus //
URL: *http://www.scgis.ru/russian/cp1251/h_dgggms/1-2007/informbul-1_2007/planet-3.pdf.*

10. *Zolotov M.Y., Owen T., Atreya S. et al*. An Endogenic Origin of Titan's Methane // Am. Geophys. Union. Fall Meeting. 2005. Abstract P43B-04.

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