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Titan's internal structure for the model of the homogeneous accretion

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Abstract

Based of geophysical data on mass, average density and moment of inertia, as well as thermodynamic data on equations of state of water, high-pressure ices, and meteorite matter, we analyzed models of the Titan's internal structure and degree of its differentiation. The new numerical model has been applied. We have been employed constraints from a model of global convection in the mantle and a model of the homogeneous accretion of the satellite. Thickness and aggregate state of water-ice shell, size of the rock-iron cores, ice concentration in the ice-rock mantle, and total H_2O content in the satellite were determined. We found the probable thickness of the water-ice shell ~260-280 km, bulk concentration of H_2O ~ 49%, radius of the rock-iron core is 1080-1120 km

1. Computer simulation

Following [1-4], we consider the main parameters of the Titan internal structure in combination with geophysical observations. Our tasks included: (1) study of differentiation degree of the satellite; (2) determination of thickness and aggregate state of its water-ice shell; (3) determination of ice content in the mantle and total ice concentration in the satellite; (4) revealing constraints on the density distribution in the mantle and sizes of the rock core. Modeling was carried out on the basis of equations of hydrostatic equilibrium, moment of inertia and mass of the satellite, equations of state of water and high-pressure water ices. Density distribution in the interior depends on the ice content in the rock-ice mantle. We have employed that the amount of ice in the rock-ice mantle is constant for all depths. This constraint is a result of global convection in the satellite's rock-ice mantle. According to our model, the satellite was divided into three areas: pure ice or water-ice shell, rock-ice mantle and rock-iron (Fe-Si) core free of ice. The boundaries between the regions were determined by calculations. We assume a conductive heat transfer within the icy crust. The temperature gradient in the water and ice–rock mantle is set equal to adiabatic. We applied the Monte Carlo method for solving the problem. In our calculations we take into account uncertainties in the moment of inertia and mass of the satellite [5]. The density of the satellite's inner rock-iron core was assumed to be 3.62 g/cm^3, the density of the Fe-Si component in the rock-ice mantle was chosen in the range typical for the ordinary L/LL chondrites (3.15 to 3.62 g/cm^3) [1,2,6].

2. Internal structure of Titan

Model with a constant amount of ice in the rock-ice mantle. The heat flux is taken of 7.0 mW/m^2 [7], which corresponds both to its radiogenic and tidal heating. The results of calculations show that Titan may have been formed as a partially differentiated satellite with the water-ice shell maximum thickness of 470 km. The water ocean's depth is about 310 km and the thickness of the outer Ih-crust is equal to 80 km. Ices V and VI located under the ocean have the total thickness of about 120 km. The total H2O content of Titan is 45-52%. The undifferentiated rock-ice mantle has an average density of 1.4 - 2.6 g/cm^3.

Fe-Si core with the density of 3.62 g/cm^3 has a radius which inversely depends on the thickness of Titan's water-ice shell. Maximum allowed size of the inner rock-iron core (1350 km) is achieved at the minimum thickness of the water-ice shell, and this corresponds to the particular case of another two-layer model of the satellite (Fe-Si core + rock-ice mantle). Such a model does not assume the presence of the internal ocean and thus is not considered in this study.

Titan's internal structure for the model of the homogeneous accretion. In this section, we assumed that the satellite was formed by homogeneous accretion of planetesimals with small masses. Accretion heating did not lead to the melting of ice and differentiation ice-rock mixture onto the pure ice and silicate mantle. Rock-ice mantle of the satellite consists of an undifferentiated mixture of ice and rock similar to the composition of planetesimals.

Ice crust and a Fe-Si core were created in the last stage of accretion, when the heating of the surface layers was sufficient for partial melting of ice. A heavy stone planetesimals fall to the center of the satellite and form a Fe-Si core. The lighter ice and water formed a water-ice shell.

For this model we have adopted the following constraints:

1. The average ratio of water / rock for planetesimals and for the rock-ice mantle is equal.
2. The average ratio of water / rock for satellite and for the rock-ice mantle is equal.

3. The average ratio of water / rock for ice-water crust + Fe-Si core and for the satellite is equal.
4. The ratios of water / rock in the mantle for all depths are equal.
Estimates for the rock-iron core radius, thickness of the water-ice shell and the amount of bulk H_2O are shown in Fig. 1 and Fig2.

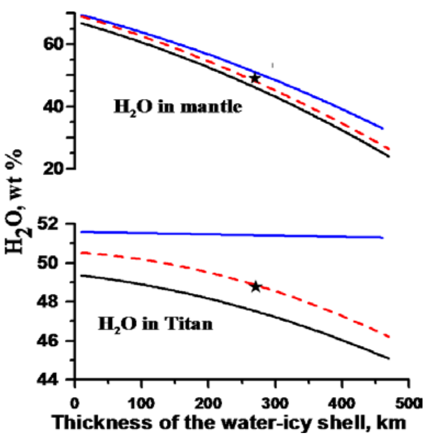

Figure 1: The total content of H2O in the ice-rock mantle and Titan, depending on the density of Fe-Si component in the mantle and the thickness of the outer icy shell. Density 3.62 g/cm^3 (upper line) and 3.15 g/cm^3 (lower line). The red dashed line is the amount of H_2O in ice + hydrous rock. Stars denote a solution for the model of the homogeneous accretion.

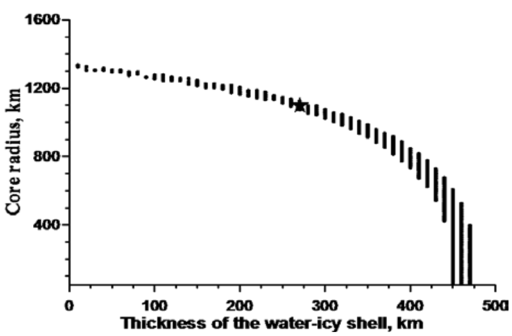

Figure 2: Titan's rock-iron core radius as a function of thickness of the outer water-ice shell.
Stars denote a solution for the model of the homogeneous accretion.
Density of Fe-Si component - 3.15 g/cm^3. H_2O content in the hydrous silicates was taken account.

The thickness of the water-icy shell is 260-280 km, bulk concentration of H_2O – 49%, radius of rock-iron core is 1080-1120 km.
Density of Fe-Si component - 3.15 g/cm^3. The thickness of the water-icy shell 240-260 km, bulk concentration of H_2O – 49%, radius rock-iron core - 1110-1150 km.
Density of Fe-Si component - 3.62 g/cm^3. The thickness of the water-ice shell is 260-280 km, bulk concentration of H_2O – 51.5%, radius of rock-iron core is 1070-1110 km.

Our calculations reflect the possible similarity of the composition and internal structure of Titan and Callisto [4].

Acknowledgements

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