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Models of Titan with rock–ice or hydrous silicate mantle

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Abstract

In this paper, two competitive models of the internal structure of Saturn's icy moon, Titan, have been considered: 1) the model of partially differentiated satellite, with a large internal region composed by homogeneous rock and ice mixture (rock-ice mantle), and 2) model of fully differentiated Titan, in which a complete separation of rock from ice occurred, and intermediate mantle composed of hydrous minerals was formed. It is shown that both models demonstrate a good agreement with the measured physical characteristics of Titan (mass, density, and moment of inertia). Titan's model with hydrated (serpentine) mantle gives an ice/rock ratio in the satellite equal to 0.5-0.6. The ice/rock ratio from the alternative model with rock-icy mantle is close to 1 that is typical for large icy moons of Jupiter.

1. Introduction

The presently known models of the Titan internal structure, which allow of reconciling the values of the satellite's moment of inertia with its mass and density, consider Titan as consisting of three main structural areas: 1) the outer H_2O-shell, composed of high-pressure water ices ± internal ocean with dissolved salts and volatiles; 2) the inner iron–silicate (Fe-Si) core of constant density and 3) the mantle layer located between them. Depending on chosen model, the mantle can be represented by either a homogeneous rock-ice mixture [2, 5] or by a hydrated material of low density, such as serpentine (antigorite) [1, 3]. A number of models assume the existence of a small metallic core in the satellite's center [3].

In this study the detailed calculations of the Titan's internal structure were made by using models with both rock-ice and hydrous silicate mantle. In these models we additionally estimated a progressive change in a satellite's mantle density with its depth and H_2O content in the water-ice-containing interiors of Titan.

2. Models description and results

The model of Titan with intermediate rock-ice mantle was thoroughly investigated in [2]. When calculating, the rock-ice mantle was modeled on the assumption about the existence of the global convection in the mantle reservoir. The density of mantle's Fe–Si component varied over the range 3.15-3.62 g/cm^3 as the density of ordinary L/LL chondrites [4]. The ice-free Fe–Si core was considered incompressible with a given density of 3.62 g/cm^3. The basic criterion of the model validity is the equality of the calculated mass and moment of inertia of Titan to its geophysical measured values.

The main calculation results for the "rock-ice mantle" model are as follows:

- The satellite can be formed with any thickness of the water-ice shell in the range of 0 to 450-470 km. It corresponds to the size of the central rocky core from 1300 km (the model with minimum thickness of H_2O-shell) up to the core absence (the model with maximum thickness of H_2O-shell and underlying rock/ice mantle up to the satellite's center).
- The density of rock-ice mantle is about 1.22-2.64 g/cm^3 with the H_2O content 24-70% (Fig. 1).
- The total H_2O content in Titan is 45-51% (ice/rock ratio is close to 1), which is similar to Ganymede (46-48%) and Callisto (49-55%) (Fig. 2).

The second model of Titan refers to the structure of fully differentiated satellite. The main difference from the previous model is in the composition of intermediate mantle. We assumed that it consisted of hydrated silicate minerals, whose density is quite low and varies with depth in accordance with minerals equations of state. The density of the mantle's hydrous silicates under standard conditions was determined from calculations. The density of the inner Fe-Si core was initially chosen as 3.15-3.62 g/cm^3 and increased with depth.

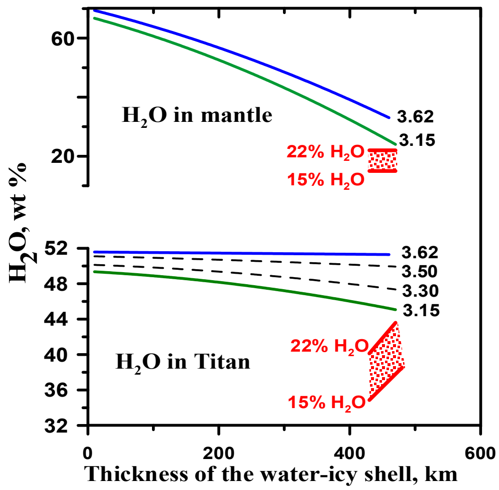

Figure 1: The water content in Titan's mantle and in the satellite as a whole depending on the density of Fe-Si component (numbers at the curves, in g/cm^3) and thickness of the H_2O-shell. The red color refers to the "hydrous silicate mantle" Titan's model, and the other colors - to the "rock–ice mantle" model.

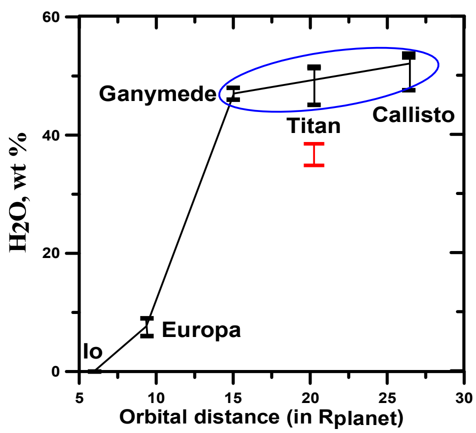

Figure 2: H_2O content in the large icy satellites of Jupiter and Saturn. The red symbols indicate a "hydrous silicate mantle" Titan's model with 15% H_2O.

In accordance with the restrictions on Titan's mass and moment of inertia the following results from the "hydrous silicate mantle" model were obtained:

– The satellite can be formed only in a narrow range of possible thicknesses of the water-ice shell (430-480 km). The corresponding sizes of the central Fe-Si core varied from 930 km up to its total absence.
– The density of the mantle's hydrous substance under standard conditions is 2.31-2.44 g/cm^3. Taking into account silicates compressibility under pressure, the density of the satellite's mantle varied between 2.33 and 2.62 g/cm^3 with depth.
– Because of indeterminacy of the mantle's mineral composition, the H_2O content of Titan's hydrated mantle was taken in the range from 15% (the serpentine group minerals) to 22% - the water content in CI chondrites. This assumption led to the related estimates of the bulk amount of H_2O in Titan as 35-38% and 40-44% (Fig. 1, 2), which reflect the H_2O/rock ratio in the satellite equal to 0.5-0.6 (the model with the serpentine mantle) and 0.7-0.8 (the CI chondrite mantle).

The estimations of H_2O content in Titan obtained by "hydrous silicate mantle" model are found to be more than 10% lower than those derived from the "rock–ice mantle" model. In addition, it is logical to assume that Jupiter and Saturn satellite systems were made up of the substance with the similar composition. In this case the ice/rock ratio in the satellites can remain identical (or non-decreasing, at least) as the distance of the central planet from the Sun increasing. The lower bulk water content in Titan as compared with that in Callisto (the reverse trend in the H_2O content) is quite difficult to explain, even in general terms.

Acknowledgements

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